ESTIMATING DISCHARGE IN UNGAUGED CATCHMENT OF SUNGAI MUAR

MUSLIM BIN MUHAMMAD

Bachelor of Engineering (Hons) in Civil Engineering

UNIVERSITI MALAYSIA PAHANG

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ESTIMATING DISCHARGE IN UNGAUGED CATCHMENT OF SUNGAI MUAR

MUSLIM BIN MUHAMMAD

A thesis in fulfillment of the requirement for the award of the degree of Bachelor of Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2016

SUPERVISOR'S DECLARATION

"I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Civil Engineering."

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DEDICATION

Praised to be to Allah, the Lords of the Worlds

All glory and honor to Him.

To my beloved families

To my fellow friends and educators.

ACKNOWLEDGEMENT

Praised be to Allah, the Lord of All Mighty. First most, thanks to god and his willingness, I have accomplished this final year project as a requirement to graduates and acquire a bachelor degree in civil engineering from Universiti Malaysia Pahang (UMP). There are numbers of people without whom this achievement might not have been success, and to whom I am greatly indebted.

I wish to express my gratitude to my supervisor, Dr. Jacqueline Isabella Ak. Gisen, for her hard work and well guidance throughout her entire experimental and thesis process and for believing in my abilities, and for giving me the foundation to be in this area of knowledge.

To my family who are always behind my back, supporting me through thick and thin, no words to be describe how grateful I am to be part of the family. Thank you for all the supports and prayers that accompany me in obtaining succession my journey.

Last but not least, fellow friends. Thank you to all that helping me out directly or indirectly in my study and also in my life. Good luck to each of you in your future.

To all of you, thank you for everything.

ABSTRACT

River discharge is one of the most important parameters in river basins study to forecast drought or flood events from a time-series of stream flow and rainfall runoff. Unfortunately in Malaysia, the existing discharge stations are limited and cater only small parts a basin. This study aims to estimate the discharge in ungauged catchment of Sungai Muar, using HEC-HMS hydrological modelling software. In this study, maps and hydrological data were collected from SRTM and DID, and the data were pre-analyzed for modelling data input. Clark Unit Hydrograph method was used HEC-HMS to simulate the daily stream flow through calibration against available gauged data. From the result obtained, Clark Unit hydrograph method is applicable in estimating flow discharge in ungauged Muar catchment through projection of calibration discharge -simulation based one available data. The results indicate that this hydrological scheme that has been developed is good in simulating hydrograph for low flow period but a little weaker for high flow period as Root Mean Square error value for low flow 11.46 m^3/s smaller than high flow simulation 18.45 m^3/s. While Nash-Sutcliffe Efficiency for the low flow value is 0.23 bigger than high flow simulation value 0.017. From these two error analysis, it is proven that low flow simulation is more accurate compare to high flow simulation.

ABSTRAK

Luahan sungai adalah salah satu parameter yang paling penting di dalam kajian lembangan sungai untuk meramal kejadian kemarau atau banjir dari masa siri aliran sungai dan aliran hujan. Malangnya di Malaysia, stesen pelepasan yang sedia ada adalah terhad dan hanya memenuhi bahagian lembangan kecil. Kajian ini bertujuan untuk menganggarkan pelepasan di kawasan tadahan Ungauged Sungai Muar , menggunakan perisian pemodelan hidrologi HEC-HMS. Dalam kajian ini , peta dan data hidrologi di ambil dari SRTM dan JPS , dan data data di pra-analis untuk data input model. Kaedah Clark Unit Hidrograf digunakan dalam HEC - HMS untuk mensimulasikan aliran sungai setiap hari melalui penentukuran yang diukur terhadap data. Dari keputusan yang diperolehi , kaedah Clark Unit Hidrograf boleh digunakan dalam menganggarkan pelepasan aliran dalam Ungauged Muar pelepasan tadahan melalui unjuran data penentukuran yang sedia ada -simulasi yang berasaskan . Keputusan yang diperolehi menunjukkan bahawa skim hidrologi yang telah dihasilkan adalah baik untuk simulasi hidrograf untuk tempoh aliran rendah tetapi sedikit lemah untuk tempoh aliran tinggi kerana nilai Root Mean Square Error untuk aliran rendah 11.46 m3 / s lebih kecil daripada aliran tinggi simulasi 18.45 m3 / s . Sementara itu, Nash- Sutcliffe Efficiency untuk nilai aliran rendah adalah 0.23 lebih besar daripada nilai aliran simulasi yang tinggi 0.017. Daripada kedua-dua analisis, ia membuktikan bahawa simulasi aliran rendah adalah lebih tepat berbanding dengan simulasi aliran tinggi.

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LIST OF SYMBOLS

Q_P	Peak Discharge
C	Runoff Coefficient
I	Rainfall Intensity
A	Catchment Area
Q	Runoff
P	Peak Discharge
C	Cumulative Rainfall
S	Maximum Soil Water Storage Potential
L	Lag
T_C	Time Of Concentration
R	Storage Coefficient

LIST OF ABBREVIATIONS

HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
IDF	Intensity Duration Frequency
DID	Department of Irrigation and Drainage
SCS	Soil Conservation Service
UH	Unit Hydrograph
RMSE	Root mean square error
NSE	Nash-Sutcliffe Efficiency

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Water discharge is a very important parameters to forecast flood and drought. Malaysia, are very common with floods and drought season. Based on study by National Weather Service Weather Forecast Office, flood can be defined as an overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch. Ponding of water at or near the point where the rain fell. Flooding is a longer term event than flash flooding: it may last days or weeks. Flood is a general and temporary condition where two or more acres of normally dry land or two or more properties are inundated by water or mudflow. Flood event usually happens during the end of the year, which is rainy season from November to December. In Malaysia, flood event usually happens during the end of the year, during the North East Monsoon season from October to January. High frequency of rainfall causes high flow rate in a river, and when the existing drainage system unable to cope with the high flow rate and volume of runoff, flood occurs. Flood event can also occur due to excessive or concentrated precipitation, rapid or heavy snowmelt, storm surge, or embankment failure (White, 2010). Plus, when flows generated by rainfall overtop the banks of a river, constructed channel, or when the amount of runoff exceeds the capacity of underground drainage systems.

Increasingly rapid development is also a major factor of flooding. This is because the surface flow slowed down as a result of changes in land use (from impervious surface such as forest to impervious surface such as concrete, cement and asphalt) watercourse are blocked, decreasing the ability of the river through the deposition of silt and convective storm event great. The majority of what is classed as problem flooding occurs when urban development and infrastructure such as roads have constricted the floodplain or blocked natural drainage lines and flow paths.

Floods event can cause a major of damage to the properties and threatening the residents. Flooding is a common natural hazard that able to damages properties, human lives, and the environment. Flooding may also disrupt normal drainage systems in cities and typically overwhelm sewer systems. Thus, raw or partially raw sewage spills are common in flooded area. Additionally, if the flood is severe enough, destruction of buildings that can contain a large array of toxic materials (paints, pesticides, gasoline, etc.) can cause the release of these materials into the local environment, which is not good.

On the other hand, drought is a deficiency in precipitation over an extended period, generally a season or more, following in a water shortage inflicting negative influences on plants, animals, and human beings. It is every day, recurrent feature of weather that occurs in actually all zones, from very moist to very dry. Drought is a brief aberration from everyday climatic conditions, thus it is able to vary significantly from one vicinity to any other. Drought is different than aridity that is a permanent function of climate in regions in which low precipitation is the norm, as in a wasteland.

Drought can be caused by many factors such as lack of precipitation, surface water flow, human factors and global warming. Drought is frequently recorded as a result of climate warming and elevated concentration of greenhouse gases, which affect the carbon and water cycles in terrestrial ecosystems, particularly in arid and semi-arid regions. In Malaysia, dry season usually takes place from May until September. Lack of rainfall will affect the farmers, thus causing the agriculture drought. Besides that, human activities such as deforestation as the forest play a major role in water cycle, as they help in reducing the evaporation and also contribute to atmospheric moisture in the form of transpiration. When deforestation is actively conducted, catchment area will reduce automatically reducing the ability of the ground to hold water for more evaporation and make it easier for desertification to occur. It can set off drying conditions, especially for smaller water bodies. Cutting down trees is known to reduce a forest's watershed potential.

Prolonged drought will cause the water scarcity where involving water stress, water shortage or deficits, and water crisis. The relatively new concept of water stress is difficulty in obtaining sources of fresh water for use during a period of time; it may result in further depletion and deterioration of available water resources. Water shortages may be caused by climate change, such as altered weather-patterns (including droughts or floods), increased pollution, and increased human demand and overuse of water. The term *water crisis* labels a situation where the available potable, unpolluted water within a region is less than that region's demand. When this condition is continuously, the water restriction are put into place by the local government. This is very important as the community need the water in living.

Decreasing the water level in a river will cause the salt intrusion. Besides, human activities such as sand mining can make the salt intrusion to occur as the estuaries becomes more deep than usual. As for the Muar estuary, the densely populated Muar town is situated on the banks of the river mouth. This estuary is relatively deep due to dredging and sand mining. Salt intrusion is a threat for the people who live near the estuaries because it will deteriorates water supply quality and makes it unusable for daily consumption or agricultural activities. In addition, change in the intrusion may disturbed the estuarine ecosystem resulting the slow rate of growing mangrove or making them die and reduce the aquatic varieties and destroy the habitats of fireflies (Van Breemen, 2008).

In responding to these problems, there are numbers of software which are designed to analyze rainfall and runoff process. One of them is Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) which is used to predict rainfall data and to determine runoff process. The rainfall-runoff relationship can be obtained by producing a hydrograph. Form hydrograph we can predict the high flow and low flow discharge. Thus, these information can used as warning system for the people to take the early precautions to face floods and drought problem as Muar River basin is one of the states in Malaysia that facing flood problems in every year.

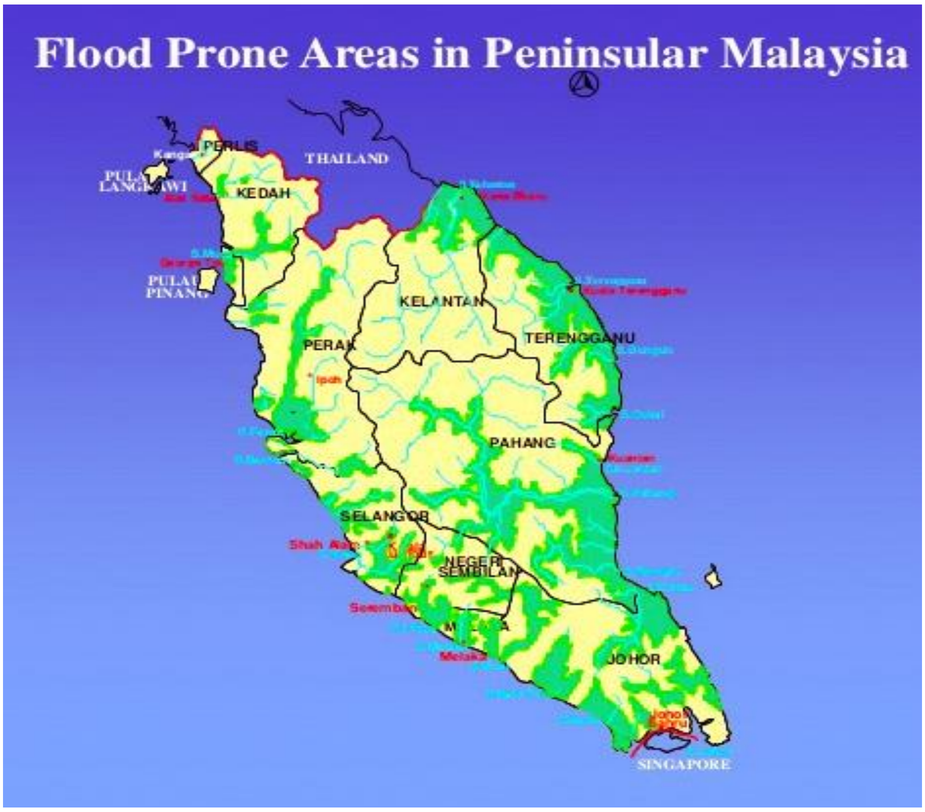

Figure 1.1: Flood prone areas in peninsular Malaysia

(Source : http://www.slideshare.net/iwlpcu/integrated-water-resources-management-in-malaysia)

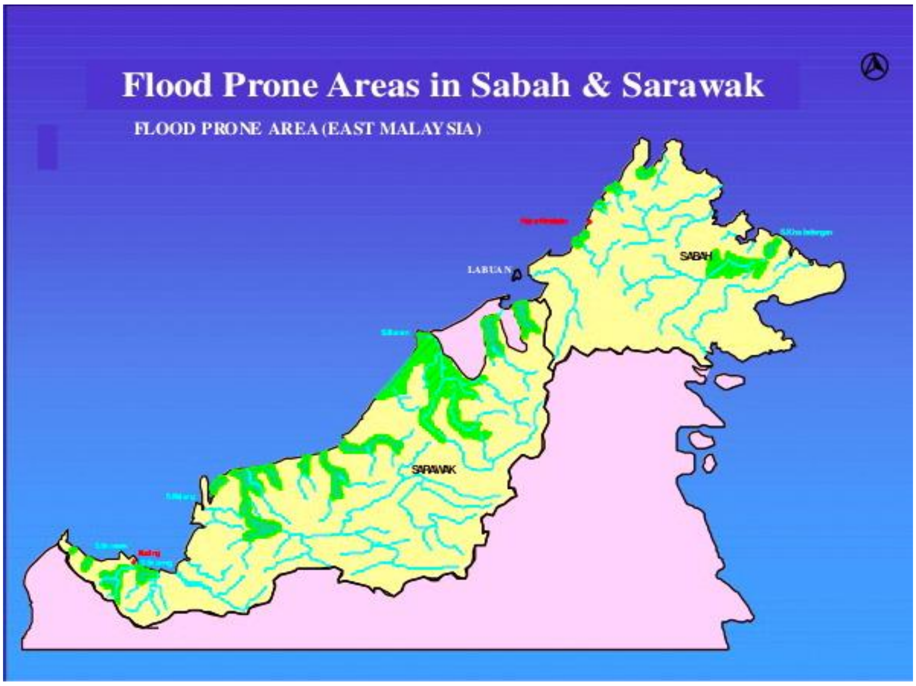

Figure 1.2: Flood prone areas in Sabah and Sarawak

(Source : http://www.slideshare.net/iwlpcu/integrated-water-resources-management-in-malaysia)

1.2 PROBLEM STATEMENT

In Muar River Basin, the discharge stations are limited and cater only small parts of the entire basin. For the big catchment area like Muar River basin, this will make the estimation of the discharge become inaccurate.

For river basin study, we need to know for the entire basin by doing the hydrological modelling. Hydrological modelling is one of the best way to reduce the impacts of flooding by taking extra precautions. In hydrological modelling, it is essential to model the rainfall distribution over the whole catchment.

1.3 OBJECTIVES

The main objective of this study is to estimate the discharge of ungauged catchment in Sungai Muar using HEC-HMS hydrological modelling

Sub-objectives are as follows

I. To simulate river flow in Muar basins from surface runoff data

II. To calibrate and validate simulated result against measurement data

1.4 SCOPE OF STUDY

The data collation, a set of secondary data was collected such as hydrological data, stream flow data, rainfall stations coordinate on topographic map. These data was obtained from Department of Irrigation and Drainage (DID). The acquired data was needed to perform the hydrological study. It is important to study step by step about the hydrological cycle so that we could know the process of the precipitation and the discharge.

We do the calibration of rainfall-runoff models with respect to local observational data that is used to improve model predictability. The study is limited in Muar River Basin only.

1.5 SIGNIFICANT OF STUDY

This study will serve the systematic planning on water management system for the relevant parties in preparation for flood or drought problem. For the society who live near the river basin, this study will serve the awareness among them about the water related disaster to minimize damages and losses. Flooding has destroyed roads, bridges, farms, houses and automobiles. People become homeless. All these come at a heavy cost to people and the government. It usually takes years for affected communities to be rebuilt and business to come back to normalcy. Thus, occurrence of disaster due extreme climate change such as floods, could impact damaging effect on the economy, social and psychology of the people affected. Recent floods in Johor had displaced 110,000 people, damaging an estimate of RM 3.5 billion worth of infrastructures and RM 2.4 billion of economics losses.

CHAPTER 2

LITERATURE REVIEW

2.1 STUDY AREA

Sungai Muar or known as Muar River is located in peninsular Malaysia, Johor. To be more specific, Muar Basin is located in west of Johor. Muar River is a river which flows through states of Johor, Negeri Sembilan and Pahang in Malaysia. The river also flows through Muar town. It can accommodate a population 328,695 people (census made on year 2000). Muar is located at coordinates 2˚3' N 102˚34'E, on Sungai Muar estuary. Main town of Sungai Muar is Muar which also known as Bandar Maharani, Bandar Diraja. In this study, the Muar Basin is selected as the study area. The area of Muar Basin is 5031 km2 extending from latitude coordinate 2.039272, to the longitude is 102.569092. Length of river starting from the top of the network to the river mouth is 225 km.

