MODELLING OF RAINFALL-RUNOFF RELATIONSHIP AT SUBCATHCHMENT OF UNIVERSITI MALAYSIA PAHANG, GAMBANG CAMPUS

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Thesis submitted in fulfilment of requirement
for the award of the degree of
B. Eng. (Hons) Civil Engineering

Faculty of Civil Engineering & Earth Resources
UNIVERSITI MALAYSIA PAHANG

JANUARY 2016

SUPERVISOR'S DECLARATION

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DEDICATION

Praise be to ALLAH S.W.T the Lord of The World

Who says (interpretation of meaning)

"Give thanks to me and your parent. To me is final destination"

[Quran,Luqman 31:14]

I wish to dedicate this project report, to those I love and who gave me the support all my life. To my mom, Zafiah binti Drahman and my lovely dad, Rosli binti Harun, family and siblings Mohd Syahiddin, Siti Hamimah and Siti Hanis Masyirah, a big thanks to Pn. Shairul Rohaziawati binti Samat for their support and encouragement.

Thank you so much, I love all of you with full of my heart.

ACKNOWLEDGEMENT

With the blessing of the Al-mighty, Alhamdulilah finally I had completed my Degree Project on the time. Throughout the preparation of this Final Year Project Report, I have been guided by the expertise of many people along my way. Pn. Shairul Rohaziawati binti Samat, who is my Final Year Project Report supervisor, has been very helpful in my Final Year Project Report. She has always been enthusiastic in checking my work for accuracy, assisting me to solve the problems and offering me numerous suggestions for my own improvement. This thesis would not been able to complete without En. Norasman bin Othman which is my co-supervisor for his guidance and advice, ideas and willingness to guide me and to lead me in this research.

In addition, I would like to thank the Jabatan Pembangunan dan Pengurusan Harta (JPPH), Universiti Malaysia Pahang (UMP) for their cooperation and kindness. I would like to acknowledge my friends for their encouragement, motivation and assistance in everything. I really appreciate with their cooperation to complete my project.

Besides that, I would like to extend my sincere appreciation to the Laboratory Assistance, Pn Kamariah bin Mat Peah and En Syed Najmuddin bin Sy Mohamad Nordin to help me in provision of relevant material during the preparation. Lastly, I would like to thank my family for their support and understand my commitment towards this thesis writing. I will keep in my mind all of your supporting and attention forever.

ABSTRACT

Universiti Malaysia Pahang (UMP) has drainage system that is insufficient to cattle the capacity of the runoff especially in Block W due to urbanization. Drainage design in UMP not take account the future development so, it's not able to function properly. Before this, drainage system in UMP is design for the Malaysia Electrical Corporation's (MEC) factory. Based on "Manual Saliran Mesra Alam" (MASMA) the design of minor drainage is for five years Average Recurrence Interval (ARI). Due to that design year, UMP exposed to serious flash flood. Therefore, this study is to determine the rainfall-runoff relationship, analyse rainfall-runoff data using Snyder and Clark method in HEC-HMS computer program. The study area is the drainage system with 0.11 slopes of UMP surrounding laboratories, Block W and new buildings with 0.8 m^2. From this study, it was found that runoff is depending on the rainfall intensity. Using HEC-HMS gave satisfying results and it is suitable for simulating future urbanization. In this software, hydrology parameter such as loss rate, transform and base flow are important to simulate the data. However, it is difficult to obtain accurate and suitable parameters for a catchment area. Nine storm event were used for calibration in order to get an optimum values for catchment area of UMP. After the comparison between Snyder and Clark Time Area method, Snyder method is the best method for UMP area with the Efficiency Index of 75.09%.

ABSTRAK

Universiti Malaysia Pahang (UMP) mempunyai sistem saliran yang tidak mencukupi untuk menahan kapasiti air larian terutamanya di Block W akibat daripada pembangunan. Reka bentuk saliran di UMP tidak mengambil kira pembangunan pada masa hadapan, jadi ia tidak berfungsi dengan baik. Sebelum ini, sistem saliran di UMP direka untuk kilang Malaysia Electrical Corporation (MEC). Berdasarkan “Manual Saliran Mesra Alam” (MASMA), sistem saliran ini direka berdasarkan sistem saliran minor untuk lima tahun Purata Kala Kembali (ARI). Akibat daripada reka tahun tersebut, UMP terdedah kepada banjir kilat yang serius. Maka kajian ini untuk mengetahui kaedah yang terbaik untuk menganalisis data hujan-air larian dengan menggunakan kaedah Snyder dan Clark Time Area dalam perisian HEC-HMS. Kawasan kajian mempunyai sistem saliran dengan kecerunan 0.011 yang meliputi makmal , Blok W dan bangunan-bangunan baru dengan keluasan 0.8 m^2. Daripada kajian, didapati air larian bergantung kepada kelebatan hujan. Dengan menggunakan perisian HEC-HMS akan memberikan keputusan yang memuaskan dan bersesuaian untuk simulasi pembangunan pada masa hadapan. Dengan meggunakan perisian ini, parameter seperti “Loss Rate”, “Transform” dan aliran dasar adalah penting untuk data simulasi. Tetapi sukar untuk mendapatkan parameter yang tepat dan sesuai untuk kawasan tadahan. Sembilan peristiwa hujan digunakan untuk kalibrasi bertujuan untuk mendapatkan nilai optimum untuk kawasan tadahan di UMP. Selepas perbandingan antara kaedah Snyder dan Clark Time Area, didapati Snyder adalah kaedah yang terbaik untuk kawasan UMP dengan Indek Kecekapan sebanyak 75.09%.

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LIST OF SYMBOLS

m^3	-	Meter cube
m^2	-	Meter square
km	-	Kilometer
mm	-	Millimeter
m^3/s	-	Meter cube per second
n	-	Number of subareas
t_r	-	Effective rainfall duration
t_R	-	Effective duration
t_{lR}	-	Basin lag
t_l	-	Basin lag time
t_b	-	Basin time
q_p	-	Peak direct runoff rate
q_{pR}	-	Peak discharge per unit watershed area
q_u	-	Unit peak discharge
Q_p	-	Peak runoff
A	-	Drainage area
i	-	Rainfall runoff intensity
I_a	-	Initial abstraction including surface storage, intercept and Infiltration prior to runoff
P	-	Accumulated rainfall (potential maximum runoff)
L	-	Length
L_c	-	Distance in kilometers (miles) from the outlet to a point On the stream nearest the centroid
C_1	-	0.75 (1.0 for English units)

C_t	-	Coefficient represent variation in watershed slopes and storages characteristic
C_2	-	2.75 (640 for English units)
C_p	-	Coefficient represents the effects of retention and storage
C_w	-	1.22 (440 for English units) for 75% and 2.14 (770 for English units) for 50%
C_A	-	Routing coefficients
C_B	-	Routing coefficients
C_3	-	5.56 (1290 for English system)
cfs	-	Cubic square foot
km^2	-	Kilometer square
u	-	Ratio of the total runoff volume to the area under the dimensionless hydrograph
W_{50}	-	Widths of the UH at values of 50%
W_{75}	-	Widths of the UH at values of 75%
Q	-	Flow rate of runoff
R	-	Hydraulic radius
I_t	-	Average inflow to storage at time *t*
min	-	Minute
S	-	Slope
S_t	-	Storage at time *t*
P	-	Wetted parameter
t_c	-	Time concentration
T_{lag}	-	Snyder’s standard lag (hours)
O_t	-	Average outflow during period *t*
Q_i	-	Observed discharge at time,i

Q_{ag}	-	Mean of observed discharge
R	-	Storage attenuation coefficient
N	-	Number of discharge data
n	-	Manning roughness coefficient
F_i	-	Simulated discharge at time,i
$\sum$	-	Summation
SS	-	Sum of square

LIST OF ABBREVATION

UMP	Universiti Malaysia Pahang
MEC	Malaysia Electrical Corporation
MASMA	Manual Saliran Mesra Alam
ARI	Average Recurrence Interval
HEC-HMS	Hydrologic Engineering Centre Hydrologic Modelling System
JPS	Jabatan Pengairan dan Saliran
DID	Department of Irrigation and Drainage (DID)
SCS	Soil Conservation Service
SWMM	Storm Water Management Model (SWMM)
HEC-RAS	Hydrologic Engineering Center-River Analysis System
UH	Unit Hydrograph

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Malaysia has been a successful developing country in South East Asia which has the rapid of development growth rate. The continuous growth of population and massive development will affect the physical characteristics of an area and change the hydrological practice. Increasing number of impervious and then combined with heavy rain and poor drainage systems have reduce the amount of water to infiltrated into the soil, thus increase surface runoff.

In Malaysia, flood is the most common natural hazard. The peninsula is geographically located in the wet equatorial tropics where seasonal monsoon winds bring forth heavy rain from Siberia spells generating extensive seasonal monsoon floods along the east coast of Kelantan, Terengganu, Pahang and East Johore. This is especially in the peninsula's East Coast region where the occurrence of such flood is considered a way of life (Chan, 1995).

It is frequent and widespread, often escalating into disaster which cripples the economy, communications, public services and result in property damage and loss of life (Chan, 1996). Therefore, estimation of surface runoff from upstream area is important in establishing flood control in downstream area.

Unplanned development and rapid urbanization process can cause certain area change the originality of earth and can lead to disasters. Flash flood is usual disaster occurring in Kuala Lumpur. As reported through the news, the flash flood cause the road submerged and thousands of road users were stuck in the traffic jam on several areas in Kuala Lumpur. Then, the Northeast Monsoon brought heavy rain through series of extreme and persistent storm causing devastating monsoon flood. In addition, early year 2013, two students became victims of the flood that occurred in Machang, Kelantan. This disaster gives serious impact when there is loss of life

` When the rivers and drainage are not able to endure the sudden water capacity at the catchment area, flash floods happen. This phenomenon has caused serious flash flooding in big cities in Malaysia nowadays. The flash flood occurred in Kuantan, Pahang, on 25 December 2012 is caused several roads and premises, and shopping malls had to close for business. At the end of year 2013, the worst flood occurred at East Coast of Malaysia that left Kuantan, almost paralysed during the end of 2013.

1.2 PROBLEM STATEMENT

In monsoon season 17 December 2014, flooding problem occurred in Kolej Kediaman II, Universiti Malaysia Pahang (UMP), Gambang Campus as a result of development in catchment area and obstruction in waterway flow as shows in Figure 1.1. While natural conditions are shown to foster and create monsoon floods, the incident of flash flood, particularly in Universiti Malaysia Pahang is largely the consequence of human action.

Rainfall will infiltrate more in an undeveloped area (pervious) compare to developed area (impervious). So, the large amount of rainfall in a developed area, only a little amount will infiltrate in soil and the rest of them will flow to the lower level of the ground as a runoff then the water flow to the drain. One of the reason flash floods happen in UMP due to clogging of drain cause by human activities shows in Figure 1.2. The rising student population contributes to high disposal of rubbish and prevent the smooth flow of water. The drain unable to support the amount of water thus an overflow occur causing flash flooding.

Figure 1.1: Flash Flood at Kolej Kediaman II, Gambang Campus.

Figure 1.2: Clogged Drainage System

Before this, drainage systems in UMP were design for the Malaysia Electrical Corporation's (MEC) factory. Based on "Manual Saliran Mesra Alam" (MASMA) the design of minor drainage is for five years Average Recurrence Interval (ARI). Due to that design, drainage system in UMP is no longer possible to accommodate the capacity of runoff especially in front of Block W. That can caused floods even after a low intensity of rainfall.

Flood can also happen due the shortage of vegetation covers to intercept the precipitation from entering the river system directly. Due to this, the flood can cause significant number casualties, disease epidemics, property and crop damage and other intangible losses. By deepening and widening the drains is obviously not the best solution for this problem but it cost too much and in cases there never enough space for it.

The brilliant solution is using different approaches by focuses on the storm water control at source, retention and detention to gain maximum benefit. In this study, Hydrologic Engineering Centre Hydrologic Modelling System (HEC-HMS) had been used to analyze the rainfall-runoff. By using this software, we can determine the rainfall-runoff relationship by producing hydrograph. Therefore, this study needs in order to estimate the surface runoff from the upstream area to establish flood control at UMP Gambang Campus.

1.3 OBJECTIVE

The objectives of this study are as the following:

i. To analyse rainfall-runoff relationship using Synder and Clark Time Area method.

ii. To calibrate and validate transformation model in a sub-catchment Universiti Malaysia Pahang, Gambang Campus.

iii. To identify the most appropriate transformation method for sub-catchment of Universiti Malaysia Pahang Gambang Campus.

1.4 SCOPE OF STUDY

The scopes of this study only focus in sub-catchment area in Universiti Malaysia Pahang, Gambang Campus. In order to achieve the objectives, the scopes of this study are as the following:

i. Collect Hydrological Data which is rainfall and flow rate data of Universiti Malaysia Pahang Gambang Campus sub-catchment within the period of four months (October – December 2015).

ii. Calibrate and validate the data using HEC-HMS software.

iii. The two-transformation method which is Snyder and Clark Time Area method used to produce reliable flood flow estimation for sub-catchment of Universiti Malaysia Pahang Gambang Campus.

1.5 SIGNIFICANCE OF STUDY

From this study, the relationship between rainfall and runoff can be obtained using HEC-HMS software. Besides that, the comparison between two method which is Snyder and Clark Time Area method that used to analyzed relationship between rainfall and runoff can be determined. So, this study can be reference for future researcher to analyze the flood by using the data collected and appropriate method in sub-basin of Universiti Malaysia Pahang, Gambang Campus.

It is important to do this study because we can determine the rainfall quantity and the runoff capacity. The relationship between rainfall-runoff also can be determine. This study can provide Jabatan Pengairan dan Saliran (JPS) all the information needed in design facilities to reduce any damage cause by flood. Data from this study might as a guideline during design the drainage system and future development in UMP. The problem like flash flood and insufficient capacity of drainage can be prevented.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Situated between 1° and 6°N, Southeast Asia has long experienced a monsoon climate with dry and wet season throughout the year. Malaysia has 189 water basins with a mean annual rainfall precipitation around 2500 mm and locally in excess of 5000 mm, the very intense rainstorms in the steep mountains of Malaysia have caused frequent and devastating flash floods. In the valleys floodwater spread over very wide flood plains developed for agriculture, predominantly rice paddies and oil palm.

Flooding has been a major concern in recent decades. Malaysia can be categorized as one of the developing countries in Asia that is rapidly emerging in industrialization. Urbanization and deforestation exacerbate flooding problem due to the increased runoff from the impervious areas. The industrial developments fostered a new way of urban life and flood control in Malaysia is undergoing significant changes. There has been major and tragic flooding in Malaysia since 1926.

The combination of natural and human factors has produced different types of floods such as monsoon and flash flood. It make that flood is a major disaster in Malaysia due to regular and heavy rainfall every year from October to March. Flood occurrence has become a national issue as it threatens life and property and disrupts social and economic activities.

2.2 TYPE OF FLOODS IN MALAYSIA

Malaysia is a country that is freed from natural disaster such as earthquakes, volcano and typhoon. The most common natural disaster experiencing in Malaysia is flood. The type of flood occur in this country are monsoon flood and flash flood. It is difficult to distinguish between floods happen because of nature or human. In Malaysia, floods are caused combination of natural and human factors, flash flood mostly in urbanized catchment due to human factor. Then, monsoon flood which are more common and severe largely attributed to the physical geography.

Monsoon floods characterized by low intensity long duration rainfall and unpredictable flash flood characterized by high intensity short duration rainfall (Lee Loke Chong, 2008). The northeast monsoon flood occur during the months of November to March with heavy rains to the east coast states of the Peninsula, northern part of Sabah and southern part of Sarawak. Monsoon floods are brought by monsoon winds which deposit heavy rainfall during southwest monsoon season during May to September. They are seasonal in nature, of longer duration and are more severe especially during the northeast monsoon.

Flash flood is a local flood that occurred within 4 to 6 hours after a high intensity storm event usually in urbanised lowland area. Flash flood phenomenon usually is due to inability of the drainage system to fulfil the stormwater volume. Flash flood in an urbanised area such as Kuala Lumpur has higher frequency and magnitude than in rural settlement. Flash flood can be the most dangerous kind of flood because they combine the destructive power of a flood with incredible speed and unpredictability. It happen when the ground under a storm becomes saturated with water so quickly that it cannot be absorbed, hence the runoff collects in lowland area and flow downstream become suddenly in rising water.

As reported in news on 12 November 2015, flash floods happen in several areas in Kuala Lumpur. Among the areas affected were Kampung Datuk Keramat, Jalan Semarak, Jalan Sentul, Jalan Kampung Pandan, and Jalan Ampang. However, the flood waters receded about half an hour later.

2.3 FACTORS OF FLOOD

Flooding can be caused by many factors. The factor of flooding can be by natural factor, man-made or any combination of these two factors. Reported by Department of Irrigation and Drainage Malaysia, there are two major categories of causes of flood in Malaysia, which are natural factor and human activities. The first catagory is natural factor, the heavy rainfall in Malaysia especially in monsoon season caused flash flood and resulting in stagnant water. The second category that Department of Irrigation and Drainage (DID) categorized of factor of flood is man-made category. It is including dumping of solid waste into river, sediment from construction site and increased impervious area.

Flash flooding have many reason for it occurrence, one of them is the due to clogging of drain cause by human activities. Increase the density of population contributes to high disposal of waste and will cause pollutions to that area. The rubbish and sediment from construction works and soil erosion will cause highly pollution and prevents the smooth flow of water. When heavy rainfall occur, the drain unable to support the amount of water thus an overflow occur causing flash flooding.

Soil and rock type can also influence what happens to precipitation when it reaches the ground. Impermeable soils and rocks such as clay or shale do not allow water to infiltrate, this forces water to run off reducing river lag times and increasing flood risk. Permeable rocks allow water to infiltrate into them. If permeable rocks allow water in through cracks, fissures and bedding planes but not through their pores they are said to be pervious (such as limestone). Porous rocks allow water to penetrate into their pores such as sandstone. Decreasing amount infiltration of the rainfall causing the water accumulates and flash flooding occurs.

Other than that, the increased of floods occurrence especially in urban area are largely due to urbanization process. Human life cannot get away from the process of urbanization as people always want advancement and want to enjoy surviving. That result in increase of impervious surface which shortened the time of concentration and increase the magnitude of the runoff discharge. Figure 2.1 show the peak in urban area is higher due to impervious area and water flow faster in concrete drain. The whole urban system is designed to move water from the surface into underground pipes and away from urban area which have value. This also can lead to floods in the rural area.

