ESTABLISHMENT OF DESIGN STREAMFLOW HYDROGRAPH IN THE ROMPIN RIVER BASIN

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ABSTRAK

Lembangan Sungai Rompin salah satu kawasan daerah di Malaysia yang sering terjejas oleh banjir. Terdapat dua jenis banjir yang berlaku di Lembangan Sungai iaitu banjir monsun dan banjir kilat. Sejak masalah banjir dikenakan kesan yang tinggi terhadap ekonomi sosial dan kesejahteraan seperti korban dan harta benda yang rosak. Adalah penting untuk memahami proses hidrologi yang melibatkan lembangan sungai untuk seterusnya mengurangkan isu banjir. Tujuan kajian ini adalah untuk mensimulasikan, menentukur dan mengesahkan modul hidrografi dan membangunkan Curian IDF dan merancang hujan untuk Sungai Rompin. Model hidrologi dalam kajian ini adalah model HEC-HMS. Data hidrologi yang dikumpul untuk 6 stesen hujan dan 2 stesen aliran sungai dari tahun 1990 hingga 2013 digunakan sebagai data masukan untuk proses pengesahan dan ramalan. Corak hujan yang direka untuk stesen-stesen terpilih ditentukan untuk Interval Gelombang Purata (ARI) selama 2 tahun, 5 tahun, 10 tahun, 50 tahun dan 100 tahun berdasarkan Curves Frequency-Frequency-Intensity (IDF) yang dibangunkan. Untuk pemodelan hidrologi, hidrograf Unit Clark dipilih sebagai kaedah transformasi larian hujan untuk kajian ini di mana parameter Tc dan R dianggarkan menurut Prosedur Hidrologi 27 yang dibangunkan oleh Jabatan Pengairan dan Saliran (JPS) Malaysia. Nombor Curve SCS digunakan sebagai kekasaran permukaan, manakala untuk aliran asas dan aliran laluan, bulanan tetap digunakan. Melalui kajian ini, hasil kajian menunjukkan bahawa model HEC-HMS dapat mensimulasikan aliran hidrograph sungai untuk Sungai Rompin semasa musim aliran tinggi. Ramalan pola aliran aliran masa depan untuk seluruh lembangan dibangunkan berdasarkan ARI yang ditetapkan. Hasil kajian ini adalah penting untuk dijadikan alat sokongan membuat keputusan untuk reka bentuk banjir tebatan. Selain itu, ia juga dapat memberikan jumlah air untuk kejadian hujan tertentu yang penting untuk operasi dan pengurusan di Sungai Rompin dan bekalan air banjir.

ABSTRACT

The Rompin River Basin one of the district area in Malaysia that often affected by flood. There are two types of floods occur in the River Basin namely the monsoon flood and flash flood. Since flood problems imposed high impact on the social economy and well-being such as casualties and properties damaged. It is important to understand the hydrological processes involved river basin to subsequently mitigate the flood issues. The purpose of this study are to simulate, calibrate and validate the hydrographical module and develop the IDF Curve and design rainfall for the Rompin River Basin. Hydrological model in this study was the HEC-HMS model. Hydrological data collected for 6 rainfall stations and 2 streamflow stations from 1990 to 2013 were used as the input data for verification and prediction processes. Designed rainfall patterns for the selected stations were determined for the Average Recurrence Interval (ARI) of 2 years, 5 years, 10 years, 50 years and 100 years based on the developed Intensity-Duration Frequency (IDF) Curves. For the hydrological modelling, Clark Unit hydrograph was selected as the rainfall runoff transformation method for this study in which the parameters Tc and R were estimated according to the Hydrology Procedure 27 developed by the Department of Irrigation and Drainage (DID) Malaysia. The SCS Curve Number is used as the surface roughness, while for the baseflow and lag routing, constant monthly is used. Through this study, the results show that the HEC-HMS model can sufficiently simulate streamflow hydrograph for Rompin River Basin during high flow season. Prediction of future streamflow patterns for the entire basin were developed based on the designated ARI. The outcome of this study are important to serve as decision-making supporting tool for the design of flood mitigation. Besides, it can also provide water volume for a certain rainfall event which is essential for the operational and management in Rompin River Basin water supply and flood control.

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LIST OF SYMBOLS

A	Catchment Area (kilometre square)
S	Weighted Slope of the Main Stream (kilometre)
L	Main Stream Length (kilometre)
R	Storage Coefficient (hour)
Tc	Time of Concentration (hour)
Q_B	Base flow (m^3/s)
i	Average Rainfall Intensity (mm/hr)
ARI	Average recurrence interval
T	ARI ($0.5 \leq T \leq 12$ month and $2 \leq T \leq 100$ year)
d	Storm duration (hours), $0.0833 \leq d \leq 72$
λ, κ, θ and η	Fitting constants dependent (Table 2. B1 in MSMA2)
y	observed discharge for RMSE calculation
yi	simulated discharge for RMSE calculation
Obs	Observed Discharge
Sim	Simulated Discharge
Omean	Mean of Observed Discharge

LIST OF ABBREVIATIONS

CN	Curve Number
DEM 30m	Digital Elevation Model 30m
DID	Department of Irrigation and Drainage
GIS	Geographic Information System
HEC-HMS	Hydrologic Engineering Centre- Hydrologic Modelling System
USDA	United Stated Department of Agriculture
HP-27	Hydrological Procedure 27
MSMA2	Urban Storm Water Management Manual for Malaysia 2
NSE	Nash-Sutcliffe Efficiency
RMSE	Root Mean Square Error
RRB	Rompin River Basin
SCS CN	Soil Conservation Service Curve Number
SRTM	Shuttle Radar Topography Mission
UH	Unit Hydrograph
USACE	United States Army Corps of Engineers

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is well-known for its tropical humid climate with year-round rainfall which contributes to the high rate of water resources (Tahir,2007). However, at some point or certain event, excessive water flow causing the occurrence of the floods. Pahang is a wet state and abounds with streams, even in gently undulating areas. This encourage agriculture activities at the low lying region. The streams passing through the basins serve as irrigation demands or ponds dug for agricultural activities. Pahang consists of several districts that are active in agriculture. Most of the agriculture irrigation schemes are located within the Rompin and Pekan District.

Rompin District is often effected by flood particularly during the Northeast Monsoon season which occurs between October to March (Suhaila and Jemain,2007). This phenomenon has been proven in the report IADP Rompin-Endau Scheme (Ranhill Consulting Sdn Bhd, 2011). The total flood prone areas in Rompin is reported be about 1100 km^2. According to DID flood report, the worst flood event happened in the Rompin District year 2007 where the highest water level was recorded at is 45 m that exceeding the danger level of 35.4m as shown in Table 1.1.

The unpredictable flood event in the Rompin District due to climate change has made it harder to design the hydrologic structure for flood mitigation and other purpose. Hence, Malaysia has produced several procedures and standards to be considered in future flood study such as Hydrological Procedure (HP1) and Urban Storm Water Management Manual for Malaysia (MSMA2). These hydrological procedures were used in this study to develop the IDF Curve and design temporal rainfall pattern. Furthermore, Hydrological Procedure (HP27) was referred to establish hydrological modelling setup for the simulation of streamflow hydrographs in The Rompin River Basin.

Hydrological modelling required rainfall data as the input which was then transform into runoff subsequently generated the streamflow pattern. The most commonly used hydrological modelling that can be downloaded without charges is the is Hydrologic Engineering Centre – Hydrologic Modelling System (HEC-HMS) for determining runoff process and predicting streamflow patterns (Razi et.al., 2010).

With application of the HEC-HMS hydrologic model, the rainfall-runoff relationship can be obtained by producing a hydrograph (Tassew,2019). By utilising the rainfall and streamflow data collected from the Department of Irrigation and Drainage (DID), a hydrological model was setup to represents the basin's hydrological response to the streamflow pattern in the Rompin River. Despite streamflow pattern, the hydrologic model also provides water volume information which is important when dealing with potential drought or flood (Yusop et.al.,2007).

Table 1.1 : Flood Level in Rompin District (2007) Based on DID Report

River	Water Level (m)	Warning Level (m)	Danger Level (m)
River. Pukim	45.00	35.20	35.40
River. Keratong (Kg. Rekoh)	27.30	29.20	29.40
River. Keratong (Bkt. Serok)	22.98	23.70	23.90
River. Rompjn (Kg. Kerpai)	5.10	3.00	3.20
Jln. Kg. Kurnia	1.60	2.20	2.40
River. Rompin (Kg. Gadak)	14.38	10.50	10.70
River. Rompin (Kg. Aur)	19.94	16.00	16.20
River. Rompin (Jam. Sabak)	3.32	2.20	2.40

1.2 Problem Statement

High precipitation brought by the Northeast Monsoon season to the Rompin River Basin between the month of October to March contributes huge amount of runoff into the river system. As the consequences, overflows and induced flood at river banks, downstream and lowland areas which further lead to damage of properties and loss of human lives. Thus, flood mitigation study has become essential to seek for better solution in solving the flood issues. In flood study, hydrological information such as rainfall and streamflow data are crucial to estimate the amount of rainfall runoff. However, most of the rivers in Malaysia including the Rompin River Basin have very limited streamflow data that can be used for hydrograph analysis. This limitation consequently leads to the lacking of study flood since the analysis has become complicated when data for reference is insufficient. Additionally, there is very limited available flood study for the Rompin River Basin indicating restricted hydrological scheme module that can be referred to perform predictive simulation of the potential floods. Thus, the flood study in the Rompin River Basin would require an entirely new hydrological modelling setup for the streamflow hydrograph generation.

HEC-HMS hydrological model is the most widely used in conducting flood studies. The hydrological model is able to analyse the streamflow process and determine the rainfall-runoff processes in the Rompin River Basin. The HEC-HMS model includes various hydrologic analysis procedures such as infiltration, unit hydrographs and hydrologic routing. Moreover, for future estimation streamflow, HEC-HMS also includes necessary procedures for continuous simulation.

Considering the unpredictable rainfall pattern in the Rompin River Basin, there is a need to develop IDF Curve and design rainfall for this area and simulate the streamflow discharge for the Rompin River Basin. The MSMA2 and HP1 hydrological guidelines are useful in developing IDF Curve for all selected rainfall stations and design rainfall pattern in Rompin River Basin. For the Rompin District, only 4 readily available IDF Curve presented in MSMA2. Therefore, it is essential to develop IDF Curve for the other rainfall stations that not included in MSMA2.

Either than that, the limited information of flood prediction study in the Rompin River Basin makes it difficult to predict the potential flood in future. Lack of the rainfall pattern and streamflow hydrograph information, the area will be difficult to predict the flood situation in future. Design rainfall pattern is essential to generate the designed streamflow hydrograph that can be used in future flood study and helped policy makers to make decisions on water planning and management for areas within the Rompin River Basin.

1.3 Objectives of Study

The objectives of this research are as the following:

a) To generate, calibrate and validate design rainfall event & streamflow hydrograph for Rompin River Basin.
b) To develop Intensity Duration Frequency (IDF) Curve and design rainfall for Rompin River Basin to generate design streamflow hydrograph.

1.4 Scope of Study

In this scope of research, the hydrological area selected is the Rompin River Basin. In this basin, there are 6 existing rainfall stations and 2 streamflow stations. Data of rainfall and streamflow collected and utilized in this study were from 1990 to 2017. Since this study focused on flood management, only the data for wet periods were used for analysis. The sub-basins were generated based on the data from the digital elevation model. For the distribution of rainfall in the sub-basins, they were compiled using Thiessen Polygon method in references to the location of the rainfall stations. Basin map and hydrological data from GIS Software and Department of Irrigation and Drainage (DID) were collected and analysed for model input in HEC-HMS.

In HEC-HMS hydrological model, there are 3 main components namely the Basin Model, Meteorological Model, and Control Specification. The methods selected for the loss, transformation, baseflow and routing in the Basin Model were SCS CN, Clark Unit Hydrograph, monthly constant, and Muskingum Cunge, respectively. For the Meteoroidal Model, the rainfall data distribution adopted was the rainfall hyetograph. The period of rainfall event chosen in this study focused on the wet season. A total of 3 rainfall events were applied for the calibration and validation processes.

The streamflow pattern can be used in prediction of potential flood in future. In order to perform the flood prediction, it required several steps which includes the Intensity-Duration-Frequency (IDF) Curves and design rainfall. The IDF Curves and design rainfall is the most commonly used in design storm events which can produce the streamflow hydrograph pattern. The IDF Curve for all the rainfall stations were developed using the Gumbel's statistical method and designed for rainfall of 2-year, 5-year, 10-year, 50-year and 100-year ARI following the procedure in MSMA2 and Hydrological Procedure 1 (HP1). In the hydrological modelling, the calibration and validation processes were conducted by comparing the simulated streamflow result from the model with the observed data. Since the time concentration estimated in MSMA2 is in 3 days, the design rainfall depth can be determined in reference to the temporal rainfall pattern table in MSMA2.

1.5 Significance of Study

The finding of this study revealed the hydrological scheme developed hydrological model. The hydrological model is set up by entering the data based on the 3 basic component of the model which are basin model, meteorological model and control specification. Hydrological scheme is important as the preparation for entire hydrological and hydraulics modelling processes. The methods selected for the loss, transformation, baseflow and routing in the Basin Model were SCS CN, Clark Unit Hydrograph, monthly constant, and Muskingum-Cunge, respectively. For the Meteoroidal Model, the rainfall data distribution adopted was the rainfall hyetograph. The period of rainfall event chosen in this study focused on the wet season. A total of 3 rainfall events were applied for the calibration and validation processes.

This study also revealed the streamflow hydrograph pattern of Rompin river Basin. The hydrograph can be used as input in hydraulic model for flood level. This study simulated the rainfall-runoff relationship of Rompin River Basin by using HEC-HMS. After the validation and calibration process were completed, the hydrological scheme established with the input of the design rainfall for all the ARI is were utilised to predict the pattern of streamflow hydrograph. The results obtained are useful to solve and seek better solution to mitigate flood problems in the Rompin River Basin. Furthermore, it can also assist policy makers to make decisions on water planning and management for areas within the Rompin River Basin.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Water is essential for all living things to maintain life and survive. (Martino,2003). Water is produced through natural water cycle and environment where the water supply is mainly coming from rivers and streams. However, it also can be a disaster when there is too much of it and not properly managed. therefore, it is important to understand the hydrological processes of an area as the basic knowledge of water resource management.

2.2 Hydrology

Hydrology can be simply defined as a study of water. The term hydrology is the study of earth, their occurrence, circulation and distribution, their chemical and physical properties and their reaction with the environment including their relation to living things (Ray, 1975). It also deals with the relationship of water with the environment within each phase of hydrologic cycle. Due to rapid urbanisation and industrialisation including deforestation, land cover change, irrigation, various changes have been occurred in hydrologic systems. Along with climate change, soil heterogeneity has also got a direct impact on the discharges of many rivers in and around the world.

Different hydrologic phenomena and hydrologic cycle are to be thoroughly studied in order to find out these variations. Now days, various hydrological models have been developed across the world to find out the impact of climate and soil properties on hydrology and water resources. Each model has got its own unique characteristics. The inputs used by different models are rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology and other physical parameters. All these models can be applied in very complex and large basins.

2.3 Hydrological Cycle

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

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

After deducting the losses, the remaining portion of precipitation becomes overland flow or direct runoff, which typically flows in a downward gradient to accumulate in local streams that subsequently flows to rivers. Surface water and ground water flows from high elevations to the lower elevations and may eventually be discharged into the ocean, especially after heavy rainfall events. However, a large amount of surface water and part of ground water are returned to the atmosphere by evaporation, thus completing the natural hydrologic cycle as shown in Figure 2.1.

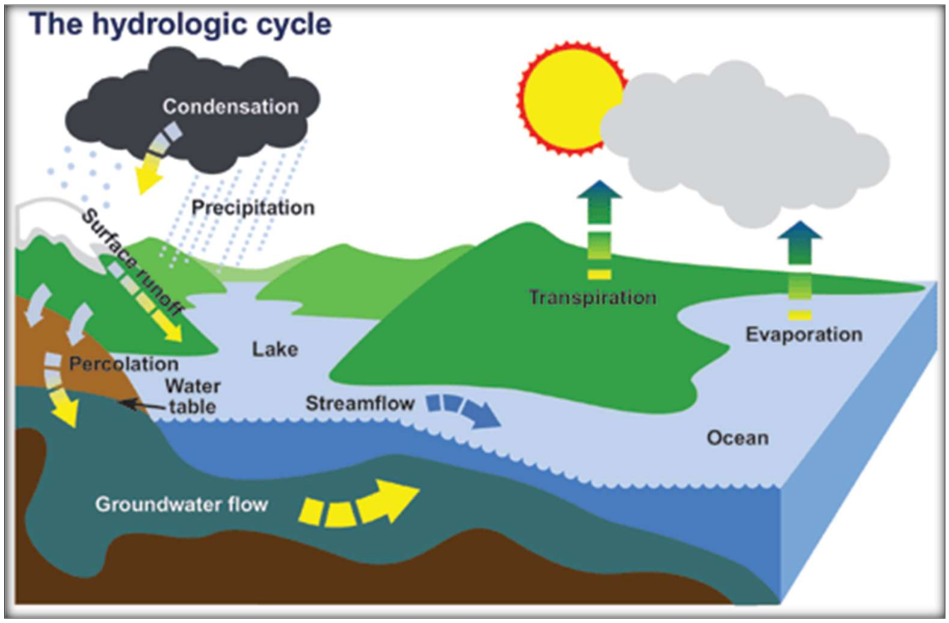

Figure 2.1 : Hydrological Cycle

Source : Environment and Climate Change Canada (2013)

2.4 Hydrological Characteristics

2.4.1 Rainfall

Rainfall is one of the hydrological characteristics which can be define as one form of precipitation that normally measured in millimetre or inches. There are several form of precipitation which are dew, snow, frost, fog and hail. The rise in the intensity of rainfall events can bring a great concern to society which can affect the human activities in the climate system especially global warming (Chou, Chen, Tan and Chen,2012). Extreme rainfall for continuous time duration often leads to huge cause of flooding and other dangerous situations. According to Weng Chan in his studies in 1997 has mentioned that Peninsular Malaysia was suffered serious damage and losses of millions economically due to unpredictable rainfall events. In response to the unpredictable rainfall events, development of IDF Curve and simulation of streamflow hydrograph is increasingly essential, not only for the purpose of hydrological study but also for design of flood mitigation, urban drainage system design and other environment project related.

2.4.2 Runoff

Runoff can be simply defined as a flow from a basin into a stream (URIVERS, 2016). It is also one of hydrologic characteristics where the flow of rainfall is directly falls into the river or stream. There are many source of runoff such as direct runoff (directly from precipitation), surface runoff flowing through land surfaces and channels, subsurface runoff and groundwater runoff. The total amount of runoff in a channel is known as streamflow, which is considered as direct runoff or baseflow.

2.5 Rainfall-Runoff Relationship

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

2.6 Hydrograph

The definition of a flood hydrograph, or some of its key features like the peak flow, is needed for designing several structures like bridges, check dams, levees, riverbank protections, flood mitigation system and others. (Alberto Montanari, 2015). A hydrograph is a graphical representation of river flow pattern over time for a certain location. It is the results from a combination of physiographic and meteorological conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, and baseflow. The shape of a hydrograph depends on precipitation pattern characteristics and basin properties (Kharagpur, 2018).

2.7 Hydrological Modelling

The Hydrologic Modelling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of river and watersheds. It is designed to be applicable in a wide range of geographic areas to solve the widest possible range of problems. HEC-HMS also mostly used in analysing urban flooding, study of flood frequency, flood warning system planning, design of reservoir spillway capacity, stream restoration design and others. (US. Army Corps of Engineers, 2008). The hydrologic element options available in HEC-HMS are shown in Table 2.1. The distributed modelling approach in HEC-HMS required three (3) major components which are Basin Model: Hydrological Procedure 27 (HP27), Meteorological Model: Thiessen Polygon and Control Specifications. For this study, the losses Method used is SCS Curve Number, the transform method is Clark Unit Hydrograph, the baseflow method is Constant monthly and lastly, the routing method used is muskingum-cunge method.

Table 2.1 : Hydrologic element options available in HEC-HMS

Hydrologic Element	Options in HEC-HMS
Losses	Initial/Constant Deficit/Constant Green-Ampt **SCS Curve Number**
Transformation of Rainfall to Runoff	Modified Clark Kinematic Wave Gridded Snyder Unit Hydrograph **Clark Unit Hydrograph** SCS Dimensionless Unit Hydrograph Input Unit Hydrograph
Baseflow	Exponential Recession Constant Monthly
Routing	Lag Muskingum Modified Plus **Muskingum-Cunge** Straddle Stagger

2.7.1 Basin Model: Hydrological Procedure (HP27)

The basin model is the representation of the physical watershed (M. Ali et al., 2011). Hydrological elements such as sub-basins, junction and river reaches are added and linked to create a basin model. Sub-basin tool is used to represent the sub-catchment in the main basin while the reaches are used to convey streamflow downstream in the basin model. Inflows may come from one or more upstream hydrological elements and they are connected to the downstream elements by junctions. The inflow into the junction can come from one or more upstream elements. In this study, hydrological procedure 27 (HP27) is used as reference for basin model. The method used is Clark Unit Hydrograph that consist of 3 parameters which are Time of Concentration (Tc), Storage Coefficient (R), and Baseflow (Q_B).

The Equation for all 3 parameters are as followed:

$$Tc = 2.32\ A^{-0.118}\ L^{0.9573}\ S^{-0.5074} \quad \text{(Eqn. 2.1)}$$

$$R = 2.976\ A^{-0.1943}\ L^{0.9995}\ S^{-0.4588} \quad \text{(Eqn. 2.2)}$$

$$Q_B = 0.11\ A^{0.85889} \quad \text{(Eqn. 2.3)}$$

Where, A = Catchment Area in km^2

L = Main Stream Length in km

S = Slope

2.7.2 Precipitation Model: Thiessen Polygon

The temporal distribution of the historical event or predictive design storm is input in the form of the total rain depth and distribution histogram or directly as the desired distribution of the precipitation amounts in each time step. Spatial distribution of the precipitation can be cell-by-cell, sub basin-by-sub basin, by rain gauge location and weighting such as Thiessen Polygon or by an automated inverse distance-squared weighting method spread among points of known values. The precipitation model also known as meteorological model in the HEC-HMS model which helps to calculate the precipitation input required by each sub-basin element. In this study, the precipitation model was developed using ArcGIS Model. Data maps obtained from Google Earth is used as input in ArcGIS model to produce map of meteorological model to be used in HEC-HMS.

2.7.3 Control Specifications

Control specification is a set of time span used in simulation of HEC-HMS. The information such as time and date of the rainfall, actual (observed) hydrographs to be used in comparison with simulated hydrograph, time interval for computation and input or output specifications are required in this component. For this study, the data is set for 10 days of event from 13th December until 22nd December of 2000, 2010 and 2012 for calibration and validation process. The daily rainfall data that obtained from DID is used to produce simulated streamflow hydrograph and the daily streamflow data also obtained from DID is used as observed streamflow hydrograph.

2.7.4 Loss Method: SCS Curve Number Method

The Curve Number (CN) were considered as weighted value that is used in the calibration process of the model. The model simulation was performed for different percentage of CN separately to find the best-fit curve number for the study area. Selection of lower CN value shows that the runoff potential is low and higher CN value indicate a high runoff potential. The imperious (%) value is needed in the area of the sub-basin to be specified as a portion of total area. However, no loss calculations are carried out on the impervious (%) area since the precipitation is assumed become excess precipitation and subjected to direct runoff.

2.8 Intensity-Duration Frequency (IDF) Curve

Intensity-Duration-Frequency (IDF) Curves is commonly used for design rainstorm events. The rainstorm with different recurrence intervals were calculated to predict the flooding potential in future. the Gumbel's statistical method is chosen for distribution frequency method of annual maximum rainfall series in 24 hours for all stations. The rainfall volumes of storms with different periods could be calculated, and the recurrence interval were arbitrarily selected as T = 2-year, 5-year, 10-year, 50-year and 100-year ARI. The equation of rainfall intensity values (i) as referred to Urban Storm Water Management Manual for Malaysia (MSMA2) of IDF Curve are as followed:

$$\mathrm{i} = \frac{\lambda \mathrm{T}^{k}}{(t+\theta)^{n}} \qquad \text{(Eqn. 2.4)}$$

where,

i = Average rainfall intensity (mm/hr);

T = Average recurrence interval: ARI ($0.5 \leq T \leq 12$ month and $2 \leq T \leq 100$ year);

d = Storm duration (hours), $0.0833 \leq d \leq 72$;

λ, κ, θ and η = Fitting constants dependent on the rain gauge location (Table 2.B1 in Appendix 2.B in MSMA2)

2.9 Design Rainfall

It is important to emphasise that the rainfall temporal patterns are intended for use in hydrograph generation design storms. This rainfall temporal patterns should not be confused with the real rainfall data in historical storms, which is usually required to calibrate and validate hydrological and hydraulic simulation results.

The standard time intervals recommended for urban storm water modelling are listed in Table 2.4 of MSMA2. The design temporal patterns to be used for a set of durations are given in Appendix 2.C of MSMA2. For this study, annual maximum rainfall of 3 days durations were obtained from MSMA2 and used for frequency analysis to derive the design rainfall depth.

2.10 Relationship between hydrograph with IDF Curve and Design Rainfall

The concern in water management task such as design of flood mitigation and flood control is always the characteristics of flood hydrograph. Meanwhile, storms are independent and typically generate different flood disasters; these variations are complex and difficult to understand clearly. This study employs probability distribution to standardize storms. After the output (peak discharge, m^3/s) value of streamflow hydrograph is produced, the output value is subjected to a frequency analysis (IDF Curve) to determine the derived flood frequency curve.

As mentioned by Rahman et al. (2002), this relationship is useful to solve the rainfall intensity probability theorem and design rainfall temporal pattern by developing several random events by allowing for correlation among various input variables then use the generated variable set to generate flood peaks using a calibrated rainfall-runoff model.

Plus, the time of concentration value gained in hydrograph can be used in IDF Curve as storm duration to determine the maximum rainfall intensity for desired ARI which is used for reservoir spillway design, flood study, flood mitigation, structural design such as dam, bridges, riverbank protection and others.

2.11 Advantage of HEC-HMS

As mentioned in previous sub topic, HEC-HMS is designed to be applicable in a wide range of geographic areas to solve the widest possible range of problems. The advantage of using HEC-HMS are as followed (Crick, 2018):

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

2.12 Flood History

Natural disaster such as flood brought a huge impact to the community and economy system (Yendra, (2017). Flood is one of common disaster happened in Malaysia. Trophical Country like Malaysia has recorded annual monthly rainfall of 254.80 mm from 1901 until 2015 . It showed that Malaysia has received a high precepitation every month especially during monsoon season. Flood in Pahang occurs during the Northeast monsoon season, which occurs between October to March. The Northeast monsoon brought widespread and prolonged rainfall that often lasting several days. Rompin District is one of the district in Pahang that frequently received severe flood for almost every year. Based on the National Register of River Basins study carried out in 2002, the total flood prone area in the Rompin District is estimated around 1100 km2. The annual average flood damage for Rompin District was estimated to be about RM 308,000 with 2624 people affected. (Department of Irrigation and Drainage, 2010-2018). Table 2.2 shows the flood history record collected from DID.

Table 2.2 Record of Flood History Collected from DID (2013-2018)

YEAR	FLOOD DEPTH (m)	AREA OF FLOOD (Km^2)	TYPE OF FLOOD	FLOOD CAUSE
2018	2.5	2.5	Monsoon	Heavy Rain and Dropping of Water Level at Upstream
2017	2.5	2.5	Monsoon	Heavy Rain for 3 days and Dropping of Water Level at Upstream
2015	0.6	-	Monsoon	Haevy Rain and Low Area
2014	0.5	-	Monsoon	Heavy Rain and Overflow
2013	-	-	Monsoon	Heavy Rain

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research was conducted for the purpose to simulate design rainfall and streamflow hydrograph for the Rompin River Basin. The Hydrologic Engineering Centre-Hydraulic Modelling System (HEC-HMS) was used to simulate the streamflow hydrograph pattern for this study. In order to set up the model, the hydrological information such as rainfall and streamflow data were utilised. After the model have been setup, the model was simulated to produce the streamflow hydrograph. The calibration process was conducted to adjust the values of calibration parameters to fit the simulated hydrograph curve to the observed hydrograph. Then, the validation process of streamflow hydrograph was performed to test correctness of the calibrated parameters with several set of rainfall event. The design rainfall and IDF Curve were developed to establish the designed streamflow hydrograph to be used for flood prediction in future study.

3.2 Methodology Flowchart

Procedures to estimate the streamflow hydrograph for the Rompin River Basin are listed in Figure 3.1. The procedures began with preliminary study which includes the selection of study area and site visit. Next, the data collection (rainfall data, streamflow data, Curve Number Grid Map), hydrological modelling, calibration process and prediction processes were performed. The calibration process was repeated if the validation result failed until the validation showed sufficient result. Then, the procedures continued with error analysis adopting the methods (Root Mean Square Error (RMSE) and Nash Sutcliffe Efficiency (NSE)). Lastly, IDF Curve and design rainfall for flood prediction .