It is the one of the most popular tourist attractions in Malaysia to be visited and explored for its food, coffee and historical buildings from the pre-war. Bandar Maharani is declared the Royal City of Johor and it is the fourth largest city after Johor Bharu, Batu Pahat and Kluang. Muar which is sub-divided into the Muar district and the new Ledang district, which was upgraded into a full-fledged district from the Tangkak sub-district earlier. Muar district is the only district covering the whole area formerly borders Malacca in the northern part. Upon the upgrading of Ledang district, the Muar district now covers only the area south of Sungai Muar, whilst the northern area beyond the river is in within Ledang district. However, both divided administrative districts are still collectively and fondly called and referred to as the region or area of Muar as a whole by their residents and outsiders.

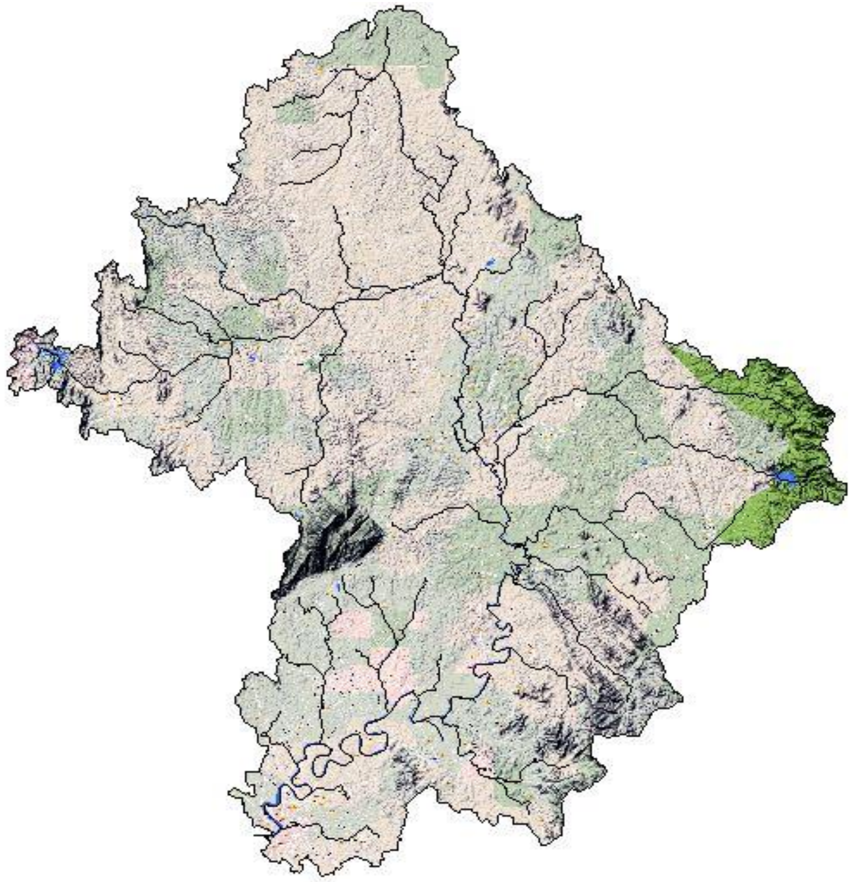

Figure 2.1: Muar River Basin

Muar is famous for its agricultural products. The main natural products that are commercially produced are palm oil, gambier, mangosteen, rambutan and durian. Palm oil have become the main agriculture product as the Johor government promotes plantation of Palm Oil trees throughout the state of Johor. There's also a furniture industry, which export to the international markets such as Europe and America. Besides that, fishing, canoeing or savoring seafood also popular near Sungai Muar as the sun blazes in the sky and burnishes the placid waters in the afterglow. In fact, Muar is actually very popular for its local delicacies where any of the travelers visiting Muar can enjoy delicious and inexpensive foods served by food stalls or restaurants located at various areas of

Muar. One of the most preferred and famous local delicacy in Muar is known as "Otak-Otak" This is a mix blends of fish or prawn in various spices, wrapped normally in coconut leaf.

Muar River Basin receives an annual rainfall average of approximately 1900 mm. The lowest value of average annual rainfall is recorded at Kuala Pilah (1600 mm), while the largest is at around Labis (2500 mm). There are three stream flow gauging stations within Muar River Basin located at Buluh Kasap, Jln Gemas, and Sg. Segamat. The annual average flow rate observed at the gauging station in Buloh Kasap is approximately 47 m^3/s.

Muar River has a total of nine rain gage measurement station (yellow) and one stream flow (red) station ; Pintu Kawalan Tg Agas, Ldg. Eng Kee, Ldg. Ban Heng, Ldg. Bkt. Serampang, Ldg. Sg. Labis, Felcra Tebing Tinggi, Ldg. Segamat, Ldg Gomali and Ldg. Mados Sermin

Figure 2.2: Rainfall and Streamflow Station locations on Google Maps

Table 3.1: Rainfall and Streamflow Station

STATION ID	NAME
RF2025001	PINTU KAWALAN TG. AGAS, MUAR
RF2225026	LADANG ENGKEE, TANGKAK
RF2228016	LDG. BAN HENG, MUAR
RF2326023	LDG. BKT SERAMPANG, TANGKAK
RF2330009	LDG. SG. LABIS, LABIS
RF2427001	FELCRA TEBING TINGGI, SEGAMAT
RF2428011	LDG. SEGAMAT, SEGAMAT
RF2626002	LDG. GOMALI, BATU ENAM
RF2628001	LDG. MADOS SERMIN, JOHOR
SF2528414	SUNGAI SEGAMAT, JOHOR

A mega flood mitigation project that cost RM 210 million has been proposed along Sungai Muar to curb flooding along the stretch of the river between Segamat and Muar. The project is a one of the flood mitigation programmed being implemented that covers some 6,138 km^2 of catchment area along the river up to Negeri Sembilan and even Pahang. The first phase of the mitigation project involved the Segamat district, while the second phase covered the Ledang and Muar districts. The second phase project also involved strengthening the riverbank at Tanjung Olak and Belemang and upgrading works at Sungai Pagoh. Although the mitigation project in Muar will not completely prevent flooding in the district, the project is at least speed up water flow into the sea.

2.2 INTRODUCTION OF HYDROLOGY

Hydrology is a study of water. Water is one of the basic needs for human to live. Nigel (2000) claimed that, people need water for drinking, washing, and preparing meals for every day, farmers need water to plant vegetation, development and industry need water as a raw material and for cooling agent, river are used as a transportation network. Without it, there will be no live on this planet. The water supply on this earth for our use is limited by nature. Although there is a lot of water on earth, not all of them we can use.

Which make them worsen, increasing the chemical waste into the river make our water become less in quality.

According to United States Geological Survey (USGS), hydrology is the science that includes the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle. Hydrology is more significant these days because we plan ahead of time to deal with extremes like scarcity of water leading to droughts. Drought can be caused by many factors such as lack of precipitation, surface water flow, human factors and global warming. Lack of rainfall will affect the farmers, thus causing the agriculture drought. Besides that, human activities such as deforestation as the forest play a major role in water cycle, as they help in reducing the evaporation and also contribute to atmospheric moisture in the form of transpiration. When deforestation is actively conducted, the catchment area will reduce and automatically reducing the ability of the ground to hold water for more evaporation and make it easier for desertification to occur. No rainfall event for a long period will leads to the water shortage. Thus, the supply of water will insufficient than the demands. If this situation continues, it will cause the El- Nino phenomenon. “El Nino’s strong impact will be felt by all the states in the peninsula, Sabah as well as in the Miri and Limbang divisions in Sarawak by the end of this month.” The Sunday Daily.

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Water is divided into two categories which is surface water and ground water. River, lake or reservoir can be an example of the surface water, which provides the water supply to the nearest cities. Groundwater, pumped below from the earth’s surface. It is cheaper, convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies.

2.3 PRINCIPLE OF HYDROLOGY

2.3.1 Hydrological Cycle

Hydrological cycle describes the continuous movement of water on, above and below the surface of the earth. The hydrologic cycle refers to the process beginning with the water falling to the earth either in liquid form or solid form through the precipitation. The water is captured then taken up by vegetation, retained in the soil, or penetrates through the soil through infiltration. Then, water moved entering into the streams, rivers, lakes, groundwater reservoir or the sea. During the day, it returns to the atmosphere by evaporation process or evapotranspiration process which is from the plant and restart the cycle again.

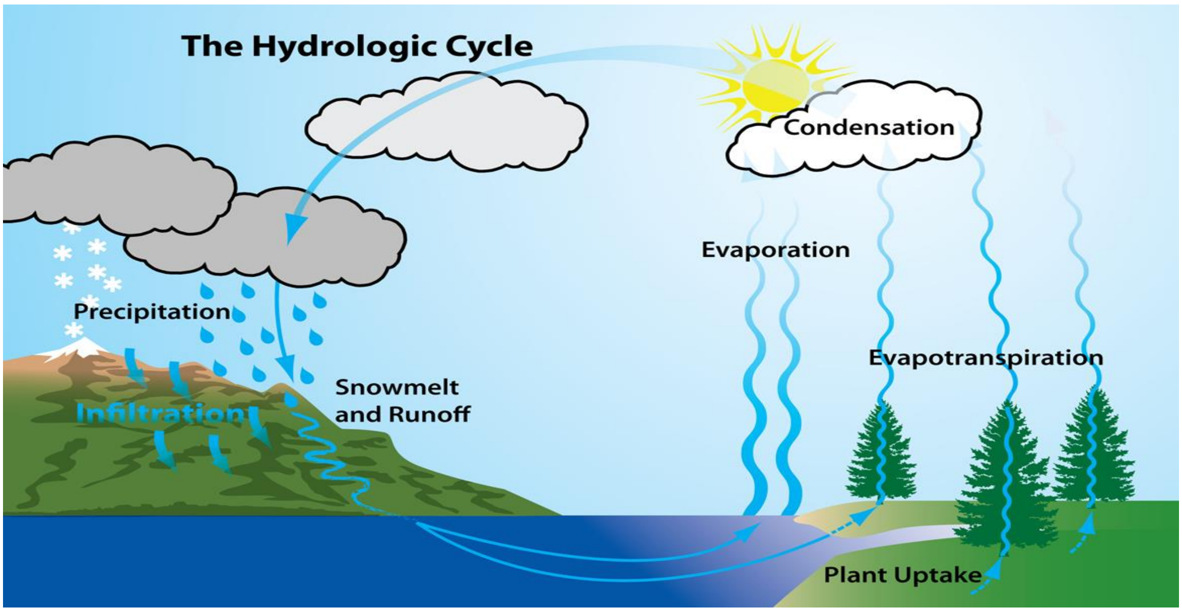

Figure 2.3 : Hydrological Cycle

(Source : http://nj.gov/drbc/hydrological/)

2.3.2 Watershed

A watershed describes an area of land that contains a common set of streams and rivers that all drain into a single larger body of water, such as a larger river, a lake or an ocean. It can cover a small or large land area. Small watershed is a part of larger watershed. For example, the Meramec River watershed, which is supplied by even smaller watersheds from dozens of streams, drains into the Mississippi River. All the stream flowing into small rivers to the larger rivers and finally to the ocean, forming an interconnecting waterways network.

A watershed is a basic geographical unit, which can be used to study geomorphological features. Quantitative research on watershed morphological characteristics plays a significant role in geomorphology (Strahler, 1957, Sutherland, 1994, Zheng, 2000, and Liu et al., 2009). Major indexes of watershed geomorphology include area, plan shape, altitude, slope, asymmetry, and drainage structure. Plan shape of a watershed is one of the most basic watershed attributes, which influences hydrological conditions including water flow and the formation of floods (Cheng and Jiang, 1986, Lu, 1991, Tuttle et al., 1996, Déborah et al., 2003, Debarry, 2004 and Ivanov, 2006). Jane and Qiong (2008), and Christian and Crosta Giovanni (2008), claims that watershed shape also affects hill slope erosion Classic Hack's (1957) law implies that with the increase in the watershed area, the watershed shape will become narrower (Willemin, 2000).

2.3.3 Rainfall

Rainfall can be determined as a water in a droplets form falling down to the earth in a certain amount within a given time and area. In precipitation, water vapor path and cloud liquid water path over northern high-latitude open seas revealed that precipitation changes are mostly due to the changes in cloud liquid water path rather than local evaporation. Rainfall is recognized as one of the main natural processes to improve air quality Duhanyan and Roustan (2011) and Elperin et al.(2011) , and it can greatly enhance the positive reductions achieved by anthropogenic control measures (Leung and Gustafson, 2005).

2.3.4 Runoff

Annual runoff frequency analysis is essential for water resources development, the statistics of annual runoff are assumed to be stationary, i.e., the annual runoff probability distribution and its parameters remain unchanged in time. In non-stationary situations, the statistics of annual runoff might be altered due to climate change or human activities. However, the higher temperatures in the future may impact the precipitation, potential evapotranspiration and climate–runoff relationship in ways that are different from past observations Therefore, the probability distribution of annual runoff in the future will be different from the past, and estimation of the future water resources situation from the fitted distribution based on the historic observations would lead to errors. However, the process of runoff has significant randomness and the runoff series is non-stationary (Zhou and Zhou, 2004).

Runoff models can be divided into two main categories: conceptual and empirical. Conceptual models attempt to simulate complex and nonlinear physical processes, e.g., evaporation, evapotranspiration, infiltration, surface flow, subsurface flow and groundwater flow, by employing complex mathematical formulas composed of a large number of parameters (Lidén and Harlin, 2000 and Franchini and Pacciani, 1991). While the conceptual models are useful for our understanding of the physical mechanisms involved in the river flow (or any other hydrological) process, unfortunately, there are a lot of difficulties in their application (Sivakumar et al., 2002).

Runoff is a key water loss component with strong impact on crop production, vegetation restoration and ecosystem services such as water resource conservation (Gyssels et al., 2005 and Valentin et al., 2005). Soil erosion by surface runoff is recognized as the main process causing land degradation and desertification. Runoff initiation is the result of rainfall intensity exceeding soil infiltrability, thereby leading to temporary saturated conditions at/near the soil surface (Horton, 1945 and Cantón et al., 2011).

2.3.5 Streamflow

The water discharge that occurs in a natural channel more general term than runoff, streamflow may be applied to discharge whether or not it is affected by diversion or regulation. When precipitation falls on the land surface, it may initially distribute to fill depression storage, infiltrate to fill soil moisture and groundwater or travel as interflow to a receiving stream. A stream flow and subsurface flow are linked components of the continental hydrological cycle whose interactions strongly impact the response of hydrologic systems to atmospheric forcing. Stream flow data can be obtained from gauging stations at the Muar River.

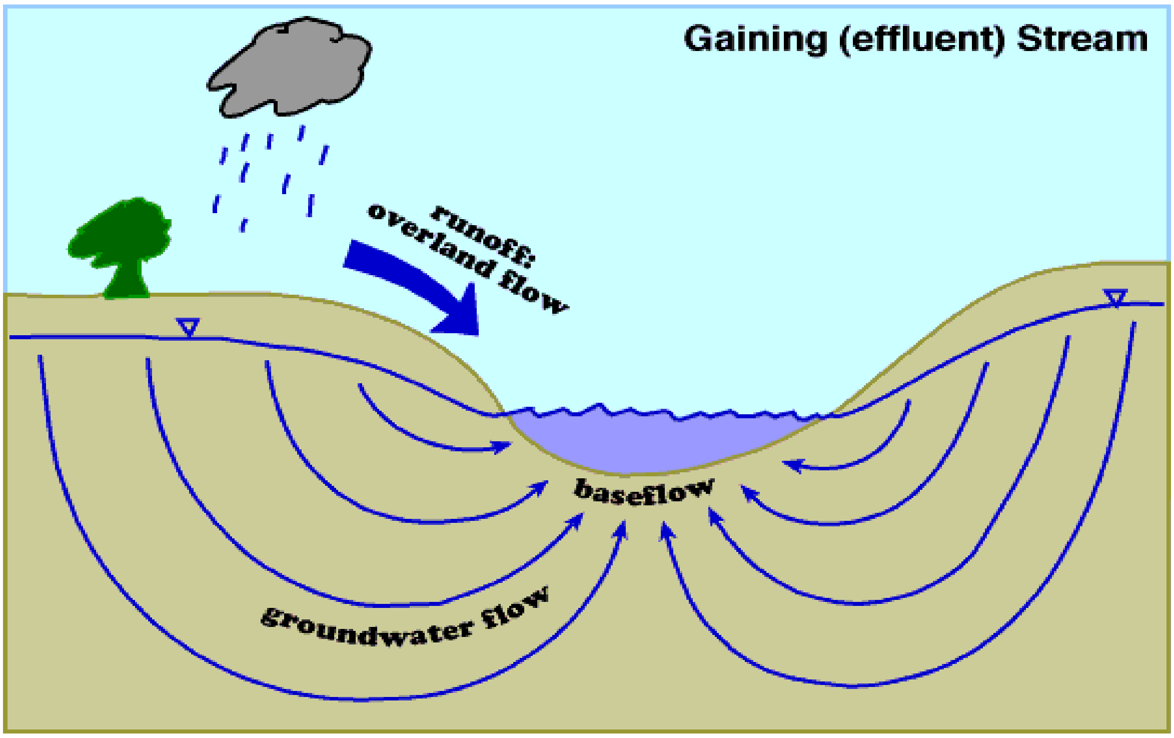

Figure 2.4 : Streamflow and Baseflow

2.4 HEC-HMS SOFTWARE

2.4.1 HEC-HMS Component

The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can be represented by a mathematical model. Each mathematical model included in the program is suitable for use in different environments and under different conditions. The HEC model is designed to simulate the surface runoff response of a basin to precipitation by representing the basin with interconnected hydrologic and hydraulic components. It is primarily applicable to flood simulations. In HEC-HMS, the basin model comprises three vital processes; the loss, the transform and the base flow. Each element in the model performs different functions of the precipitation-runoff process within a portion of the basin or basin known as a sub-basin.