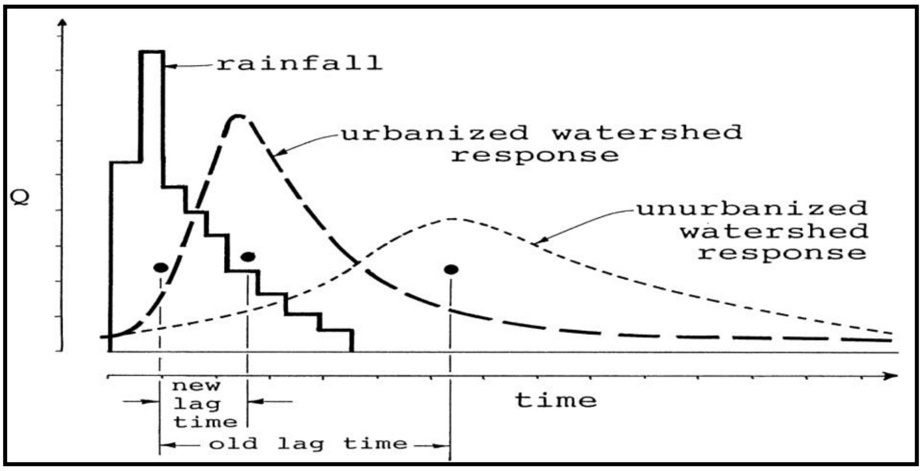


Figure 2.1: The peak in urban area is higher due to impervious area and water flow faster in concrete drain.

Source: Leopold, L.B. (1968)

2.4 EFFECT OF FLOOD

There are two categorized in effect of flood which is tangible and intangible effects. Effect of flood that can cause monetary loss can be referred as tangible effects or can be described as direct effects of flood that contact with human and property. Tangible effects have an impact on the physical assets such as human and infrastructure. While, intangible effects refer to the flood impact that cannot cause monetary loss. This mean that intangible or indirect effects are like interruption of production of goods and services that happen due to interruption of transport, utility services and markets.

When flood happen, many structure have been totally submerged by flood water. The structures including flood wall and bridges that are built for living and businesses are completely destroyed by flood. The damage of building and structure become extremely destroyed if the water of flooding remains stagnant for a couple of days.

Roads infrastructures also get a serious impact cause by flood disaster. The disaster can damage and destruction of roads, railways, and bridges. The first enemy to bitumen is water. Water penetrates into the deeper layers of bitumen roads and cause disturbed subgrade layer. Then, the incident can cause in broken roads and potholes that can be seen along the roads.

Floods make an enormous impact on the environment and society. Floods destroy drainage system in cities, causing raw sewerage to spill out into bodies of water. This can lead to catastrophic effects on the environment as many toxic materials can be released into river, and ocean, killing marine life.

The most critical impact that happens due to flood disaster is loss of life including human lives. Floods have caused the death of about 200,000 people and more than 1.4 billion people are killed every year over the world. The loss of human and animal life was higher when high velocity of floodwater submerged the area.

2.5 RAINFALL-RUNOFF RELATIONSHIP

During a given rainfall, water is continually being abstracted to moisten the upper levels of the soil surface; however, this infiltration is only one of many continuous abstractions. Rainfall is also intercepted by trees, plants, and roof surfaces, and at the same time is evaporated. Once rain fall and fulfills initial requirements of infiltration, natural depressions collect falling rain to form small puddles, creating depression storage.

In addition, numerous pools of water forming detention storage build up on permeable and impermeable surface within the watershed. This stored water gather in small rivulets, which carry the water originating as overland flow into small channels, then into larger channels, and finally as channel flow to the watershed outlet (Lewis and Viessman, 2003).

The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content (previous rainfall or dry season). The initial capacity of a dry soil is high but, as the storm continues, the soil capacity will decrease until it reaches a steady value as final infiltration rate (Lewis and Viessman, 2003). The rainfall-runoff relationship is shown in Figure 2.2.

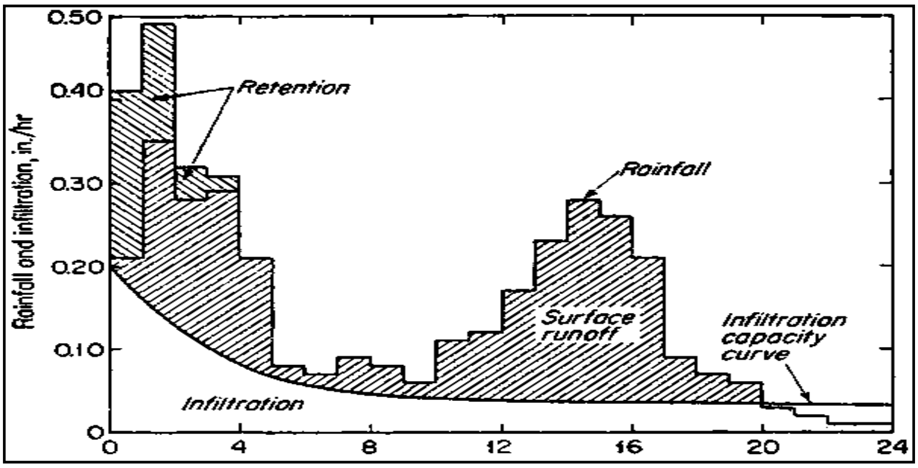


Figure 2.2: Schematic diagram of rainfall-runoff relationship

Source: http://www.fao.org

The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration.

2.6 METHOD FOR RUNOFF CALCULATION

Four techniques are commonly used to estimate runoff, i.e Rational Method, Graphical Peak Discharge Method, Tabular Method (TR-55), and Unit Hydrograph Method. The primary factors used to decide on a runoff calculation method are the size of the drainage area and the output information required. The plan approving authority may require or accept other calculation methods deemed more appropriate for local conditions.

2.6.1 Rational Method

Many methods to compute runoff have been developed over the years, and the first and most enduring of this is Rational Method. Most methods are based on empirical relationships among drainage area, time of concentration, rainfall, and other factors. However, the Rational Method, introduced in England in 1889, has its genesis in pure reasoning, from which it received its name.

The Rational Method is used to compute the peak runoff, Q_p, following a rainfall event. It makes no attempt to estimate runoff before and after the peak, but simply the one quantity of flow that is greatest.

Originally, the Rational Method formula for peak runoff was given as:

$$Q_p = A_i \tag{2.1}$$

Where:

Q_p = peak runoff (cfs)

A = drainage area (acres)

i = rainfall intensity (in/h)

This was based on the completely impervious drainage basin in which all rainfall is converted to runoff. Later, a proportionally factor, *c*, called the runoff coefficient, was added in an attempt to account for infiltration into the ground and for evaporation. So the formula become

$$Q_p = A_{ci} \tag{2.2}$$

where *c* is the dimensionless runoff coefficient. Values of *c* vary between 0.0 and 1.0.

2.6.2 Graphical Peak Discharge Method

In the Graphical Peak Discharge Method, runoff is calculated using the following formula:

$$q_p = q_u A_m Q F_p \tag{2.3}$$

Where:

q_p = Peak discharge (ft^3/s, also written as cfs)
q_u = Unit peak discharge (cfs/$mi.^2$/in., also written as csm/in)
A_m = Drainage area ($mi.^2$)
Q = Runoff (in.)
F_p = Pond and swamp adjustment factor (no units)

2.6.3 Tabular Method

The Tabular Hydrograph method is used to develop the composite hydrograph. First the method extracts a specific unit hydrograph from a table based on a number of sub area and rainfall variables. The variables found to have significant influence on the shape of the unit hydrograph are *Rainfall Type*, I_a/P, T_c and T_t. Where T_c is the time of concentration within the subarea and T_t is the travel time from the subarea outlet to the watershed outlet.

2.6.4 Unit Hydrograph Method

Unit hydrograph analysis is used for watersheds greater than 1 square mile (640 acres) in Orange County, California. Losses are accounted for by calculating an effective precipitation. Runoff hydrographs are computed using a unit hydrograph, which is developed using an S-graph. A small area hydrograph can be used instead of a full blown unit hydrograph analysis for watersheds with a T_c < 25 min.

Synthetic hydrograph also the common method uses to analyze rainfall. Some important and popular methods are: Soil Conservation Service, Snyders's unit hydrograph and Clark Unit Hydrograph.

2.6.4.1 Soil Conservation Service (SCS)

Techniques developed by the U.S Soil Conservation Service for calculating rates of runoff require the same basic data as the rational method: drainage area, a runoff factor, time of concentration and rainfall. The SCS approach however is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression, storage and an infiltration rate that decreases during the course of a storm. With the SCS method the direct runoff can be calculated for any storm, either real or fabricated by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

The SCS runoff equation is therefore a method of estimating direct runoff from 24 hr or 1 day storm rainfall. The equation is:

$$Q = (P-I_a)^2 / (P-I_a) + S \tag{2.4}$$

Where:

Q = accumulated direct runoff (in)

P = accumulated rainfall (potential maximum runoff) (in)

I_a = initial abstraction including surface storage, interception and infiltration prior to runoff (in)

S = potential maximum retention (in)

The relationship between I_a and S was developed from experimental watershed data. It eliminates the need for estimating I_a for common usage. The empirical relationship used in SCS runoff equation is

By substituting $$I_a = 0.2S \tag{2.5}$$

The SCS runoff equation (2.4) becomes:

$$Q= (P-0.2S)^{2}/ (P+0.8S) \quad (2.6)$$

S is related to the soil and cover the conditions of watershed through the curve number (CN) or runoff factor. *CN* has a range of 0-100, and *S* is related to *CN* by:

$$S = (1000/CN)-10 \quad (2.7)$$

2.4.6.2 Snyder's Unit Hydrograph

According to the U.S. Army Crops of Engineer, the synthetic unit hydrograph of Snyder (1938) is based on relationships found between three characteristics of a standard unit hydrograph and descriptors of basin morphology. The hydrograph characteristics are the effective rainfall duration t_r, the peak direct runoff rate, q_p and the basin lag time, t_l. From these relationships, five characteristics of a required unit hydrograph for a given effective rainfall duration may be calculated.

Standard unit hydrograph is associated with specific effective rainfall duration, t_r, define by the following relationship with basin lag, t_l

$$t_l = 5.5\, t_r \quad (2.8)$$

For a standard unit hydrograph the basin lag, t_l and the peak discharge, q_p, are given by,

$$t_l = C_1 C_t\, (LL_c)^{0.3} \quad (2.9)$$

and

$$q_p = \frac{C_2 C_p A}{t_l} \quad (2.10)$$

The basin lag time of the standard unit hydrograph (Equation 2.9) is in unit of hours, L is the length of the main stream in kilometers (miles) from the outlet to the upstream divide, L_c is the distance in kilometers (miles) from the outlet to a point on the stream nearest the centre of the watershed area, and C_1 = 0.75 (1.0 for English units). The product LL_c is a measure of watershed shape. C_t is a coefficient derived from gauged watersheds in the same region, and represents variations in watershed slopes and storage characteristics. The peak discharge of the standard unit hydrograph (Equation 2.10) is in m^3/s (cfs), A is the basin area km^2 (mi^2) and C_2 = 2.75 (640 for English units). As C_t and C_p is a coefficient derived from gauge watersheds in the area, and represents the effects of retention and storage.

Estimation of model parameters C_p and C_t as in any modal parameter estimation problem, observations of the input (i.e, effective precipitation) and the output (i.e., direct runoff hydrograph) must be available. In addition, the values of L and L_c must also be available (e.g. from survey, maps, etc.).

From the concurrent input-output observation, a unit hydrograph for the basin in question, also called derived unit hydrograph, can be developed. From the derived unit hydrograph of the watershed, values of its associated effective duration t_R in hours, its basin lag t_{lR} in hours, and its peak discharge q_{pR} in m^3/s are obtained. If t_{lR} = 5.5 t_R then the derived unit hydrograph is a standard unit hydrograph and $t_r = t_R$, $t_l = t_{lR}$, and $q_p = q_{pR}$, and C_t and C_p are computed by the equations for t_l and q_p given above (Equation 2.9, Equation 2.10).

If t_{lR} is quite different from 5.5 t_R the basin lag of standard unit hydrograph for the basin is computed using:

$$t_l = t_{lR} + \frac{t_r - t_R}{4} \tag{2.11}$$

This equation must be solved simultaneously with the equation for the standard unit hydrograph lag time, $t_l = 5.5\, t_r$, in order to obtain t_r and t_l. With these values of t_r and t_l. The value of C_t is obtained using (Equation 2.9) for t_l corresponding to the standard unit hydrograph; the value of C_p is obtained using the expression for q_p corresponding to the standard unit hydrograph, but using $q_p = q_{pR}$ and $t_l = t_{lR}$.

When an ungauged watershed appears to be similar to a gauge watershed, the coefficients C_t and C_p for the gauge watershed can be used in the above equations to derive the required synthetic unit hydrograph for the ungauged watershed.

Development of a Required Unit Hydrograph (assume that C_t, C_p, L and L_c are known). If a t_R unit hydrograph is required, that is, if a unit hydrograph whose associated effective rainfall pulse duration is t_R, is required, proceed as follows:

Use (Equation 2.9) to determine the lag-time, t_l. if t_R meets the criterion for a standard unit hydrograph, that is, if $t_l = 5.5\ t_r$ then the required unit hydrograph is a standard unit hydrograph and (Equation 2.9) and (Equation 2.10) can be used directly to estimate the peak discharge and the time to peak of the required unit hydrograph. That is

$$t_{lR} = t_l = C_1 C_t (L L_c)^{0.3} \qquad (2.12)$$

$$q_{pR} = q_p = \frac{C_2 C_p A}{t_l} \qquad (2.13)$$

If t_R does not meet the criterion of (Equation 2.1) then the required unit hydrograph is not a standard unit hydrograph and (Equation 2.9) and (Equation 2.10) cannot be used directly to estimate the peak discharge and the time to peak of the required unit hydrograph. In this case, the lag-time of the required unit hydrograph, t_{lR}, is,

$$t_{lR} = t_l + \frac{t_r - t_R}{4} \qquad (2.14)$$

where t_l is obtained from (Equation 2.13), t_r is obtained from (Equation 2.8) and is t_R given. The peak discharge of the required Unit Hydrograph (UH), q_{pR}, is,

$$q_{pR} = \frac{q_p t_l}{t_{lR}} \qquad (2.15)$$

where q_p is obtained from Equation (2.10) .

Assuming a triangular shape for the UH, and given that the UH represents a direct runoff volume of 1cm (1 in), the base time of the required UH may be estimated by,

$$t_b = \frac{C_3 A}{q_{pR}} \tag{2.16}$$

Where C_3 is 5.56 (1290 for the English system).

As an aid in drawing adequate UH, the U.S. Army Crops of Engineers developed relationships for the widths of the UH at values of 50% (W_{50}) and 75 % (W_{75}) of q_{pR}. The width in hours of the UH at a discharge equal to a certain percent of the peak discharge q_{pR} is given by Chow et al. (1988) as,

$$W_{\%} = C_w \left[\frac{q_{lR}}{A}\right]^{-1.08} \tag{2.17}$$

Where the constant C_w is 1.22 (440 for English units) for the 76% width and equal to 2.14 (770 for English units) for the 50% width. Usually, one-thirds of this width is distributed before the peak time and two-thirds after the peak time, as recommended by the U.S. Army Crops Engineers. However, several other authors have recommended different distribution ratios. For example, Hudlow and Clark (1969) recommended a partition of 4/10 and 6/10 respectively.

2.6.4.3 Clark Unit Hydrograph (TC& R)

The process of translation and attenuation dominated the movement of flow through a watershed. Translation is the movement of flow down gradient through the watershed in response to gravity. Attenuation results from the frictional forces and channel storage effects that resist the flow. Clark (1945) noted that the translation of flow throughout the watershed could be described by a time-area curve, which expresses the curve of the fraction of watershed area contributing runoff to the watershed outlet as a function of time since the start of effective precipitation. Effective precipitation is that precipitation that is neither retained on the land surface nor infiltrated into the soil (Chow e.t. al, 1988).

The time-area curve is bounded in time by the watershed T_c. Thus, T_c is a hydrograph parameter of the Clark unit-hydrograph method. Attenuation of flow can be represented with a simple, linear reservoir for which storage is related to outflow as,

$$S=RO \tag{2.18}$$

where:

S = is the watershed storage,

R = is the watershed-storage coefficient, and

O = is the outflow from the watershed.

Therefore, Clark (1945) proposed that a synthetic unit hydrograph could be obtained by routing 1 inch of direct runoff to the channel in proportion to the time-area curve and routing the runoff entering the channel through a linear reservoir (smig.usgs.gov/SMIG/features_0301/clark.pdf, 2005).

2.7 MODELLING AND RAINFALL RELATIONSHIP

In particular, when (or preferably before) alterations are made to the land area or drainage network, stormwater managers need to understand and anticipate how the alteration is likely to affect the volume, flow rate, and quality of runoff moving through the system, cause the flood and in turn, how the stormwater is likely to impact the people, property, and natural resources of the area. Modelling is a tool that can be used to understand and evaluate complex processes.

Some kind of stormwater model is needed whenever an estimate of the expected volume, rate, or quality of stormwater is desired. Modelling is also often necessary for the design of hydraulic structures. If monitoring data exists for the specific combination of precipitation and site conditions under consideration, modelling may not be necessary. However, in many cases the conditions to be analysed do not fit precisely with the conditions monitored in the past and modelling will be necessary.

2.8 COMPUTER MODELS AND SOFTWARE FOR RAINFALL-RUNOFF ANALYSIS

There are many new computational software has been developed recently to cover most aspects of urban hydrology, hydraulics and stormwater. Computational software is a tool that can be used to understand and evaluate complex process. An engineer, hydrologist or local staffs use computational power of computers to automate the tedious and time consuming manual calculations.

By using computational software, engineers are able to isolate parts of the hydrologic cycle or their infrastructure system into manageable pieces to better understand the movement of water in the catchment area. According to engineer design objectives and available resources, one or more of these pieces of software will typically use in stormwater facility design. This tool in general is a versatile tool that can be applied to any number of situations.

However, these computer modelling requires a good knowledge of the operations of the software model and how these processes are represented in computer model. The engineer must have many attributes, including an understanding of hydrologic, hydraulic and other process inherent in catchment area by the software he is planning to use.

2.9 HYDROLOGIC AND HYDRAULIC MODELS AND SOFTWARES

Hydraulic models are used to predict the water surface elevations, energy grade lines, flow rates, velocities, and other flow characteristics throughout a drainage network that result from a given runoff hydrograph or steady flow input. Generally, the output (runoff) from a hydrologic model is used in one way or another as the input to a hydraulic model. The hydraulic model then uses various computational routines to route the runoff through the drainage network, which may include channels, pipes, control structures, and storage areas. Combined hydraulic and hydrologic models provide the functions of both hydraulic models and hydrologic models in one framework. A combined model takes the results from the hydrologic portion of the model and routes it through the hydraulic portion of the model to provide the desired estimates.

2.9.1 Hydrologic Engineering Center–Hydrologic Modelling System (HEC-HMS)

HEC-HMS is a rainfall-runoff model developed by the U.S. Army Corps of Engineers to compute runoff hydrographs for a network of watersheds. The model evaluates infiltration losses, transforms precipitation into runoff hydrographs, and routes hydrographs through open channel routing. A variety of calculation methods can be selected including SCS curve number or Green and Ampt infiltration, Clark, Snyder or SCS unit hydrograph methods, and Muskingum, Puls, or lag routing methods. Precipitation inputs can be evaluated using a number of historical or synthetic methods and one evapotranspiration method.