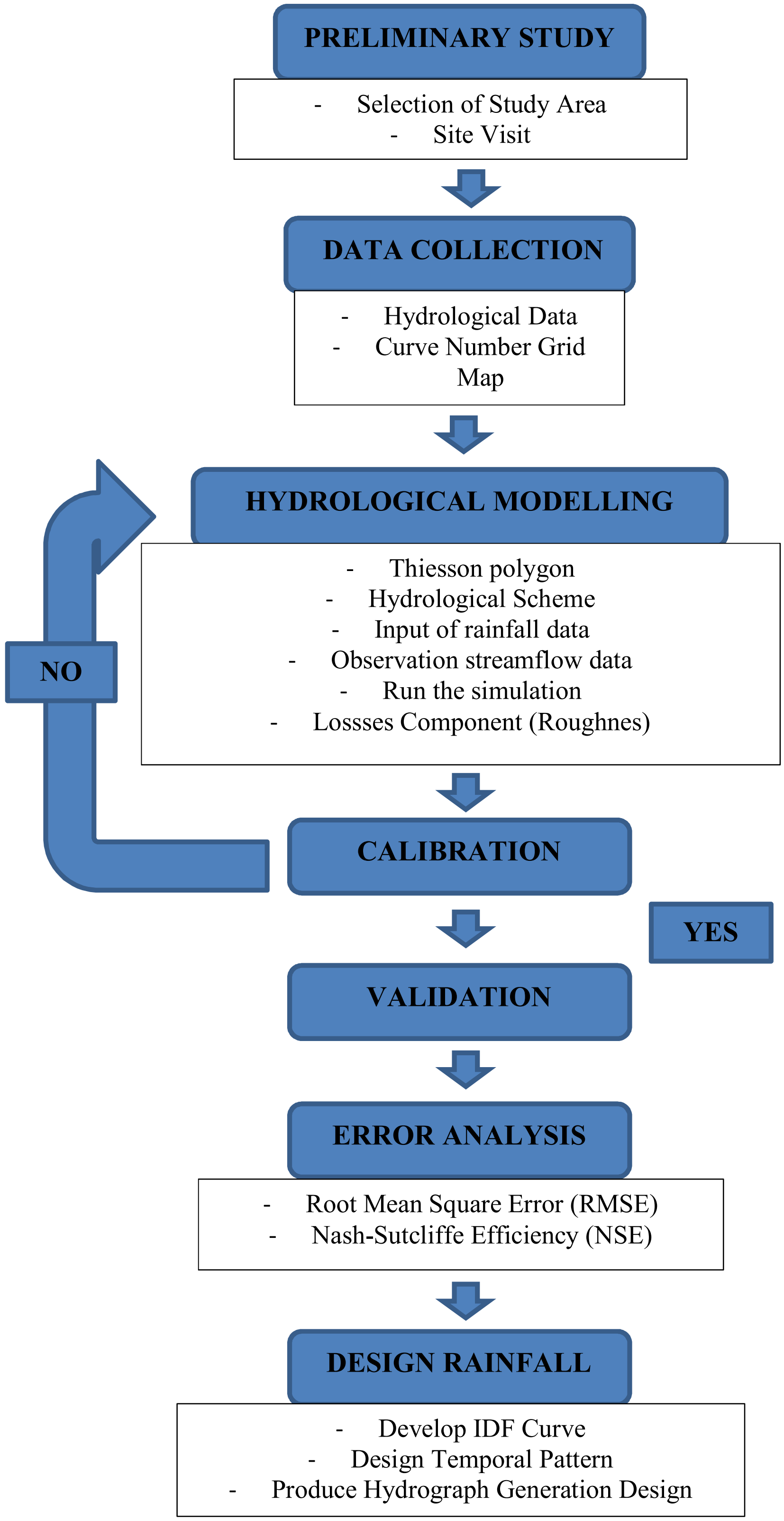

Figure 3.1 Methodology flow chart

3.3 Preliminary Study

3.3.1 Selection of Study Area

The selected area for this study is the Rompin River Basin as shown in Figure 3.2 which located at Pahang State that flows through the south-eastern before emptying into the South China Sea. In Rompin, the estimated flood prone area is 1124.21 square kilometres. In terms of land use, 9.89 square kilometres of the flood prone areas are urban areas, 307.68 square kilometres agricultural areas, 532.42 square kilometres forest and 274.22 square kilometres others (mining, swamp, pasture/grassland and unused land). Rompin is one of the district in which the economy is partly depending on agriculture activities. Rompin River Basin receives heavy rainfall during the North East Monsoon that occurs between October and March. The north-east monsoon brings widespread and prolonged rainfall often lasting several days.

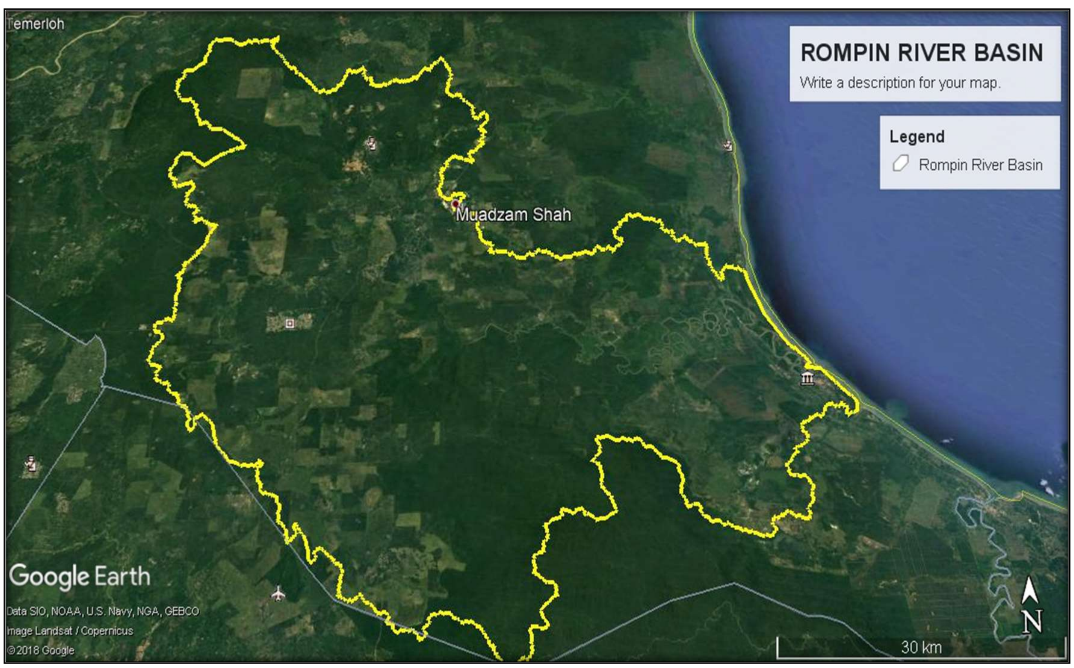

Figure 3.2 : Rompin River Basin

3.3.2 Site Visit

A site visit was held to have a better understanding of the Rompin River Basin. The site visit included observation of the rainfall and streamflow gauging stations, type of land-uses in the basin, and the location of the irrigation ditch. Identification of the rainfall and streamflow gauging stations is vital to the hydrologic modelling due to its importance in the calibration and validation stages. Type of land-uses beside served as references for the selection of the loss coefficient, the SCS Curve Number.

The presence of irrigation ditch for the paddy scheme in RRB as shown in Figure 3.3 has made the water resources management in that basin becomes even more crucial since the paddy area cannot be too wet during the harvest and too dry during the replanting. According to the local authority in the Rompin District, the paddy areas are often facing flood problems during the monsoon. Although several bunds have been constructed to solve these issues, but they seem to be insufficient or ineffective.

Figure 3.3 The irrigation ditch in the paddy scheme of RRB

3.4 Hydrological Data Collection

3.4.1 Hydrological Data

For hydrological modelling, hydrological information such as rainfall and streamflow data were required. The data collected is important as the input and observation in simulating, calibrating and validating processes of this study. In the Rompin River Basin, there are 9 rainfall stations, and 2 Streamflow and water level stations available according to the Department of Irrigation and Drainage (DID) inventory. However, only 6 nearest rainfall station were used for this study and 2 existed streamflow data. Table 3.1, Table 3.2 and Table 3.3 show the name and station number of the gauging stations considered and used in HEC-HMS modelling and summary of missing data. Table 3.4 shows the selected month for calibration and validation process and Figure 3.4 to Figure 3.10 and Appendix A show the average rainfall monthly. The highest average rainfall occurs between October to March during North East Monsoon Season.

Table 3.1 Rainfall stations

STATION NO.	STATION NAME	AVAILABLE YEAR
RF2828173	Kg. Gambir	1990 - 2017
RF2829001	Ulu Sg. Chanis	1990 - 2017
RF2831179	Kg. Kedaik	1990 - 2017
RF2834001	Per. Endau Rompin	1990 - 2017
RF3028001	River. Kepasing	1990 - 2017
RF3030178	P. Batu Bukit Raidan	1990 - 2017

Table 3.2 Streamflow stations

STATION NO.	STATION NAME	AVAILABLE YEAR
SF2928401	Sg.Keratong di Jam. Bahau Keratong	1990 - 2017
SF3030401	Sg. Rompin di Jam. Kuantan/Segamat	1990 - 2017

Table 3.3 Summary of missing data

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

Table 3.4 Selected month for calibration and validation

PERIOD	CALIBRATION	VALIDATION
Wet period	- 2010 Dec	- 2000 Dec - 2012 Dec

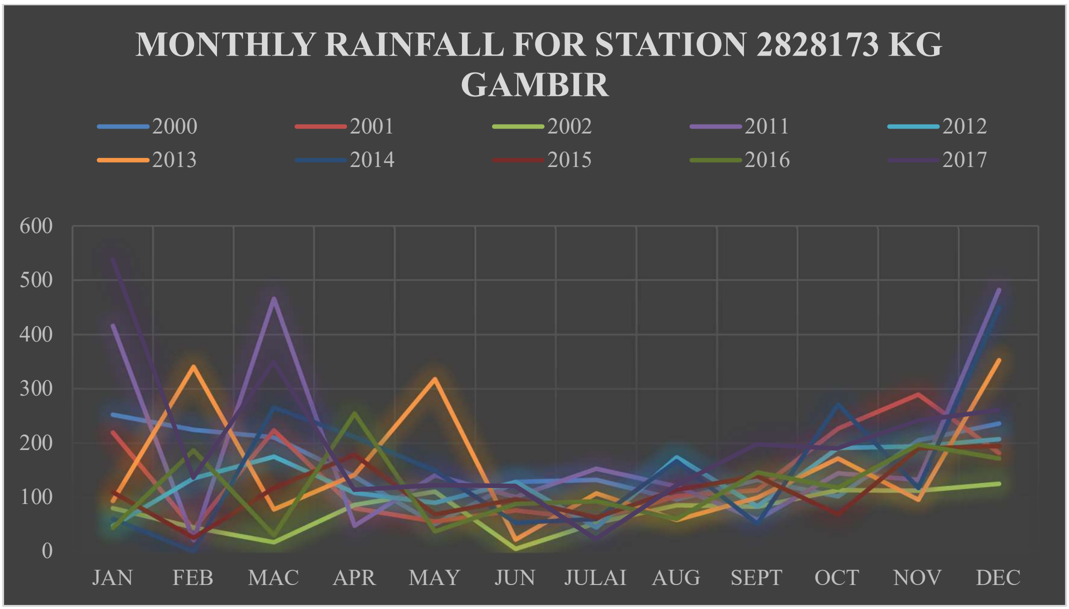

Figure 3.4 Average monthly rainfall graph for station 2828173 Kg Gambir

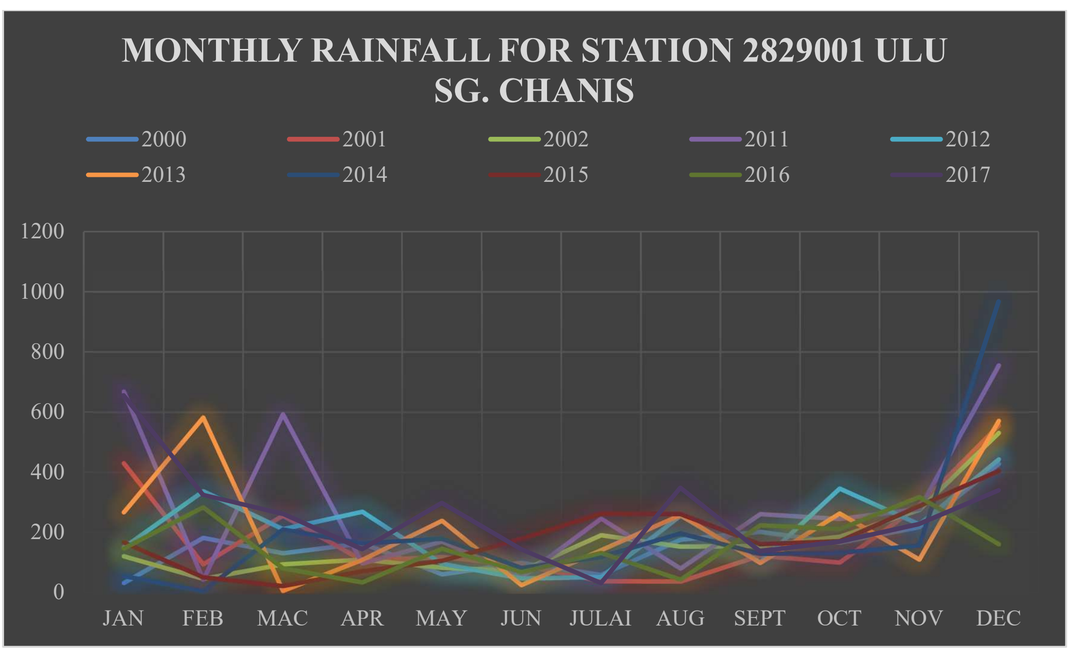

Figure 3.5 Average monthly rainfall graph for station 28290001 Ulu Sg. Chanis

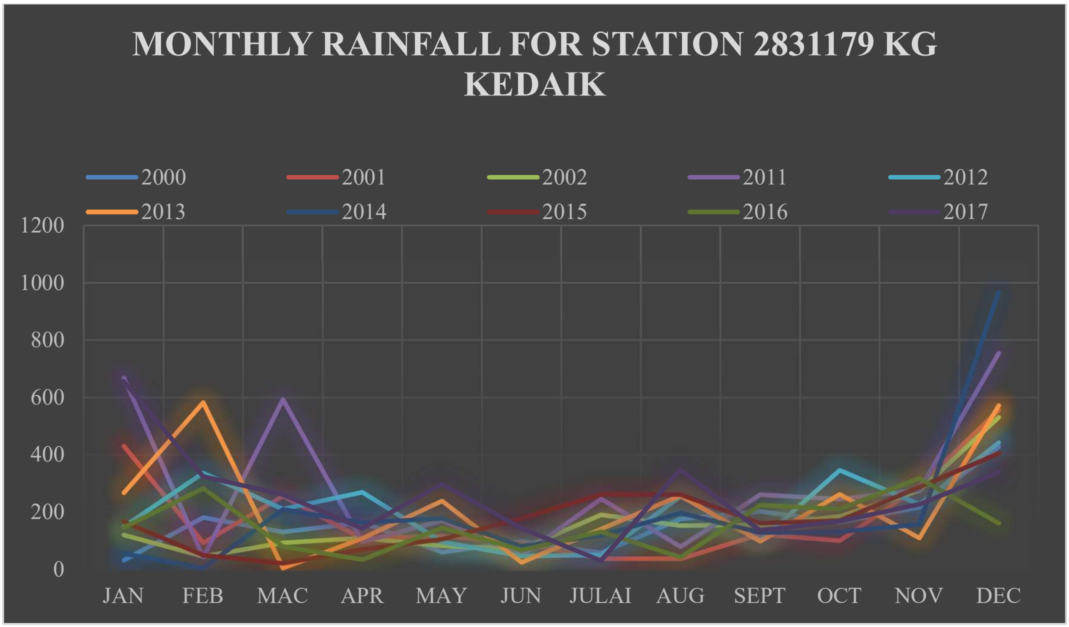

Figure 3.6 Average monthly rainfall graph for station 2831179 Kg. Kedaik

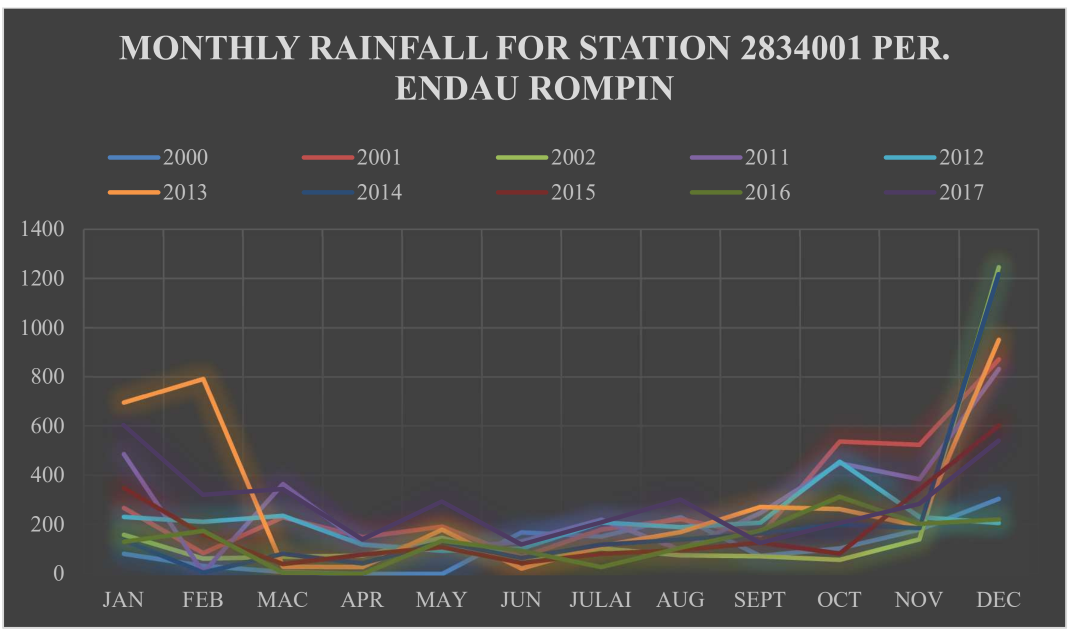

Figure 3.7 Average monthly rainfall graph for station 2834001 Per Endau Rompin

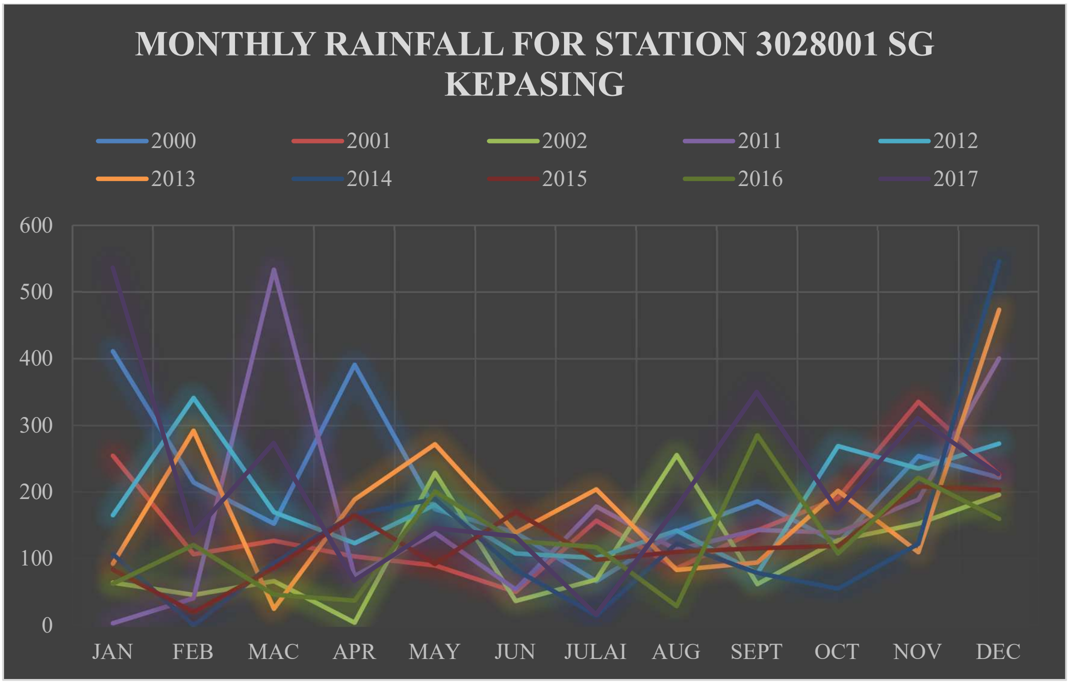

Figure 3.8 Average monthly rainfall graph for station 3028001 Sg. Kepasing

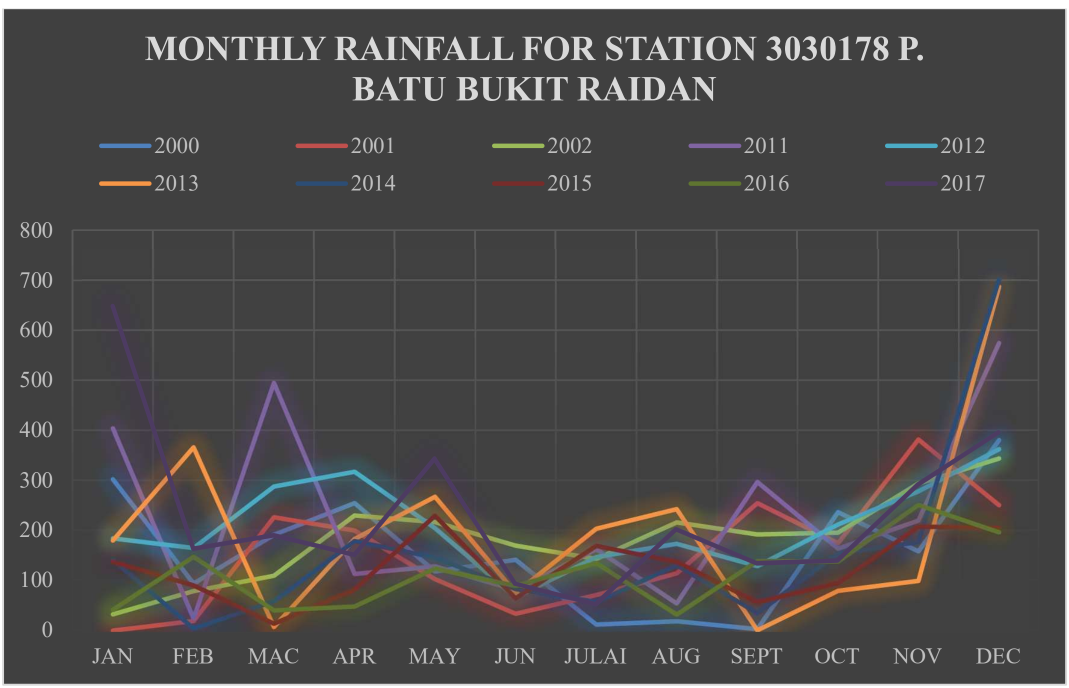

Figure 3.9 Average monthly rainfall graph for station 3030178 P. Batu Bukit Raidan

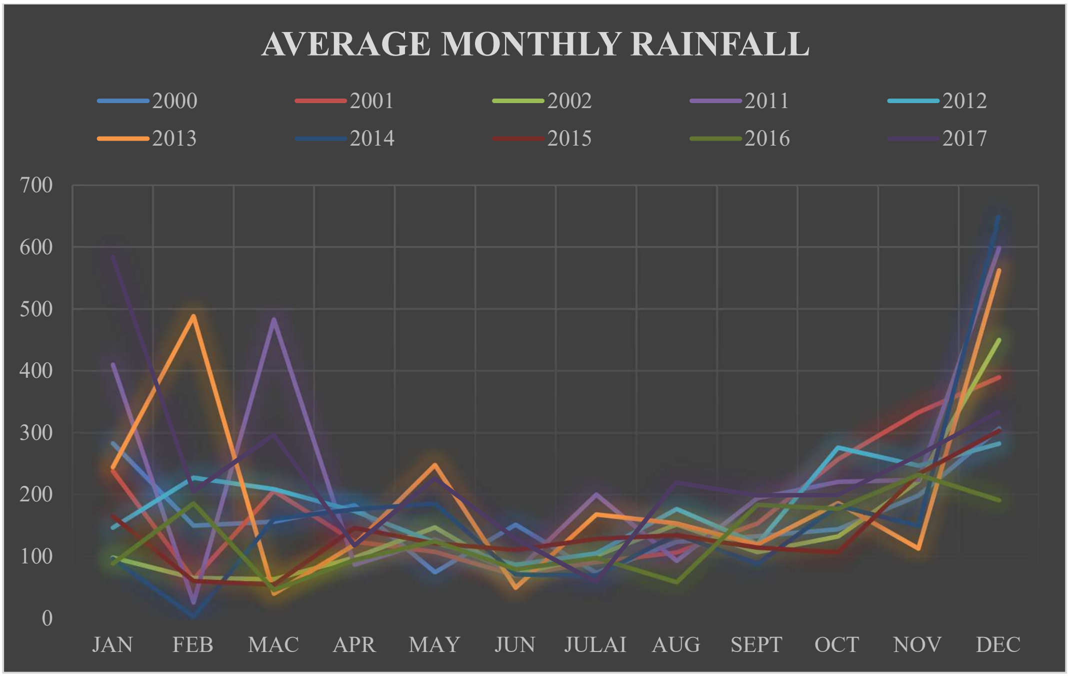

Figure 3.10 Average monthly rainfall graph for total rainfall of the year all 6 rainfall stations

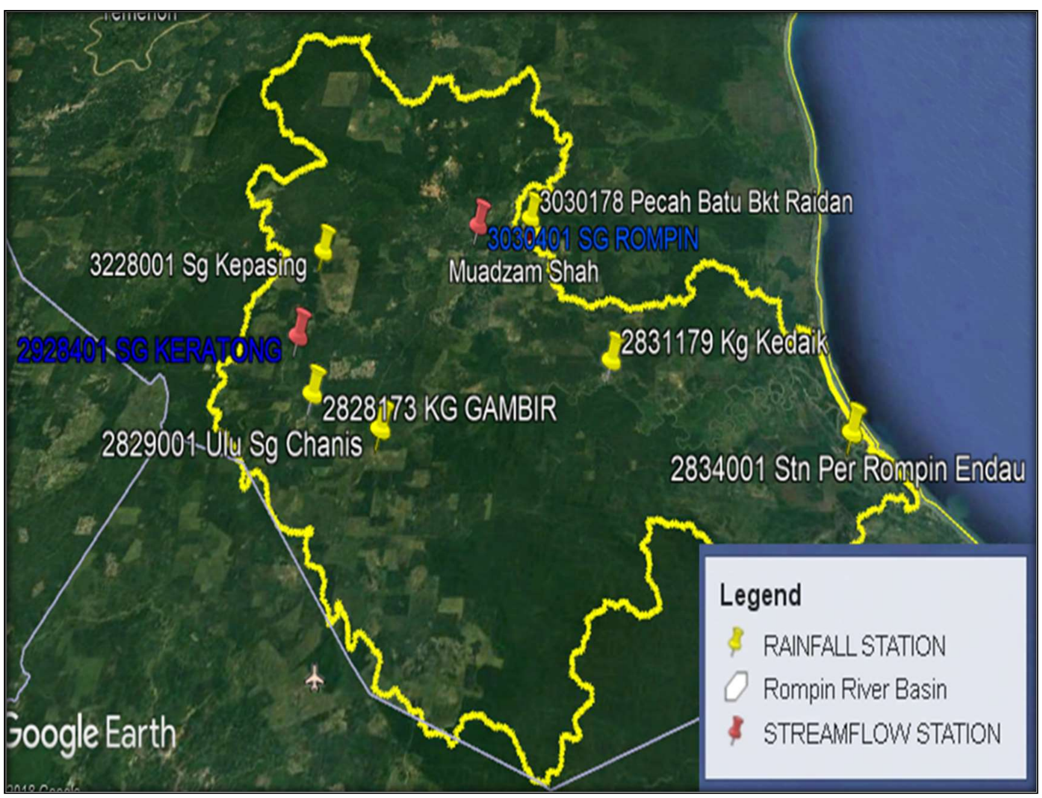

Figure 3.11 Location of Rainfall and Streamflow Stations

3.4.2 Curve Number Grid Map

The Curve Number (CN) Grid Map was developed using ArcGIS Software as shown in Figure 3.12. It was produced with the combination of soil map and landuse map. The curve number was used to represent the roughness parameter.

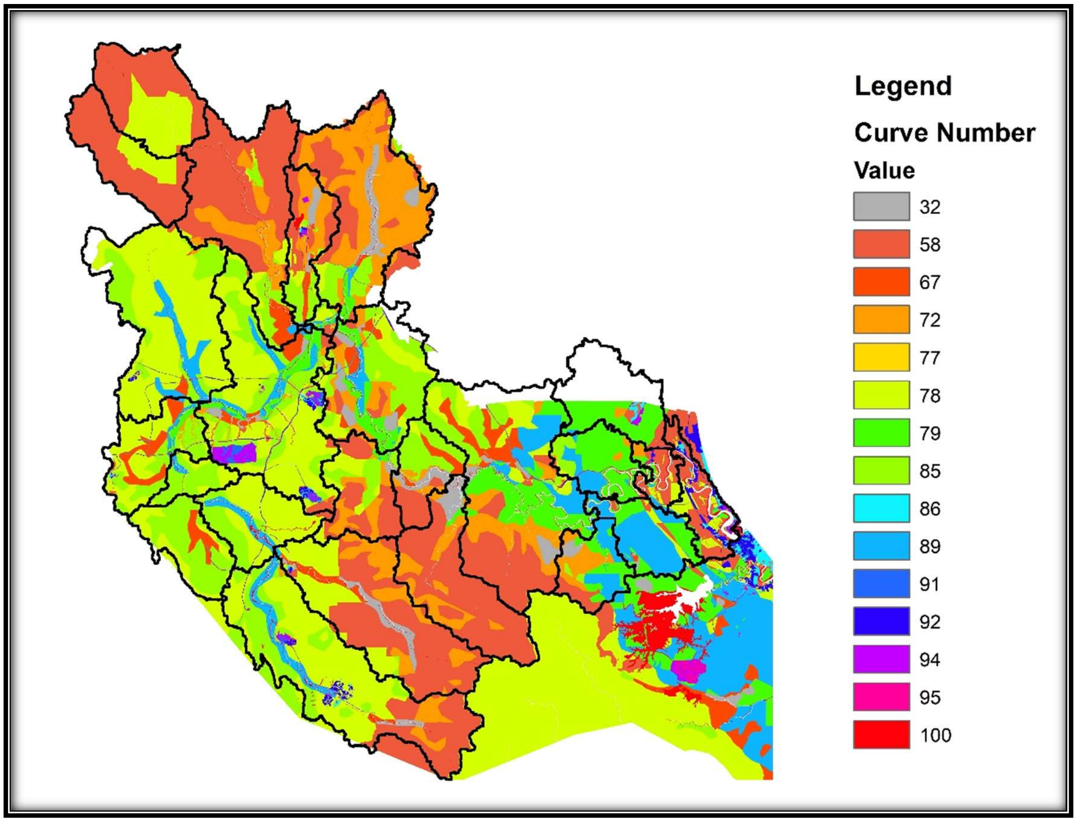

Figure 3.12 Curve Number Grid Map

3.5 Hydrological Modelling

3.5.1 Hydrological Scheme

Figure 3.13 shows the hydrological scheme developed in HEC-HMS model. There were 22 sub-basins in total, 12 reaches and 12 junction elements have been schematized for the Rompin River Basin. Table 3.5 and 3.6 show the sub-basin characteristics data includes total depth of each rainfall station and area of the sub-basin. The selected streamflow data was used as input data at streamflow station with related sub-basin to produce the observed streamflow hydrograph. Table 3.7 shows the methods and parameter used in the simulation of hydrological model.