2.4.2 Capabilities of HEC-HMS

The program has an extensive array of capabilities for conducting hydrologic simulation. Many of the most common methods in hydrologic engineering are presented in ways that are easy to utilize. HEC-HMS is a mathematical watershed model that contains several methods with which to simulate surface runoff and river/reservoir flow in river basins. The hydrologic model, together with flood damage computations provides a basis for evaluation of flood control projects.

2.4.3 Watershed Physical Description

The physical representation of a watershed is accomplished with a basin model. Hydrologic elements are connected in a dendritic network to simulate a runoff process. Available elements are sub-basin, reach, junction, reservoir, diversion, source and sink. Computation proceeds from upstream elements in a downstream direction. A classification of different methods is available to simulate infiltration losses. Options for event modeling include Initial constant, SCS curve number and Gridded SCS curve number. The one-layer deficit constant method can be used for simple continuous modeling. The five-layer soil moisture accounting method can be used for simple continuous modeling of complex infiltration and evapotranspiration environments. Gridded methods are available for both the deficit constant and soil moisture accounting methods. Seven methods are included for transforming excess precipitation into surface runoff. Unit hydrograph method includes the Clark, Snyder and SCS techniques. User-specified unit hydrograph or S-graph ordinates can also be used. The modified Clark method, Mod Clark, is a linear quasi-distributed unit hydrograph method that can be used with gridded meteorological data. An implementation of kinematic wave method with multiple planes and channels is also included.

The constant monthly method can work well for continuous simulation. The linear reservoir method conserves mass by routing infiltrated precipitation to the channel. The nonlinear Boussinesq method provides a response similar to the recession method, but the parameters can be estimated from measurable qualities of the watershed. A total of six hydrologic routing methods are included for simulating flow in open channels. Routing with no attenuation can be modeled with the lag method.

2.4.4 Hydrological Simulation

The time span of a simulation is managed by control specifications, which include a starting date and time and an ending date and time, and a time interval. A simulation run is created by combining a basin model, meteorological model, and control specifications. Run options include a precipitation or flow ratio, capability to save all basin state information at a point in time and ability to begin a simulation run from previously saved state information. Simulation results can be viewed from the basin map. Global and element summary tables include information on peak flow and total volume. A time-series table and graph are available for elements. Results from multiple elements and multiple simulation runs can also be viewed.

2.4.5 HEC-HMS Model Limitations

Every simulation system has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation and simplified flow representation. Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results. Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite.

2.4.6 Model Formulation

All of the mathematical models included in the program are deterministic. This means that the boundary conditions, initial conditions, and parameters of the models are assumed to be exactly known. This guarantees that every time a simulation is computed it will yield exactly the same results as all previous times it was computed. Deterministic models are sometimes compared to stochastic where the same boundary conditions, initial conditions, and parameters are represented with probabilistic distributions. Plans are underway to develop a stochastic capability through the analysis tool. All of the mathematical models included in the program use constant parameter values; that is, they are assumed to be time stationary. During long periods of time it is possible for parameters describing a watershed to change as the result of human or other processes at work in the watershed. These parameter trends cannot be included in a simulation at this time. There is a limited capability to break a long simulation into smaller segments and manually change parameters between segments. Plans are underway to develop a variable parameter capability through an as yet undetermined means.

The program first computes evapotranspiration and then computes infiltration. In the physical word, the amount of evapotranspiration depends on the amount of soil water. The amount of infiltration also depends on the amount of soil water. However, evapotranspiration removes water from the soil at the same time infiltration adds water to the soil. To solve the problem properly, the evapotranspiration and infiltration processes must be simulated simultaneously with the mathematical equations for both processes numerically linked. This program does not currently include such coupling of the process models. Errors due to the use of uncoupled models are minimized as much as possible by using a small time interval for calculations. While preparations have been made to support the inclusion of coupled plant-surface-soil models, none have been added at this software.

2.4.7 Flow representation

The design of the basin model only allows for dendritic stream networks. The best way to visualize a dendritic network is to imagine a tree. The main tree trunk, branches and twigs correspond to the main rivers, tributaries, and headwater streams in a watershed. The key idea is that a stream does not separate into two streams. The basin model allows each hydrologic element to have only one downstream connection, so it is not possible to split the outflow from an element into two different downstream elements. The diversion element provides a limited capability to remove some of the flow from a stream and divert it to a different location downstream in the network. Likewise, a reservoir element may have an auxiliary outlet.

However, in general, branching or looping stream networks cannot be simulated with the program and will require a separate hydraulic model which can represent such networks. The design of the process for computing a simulation does not allow for backwater in the stream network. The computer process begins at headwater sub-basins and proceeds down through the network. Each element is computed for the entire simulation time window before proceeding to the next element.

2.5 ANALYSIS OF RAINFALL-RUNOFF DATA

2.5.1 Clark's Unit Hydrograph Methods

The movement of water through a catchment is dominated by the process of translation and attenuation. Translation is a movement of water through the catchment because of gravity force while attenuation is the result on friction force and channel storage effect. According to Clark (1945), the translation of flow could be described by the time area curve. This time area curve shows the fraction of catchment area contributing runoff to the catchment outlet as a fraction of time since the start of effective rainfall. Effective rainfall is the rainfall that is not lost through infiltration or retained on the land surface. i.e. it represents the direct runoff. The time area curve is bounded by the time of concentration, *T*c of a catchment, which is a parameter of the Clark unit hydrograph.

2.5.2 Clark Parameter Determination

The *T*c and *R* values for the Clark unit hydrograph method were determined by calibrating HEC-HMS model. The 228 storms used in deriving the rainfall runoff relationships for the 41 catchments were used to estimate *T*c and *R*. In the calibration runs, a loss model is required for HEC-HMS to estimate direct runoff from catchment rainfall, and as HEC-HMS does not include a loss model allowing the deduction of a proportion of rainfall to estimate direct runoff, the initial loss – continuing loss model is adopted for calibration purposes. The Tc and R for Sg. Damansara and Sg. Langat at Mile 10 were obtained from the paper by Hong (1990)

Equations relating Tc, R and catchment characteristics are required to estimate Tc and R for ungauged catchments. A multiple linear regression program (HEC 1970) was used to determine the mathematical relationships of Tc and R with catchment characteristics such as area, slope and length of mainstream for the 43 catchments of Peninsular Malaysia. Generally, Tc and R are correlated to catchment size, slope and main stream length, and slope and main stream length only, it was found that overall Tc and R correlate better with catchment size, stream slope, and main stream length.

$$T_C = 2.32\, A^{-0.1188}\, L^{0.9573}\, S^{-0.5074} \tag{2.1}$$

$$R = 2.976\, A^{-0.1943}\, L^{0.9995}\, S^{-0.4588} \tag{2.2}$$

Where:A = catchment area in km^2
L = main stream length in km
S = weighted slope of main stream in m/km

2.5.3 Time Lag

Lag denoted as L is the delay in between the time runoff from a rainfall event over a watershed begins until runoff reaches its maximum peak. In cases where only a peak discharge and hydrograph are desired at the watershed outlet and watershed characteristics are fairly homogeneous, the watershed may be treated as a single area. A time of concentration for that single area is required. However, if land use, hydrologic soil group, slope, and other watershed characteristics are not homogenous throughout the watershed, the watershed may be divided into a number of smaller subareas, which requires a time of concentration estimation for each subarea.

The equation of lag is as follow:

$$L = 0.6T_C \tag{2.3}$$

Where: T_c = Time concentration

L = lag (h)

2.6 BASEFLOW

A baseflow is required to derive the total design hydrograph. It is difficult to predict the statistical characteristics of baseflow prior to a major flood. For this study, baseflow of the recorded hydrographs for the catchments before the occurrence of the floods were averaged and plotted as shown in Figure 2.4 . Baseflows were taken for rather dry and moderate wet antecedent catchment conditions. A best fit was derived for general use. The equation is:

$$Q_B = 0.11\, A^{0.85889} \tag{2.4}$$

Where: Q_B = baseflow in m^3/s

A = catchment area in km^2

2.7 ROOT MEAN SQUARE ERROR, R.M.S. Error.

The regression line predicts the average *y* value associated with a given *x* value. Note that is also necessary to get a measure of the spread of the *y* values around that average. To construct the Root Mean Square error, we need to determine the residuals. Residuals are the difference between the actual values and the predicted values. Holmes (2000) denoted them by $\hat{y}_i - y_i$ where y_i is the observed value for the observation and $\hat{y}$ is the predicted value.

They can be positive or negative as the predicted value under or over estimates the actual value. Squaring the residuals, averaging the squares, and taking the square root gives us the Root Mean Square error. Then, we use the Root Mean Square error as a measure of the spread of the *y* values about the predicted *y* value.

$$RMSErrors = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y} - yi)^2}{n}} \qquad (2.5)$$

Where: y_i = observed value

$\hat{y}$ = predicted value

n = number set of data

2.8 NASH- SUTCLIFFE MODEL EFFICIENCY COEFFICIENT, NSE

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line.

The equation is

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Y_0^t - Y_s^t)^2}{\sum_{t=1}^{T}(Y_0^t - \overline{Y_m})^2} \qquad (2.6)$$

Where: Yo = i^{th} observation for the constituent being evaluated

Ys = i^{th} simulated value for the constituent being evaluated

Ym = mean of observed data for the constituent being evaluated

n = total number of observations

NSE ranges between −∞ and 1.0 inclusive, with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values less than 0.0 indicates that the mean observed value is better predictor than the simulated value, which indicates unacceptable performance. NSE was recommended for two major reasons. First, it is recommended for use by Legates and McCabe (1999), and second it is very commonly used, which provides extensive information on reported values. NSE also found to be the best objective function for reflecting the overall fit of a hydrograph. According to Legates and McCabe (1999), a modified NSE that is less sensitive to high extreme values due to the squared differences, but that modified version was not selected because of its limited use and resulting relative lack of reported values.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is a set of experimental method to test and prove the particular hypothesis. This research adopted several methods that are needed to be undertaken to give the best result. The methods include are data collection, data analysis, calibration and validation. There are several software that used in this study which are AutoCAD, ArcGIS, Microsoft Excel, Google Earth and HEC-HMS.

AutoCAD was used in this study to measure the length of the river and the area of each sub basin. While ArcGIS was used to measure the slope difference between upstream and downstream of the river. To locate the location of the rainfall station and stream flow station, we have used Google Earth. Microsoft Excel was used to transform raw data into a tabulated data so that easier to transfer into HEC-HMS so that the hydrological model can be run. HEC-HMS is a free software and widely used over the world. HEC-HMS is design to be applicable in a wide range of geographical areas for solving a lot of issues including large river basin, water supply and flood hydrology. According to Ponce (1989) HEC-HMS model is designed to simulate the precipitation - runoff processes of dendritic watershed systems and with soil moisture accounting (SMA) algorithm, it accounts for watershed's soil moisture balance over a long-term period and is suitable for simulating daily, monthly, and seasonal stream flow.

3.2 FLOW CHART

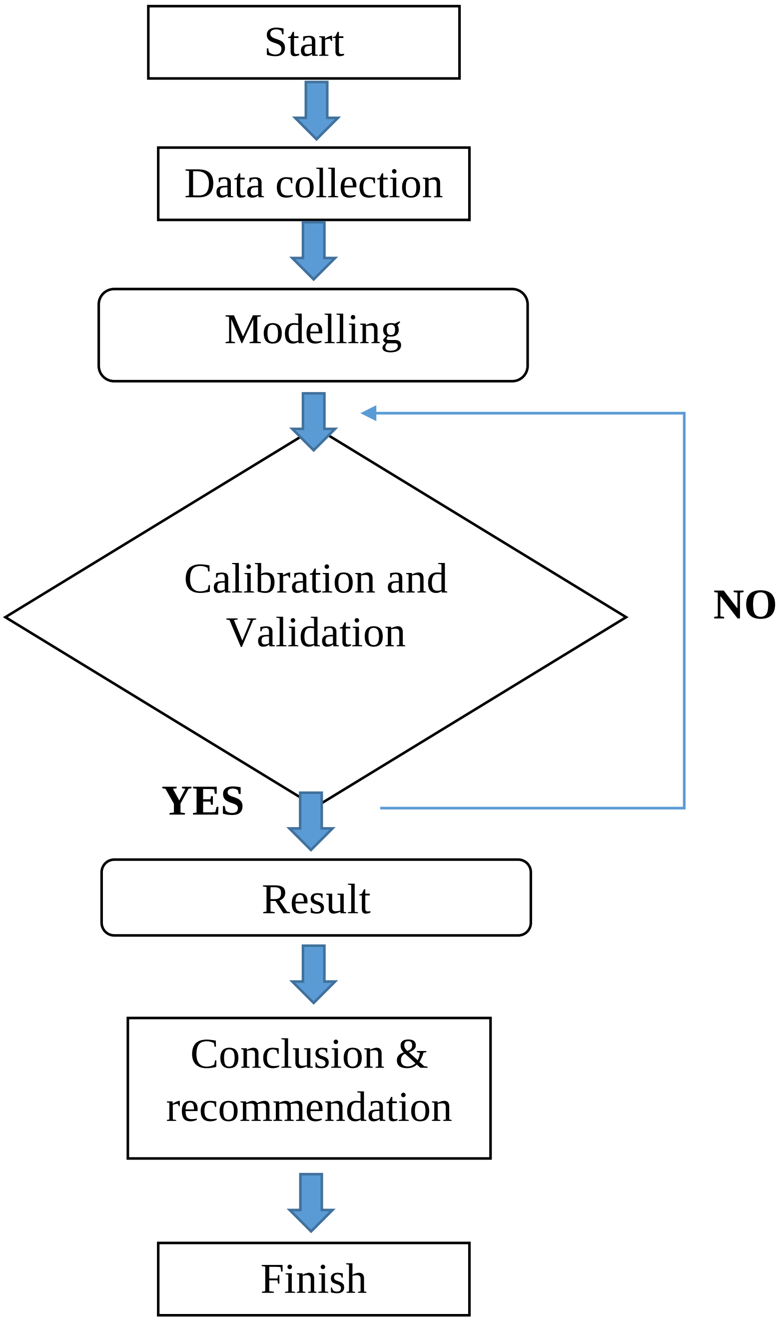

Figure 3.1 : Flow Chart Diagram

3.3 DATA COLLECTION

3.3.1 Hydrological Data

Data was collected from Department of Irrigation and Drainage Malaysia (DID). The acquired data that were collected are rainfall data and streamflow data. The location of rainfall stations that are available include Pintu Kawalan Tg Agas, Ldg. Eng Kee, Ldg. Ban Heng, Ldg. Bkt. Serampang, Ldg. Sg. Labis, Felcra Tebing Tinggi, Ldg. Segamat, Ldg Gomali and Ldg. Mados Sermin. Rainfall data that was collected ranges from 2010 to 2016. To calibrate the model, it is important to identify suitable rainfall stations and around the study catchment area. There are nine rainfall station available in the Muar River Basin. These daily rainfall data were used as input data for the development of the hydrograph simulation. Unfortunately, a lot of data that were obtained are incomplete and missing. So, the rainfall data used for the input was chosen based on the less missing value on the particular month. There are only one available stream flow station in this study area and it is located at Sungai Segamat. The stream flow data also was chosen based on the rainfall data selection and the less missing value for the particular month. Data collected covering from the year 2010 to year 2015.

3.3.2 Topography Map

Terrain map for the Muar River Basin was obtained from Maps Shuttle Radar Topography Mission (STRM) Digital Elevation Model (DEM) of 90 m resolution. The river network in the basin was delineated by using ArcGIS 10.2 and the exact location of stations was obtained from Google Earth. Area covered by each land use type, the total area of the catchment and the stream lengths were measured based on the digitized maps. Within the main catchment, three sub catchments were categorized according to the distribution of rain gauge stations. The rainfall distribution percentage for sub basin were calculated using Thiessen Polygon Method. Other data such as Time concentration, storage Coefficient, Baseflow and Time Lag, were calculate using Eq. (2.1), Eq. (2.2), Eq. (2.3), and Eq. (2.4) respectively as data input for hydrological modelling process in

HEC-HMS. In this study curve number was chosen based on land use. Figure 3.2 shows the Curve Number for hydrologic soil group.