2.9.2 Storm Water Management Model (SWMM)

The original version of the SWMM was developed for EPA as single-event model especially for the analysis of combined drain overflows (Metcalf and Eddy Inc.1971)**.**

SWMM is a rainfall-runoff simulation model. It is use in planning and designing process for drainage system in town area. It is also can be used to determine quantity and quantity rainfall-runoff. SWMM model that is used for this hydrology analysis have been the Kinematic Wave that is Deterministic-lumped model and Green-Ampt that is Deterministic-distributed model. SWMM can be divided to few blocks such as:

i. Transport block
ii. Extrant block
iii. Storage/treatment block
iv. Statistic block

SWMM also contain a flexible set of hydraulic modelling capabilities used to route runoff and external inflows through the drainage system network of pipes, channels, storage/treatment units and diversion structures.

2.9.3 Hydrologic Engineering Center-River Analysis System (HEC-RAS)

The HEC-RAS analysis model has several improvements over that of the original HEC-2 analysis model. HEC-RAS is capable of modelling subcritical, supercritical and mixed flow regime water surface profile. Floodway encroachments can be entered by the user to determine the change in water surface elevation. The user can specify the allowable change in the water surface elevation. The program will then compute then extend of the floodway encroachment.

Included with HEC-RAS are completely new bridge and culvert hydraulic routines, allowing multiple bridges and culverts to be modelled at a single roadway crossing. In addition, other hydraulic structures, such as weirs and spillway, can be modelled. At multiple opening crossings, the model evaluates each opening as a separate entity and distributes the total flow through the openings such that the energy loss in each is equal. The bridge routines allow the modeller to analyse any shape or size bridge.

2.9.4 MIKE II

MIKE11 is an application of a numerical model using the 1D river modelling developed by the Danish Hydrologic Institute.The MIKE11 model is used for simulating flows in rivers, estuaries, drainage networks and other water bodies. The model solves both branched and looped networks and can simulate hydraulic structures such as culverts and bridges. The model computational scheme can be applied to vertically homogeneous flow conditions extending from steep river flows to tidally influenced estuaries.

MIKE11 requires input at the open ends of the model. Hydrographs generated from rainfall – runoffs modelling with NAM are used as input into the model’s upstream open boundaries, whilst the downstream boundaries were modelled using tidal data. Evaporational loses have been included in the model to simulate the observed loses due to evapotranspiration from riparian vegetation and the free water surface of the river.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains the method of running the study according to the best technique. It clarifies the concept of study, tools that were used, needed data information and suitable techniques. Various approaches were taken into consideration during the planning and implementing the identified works to ensure the study could be conducted smoothly and success. With the aim to determine the rainfall-runoff relationship, a few methodologies as shown in flow chart have been practiced.

Data on rainfall and runoff are collected every 10 minutes for three months in sub-catchment of Universiti Malaysia Pahang Gambang Campus. After the data was collected, Snyder and Clark Time Area method in HEC-HMS software used to compute all the data. Hydrograph produced from the software to be compared and the most appropriate method to analyse the rainfall-runoff relationship determined.

3.2 FLOW CHART OF METHODOLOGY

Figure 3.1 shows the overall processed involved in the study from start until finish.

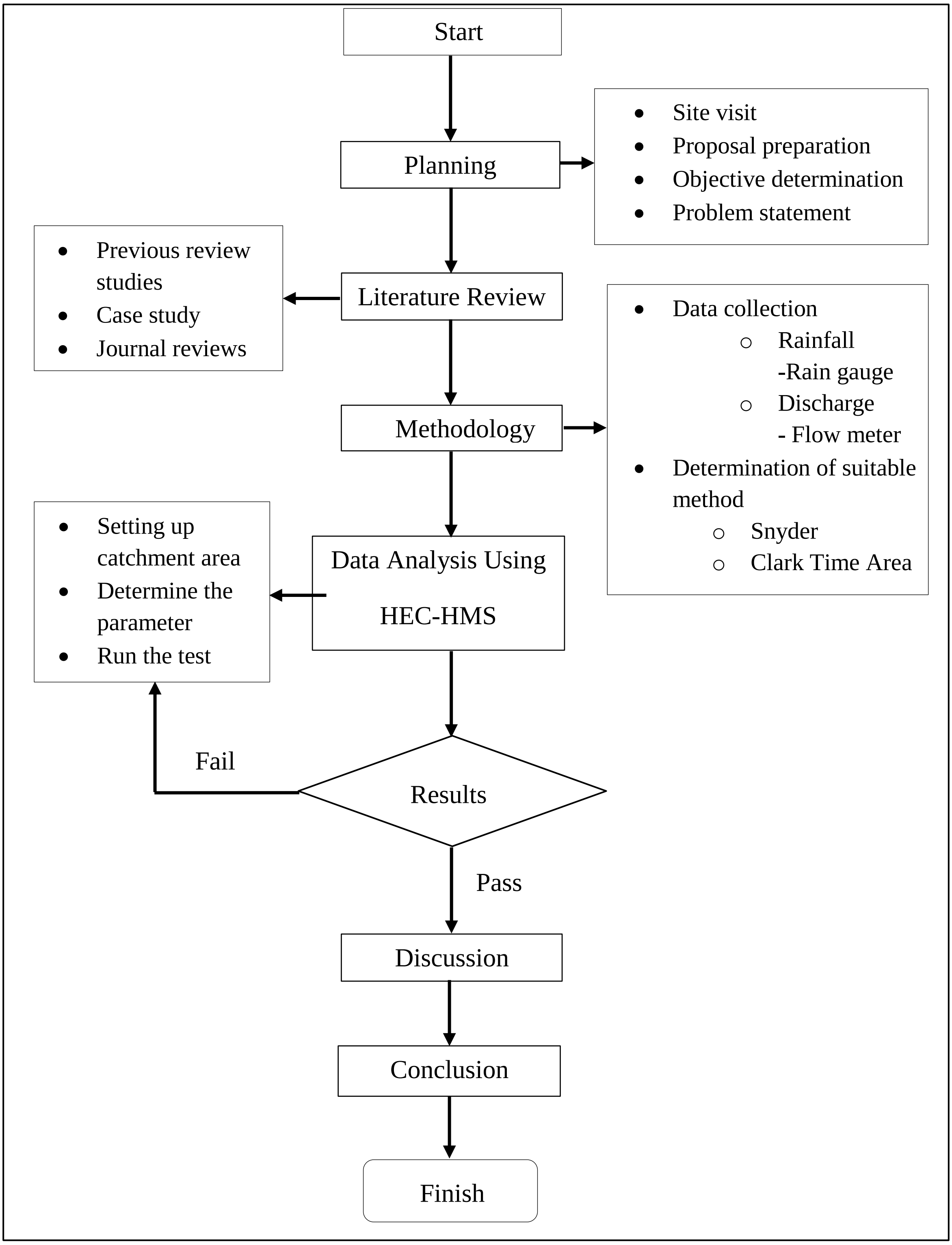


Figure 3.1: Overall Processed Involved in the Study

3.3 STUDY AREA

The study area is part of Gambang Catchment, which is sub-catchment of Universiti Malaysia Pahang, Gambang Campus. UMP is large area that cover about 0.000426 km^2 and located at about 30 km from west of Kuantan. The location of inlet of study area is at the intersection drainage from laboratory and the drainage along the side road and the outlet is at the main gate of UMP. Figure 3.2 shows the plan of study area in UMP.

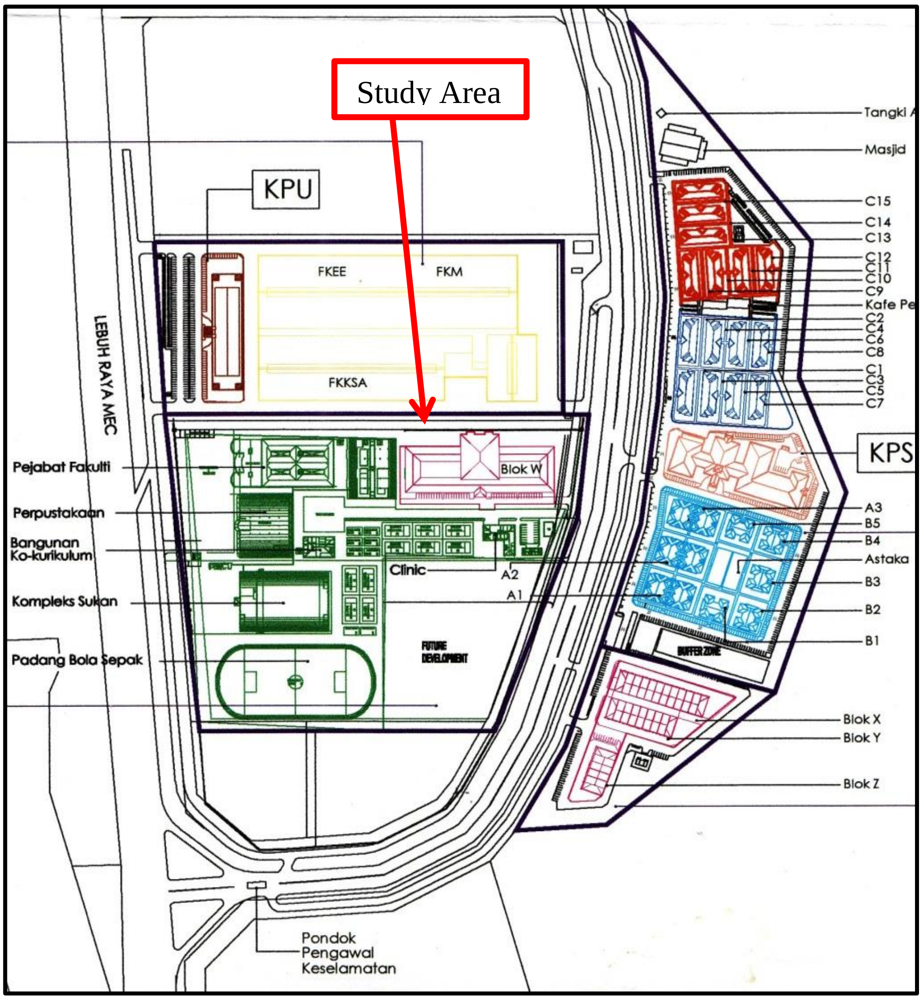


Figure 3.2: Plan of study area in Universiti Malaysia Pahang, Gambang Campus.

The study area was consists of with lecture halls, laboratory, sport complex, co-curriculum building, lecture room, faculties, library and clinic. UMP is still developing and percentage of impervious area is 50% then its keep increases every year. The area in this study was estimated is 0.8 m^2 The topography in this catchments area is almost flat with slope is 0.011. Figure 3.3 shows the layout of study area where the drainage system is in purple line and the location of flow logger is crossed in red colour and rain gauge was installed at field Kolej Kediaman II.

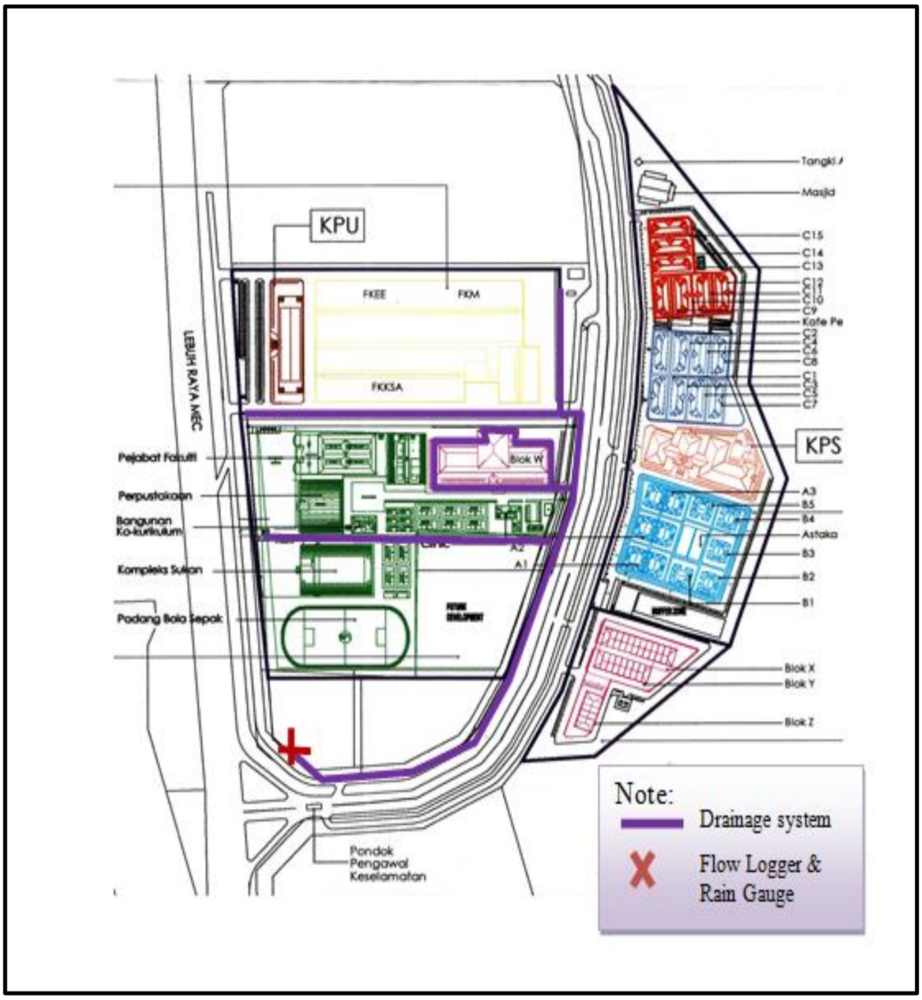


Figure 3.3: Layout of Drainage System.

The drainage system within catchment has generally been straightened and lined. Besides that, this drainage system is a typical traditional type of drainage system and made from concrete and trowel finish. The drainage is about 700 m long before reach the outlet of study area. Figure 3.4 and figure 3.5 show the upstream of the drainage system and downstream of the drainage system.

Figure 3.4: Upstream of Drainage System

Figure 3.5: Downstream of Drainage System

3.4 DATA COLLECTION

In this study, the data that needed are rainfall and flow rate in every 10 minutes. It is important to collect the rainfall and flow rate data to determine the rainfall-runoff relationship. To collect the rainfall and runoff data, there are two equipments were used.

3.4.1 Rainfall Data

The rain gauge is installed at the Kolej Kedaiman II field to obtain the rainfall data in order to determine the rainfall depth. Rainfall data are collected every 10 minutes for three months from October to December 2015.

3.4.2 Water Level Data

Flow meter is used to measure the water level and was installed at the outlet of the sub-catchment. Water level was collected from October to December. From the water level, runoff data can be obtained. The manning equation,

$$Q = \frac{(A\, R^{2/3} S^{1/2})}{n} \tag{3.1}$$

Where:

Q	= Flow Rate of Runoff
n	= Manning Roughness Coefficient
A	= Area of Cross Section
R	= Hydraulic Radius (R=A/P)
S	= Slope
P	= Wetted Parameter

3.5 EQUIPMENT

The instrument used in this monitoring programme consists of rain gauges and flow meter. The flow meter is placed at the outlet of the study area which is at UMP main gate to determine the flow of the runoff. One rain gauge was installed at field Kolej Kediaman II to collect the rainfall data. It was placed at the clear and unobstructed structure location is necessary to obtain accurate rainfall reading.

3.5.1 Rain Gauge

The HOBO Rain Gauge is an instrument that uses a tipping bucket design for rainfall measurement. It has a 15.2 cm diameter orifice and is factory-calibrated to tip at 0.2 mm of rainfall. Rain gauge is used to measure the amount of rainfall over a set of period time. HOBOware Pro software needed to install and download the data of rainfall from HOBO rain gauge then the data can be analysed. Figure 3.6 shows that rain gauge that is used for rainfall data collection.

Figure 3.6: Rain Gauge

Source: http://www.onsetcomp.com/products/data-loggers/rg3-m

3.5.2 Flow Meter

For runoff, the 4250 Area Velocity Flow Meter used. It have a sensor with two different sensor system submerged in the flow stream and contains a pressure transducer to measure level and a pair of ultrasonic transducers to measure velocity. The flow meter then calculates flow based on the cross-sectional area of the flow stream and its velocity. Figure 3.7 shows the flow meter that is used in data collection.

Figure 3.7: Flow Meter

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

Unit Hydrograph Methods (Runoff Transformations) there are numerous methods of modeling runoff transformations for each sub-catchment. The two transformation methods are the Snyder Unit Hydrograph and the Clark Time Area Unit Hydrograph. In this study, HEC-HMS software version 3.5 is used where this software can be updated and downloaded free from the Hydrologic Engineering Centers home page. Figure 3.8 main process flow of stormwater modelling using HEC-HMS.

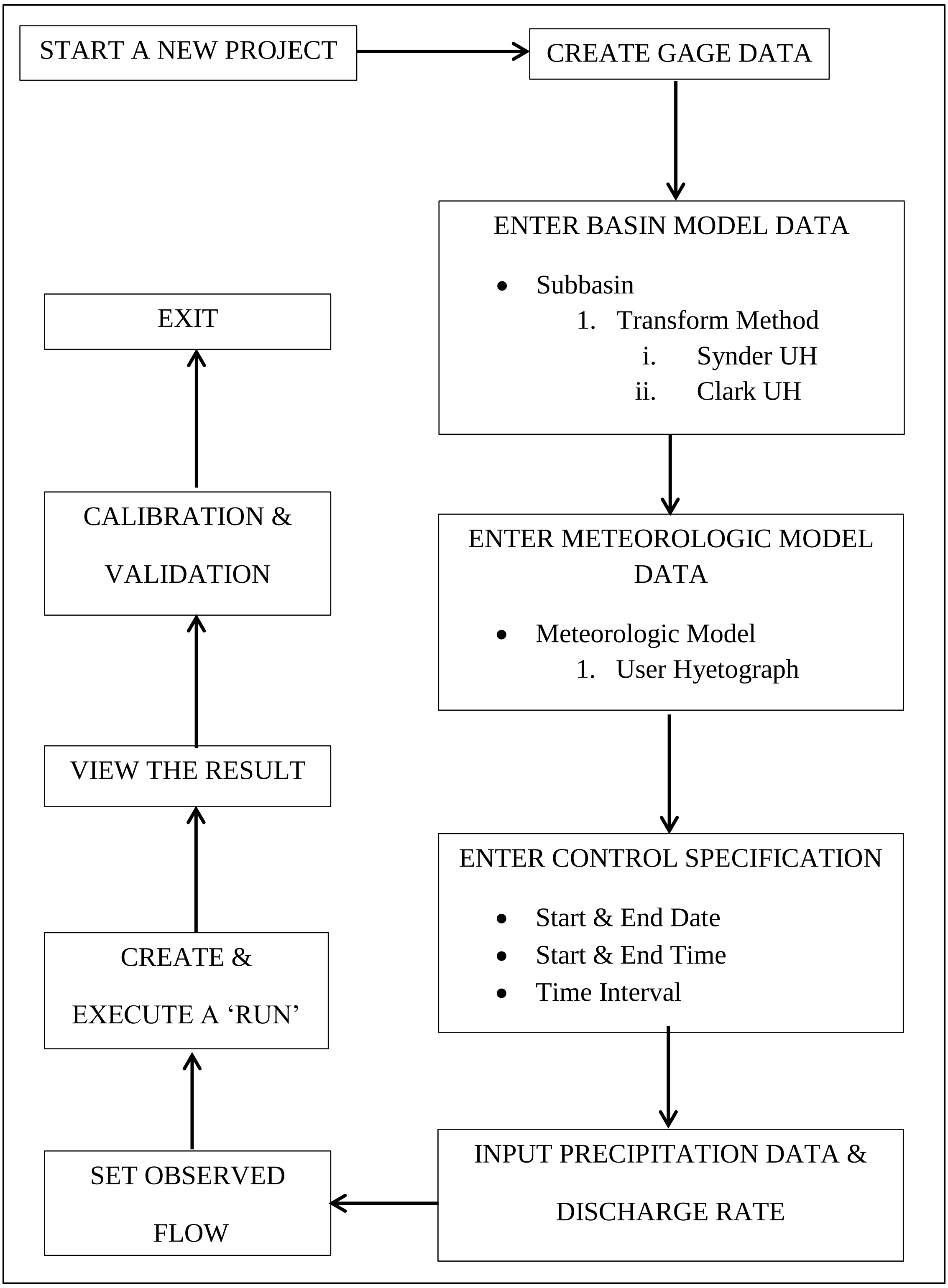


Figure 3.8: Main Process Flow of Stormwater Modelling Using HEC-HMS

Source: https://web.ics.purdue.edu/~vmerwade/education/hechms.pdf

3.6.1 Synder Unit Hydrograph

Snyder selected the lag, peak flow, and total time base as the critical characteristic of a UH. The Snyder method does not define a complete unit hydrograph, so the hydrologic model (HEC-HMS) completes the hydrograph using a trial and error procedure. With the given input parameters, t_p and C_p, the program uses hydrologic model to determine the optimal Clark parameters based on the Snyder coefficients.