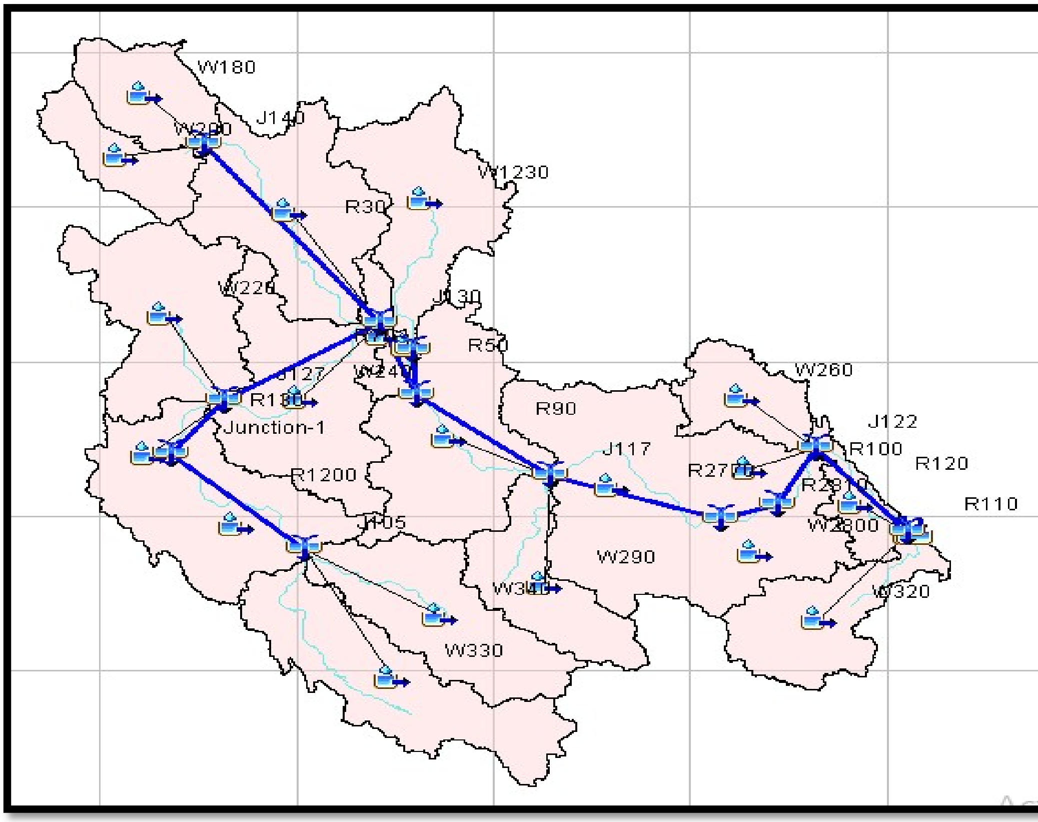

Figure 3.13 : Hydrological Scheme of RRB from HEC-HMS Model

Table 3.5 : Sub-Basin Data for HEC-HMS Model

SUB BASIN	RAINFALL STATION	TOTAL DEPTH (mm)	AREA (km^2)
W1170	Kg Gambir	110.8	334.04
W1180	Kg Gambir	110.8	283.85
W1220	Batu Bukit Raidan	182.9	253.14
W1230	Batu Bukit Raidan	182.9	115.41
W180	Sg kepasing	49.6	308.06
W190	Sg kepasing	49.6	347.65
W200	Sg kepasing	49.6	340.64
W220	Sg kepasing	49.6	145.79
W2750	Kg Kedaik	274.8	6.6928
W280	Kg Kedaik	274.8	346.61

Table 3.6 : Continous of Sub-basin Data for HEC-HMS

SUB BASIN	RAINFALL STATION	TOTAL DEPTH (mm)	AREA (km^2)
W2800	Per Endau Rompin	238.7	192.72
W2790	Per Endau Rompin	238.7	386.96
W290	Kg Kedaik	274.8	170.28
W230	Batu Bukit Raidan	182.9	124.96
W240	Sg. kepasing	49.6	269.08
W260	Kg Kedaik	274.8	56.56
W300	Per Endau Rompin	238.7	124.25
W310	Per Endau Rompin	238.7	121.13
W320	Per Endau Rompin	238.7	202.06
W330	Ulu Sg. Chanis	168.4	76.544
W340	Ulu Sg. Chanis	168.4	1.3116

Table 3.7 : Method and Parameter used in HEC-HMS

METHOD	PARAMETER
Loss – Scs Curve Number	Curve Number
	Initial Abstraction
	Imperviousness
Transform – Clark Unit Hydrograph	Storage Coefficient
	Time Of Concentration
Baseflow – Constant Monthly	Baseflow
Routing – Muskingum-Cunge	Manning's n

3.5.2 Meteorological Model : Thiessen Polygon

In this study, Thiessen Polygon was developed using ArcGIS Model as shown in Figure 3.14. There were 6 rainfall stations involved in generating the meteorological model as stated in Table 3.1. The selected rainfall data was used to produce the simulated hydrograph and Thiessen Polygon was generated to calculate the precipitation input required by each sub-basin element.

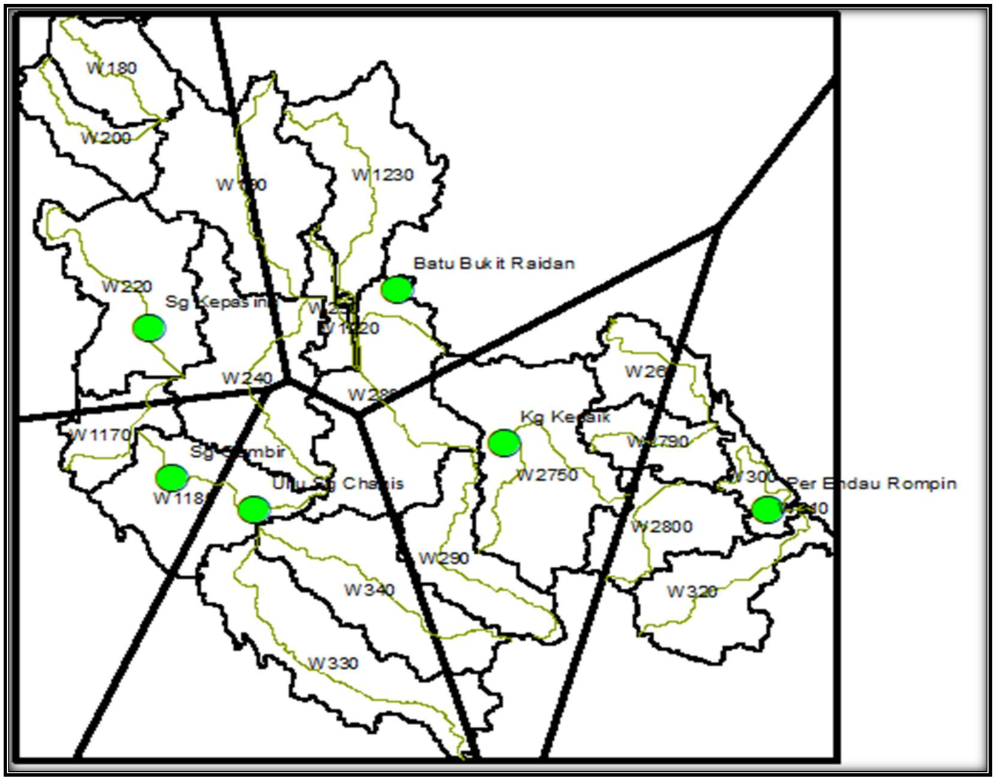

Figure 3.14 Thiessen Polygon from ArcGIS

3.5.3 Input Rainfall Data & Observed Streamflow Data

Input rainfall data and observed streamflow data were set for 10 days of rainfall event from 13th December until 22nd December of 2000, 2010 and 2012 for the calibration and validation process. The daily rainfall data that obtained from DID was used to produce streamflow hydrograph, while the daily streamflow data were used as observed streamflow hydrograph. The list of rainfall and streamflow data used for this study is shown in Appendix B and all calibration and input parameters were estimated using Equation 2.1 to 2.3

3.6 Calibration and Validation

Calibration process is the process where the simulated results were checked and adjusted to fit with the observed measurement. The model parameters calibrated such as curve number and baseflow as shown in Appendix C. The calibration process is conducted by reducing the Curve Number (CN) value and baseflow values by percentage.

As mentioned in previous chapter, validation was carried out to test the robustness of the developed model. The generated hydrograph was compared with the observed hydrograph. Calibrated model parameters were validated using different sets of hydrological data. For this study, the monthly data selected for validation are December 2010 and December 2012. The calibration process was repeated until the validation showed sufficient result if the validation result is failed.

3.7 Error Analysis

3.7.1 Root Mean Square Error (RMSE)

One of the model efficiency analysis used for this study was Root Mean Square Error (RMSE). RMSE is an indicator analysis to show the closeness between observed and simulated data. The RMSE was calculated using Equation 3.1 as followed:

$$RMSError = \frac{1}{N}\sqrt{\sum_{i=1}^{n}(\hat{y} - yi)^2} \qquad \text{(Eqn. 3.1)}$$

Where, $\hat{y}$ is observed discharge and yi is simulated discharge.

The lower RMSE value shows that the simulated data was nearly fit to the observed data (indicates good result). Meanwhile, higher RMSE value indicates the simualted data is not desirable closeness to the observed data. The calculation of RMSE for this study is shown in Appendix D.

3.7.2 Nash-Sutcliffe Efficiency (NSE)

Nash-Sutcliffe Efficiency (NSE) was also used as model efficiency analysis for this study. NSE was used to evaluate the predictive power of HEC-HMS Model same as RMSE. The value of NSE range is from negative infinity to 1 where 1 shows the perfect match of the simulated data to the observed data. Efficiency of 0 indicates the prediction of model equal to mean of the data observation. Negative value of NSE indicates mean observed data is better predictor than the simulated data. The calculation of NSE for this study is shown in Appendix D. The calculation of NSE is shown in Equation 3.2 as followed:

$$NSError = 1 - \frac{\sum(Obs - Sim)^2}{\sum(Obs - Omea\ \ )^2} \qquad \text{(Eqn. 3.2)}$$

Where, Obs is Observed discharge, Sim is simulated discharge and Omean is the mean of observed discharge.

3.8 Intensity Duration Frequency (IDF) Curve

The IDF Curve for Rompin River Basin was developed according to the procedure stated in MSMA2 and HP1. As mentioned in previous chapter, Gumbel's statistical method is chosen for distribution frequency method of annual maximum rainfall series in 24 hours for all stations. The rainfall volumes of storms with different periods were calculated, and the recurrence interval were arbitrarily selected as T = 2-year, 5-year, 10-year, 50-year and 100-year ARI. The calculation for IDF Curve is shown in Equation 3.4 and the maximum rainfall data obtained from DID is shown in Appendix A for all 6 rainfall stations.

3.9 Design Rainfall

For this study, annual maximum rainfall of 3 days durations were obtained from MSMA2 and used for frequency analysis to derive the design rainfall depth. The intensity rainfall values extracted from IDF Curve after being transform into rainfall temporal pattern were used as data input to develop the hydrograph generation design storms as shown in Appendix E for different ARI. The standard time intervals recommended for urban storm water modelling are listed in Table 2.4 of MSMA2. The design temporal patterns for Rompin River Basin to be used for a set of durations are given in Appendix 2.C of MSMA2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the hydrological model and stimulation results for the Rompin River Basin were presented with comparison between the observed discharge data (Keratong River and Rompin River) and stimulated discharge data (daily rainfall data). The calibration and validation results of different datasets were discussed separately. The model efficiency analysis used to evaluate the model performance were RMSE and NSE. The IDF Curve graph were presented for all 6 rainfall stations, all with the design rainfall based on sets of temporal pattern durations in MSMA2.

4.2 Hydrological Modelling Results

In the hydrological model (HEC-HMS), there were total of 22 sub-basins, 12 reaches and 12 junction elements have been schematized for the Rompin River Basin. For each sub-basin and river reach, the storage coefficient, time of concentration and base flow have been calculated accordingly in accordance to the HP27 guideline. The rainfall and streamflow data for this hydrological model is shown in Appendix B. The simulation has been run for 10 days of daily rainfall events from 13^{th} December until 22^{nd} December for year 2000. This simulated results were then used for calibration process. The example of the detailed results of the calibration parameters was tabulated in Table 4.1.

Table 4.1 Calculation of Clark Unit Hydrograph coefficient

NO	sub basin	Area (km2)	length,L (m)	length,L (km)	river slope,S (m/km)	storage coeffiecient, R(hr)	time concetration, tc(hr)
1	**W2800**	170.28	24715.07	24.72	0.02	2.81	3.78
2	**W2750**	386.96	38916.12	38.92	0.00	7.80	12.05
3	**W1230**	269.08	25261.22	25.26	0.02	2.61	3.63
4	**W1180**	253.14	12312.51	12.31	0.00	4.06	6.33
5	**W340**	283.85	35641.98	35.64	0.01	5.07	7.33
6	**W330**	334.04	22266.19	22.27	0.01	3.22	4.73
7	**W320**	202.06	35409.86	35.41	0.00	10.11	15.23
8	**W310**	1.31	23764.44	23.76	0.01	10.31	9.95
9	**W300**	76.54	26755.59	26.76	0.00	13.75	20.05
10	**W290**	192.72	19713.06	19.71	0.00	4.04	5.85
11	**W280**	346.61	39811.16	39.81	0.00	7.21	10.90
12	**W2790**	121.13	41119.40	41.12	0.02	5.01	6.55
13	**W260**	124.25	24767.57	24.77	0.00	9.63	14.29
14	**W1170**	115.41	2958.89	2.96	0.01	0.66	0.91
15	**W240**	340.64	31800.13	31.80	0.01	4.58	6.74
16	**W230**	56.56	52844.66	52.84	0.02	7.57	9.37
17	**W220**	308.06	39461.05	39.46	0.02	3.95	5.54
18	**W1220**	6.69	31622.51	31.62	0.01	11.90	13.26
19	**W200**	124.96	43454.96	43.45	0.00	13.67	19.84
20	**W190**	347.65	41910.09	41.91	0.02	4.51	6.45
21	**W180**	145.79	23594.87	23.59	0.03	2.31	3.01

4.3 Calibration of Hydrological Model

December 2000 rainfall event was selected for the calibration process of this study. The calibration parameter is shown in Figure 4.1 and Appendix C. Comparing the simulated streamflow hydrograph to the observed flow for both the stations at Rompin River and Keratong River indicate the model has overestimated the flow discharge. The hydrograph results comparison for the best fit of the calibration parameters are presented in Figure 4.2 for the Rompin River and Figure 4.3 for the Keratong River, respectively. Despite the overestimation, the streamflow pattern generated show similar trend to the observed. The time to peak for the Rompin River was delayed for about 72 hours compared to the observed. For the Keratong River, the peak occurred earlier than the observed by 24 hours. For the simulated hydrographs, the streamflow values at the beginning and the end of the simulation were very low compared to observed hydrograph. HEC-HMS model assumed no rainfall occurred outside of the simulation time span.

Table 4.2 shows the peak discharge of both simulated and observed streamflow hydrograph for the Rompin River and Keratong River after calibration for the month of December 2000.

Subbasin	Initial Abstraction (MM)	Curve Number	Impervious (%)
W330	0	41.58935	0
W340	0	35.54155	0
W1180	0	44.792	0
W1170	0	43.18325	0
W220	0	43.9901	0
W190	0	35.76155	0
W240	0	43.6799	0
W180	0	36.2945	0
W200	0	34.1605	0
W1230	0	36.71305	0
W230	0	40.3249	0
W1220	0	41.29345	0
W2750	0	39.9157	0
W280	0	40.0433	0
W290	0	32.6546	0
W2800	0	43.6832	0
W260	0	42.36045	0
W2790	0	42.7933	0
W320	0	46.14115	0
W300	0	38.60725	0
W310	0	45.3244	0

Figure 4.1 Calibartion Parameter

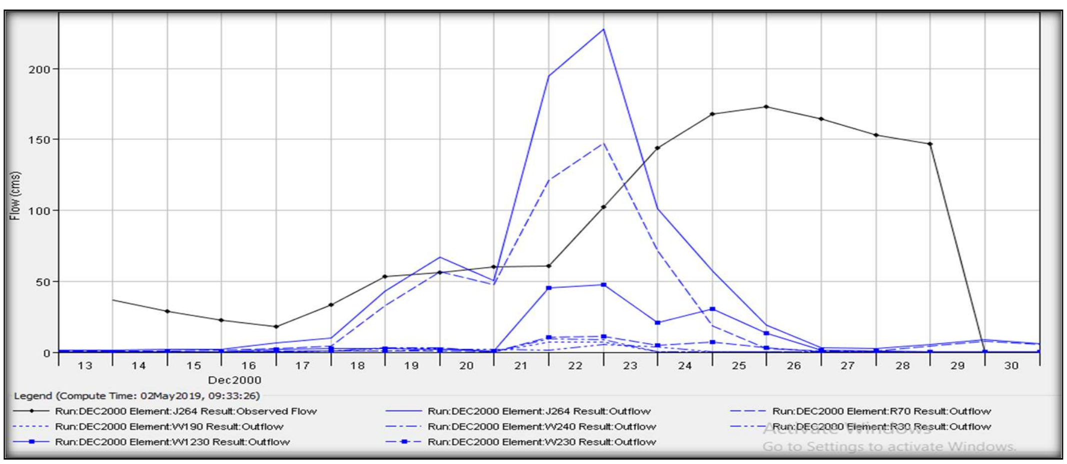

Figure 4.2 : Streamflow Hydrograph for Rompin River (Dec 2000)

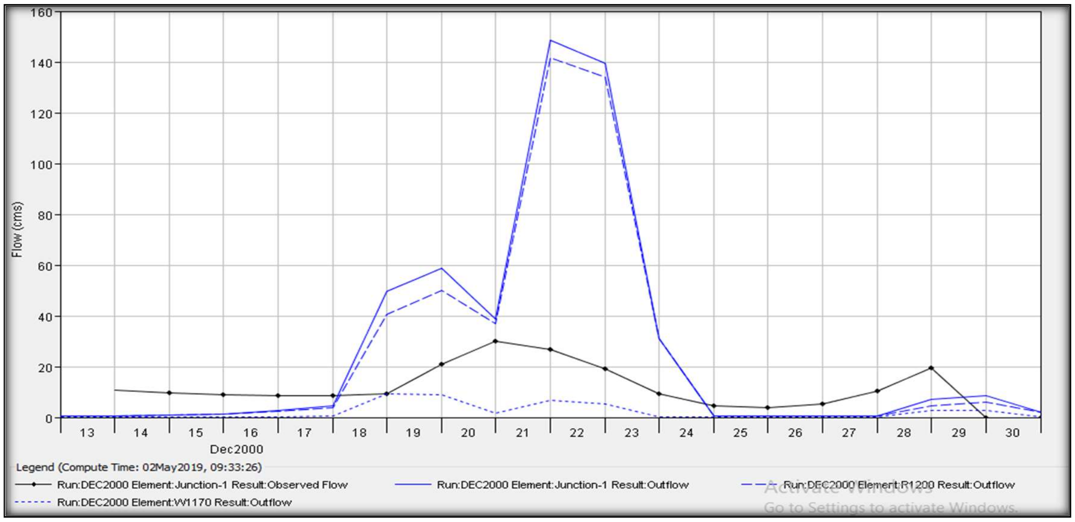

Figure 4.3 : Streamflow Hydrograph for Keratong River (Dec 2000)

Table 4.2 Peak Discharge of Steamflow Hydrograph (Dec2000)

STATION NO	STREAMFLOW	Q SIMULATED (m^3/s)	Q OBSERVED (m^3/s)	DIFF. (%)
SF3030401	ROMPIN RIVER	227.90	172.80	31.89
SF2928401	KERATONG RIVER	148.70	26.60	459.02

4.4 Validation of Hydrological Model

After the values of calibration parameter were fixed, streamflow hydrograph simulations were performed with the rainfall event on December 2010 and December 2012 for the validation. From the results, the fitness of the streamflow between simulated and observed hydrograph presented the same pattern simulated for the Rompin River on December 2010 as shown in Figure 4.4 was different where the observed hydrograph has higher peak compared to the simulated. In Figure 4.5 for the Keratong River, although the simulated hydrograph indicating an underestimation on peak compared to the observed, the difference of the peak was lower and the pattern was close to the observed hydrograph with only 24 hours delay time to peak. Figure 4.6 and 4.7 show almost the same streamflow hydrograph pattern with Figure 4.4 and 4.5 respectively. However, validation of Dec 2012 for both Rompin and Keratong River showed higher percentage difference of peak discharge with 261.28% and 114.81% respectively compared to validation month of Dec 2000. Table 4.3 and 4.4 shows the peak discharge of both simulated and observed streamflow hydrograph of Rompin River and Keratong River.

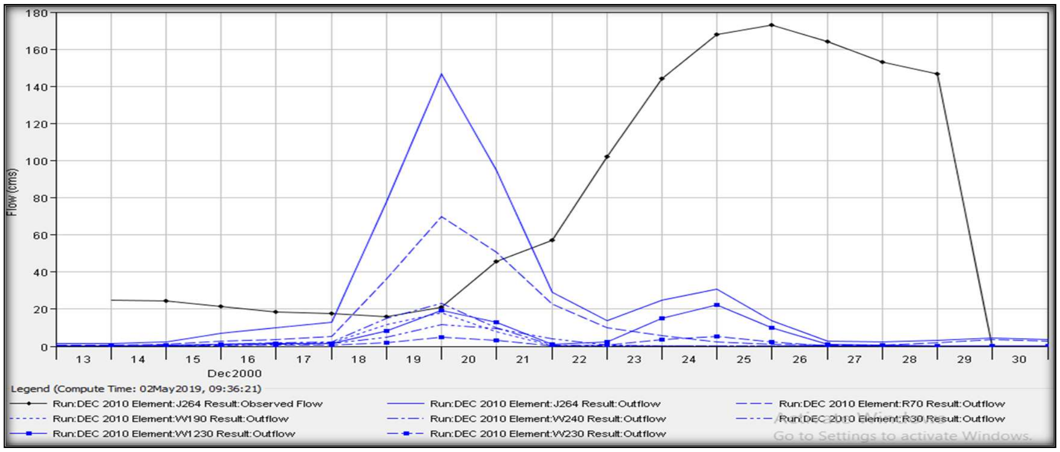

Figure 4.4 : Streamflow Hydrograph for Rompin River (Dec 2010)

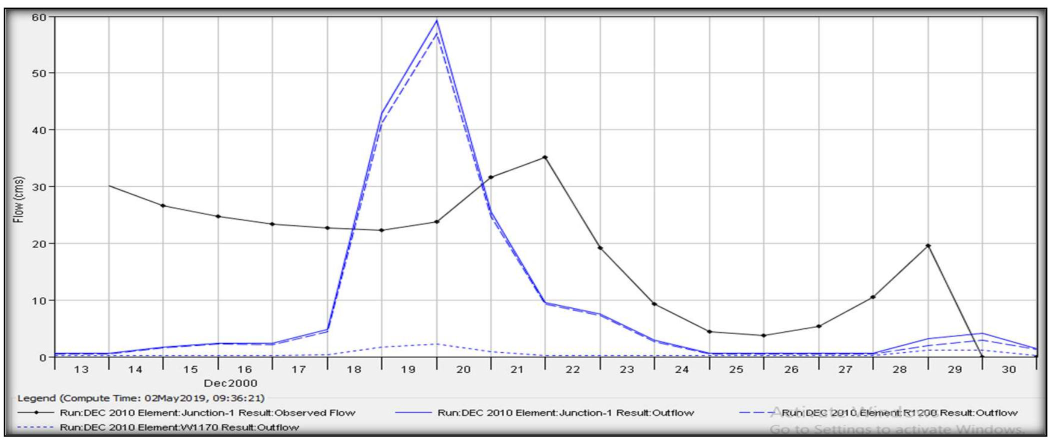

Figure 4.5 : Streamflow Hydrograph for Keratong River (Dec 2010)

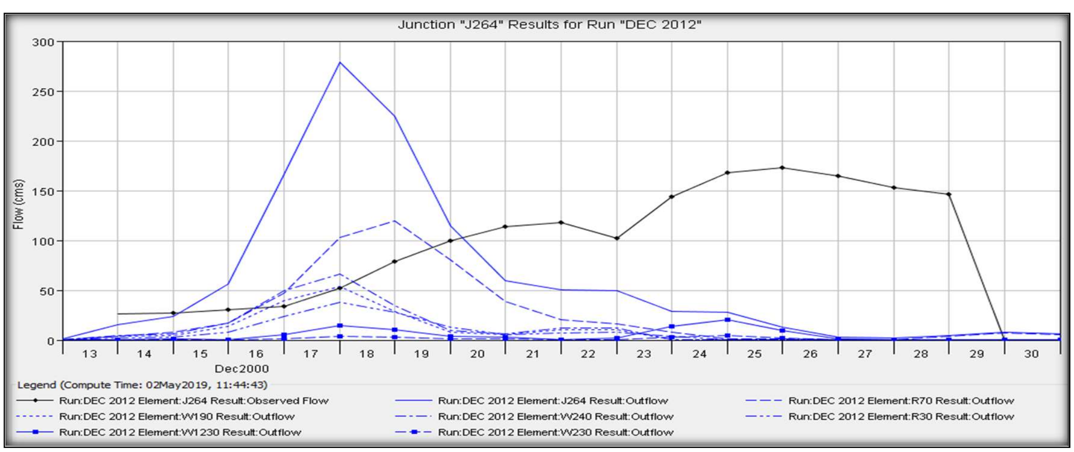

Figure 4.6 : Streamflow Hydrograph for Rompin River (Dec 2012)

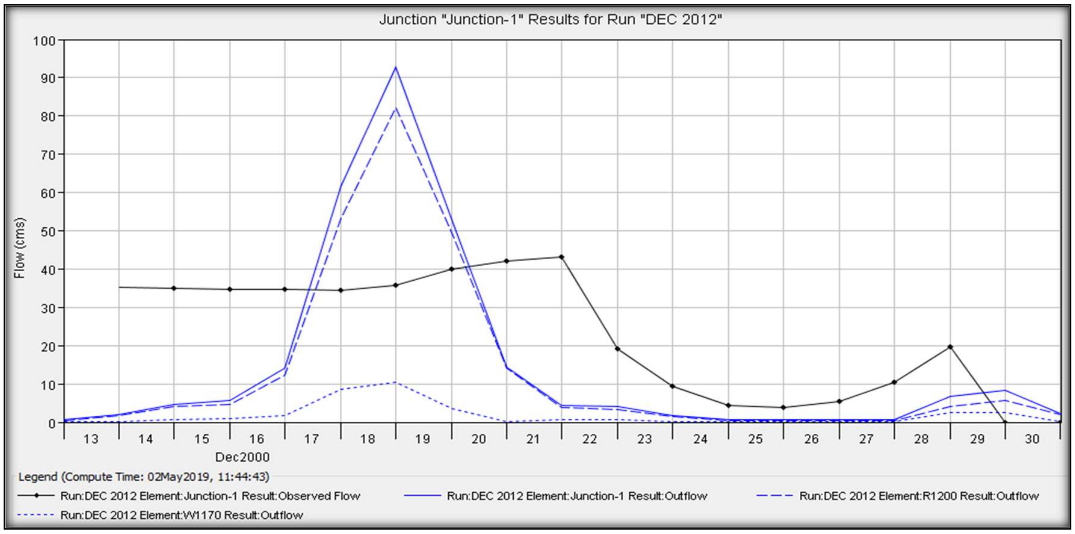

Figure 4.7 : Streamflow Hydrograph for Keratong River (Dec 2012)

Table 4.3 Peak Discharge of Steamflow Hydrograph (Dec2010)

STATION NO	STREAMFLOW	Q SIMULATED (m^3/s)	Q OBSERVED (m^3/s)	DIFF (%)
SF3030401	ROMPIN RIVER	146.80	172.80	-15.05
SF2928401	KERATONG RIVER	3.80	13.70	-72.26

Table 4.4 Peak Discharge of Steamflow Hydrograph (Dec2012)

STATION NO	STREAMFLOW	Q SIMULATED (m^3/s)	Q OBSERVED (m^3/s)	DIFF (%)
SF3030401	ROMPIN RIVER	278.70	172.80	261.28
SF2928401	KERATONG RIVER	92.80	43.20	114.82

4.5 Intensity Duration Frequency (IDF) Curve

In this study, the rainfall data of 6 rainfall stations were analysed to developed the IDF. The rainfall data used to develop IDF Curve is shown in Appendix E. The results obtained was for the ARI of 2-year, 5-year, 10-year, 50-year and 100-year shown in Figure 4.8 to 4.13. For each graph, there were two sets of IDF curves generated which representing the original IDF Curve and Calibrated IDF Curve. The original IDF Curve was the curve developed from raw rainfall data that obtained from DID. While the Calibrated IDF Curve was the curve that represent the developed IDF Curve from the calibration process to determine the best fitting. The finalized parameter for the IDF Curve of all 6 rainfall stations is shown in Table 4.5. the values of calibrated was close to the nearest station stated in MSMA2. It proved that coefficient of rainfall intensity for IDF Curve is not effected by external factor.