Sl No.	Landuse	Trestment/practice	Hudrologic condition	Hydrologic soil group			
				A	B	C	D
1	Cultivated	Straight row	…..	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
				62	71	77	81
			Good	67	75	81	83
		Bunded	Poor	59	69	769	79
			Good	95	95	5	95
		Paddy (rice)	…..				
2	Orchards	With under stony cover	…..	39	53	67	71
		Without under stony cover	……	41	55	69	73
3	Forest	Dense	….	26	40	58	61
		Open		28	44	60	64
		Shrubs		33	47	64	67
4	Pasture	…….	Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5	Wasted Land	……..	….	71	80	85	88
6	Hard Surface	…….	….	77	86	91	93

Figure 3.2: Runoff Curve Number Specification

(Source: http://www.belgardcommercial.com/resources/design_solutions/controlling_runoff_volumes)

3.3.3 Sub-basin Area

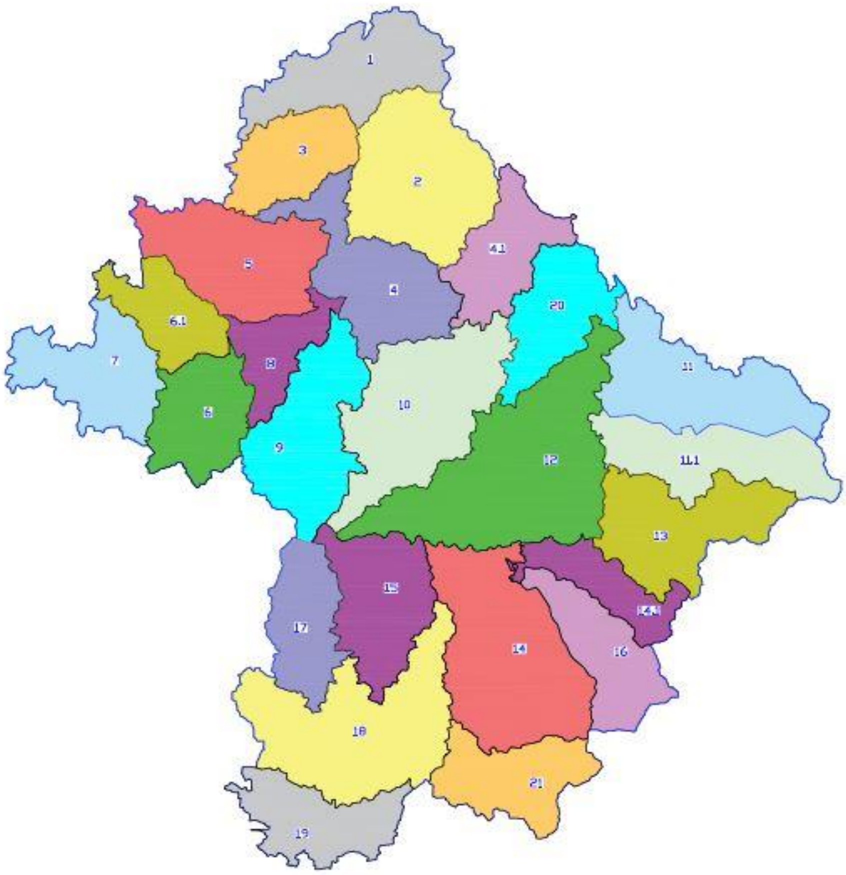

Figure 3.3: Sub Basin Area of Muar Catchment

The Muar River Basin has a very large catchment area; which is measured about 5031 km^2. Therefore, the river basin was divided into 25 smaller sub-basin areas as shown in Figure 3.3. It will provide more accurate and reliable representations of the catchment characteristics.

Table 3.2: Sub-basin area

Sub-basin	Area (km^2)	Sub-basin	Area (km^2)
1	195.847	14	233
2	276.5035	15	417.2169
3	139.06	16	214.8316
4	212.0095	17	333.0066
5	142.5557	18	103.7286
6	230.7005	19	186.2815
7	148.3543	20	150.5008
8	118.1039	21	136.1308
9	179.5259	22	333.5983
10	96.419	23	155.2191
11	227.224	24	154.7016
12	298.2854	25	155.2317
13	200.0612		

3.4 HEC-HMS HYDROLOGICAL MODELLING

The HEC-HMS is a reliable model developed by the US Army Corps of Engineers that could be used for many hydrological simulations. Hydrologic simulation employing computer models has advanced rapidly and computerized models have become essential tools for understanding human influences on river flows and designing ecologically sustainable water management approaches. This model is calibrated and validated for Muar River streamflow and need a reliable data inputs to check the suitability of the model for the study location and purpose. Therefore, this study employed three different approaches to calibrate and validate the HEC-HMS 4.1 model to Muar River catchment and generate long term flow data for the tributaries.

Daily rainfall data from streamflow and rain gauging stations was scattered within the Muar River catchment is used in this study. GIS layers that were needed as input data for the flow simulation were prepared using ArcGIS 10.2. Then, exported to HEC-HMS 4.1 for the calibration of the Muar River sub catchment using daily flow data. The model was calibrated adjusting three different methods. The model parameters were changed and the model calibration was performed by selected methods, which is Clark unit hydrograph method in order to determine the most suitable simulation method to the study catchment.

3.4.1 Setting up the Hydrological Network Scheme

Hydrological network was created based on the river network map created from ArcGIS. Based on this map, a hydrological modelling scheme was developed for the Muar Basin. In this scheme, the basin was divided into 25 sub-basins. Each sub-basin was connected in the river network by junctions and reaches. Calculated baseflow, catchment area, time of concentration and storage coefficient were inserted in the sub-basin component as data input. For reach component, only time-lag is needed. Rainfall time-series data were assigned to each sub-basin according to the gauge weight method in which the distribution of the weight is based on the percentage of area obtained from Thiesen Polygon analysis. The parameters used during analysis and simulation of rainfall-runoff relation of Muar River are SCS Curve Number (Loss Method), Clark Unit Hydrograph (Transform Method), and Constant Monthly (Base flow Method)

3.4.2 Input Data

The area of each sub basin was calculated based on Shuttle Radar Topography Mission, SRTM digital elevation model (DEM) 90 m resolution map and Google Earth. Rainfall data and streamflow data were selected based on the least missing data in a particular month. The percentage of rainfall distribution received by the each sub-basin was calculated using Thiessen Polygon Method. Baseflow was calculated using Eq. (2.4), time concentration using Eq. (2.1) and the lag time using Eq. (2.3). Input data was inserted in their compartment. The data for each sub basin must be filled correctly such as the selection of downstream, area of the particular sub basin, the choosen of loss method, transform method and baseflow method must be selected equally for all sub basin as shown in Figure 3.4. While for reach element, the input data that need to be consider is lag time as shown in Figure 3.5. Lag time was calculated using Eq. (2.3).

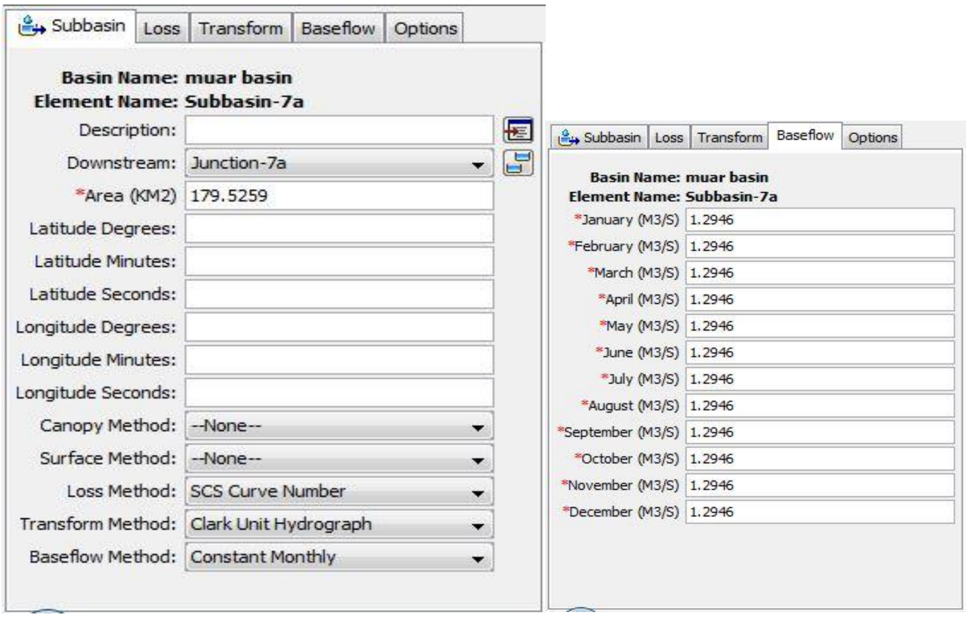

Figure 3.4: Input Data for each sub-basin

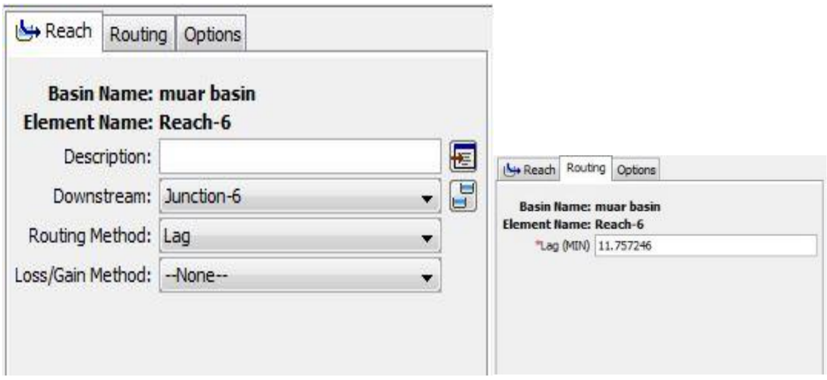

Figure 3.5: Reach input data

3.5 CALIBRATED PARAMETERS

In this study, only one parameters that need to be calibrated and changed due to fit and match the simulated hydrograph to the observed. The parameter that is calibrated is the coefficient of the baseflow. By changing coefficient of the baseflow, the peak of hydrograph can be adjusted so that the shape is good and sensible.

Another parameters used is Time Concentration, Tc, Storage Coefficinet, R ,time lag, L and curve number value which is 35. It is suitable with the study area location which mostly cover by the forest and orchards as show in Figure 3.2

CHAPTER 4

RESULT AND ANALYSIS

4.1 INTRODUCTION

The objective of this chapter is to describe and discuss on all the result obtained in fulfilling the proposed objectives. So, rainfall-runoff analysis was performed using the rainfall and topography data collected. There are nine available rainfall stations and one streamflow station that is located in the Muar River basin. The availabe data were processed and used as data input for HEC-HMS software. These data were inserted into HEC-HMS and analyzed by using Clark’s Unit Hydrograph Method. By then, simulation processes can be done to achieve the result and produced hydrograph. From the result obtained, we can coclude that the shape and pattern of simulated hydrograph is sensible to observed hydrograph. Since, the result of simulated and observed shows good agreement, this means that the Clark Unit Hydrograph transformation method is applicable and reliable in estimating the discharge of a Muar River Basin.

4.2 HEC-HMS MODELLING SCHEME

The hydrological model produced by using HEC-HMS software for Muar River Basin is shown in Figure 4.1.

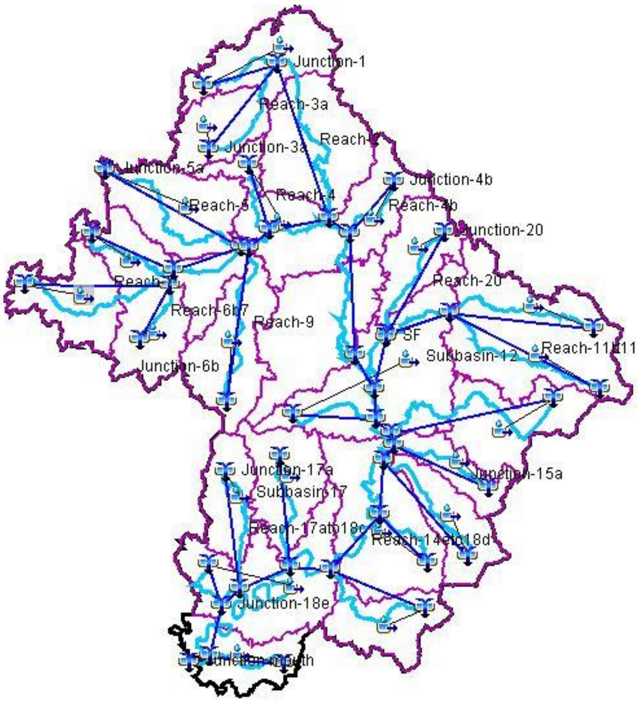

Figure 4.1: Muar River Basin Model

A hydrological modelling scheme for the Muar River was developed by using the HEC-HMS modelling scheme. The modelling started by importing the basemap of the studied catchment into the HEC-HMS software. Muar River Basin has an area of 5031 km^2 extending from latitude coordinate 2.039272, to the longitude is 102.569092. Length of river starting from the top of the network to the river mouth is 225 km. In the Muar Basin, there are in total of only 9 rainfall stations and one streamflow station available. Based on the sub-catchment shown in the map, the river network elements such as sub-basin, junction and reach were assigned in the model. From the model, there are 25 sub basin and 45 junction. All the junction is connected by 46 reach.

4.3 INPUT PARAMETERS

The first parameters that was calibrated is the coefficient of the baseflow where it is changed to smaller value. This because the initial simulated hydrograph presents a very high baseflow compared to the observation. Thus by reducing baseflow coefficient 0.05 for high flow and 0.015 for low flow, the entire streamflow hydrograph can fit the observed one better. This procedure were done for both the high flow and low flow simulation.

On the other hand, rainfall data Rainfall data and streamflow data were used as the control data to calibrate and validate the model. The only discharge data were recorded at Sungai Segamat (SF 2528414) functioned to produce the observed flow of hydrograph.

4.4 HYDROGRAPH

Hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river, or other channel or conduit carrying flow. The rate of flow is typically expressed in cubic meters or cubic feet per second (cms or cfs). For this study, two hydrographs were obtained representing the low flow during dry season (July 2010) and high flow during wet season (November 2010) condition. The observed streamflow hydrograph at Sungai Segamat (SF 2528414) was applied for calibration and validation purpose.

4.4.1 Hydrograph for low flow in July 2010

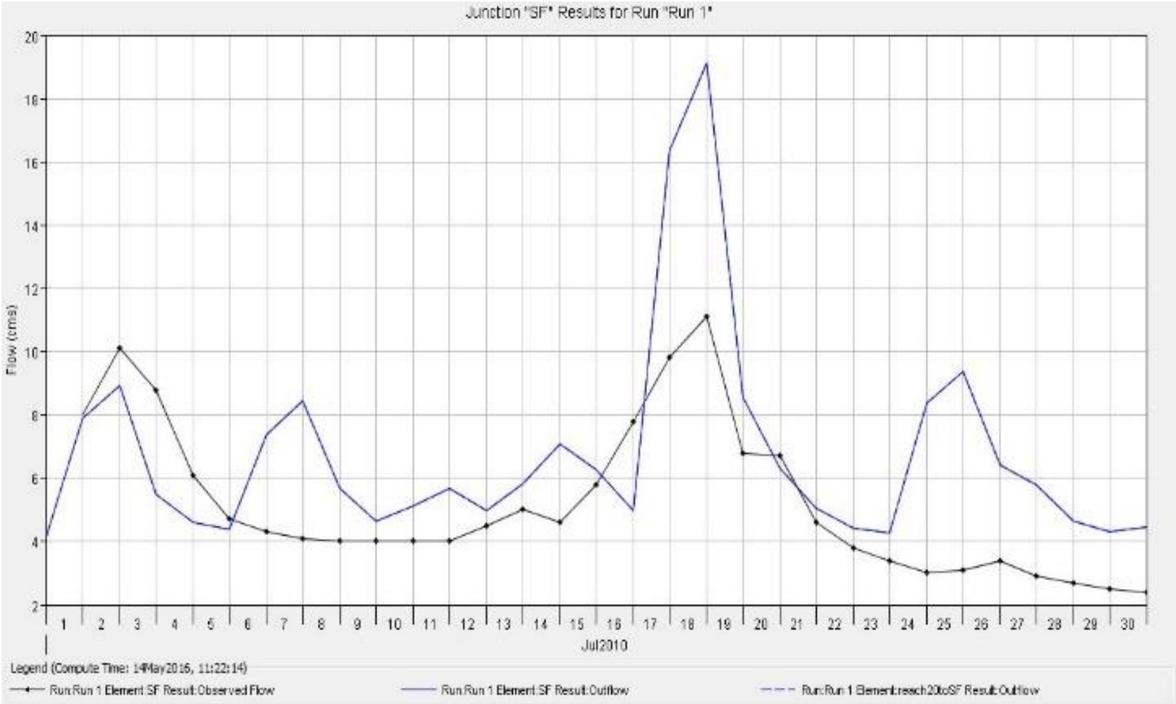

Figure 4.2: Hydrograph for July 2010 (low flow)

For July 2010, the hydrograph shows that the maximum observed and simulated flowrate occurred on the 18th with the amount of 11 m^3/s and 19 m^3/s respectively. On the second day of the month, the observe flow demonstrates the first peak with flowrate of 10 m^3/s then it decreases gradually until day seven. Then, the flow rate remain stable at 4 m^3/s follows by a slight increment up to 5 m^3/s before it reaches the maximum peaks at day 18th. After this maximum peak, the flow begins to drop until the end of the month, showing the lowest reading of 2.5 m^3/s. Meanwhile for the simulated flow, the hydrograph produced 4 peaks flow instead of two as compared to the observed. The simulated result shows the peaks occurred on day 2, 7, 18, and 25, in which the occurrence on day 2 and 18 are similar to the observed flow. Each peak flows for the simulated result shows a reading of 9 m^3/s, 8.5 m^3/s, 7 m^3/s, and 9.5 m^3/s. Meanwhile the baseflow for the low flow simulation is smaller than high flow simulation as the coefficient for both condition was changed to 0.015 and 0.05 respectively.