Standard UH

$$t_p = 5.5 t_r \quad (3.2)$$

If the duration of the desired UH for the watershed of interest is significantly different from the above equation,

$$t_{pR} = t_p - \frac{t_r - t_R}{4} \quad (3.3)$$

where:

t_r = Duration of desired UH

t_{pr} = Lag of desired UH

For standard case, Synder discovered that UH lag and peak per unit of excess precipitation per unit area of the watershed were related by:

i. Standard UH

$$\frac{U_p}{A} = C \frac{C_p}{t_p} \quad (3.4)$$

ii. For other duration

$$\frac{U_{pR}}{A} = C \frac{C_p}{t_{pR}} \quad (3.5)$$

where:

U_p	=	Peak of standard UH
A	=	Watershed drainage area
C_p	=	UH peaking coefficient
C	=	Conversion constant (2.75 for SI)

Estimation Snyder"s UH parameters:

$$t_p = CC_t(LL_c)^{0.3} \tag{3.6}$$

where:

C_t	=	Basin coefficient
L	=	Length of the main stream from the outlet to a point nearest watershed centroid
C	=	Conversion constant (0.71 for SI and 1.0 for foot-pound system)

C_t typically ranges from 1.8 to 2.0 and C_p ranges from 0.4 to 0.8 where larger values of C_p are associated with smaller values of C_t. (http://www.engr.colostate.edu/~ramirez/ce_old/classes/ce522_ramirez/snyderuh.htm)

3.6.2 Clark Time Area Unit Hydrograph

The Clark Unit Hydrograph is a synthetic unit hydrograph method. That is, the user is not required to develop a unit hydrograph through the analysis of past observed hydrographs. Instead, a time versus area curve built into the program is used to develop the translation hydrograph resulting from a burst of precipitation. The resulting translation hydrograph is routed through a linear reservoir to account for storage attenuation effects across the subbasin.

The Clark Method (1945) noted that the translation of flow throughout the watershed could be described by a time-area curve, which expresses the curve of the fraction of watershed area contributing runoff to the watershed outlet as a function of time since the start of effective precipitation. Effective precipitation is that precipitation that is neither retained on the land surface nor infiltrated into the soil. The time-area curve is bounded in time by the watershed time concentration, t_c.

Thus, t_c is a hydrograph parameter of the Clark unit-hydrograph method. Attenuation of flow can be represented by a simple, linear reservoir for which storage is related to outflow as;

$$S_t = RO_t \quad (3.7)$$

Where:

S	=	Watershed storage
R	=	Watershed storage coefficient
O	=	Outflow from the watershed

Clark's T_c is the travel time required for the last drop of effective precipitation at the hydraulically most distant point in the watershed to reach the channel network. (http://hydro.nevada.edu/courses/gey711/week06.pdf)

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the data collected using flow meter and rain gauge was analyzed in order to study the rainfall-runoff relationship and to find the most appropriate method to be used in Sub-basin of Universiti Malaysia Pahang, Gambang Campus. The data was keyed into the HEC-HMS to achieve the objective. There are nine events of rainfall are selected during 20st November 2015 until 9th December 2015.

Before analyzed the data, several parameter need to determine such as loss rate and transform parameter for both method; i.e. Snyder and Clark Time Area method. For example, for Snyder method, initial loss, constant loss rate, imperviousness, lag time, peak coefficients were used. While for Clark Time Area method, initial loss, constant loss rate, imperviousness, time concentration and storage coefficient were used.

Then, the data was been calibrated and validated using HEC-HMS software were used to analyzed the rainfall-runoff relationship. The method that has the highest efficiency index is the most appropriate method to be used in analyzing the rainfall-runoff data in sub-basin of Universiti Malaysia Pahang, Gambang Campus.

4.2 RAINFALL AND RUNOFF RELATIONSHIP ANALYSIS

The water hitting the ground surface infiltrates into the soil until it reaches a stage where the intensity of rainfall exceeds the infiltration capacity of the soil. Runoff is generated after all the depression storage such as surface puddles and ditches are filled. In this analysis, nine rainfall events are selected to analyze the rainfall-runoff relationship. All the data rainfall and runoff was taken every 10 minutes. Table 4.1 shows the maximum flowrate and rainfall depth for every event that was selected.

Table 4.1: Summary Data for Analysis

Date	Time Duration	Maximum Flowrate (m^3/s)	Rainfall Depth (mm)
20th November 2015	12:20 pm - 2:10 pm	0.234	5.6
22nd November 2015	11:00 am - 12:30 pm	0.120	2.6
24th November 2015	5:00 pm - 6:50 pm	0.293	9.0
25th November 2015	3:00 pm - 4:20 pm	0.033	1.2
26th November 2015	2:20 pm - 4:00 pm	0.147	3.2
27th November 2015	7:30 am - 9:10 am	0.033	0.6
29th November 2015	1:00 am - 4:50 am	0.140	3.2
08th December 2015	11:50 pm - 12:50 pm	0.088	6.2
09th December 2015	4:30 pm - 6:40 pm	0.132	3.2

On 20th November 2015, the rainfall event start from 12:20 pm until 2:10 pm for 1 hour 50 minutes with total precipitation is 16.2 mm. The maximum rainfall depth is 5.6 mm and the maximum flowrate is 0.234 m^3/s. Figure 4.1 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

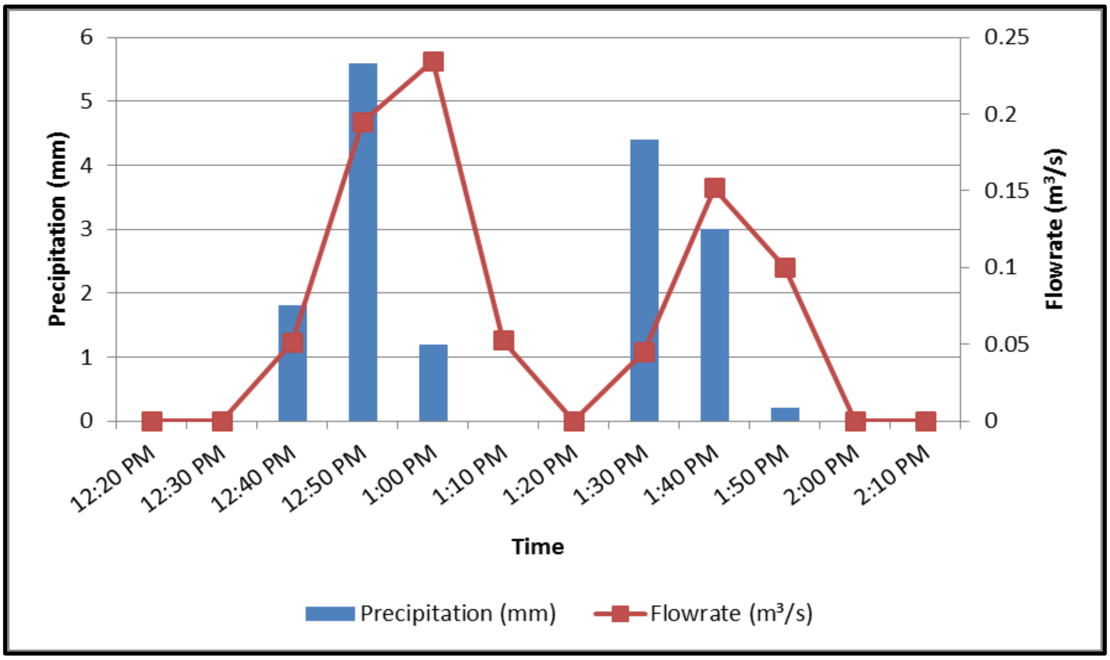


Figure 4.1: Unit Hydrograph for 20th November 2015

On 22nd November 2015, the rainfall event start from 11:00 am until 12:30 pm for 1 hour 30 minutes with total precipitation is 5.6 mm. The maximum rainfall depth is 2.6 mm and the maximum flowrate is 0.120 m^3/s. Figure 4.2 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

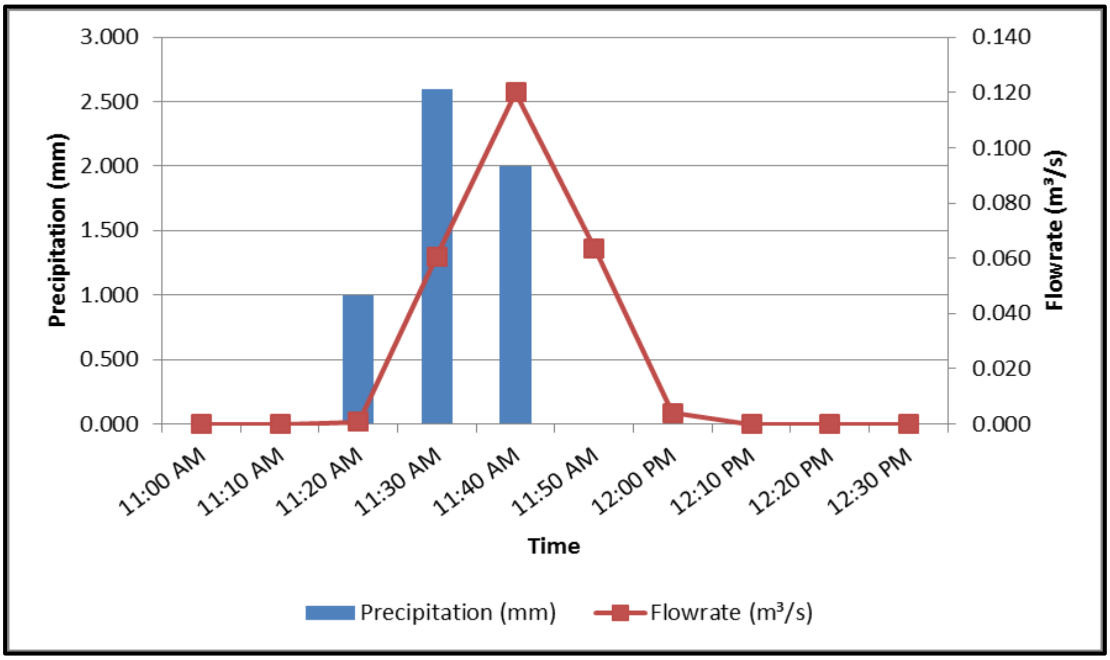


Figure 4.2: Unit Hydrograph for 22th November 2015

On 24th November 2015, the rainfall event start from 5:00 pm until 6:50 pm for 1 hour 50 minutes with total precipitation is 21.2 mm. The maximum rainfall depth is 9 mm and the maximum flowrate is 0.293 m^3/s. Figure 4.3 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

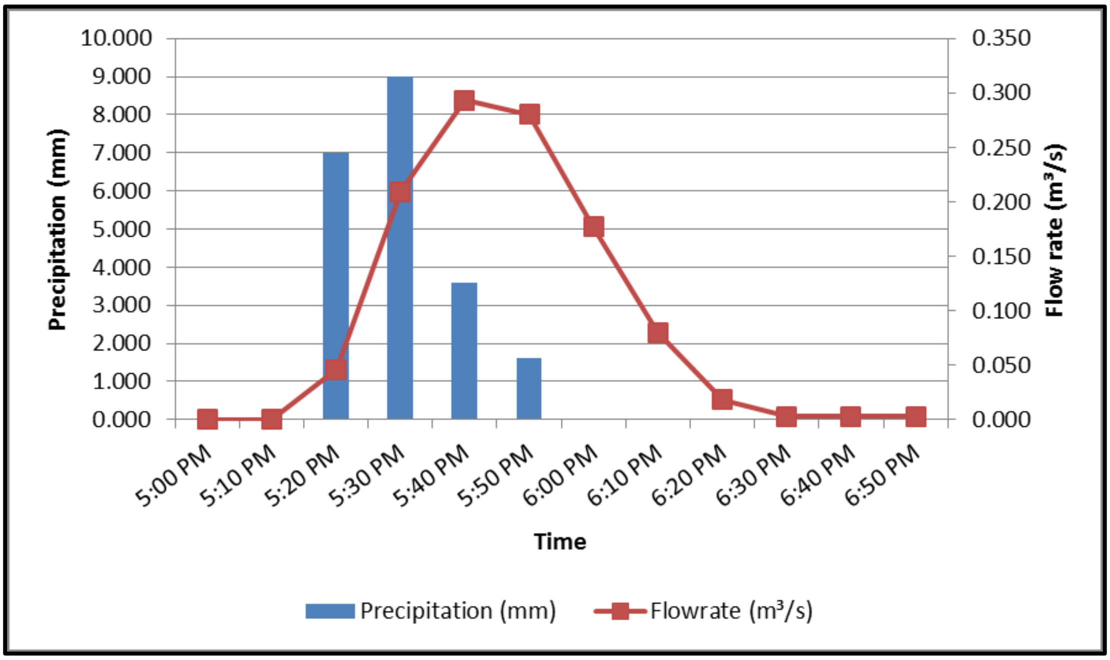


Figure 4.3: Unit Hydrograph for 24th November 2015

On 25th November 2015, the rainfall event start from 3:00 pm until 4:20 pm for 1 hour 20 minutes with total precipitation is 1.6 mm. The maximum rainfall depth is 1.2 mm and the maximum flowrate is 0.033 m^3/s. Figure 4.4 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

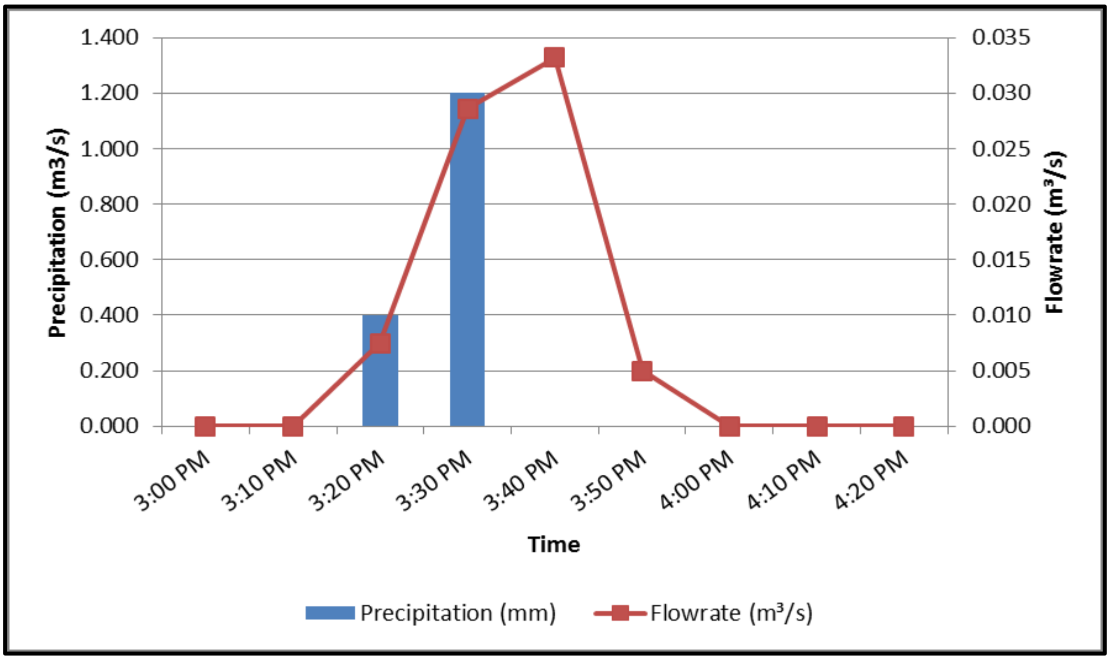


Figure 4.4: Unit Hydrograph for 25th November 2015

On 26th November 2015, the rainfall event start from 2:20 pm until 4:00 pm for 1 hour 40 minutes with total precipitation is 8.2 mm. The maximum rainfall depth is 3.2 mm and the maximum flowrate is 0.147 m^3/s. Figure 4.5 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