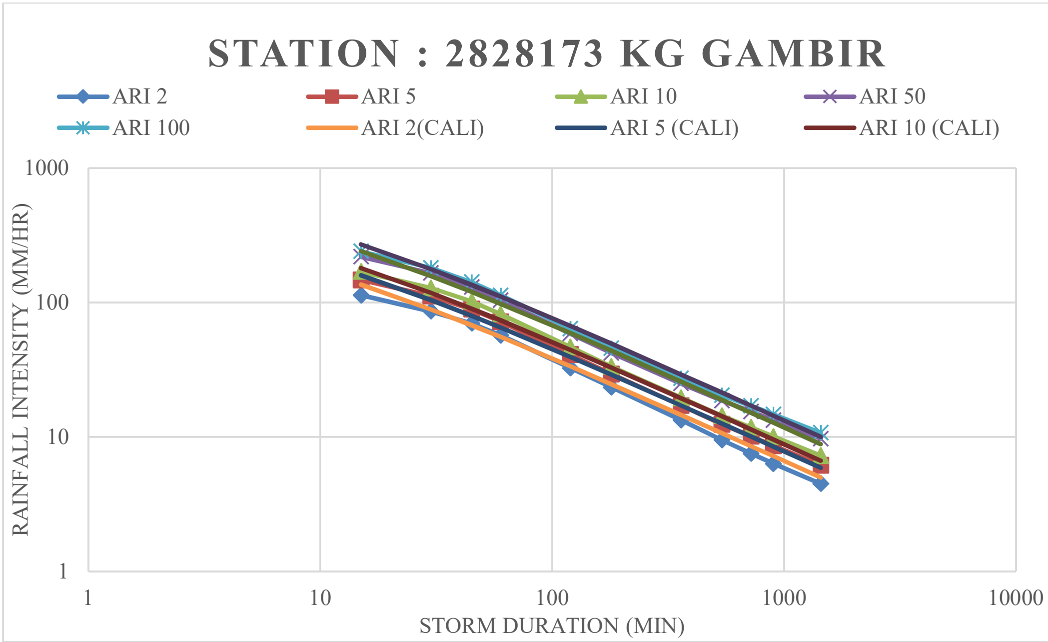

Figure 4.8 IDF Curve for Station 2828173 Kg Gambir

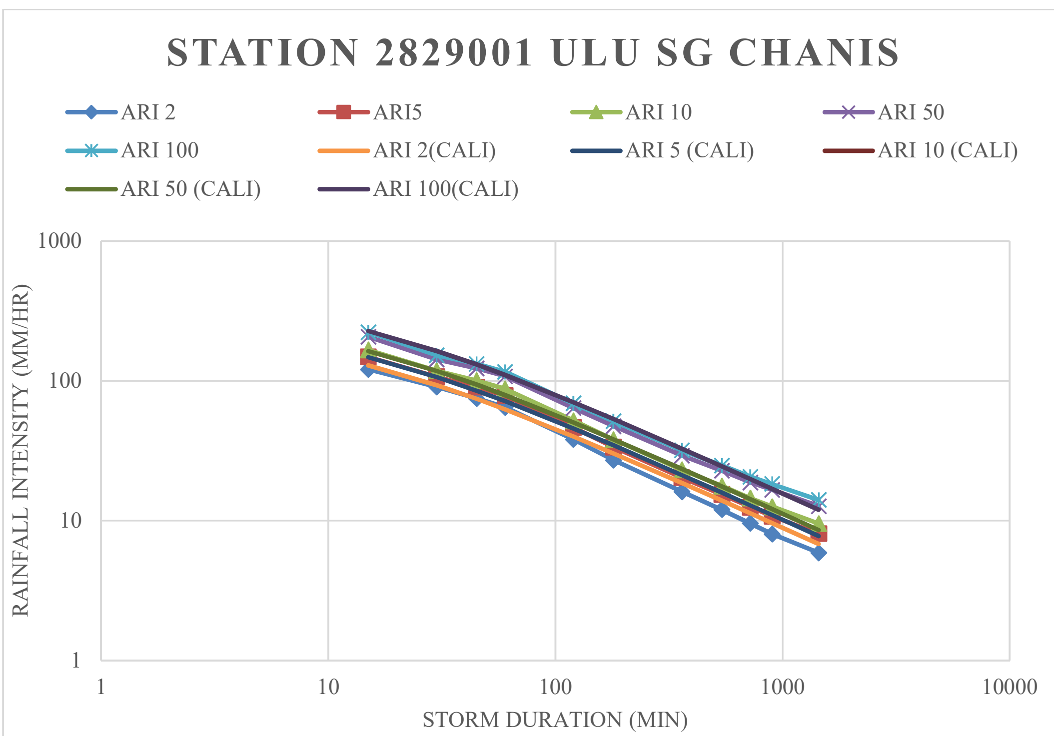

Figure 4.9 IDF Curve for Station 2829001 Ulu Sg. Chanis

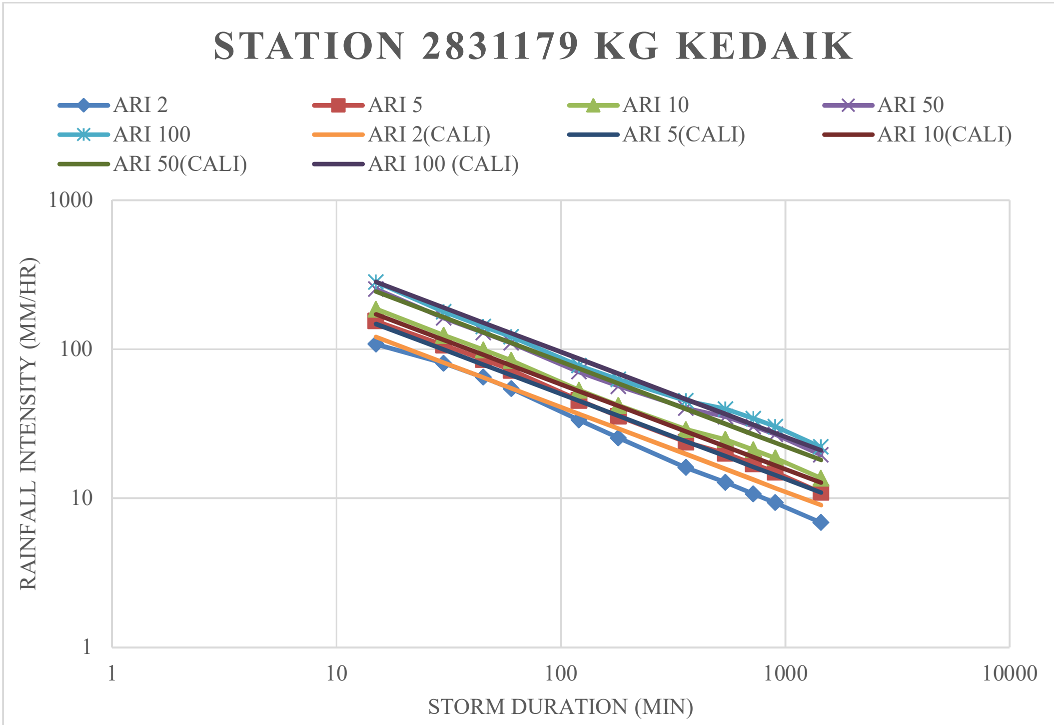

Figure 4.10 IDF Curve for Station 2831179 Kg Kedaik

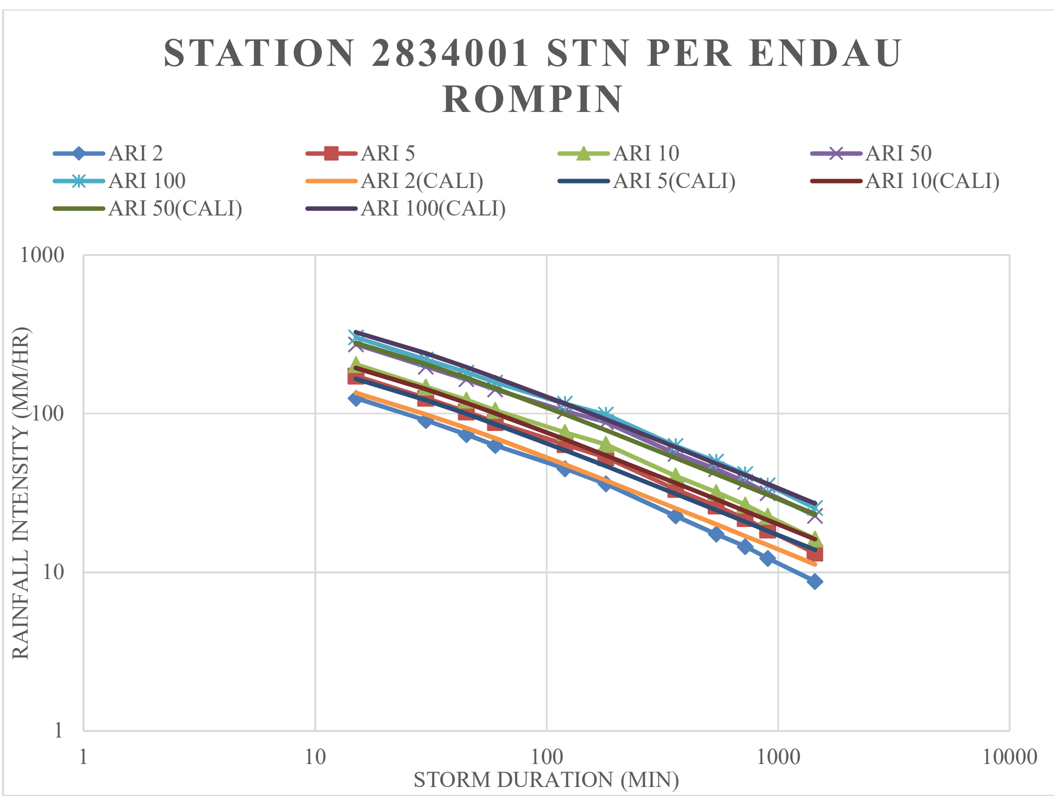

Figure 4.11 IDF Curve for Station 2834001 Per Endau Rompin

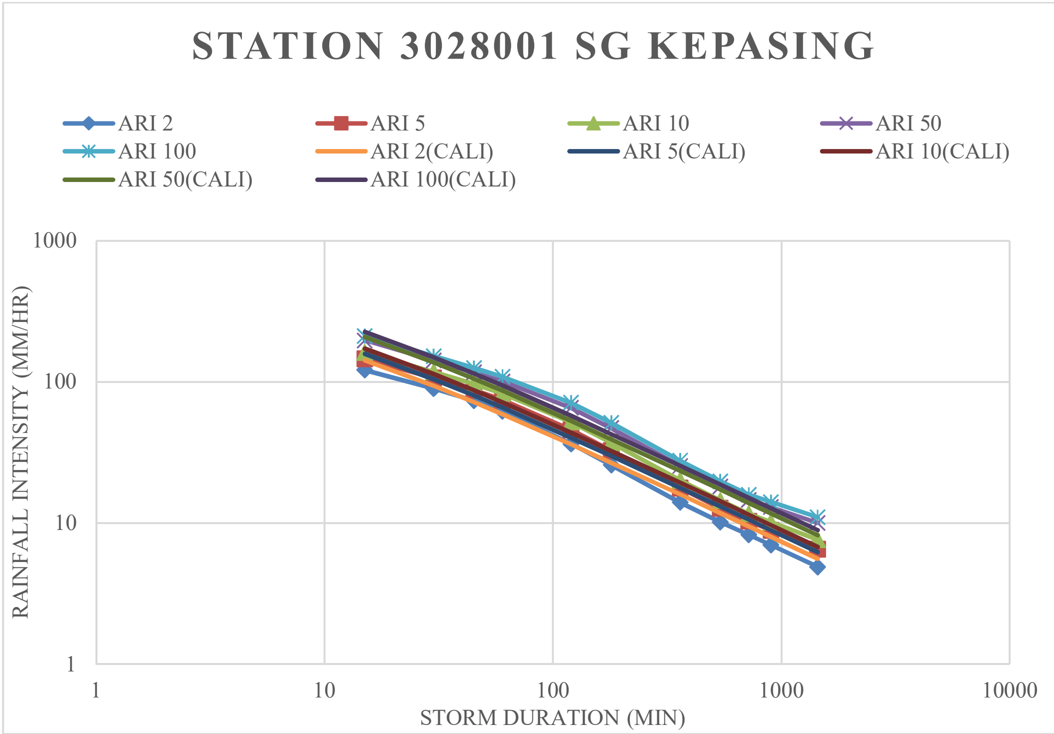

Figure 4.12 IDF Curve for Station 3028001 Sg. Kepasing

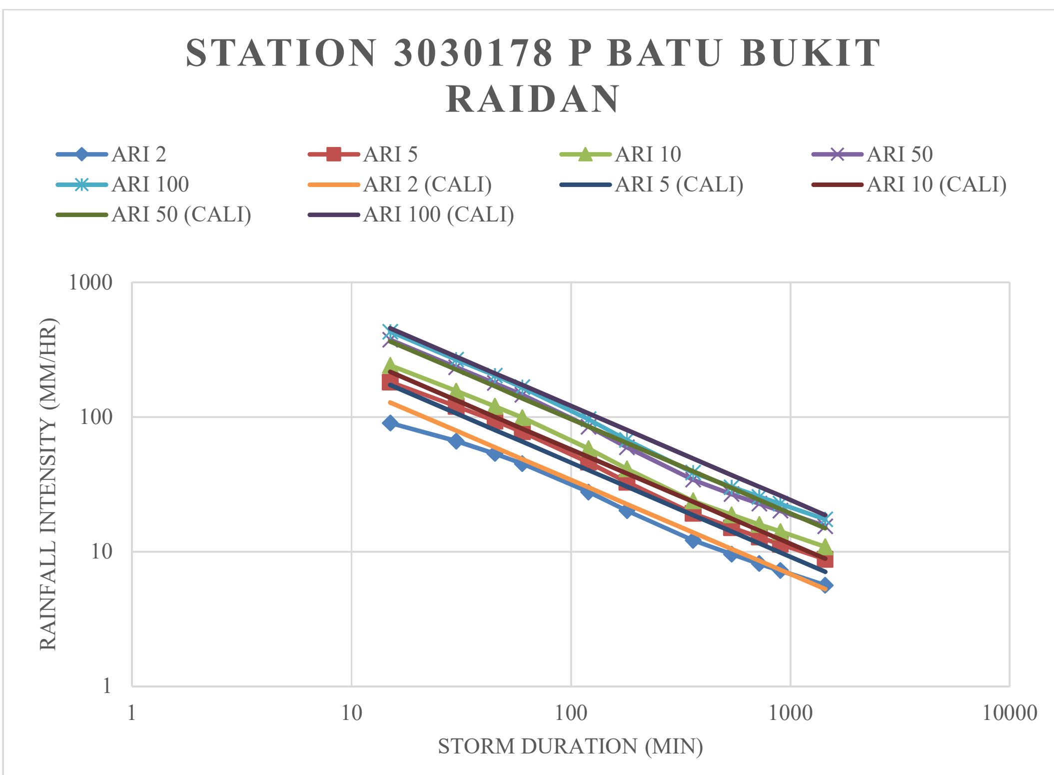

Figure 4.13 IDF Curve for Station 3030178 Batu Bukit Raidan

Table 4.5 Calibarated Parameter for IDF Curve of all rainfall stations

Station	3030178	3028001	2834001	2831179	2829001	2828173
log λ	1.59	1.77	1.81	1.67	1.81	1.72
λ	39.00	58.63	63.86	47.18	64.82	52.64
k	0.32	0.12	0.23	0.22	0.14	0.18
θ	0	0.10	0.12	0	0.20	0.10
η	0.70	0.76	0.60	0.57	0.74	0.78

4.6 Design Rainfall

For the design rainfall, the annual maximum rainfall of 3 days durations were obtained from MSMA2 and used for frequency analysis to derive the design rainfall depth. The values of the rainfall intensity obtained from the IDF Curve was transformed into the rainfall depth for the estimation of rainfall temporal pattern. Rainfall temporal pattern was used as data input to develop the hydrograph generation design storms as shown in Appendix F for different ARI. Figure 4.14 to Figure 4.40 show the histogram of design rainfall temporal pattern for all 6 rainfall stations with ARI of 2-year, 5-year, 10-year, 50-year and 100-year. Figure 4.41 to Figure 4.50 show the hydrograph generation design storms with different ARI for both Keratong River and Rompin River streamflow stations. The generated design storm hydrograph can be used to make as reference to determine the flood prediction and as precautionary measures in future. The peak discharge value obtained from the generated hydrograph is helpful design of reservoir spillway, bridges, dams and others. Table 4.6 shows the peak discharge generated for the design storm hydrograph at both Rompin River and Keratong River stations. The streamflow peak discharge of all ARI showed high values where most of the peak discharge exceeded 1000 m^3/s. This situation occurred due to high value of rainfall intensity obtained from calibrated IDF Curve. The rapidly increase of the computed rainfall depth that obtained from fraction factor in according to the MSMA2 also effected the value of streamflow discharge. The high streamflow discharge of design rainfall also due to the rainfall depth obtained from gaging data was very low compared to the rainfall depth of design rainfall. The gaging data of simulated hydrograph was utilised for 10 days of daily data while the gaging data for design rainfall was obtained for 3 days of 3 hours time interval. Therefore, it is recommended to used hourly data or smaller time interval. However, despite the overestimated of streamflow discharge value, the patterns of the streamflow hydrograph were same with observed hydrograph as expected.

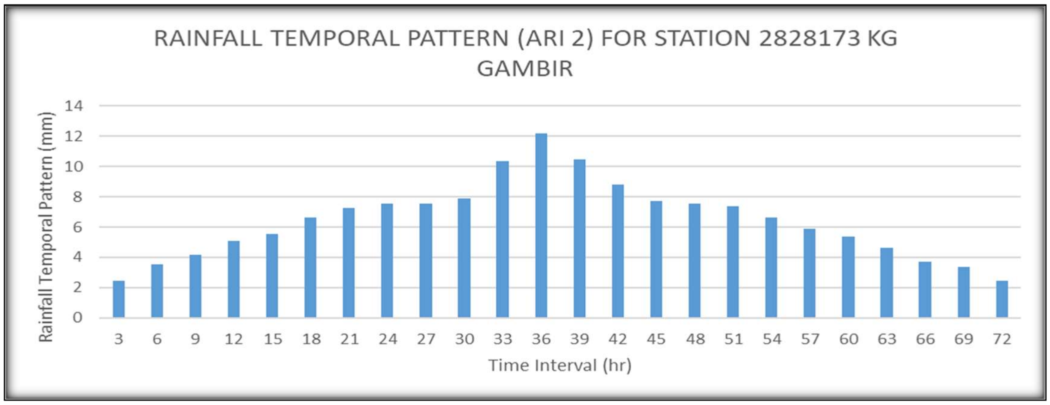

Figure 4.14 Temporal Rainfall Pattern (ARI2) for Station 2828173 Kg Gambir

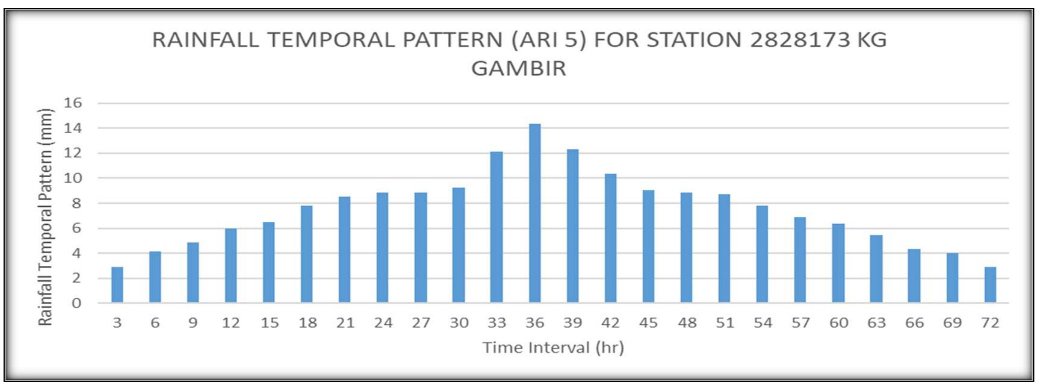

Figure 4.15 Temporal Rainfall Pattern (ARI5) for Station 2828173 Kg Gambir

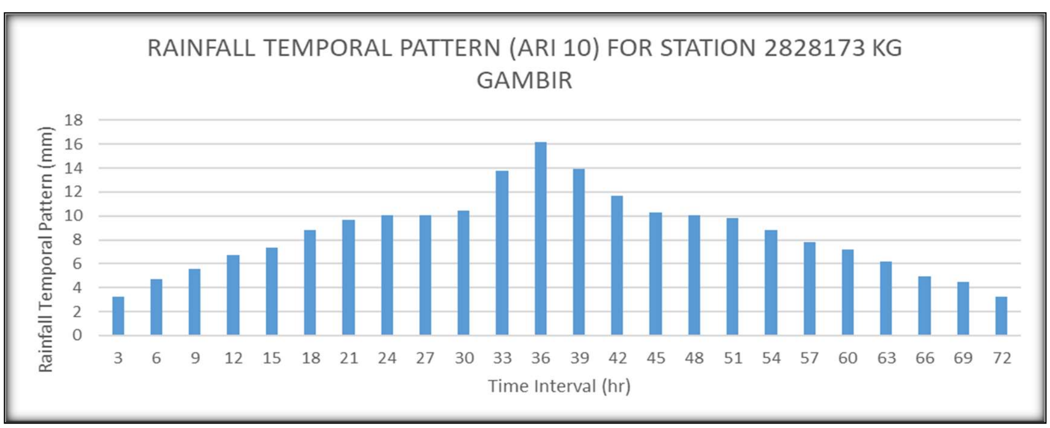

Figure 4.16 Temporal Rainfall Pattern (ARI10) for Station 2828173 Kg Gambir

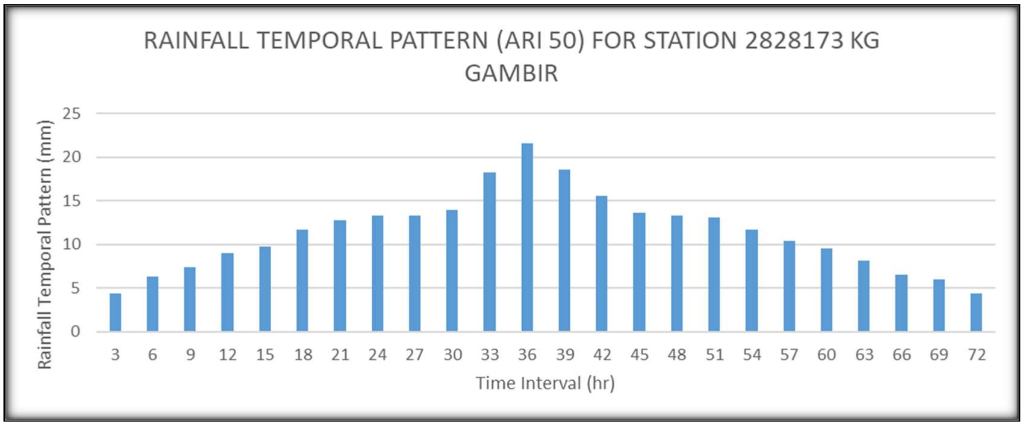

Figure 4.17 Temporal Rainfall Pattern (ARI50) for Station 2828173 Kg Gambir

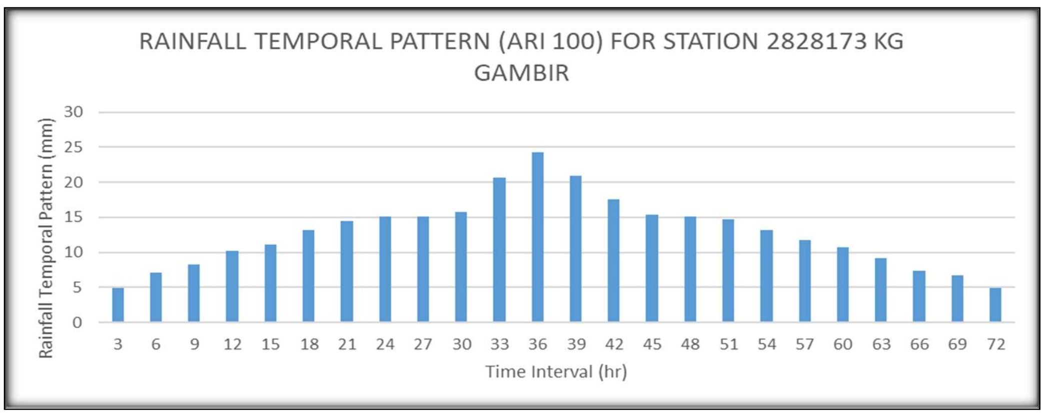

Figure 4.18 Temporal Rainfall Pattern (ARI100) for Station 2828173 Kg Gambir

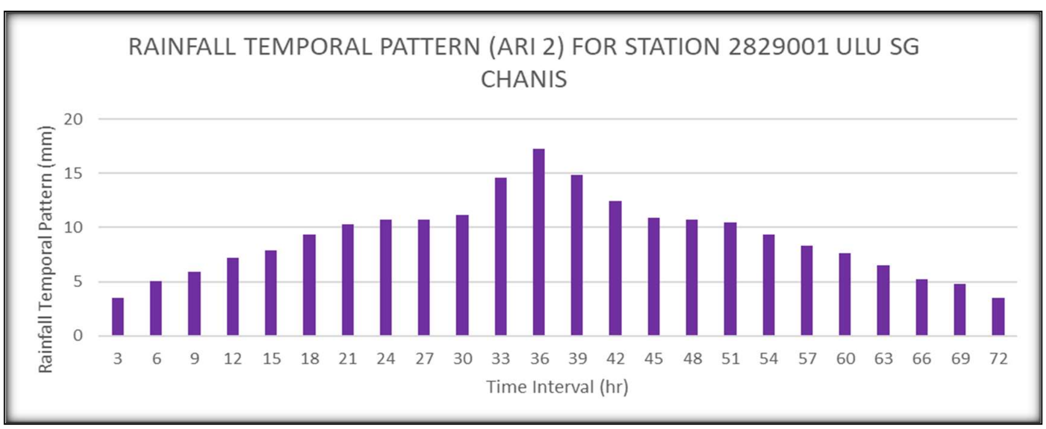

Figure 4.19 Temporal Rainfall Pattern (ARI2) for Station 2829001 Ulu Sg. Chanis

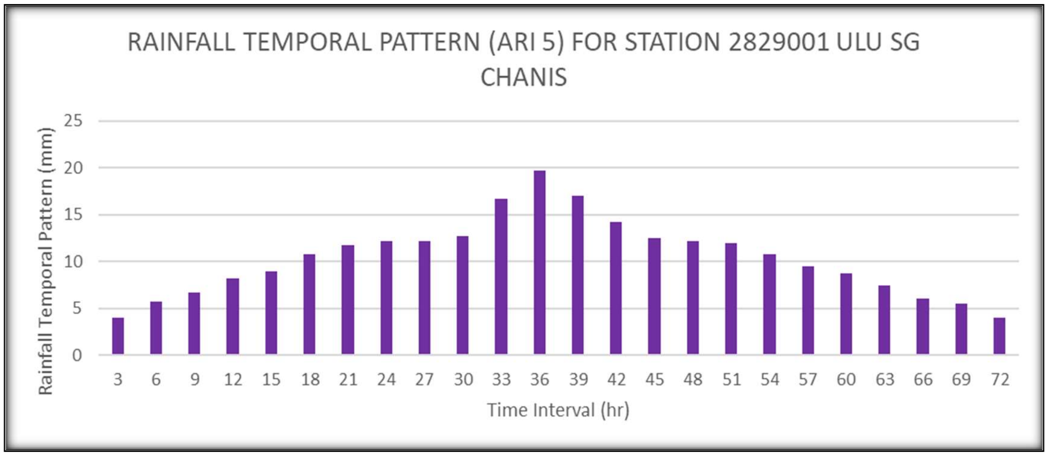

Figure 4.20 Temporal Rainfall Pattern (ARI5) for Station 2829001 Ulu Sg. Chanis

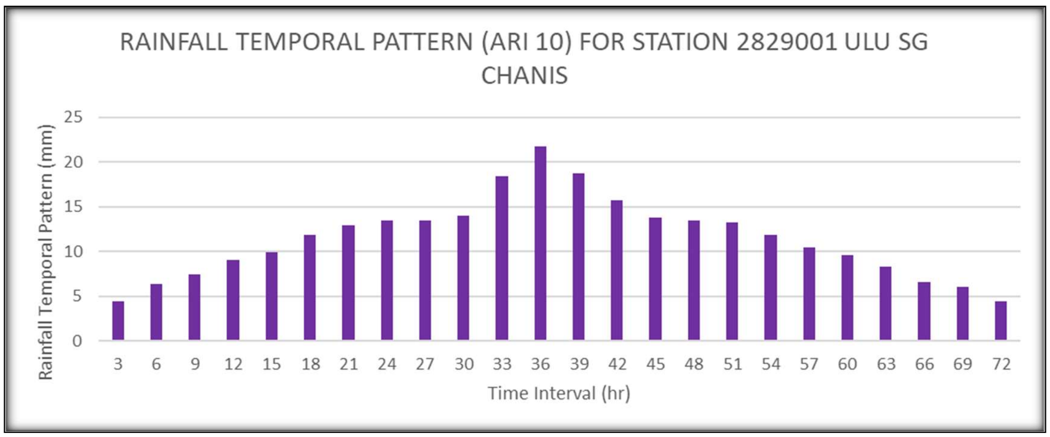

Figure 4.21 Temporal Rainfall Pattern (ARI10) for Station 2829001 Ulu Sg. Chanis

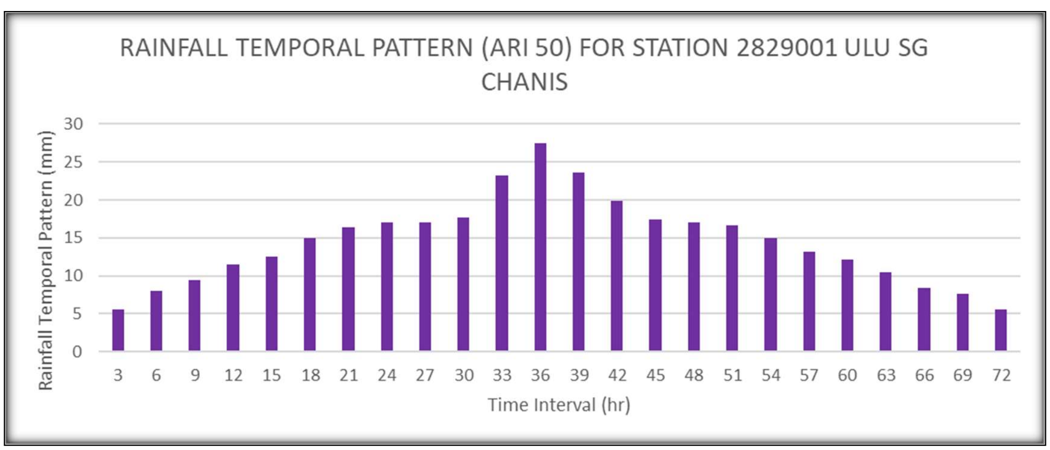

Figure 4.21 Temporal Rainfall Pattern (ARI50) for Station 2829001 Ulu Sg. Chanis

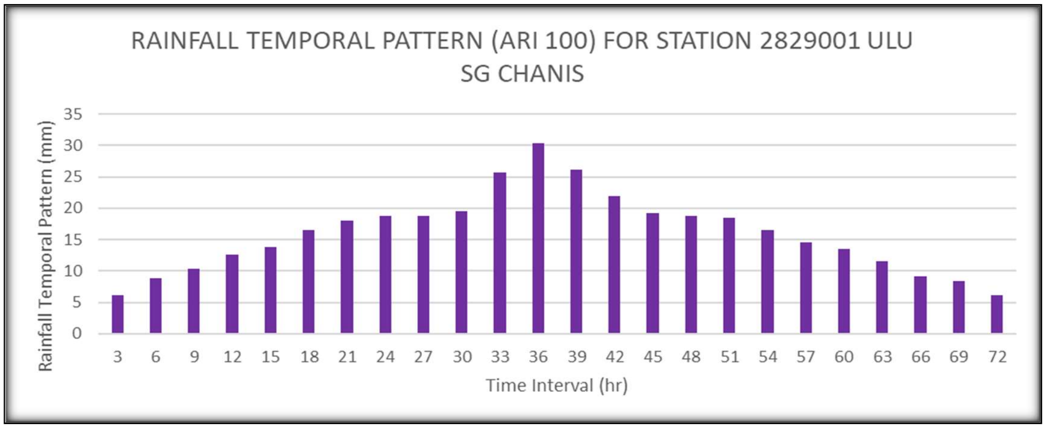

Figure 4.22 Temporal Rainfall Pattern (ARI100) for Station 2829001 Ulu Sg. Chanis