The simulated discharge for low flow especially at the maximum peak does not fit the observed satisfactorily maybe due to non-uniform distribution and low density of the rain gages. Besides that, the less accurate result may also due to the used of some unsuitable transformation methods may not be the most. However, the overall performance of HEC-HMS in modelling hydrograph is considered good.

4.4.2 Hydrograph for high flow in November 2010

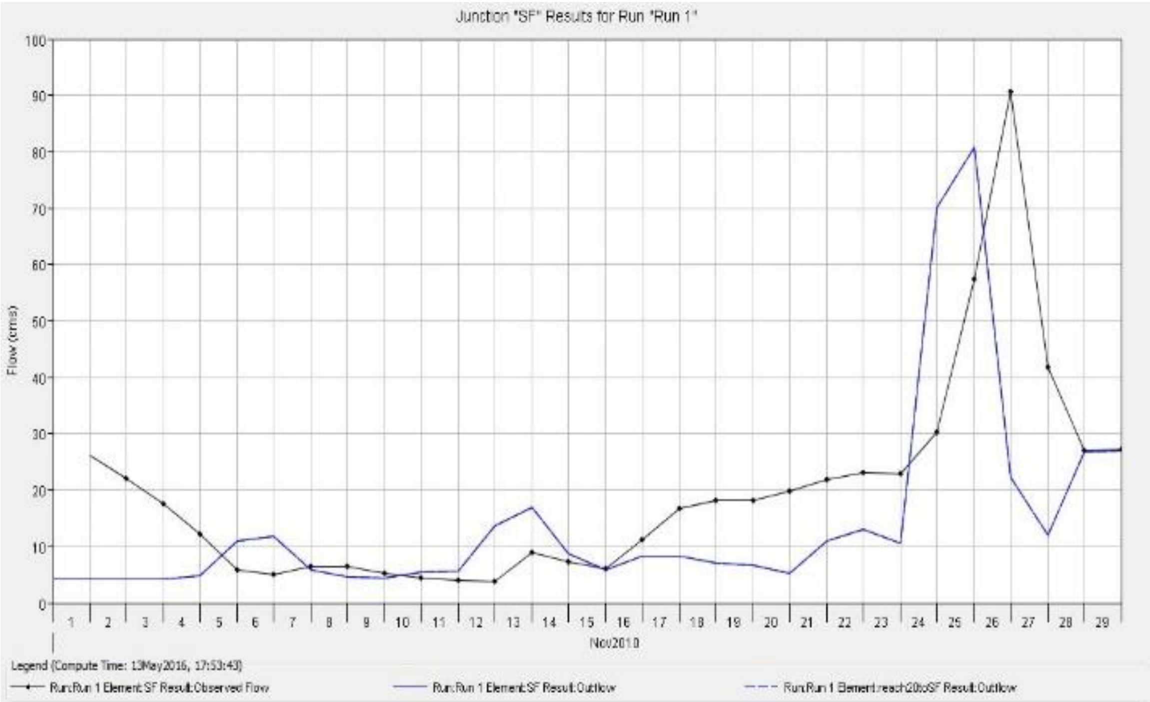

Figure 4.3 : Hydrograph for November 2010 (high flow)

The result of the simulated high flow for the month of November in 2010 shows a good agreement with the observed data. The highest peak flowrate obtained from the simulated model is 80 m^3/s, while for the observed is 90 m^3/s. Although the difference between the flowrates is minor, but the peak given by the model occurred a day earlier compare to the observed. In the first week of the month, the reading of the observed flow decreases gradually decreasing from 25 m^3/s to 5 m^3/s. From day 5 to day 12, the flowrate remains the same and then it started to increase up to 30 m^3/s on day 24, before it raises rapidly to the highest peak on day 26. After the peak, the flowrate decreases to 27 m^3/s until the end of the month. As for the simulated flow, the reading is constant at 5 m^3/s the 4th day, then it increases to the first peak at 12 m^3/s at day 6 before going down again to 4 m^3/s for the next five days. The second peak (first peak in the observed) occurred on day 13 with flowrate of 17 m^3/s. Then, the flowrate reaches its highest peak of 80 m^3/s on day 25 before it declines rapidly to 27 m^3/s and remain constant until the end of the month.

The simulated discharge for low flow especially at the maximum peak does not fit the observed satisfactorily maybe due to the non-uniform distribution and low density of the rain gages. Besides that, the less accurate result may also due to the used of some unsuitable transformation methods may not be the most. Meanwhile, the observed flowrate peak occurs a day earlier may be due to the heavy rainfall that occurs during that day. However, the overall performance of the HEC-HMS in modelling hydrograph is considered good.

4.5 ERROR ANALYSIS

4.5.1 Error Analysis Data

There are two method used to verify the result which are Root Mean Square Error method and Nash Sutcliffe Efficiency method. Both of this error analysis method are important to be carried out to know is that whether simulation is valid or not.

Table 4.1 : RMSE Data for Low Flow Simulation

Day(JULY)	observed	predicted	residual	Residual^2
1	4	4	0	0
2	8	8	0	0
3	10	9	-1	1
4	9	5.5	-3.5	12.25
5	6	4.7	-1.3	1.69
6	4.7	4.3	-0.4	0.16
7	4.5	7	2.5	6.25
8	4.2	8.3	4.1	16.81
9	4	5.8	1.8	3.24
10	4	5	1	1
11	4	5.5	1.5	2.25
12	4	5.7	1.7	2.89
13	45	5	0.5	0.25
14	5	6	1	1
15	4.5	7	2.5	6.25
16	5.8	6.2	0.4	0.16
17	7.8	5	-2.8	7.84
18	9.8	16	6.2	38.44
19	11	19	8	64
20	7	8.5	1.5	2.25
21	6.9	6.5	0.4	0.16
22	5	5.2	-0.2	0.04
23	4	4.5	0.5	0.25
24	3.3	4.2	0.9	0.81
25	3	8.3	5.3	28.09
26	3	9.2	6.2	38.44
27	3	65	61.8	3819.24
28	3	6	3	4
29	3	5	2	4
30	3	4.5	1.5	2.25
31	3	4.7	1.7	2.89
			Sum	4069.9

RMSE = 11.46 m^3/s

Table 4.2 : RMSE Data for High Flow Simulation

Day(NOV)	observed	predicted	residual	$Residual^2$
1	30	5	-25	625
2	25	5	-21	441
3	22	5	-18	324
4	15	5	-13	169
5	12	6	-6	36
6	7	11	4	16
7	5	12	7	49
8	6	6	-2	4
9	6	5	-3	9
10	7	5	-2	4
11	5	6	1	1
12	5	6	1	1
13	4	15	11	121
14	8	17	8	64
15	7	9	2	4
16	6	6	0	0
17	8	8	-3	9
18	16	8	-8	64
19	17	7	-10	100
20	18	7	-11	121
21	20	6	-15	225
22	21	12	-11	121
23	23	13	-10	100
24	23	12	-12	144
25	30	70	-40	1600
26	57	80	23	529
27	90	24	-67	4489
28	42	22	-29	841
29	28	28	0	0
30	28	28	0	0
			sum	10211

RMSE = 18.45 m^3/s

Table 4.3 : NSE data for Low Flow Simulation

day (Jul)	observed	simulated	$(Yo-Ys)^2$	$(Yo-Ym)^2$
1	4	4	0	259.21
2	8	8	0	146.41
3	10	9	1	102.01
4	9	5.5	12.25	123.21
5	6	4.7	1.69	198.81
6	4.7	4.3	0.16	237.16
7	4.5	7	6.25	243.36
8	4.2	8.3	16.81	252.81
9	4	5.8	3.24	259.21
10	4	5	1	259.21
11	4	5.5	2.25	259.21
12	4	5.7	2.89	259.21
13	45	5	1600	620.01
14	5	6	1	228.01
15	4.5	7	6.25	243.36
16	5.8	6.2	0.16	204.49
17	7.8	5	7.84	151.29
18	9.8	16	38.44	106.09
19	11	19	64	82.81
20	7	8.5	2.25	171.61
21	6.9	6.5	0.16	174.24
22	5	5.2	0.04	228.01
23	4	4.5	0.25	259.21
24	3.3	4.2	0.81	282.24
25	3	8.3	28.09	292.41
26	3	9.2	38.44	292.41
27	3	65	3844	292.41
28	3	6	9	292.41
29	3	5	4	292.41
30	3	4.5	2.25	292.41
31	3	4.7	2.89	292.41
mean	6.532258	sum	5697.41	7398.06

The NSE for high flow is 0.23. Since the value of NSE is greater than zero, thus indicates that the model predictions for low flow can be accepted.

Table 4.4 : NSE data for High Flow Simulation

day (Nov)	Observed	simulated	$(Yo-Ys)^2$	$(Yo-Ym)^2$
1	30	5	625	98.01
2	25	5	400	24.01
3	22	5	289	3.61
4	15	5	100	26.01
5	12	6	36	65.61
6	7	11	16	171.61
7	5	12	49	228.01
8	6	6	0	198.81
9	6	5	1	198.81
10	7	5	4	171.61
11	5	6	1	228.01
12	5	6	1	228.01
13	4	15	121	259.21
14	8	17	81	146.41
15	7	9	4	171.61
16	6	6	0	198.81
17	8	8	0	146.41
18	16	8	64	16.81
19	17	7	100	9.61
20	18	7	121	4.41
21	20	6	196	0.01
22	21	12	81	0.81
23	23	13	100	8.41
24	23	12	121	8.41
25	30	70	1600	98.01
26	57	80	529	1361.61
27	90	24	4356	4886.01
28	42	22	400	479.61
29	28	28	0	62.41
30	28	28	0	62.41
mean	19.7	sum	9396	9563.1

The NSE for high flow is 0.017. Since the value of NSE is greater than zero, thus indicates that the model predictions can be accepted.

4.5.2 Evaluation Model by Using Root Mean Square Error (RMSE)

Referring to the Root Mean Square Error (RMSE) in Eq. (2.5), it is known that the smaller the RMSE value, the better the result. In this study, the Root Mean Square Error values obtained for the low and high flow comparison are 11.46 m^3/s and 18.45 m^3/s, respectively. This indicates that the simulation for low flow is more accurate compare to the high flow as the RMSE value is smaller. For the high flow simulation, the RMSE value is quite significant.

4.5.3 Evaluation Model by Using Nash-Sutcliffe Efficiency Coefficient (NSE)

According to the Nash-Sutcliffe Efficiency (NSE) coefficient equation in Eq. (2.6), an efficiency of 1 (NSE = 1) corresponds to a perfect match of modeled discharge to the observed data while, whereas an efficiency less than zero ($NSE < 0$) occurs when the observed mean is a better predictor than the. Essentially, the closer the model efficiency is to 1, the more accurate the model is. The NSE coefficient computed for the simulated and observed hydrographs comparison in this study are 0.23 for low flow and 0.017 for high flow. Since NSE values for low flow condition is higher than high flow, this means that the model performs better for low flow condition.

CHAPTER 5

RECOMMENDATION AND CONCLUSION

5.1 CONCLUSION

The hydrological scheme for the Muar River Basin has been successfully developed. The results obtained from this study shows that HEC-HMS 4.1 is able to simulate and estimate discharge of Muar River flows adopting the Clark's Unit Hydrograph transformation method. The overall results also indicate that the developed modelling scheme is sufficiently good in simulating hydrograph for low flow period but a little weaker for high flow period. Clark's Unit Hydrograph transformation method simulates river flows more reliably in the study catchment compared to other available method. Therefore, the Clark Unit Hydrograph method could be recommended as the best transformation method for the Muar basin

From the statistical error analysis we can conclude that the shape and pattern of the hydrographs fit sensibly. The RMSE obtained for the high flow and low flow are 18.45 m^3/s and 11.46 m^3/s, respectively. These RMSE values are considered acceptable as the errors of difference is not large. The simulation of the results shows that the rainfall-runoff relationship can be determined by using HEC-HMS. Besides, it also concludes that software HEC-HMS can be used to predict discharge using different set of rainfall data and Clark Unit Hydrograph Method is one of the methods that can be used for simulation in HEC-HMS.

5.2 RECOMMENDATIONS

Although the results obtained are satisfying, there are still room for improvement especially for the low flow condition. In order to improve the modeling scheme, it is recommended to divide the sub-basin into smaller areas or cells size so that the result can be more accurate. It is also recommended to perform the simulation using different modelling methods in HEC-HMS and the results obtained can be compared to determine the best method to estimate the stream flow in the Muar Basin. In addition, an adjustment of the value of the parameters can be made to fit the graph such as curve number and initial abstraction. The value of parameters must be selected according to the requirement of the elements and the land use of the catchment.

Besides that, site observation may be required to understand the study area in a better view so that the calibration values for curve number and initial abstraction can be chosen more accurately. The value of curve number and initial abstraction must be selected according to the requirement of the elements and the land use of the catchment. Nevertheless, in a situation where observed data is limited, the performance of HEC-HMS Model in estimating discharge hydrograph at a point of a stream network is considered good

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APPENDIX A

Parameters of each sub-basin of Muar River

Sub-basin	Area (km2)	Time Of Concentration, tc (hour)	Storage Coefficient, R
1	195.847	16.55096	16.50149
2	276.5035	49.16257	46.63528
3	139.06	28.3567	28.94937
4	212.0095	42.69269	41.14788
5	142.5557	26.57713	26.58442
6	230.7005	26.60541	27.09798
7	148.3543	19.59541	19.77108
8	118.1039	15.38929	16.47089
9	179.5259	24.787	25.98891
10	96.419	15.08012	15.5779
11	227.224	36.07252	36.28958
12	298.2854	46.97846	43.27845
13	200.0612	13.57835	14.77186
14	233	17.34013	18.53626
15	417.2169	34.76119	33.05319
16	214.8316	43.0495	44.08426
17	333.0066	12.4197	12.06774
18	103.7286	29.23028	30.25267
19	186.2815	32.81888	32.47172
20	150.5008	28.25949	29.36527
21	136.1308	30.94625	31.94134
22	333.5983	22.11608	20.0976
23	155.2191	31.96614	31.32234
24	154.7016	27.02511	27.56946
25	155.2317	28.20995	

APPENDIX B

Transform parameter for SCS Method

Reach	Lag (min)
1	9.930576
2	29.49754
3	17.01402
4	25.61561
5	15.94628
6	15.96325
7	11.75725
8	9.233574
9	14.8722
10	9.048072
11	21.64351
12	28.18708
13	8.14701
14	10.40408
15	20.85671
16	25.8297
17	7.45182
18	17.53817
19	19.69133
20	16.95569
21	18.56775
22	13.26965
23	19.17968
24	16.21507
25	16.92597

APPENDIX C

Rainfall data for each station

(RF 2025001)