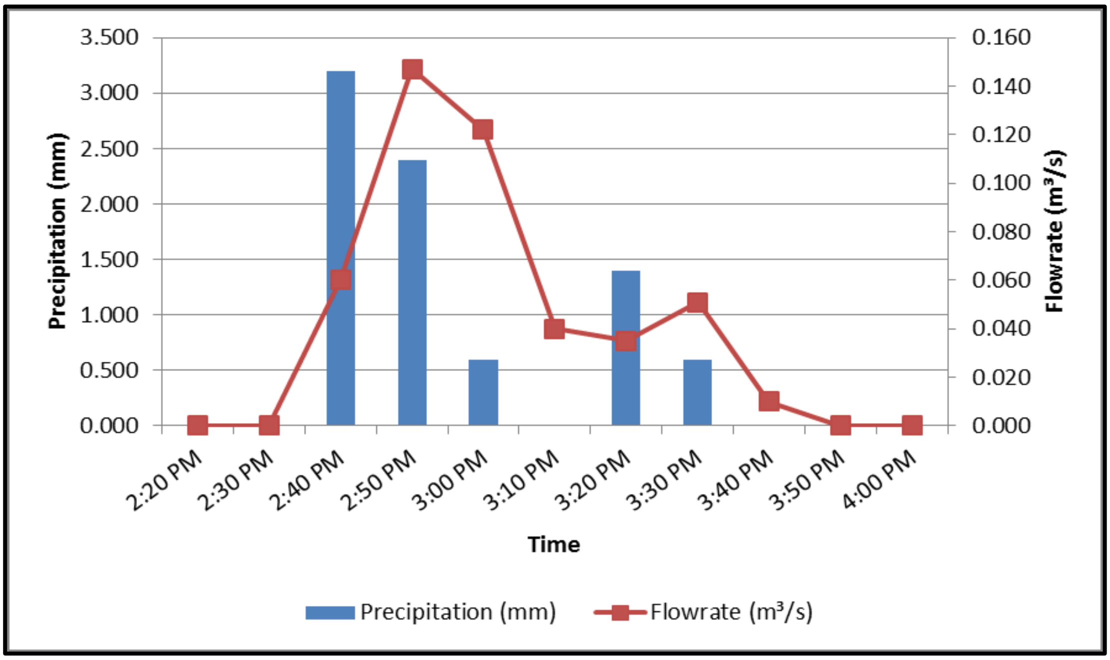


Figure 4.5: Unit Hydrograph for 26th November 2015

On 27th November 2015, the rainfall event start from 7:30 am until 9:10 pm for 1 hour 40 minutes with total precipitation is 3.6 mm. The maximum rainfall depth is 0.6 mm and the maximum flowrate is 0.033 m^3/s. Figure 4.6 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

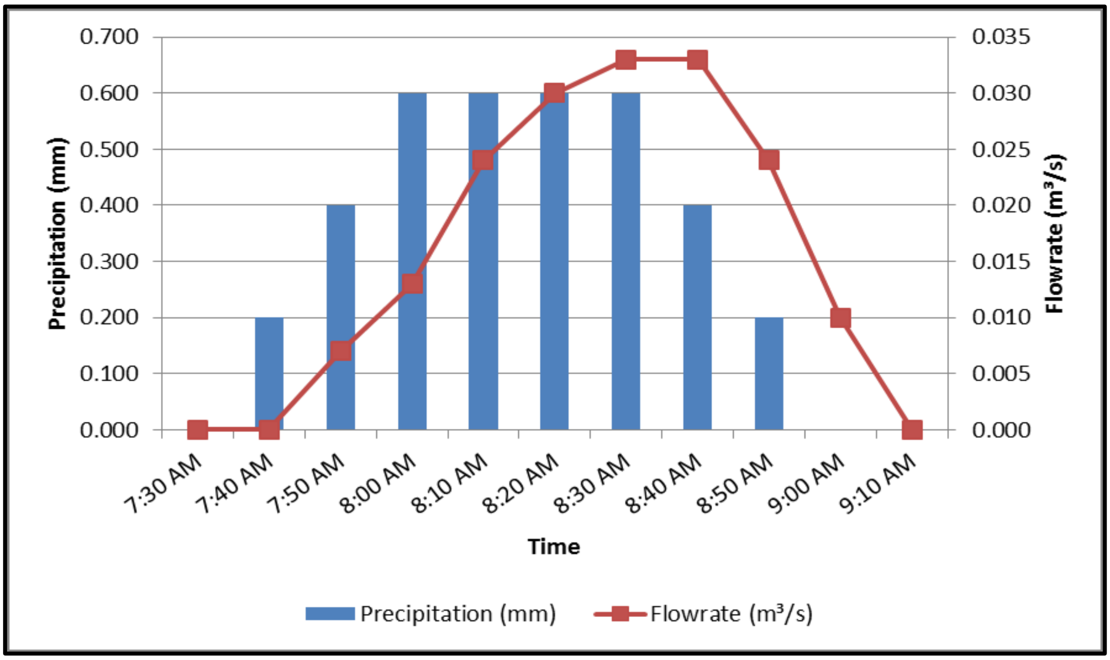


Figure 4.6: Unit Hydrograph for 27th November 2015

On 29th November 2015, the rainfall event start from 1:00 am until 4:50 am for 3 hour 50 minutes with total precipitation is 14.4 mm. The maximum rainfall depth is 3.2 mm and the maximum flowrate is 0.140 m^3/s. Figure 4.7 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

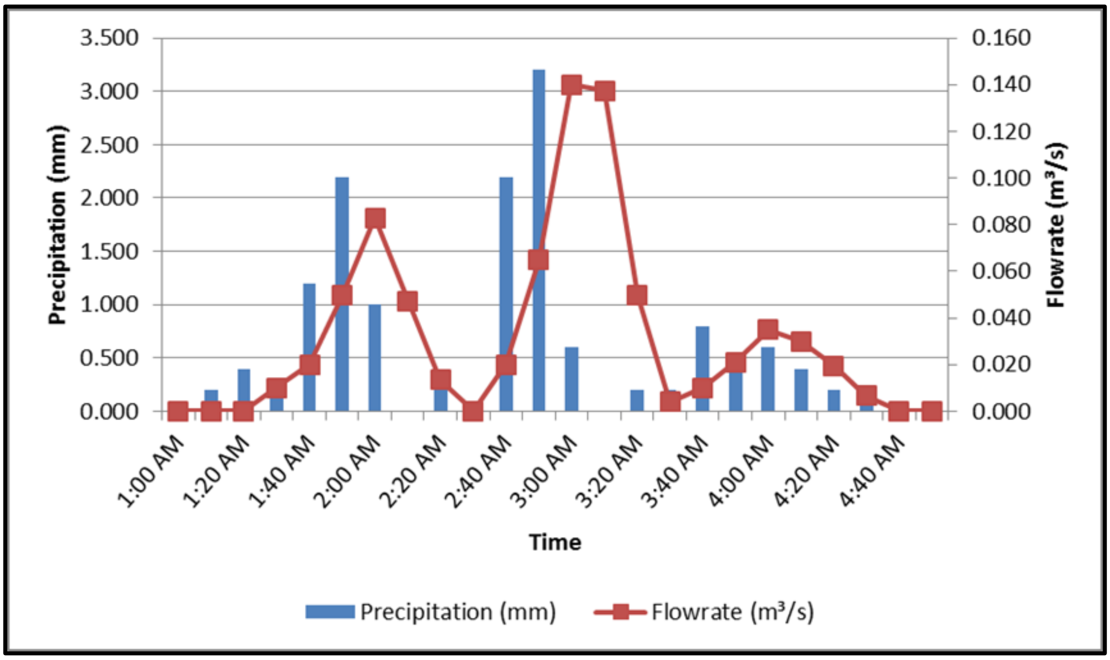


Figure 4.7: Unit Hydrograph for 29th November 2015

On 8th December 2015, the rainfall event start from 11:50 pm until 12:50 am for 1 hour with total precipitation is 9.6 mm. The maximum rainfall depth is 6.2 mm and the maximum flowrate is 0.088 m^3/s. Figure 4.8 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

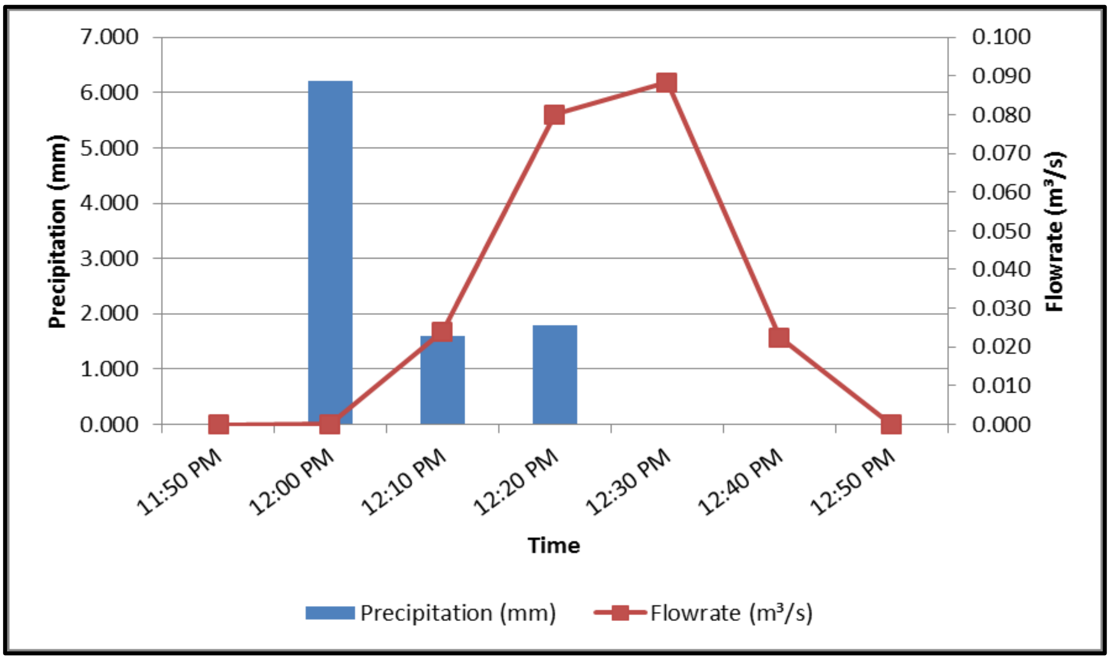


Figure 4.8: Unit Hydrograph for 8th December 2015

On 9th December 2015, the rainfall event start from 4:30 pm until 6:40 pm for 2 hour with total precipitation is 12.8 mm. The maximum rainfall depth is 3.2 mm and the maximum flowrate is 0.132 m^3/s. Figure 4.9 shows that when the rainfall increased the flowrate also increased and when the rainfall decreased the flowrate also decreased.

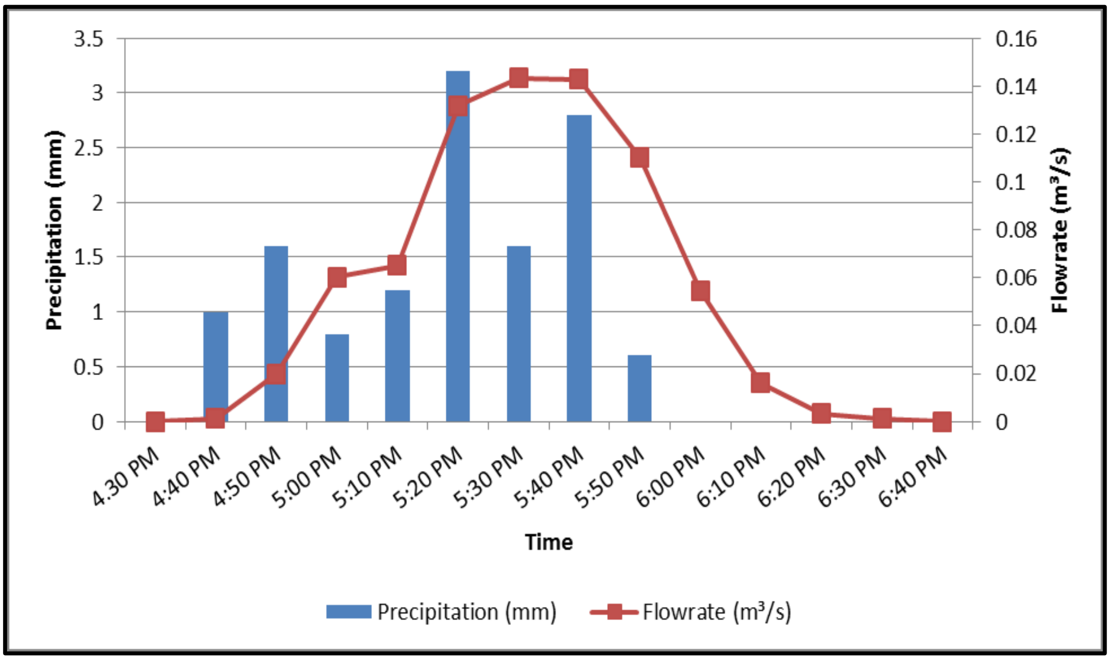


Figure 4.9: Unit Hydrograph for 9th December 2015

4.3 ANALYSIS AND SIMULATION

This process will be carried out according to the parameter and data that was computed in the HEC-HMS software. Different parameters were used according to the method selected. For example, for Snyder method, initial loss, constant loss rate, imperviousness, lag time, peak coefficients were used. While for Clark Time Area method, initial loss, constant loss rate, imperviousness, time concentration and storage coefficient were used. The result in graphic or summary can be obtained after analyzed and simulated the data. It can be viewed by right click at the sub-basin and click at view result followed by graph, summary table or time series table.

The next procedure is calibration process. The model was calibrated for the identified parameters to achieve good agreement between the simulated and observed data by adjusting model parameter values. The process can be completely manually using engineering judgment by repeatedly adjusting parameters, computing, and inspecting the goodness of fit between the computed and observed hydrograph.

The sum of square method was used as the search method for optimization. The auto-calibration process in the HEC-HMS may not converge to desired optimum results, so the model was calibrated with both manual and auto calibration. Generally, manual calibration provides the range of the parameters while the auto-calibration process optimized the result. After the model is calibrated, the model must be validated for another dataset so as to estimate the accuracy of the model.

4.3.1 Model Parameter

HEC HMS model requires parameter to analyzed the data. Among them is the precipitation loss method for overland flow, which is loss rate parameter. After the precipitation losses are accounted, a transform method must be specified for transforming overland flow into surface runoff.

i) Loss Rate

Initial loss is the value to account for interception and depression storage. No runoff occurs from previous areas until this quantity of precipitation has fallen. Constant loss rate is after the cumulative precipitation exceeds the initial loss, precipitation is lost at this constant loss rate to account for infiltration. Percentage of imperviousness represents the fraction of the area that is impervious, such as buildings, roads, pavements. Table 4.2 show the loss rate parameter for snyder and clark time area method.

Table 4.2: Loss Rate Parameter for Snyder and Clark Time Area Method

Initial Loss(mm)	25.4
Constant Loss Rate (mm/hr)	3.81
Imperviousness (%)	50

ii) Transform

i. Standard lag is time from centroid of rainfall excess to the peak flow at the point of analysis. Table 4.3 show the transform parameter for Snyder method.

ii. The peak coefficient is represent the peak flow for the unit hydrograph at the point of analysis

iii. Time concentration defined as the time required for a drop of water to travel from the most hydrologically remote point in the sub-catchment to the point of collection. Table 4.4 show the transform parameter for Clark Time Area method.

iv. The basin storage coefficient as an index of the temporary storage of the precipitation excess in the watershed as it drains to the outlet point.

Table 4.3 Transform parameter for Snyder Method

Standard lag, t_p(hr)	0.20
Peak coefficient, C_p	0.75

Table 4.4 Transform parameter for Clark Time Area Method

Time of Concentration (hr)	0.25
Storage of coefficient (hr)	0.10

4.3.2 Calibration

4.3.2.1 Snyder

Rainfall event on 20th November 2015, 22nd November 2015 and 24th November 2015 was selected for the calibration process. Following is the results of hydrograph and its summary that obtained from HEC-HMS program.

From the computed results on 20th November 2015 from HEC-HMS shown in Figure 4.10, the peak discharge is 0.20 m^3/s and 0.23 m^3/s from the observed hydrograph at gauge shown in Figure 4.11. The peak discharges occur at 1:00 pm. The rainfall event starts from 12:30 pm until 2:10 pm with the 16.2 mm for the total precipitation.

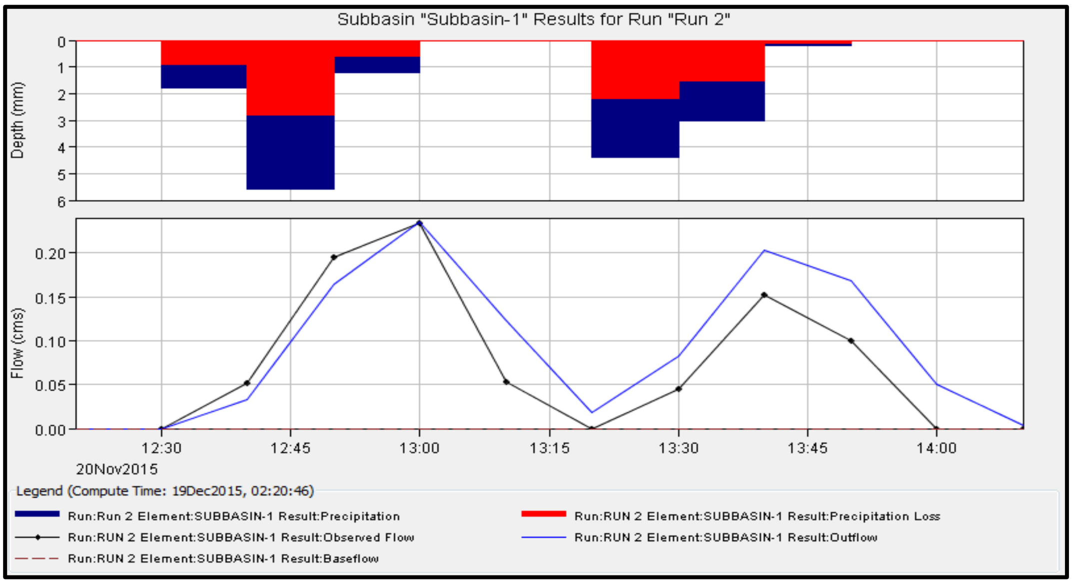
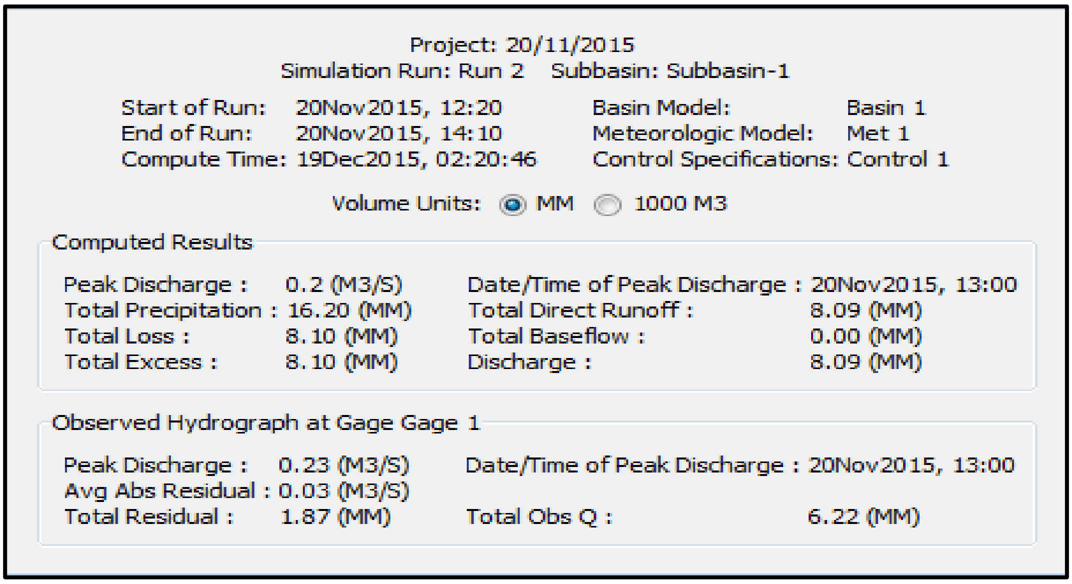


Figure 4.10: Calibration Hydrograph on 20th November 2015 for Snyder Method


Project: 20/11/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run: 20Nov2015, 12:20 Basin Model: Basin 1
End of Run: 20Nov2015, 14:10 Meteorologic Model: Met 1
Compute Time: 19Dec2015, 02:20:46 Control Specifications: Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge : 0.2 (M3/S) Date/Time of Peak Discharge : 20Nov2015, 13:00
Total Precipitation : 16.20 (MM) Total Direct Runoff : 8.09 (MM)
Total Loss : 8.10 (MM) Total Baseflow : 0.00 (MM)
Total Excess : 8.10 (MM) Discharge : 8.09 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge : 0.23 (M3/S) Date/Time of Peak Discharge : 20Nov2015, 13:00
Avg Abs Residual : 0.03 (M3/S)
Total Residual : 1.87 (MM) Total Obs Q : 6.22 (MM)

Figure 4.11: Calibration Results Summary Table of 20th November 2015 by using Snyder Method

From the computed results on 22nd November 2015 from HEC-HMS shown in Figure 4.12, the peak discharge is 0.10 m³/s and 0.12 m³/s from the observed hydrograph at gauge shown in Figure 4.13. The peak discharges occur at 11:40 am. The rainfall event starts from 11:00 am until 12:30 pm with the 5.6 mm for the total precipitation.