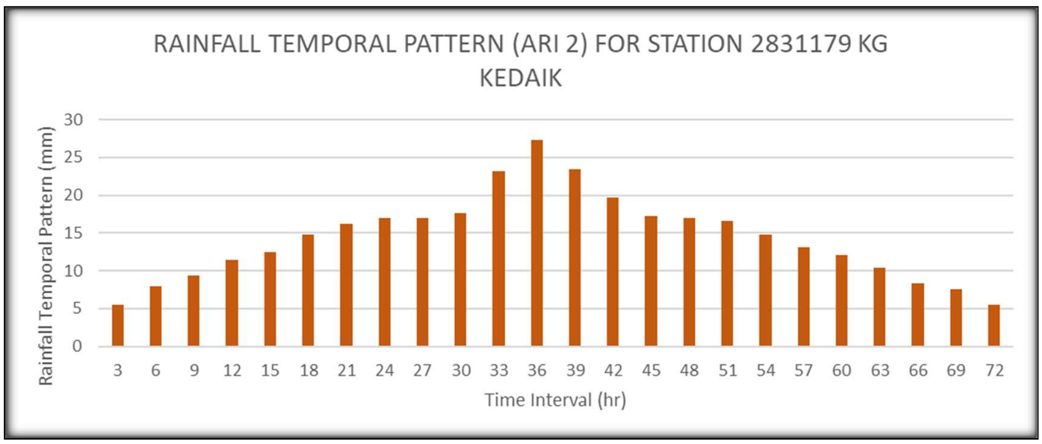

Figure 4.23 Temporal Rainfall Pattern (ARI2) for Station 2831179 Kg Kedaik

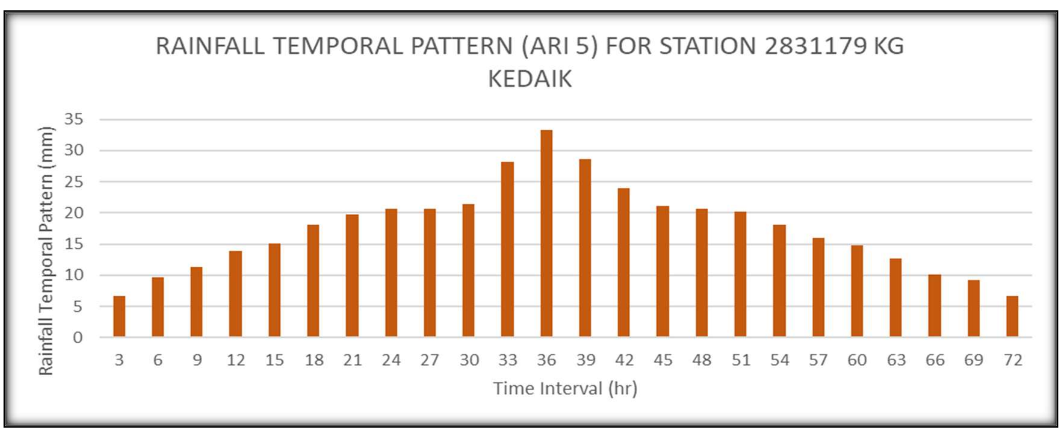

Figure 4.24 Temporal Rainfall Pattern (ARI5) for Station 2831179 Kg Kedaik

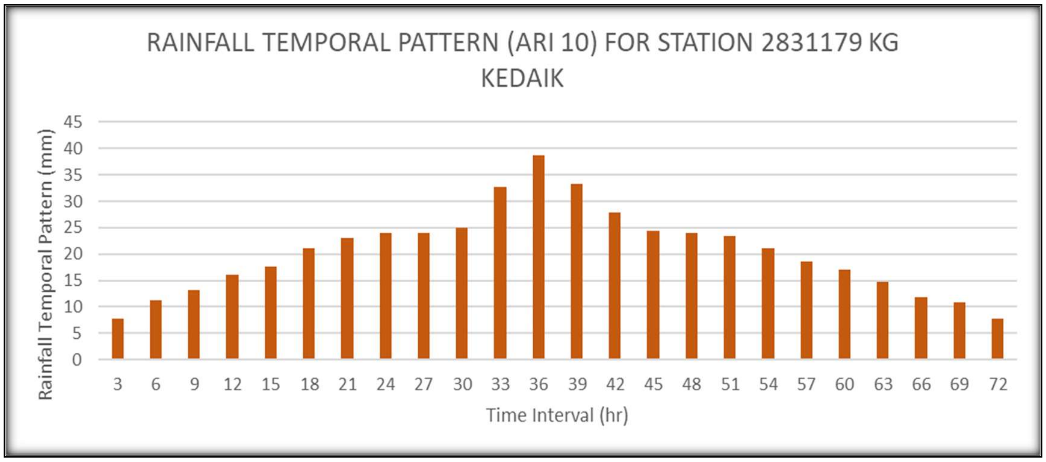

Figure 4.25 Temporal Rainfall Pattern (ARI10) for Station 2831179 Kg Kedaik

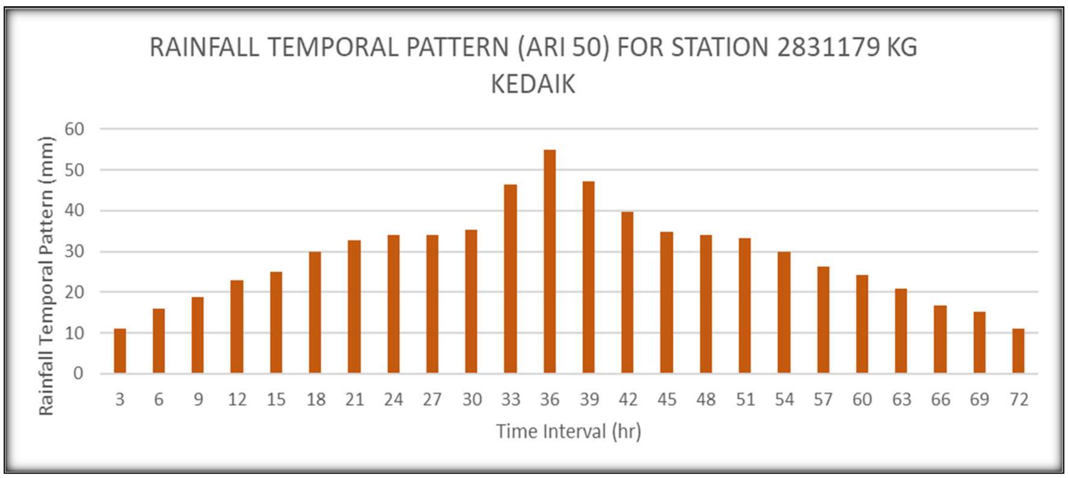

Figure 4.26 Temporal Rainfall Pattern (ARI50) for Station 2831179 Kg Kedaik

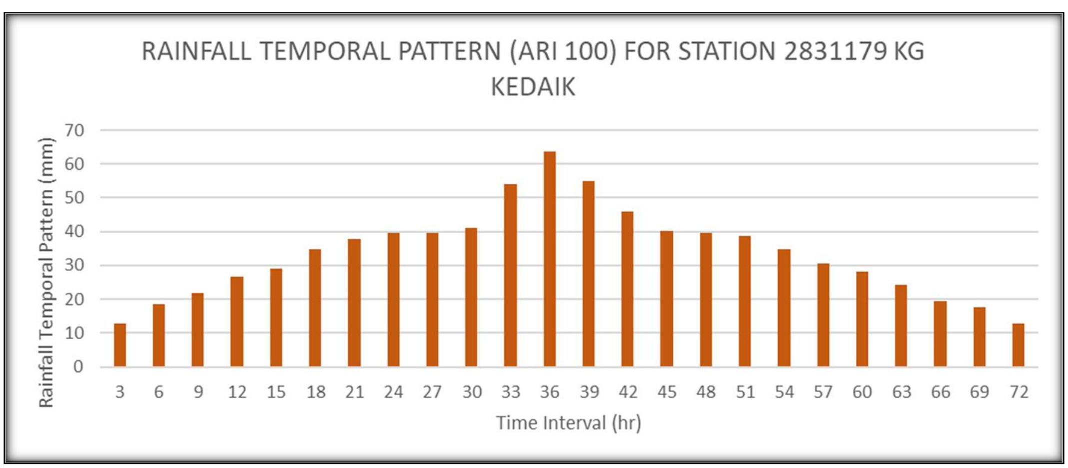

Figure 4.27 Temporal Rainfall Pattern (ARI100) for Station 2831179 Kg Kedaik

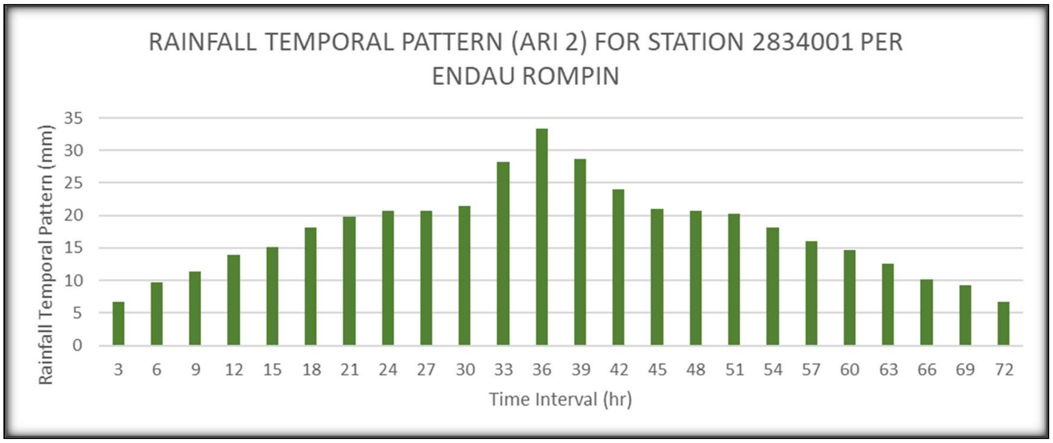

Figure 4.28 Temporal Rainfall Pattern (ARI2) for Station 2834001 Per Endau Rompin

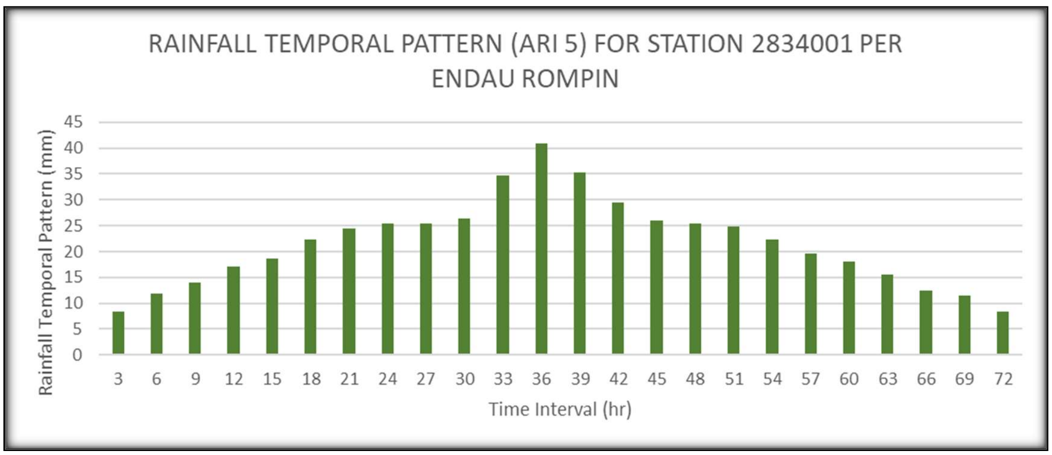

Figure 4.29 Temporal Rainfall Pattern (ARI5) for Station 2834001 Per Endau Rompin

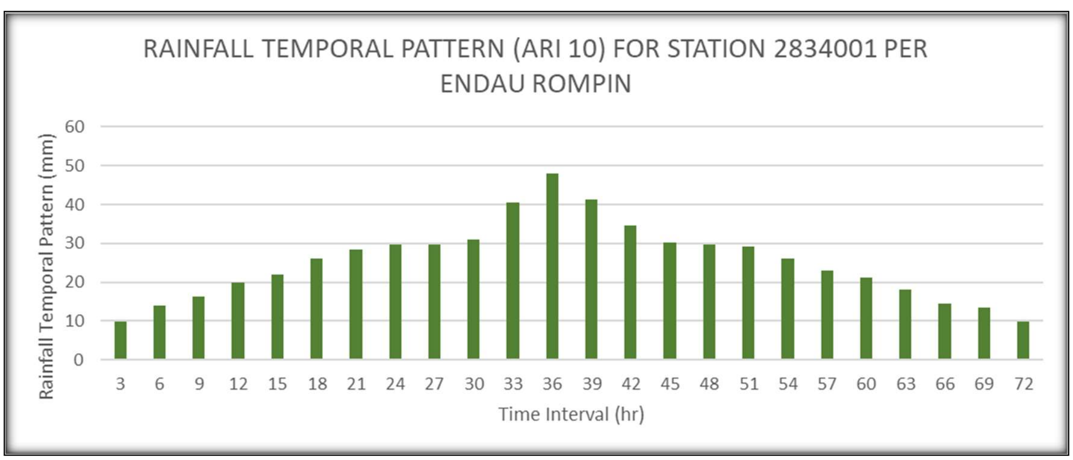

Figure 4.30 Temporal Rainfall Pattern (ARI10) for Station 2834001 Per Endau Rompin

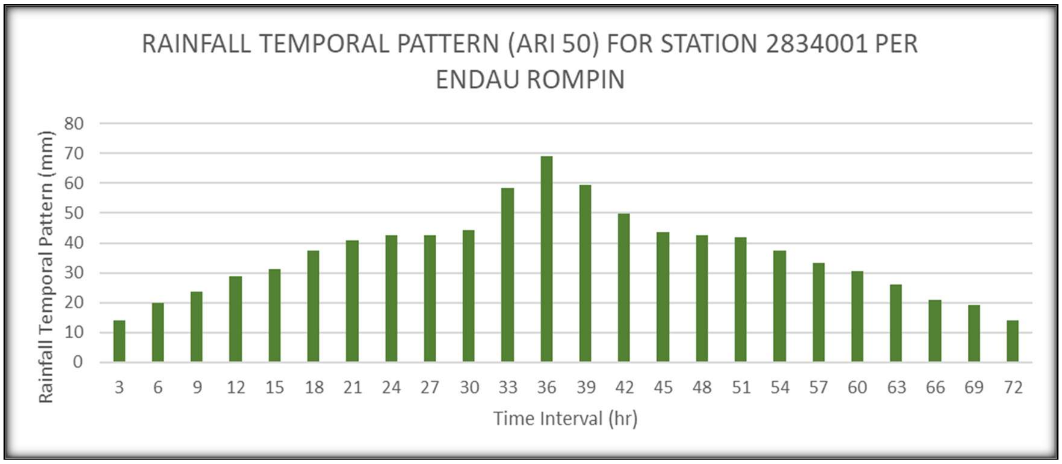

Figure 4.31 Temporal Rainfall Pattern (ARI50) for Station 2834001 Per Endau Rompin

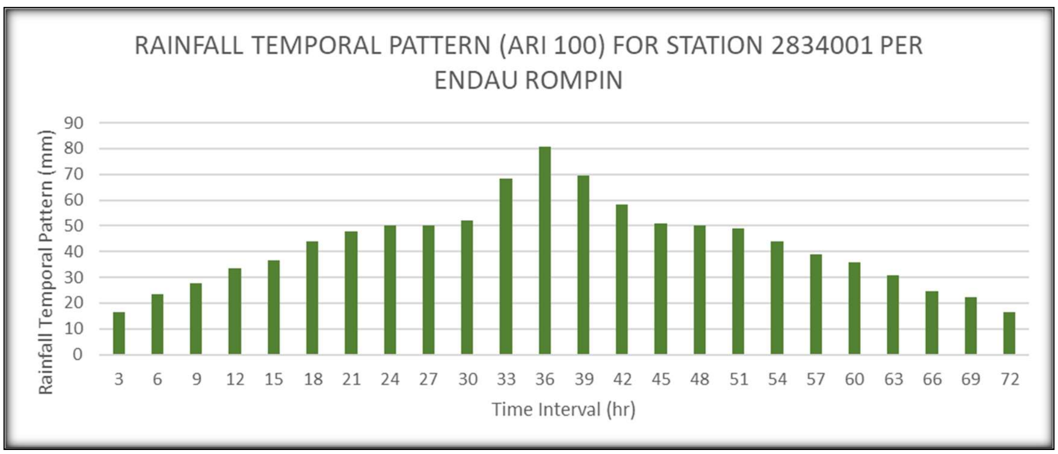

Figure 4.31 Temporal Rainfall Pattern (ARI100) for Station 2834001 Per Endau Rompin

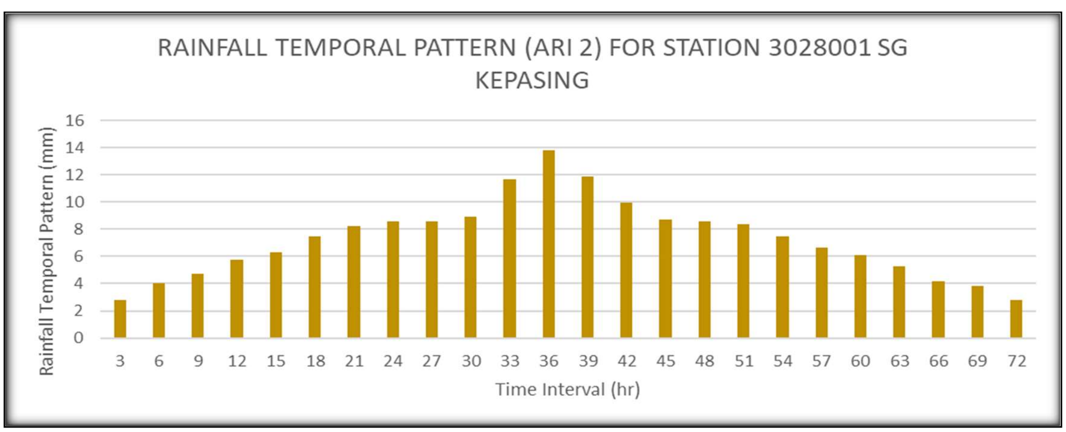

Figure 4.32 Temporal Rainfall Pattern (ARI2) for Station 3028001 Kg Kepasing

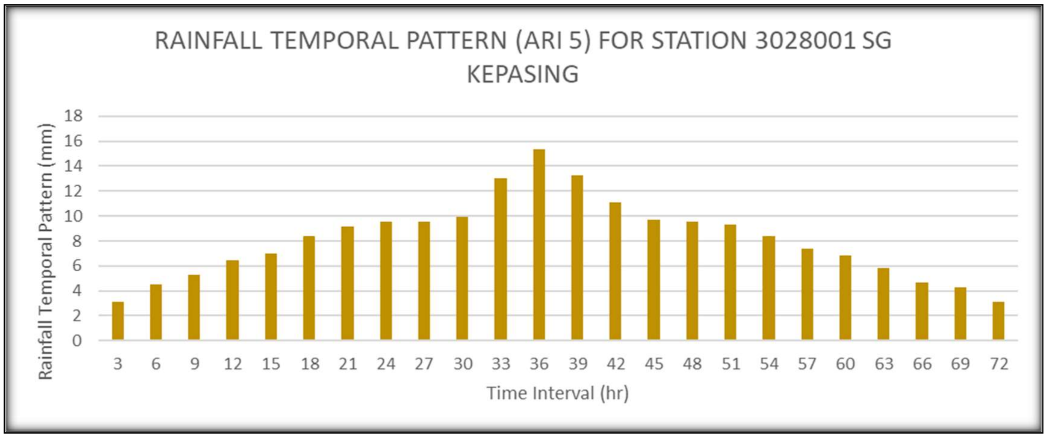

Figure 4.33 Temporal Rainfall Pattern (ARI5) for Station 3028001 Kg Kepasing

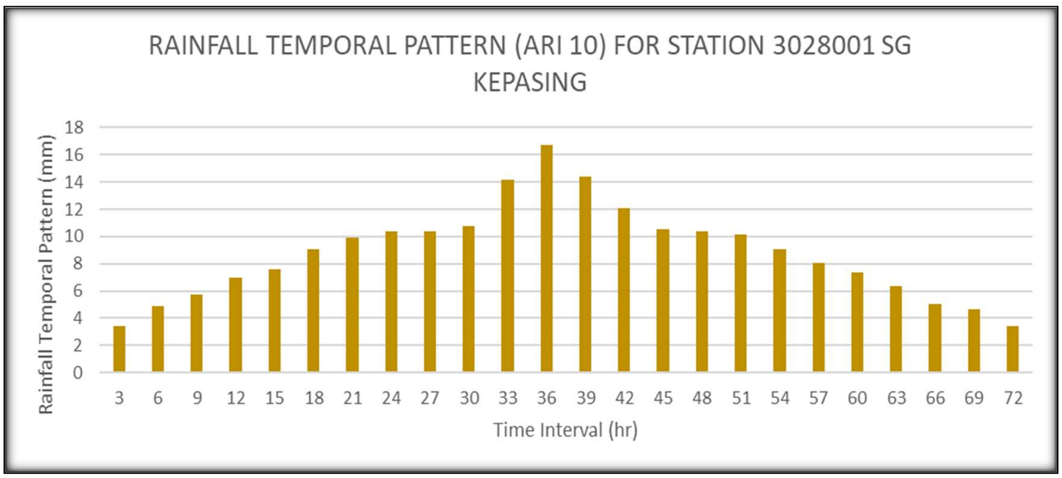

Figure 4.34 Temporal Rainfall Pattern (ARI10) for Station 3028001 Kg Kepasing

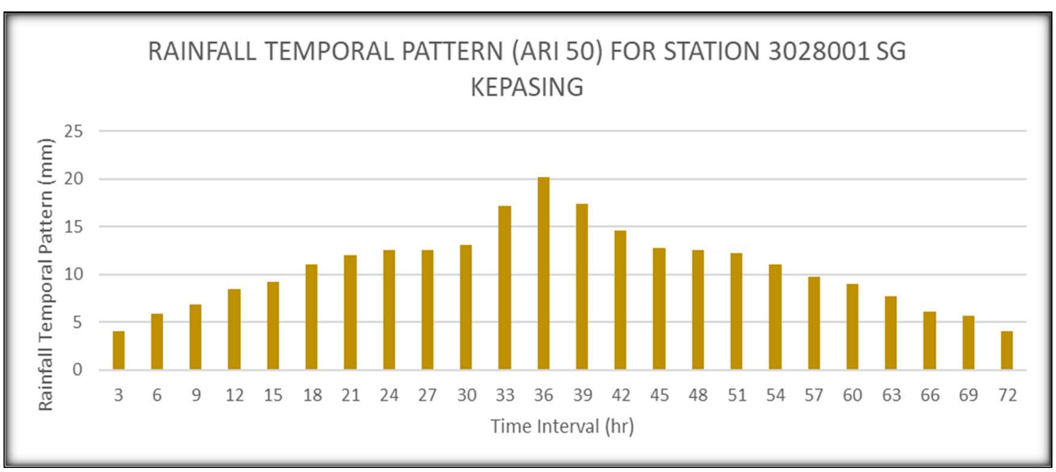

Figure 4.35 Temporal Rainfall Pattern (ARI50) for Station 3028001 Kg Kepasing

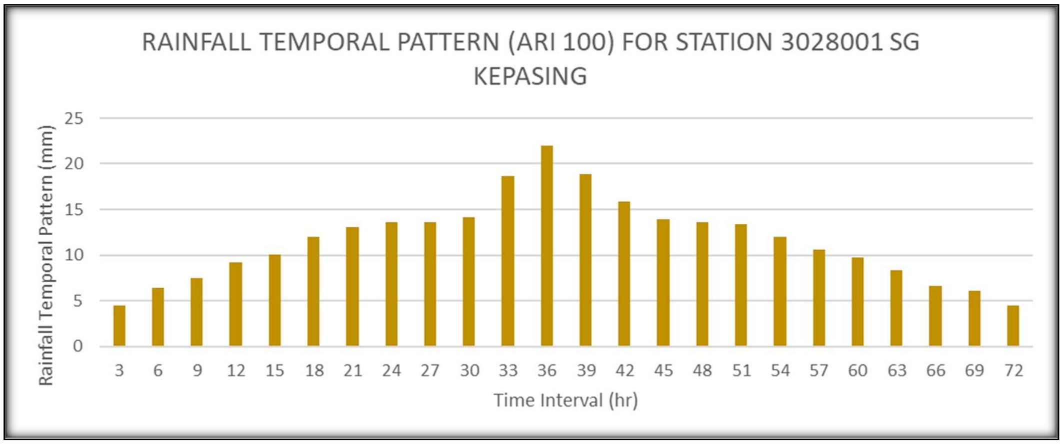

Figure 4.36 Temporal Rainfall Pattern (ARI100) for Station 3028001 Kg Kepasing

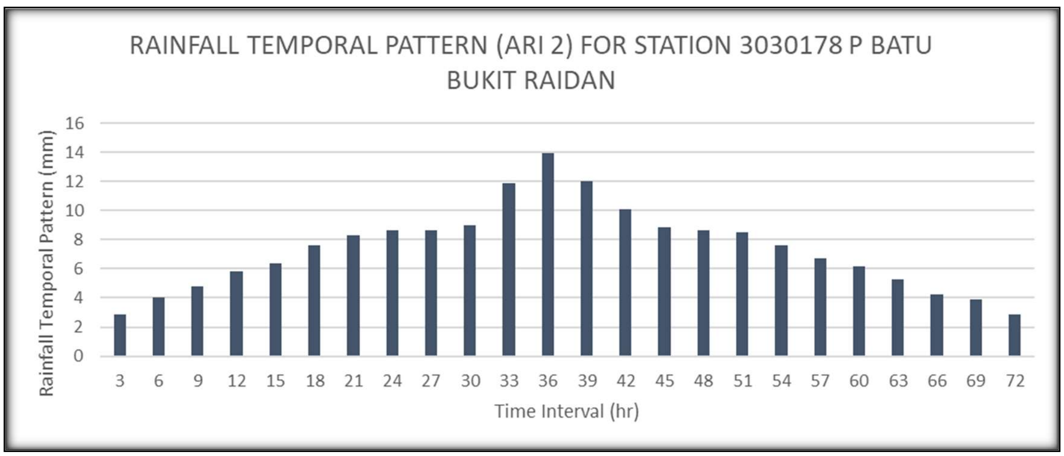

Figure 4.37 Temporal Rainfall Pattern (ARI2) for Station 3030178 P. Batu Bukit Raidan

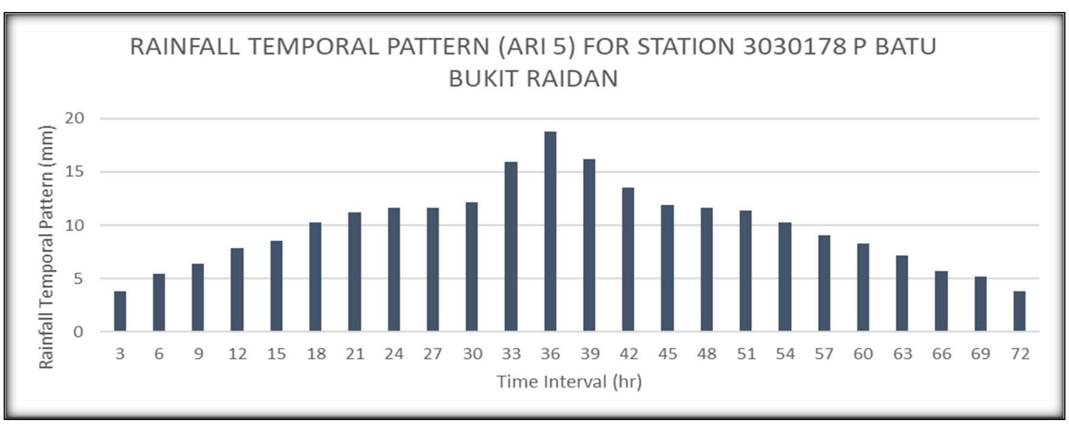

Figure 4.38 Temporal Rainfall Pattern (ARI5) for Station 3030178 P. Batu Bukit Raidan

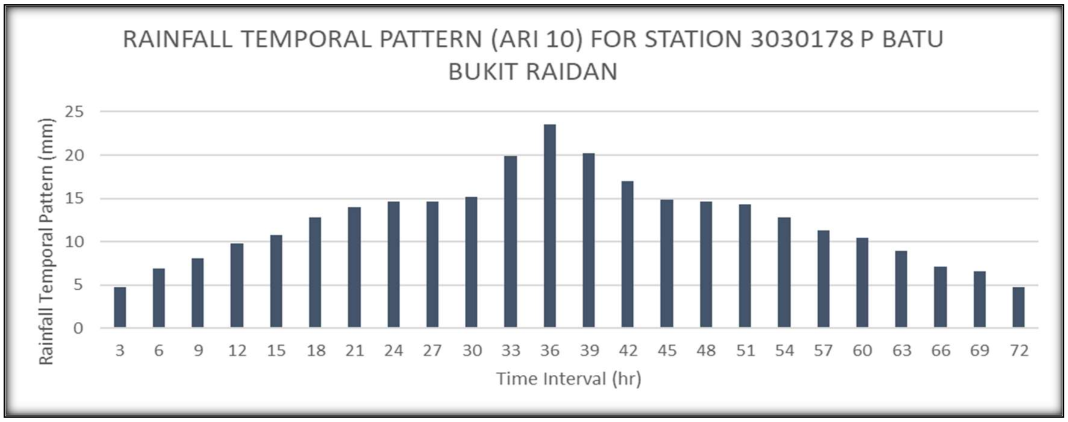

Figure 4.39 Temporal Rainfall Pattern (ARI10) for Station 3030178 P. Batu Bukit Raidan