Daily totals		Year 2010		site 20	25001 PI	NTU KAW	ALAN TG.	AGAS at	MUAR, J	OHOR		
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.5	0	0	7	0	16.5	8	0	0.5	0	10.5	0
2	19.5	0	1.5	18.5	0	0.5	3	0	13.5	6	0	3
3	10	0	0	27	0	0	0.5	11.5	11.5	0	0	0
4	0	0	0	0	0	5	0	1	10	0	0	6.5
5	0	12.5	4.5	0.5	0	4.5	0	0	0	7	2.5	0
6	9	0	2	0	0	0.5	0	17.5	13	0.5	12.5	0
7	1.5	46	0	4.5	0	0.5	0	4	0	0	6.5	0
8	0.5	0	0	0	15	0	0	35	0	0	2	0
9	0	11	0	12.5	3	0	0.5	12	0	0	4.5	18
10	0	3.5	0.5	0	0	0	0	0.5	4	0	0	0
11	0	0	0	0	8	0	29.5	0.5	0	0	11.5	0
12	0	6	24.5	0	0	0	0	0	0	42.5	1	0
13	0	0.5	7	7.5	0.5	0	19	8.5	0	0	2	0
14	0	0	61.5	0	0.5	7.5	0.5	9	0	0	3.5	0
15	0	0	6	0	0	19.5	4.5	0.5	0	0	0	7
16	0	0	0	0	0	0	0.5	7.5	3	1.5	0	8
17	0	0	0	58	0	0	0	12	0	0	2	12
18	0	3.5	1	0	40	0	7	8	0	0	0	0
19	0	0	0	0	0	0	0	14.5	0	0	1	0
20	1	0	0	0	0.5	0	0	0	0	0	1	12
21	0	3.5	6.5	0	0	136	0	0	3	6.5	0	1.5
22	63.5	15.5	0	0	12.5	11	0	0	3	0	2.5	0
23	41	0	6.5	0	0	64	17	0	10.5	2	0	0
24	0	0	0	0	0	22.5	0	0	0	0	0	0
25	0	0	0.5	0	0	2	0	0	0	0	6	0
26	0	0	8.5	25	6.5	41	0	0	30	6.5	0	0
27	0	0	0	0	0	9.5	58	51	5	1.5	0	0
28	0	0	0	0	0	43.5	0.5	3.5	0	1.5	0	0
29	0		0	0	0	0	15	0	0	5	11.5	0
30	0		6	2.5	64.5	16	1	0	72	7	9.5	0
31	0		0		0		1.5	0		27.5		0
Min	0	0	0	0	0	0	0	0	0	0	0	0.0 0.0
Tot 14	6.5	102	136.5	163	151	400	166	196.5	179	115	90	68.0 191
Max 6	3.5	46	61.5	58	64.5	136	58	51	72	42.5	12.5	18.0 136
NO>0.0	9	9	14	10	10	17	16	17	13	13	17	8 153

(RF 2225026)

Daily totals		Year 2010		site 22	25026 LD	G. ENG K	EE at TA	NGKAK,	JOHOR			
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	?	0	0	0	0	0	4.5	0.5	10.7	1.5	3.3	23.4
2	?	0	9.5	14	0	0	4	0	72.3	8	0.2	41.6
3	?	0	0.5	18.5	0	0	0	4.5	1	1.8	4	0
4	?	0	0	0	0.5	2	2	0	0	0.2	0	7
5	?	50.5	0	0	7.5	0	0	0	0	21.5	3.5	0
6	20.5	0	0	1	1.5	0	0	3.5	9	0	7	1.5
7	12.5	0	0	12	35	0	4	0	0	0	0	0
8	30	0	0	0	0	0	0	31	0	0	53.5	0
9	0	0	34.5	5.5	19	0	0	1	0.5	0	1.5	0.5
10	0	0	0.5	0	0	0	0	0.5	0	0	0	0
11	0	0	0	21	0.5	0	3.5	0	0	0	8.5	0.5
12	0	0	0	0	0	0.5	0.5	0	0	1	0.5	0
13	0	0	76.5	9.5	0	1.5	0	0	0	0	35.5	5
14	0	0	7	19.5	5	4.5	7.5	14	0	0	0.5	0
15	0	0	10.5	0	0	0.5	10.5	8	0	0	0	19.5
16	0	0	0	0	0	0	21.5	10	10	1.5	0	3.5
17	0	0.5	0	28.5	0	4	0	3	0	0	8.5	1
18	0	0.5	3	0	12.5	0	23.5	1.2	6	0	0.5	0
19	1.5	0	4	0	0	0	0	1.8	0	0	0.5	0
20	0	0	0	7.5	4	0	0	0	10	0	0	9
21	27	8.5	1.5	49.5	0	23.5	3.5	0	30	0	0	0.5
22	0	0	0.5	0	5	4	0	0	16	0	36.5	0
23	0	0.5	3	1	0	24.5	7	0.5	19.5	2	0	0
24	0	0	0	0	0	61	0	0	0.5	0	0	40
25	0	0	10	0	0	0	0	5	4	0	40.5	0
26	0	0	0.5	0.5	0.5	18	0	0	2	12	0	0
27	0	0	0	90	13.5	0.5	7.5	112.5	2.5	0	0	0
28	0	0	0	0	0	2	1.5	1	0	0	10.5	0
29	0		0	0	0	0	2	0.5	0	2.5	24.5	0.5
30	0		6	0	0	17	0.5	0	8.5	3.5	0	0
31	0		1		0		1.5	0		0		0
Min	0	0	0	0	0	0	0	0	0	0	0	0.0 0.0
Tot	91.5	60.5	168.5	278	104.5	163.5	105	198.5	202.5	55.5	239.5	153.5 182
Max	30	50.5	76.5	90	35	61	23.5	112.5	72.3	21.5	53.5	41.6 112
NO>0.0	5	5	16	14	12	14	17	17	16	11	18	14 159

(RF 2228016)

Daily totals		Year 2010		site 2	228016 L	DG. BAN	HENG at	MUAR, J	OHOR			
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	?	0	0	4	0	0	11	0	0	0	1.2	0
2	?	0	0	1	7	0	37.5	0.5	9	17	0	8.5
3	?	0	0	10.5	5.5	0	0	0	2	0	0	0
4	?	0	0	0.4	0	2.5	0.5	0	2.5	0	0	15.5
5	?	0	0	0.1	0	1.5	0.5	0	0.4	1	1	0.5
6	?	0	0	0	0	0	0	6.5	1.6	0	21	1.5
7	8.5	0	0	1	0	0	12.5	1	0	0	0	2.5
8	0.5	0	0	0	1	2	0	16.5	1	0.5	0.5	0
9	0	0	0.5	102.5	10	1.5	0	1	0	0	1	8
10	0	9	0	0	0	0	1	0	1	0	0	0.5
11	0	0.5	1	0	21	0.5	14	0	0.5	9.5	23.5	6.5
12	0	0	4.5	0	0.5	11.5	0	0	0	0	0	0
13	0	0	15	0.5	0.5	4	0	0	0	0	17.5	1.4
14	0	0	12.5	0	2.5	1	3	2	0	0	1	0.6
15	0	0	0	0	0	1.5	1	4	0	0	4.5	8.5
16	0	0.5	0	0	9.5	0	33.5	4.5	49	0	0	2.5
17	0	1	0	25	0	0	0	2	0	0	4.5	0.5
18	0	4	9.5	0	33	0	12	1.5	0	0	0	0.5
19	0	0	1.5	0.5	0	0	0	1.5	0	0	0	0
20	0.5	0	0	0.5	18	0	0.5	0	0	0	0.5	12.5
21	5	0.5	0.5	4	0	12	0	0.5	39	0	0	0
22	2.5	0	0	0.5	16	0	0	0	3.5	0	0.5	0
23	0	0	1.5	0	0	26.5	2	0	37.5	12.5	0.5	0
24	0	0	0	0.5	0	85.5	0	0	17.5	0	0	4
25	0	27	35.5	0	0	0	0	0	0	0	11.5	0
26	0	12	5.5	14.5	0.5	7.5	0	8.5	9.5	35	0	0
27	2	0	0	15.5	0	1.5	10	2	20.5	0	0	0
28	6	0	0	0	0	1.5	2	2.5	0	21	0	0
29	0.5		28	1	0	7	3	0	11.5	3	0.5	2
30	0		6.5	0	4.5	11.5	2.5	3	29.5	0	0.5	0.5
31	0		1		0		0	0		2.3		0
Min	0	0	0	0	0	0	0	0	0	0	0	0.0 0.0
Tot 2	5.5	54.5	123	182	129.5	179	146.5	57.5	235.5	101.8	89.7	76.5 1401
Max	8.5	27	35.5	102.5	33	85.5	37.5	16.5	49	35	23.5	15.5 102
NO>0.0	8	8	14	17	14	17	17	16	17	9	16	18 171

(RF 2326023)

Daily totals		Year 2010		site 23	26023 LD	G. BKT.	SERAMPA	at TAN	GKAK, JO	HOR		
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	?	0	0	0	0	1	23	0.5	0.3	0	0.6	0.5
2	?	0	0	3	0	0	13.5	0	27.2	11.5	0.4	6.5
3	?	0	0	21	0	0	0	0	0.5	0.5	2.5	0
4	?	0	0	0.5	1.5	0.5	4.5	0.5	0.5	0	0	10.5
5	?	69.5	0	2.3	4	0.5	0	0	0	88	2	0
6	0	0	0	0.2	0.5	0	0	17	11.5	0	19.5	11.5
7	11	1	0	6.5	7.5	5.5	0	1	0	0	0	3
8	4	0	0	0.5	24.5	0	0	49	0	33	11.5	0
9	0	6.5	0	3.5	0.5	1	0	0	0	2.5	0.5	9
10	0	0	0	0	0	0	25	0.5	0.5	0	0.5	4
11	0	0	0	0	17.5	2.5	7	0	0	0	10	3.5
12	0	0	0.5	0	0	0.5	0.5	0	0	0	1	0
13	1	0	24	0	20.5	21.5	0	0	0	0	99	3.5
14	0	0	18	2.5	14	5.5	22.5	7	0.5	0	1	0.5
15	0	0	0	0	0	0	10.5	5.5	0	0	0	49
16	0	1	0	0	10	0	45	25.5	36.5	0	0.5	4
17	0	1.5	0	42.5	0	19	0	7.5	0.5	0	24.5	2
18	0	8.5	5.5	0	11	0	31.5	2.2	0	0	0	0
19	0	0	9	5.5	0	0	0	0.3	0	0	1.5	0.5
20	39.5	0	0.5	1	6.5	0	1.5	0	36	0	0	15.5
21	5	0.5	6	3.5	0	33.5	4.5	0	9	0	0	0.5
22	0	0	0	0	5	1	0	2	45	0	1.5	0
23	0	2	7	0	0	17	11.5	0	1	22	0	0
24	0	0	0	1.5	0	53.5	0	0	1.5	0	0	0
25	0	0	0.5	0.5	0	0	0.5	2	0	2	76.5	10
26	0	14	0.5	3	2.5	9.5	0	0	6	59	0	0
27	0	0	0.5	2	0	0.5	4	6.5	8.5	3	0	0
28	0	0	0	0	0	0	1	1.5	13.5	0	1.5	0
29	0		32	2.5	21	0.5	0	0.5	0.5	13.5	11	0.5
30	0		14.5	0	1	11.5	0	0	28.5	0.5	0	0
31	0		1		0		1.5	0		0		0
Min	0	0	0	0	0	0	0	0	0	0	0	0.0 0.0
Tot	60.5	104.5	119.5	102	147.5	184.5	207.5	129	227.5	235.5	265.5	134.5 191
Max	39.5	69.5	32	42.5	24.5	53.5	45	49	45	88	99	49.0 99.
NO>0.0	5	9	14	18	16	18	17	17	19	11	19	18 181

(RF 2330009)

Daily total	Y	ear 2010		site 23	30009	LDG. SG.	LABIS at	LABIS,	JOHOR			
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.5	0	3.5	19	5.5	0	3	0	0	0	0	9.5
2	12.5	0	0	12.5	0	0	11	0	1.3	0.2	0	13
3	18	0	0	14.5	0	0	0.5	0	0.1	0	0	0.5
4	0.5	0	0	0	0.5	0	0	0	0	14.5	0	8
5	7	0	0	9	1	8.5	0	0	0	16.5	3.5	0
6	0	0	0	0.5	0.5	0	0	14	1.2	0	39	7.5
7	0.5	0	0	7	0	16	0.5	0	0	1	0	0
8	6.5	0	0	0	0	22.5	1.5	27.5	0.2	0	0	0
9	0	0	0	28.5	13	13.5	0	2.5	0	0.5	0	5
10	0	3.5	0	0	0	0	0	0	0.1	0	0	7.5
11	0	0	0	0	33.5	0	3	0	0	0	7.5	1
12	0	0	0	3	49	0	5.5	0	0	2.5	0	0
13	0	0	0	10	20	1	0	0	0	0	66	0
14	0	0	2.5	0	6.5	1.5	17.5	29.5	0	0	0.5	0
15	0	0	4.5	0.5	0	0	13.5	5	0.4	0	0	15
16	0	5.5	0	0	0.5	0	2.5	6	0	0	2.5	12
17	0	7	0	0	0	7	0	0	0	0	8	1
18	0	0.5	5.5	0	54.5	0	19.5	5.5	0	0	0	4
19	0	0	7.5	32.5	0	0	0	5.5	0	0	0	17.5
20	1.5	0	1	9.5	21.5	0	7	0	0.3	0	0	9
21	1.5	0	0	2	1	14.5	0	0	0	0	2	0.5
22	0	0	0	3	18	14.5	0	0	0.7	0	41.5	0
23	1	0	1.5	5	0	7	0	1.5	0	4.5	4	0
24	0	0	0	24.5	0	2	0	3.5	0	2	0	0
25	0	0	0.5	1	0	0	14	0	0	1	44.5	2.5
26	0	3	0	7	13	14.5	0	0	3	105.5	0.5	0
27	0	0	0	0	0.5	1.5	7.5	3.5	0.6	4.5	0	0
28	0	14.5	0.5	0	11.5	6.5	1	9.5	0	0	5	0
29	0		0	2	21.5	37	0	0	0.4	3.5	6	0
30	0		3.5	4.5	9.5	0	0	40	0	2.5	0	0.5
31	0		6.5		0		0.5	0		1.5		0
Min	0	0	0	0	0	0	0	0	0	0	0	0.0 0.0
Tot	49.5	34	37	195.5	281	167.5	108	153.5	8.3	160.2	230.5	114.0 153
Max	18	14.5	7.5	32.5	54.5	37	19.5	40	3	105.5	66	17.5 105
NO>0.0	10	6	11	20	19	15	16	13	12	14	14	17 167

(RF 2427001)

Daily totals		Year 2010		site 2	427001 F	ELCRA T	EBING TI	NGGI at	SEGAMAT	JOHOR		
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	8	0	0.3	0	0	0
2	0	0	0	14	0	0	0	0	9.2	3	0.5	9
3	27	0	0	8.5	0	0	0	0	0.5	0	1.5	0
4	38	0	0	14	0	0	0	0	3.5	0	0.5	7.5
5	0	0	0	0	0	0	0	0	0.5	15.5	2	0.5
6	7	0	0	7	0	4.5	8.5	6	17.5	0.5	9.5	8
7	24	0	0	0	4	0	0	0	1.5	0.5	0	0
8	0	4	0	0	58	0	1.5	38.5	18	0.5	4	0
9	0	2.5	0	0	0	0	0	0.5	0	0.5	0	10
10	0	0	0	0	12	0	0	0	0.5	0	0	0
11	0	0	0	0	0	0	8.5	0	0.5	0	6.5	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	4	15.5	0	1	0	0	7.5	0
14	0	0	0	15	0	0	18	1.5	0	0	19	0.5
15	0	0	0	0	6	0	0	3	17.5	0	0	4
16	0	10	0	20	0	0	0	57	2	0	20	8.5
17	0	21	0	12.5	21	28	0	2	0	0	7	1.5
18	0	0	0	4	0	0	24	2.5	0	0	7	2
19	7.5	0	0	3.5	0	0	0	0.5	0.5	0	0.5	3
20	4	0	0	31.5	0	0	0	0	28	10	0	4.5
21	0	0	0	0	13	21	0	0	0.5	0	0	2
22	0	0	0	5	0	0	0	0	37.5	0	8.5	0
23	0	4	0	0	0	0	0	0	0	11	0	0
24	2.2	0	0	0	0	74.5	0	0.5	0	0	20.5	6.5
25	2	0	0	4.5	0	5.5	7	0.5	0	4.5	56	5.5
26	2.3	?	0	0	0	6	0	1.5	2.5	69	0	0
27	0	0	0	0	0	0	5.5	1.5	4	4.5	0	0
28	0	0	0	15	20	0	0	0	9.5	1	0	0
29	0		78	0	30	52	0	0.5	88	22	23	0
30	3.5		30.5	0	0	2.5	0	0	8	0	0	0
31	0		0		0		4.5	0		23		0
Min	0	0	0	0	0	0	0	0	0	0	0	0.0 0.0
Tot	117.5	41.5	108.5	154.5	168	209.5	85.5	117	250	165.5	193.5	73.0 1684
Max	38	21	78	31.5	58	74.5	24	57	88	69	56	10.0 88.
NO>0.0	10	5	2	13	9	9	9	15	21	14	17	15 139

(RF 2428011)