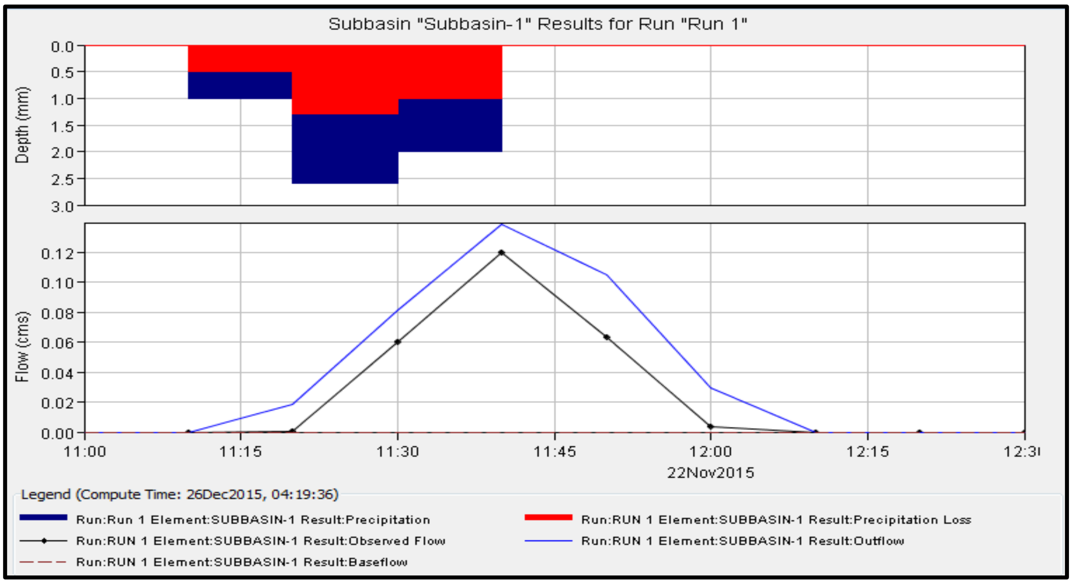


Figure 4.12: Calibration Hydrograph on 22nd November 2015 for Snyder Method

Project: 22/11/2015
Simulation Run: Run 1 Subbasin: Subbasin-1

Start of Run:	22Nov2015, 11:00	Basin Model:	Basin 1
End of Run:	22Nov2015, 12:30	Meteorologic Model:	Met 1
Compute Time:	26Dec2015, 04:19:36	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.1 (M3/S)	Date/Time of Peak Discharge :	22Nov2015, 11:40
Total Precipitation :	5.60 (MM)	Total Direct Runoff :	2.80 (MM)
Total Loss :	2.80 (MM)	Total Baseflow :	0.00 (MM)
Total Excess :	2.80 (MM)	Discharge :	2.80 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.12 (M3/S)	Date/Time of Peak Discharge :	22Nov2015, 11:40
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.94 (MM)	Total Obs Q :	1.86 (MM)

Figure 4.13: Calibration Results Summary Table of 22nd November 2015 by using Snyder Method

From the computed results on 24th November 2015 from HEC-HMS shown in Figure 4.14, the peak discharge is 0.50 m³/s and 0.29 m³/s from the observed hydrograph at gauge shown in Figure 4.15. The peak discharges occur at 5:40 pm. The rainfall event starts from 5:10 am until 6:45 pm with the 21.2 mm for the total precipitation

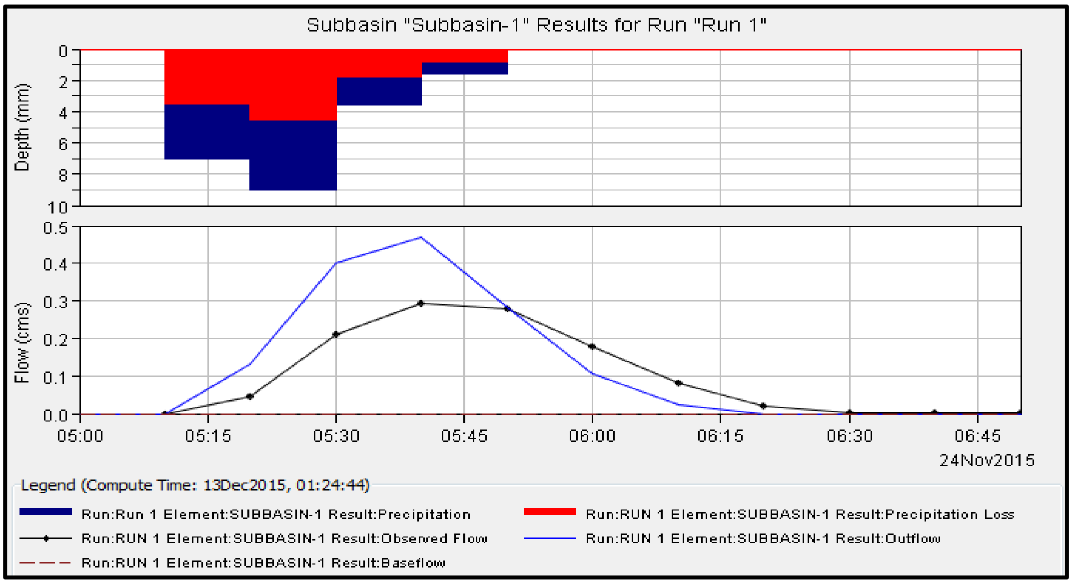
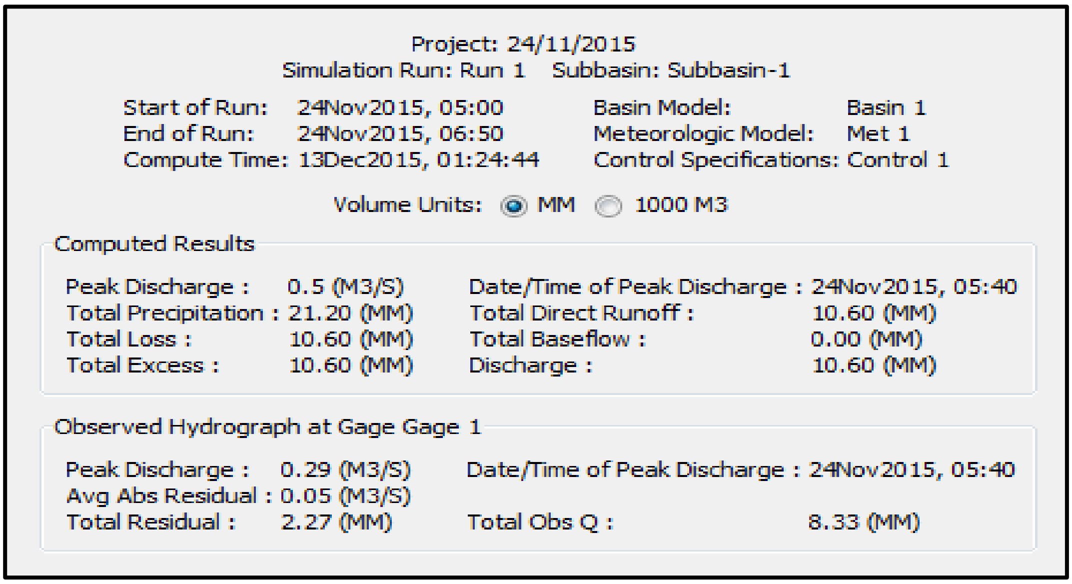


Figure 4.14: Calibration Hydrograph on 24th November 2015 for Snyder Method


Project: 24/11/2015
Simulation Run: Run 1 Subbasin: Subbasin-1

Start of Run:	24Nov2015, 05:00	Basin Model:	Basin 1
End of Run:	24Nov2015, 06:50	Meteorologic Model:	Met 1
Compute Time:	13Dec2015, 01:24:44	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.5 (M3/S)	Date/Time of Peak Discharge :	24Nov2015, 05:40
Total Precipitation :	21.20 (MM)	Total Direct Runoff :	10.60 (MM)
Total Loss :	10.60 (MM)	Total Baseflow :	0.00 (MM)
Total Excess :	10.60 (MM)	Discharge :	10.60 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.29 (M3/S)	Date/Time of Peak Discharge :	24Nov2015, 05:40
Avg Abs Residual :	0.05 (M3/S)		
Total Residual :	2.27 (MM)	Total Obs Q :	8.33 (MM)

Figure 4.15: Calibration Results Summary Table of 24th November 2015 by using Snyder Method

4.3.2.2 Clark Time Area

Rainfall event on 20th November 2015, 22nd November 2015 and 24th November 2015 was selected for the calibration process. Following is the results of hydrograph and its summary that obtained from HEC-HMS program.

From the computed results on 20th November 2015 from HEC-HMS shown in Figure 4.16, the peak discharge is 0.20 m^3/s and 0.23 m^3/s from the observed hydrograph at gauge shown in Figure 4.18. The peak discharges occur at 1:00 pm. The rainfall event starts from 12:30 pm until 2:10 pm with the 16.2 mm for the total precipitation.

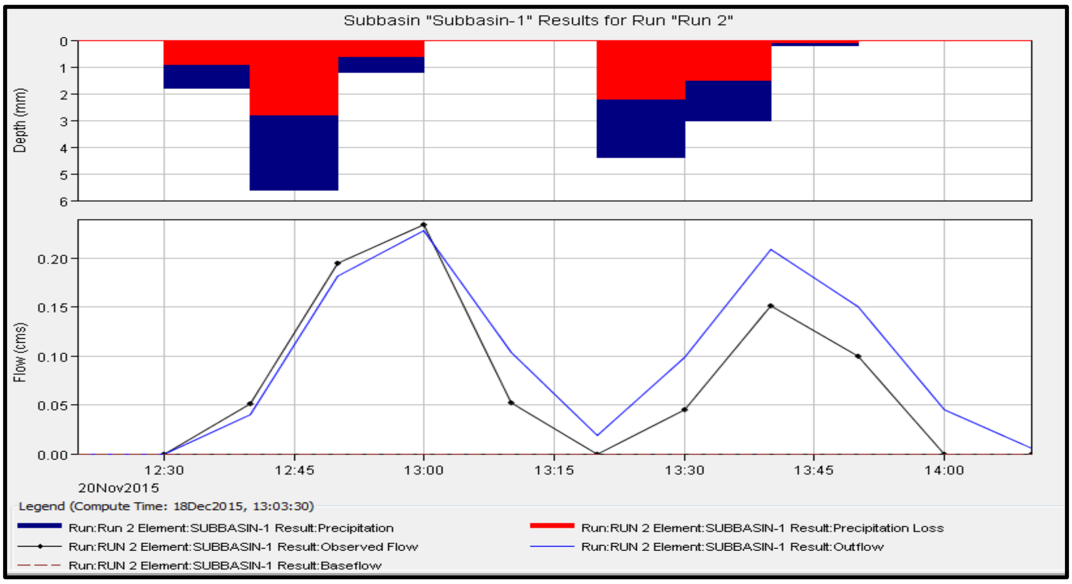
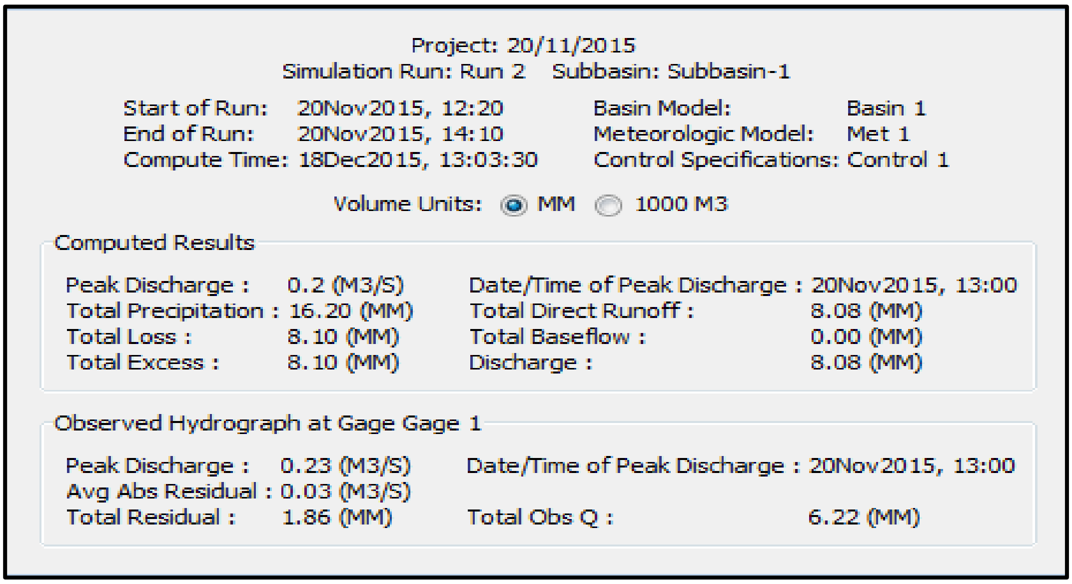


Figure 4.16: Calibration Hydrograph on 20th November 2015 for Clark Time Area Method



Project: 20/11/2015
Simulation Run: Run 2   Subbasin: Subbasin-1

Start of Run: 20Nov2015, 12:20   Basin Model: Basin 1
End of Run: 20Nov2015, 14:10   Meteorologic Model: Met 1
Compute Time: 18Dec2015, 13:03:30   Control Specifications: Control 1

Volume Units: MM   1000 M3

Computed Results

Peak Discharge :	0.2 (M3/S)	Date/Time of Peak Discharge :	20Nov2015, 13:00
Total Precipitation :	16.20 (MM)	Total Direct Runoff :	8.08 (MM)
Total Loss :	8.10 (MM)	Total Baseflow :	0.00 (MM)
Total Excess :	8.10 (MM)	Discharge :	8.08 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.23 (M3/S)	Date/Time of Peak Discharge :	20Nov2015, 13:00
Avg Abs Residual :	0.03 (M3/S)		
Total Residual :	1.86 (MM)	Total Obs Q :	6.22 (MM)

Figure 4.17: Calibration Results Summary Table of 20th November 2015 by using Clark Time Area Method

From the computed results on 22nd November 2015 from HEC-HMS shown in Figure 4.18, the peak discharge is 0.10 m³/s and 0.12 m³/s from the observed hydrograph at gauge shown in Figure 4.19. The peak discharges occur at 11:40 am. The rainfall event starts from 11:00 am until 12:30 pm with the 5.6 mm for the total precipitation.

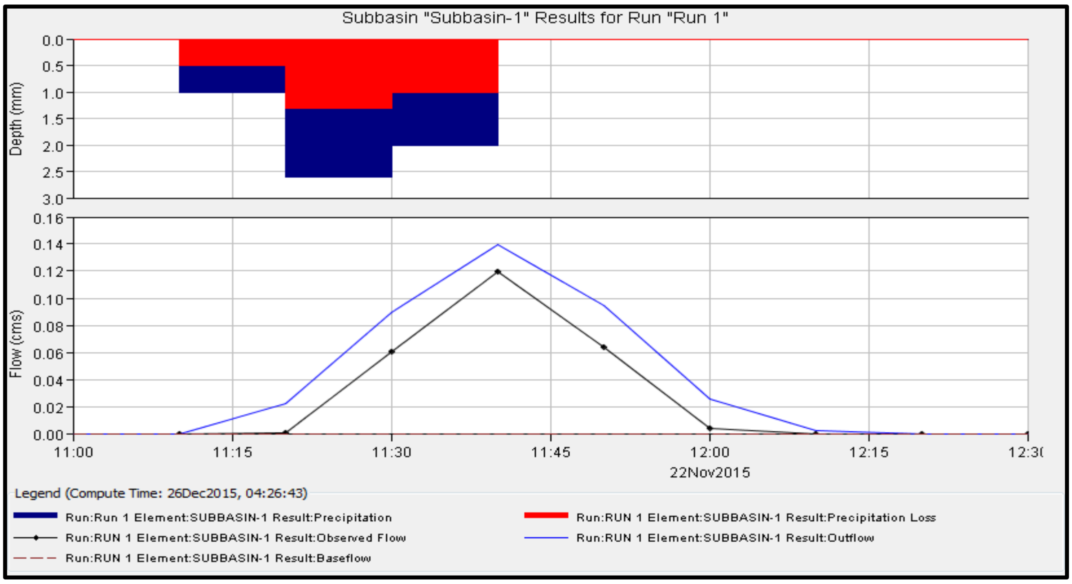
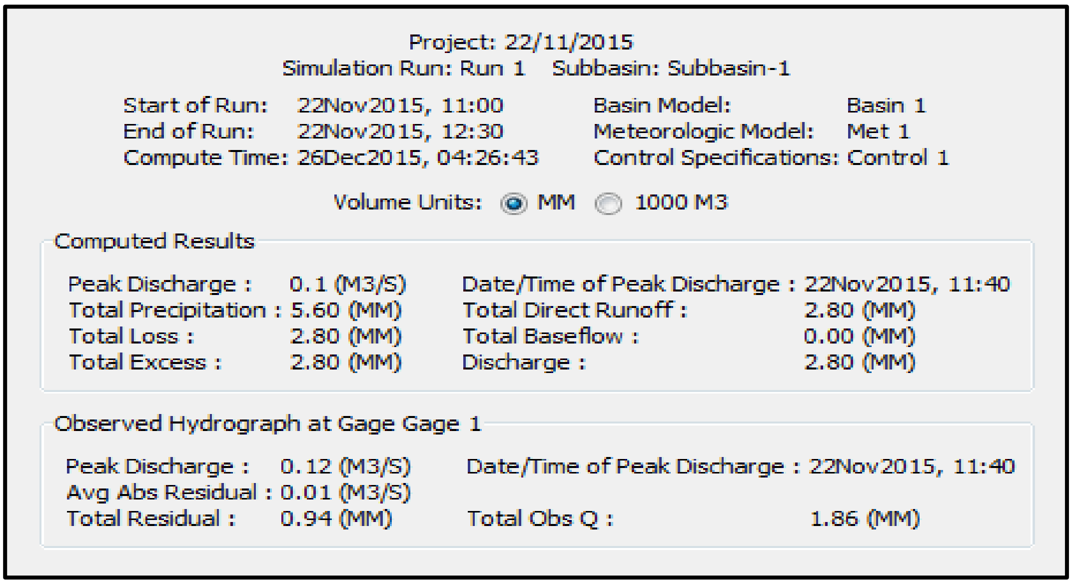