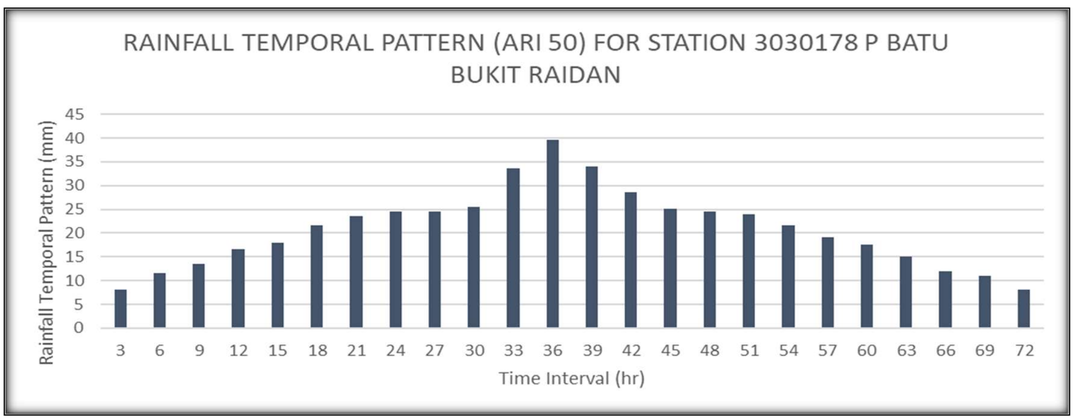

Figure 4.40 Temporal Rainfall Pattern (ARI50) for Station 3030178 P. Batu Bukit Raidan

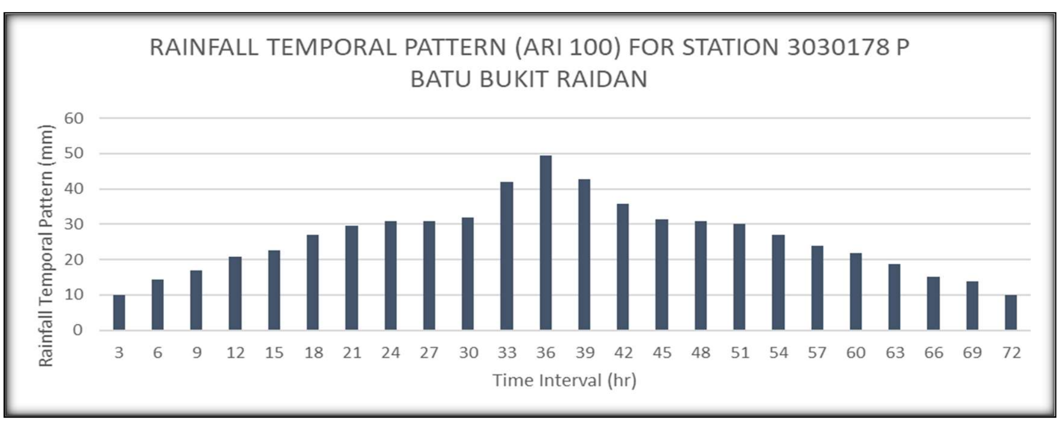

Figure 4.41 Temporal Rainfall Pattern (ARI100) for Station 3030178 P. Batu Bukit Raidan

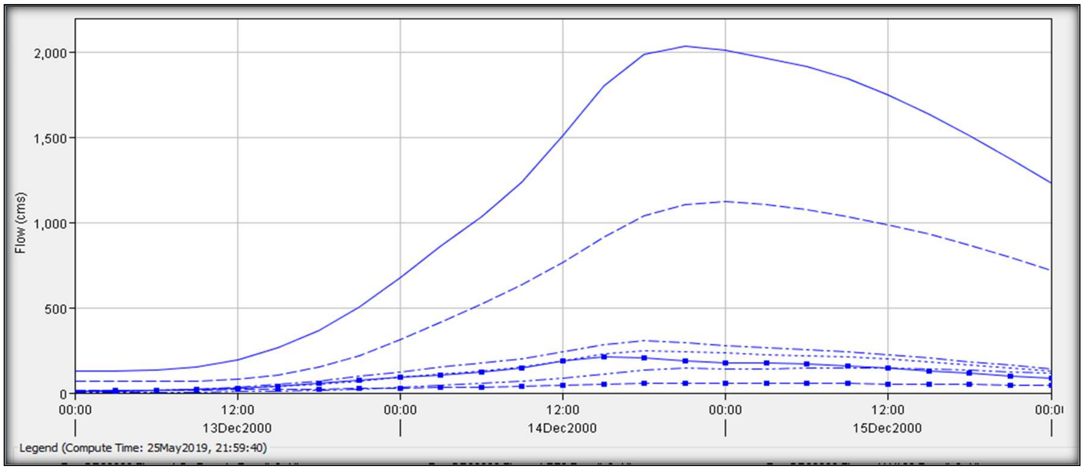

Figure 4.42 Generated Hydrograph for Design Storm of ARI2 (Rompin River)

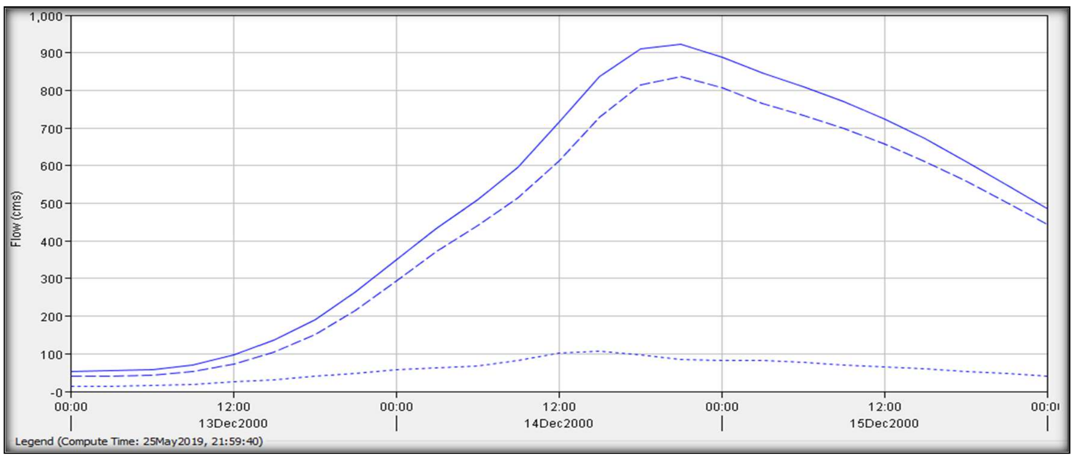

Figure 4.43 Generated Hydrograph for Design Storm of ARI2 (Keratong River)

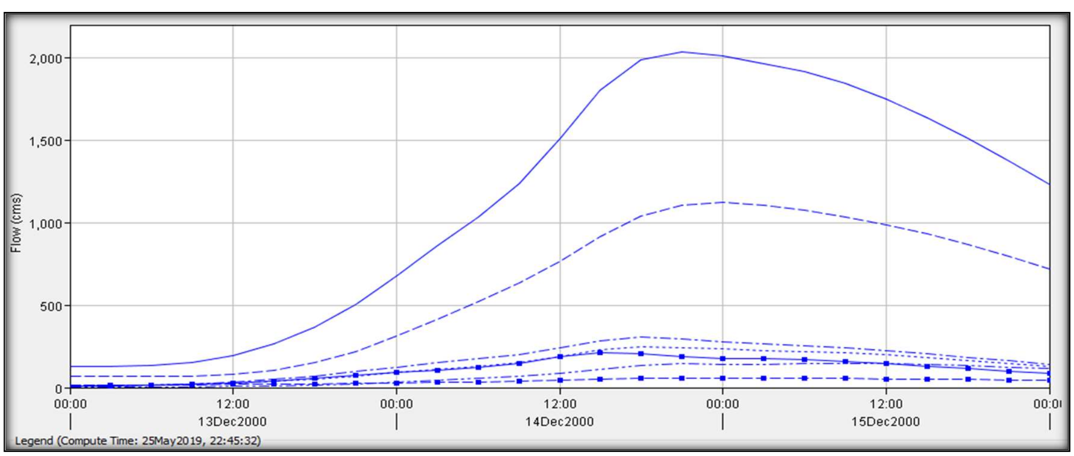

Figure 4.44 Generated Hydrograph for Design Storm of ARI5 (Rompin River)

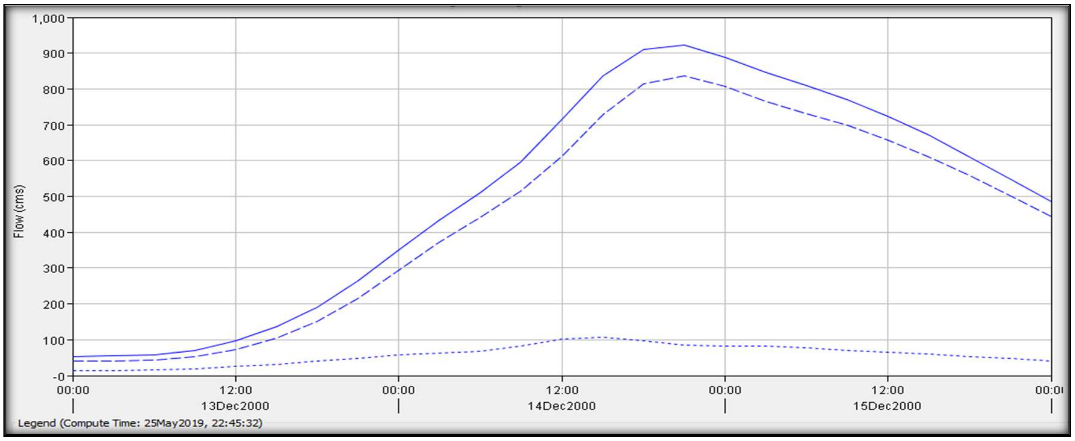

Figure 4.45 Generated Hydrograph for Design Storm of ARI5 (Keratong River)

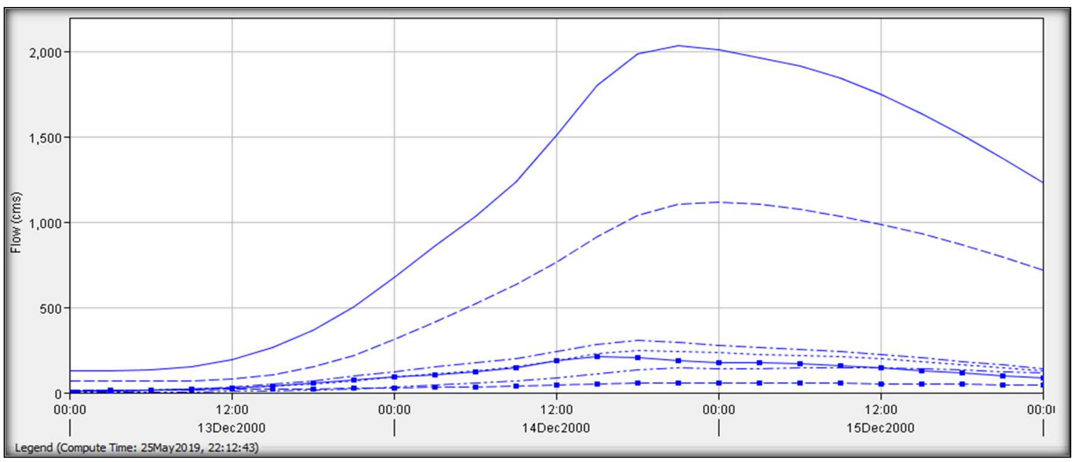

Figure 4.46 Generated Hydrograph for Design Storm of ARI10 (Rompin River)

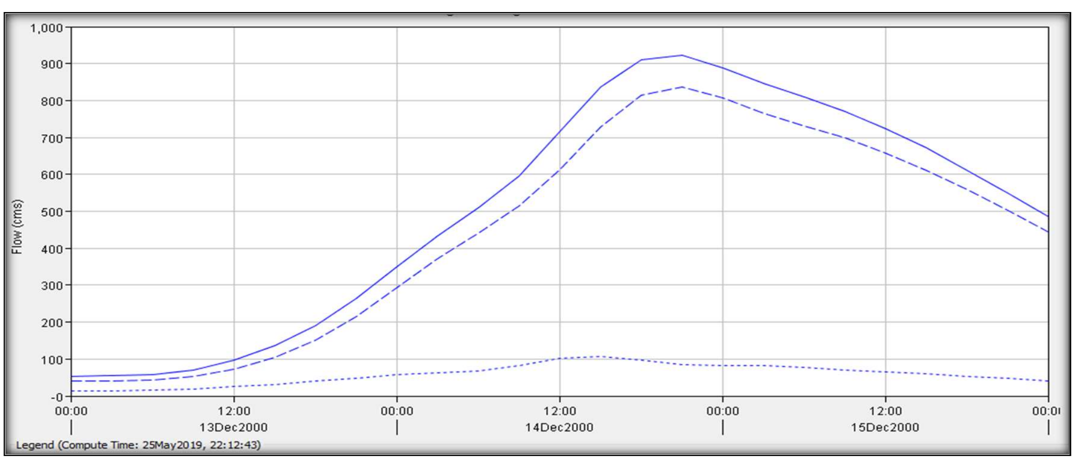

Figure 4.47 Generated Hydrograph for Design Storm of ARI10 (Keratong River)

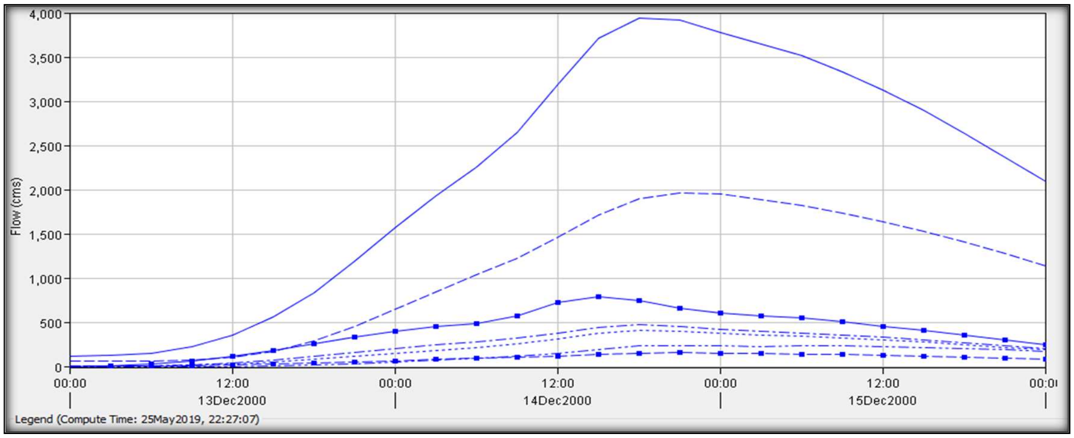

Figure 4.48 Generated Hydrograph for Design Storm of ARI50 (Rompin River)

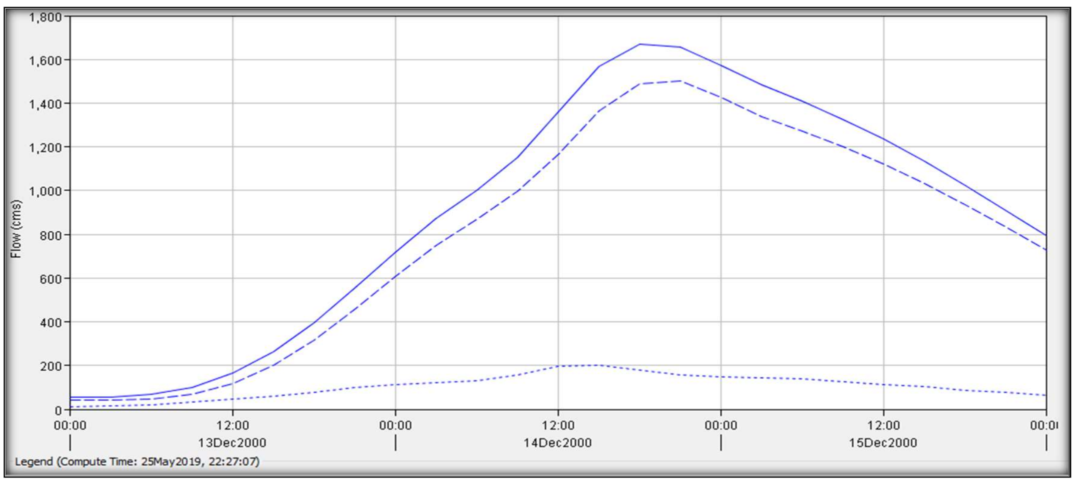

Figure 4.49 Generated Hydrograph for Design Storm of ARI50 (Keratong River)

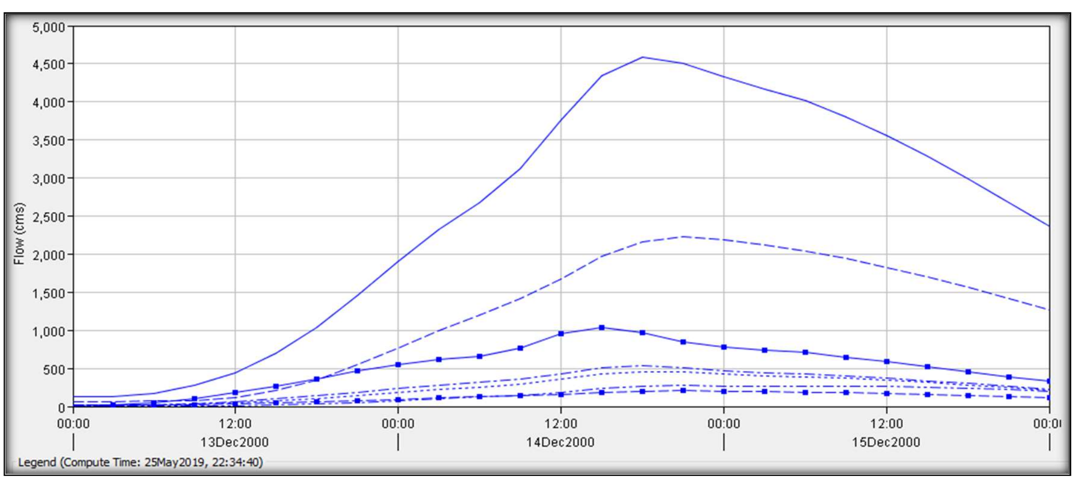

Figure 4.50 Generated Hydrograph for Design Storm of ARI100 (Rompin River)

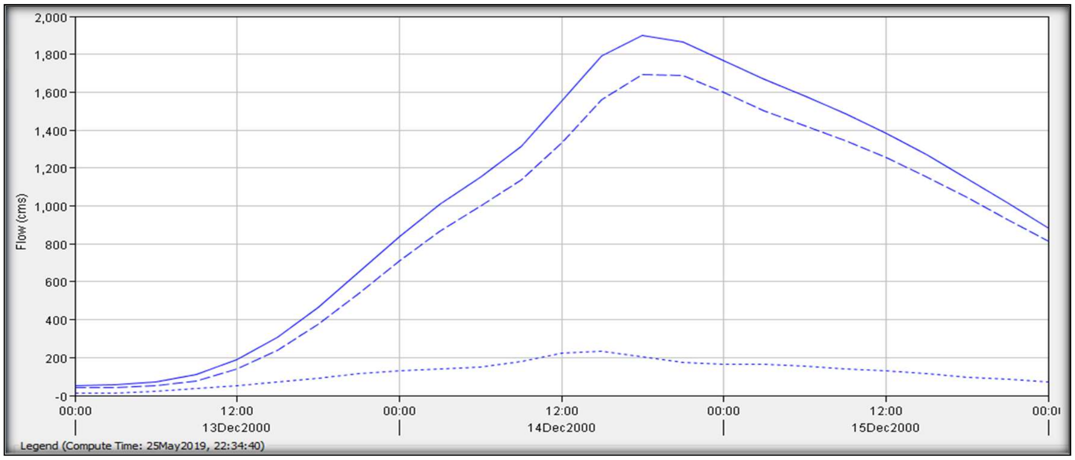

Figure 4.51 Generated Hydrograph for Design Storm of ARI100 (Keratong River)

Table 4.6 Peak Discharge of Hydrograph Design Storm at River Rompin and River Keratong Stations

ARI	**SF3030401**	**SF2928401**
	RIVER ROMPIN	RIVER KERATONG
	Peak Discharge (m3/s)	
2	2037.30	923.00
5	2037.30	923.00
10	2037.30	922.90
50	3945.60	1667.70
100	4581.40	1897.20

In overall, the results show that HEC-HMS with Clark Unit Hydrograph Method can be applied to simulate the streamflow hydrograph of the Rompin River Basin with certain level of acceptance. However, the observed streamflow hydrograph patterns for all events seem to be not satisfactory fitted to the simulated streamflow hydrograph. This uncertainty could be due to the degree of reliability of the gauging data or due to inappropriate selection of the calibration parameters as some data was not available.

The IDF Curve for all rainfall stations showed a good result after being calibrated and after some parameters being adjusted. The IDF Curves developed a good performance and can be used for future study since there is only several adjustments were made to develop a best-fit IDF Curve for Rompin River Basin.

The design rainfall (temporal pattern) histograms and hydrograph generation design storms showed a satisfying result for all 6 rainfall stations and both streamflow stations. The results obtained is can be used in flood prediction in future. There is no adjustment were made for this design rainfall.

4.7 Model Efficiency

In this study, the model efficiency of hydrological model has been evaluated using the Root Mean Square Error Analysis and Nash-Sutcliffe Efficiency. The statistical error has been computed for all selected monthly rainfall events as shown in Appendix D. Table 4.6 shows the model performance result for Rompin River and Table 4.7 shows the model performance result for Keratong. River From the tables, it shows there is a large error for both error analyses especially RMSE. This is due to the difference that are contributed by high peak of simulated hydrograph and observed hydrograph. Lower RMSE value indicated desirable closeness of the simulated model to the observed model. The negative value of NSE indicated mean observed data is better predictor than the simulated data. The positive indicator than near to 1 showed the simulated data nearly matched to the observed data.

Table 4.6 : RMSE and NSE Result for Rompin River

Error Analysis	Dec 2000	Dec 2010	Dec 2012
RMSE	3774.41	2.59	273.81
NSE	-0.98	0.59	-1.14

Table 4.7 : RMSE and NSE Result for Keratong River

Error Analysis	Dec 2000	Dec 2010	Dec 2012
RMSE	3774.40	4208.22	6024.82
NSE	-0.98	-0.98	-2.25

CHAPTER 5

CONCLUSION

5.1 Introduction

The IDF Curve for Rompin River Basin have been successfully developed with several parameter adjustments. The IDF Curve for all rainfall stations showed a good result after being calibrated and can be used for future study since there is only several adjustments were made to develop a best-fit IDF Curve for Rompin River Basin.

The streamflow hydrographs for Rompin River Basin have been successfully simulated using HEC-HMS model for all 3 monthly rainfall events: December 2000, December 2010 and December 2012.

The calibration process for the monthly rainfall events selected have been completed at both streamflow station (River Keratong and River Rompin) by adjusting the calibration parameter in the HEC-HMS model. It is found that there were difficulties in fitting the simulated discharge to the observed especially at peak of the hydrographs. This unsatisfactory result could be due to some parameters used were not appropriate as some data was not available. Therefore, the adjustment of calibration parameters was made by ensuring most part of the simulated hydrograph match the observed hydrograph.

Validation process was conducted using different set of data to ensure the calibration process were correctly defined. Based on the validation results, statistical error analysis using RMSE and NSE have been performed. From the error analysis result, it shows there is a large error for both error analyses especially RMSE. This is due to the difference that are contributed by high peak of simulated hydrograph and observed hydrograph. Despite the low performance, the overall modelling results are still considered acceptable with sufficient streamflow hydrograph pattern for some cases with the best RMSE value of 2.59 and NSE value of 0.59.

The IDF Curve and design rainfall for Rompin River Basin have been successfully developed. The IDF Curve was developed and calibrated for ARI 2-year, 5-year, 10-year, 50-year, and 100-year. There is no parameter adjustment for design rainfall since the results obtained is satisfying according to the standard in MSMA2.

5.2 Recommendation

Based on this study, there are some aspects that should be enhanced in order to improve the accuracy of the result. Since there are difficulties in develop better curve graph of IDF Curve for design rainfall pattern, trail of θ value is needed as adjustment parameter to obtain a better IDF Curve Graph.

Regarding the raw hydrological data collected from DID, it was found that there were several of missing data. These missing data values shall be carefully analyzing to avoid significant errors in the whole process of this study. Gap filling is recommended to be done using appropriate statistical measures.

In this study, the calibration and validation analyses have shown that it is difficult to fit the simulated streamflow hydrograph with observed streamflow hydrograph. In this study, Adjustment of lag time parameter is needed to match the lag time for simulated streamflow hydrograph to reach its peak at same time as observed streamflow hydrograph.

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APPENDIX A
AVERAGE MONTHLY RAINFALL DATA

Average Monthly Rainfall Data (mm) used for station 2828173 Kg Gambir

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	252.5	224.5	210.7	138.7	50.8	128.8	132.5	96.5	132.8	102.1	205.2	236.3
2001	219.5	42	223.8	80.7	56.1	76.4	59.6	102.4	114	227	289.8	182.2
2002	80.7	45	18	86.5	111	5.5	53.5	86	83.4	113.6	112.4	125.5
2011	416	21.5	466	48.5	141	101	153	120.5	59.5	145	132.5	482
2012	47.5	135.5	175.5	109	90.5	128.5	45	174	84	191.5	194	207.5
2013	93.5	340.5	78.5	142	318	22.5	107.5	59	100	172	96	353
2014	60.5	1.5	266	211.5	149	54	60.5	167	51.5	271.5	117.5	450
2015	110	26	117.5	178.5	69	97	63.5	114.5	139	69.5	190.5	195
2016	44.5	187	30.5	254.5	38	88	93	60.5	146.5	118	197.5	172
2017	538.5	136	349.5	113.5	122	120.5	23	121	197.5	190	241	260.5
AVERAGE	186.32	115.95	193.6	136.34	114.54	82.22	79.11	110.14	110.82	160.02	177.64	266.4

Average Monthly Rainfall Data (mm) used for station 2829001 Ulu River. Chanis

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	618.4	154.8	244.1	148.5	44.3	232.9	21.2	80.7	200.9	135.9	177.9	269.3
2001	256.7	36.1	174.1	107.4	89.1	100.5	43.2	81.1	130.2	314	178.4	250.9
2002	135.7	113.7	25.5	87	97.5	90.5	49	125.5	81	117.2	356.7	256.5
2011	482.5	22	446	68.5	91.5	31	241.5	93.5	159	181.5	140.5	547
2012	101.5	174	175	104	71	69	78.5	126	122	183.5	318	203.5
2013	138.5	556	94.5	67	212.5	16.5	240	109	150.5	142	71	339
2014	78.5	1	256.5	295	323	60.5	45.5	60	74	280	138.5	9.5
2015	143.5	15.5	50	303.5	122.5	108.5	98	87.5	90	105	164	211
2016	106.5	202.5	73	196	105.5	11	85.5	80.5	132.5	176	202.5	236.5
2017	520.5	152	359.5	93	153.3	166.7	25.5	171	251	321	223.5	236.5
AVERAGE	258.23	142.76	189.82	146.99	131.02	88.71	92.79	101.48	139.11	195.61	197.1	255.97

Average Monthly Rainfall Data (mm) used for station 2831179 Kg Kedaik

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	32.3	182.1	131.6	164.6	61.1	99	58.8	176.7	202.4	165.9	217.8	428.4
2001	429.9	93.9	255.9	106.9	118.1	92.2	38.5	37.5	123	100.5	290.7	556.6
2002	120.8	46.2	94	109.9	83.4	72	191	153.5	155	186	275.1	530.9
2011	668.5	43.5	593.5	97	170.5	50	246.5	80	261	245.5	278	755
2012	150	337	211	269.5	96.5	47.5	52	256	101.5	346.5	227.5	443
2013	267.5	582.5	6	109.5	239	25	141.5	258.5	99	263	110	571.5
2014	55.5	5.5	210.5	164	179	82	119.5	197.5	129	132.5	157.5	967
2015	167.5	51	22	71	106.5	179	263	261.5	161.5	171.5	287.8	404.7
2016	147.5	284	81	34.5	146	68	132	43	224.5	211.5	318	161.5
2017	655.5	324	261.5	143	297.5	143.5	30.5	347	136	167.9	227.1	339.5
AVERAGE	269.5	194.97	186.7	126.99	149.76	85.82	127.33	181.12	159.29	199.08	238.95	515.81

Average Monthly Rainfall Data (mm) used for station 2834001 Per. Endau Rompin

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	81.8	33.5	8.6	0	0	169.3	152.4	230.1	73.7	104.3	180.2	304.5
2001	268.8	85.3	230.7	149.5	191.9	69.2	180.2	222.8	156.5	538	524	871.5
2002	159.9	63	70	75	147.5	56.5	104.5	76	72.5	57.5	141.5	1246
2011	486	6	365	121	98.5	133	221	98.5	248	450	385	833
2012	232	212	236.5	118.5	94	103	209	190.5	208.5	456	231	206.5
2013	695.5	792	30	28.5	180	22.5	114.5	170.5	272.5	263.5	194.5	951.5
2014	137	6.5	82	43.5	129.5	64.9	118.6	140	164	202.5	186	1216.5
2015	349.5	161	40.5	78	109	46	82.5	97.5	127	83	342.4	602.1
2016	131.5	175	5.5	0	135	95	28	107	177	314	203.5	222
2017	603.5	320	343.5	138.5	292.5	118	206.5	300	123.5	205	283	540.5
AVERAGE	314.55	185.43	141.23	75.25	137.79	87.74	141.72	163.29	162.32	267.38	267.11	699.41

Average Monthly Rainfall Data (mm) used for station 3028001 River. Kepasing

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	411.4	214.7	152.9	391.2	174.5	139.2	66.5	141.3	186.1	123.5	254.6	222
2001	255.1	106.6	127.2	103.7	90.2	50.2	157.6	85.4	143	191.2	335.6	226
2002	64.5	46	66.5	4.5	229	37	69.1	256	62	128	153	196
2011	3.5	41	534	74.5	139	54	178.5	113.5	143.5	139.5	189	400.5
2012	165.5	341.5	170	123.5	181.5	108	101.5	142.5	78.5	269.5	235.5	273
2013	93	292.5	25	189	272	139.5	204.5	83.5	94.5	202	110	474
2014	107	0.5	94	167	190	84	15	123	79	55.5	122.5	546
2015	84	20	86	166	92.5	170.5	98.5	110.5	116	119.5	209	203.5
2016	62.5	121	46.5	37.5	201	126.5	117.5	29	285.5	108	222	160
2017	536.5	138	273.5	67	145	133.5	16	176.5	350	172.5	311	227
AVERAGE	178.3	132.18	157.56	132.39	171.47	104.24	102.47	126.12	153.81	150.92	214.22	292.8