Daily totals		Year 2010		site	2428011	LDG. SEG	AMAT at	SEGAMAT	JOHOR			
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	?	?	?	?	0	0	0	0	0	0	0	0.3
2	?	?	?	?	0	0	21.5	0	1	27	0	9.7
3	?	?	?	?	0	0	0.5	0	1	0	0	0.5
4	?	?	?	?	15	0	0	0	1	1	0	9
5	?	?	?	?	0	0	0.5	0	0	5.5	2	2
6	?	?	?	?	0	0	0	0	22	0	13.5	13
7	?	?	?	?	3.5	2.5	15.5	0	1	3	0	0
8	?	?	?	?	0	0	1	44.5	0	4	0	0
9	?	?	?	?	7	0	0.5	0.5	0	0.5	0	6
10	?	?	?	0	0	0	0	0	0.5	0	0	0.5
11	?	?	?	0	4	39	5	0	0	0	4	0
12	?	?	?	4	0.5	0	0	28.5	0	11	0.5	0
13	?	?	?	8	11.5	1.5	0	0	0	0	27	0
14	?	?	?	0	2.5	0	0	6	0	0	15	0
15	?	?	?	8.5	0	0	0	1.5	4.5	0	0.5	4.5
16	?	?	?	0	0.5	0	1.5	124.5	0	0	3	11
17	?	?	?	1	0	15.5	0	1	0	0	13.5	0.5
18	?	?	?	0	13	0.5	75.5	0.5	0	0	0.5	5
19	?	?	?	26.5	0	0	0	0.5	0.5	0	8.5	9.5
20	?	?	?	0.5	0.5	0	0.5	0	38.5	4.5	0	6
21	?	?	?	4.5	0	38.5	0	0	5	0.5	1	1.5
22	?	?	?	0	10	4	0	0	4.5	1.5	0	0
23	?	?	?	7.5	0	2	0	1.5	0	42.5	0	0
24	?	?	?	8	0	36.5	0	0	3	4.5	15	0
25	?	?	?	19	0	0	7	0	0	5.5	98.5	0
26	?	?	?	8	0	1	0	0	19	44.5	0.5	0
27	?	?	?	0	0	2.5	3	7	6.5	6	0	0
28	?	?	?	0	0.5	0	0	0.5	4	1.5	0	0
29	?		?	0	84	20	0	0.5	0	11	33	0
30	?		?	0	1	0	0	0.5	0	2	0	0
31	?		?		0		1	0		9.5		0
Min	?	?	?	0	0	0	0	0	0	0	0	0.0 0.0
Tot	?	?	?	95.5	153.5	163.5	133	217.5	112	185.5	236	79.0 1375
Max	?	?	?	26.5	84	39	75.5	124.5	38.5	44.5	98.5	13.0 124
NO>0.0	0	0	0	11	14	12	13	14	15	19	16	15 129

(RF 2626002)

Daily totals		Year 2010		site	2626002	LDG. GOM	at BATU	ENAM,	JOHOR			
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	?	?	?	?	?	?	63	?	?	?	0.5	0
2	?	?	?	?	?	?	3.5	?	?	?	0	5
3	?	?	?	?	?	0	1	?	?	?	0	2
4	?	?	?	?	?	0	0	?	?	?	0	8
5	?	?	?	?	?	0	0	?	?	?	0	9
6	?	?	?	?	?	0	0	?	?	?	11	10
7	?	?	?	?	?	39.5	7	?	?	4	33	0
8	?	?	?	?	?	0	0.5	?	?	0	0	2
9	?	?	?	?	?	6.5	0	?	?	0	0	22
10	?	?	?	?	?	0	0.5	?	?	0	0	28
11	?	?	?	?	?	0	0	?	?	0	2	0
12	?	?	?	?	?	5.5	0	?	?	0	0	0
13	?	?	?	?	?	34	?	?	?	0	2	0
14	?	?	?	?	?	6	?	?	?	8.5	43	0
15	?	?	?	?	?	0	?	?	?	0	0	1
16	?	?	?	?	?	0	?	?	?	0	0	5.5
17	?	?	?	?	?	15	?	?	?	0	20	17.5
18	?	?	?	?	?	0.5	?	?	?	0	0	3
19	?	?	?	?	?	0	?	?	?	0	0	13.5
20	?	?	?	?	?	0	?	?	?	0	0	7
21	?	?	?	?	?	38.5	?	?	?	0	10	1
22	?	?	?	?	?	2	?	?	?	74	0	0
23	?	?	?	?	?	5	?	?	?	7.5	0	0
24	?	?	?	?	?	10.5	?	?	?	6.5	20	0
25	?	?	?	?	?	0	?	?	?	0.5	9	0
26	?	?	?	?	?	1	?	?	?	55.5	0	0
27	?	?	?	?	?	0	?	?	?	5	0	0.5
28	?	?	?	?	?	0	?	?	?	6.5	0	0
29	?		?	?	?	1.5	?	?	?	8.5	14	0
30	?		?	?	?	27.5	?	?	?	0	0	0
31	?		?		?		?	?		16		0
Min	?	?	?	?	?	0	0	?	?	0	0	0.0 0.0
Tot	?	?	?	?	?	193	75.5	?	?	192.5	164.5	135.0 76
Max	?	?	?	?	?	39.5	63	?	?	74	43	28.0 74.
NO>0.0	0	0	0	0	0	14	6	0	0	11	11	16 58

(RF 2628001)

Daily totals		Year 2010		site	2628001	LDG. MAD	SERMIN	at JOHOR				
Rain mm												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	?	?	?	?	0	0	9.5	0	0	0	0	0
2	?	?	?	?	0	0	8.5	0	0.5	9.5	0	35.6
3	?	?	?	?	2.5	0	0.5	0	1	0	0	3.4
4	?	?	?	?	0	0.5	0.5	0	6	3.5	0	11
5	?	?	?	?	0	0	0	0	1.4	15.5	2	20
6	?	?	?	?	0	0	0.5	0	2.6	0	21.5	5.5
7	?	?	?	?	1	65.5	24.5	0	0	9.5	0	0
8	?	?	?	?	0	0.5	1.5	22	0.5	0	1	0
9	?	?	?	64.5	2	0	0	7.5	0	0.5	0	16.5
10	?	?	?	0	0	0	0	0	0	0	0	8.5
11	?	?	?	0	0	21	0	0	0	0	1	0
12	?	?	?	0	1.5	2	0	2	0	41.5	0	0
13	?	?	?	26	11.5	0	0	8	0	0	7.5	0
14	?	?	?	0	7.5	0	0	0	8	0	0	0.5
15	?	?	?	0	0	0.5	0	0.5	65.5	0	0	1
16	?	?	?	0	17	0	0.5	16.5	3	0	0	20
17	?	?	?	5	0	13	0	5	0	0	14	1
18	?	?	?	0	2	2.5	38.5	13	0	0	0.5	5.5
19	?	?	?	9.5	0	0	0	0	4	0	11	35.5
20	?	?	?	0	1	0	0	0	9	0	0	8
21	?	?	?	0	0	36	5	0	0	11.5	0	0.5
22	?	?	?	1.5	33	4	0	0	0.5	58	5.5	3
23	?	?	?	0	0	1	0	0.5	0	52.5	10	0
24	?	?	?	0.5	5.5	4.5	0	0.5	2.5	39.5	0	0
25	?	?	?	14.5	0	6.5	39.5	2	1	0	109	39
26	?	?	?	3	0	0	0	0	22.5	13	0.5	0
27	?	?	?	0	0.5	0	0	8.5	57.5	5	0	0
28	?	?	?	0	0	0	0	0	0	7	5.5	0
29	?		?	1	7	14	0	0	0	0.5	0.5	0
30	?		?	0	0	0.5	0	0.5	0.5	5.5	0	0
31	?		?		0		1.5	0		26		0.5
Min	?	?	?	0	0	0	0	0	0	0	0	0.0 0.0
Tot	?	?	?	125.5	92	172	130.5	86.5	186	298.5	189.5	215.0 149
Max	?	?	?	64.5	33	65.5	39.5	22	65.5	58	109	39.0 109
NO>0.0	0	0	0	9	13	15	12	13	17	16	14	18 127

APPENDIX D

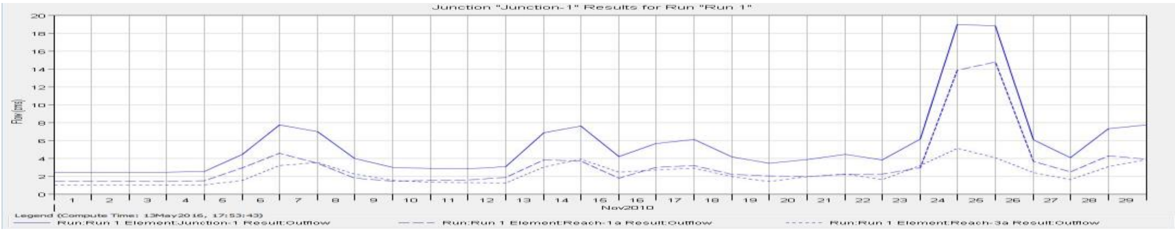
Streamflow Data Station (SF 2528414)

Daily means		Year 2010		site 25	28414 SG.	SEGAMAT	at SEG	AMAT JOH	R			
Flow m3/s												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4	2.5	1.7	3.5	2.6	5.5	12	2.3	5.6	14.6	25.1	27.2
2	3.9	2.4	1.6	4.7	2.4	4.2	8	2.1	2.8	11.3	26.2	25.6
3	5.3	2.3	1.6	4.9	2.2	3.6	10.1	2.1	2.5	9.8	22.1	26.6
4	22.1	2.1	1.6	7.2	2	3.1	8.8	2.1	2.5	8.5	17.5	32.9
5	19.4	2	1.6	5.4	3.6	2.8	6.1	1.9	2.5	5.6	12.2	42.2
6	18.5	1.9	1.5	3.9	2.7	2.9	4.7	1.9	2.5	4.4	5.9	32.5
7	27.3	1.9	1.4	3.4	2.1	2.5	4.3	1.9	2.5	4.4	5	26.1
8	32.2	1.8	1.4	3.3	2.3	5.5	4.1	2.2	2.5	4.4	6.5	25.8
9	21.6	1.8	1.3	3	2.1	8.6	4	6.2	2.5	4	6.5	26.5
10	15.2	1.7	1.3	4.6	3.6	5.5	4	6.2	2.5	3.7	5.3	25.7
11	11	1.7	1.2	6	4.8	4	4	4.4	2.5	3.9	4.4	23.5
12	10	1.6	1.2	3.7	3.2	4.1	4	3.4	2.4	4.7	4	21.6
13	8.7	1.5	1.2	2.9	2.7	4.3	4.5	6.3	2	4.6	3.7	20.3
14	5.7	1.7	1.2	20.8	7.5	3.7	5	5.7	1.9	4.6	8.9	18.5
15	4.5	1.9	1.3	16.6	4.8	3.5	4.6	7	1.9	4	7.2	16.7
16	4.3	1.9	1.4	5.2	5.1	3.5	5.8	16	2.7	3.4	6	16.4
17	4	2.6	1.3	3.6	4.1	3.4	7.8	65.3	3.7	3.4	11.2	12.6
18	3.7	5.8	1.3	4.1	4	3.1	9.8	22.8	3.7	4.1	16.7	10.1
19	3.4	4.3	1.3	3.9	4.7	3.8	11.1	14.8	3.2	5.9	18.1	12.5
20	3.7	3.1	1.6	8.9	3.9	6.3	6.8	11.8	3.9	7.6	18.1	31.3
21	5	2.5	1.7	7.2	3.4	8.9	6.7	11	6.3	9.4	19.9	26.1
22	10.3	2.1	1.9	4.3	3.1	13.3	4.6	10.7	6.3	11.2	21.8	17
23	5.6	2	1.9	3.6	6.6	31.2	3.8	10.2	6.3	12.9	23	14.6
24	4.4	1.9	2.7	3.8	5.7	11.4	3.4	7.2	5.4	14.7	22.9	13
25	3.8	1.9	2.3	3.3	3.8	27.2	3	4.3	3.7	16.7	30.2	12.1
26	3.4	1.8	1.9	3.2	3.1	17.4	3.1	3.4	3	20.3	57.3	13
27	3.6	1.7	1.8	3.2	2.7	7	3.4	2.9	13.1	30	90.6	10.5
28	3.7	1.7	1.6	3.4	2.5	5.4	2.9	3.6	46.1	45.1	41.7	8.4
29	3.3		1.4	2.7	2.5	5.5	2.7	4.9	49.7	27.5	26.9	6.4
30	3		1.3	2.8	16.6	9.4	2.5	3.3	21.8	23.8	27.2	4.9
31	2.8		1.6		11.2		2.4	6.2		22.8		4.8
Min	2.8	1.5	1.2	2.7	2	2.5	2.4	1.9	1.9	3.4	3.7	4.8 1.2
Mean	9	2.2	1.6	5.2	4.2	7.4	5.4	8.2	7.3	11.3	19.7	19.5 8.5
Max	32.2	5.8	2.7	20.8	16.6	31.2	12	65.3	49.7	45.1	90.6	42.2 90.