Figure 4.18: Calibration Hydrograph on 22nd November 2015 for Clark Time Area Method


Project: 22/11/2015
Simulation Run: Run 1 Subbasin: Subbasin-1

Start of Run: 22Nov2015, 11:00 Basin Model: Basin 1
End of Run: 22Nov2015, 12:30 Meteorologic Model: Met 1
Compute Time: 26Dec2015, 04:26:43 Control Specifications: Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.1 (M3/S)	Date/Time of Peak Discharge :	22Nov2015, 11:40
Total Precipitation :	5.60 (MM)	Total Direct Runoff :	2.80 (MM)
Total Loss :	2.80 (MM)	Total Baseflow :	0.00 (MM)
Total Excess :	2.80 (MM)	Discharge :	2.80 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.12 (M3/S)	Date/Time of Peak Discharge :	22Nov2015, 11:40
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.94 (MM)	Total Obs Q :	1.86 (MM)

Figure 4.19: Calibration Results Summary Table of 22nd November 2015 by using Clark Time Area Method

From the computed results on 24th November 2015 from HEC-HMS shown in Figure 4.20, the peak discharge is 0.40 m³/s and 0.29 m³/s from the observed hydrograph at gauge shown in Figure 4.21. The peak discharges occur at 5:40 pm. The rainfall event starts from 5:10 am until 6:45 pm with the 21.2 mm for the total precipitation**.**

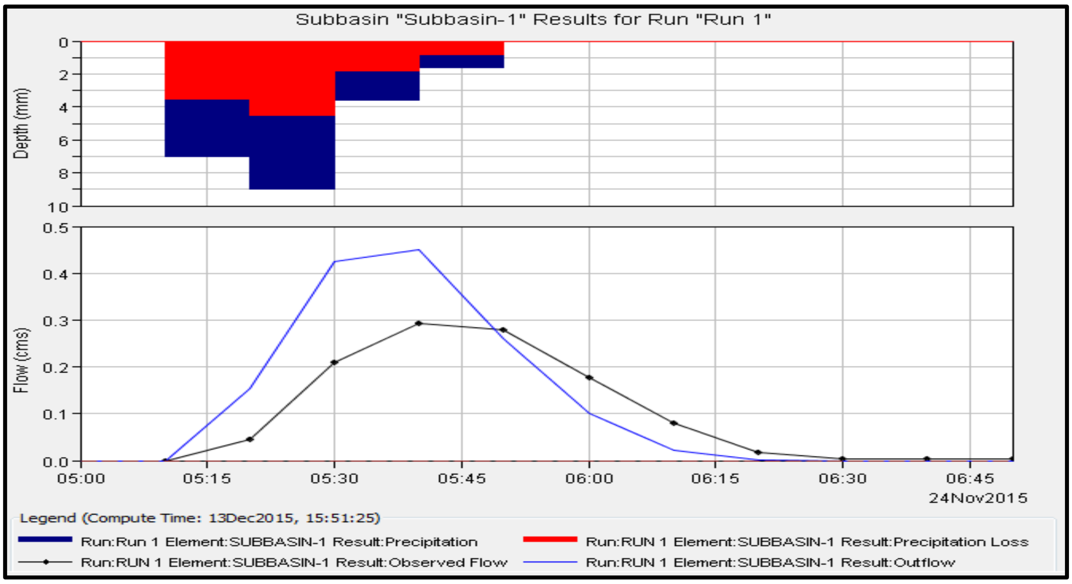


Figure 4.20: Calibration Hydrograph on 24th November 2015 for Clark Time Area Method

Project: 24/11/2015
Simulation Run: Run 1 Subbasin: Subbasin-1

Start of Run:	24Nov2015, 05:00	Basin Model:	Basin 1
End of Run:	24Nov2015, 06:50	Meteorologic Model:	Met 1
Compute Time:	13Dec2015, 15:51:25	Control Specifications:	Control 1

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge :	0.4 (M3/S)	Date/Time of Peak Discharge :	24Nov2015, 05:40
Total Precipitation :	21.20 (MM)	Total Direct Runoff :	10.60 (MM)
Total Loss :	10.60 (MM)	Total Baseflow :	0.00 (MM)
Total Excess :	10.60 (MM)	Discharge :	10.60 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.29 (M3/S)	Date/Time of Peak Discharge :	24Nov2015, 05:40
Avg Abs Residual :	0.06 (M3/S)		
Total Residual :	2.27 (MM)	Total Obs Q :	8.33 (MM)

Figure 4.21: Calibration Results Summary Table of 24th November 2015 by using Clark Time Area Method

4.3.3 Validation

4.3.2.1 Snyder

Rainfall event on 25th November 2015, 26th November 2015, 27th November 2015, 29^{td} November 2015, 8nd December 2015 and 9th December 2015 was selected for the validation process. Following is the results of hydrograph and its summary that obtained from HEC-HMS program.

From the computed results on 25th November 2015 from HEC-HMS shown in Figure 4.22, the peak discharge is 0.046 m^3/s and 0.03 m^3/s from the observed hydrograph at gauge shown in Figure 4.23. The peak discharges occur at 3:40 pm. The rainfall event starts from 3:00 pm until 4:20 pm with the 1.6 mm for the total precipitation.

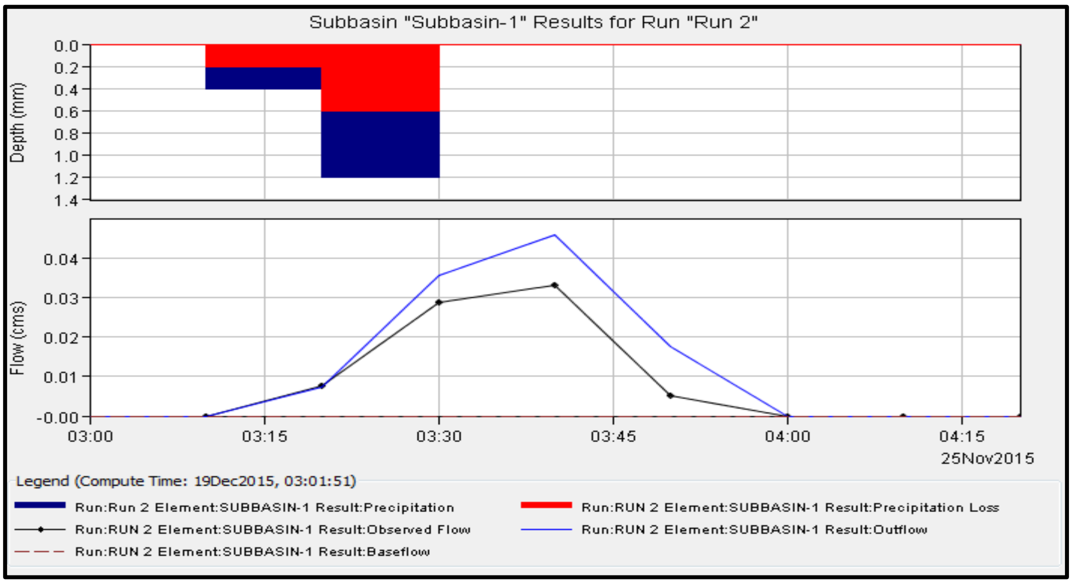
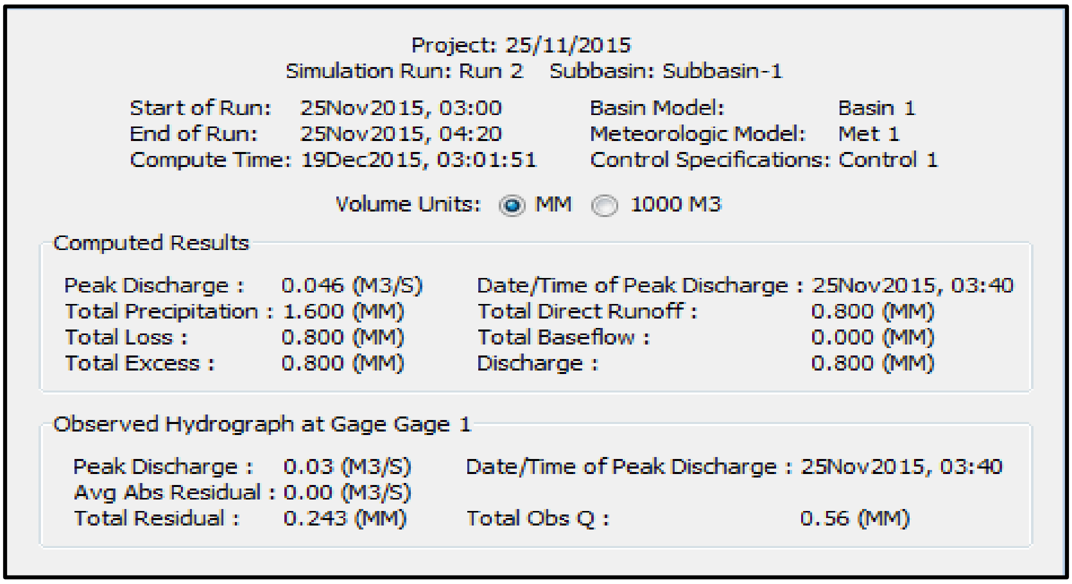


Figure 4.22: Validation Hydrograph on 25th November 2015 for Snyder Method


Project: 25/11/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run: 25Nov2015, 03:00 Basin Model: Basin 1
End of Run: 25Nov2015, 04:20 Meteorologic Model: Met 1
Compute Time: 19Dec2015, 03:01:51 Control Specifications: Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge : 0.046 (M3/S) Date/Time of Peak Discharge : 25Nov2015, 03:40
Total Precipitation : 1.600 (MM) Total Direct Runoff : 0.800 (MM)
Total Loss : 0.800 (MM) Total Baseflow : 0.000 (MM)
Total Excess : 0.800 (MM) Discharge : 0.800 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge : 0.03 (M3/S) Date/Time of Peak Discharge : 25Nov2015, 03:40
Avg Abs Residual : 0.00 (M3/S)
Total Residual : 0.243 (MM) Total Obs Q : 0.56 (MM)

Figure 4.23: Validation Results Summary Table of 25th November 2015 by using Snyder Method

From the computed results on 26th November 2015 from HEC-HMS shown in Figure 4.24, the peak discharge is 0.151 m³/s and 0.15 m³/s from the observed hydrograph at gauge shown in Figure 4.25. The peak discharges occur at 2:50 pm. The rainfall event starts from 2:20 pm until 4:00 pm with the 8.2 mm for the total precipitation.

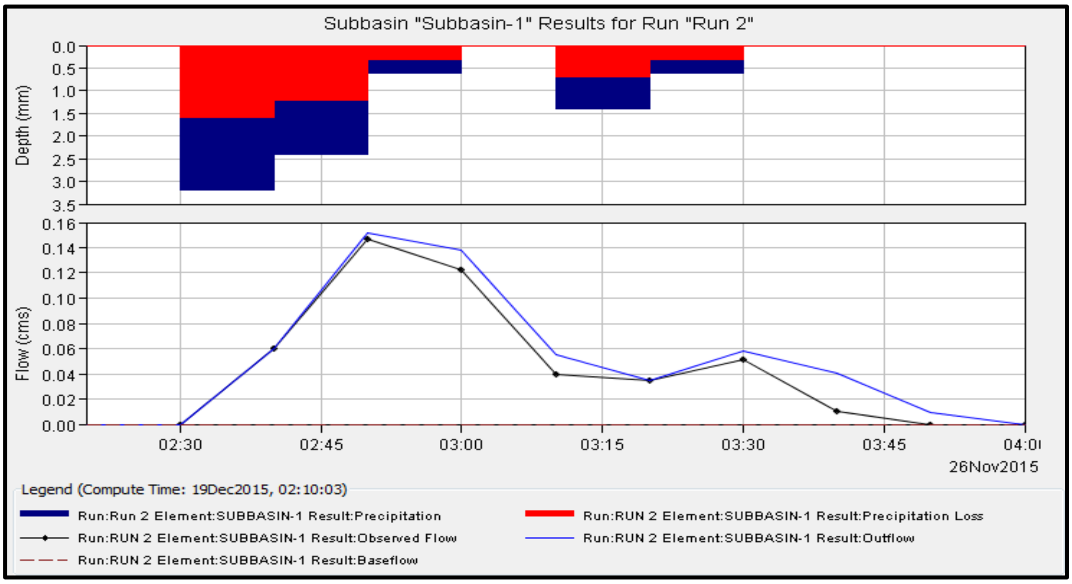


Figure 4.24: Validation Hydrograph on 26th November 2015 for Snyder Method

Project: 26/11/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run:	26Nov2015, 02:20	Basin Model:	Basin 1
End of Run:	26Nov2015, 04:00	Meteorologic Model:	Met 1
Compute Time:	19Dec2015, 02:10:03	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.151 (M3/S)	Date/Time of Peak Discharge :	26Nov2015, 02:50
Total Precipitation :	8.200 (MM)	Total Direct Runoff :	4.100 (MM)
Total Loss :	4.100 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	4.100 (MM)	Discharge :	4.100 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.15 (M3/S)	Date/Time of Peak Discharge :	26Nov2015, 02:50
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.613 (MM)	Total Obs Q :	3.49 (MM)

Figure 4.25: Validation Results Summary Table of 26th November 2015 by using Snyder Method

From the computed results on 27th November 2015 from HEC-HMS shown in Figure 4.26, the peak discharge is 0.04 m³/s and 0.03 m³/s from the observed hydrograph at gauge shown in Figure 4.27. The peak discharges occur at 8:20 pm. The rainfall event starts from 7:30 am until 9:10 am with the 3.6 mm for the total precipitation.

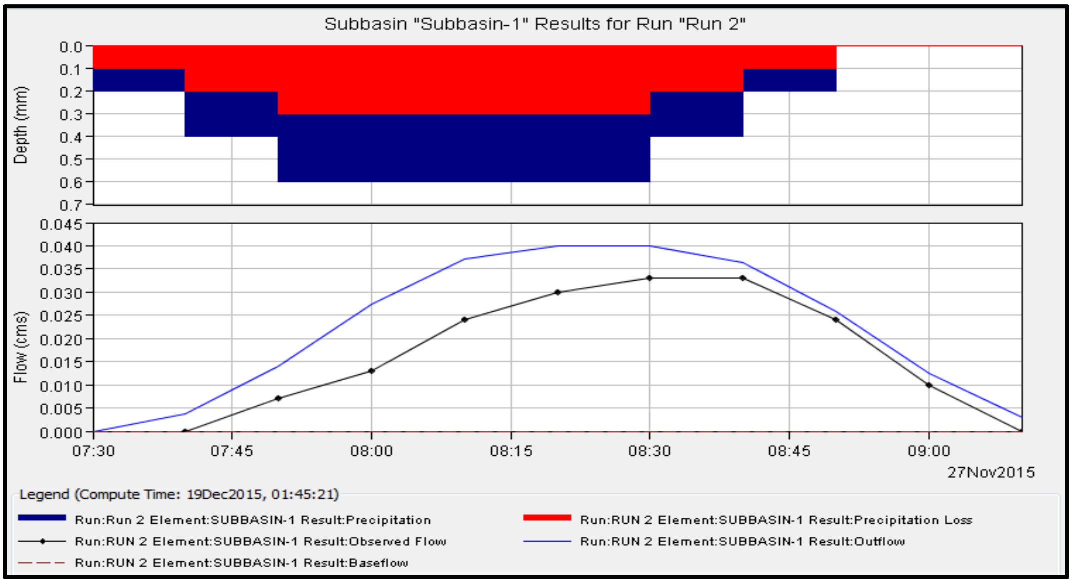
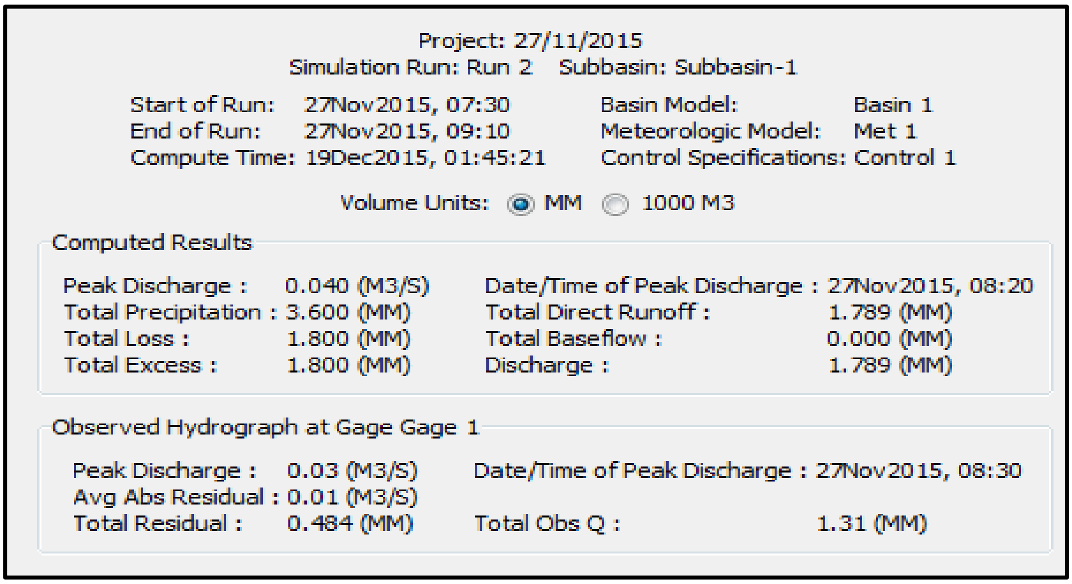


Figure 4.26: Validation Hydrograph on 27th November 2015 for Snyder Method


Project: 27/11/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run: 27Nov2015, 07:30 Basin Model: Basin 1
End of Run: 27Nov2015, 09:10 Meteorologic Model: Met 1
Compute Time: 19Dec2015, 01:45:21 Control Specifications: Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.040 (M3/S)	Date/Time of Peak Discharge :	27Nov2015, 08:20
Total Precipitation :	3.600 (MM)	Total Direct Runoff :	1.789 (MM)
Total Loss :	1.800 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	1.800 (MM)	Discharge :	1.789 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.03 (M3/S)	Date/Time of Peak Discharge :	27Nov2015, 08:30
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.484 (MM)	Total Obs Q :	1.31 (MM)

Figure 4.27: Validation Results Summary Table of 27th November 2015 by using Snyder Method

From the computed results on 29th November 2015 from HEC-HMS shown in Figure 4.28, the peak discharge is 0.15 m³/s and 0.14 m³/s from the observed hydrograph at gauge shown in Figure 4.29. The peak discharges occur at 8:20 pm. The rainfall event starts from 1:00 am until 4:50 am with the 14.4 mm for the total precipitation.