Average Monthly Rainfall Data (mm) used for station 3030178 P. Batu Bukit Raidan

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	302.5	94	191.5	254.5	118	141.5	12	18.5	2.8	236.9	158.3	380.5
2001	0	19.3	226.6	199.6	103	33.5	71	114.4	254.7	174.6	381.4	250.4
2002	32.5	79	109.5	230	216.5	169.5	143.5	215.9	192.3	195.5	294	344
2011	404	24	495	113	128.5	81.5	162.5	54.5	297	164	220	574
2012	184.5	165	287.5	317.5	205	66.5	147	173.5	129	212	278	362.5
2013	180	366	7.5	183	267.5	75.5	203.5	242.5	0.5	79.5	99.5	687
2014	141.5	4.5	58.5	179	145.5	83	57.5	130.5	35	154	177	701
2015	137.5	90.5	14	82	229.5	64.5	169	137	56.5	95	207.5	205.5
2016	41.5	147.5	40.5	48	124	89	135	32	139	138	251	196
2017	648.5	162.5	189.5	150.5	343	92.5	52	201.5	133.5	139	290.5	395.5
AVERAGE	207.25	115.23	162.01	175.71	188.05	89.7	115.3	132.03	124.03	158.85	235.72	409.64

Average Monthly Rainfall Data (mm) used for station all 6 Rainfall Stations

YEAR/MONTH	JAN	FEB	MAC	APR	MAY	JUN	JULAI	AUG	SEPT	OCT	NOV	DEC
2000	283.15	150.6	156.5667	182.9167	74.78333	151.7833	73.9	123.9667	133.1167	144.7667	199	306.8333
2001	238.3333	63.86667	206.3833	124.6333	108.0667	70.33333	91.68333	107.2667	153.5667	257.55	333.3167	389.6
2002	99.01667	65.48333	63.91667	98.81667	147.4833	71.83333	101.7667	152.15	107.7	132.9667	222.1167	449.8167
2011	410.0833	26.33333	483.25	87.08333	128.1667	75.08333	200.5	93.41667	194.6667	220.9167	224.1667	598.5833
2012	146.8333	227.5	209.25	173.6667	123.0833	87.08333	105.5	177.0833	120.5833	276.5	247.3333	282.6667
2013	244.6667	488.25	40.25	119.8333	248.1667	50.25	168.5833	153.8333	119.5	187	113.5	562.6667
2014	96.66667	3.25	161.25	176.6667	186	71.4	69.43333	136.3333	88.75	182.6667	149.8333	648.3333
2015	165.3333	60.66667	55	146.5	121.5	110.9167	129.0833	134.75	115	107.25	233.5333	303.6333
2016	89	186.1667	46.16667	95.08333	124.9167	79.58333	98.5	58.66667	184.1667	177.5833	232.4167	191.3333
2017	583.8333	205.4167	296.1667	117.5833	225.55	129.1167	58.91667	219.5	198.5833	199.2333	262.6833	333.25

APPENDIX B
RAINFALL AND STREAMFLOW DATA FOR HYDROLOGICAL MODEL

Data for simulation hydrological model (December 2000)

DEC 2000									
days	Rainfall Station (mm)						days	Streamflow Station (m^3/s)	
	Kg Gambir	Ulu Sg Chanis	Kg Kedaik	Sg kepasing	Batu Bukit Raidan	Per Endau Rompin		Sg Keratong	Sg Rompin
13	0	1.6	0.7	0	0	0	13	12.2	46.6
14	0	0	0.9	0	0	0	14	10.63	36.5
15	2.2	8.4	2.7	1.5	0.8	0	15	9.56	28.7
16	1.1	1.3	0	0	0.6	0	16	8.92	22.8
17	6.9	8.3	61.2	8.2	28.6	0	17	8.67	18.2
18	6.4	2.7	1.8	1.3	7.1	0	18	8.64	33.6
19	64.9	44	12.9	15.2	12.1	0	19	9.28	53.5
20	0	0	0.6	0	0	0	20	20.78	56.1
21	7.4	26.6	28	0.6	2.7	93.1	21	29.97	59.9
22	21.9	75.5	166	22.8	131	145.6	22	26.59	60.8
SUM OF							**SUM OF**		
10 DAYS	**110.8**	**168.4**	**274.8**	**49.6**	**182.9**	**238.7**	**10 DAYS**	**145.24**	**416.7**

Data for simulation hydrological model (December 2010)

DEC 2010									
days	Rainfall Station (mm)						days	Streamflow Station (m^3/s)	
	Kg Gambir	Ulu Sg Chanis	Kg Kedaik	Sg kepasing	Batu Bukit Raidan	Per Endau Rompin		Sg Keratong	Sg Rompin
13	0	0.5	5	0	5.5	7	13	33.59	26.9
14	1	1	2.5	1	1.5	3	14	30.13	24.8
15	0.5	13	24	0.5	12	13.5	15	26.66	24.4
16	0.5	0.5	6	12.5	12.5	2.5	16	24.66	21.6
17	4.5	5	5	3.5	5	5.5	17	23.43	18.4
18	5.5	8.5	19.5	7	7	57.5	18	22.68	17.8
19	24.5	54.5	46.5	32.5	42	79.5	19	22.25	15.8
20	7	7.5	5.5	16	44	27	20	23.78	20.9
21	0.5	1	3	0.5	2.5	21.5	21	31.57	45.5
22	0.5	5	23	0	0.5	88.5	22	35.18	56.9
SUM OF							**SUM OF**		
10 DAYS	**44.5**	**96.5**	**140**	**73.5**	**132.5**	**305.5**	**10 DAYS**	**273.93**	**273**

Data for simulation hydrological model (December 2012)

DEC 2012									
days	Rainfall Station (mm)						days	Streamflow Station (m^3/s)	
	Kg Gambir	Ulu Sg Chanis	Kg Kedaik	Sg kepasing	Batu Bukit Raidan	Per Endau Rompin		Sg Keratong	Sg Rompin
13	1.5	4.5	10.5	5	2.5	17.5	13	35.62	20.2
14	8	13.5	29.5	28	21	64	14	35.29	25.9
15	10	4.5	11.5	4	7	15	15	34.94	26.9
16	7	2.5	0	32	1	0	16	34.7	30.1
17	13	19	35	44	38	19.5	17	34.69	34.1
18	44	37	26	32.5	42	8.5	18	34.38	52.1
19	15	22.5	9	2.5	2.5	13.5	19	35.83	79.1
20	0.5	2	7.5	6	10	2	20	40.08	99.8
21	0	0.5	4.5	0	0.5	0.5	21	42.13	114.1
22	2	1	0	11	0	0.5	22	43.17	118.1
SUM OF 10 DAYS	**101**	**107**	**133.5**	**165**	**124.5**	**141**	**SUM OF 10 DAYS**	**370.83**	**600.4**

APPENDIX C
HYDROLOGICAL MODEL PARAMETER

Area (km^2) for 22 Sub-Basins in Rompin River Basin Storage Coefficient and Time of Concentration for 22 Sub-Basins in Rompin River Basin Baseflow (m^3/s) value for 22 Sub-Basins in Rompin River Basin

Subbasin	Area (KM2)
W330	334.04
W340	283.85
W1180	253.14
W1170	115.41
W220	308.06
W190	347.65
W240	340.64
W180	145.79
W200	124.96
W1230	269.08
W230	56.560
W1220	6.6928
W2750	386.96
W280	346.61
W290	192.72
W2800	170.28
W260	124.25
W2790	121.13
W320	202.06
W300	76.544
W310	1.3116

Subbasin	Time of Concentration (HR)	Storage Coefficient (HR)
W330	3.7794	3.2187
W340	12.051	5.0747
W1180	3.6327	4.0576
W1170	6.3349	0.65864
W220	7.3340	3.9460
W190	4.7321	4.5051
W240	15.227	4.5769
W180	9.9546	2.3110
W200	20.045	13.666
W1230	5.8462	2.6140
W230	10.899	7.5738
W1220	6.5515	11.901
W2750	14.287	7.8031
W280	0.91342	7.2105
W290	6.7399	4.0420
W2800	9.3707	2.8142
W260	5.5374	9.6301
W2790	13.260	5.0051
W320	19.840	10.115
W300	6.4458	13.7482397
W310	3.0088	10.308

Subbasin	January Baseflow (M3/S)
W330	0.13886
W340	0.13886
W1180	0.13886
W1170	0.13886
W220	0.13886
W190	0.13886
W240	0.13886
W180	0.13886
W200	0.13886
W1230	0.13886
W230	0.13886
W1220	0.13886
W2750	0.13886
W280	0.13886
W290	0.13886
W2800	0.13886
W260	0.13886
W2790	0.13886
W320	0.13886
W300	0.13886
W310	0.13886

APPENDIX D
MODEL EFFICIENCY DATA

December 2000 – River Keratong

DEC 2000 (SG KERATONG)				
SIMULATED (m3/s)	OBSERVED (m3/s)	Omean (m3/s)	(O-S)^2	(O-M)^2
0.6	0	10.79473684	0.36	116.5263
0.6	10.6	10.79473684	100	0.037922
1	9.6	10.79473684	73.96	1.427396
1.4	8.9	10.79473684	56.25	3.590028
2.8	8.7	10.79473684	34.81	4.387922
4.5	8.6	10.79473684	16.81	4.81687
49.5	9.3	10.79473684	1616.04	2.234238
58.8	20.8	10.79473684	1444	100.1053
38.6	30	10.79473684	73.96	368.8421
148.7	26.6	10.79473684	14908.41	249.8063
139.5	19.2	10.79473684	14472.09	70.64845
31.3	9.3	10.79473684	484	2.234238
0.6	4.4	10.79473684	14.44	40.89266
0.6	3.8	10.79473684	10.24	48.92634
0.6	5.4	10.79473684	23.04	29.10319
0.6	10.4	10.79473684	96.04	0.155817
7.2	19.5	10.79473684	151.29	75.78161
8.7	0	10.79473684	75.69	116.5263
2.1	0	10.79473684	4.41	116.5263
		TOTAL	33655.84	1352.569
Omean	10.79473684			
RMSE	885.68			
NSE	-23.8828919			

December 2000 – River Rompin

DEC 2000 (SG ROMPIN)				
SIMULATED (m3/s)	OBSERVED (m3/s)	Omean (m3/s)	(O-S)^2	(O-M)^2
1.5	0	74.78421053	2.25	5592.678
1.5	36.5	74.78421053	1225	1465.681
1.8	28.7	74.78421053	723.61	2123.754
2.2	22.8	74.78421053	424.36	2702.358
6.4	18.2	74.78421053	139.24	3201.773
9.8	33.6	74.78421053	566.44	1696.139
43.2	53.5	74.78421053	106.09	453.0176
67.2	56.1	74.78421053	123.21	349.0997
50.7	59.9	74.78421053	84.64	221.5397
194.6	60.8	74.78421053	17902.44	195.5581
227.9	102.2	74.78421053	15800.49	751.6255
101	144.1	74.78421053	1857.61	4804.679
57.1	167.8	74.78421053	12254.49	8651.937
19.4	172.8	74.78421053	23531.56	9607.095
3	164.2	74.78421053	25985.44	7995.183
2.6	153.1	74.78421053	22650.25	6133.363
5.4	146.6	74.78421053	19937.44	5157.508
8.7	0	74.78421053	75.69	5592.678
6.1	0	74.78421053	37.21	5592.678
		TOTAL	143427.5	72288.35
Omean	74.78421053			
RMSE	3774.406842			
NSE	-0.984102133			

December 2010 – River Keratong

DEC 2010 (SG KERATONG)				
SIMULATED (m3/s)	OBSERVED (m3/s)	Omean (m3/s)	(O-S)^2	(O-M)^2
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.4	0.9	1.942105263	0.25	1.085983
0.6	1.3	1.942105263	0.49	0.412299
0.7	1.5	1.942105263	0.64	0.195457
3.8	8.8	1.942105263	25	47.03072
6	13.7	1.942105263	59.29	138.2481
3	6.5	1.942105263	12.25	20.7744
0.4	0.6	1.942105263	0.04	1.801247
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
0.1	0.3	1.942105263	0.04	2.69651
		TOTAL	98.44	241.9063
Omean	1.942105263			
RMSE	2.590526316			
NSE	0.593065606			

December 2010 – River Rompin

DEC 2010 (SG ROMPIN)				
SIMULATED (m3/s)	OBSERVED (m3/s)	Omean (m3/s)	(O-S)^2	(O-M)^2
1.5	0	68.25789474	2.25	4659.14
1.5	24.8	68.25789474	542.89	1888.589
2.4	24.4	68.25789474	484	1923.515
6.9	21.6	68.25789474	216.09	2176.959
9.9	18.4	68.25789474	72.25	2485.81
12.8	17.8	68.25789474	25	2545.999
77.9	15.8	68.25789474	3856.41	2751.831
146.8	20.9	68.25789474	15850.81	2242.77
94.8	45.5	68.25789474	2430.49	517.9218
29	56.9	68.25789474	778.41	129.0018
13.8	102.2	68.25789474	7814.56	1152.067
24.7	144.1	68.25789474	14256.36	5752.025
30.6	167.8	68.25789474	18823.84	9908.631
13.9	172.8	68.25789474	25249.21	10929.05
2.6	164.2	68.25789474	26114.56	9204.888
2.3	153.1	68.25789474	22740.64	7198.183
3	146.6	68.25789474	20620.96	6137.485
4.4	0	68.25789474	19.36	4659.14
3.8	0	68.25789474	14.44	4659.14
		TOTAL	159912.5	80922.15
Omean	68.25789474			
RMSE	4208.224474			
NSE	-0.976128134			

December 2012 – River Keratong

DEC 2012 (SG KERATONG)				
SIMULATED (m3/s)	OBSERVED (m3/s)	Omean (m3/s)	(O-S)^2	(O-M)^2
0.6	0	21.43157895	0.36	459.3126
2	35.3	21.43157895	1108.89	192.3331
4.6	34.9	21.43157895	918.09	181.3984
5.7	34.7	21.43157895	841	176.051
14	34.7	21.43157895	428.49	176.051
61.7	34.4	21.43157895	745.29	168.1799
92.8	35.8	21.43157895	3249	206.4515
53	40.1	21.43157895	166.41	348.5099
14.3	42.1	21.43157895	772.84	427.1836
4.4	43.2	21.43157895	1505.44	473.8642
4	19.2	21.43157895	231.04	4.979945
1.8	9.3	21.43157895	56.25	147.1752
0.7	4.4	21.43157895	13.69	290.0747
0.6	3.8	21.43157895	10.24	310.8726
0.6	5.4	21.43157895	23.04	257.0115
0.6	10.4	21.43157895	96.04	121.6957
6.6	19.5	21.43157895	166.41	3.730997
8.2	0	21.43157895	67.24	459.3126
2.2	0	21.43157895	4.84	459.3126
		TOTAL	10404.6	4863.501
Omean	21.43157895			
RMSE	273.8052632			
NSE	-1.139323069			

December 2012 – River Rompin

DEC 2012 (SG ROMPIN)				
SIMULATED (m3/s)	OBSERVED (m3/s)	Omean (m3/s)	(O-S)^2	(O-M)^2
1.5	0	85.84210526	2.25	7368.867
15	25.9	85.84210526	118.81	3593.056
24.1	26.9	85.84210526	7.84	3474.172
56.3	30.1	85.84210526	686.44	3107.182
166.6	34.1	85.84210526	17556.25	2677.245
278.7	52.1	85.84210526	51347.56	1138.53
224.3	79.1	85.84210526	21083.04	45.45598
114.5	99.8	85.84210526	216.09	194.8228
59.9	114.1	85.84210526	2937.64	798.5086
50.2	118.1	85.84210526	4610.41	1040.572
49.5	102.2	85.84210526	2777.29	267.5807
28.5	144.1	85.84210526	13363.36	3393.982
27.8	167.8	85.84210526	19600	6717.097
12.9	172.8	85.84210526	25568.01	7561.675
2.5	164.2	85.84210526	26146.89	6139.96
2.3	153.1	85.84210526	22740.64	4523.624
4.9	146.6	85.84210526	20078.89	3691.522
8.1	0	85.84210526	65.61	7368.867
6	0	85.84210526	36	7368.867
		TOTAL	228943	70471.59
Omean	85.84210526			
RMSE	6024.816316			
NSE	-2.248728061			

APPENDIX E
RAINFALL DATA FOR IDF CURVE

Rainfall Data (mm) used for station 2828173 Kg Gambir

	15min	30min	45min	60min	120min	180min	360min	540min	720min	900min	1440min
1976	12.70	25.30	33.50	36.50	45.50	45.50	45.50	45.50	45.50	45.50	64.00
1977	11.00	22.00	33.10	44.10	49.50	50.00	62.40	77.00	85.00	86.50	90.50
1978	21.60	43.20	60.50	61.00	73.30	99.50	103.00	103.00	103.00	103.00	103.00
1979	11.20	22.30	33.50	44.60	63.00	75.00	75.50	76.00	76.00	76.00	80.00
1980	21.60	21.60	28.50	28.90	34.50	45.30	50.00	52.00	52.50	53.00	68.70
1981	31.50	33.80	48.50	64.70	94.80	100.50	100.50	100.50	100.50	101.00	101.00
1982	25.50	28.70	43.00	57.30	63.50	63.50	67.00	67.50	67.50	67.50	77.00
1983	39.00	39.00	39.50	39.90	41.00	43.30	54.30	72.50	82.00	84.50	88.50
1984	21.90	41.00	52.10	59.10	69.50	82.80	105.10	117.50	118.50	118.50	166.50
1985	35.10	45.70	56.70	65.50	77.80	82.50	111.30	117.50	117.50	117.50	117.50
1986	33.80	58.40	70.60	82.70	86.00	88.40	92.00	93.00	93.00	95.20	120.00
1987	37.40	50.20	57.30	57.90	70.50	79.00	103.30	115.50	119.20	126.30	158.30
1988	41.10	67.10	78.40	83.40	90.50	90.50	134.00	181.70	210.50	220.50	224.50
1989	23.50	40.50	51.70	59.00	59.50	73.20	86.00	97.30	113.20	138.80	176.50
1990	24.80	35.30	45.00	45.00	63.00	64.50	64.50	65.00	71.40	86.50	102.50
1991	26.10	38.40	51.80	58.30	63.50	65.00	89.60	115.10	122.00	138.30	189.50
1992	27.10	39.80	46.20	48.20	60.50	60.50	61.00	67.00	80.00	91.50	105.00
1993	21.80	40.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	58.00
1994	19.90	36.10	42.90	45.00	48.50	48.50	58.50	58.50	58.50	58.50	59.60
1995	44.00	45.90	47.00	47.40	52.30	70.50	71.50	71.50	72.50	80.50	91.50
1996	33.50	49.00	54.00	56.00	63.50	82.00	108.50	113.50	132.00	148.00	194.00
1997	38.50	75.10	83.00	84.00	91.50	93.00	95.00	95.00	114.50	114.60	116.50
1998	27.40	34.70	41.00	41.40	44.00	44.00	72.80	85.50	95.30	103.10	110.10
1999	44.50	72.00	89.00	95.50	101.50	104.00	104.50	104.50	104.50	104.50	104.50
2000	34.50	59.00	71.50	75.00	77.50	78.00	78.00	78.00	78.00	78.00	78.00
2001	27.30	44.80	54.00	56.80	59.70	61.20	64.90	64.90	64.90	64.90	67.00
2002	30.00	49.20	61.10	62.00	78.50	82.00	105.50	107.00	115.50	116.00	116.00
2003	31.00	49.50	58.50	60.00	60.50	60.50	61.00	61.00	61.00	61.00	67.00
2004	40.00	54.50	56.00	58.00	82.50	89.50	115.00	126.50	142.00	153.00	175.50
2005	29.00	42.50	47.00	55.00	69.50	73.00	81.00	81.00	81.00	82.00	83.00
2006	40.00	58.00	72.50	80.50	100.50	100.50	101.50	102.00	103.00	104.00	104.00
2007	32.00	52.50	61.00	62.50	63.00	63.00	63.00	63.00	63.00	63.00	63.00
2008	?	?	?	?	?	?	?	?	?	?	?
2009	26.50	50.00	66.00	73.50	85.50	92.00	96.50	96.50	96.50	96.50	97.00
2010	30.50	44.00	56.00	61.00	62.00	62.00	62.00	62.00	62.00	62.00	112.50
2011	30.20	39.50	56.90	65.20	74.60	78.20	96.10	108.10	120.70	149.40	170.70
2012	31.20	54.50	68.70	72.50	75.10	76.50	88.70	91.90	100.20	100.90	120.70
2013	46.90	66.10	77.60	80.50	81.10	90.70	115.40	124.00	125.00	126.00	126.30
2014	25.00	44.30	55.50	58.10	64.00	90.40	116.20	120.40	137.30	150.10	165.00
2015	40.90	61.70	68.90	71.60	80.50	81.00	81.30	101.00	103.50	112.50	149.90
2016	26.60	40.00	45.60	52.30	67.60	71.60	82.00	82.10	82.20	82.20	82.50
2017	28.90	38.50	43.50	48.70	64.80	72.60	98.20	109.20	109.40	114.90	155.50
2018	31.10	52.60	67.40	71.40	74.10	76.10	83.00	83.20	126.90	136.40	151.90
MEAN	29.91	45.39	55.15	59.81	68.34	73.61	84.45	90.38	96.40	101.29	115.54
STD.DEV.	9.594448	14.4143566	16.3137004	17.0750062	19.009476	20.363582	25.3561659	29.9776412	34.5868218	38.2452407	45.3359594

Rainfall Data (mm) used for station 2829001 Ulu River Chanis

	15min	30min	45min	60min	120min	180min	360min	540min	720min	900min	1440min
1981	26.60	49.70	68.90	80.80	97.00	101.00	102.50	102.50	102.50	102.50	102.50
1982	30.00	47.90	65.40	78.00	78.00	78.50	78.50	78.50	78.50	78.50	83.50
1983	22.80	36.00	45.20	52.60	66.50	71.20	76.00	99.30	109.70	116.00	121.50
1984	10.00	20.00	30.00	33.50	60.90	81.40	81.50	81.50	81.50	88.50	97.50
1985	17.10	33.70	44.60	48.30	62.80	67.00	95.50	118.00	120.50	121.50	182.10
1986	24.40	37.30	48.70	55.70	62.00	62.00	62.00	62.00	62.00	62.00	62.00
1987	30.80	39.50	45.90	54.60	67.70	77.00	123.90	133.00	158.00	159.50	211.40
1988	33.80	42.20	50.60	82.70	93.50	96.50	119.70	146.90	169.40	200.30	246.10
1989	26.80	46.80	59.30	67.00	78.90	80.30	102.20	142.20	168.30	176.50	180.00
1990	24.11	39.00	52.50	60.50	67.20	70.60	72.50	73.50	74.50	81.00	108.00
1991	20.30	36.50	42.50	50.50	57.00	71.10	71.80	91.20	106.00	115.50	147.50
1992	24.00	38.00	51.60	54.50	57.50	57.50	77.60	92.50	103.00	107.00	129.60
1993	37.20	57.70	72.20	80.40	81.00	81.00	103.10	142.50	182.10	209.50	284.10
1994	30.10	41.70	52.90	64.50	69.00	69.00	72.00	75.50	75.50	75.50	141.00
1995	25.00	44.40	55.30	63.50	80.20	85.90	120.40	158.70	177.90	205.70	236.00
1996	23.20	42.00	60.20	77.20	102.00	120.30	127.50	136.50	151.30	159.20	187.50
1997	40.90	50.10	55.00	58.00	60.00	60.00	60.00	60.50	60.50	60.50	73.00
1998	30.00	41.50	54.30	68.30	82.00	82.00	82.50	82.50	82.50	82.50	82.50
1999	28.00	44.50	45.00	51.50	79.50	100.50	132.00	159.50	168.00	174.00	178.00
2000	49.20	54.60	70.80	84.70	132.30	162.90	167.60	167.60	173.50	207.60	229.60
2001	39.40	46.10	53.40	58.70	61.30	66.40	102.90	112.70	116.90	117.90	174.50
2002	31.00	37.00	40.50	45.80	49.00	50.90	64.10	64.10	64.80	70.90	80.30
2003	37.30	53.30	66.20	77.20	103.10	103.70	104.30	106.50	106.50	106.50	152.20
2004	43.00	58.00	69.00	76.00	78.00	79.50	107.50	139.50	140.50	143.00	168.00
2005	27.50	44.50	55.00	73.50	105.50	121.00	164.50	198.50	207.50	222.50	259.00
2006	37.50	56.50	68.00	83.00	94.50	100.00	101.50	101.50	101.50	101.50	102.00
2007	35.00	58.00	77.50	84.50	89.00	89.50	134.50	155.00	165.00	168.00	234.50
2008	30.50	49.00	56.50	58.50	59.50	65.00	93.00	104.00	124.50	129.50	131.00
2009	36.60	61.90	66.10	69.50	82.70	95.50	127.30	135.30	136.00	136.20	136.50
2010	40.10	60.20	82.10	94.20	96.50	96.60	96.70	96.90	97.00	97.00	99.90
2011	38.30	47.80	56.10	61.20	63.30	65.50	65.70	66.00	66.00	66.00	66.50
2012	34.00	49.50	54.00	58.80	73.70	77.00	105.00	117.50	117.60	124.10	171.40
2013	31.10	45.00	50.10	53.90	55.00	55.30	67.60	83.20	88.90	96.50	97.70
2014	36.20	45.60	51.90	59.00	76.70	94.60	152.80	166.70	171.40	177.00	185.10
2015	37.00	67.10	96.00	111.10	118.30	118.50	147.20	154.70	155.40	155.80	202.00
2016	31.30	58.90	77.10	89.30	98.30	99.60	99.70	99.90	100.00	100.20	109.70
2017	36.20	41.80	53.00	62.10	85.40	89.80	90.90	92.90	93.60	94.40	97.70
2018	39.90	54.80	70.00	78.00	83.60	86.40	96.70	121.00	147.90	173.10	199.20
MEAN	31.48	46.79	58.25	67.40	79.17	85.01	101.33	113.69	121.22	127.98	151.33
STD.DEV.	7.779592	9.394978	12.99207	15.5716	18.74509	22.08402	28.549334	34.97191	40.31172	46.59854	59.40341

Rainfall Data (mm) used for station 2831179 Kg Kedaik

	15min	30min	45min	60min	120min	180min	360min	540min	720min	900min	1440min
1975	16.10	32.30	48.40	64.60	73.50	74.50	76.00	76.00	79.50	79.50	80.00
1976	6.90	13.90	20.80	25.00	25.50	25.50	25.50	25.50	25.50	25.50	25.50
1977	7.90	9.50	10.30	10.50	11.50	11.50	14.00	14.00	14.00	14.00	17.00
1978	18.30	23.10	27.20	30.10	56.50	56.50	73.70	85.00	85.00	85.00	87.50
1979	3.80	7.70	11.50	15.30	30.70	46.00	57.00	57.50	59.50	59.50	74.90
1980	72.90	72.90	72.90	72.90	73.00	75.30	84.30	93.40	100.60	103.10	111.60
1981	58.30	59.30	59.70	60.90	61.90	66.70	70.90	71.00	71.10	71.10	74.80
1982	25.50	25.50	25.50	25.50	43.50	43.50	43.70	43.90	44.10	44.30	58.80
1983	11.00	17.50	17.50	17.50	17.50	17.50	18.50	18.50	18.50	18.50	28.50
1984	22.50	39.80	46.20	50.40	59.50	63.80	100.90	131.70	141.50	143.50	185.60
1985	20.80	38.30	45.80	49.20	81.50	109.60	142.90	162.00	165.00	165.50	190.00
1986	19.20	38.30	53.20	65.80	85.50	85.50	86.00	86.00	86.00	86.50	109.50
1987	25.50	37.00	48.80	58.40	68.50	74.40	96.60	110.40	121.00	131.50	147.50
1988	31.00	48.80	56.10	60.50	64.50	80.80	129.80	167.60	225.00	282.80	393.10
1989	45.00	45.00	45.00	49.40	64.00	79.00	84.00	105.40	121.90	144.50	180.50
1990	22.40	37.50	43.00	43.00	44.50	44.50	54.00	73.50	92.80	115.00	167.00
1991	35.60	50.20	64.20	69.00	69.30	76.90	81.00	90.70	120.90	141.50	183.50
1992	30.40	51.70	60.60	62.00	73.20	87.60	113.00	127.70	154.20	175.40	216.00
1993	20.60	34.80	48.70	61.50	90.00	108.80	129.00	137.50	146.00	154.10	158.00
1994	33.70	42.90	58.70	72.50	87.30	111.00	143.00	165.50	180.10	198.40	209.50
1995	28.70	44.00	60.30	75.60	106.70	139.40	205.60	252.90	272.50	289.00	293.70
1996	30.00	49.00	61.50	71.00	98.00	119.50	167.50	233.50	274.00	324.50	365.00
1997	25.50	30.50	36.00	44.30	55.00	55.00	58.40	74.50	76.00	76.50	77.50
1998	32.50	53.50	64.00	78.50	148.00	181.00	271.00	355.50	391.50	422.00	433.50
1999	32.80	49.40	57.00	59.20	62.40	67.50	96.00	109.50	126.50	135.00	174.00
2000	24.70	28.70	30.00	31.20	42.70	45.80	49.70	53.20	59.70	68.70	68.70
2001	33.90	47.60	48.10	48.10	59.10	75.20	95.50	140.90	163.30	182.10	187.10
2002	26.00	37.00	49.00	60.00	90.50	95.50	123.50	134.50	135.00	138.00	196.50
2003	49.50	70.50	79.50	81.00	93.50	106.00	172.50	194.00	202.00	211.00	223.00
2004	30.00	45.00	52.50	53.50	63.50	66.00	97.00	112.50	123.00	134.50	174.50
2005	27.50	51.00	74.00	92.00	112.00	141.00	185.50	278.50	298.00	312.50	344.50
2006	31.50	54.50	72.50	78.00	79.00	79.00	79.50	101.50	113.50	126.50	161.00
2007	33.50	56.50	70.50	81.50	91.50	101.00	162.50	206.00	257.50	295.00	422.50
2008	19.50	28.50	29.50	32.50	33.00	33.10	33.50	33.50	33.50	33.50	33.50
2009	26.40	43.60	53.30	69.00	71.00	71.10	71.50	71.60	71.80	79.20	93.10
2010	32.90	37.60	50.10	54.40	63.30	77.70	86.90	89.10	89.40	94.60	101.60
2011	38.40	57.10	64.40	71.50	91.00	96.50	135.50	165.00	182.00	186.50	191.50
2012	37.80	69.90	87.00	97.60	108.00	109.70	113.10	117.00	122.70	144.50	200.80
2013	37.20	47.80	60.00	66.70	75.40	78.00	96.70	117.80	140.10	155.40	170.60
2014	36.40	50.60	57.80	62.20	77.10	89.30	139.40	196.80	245.00	267.00	302.90
2015	27.80	48.80	61.60	75.50	112.90	135.40	186.70	261.90	317.20	340.20	376.70
2016	33.50	53.60	62.50	67.00	67.50	93.80	108.10	108.50	121.60	145.00	173.10
2017	32.60	46.00	57.60	63.70	70.50	101.60	146.40	198.00	230.70	263.40	302.50
2018	27.60	51.20	61.30	66.60	92.80	104.10	116.70	138.00	167.40	191.30	280.60
MEAN	29.17	42.68	51.46	57.83	71.50	81.84	105.06	126.98	142.41	155.80	182.89
STD.DEV.	13.19887	14.78569	17.56642	20.15327	26.81447	33.88888	52.71406	73.52551	85.4634	95.23893	110.4978