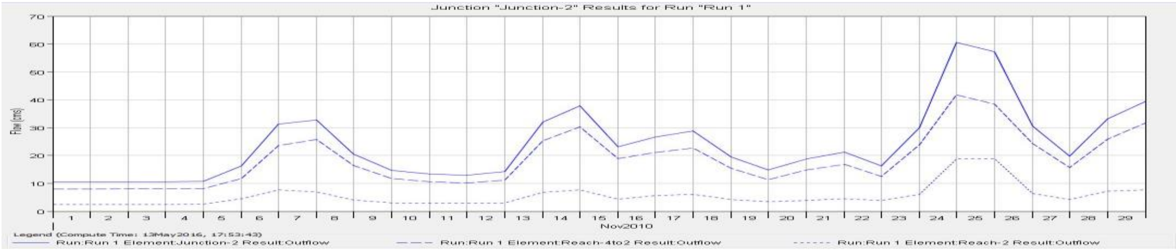
APPENDIX E

Simulated hydrograph for high flow at all junction

Junction 1

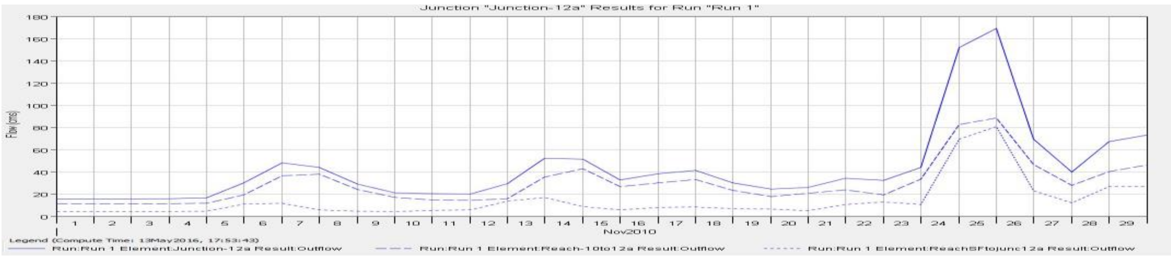


Junction 2

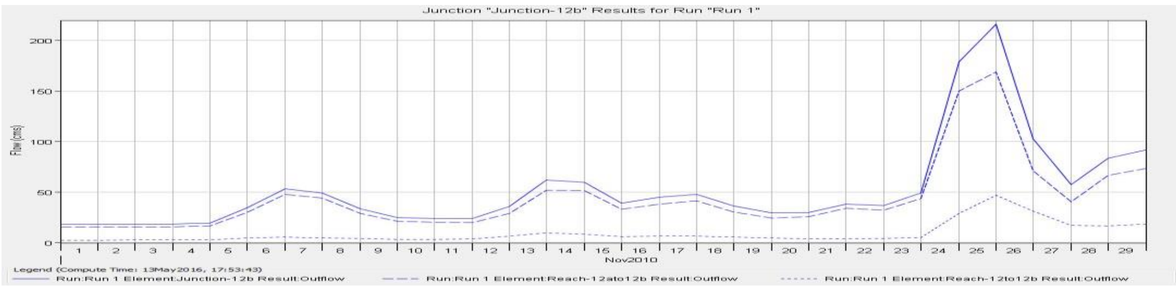


Junction 10

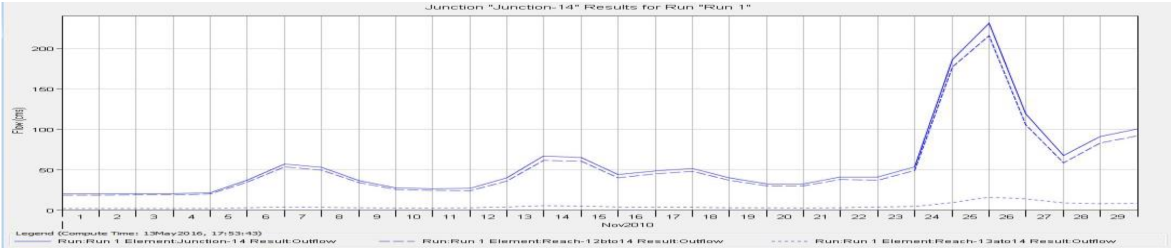
Junction 12a



Junction 12b



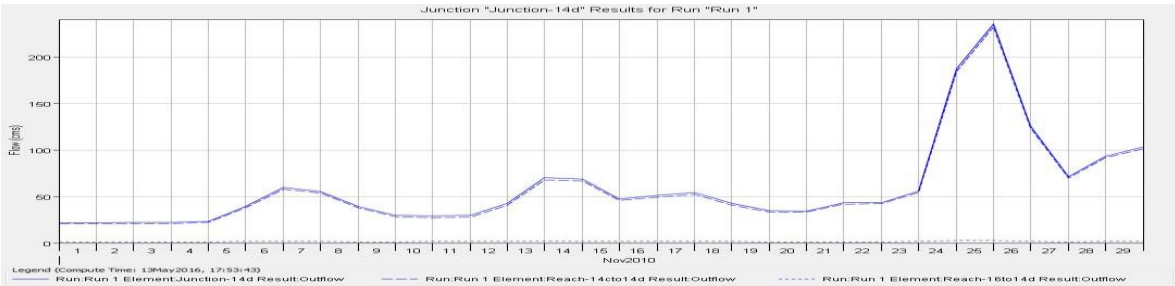
Junction 14



Junction 4b1

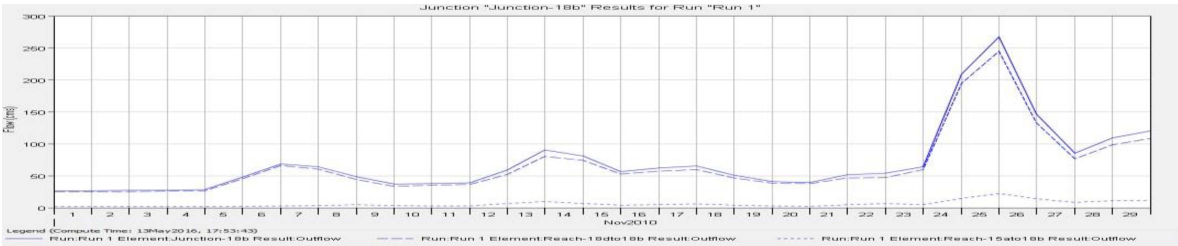
Junction 14c

Junction 14d

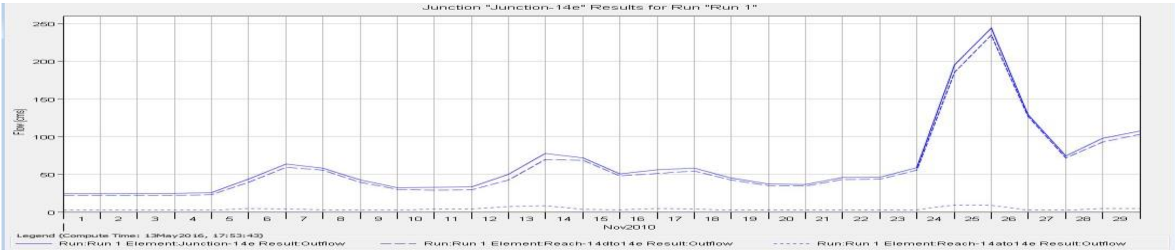


Junction 18c

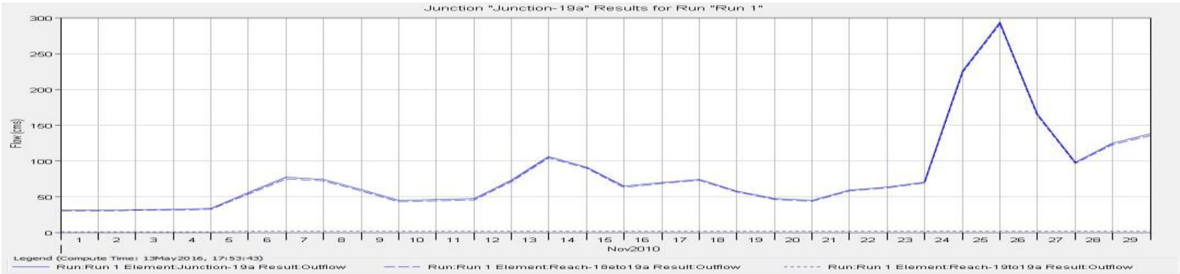
Junction 18b



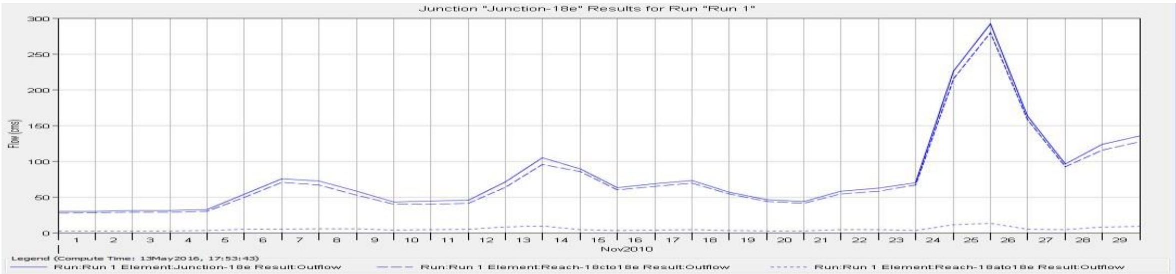
Junction 14e



Junction 19a



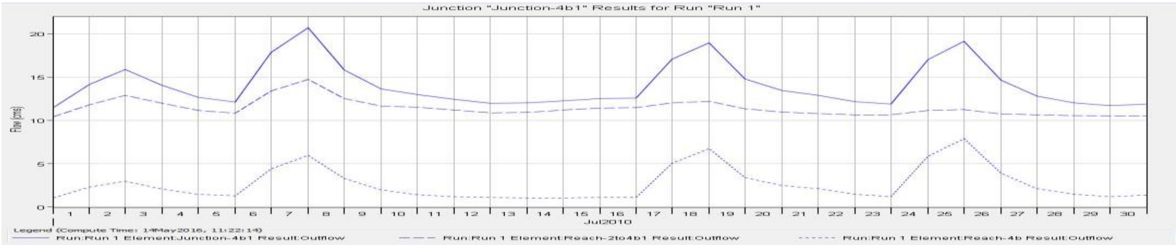
Junction 18e



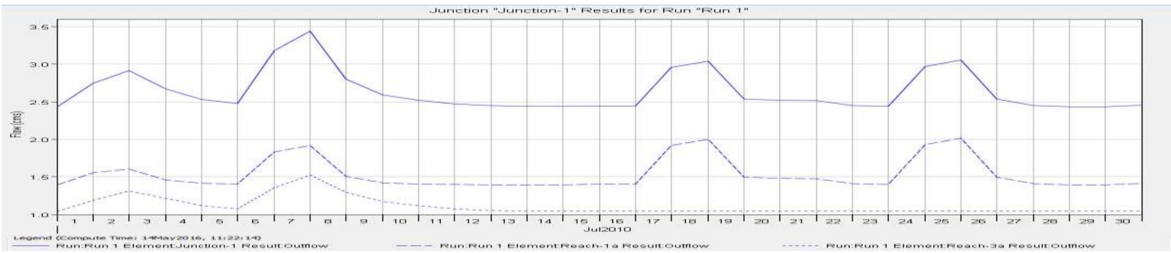
APPENDIX F

Simulated hydrograph for low flow at all junction

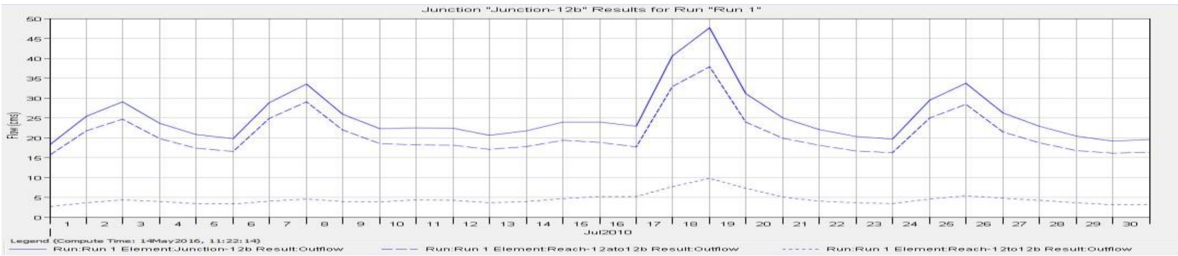
Junction 1



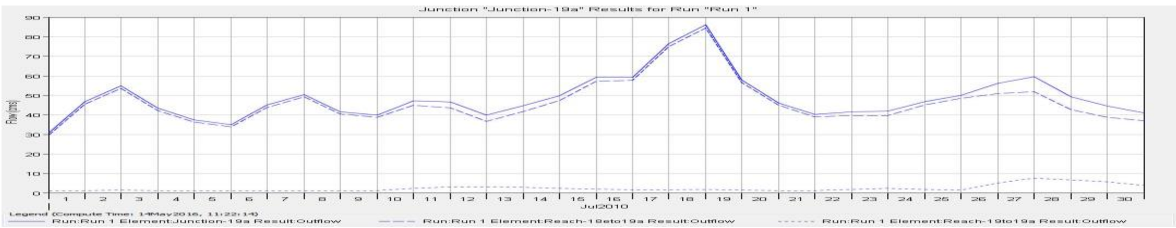
Junction 2



Junction 10



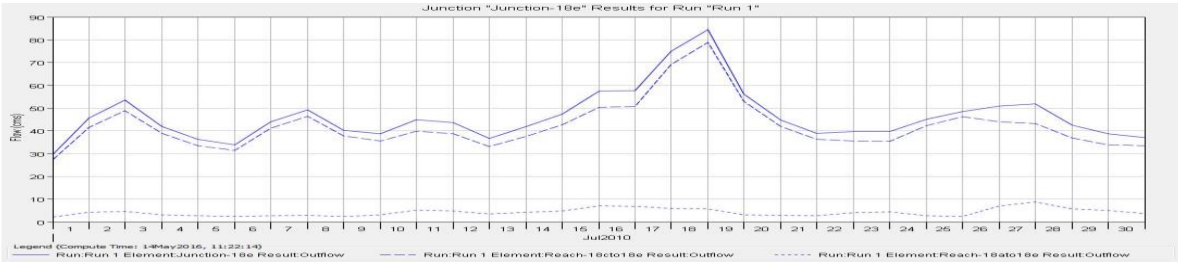
Junction 12a



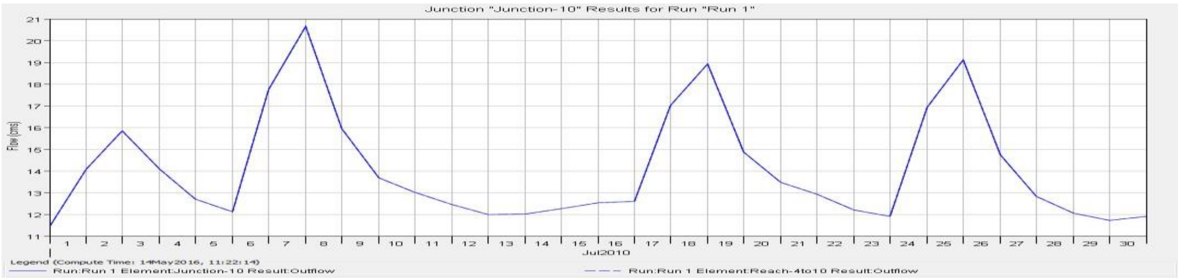
Junction 12b

Junction 14

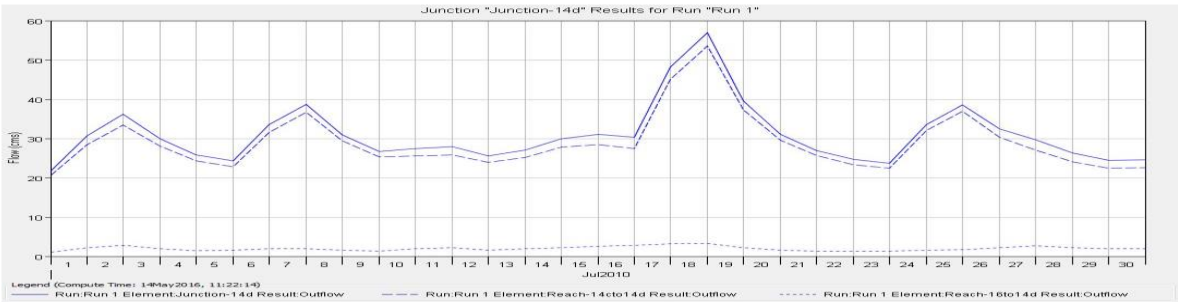
Junction 4b1



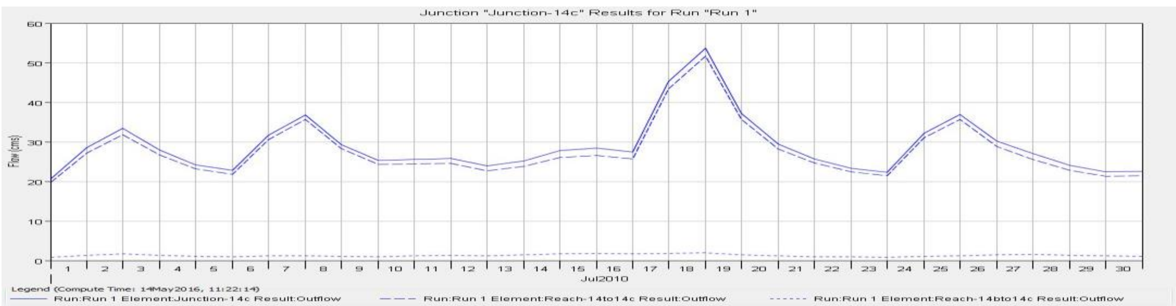
Junction 14c



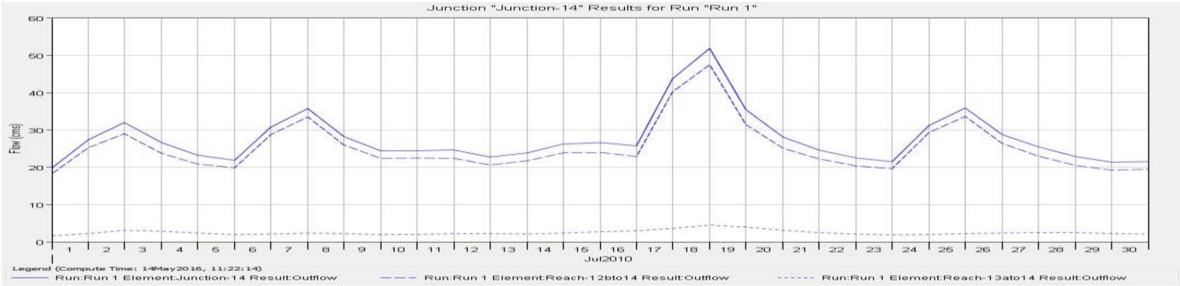
Junction 14d



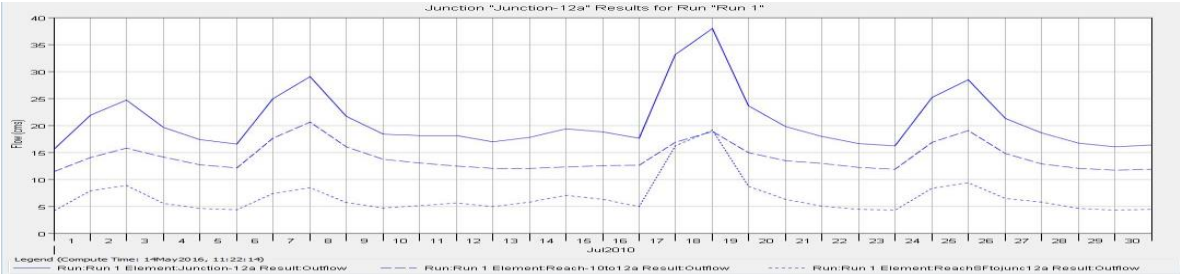
Junction 18c



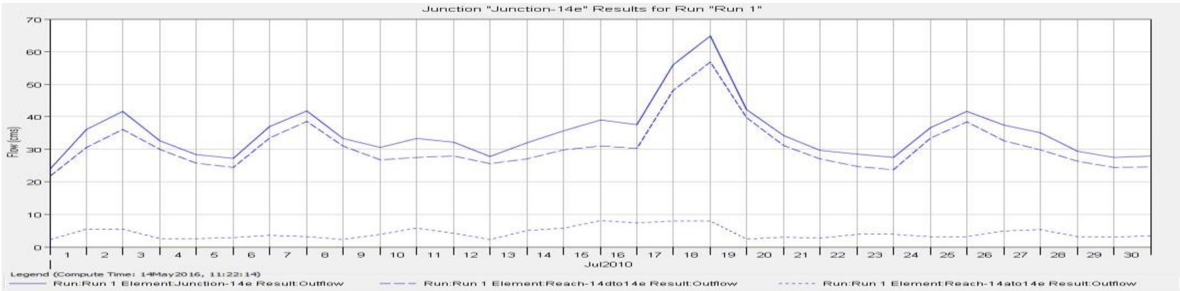
Junction 18b



Junction 14e



Junction 19a



Junction 18e