Rainfall Data (mm) used for station 2834001 Per Endau Rompin

	15min	30min	45min	60min	120min	180min	360min	540min	720min	900min	1440min
1986	12.50	43.00	57.70	65.70	98.60	103.20	103.50	103.80	108.90	114.00	120.50
1987	25.50	35.70	53.40	70.30	136.40	204.70	237.50	246.00	248.50	250.00	251.10
1988	41.00	46.90	60.90	74.30	119.00	129.40	214.00	286.60	356.00	401.90	522.00
1989	22.80	45.60	49.60	55.10	80.00	110.00	157.20	187.50	188.90	191.00	220.40
1990	56.00	61.40	66.90	72.30	100.80	128.00	176.70	196.00	216.00	221.00	226.50
1991	23.60	32.50	40.50	48.50	66.50	66.70	84.00	107.30	121.90	136.30	168.00
1992	26.60	44.20	52.20	66.00	100.80	127.20	176.90	215.60	267.50	278.20	303.10
1993	50.00	50.00	50.00	52.50	99.70	128.50	151.80	177.50	191.30	201.60	218.50
1994	39.00	53.40	74.60	95.70	137.10	147.00	164.40	189.90	198.70	209.50	231.00
1995	?	?	?	?	?	?	?	?	?	?	?
1996	?	?	?	?	?	?	?	?	?	?	?
1997	5.20	10.40	13.00	13.00	23.40	34.00	34.50	34.50	34.50	34.50	34.50
1998	36.30	40.50	44.80	49.10	61.00	62.90	63.00	63.00	63.00	64.10	77.10
1999	24.80	25.50	26.20	26.80	30.80	40.90	52.10	61.40	72.80	77.30	88.50
2000	32.70	36.60	40.40	44.20	61.70	74.90	82.80	82.90	88.40	89.00	89.40
2001	52.50	78.00	94.00	101.00	109.00	117.50	118.50	125.80	131.50	141.90	228.50
2002	48.00	68.50	77.50	82.50	130.00	182.50	196.00	238.00	243.00	247.50	274.50
2003	35.50	52.00	66.50	73.00	124.50	141.00	224.50	264.00	291.50	292.00	340.50
2004	53.50	100.00	130.00	145.50	170.50	171.50	174.50	174.50	174.50	175.50	225.50
2005	31.00	41.00	56.50	68.00	92.00	108.00	127.00	127.00	136.00	141.00	185.50
2006	35.50	52.00	62.00	68.50	99.50	125.50	159.50	162.50	163.00	164.50	176.00
2007	34.00	50.00	67.50	69.50	75.50	93.50	169.50	213.50	265.50	275.00	323.00
2008	34.50	42.90	55.80	60.40	75.00	84.00	103.50	106.00	126.50	127.00	137.50
2009	22.90	36.50	39.90	51.80	57.30	70.00	105.00	122.50	140.90	153.50	170.90
2010	30.80	45.20	49.30	53.30	84.20	88.40	93.70	98.40	103.30	113.10	177.60
2011	30.10	41.90	49.90	53.90	77.10	78.70	86.00	110.30	117.60	117.90	118.60
2012	41.50	72.20	80.40	102.50	190.90	254.10	277.70	289.10	289.40	327.70	365.50
2013	32.50	55.00	78.10	92.90	125.60	181.60	226.60	264.80	280.50	283.10	291.00
2014	32.40	53.60	61.60	64.80	91.90	108.70	164.80	216.70	295.20	330.40	411.80
2015	32.00	48.90	62.40	80.30	144.70	214.30	311.30	405.10	422.50	441.70	465.20
2016	32.00	45.50	64.20	78.00	92.00	101.50	104.70	131.40	193.40	210.80	224.90
2017	30.60	46.70	53.20	55.20	71.00	89.00	123.80	167.20	201.00	210.40	231.70
2018	34.50	51.00	62.80	66.30	84.60	89.90	120.90	151.90	187.10	207.20	244.80
MEAN	33.54	48.60	59.41	67.77	97.13	117.97	147.93	171.64	190.93	200.92	230.44
STD.DEV.	13.49415	19.50934	24.67699	28.6177	42.67069	56.94267	72.81608	88.80756	98.49485	105.5138	121.6986

Rainfall Data (mm) used for station 3028001 River Kepasing

	15min	30min	45min	60min	120min	180min	360min	540min	720min	900min	1440min
1977	30.60	46.50	66.00	77.40	87.00	87.00	87.00	87.00	88.50	88.50	88.50
1978	36.80	43.90	48.70	53.20	68.00	68.00	68.00	68.00	68.00	68.00	68.50
1979	23.80	37.10	49.00	50.40	54.00	54.50	83.00	95.00	111.70	131.50	182.10
1980	22.80	41.20	51.30	61.40	77.90	81.30	88.00	91.00	91.50	91.50	103.50
1981	42.00	59.00	69.70	76.60	82.60	86.50	94.90	96.50	97.20	117.00	117.00
1982	27.80	38.10	49.70	58.40	93.10	112.00	112.00	112.00	112.00	112.00	112.00
1983	35.70	47.60	55.60	64.80	67.00	68.50	68.50	68.50	68.50	68.50	68.50
1984	26.70	43.00	51.10	58.90	63.50	63.50	89.80	103.50	106.30	107.60	131.50
1985	31.30	50.10	61.20	71.80	86.00	87.50	89.90	91.00	94.50	96.00	105.00
1986	37.30	69.70	83.40	86.40	98.40	101.50	106.50	106.50	106.50	106.50	120.50
1987	18.70	27.40	37.40	47.40	88.00	108.80	133.00	139.70	150.50	153.00	216.00
1988	33.90	56.50	68.60	72.50	73.50	73.50	94.50	120.50	125.90	167.50	218.50
1989	24.20	34.00	49.20	54.70	72.00	73.50	76.50	76.50	86.30	88.00	92.00
1990	25.60	36.10	46.70	56.20	63.20	71.50	71.50	71.50	75.00	75.00	75.00
1991	29.90	39.10	47.00	47.00	55.10	56.00	73.00	85.40	120.70	136.90	159.50
1992	25.70	40.10	41.50	49.20	57.50	58.50	62.00	82.70	95.70	110.30	126.00
1993	34.20	46.10	54.90	60.50	62.00	65.50	68.00	80.70	105.20	127.80	154.50
1994	36.90	35.40	41.70	45.50	53.50	58.00	58.00	58.00	68.50	71.00	71.50
1995	38.00	53.50	58.50	70.00	81.50	82.00	82.00	82.60	109.20	123.30	148.00
1996	30.20	37.40	49.30	56.90	64.50	73.50	76.00	102.00	108.00	132.50	160.50
1997	34.50	46.50	59.90	63.50	65.50	66.00	73.50	73.50	83.50	83.50	89.50
1998	41.00	58.00	63.00	64.50	65.00	65.50	72.00	86.50	88.50	89.50	91.00
1999	19.90	35.20	46.20	55.40	61.30	84.60	96.40	96.50	96.60	96.60	96.60
2000	36.20	53.10	73.20	84.70	122.20	141.40	150.00	153.10	154.40	154.40	154.40
2001	47.50	65.80	79.60	79.60	80.20	82.30	87.10	87.70	93.20	94.10	94.10
2002	28.00	40.50	43.50	48.50	49.00	54.50	56.00	82.50	83.50	84.00	84.00
2003	26.00	39.00	50.50	52.50	54.00	54.00	62.50	71.50	88.50	94.50	112.50
2004	22.00	38.50	51.50	61.50	69.00	69.00	69.00	70.00	71.00	71.00	82.00
2005	47.50	47.50	61.00	68.00	74.00	74.00	78.00	81.50	90.00	97.50	116.00
2006	21.50	38.00	46.00	54.00	70.50	73.00	75.00	77.00	89.00	92.00	109.00
2007	23.00	32.00	36.00	38.50	42.50	42.50	42.50	42.50	42.50	42.50	45.50
2008	27.50	51.40	63.20	67.80	90.80	93.10	93.80	120.00	120.10	120.20	120.50
2009	36.40	51.90	57.10	58.30	70.80	98.40	119.70	123.50	124.50	125.10	125.80
2010	33.80	46.40	56.50	63.50	77.10	78.20	80.60	80.80	80.90	81.00	81.00
2011	31.60	52.90	68.20	79.60	82.00	85.00	124.00	152.50	160.50	164.50	164.50
2012	33.10	52.90	62.80	71.60	78.70	80.00	81.60	81.70	81.80	82.00	116.10
2013	29.30	54.20	71.20	85.40	100.80	101.00	101.10	101.20	101.30	101.50	101.50
2014	37.60	53.70	71.70	85.10	89.60	89.80	90.10	109.90	134.10	152.40	169.90
2015	36.50	55.60	59.70	61.20	63.30	66.50	73.50	96.30	115.40	136.60	195.90
2016	35.20	60.80	76.70	101.10	157.30	160.00	160.20	160.30	160.50	160.50	160.90
2017	31.30	45.40	51.30	53.90	83.10	100.60	121.10	139.30	158.40	162.40	221.10
2018	31.20	54.00	74.70	92.60	113.90	117.00	117.30	117.50	142.00	174.70	195.10
MEAN	31.49	46.55	57.24	64.52	76.40	81.13	88.26	95.81	103.57	110.31	124.89
STD.DEV.	6.875385	9.501508	11.74896	14.09623	21.057986	23.236656	24.874493	26.2431537	27.7298684	32.42700164	44.5778595

Rainfall Data (mm) used for station 3030178 P. Batu Bukit Raidan

	15min	30min	45min	60min	120min	180min	360min	540min	720min	900min	1440min
1979	26.80	40.20	59.30	70.20	89.90	104.00	104.50	104.50	106.50	108.00	109.50
1980	39.90	66.80	77.60	81.50	81.50	82.00	93.60	115.30	149.50	158.50	206.90
1981	8.20	15.20	19.20	19.90	20.80	21.20	27.60	41.40	55.30	69.10	110.50
1982	0.50	0.90	1.40	1.80	3.70	5.50	11.00	16.50	22.00	27.50	44.00
1983	?	?	?	?	?	?	?	?	?	?	?
1984	?	?	?	?	?	?	?	?	?	?	?
1985	?	?	?	?	?	?	?	?	?	?	?
1986	?	?	?	?	?	?	?	?	?	?	?
1987	1.50	2.90	4.40	5.90	11.70	17.60	35.10	52.70	70.30	87.80	140.50
1988	2.80	5.70	8.50	11.40	22.70	34.10	68.10	102.20	136.30	170.30	272.50
1989	1.90	3.90	5.80	7.70	15.40	23.10	46.30	69.40	92.50	115.60	185.00
1990	1.00	2.10	3.10	4.20	8.40	12.60	25.10	37.70	50.30	62.80	100.50
1991	2.10	4.10	6.20	8.30	16.60	24.90	49.80	74.60	99.50	124.40	199.00
1992	2.80	5.60	7.00	7.10	11.40	16.40	32.90	49.30	65.80	82.20	131.50
1993	1.20	2.40	3.50	4.70	9.50	14.20	28.40	42.60	56.80	70.90	113.50
1994	26.50	28.20	34.30	40.40	54.40	67.00	67.50	67.50	80.50	100.60	161.00
1995	57.00	62.00	66.90	79.00	91.50	91.50	93.50	127.80	143.30	157.20	185.00
1996	35.50	46.00	53.50	56.50	57.00	58.00	61.50	62.00	62.00	62.00	70.50
1997	13.80	24.00	34.00	43.60	65.00	81.00	104.50	106.50	106.50	115.20	117.50
1998	28.50	48.50	52.00	52.50	80.00	98.50	116.00	150.50	157.50	160.00	171.50
1999	42.90	64.50	76.50	81.50	85.00	87.00	87.50	97.50	107.00	119.00	165.00
2000	28.70	34.10	39.40	45.30	54.00	55.50	56.00	56.00	71.00	84.00	94.00
2001	28.70	51.80	63.10	78.50	91.90	92.40	102.80	116.20	123.50	129.80	131.70
2002	30.00	43.50	49.50	63.40	87.90	92.70	94.60	94.60	94.60	94.60	95.50
2003	143.50	143.50	143.50	143.50	143.50	143.50	143.50	143.50	143.50	143.50	161.50
2004	?	?	?	?	?	?	?	?	?	?	?
2005	?	?	?	?	?	?	?	?	?	?	?
2006	?	?	?	?	?	?	?	?	?	?	?
2007	?	?	?	?	?	?	?	?	?	?	?
2008	?	?	?	?	?	?	?	?	?	?	?
2009	21.30	32.60	44.70	48.70	49.50	49.60	49.80	49.90	50.00	50.00	50.00
2010	33.30	62.40	80.40	81.50	83.50	83.90	98.20	99.10	99.20	99.30	101.50
2011	31.00	43.60	59.20	73.50	97.30	98.40	135.10	166.00	181.10	187.20	188.30
2012	29.80	49.00	67.00	79.40	94.20	94.70	116.30	123.60	125.50	130.30	153.60
2013	28.30	44.10	47.20	48.60	57.80	58.60	59.90	68.40	73.20	75.60	79.20
2014	40.50	61.50	65.60	69.20	101.10	118.60	135.60	186.90	244.80	271.30	308.80
2015	36.50	51.90	68.60	82.30	97.40	97.60	128.30	178.00	211.30	257.00	270.30
2016	31.50	51.60	65.80	71.50	81.10	81.40	83.70	84.00	84.20	84.30	84.50
2017	26.80	38.30	45.70	51.10	88.20	92.60	109.20	126.30	146.50	175.70	256.30
2018	29.60	52.90	68.30	76.00	85.60	98.80	144.00	154.40	155.20	156.30	176.60
MEAN	26.85	38.19	45.85	51.25	62.50	67.64	80.96	95.64	108.55	120.32	149.54
STD.DEV.	25.84459	30.45439	34.05399	36.72083	41.56723	43.07102	48.15797	56.25073	63.63636	70.36221	85.8298

APPENDIX F
RAINFALL TEMPORAL PATTERN DATA FOR DESIGN RAINFALL

Design Rainfall Temporal Pattern for Station 2828173 Kg Gambir

NO	TIME (hr)	fraction	2828173				
			KG GAMBIR				
			ARI 2	ARI 5	ARI 10	ARI 50	ARI 100
			2.140802433	2.517746328	2.846389184	3.784530165	4.278527034
			154.1377752	181.2777356	204.9400212	272.4861719	308.0539464
			for tc = 3days				
1	3	0.016	2.466204403	2.900443769	3.27904034	4.35977875	4.928863143
2	6	0.023	3.545168829	4.169387919	4.713620488	6.267181953	7.085240768
3	9	0.027	4.16171993	4.894498861	5.533380573	7.357126641	8.317456554
4	12	0.033	5.086546581	5.982165275	6.7630207	8.992043672	10.16578023
5	15	0.036	5.548959906	6.525998481	7.377840764	9.809502188	11.08994207
6	18	0.043	6.627924332	7.79494263	8.812420913	11.71690539	13.2463197
7	21	0.047	7.244475433	8.520053573	9.632180998	12.80685008	14.47853548
8	24	0.049	7.552750983	8.882609044	10.04206104	13.35182242	15.09464338
9	27	0.049	7.552750983	8.882609044	10.04206104	13.35182242	15.09464338
10	30	0.051	7.861026534	9.245164515	10.45194108	13.89679477	15.71075127
11	33	0.067	10.32723094	12.14560828	13.73098142	18.25657352	20.63961441
12	36	0.079	12.17688424	14.32094111	16.19026168	21.52640758	24.33626177
13	39	0.068	10.48136871	12.32688602	13.93592144	18.52905969	20.94766836
14	42	0.057	8.785853185	10.33283093	11.68158121	15.5317118	17.55907495
15	45	0.05	7.706888759	9.06388678	10.24700106	13.62430859	15.40269732
16	48	0.049	7.552750983	8.882609044	10.04206104	13.35182242	15.09464338
17	51	0.048	7.398613208	8.701331308	9.837121019	13.07933625	14.78658943
18	54	0.043	6.627924332	7.79494263	8.812420913	11.71690539	13.2463197
19	57	0.038	5.857235457	6.888553952	7.787720807	10.35447453	11.70604996
20	60	0.035	5.394822131	6.344720746	7.172900743	9.537016016	10.78188813
21	63	0.03	4.624133255	5.438332068	6.148200637	8.174585157	9.241618393
22	66	0.024	3.699306604	4.350665654	4.918560509	6.539668125	7.393294714
23	69	0.022	3.391031054	3.988110183	4.508680467	5.994695781	6.777186822
24	72	0.016	2.466204403	2.900443769	3.27904034	4.35977875	4.928863143

Design Rainfall Temporal Pattern for Station 2829001 Ulu River Chanis

NO	TIME (hr)	fraction	2829001				
			ULU SG CHANIS				
			ARI 2	ARI 5	ARI 10	ARI 50	ARI 100
			3.03321129	3.461986796	3.826168002	4.82642328	5.3341354
			218.3912129	249.2630493	275.4840962	347.5024761	384.0577488
			for tc = 3days				
1	3	0.016	3.494259406	3.988208788	4.407745539	5.560039618	6.14492398
2	6	0.023	5.022997896	5.733050133	6.336134212	7.992556951	8.833328222
3	9	0.027	5.896562748	6.73010233	7.438070597	9.382566856	10.36955922
4	12	0.033	7.206910025	8.225680626	9.090975174	11.46758171	12.67390571
5	15	0.036	7.862083664	8.973469774	9.917427462	12.51008914	13.82607896
6	18	0.043	9.390822154	10.71831112	11.84581614	14.94260647	16.5144832
7	21	0.047	10.26438701	11.71536332	12.94775252	16.33261638	18.05071419
8	24	0.049	10.70116943	12.21388941	13.49872071	17.02762133	18.81882969
9	27	0.049	10.70116943	12.21388941	13.49872071	17.02762133	18.81882969
10	30	0.051	11.13795186	12.71241551	14.0496889	17.72262628	19.58694519
11	33	0.067	14.63221126	16.7006243	18.45743444	23.2826659	25.73186917
12	36	0.079	17.25290582	19.69178089	21.7632436	27.45269562	30.34056215
13	39	0.068	14.85060248	16.94988735	18.73291854	23.63016838	26.11592692
14	42	0.057	12.44829913	14.20799381	15.70259348	19.80764114	21.89129168
15	45	0.05	10.91956064	12.46315246	13.77420481	17.37512381	19.20288744
16	48	0.049	10.70116943	12.21388941	13.49872071	17.02762133	18.81882969
17	51	0.048	10.48277822	11.96462637	13.22323662	16.68011885	18.43477194
18	54	0.043	9.390822154	10.71831112	11.84581614	14.94260647	16.5144832
19	57	0.038	8.29886609	9.471995873	10.46839565	13.20509409	14.59419445
20	60	0.035	7.643692451	8.724206725	9.641943366	12.16258666	13.44202121
21	63	0.03	6.551736387	7.477891478	8.264522885	10.42507428	11.52173246
22	66	0.024	5.241389109	5.982313183	6.611618308	8.340059427	9.217385971
23	69	0.022	4.804606684	5.483787084	6.060650116	7.645054475	8.449270473
24	72	0.016	3.494259406	3.988208788	4.407745539	5.560039618	6.14492398

Design Rainfall Temporal Pattern for Station 2831179 Kg Kedaik

NO	TIME (hr)	fraction	2831179				
			KG KEDAIK				
			ARI 2	ARI 5	ARI 10	ARI 50	ARI 100
			4.79316827	5.848108905	6.797810655	9.640852792	11.20647596
			345.1081154	421.0638412	489.4423671	694.141401	806.8662688
			for tc = 3days				
1	3	0.016	5.521729847	6.737021459	7.831077874	11.10626242	12.9098603
2	6	0.023	7.937486655	9.684468347	11.25717444	15.96525222	18.55792418
3	9	0.027	9.317919117	11.36872371	13.21494391	18.74181783	21.78538926
4	12	0.033	11.38856781	13.89510676	16.15159812	22.90666623	26.62658687
5	15	0.036	12.42389216	15.15829828	17.61992522	24.98909044	29.04718568
6	18	0.043	14.83964896	18.10574517	21.04602179	29.84808024	34.69524956
7	21	0.047	16.22008143	19.79000053	23.00379126	32.62464585	37.92271463
8	24	0.049	16.91029766	20.63212822	23.98267599	34.01292865	39.53644717
9	27	0.049	16.91029766	20.63212822	23.98267599	34.01292865	39.53644717
10	30	0.051	17.60051389	21.4742559	24.96156072	35.40121145	41.15017971
11	33	0.067	23.12224373	28.21127736	32.7926386	46.50747387	54.06004001
12	36	0.079	27.26354112	33.26404345	38.665947	54.83717068	63.74243523
13	39	0.068	23.46735185	28.6323412	33.28208097	47.20161527	54.86690628
14	42	0.057	19.67116258	24.00063895	27.89821493	39.56605986	45.99137732
15	45	0.05	17.25540577	21.05319206	24.47211836	34.70707005	40.34331344
16	48	0.049	16.91029766	20.63212822	23.98267599	34.01292865	39.53644717
17	51	0.048	16.56518954	20.21106438	23.49323362	33.31878725	38.7295809
18	54	0.043	14.83964896	18.10574517	21.04602179	29.84808024	34.69524956
19	57	0.038	13.11410839	16.00042596	18.59880995	26.37737324	30.66091821
20	60	0.035	12.07878404	14.73723444	17.13048285	24.29494904	28.24031941
21	63	0.03	10.35324346	12.63191523	14.68327101	20.82424203	24.20598806
22	66	0.024	8.282594771	10.10553219	11.74661681	16.65939362	19.36479045
23	69	0.022	7.59237854	9.263404506	10.76773208	15.27111082	17.75105791
24	72	0.016	5.521729847	6.737021459	7.831077874	11.10626242	12.9098603

Design Rainfall Temporal Pattern for Station 2834001 Per Endau Rompin

NO	TIME (hr)	fraction	2834001				
			PER ENDAU ROMPIN				
			ARI 2	ARI 5	ARI 10	ARI 50	ARI 100
			5.850086842	7.196752197	8.417816049	12.11257695	14.16770257
			421.2062526	518.1661582	606.0827555	872.1055403	1020.074585
			for tc = 3days				
1	3	0.016	6.739300042	8.29065853	9.697324088	13.95368864	16.32119337
2	6	0.023	9.687743811	11.91782164	13.93990338	20.05842743	23.46171546
3	9	0.027	11.37256882	13.99048627	16.3642344	23.54684959	27.5420138
4	12	0.033	13.89980634	17.09948322	20.00073093	28.77948283	33.66246132
5	15	0.036	15.1634251	18.65398169	21.8189792	31.39579945	36.72268507
6	18	0.043	18.11186886	22.2811448	26.06155849	37.50053823	43.86320717
7	21	0.047	19.79669387	24.35380943	28.48588951	40.98896039	47.94350551
8	24	0.049	20.63910638	25.39014175	29.69805502	42.73317147	49.98365468
9	27	0.049	20.63910638	25.39014175	29.69805502	42.73317147	49.98365468
10	30	0.051	21.48151888	26.42647407	30.91022053	44.47738255	52.02380385
11	33	0.067	28.22081893	34.7171326	40.60754462	58.4310712	68.34499722
12	36	0.079	33.27529396	40.93512649	47.88053768	68.89633768	80.58589224
13	39	0.068	28.64202518	35.23529875	41.21362737	59.30317674	69.3650718
14	42	0.057	24.0087564	29.53547101	34.54671706	49.71001579	58.14425137
15	45	0.05	21.06031263	25.90830791	30.30413778	43.60527701	51.00372927
16	48	0.049	20.63910638	25.39014175	29.69805502	42.73317147	49.98365468
17	51	0.048	20.21790013	24.87197559	29.09197226	41.86106593	48.9635801
18	54	0.043	18.11186886	22.2811448	26.06155849	37.50053823	43.86320717
19	57	0.038	16.0058376	19.69031401	23.03114471	33.14001053	38.76283424
20	60	0.035	14.74221884	18.13581554	21.21289644	30.52369391	35.70261049
21	63	0.03	12.63618758	15.54498474	18.18248267	26.16316621	30.60223756
22	66	0.024	10.10895006	12.4359878	14.54598613	20.93053297	24.48179005
23	69	0.022	9.266537558	11.39965548	13.33382062	19.18632189	22.44164088
24	72	0.016	6.739300042	8.29065853	9.697324088	13.95368864	16.32119337

Design Rainfall Temporal Pattern for Station 3028001 River. Kepasing

NO	TIME (hr)	fraction	3028001				
			SG KEPASING				
			ARI 2	ARI 5	ARI 10	ARI 50	ARI 100
			2.423387528	2.702574842	2.934947243	3.554493542	3.860115495
			174.483902	194.5853886	211.3162015	255.9235351	277.9283157
			for tc = 3days				
1	3	0.016	2.791742433	3.113366217	3.381059224	4.094776561	4.446853051
2	6	0.023	4.013129747	4.475463938	4.860272635	5.886241306	6.392351261
3	9	0.027	4.711065355	5.253805492	5.705537441	6.909935446	7.504064523
4	12	0.033	5.757968768	6.421317823	6.97343465	8.445476657	9.171634417
5	15	0.036	6.281420474	7.005073989	7.607383254	9.213247262	10.00541936
6	18	0.043	7.502807788	8.367171709	9.086596665	11.00471201	11.95091757
7	21	0.047	8.200743396	9.145513264	9.931861471	12.02840615	13.06263084
8	24	0.049	8.5497112	9.534684041	10.35449387	12.54025322	13.61848747
9	27	0.049	8.5497112	9.534684041	10.35449387	12.54025322	13.61848747
10	30	0.051	8.898679004	9.923854818	10.77712628	13.05210029	14.1743441
11	33	0.067	11.69042144	13.03722104	14.1581855	17.14687685	18.62119715
12	36	0.079	13.78422826	15.3722457	16.69397992	20.21795927	21.95633694
13	39	0.068	11.86490534	13.23180642	14.3695017	17.40280038	18.89912547
14	42	0.057	9.945582417	11.09136715	12.04502349	14.5876415	15.84191399
15	45	0.05	8.724195102	9.729269429	10.56581008	12.79617675	13.89641578
16	48	0.049	8.5497112	9.534684041	10.35449387	12.54025322	13.61848747
17	51	0.048	8.375227298	9.340098652	10.14317767	12.28432968	13.34055915
18	54	0.043	7.502807788	8.367171709	9.086596665	11.00471201	11.95091757
19	57	0.038	6.630388278	7.394244766	8.030015657	9.725094332	10.561276
20	60	0.035	6.106936572	6.810488601	7.396067053	8.957323727	9.727491049
21	63	0.03	5.234517061	5.837561658	6.339486045	7.677706052	8.33784947
22	66	0.024	4.187613649	4.670049326	5.071588836	6.142164841	6.670279576
23	69	0.022	3.838645845	4.280878549	4.648956433	5.630317771	6.114422945
24	72	0.016	2.791742433	3.113366217	3.381059224	4.094776561	4.446853051

Design Rainfall Temporal Pattern for Station 3030178 P Batu Bukit Raidan

NO	TIME (hr)	fraction	3030178				
			BATU BUKIT RAIDAN				
			ARI 2	ARI 5	ARI 10	ARI 50	ARI 100
			2.454124144	3.301487892	4.131931551	6.956803057	8.706690736
			176.6969384	237.7071282	297.4990717	500.8898201	626.881733
			for tc = 3days				
1	3	0.016	2.827151014	3.803314052	4.759985147	8.014237121	10.03010773
2	6	0.023	4.064029582	5.46726395	6.842478649	11.52046586	14.41827986
3	9	0.027	4.770817336	6.418092463	8.032474936	13.52402514	16.92580679
4	12	0.033	5.830998966	7.844335232	9.817469366	16.52936406	20.68709719
5	15	0.036	6.361089781	8.557456617	10.70996658	18.03203352	22.56774239
6	18	0.043	7.59796835	10.22140651	12.79246008	21.53826226	26.95591452
7	21	0.047	8.304756103	11.17223503	13.98245637	23.54182154	29.46344145
8	24	0.049	8.65814998	11.64764928	14.57745451	24.54360118	30.71720492
9	27	0.049	8.65814998	11.64764928	14.57745451	24.54360118	30.71720492
10	30	0.051	9.011543856	12.12306354	15.17245266	25.54538082	31.97096838
11	33	0.067	11.83869487	15.92637759	19.9324378	33.55961795	42.00107611
12	36	0.079	13.95905813	18.77886313	23.50242666	39.57029579	49.52365691
13	39	0.068	12.01539181	16.16408472	20.22993688	34.06050777	42.62795785
14	42	0.057	10.07172549	13.54930631	16.95744709	28.55071975	35.73225878
15	45	0.05	8.834846918	11.88535641	14.87495359	25.044491	31.34408665
16	48	0.049	8.65814998	11.64764928	14.57745451	24.54360118	30.71720492
17	51	0.048	8.481453041	11.40994216	14.27995544	24.04271136	30.09032318
18	54	0.043	7.59796835	10.22140651	12.79246008	21.53826226	26.95591452
19	57	0.038	6.714483658	9.032870873	11.30496472	19.03381316	23.82150585
20	60	0.035	6.184392843	8.319749489	10.41246751	17.5311437	21.94086066
21	63	0.03	5.300908151	7.131213847	8.924972151	15.0266946	18.80645199
22	66	0.024	4.240726521	5.704971078	7.139977721	12.02135568	15.04516159
23	69	0.022	3.887332644	5.229556821	6.544979578	11.01957604	13.79139813
24	72	0.016	2.827151014	3.803314052	4.759985147	8.014237121	10.03010773