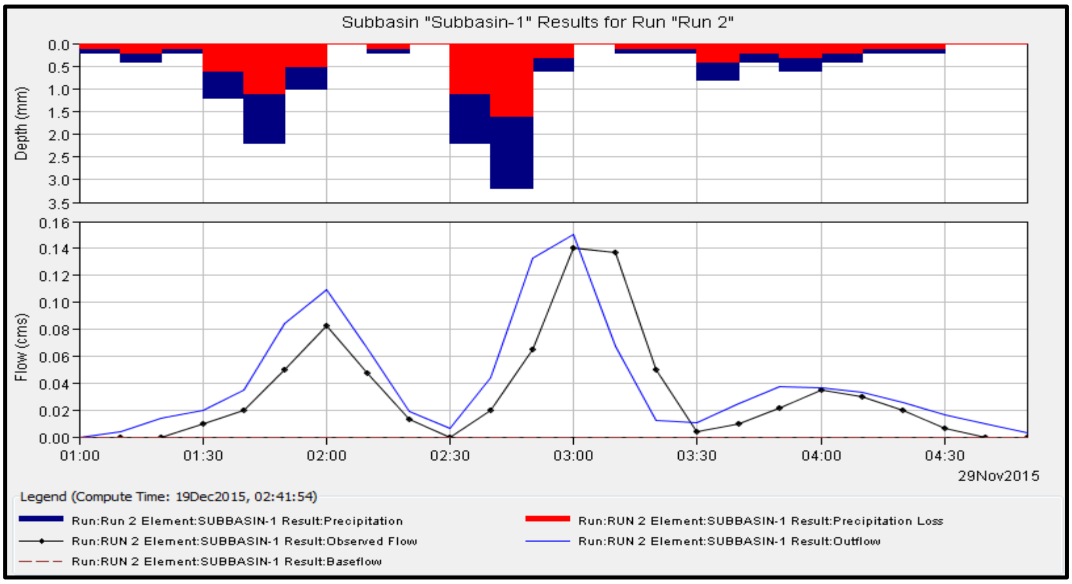


Figure 4.28: Validation Hydrograph on 29th November 2015 for Snyder Method

Project: 29/11/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run:	29Nov2015, 01:00	Basin Model:	Basin 1
End of Run:	29Nov2015, 04:50	Meteorologic Model:	Met 1
Compute Time:	19Dec2015, 02:41:54	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.150 (M3/S)	Date/Time of Peak Discharge :	29Nov2015, 03:00
Total Precipitation :	14.400 (MM)	Total Direct Runoff :	7.189 (MM)
Total Loss :	7.200 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	7.200 (MM)	Discharge :	7.189 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.14 (M3/S)	Date/Time of Peak Discharge :	29Nov2015, 03:00
Avg Abs Residual :	0.02 (M3/S)		
Total Residual :	1.478 (MM)	Total Obs Q :	5.71 (MM)

Figure 4.29: Validation Results Summary Table of 29th November 2015 by using Snyder Method

From the computed results on 8th December 2015 from HEC-HMS shown in Figure 4.30, the peak discharge is 0.087 m³/s and 0.09 m³/s from the observed hydrograph at gauge shown in Figure 4.31. The peak discharges occur at 12:30 pm. The rainfall event starts from 12:00 am until 12:50 am with the 3.4 mm for the total precipitation.

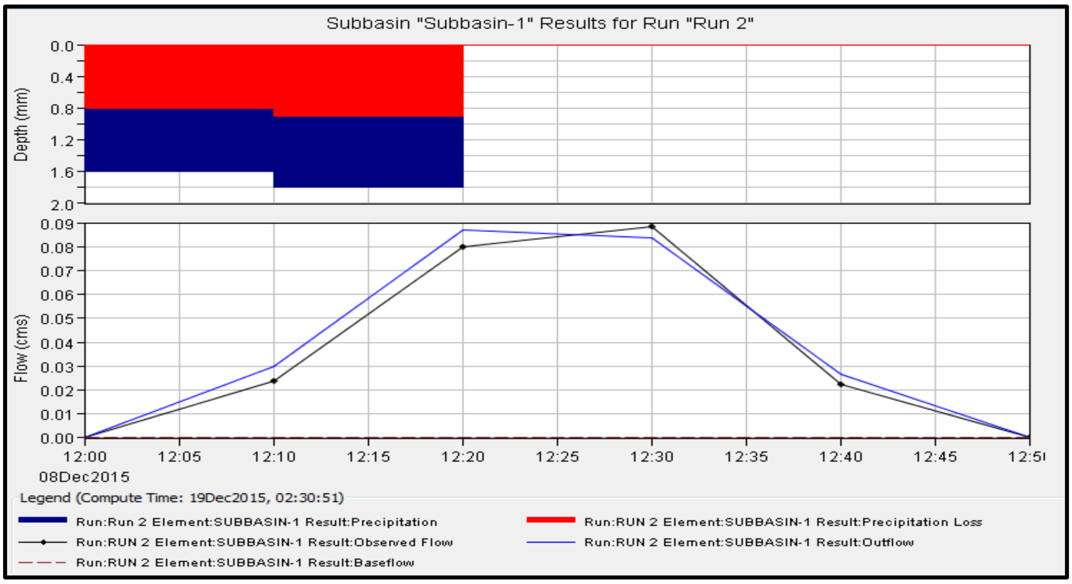


Figure 4.30: Validation Hydrograph on 8th December 2015 for Snyder Method

Project: 08/12/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run:	08Dec2015, 12:00	Basin Model:	Basin 1
End of Run:	08Dec2015, 12:50	Meteorologic Model:	Met 1
Compute Time:	19Dec2015, 02:30:51	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.087 (M3/S)	Date/Time of Peak Discharge :	08Dec2015, 12:20
Total Precipitation :	3.400 (MM)	Total Direct Runoff :	1.700 (MM)
Total Loss :	1.700 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	1.700 (MM)	Discharge :	1.700 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.09 (M3/S)	Date/Time of Peak Discharge :	08Dec2015, 12:30
Avg Abs Residual :	0.00 (M3/S)		
Total Residual :	0.089 (MM)	Total Obs Q :	1.61 (MM)

Figure 4.31: Validation Results Summary Table of 8th December 2015 by using Snyder Method

From the computed results on 9th December 2015 from HEC-HMS shown in Figure 4.32, the peak discharge is 0.154 m³/s and 0.14 m³/s from the observed hydrograph at gauge shown in Figure 4.33. The peak discharges occur at 5:30 pm. The rainfall event starts from 4:30 am until 6:40 am with the 12.8 mm for the total precipitation

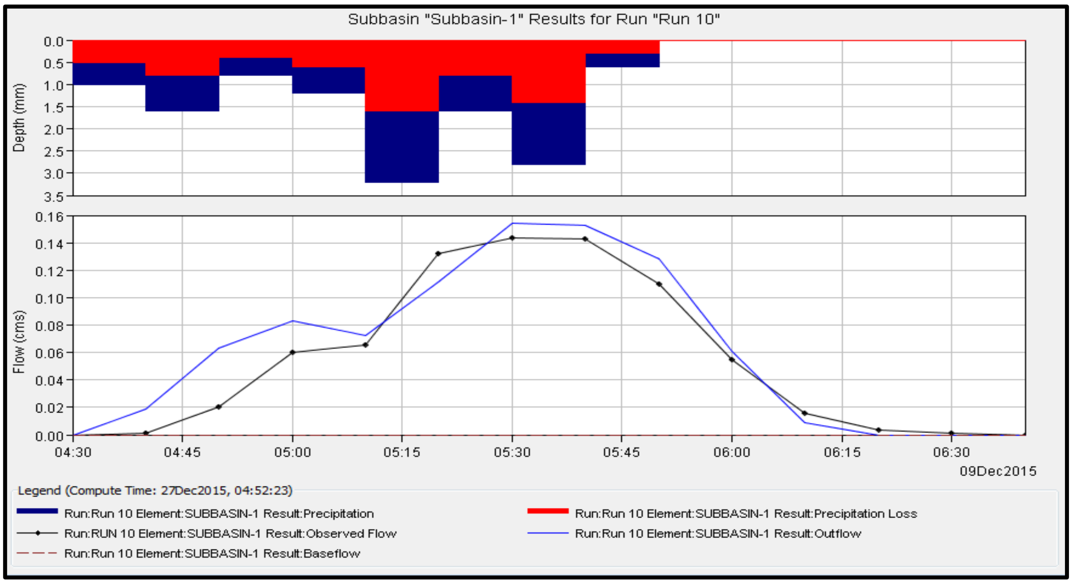


Figure 4.32: Validation Hydrograph on 9th December 2015 for Snyder Method

Project: 09/12/2015
Simulation Run: Run 10 Subbasin: Subbasin-1

Start of Run:	09Dec2015, 04:30	Basin Model:	Basin 1
End of Run:	09Dec2015, 06:40	Meteorologic Model:	Met 1
Compute Time:	27Dec2015, 04:52:23	Control Specifications:	Control 1

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge :	0.154 (M3/S)	Date/Time of Peak Discharge :	09Dec2015, 05:30
Total Precipitation :	12.800 (MM)	Total Direct Runoff :	6.400 (MM)
Total Loss :	6.400 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	6.400 (MM)	Discharge :	6.400 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.14 (M3/S)	Date/Time of Peak Discharge :	09Dec2015, 05:30
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.776 (MM)	Total Obs Q :	5.62 (MM)

Figure 4.33: Validation Results Summary Table of 9th December 2015 by using Snyder Method

4.3.2.2 Clark Time Area

Rainfall event on 25th November 2015, 26th November 2015, 27th November 2015, 29td November 2015, 8nd December 2015 and 9th December 2015 was selected for the validation process. Following is the results of hydrograph and its summary that obtained from HEC-HMS program.

From the computed results on 25th November 2015 from HEC-HMS shown in Figure 4.34, the peak discharge is 0.043 m^3/s and 0.03 m^3/s from the observed hydrograph at gauge shown in Figure 4.35. The peak discharges occur at 3:40 pm. The rainfall event starts from 3:00 pm until 4:20 pm with the 1.6 mm for the total precipitation.

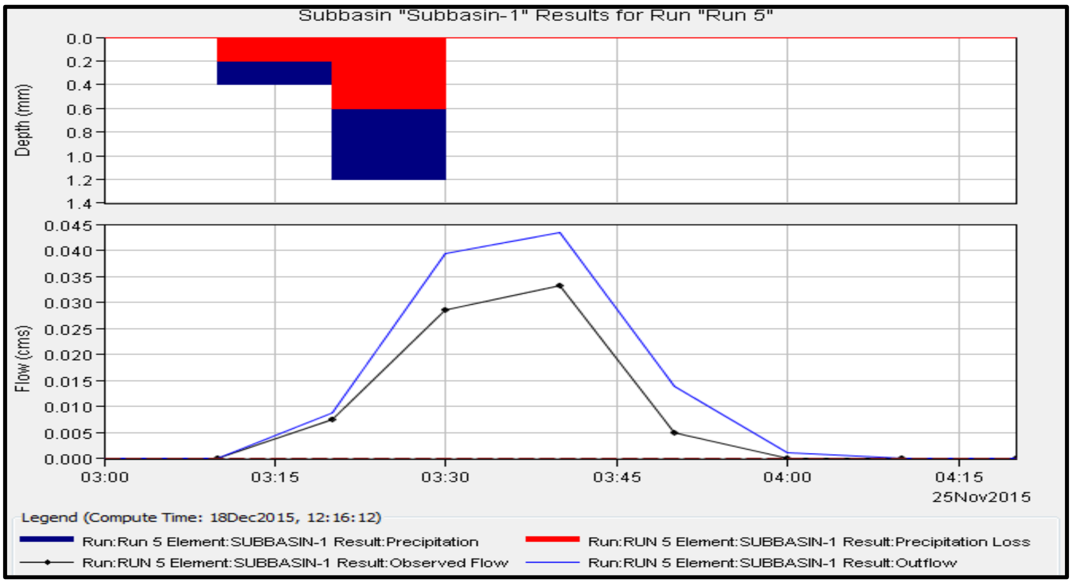
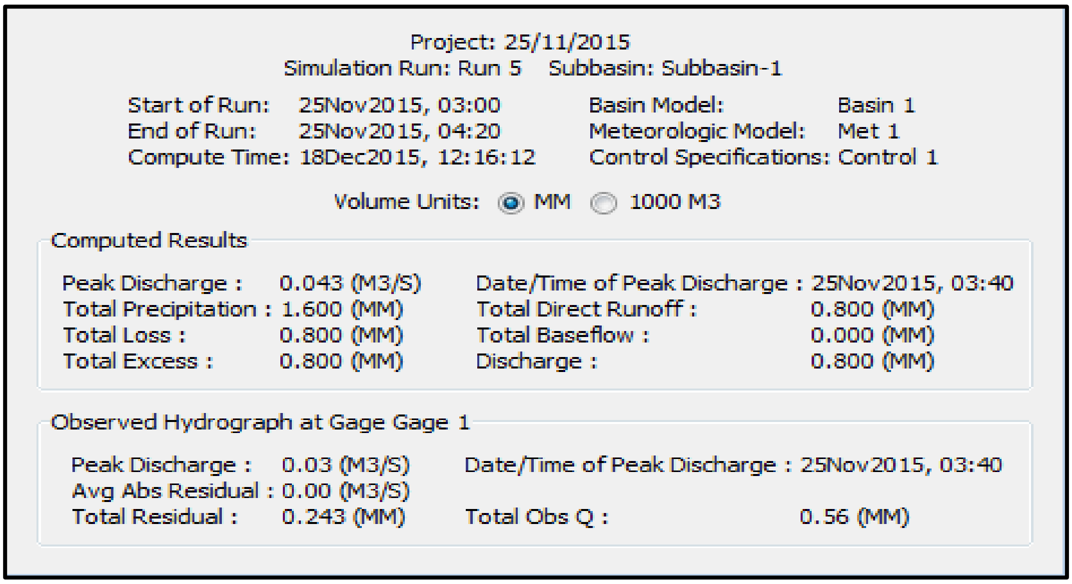


Figure 4.34: Validation Hydrograph on 25th November 2015 for Clark Time Area Method


Project: 25/11/2015
Simulation Run: Run 5 Subbasin: Subbasin-1

Start of Run:	25Nov2015, 03:00	Basin Model:	Basin 1
End of Run:	25Nov2015, 04:20	Meteorologic Model:	Met 1
Compute Time:	18Dec2015, 12:16:12	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.043 (M3/S)	Date/Time of Peak Discharge :	25Nov2015, 03:40
Total Precipitation :	1.600 (MM)	Total Direct Runoff :	0.800 (MM)
Total Loss :	0.800 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	0.800 (MM)	Discharge :	0.800 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.03 (M3/S)	Date/Time of Peak Discharge :	25Nov2015, 03:40
Avg Abs Residual :	0.00 (M3/S)		
Total Residual :	0.243 (MM)	Total Obs Q :	0.56 (MM)

Figure 4.35: Validation Results Summary Table of 25th November 2015 by Clark Time Area Method

From the computed results on 26th November 2015 from HEC-HMS shown in Figure 4.36, the peak discharge is 0.157 m³/s and 0.15 m³/s from the observed hydrograph at gauge shown in Figure 4.37. The peak discharges occur at 2:50 pm. The rainfall event starts from 2:20 pm until 4:00 pm with the 8.2 mm for the total precipitation.

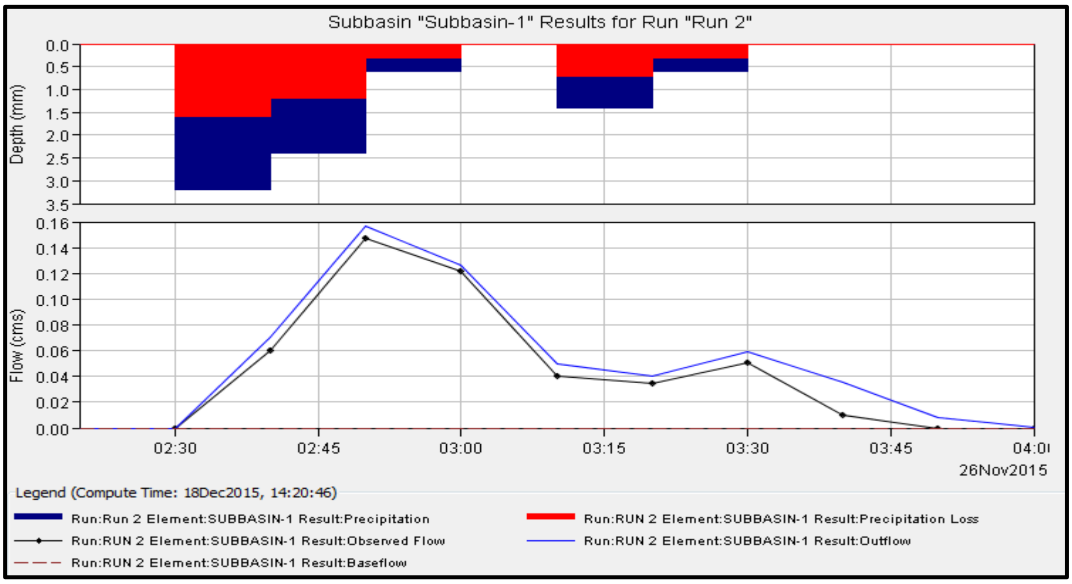


Figure 4.36: Validation Hydrograph on 26th November 2015 for Clark Time Area Method

Project: 26/11/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run:	26Nov2015, 02:20	Basin Model:	Basin 1
End of Run:	26Nov2015, 04:00	Meteorologic Model:	Met 1
Compute Time:	18Dec2015, 14:20:46	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.157 (M3/S)	Date/Time of Peak Discharge :	26Nov2015, 02:50
Total Precipitation :	8.200 (MM)	Total Direct Runoff :	4.098 (MM)
Total Loss :	4.100 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	4.100 (MM)	Discharge :	4.098 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.15 (M3/S)	Date/Time of Peak Discharge :	26Nov2015, 02:50
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.610 (MM)	Total Obs Q :	3.49 (MM)

Figure 4.37: Validation Results Summary Table of 26th November 2015 by Clark Time Area Method

From the computed results on 27th November 2015 from HEC-HMS shown in Figure 4.38, the peak discharge is 0.04 m³/s and 0.03 m³/s from the observed hydrograph at gauge shown in Figure 4.39. The peak discharges occur at 8:20 pm. The rainfall event starts from 7:30 am until 9:10 am with the 3.6 mm for the total precipitation.

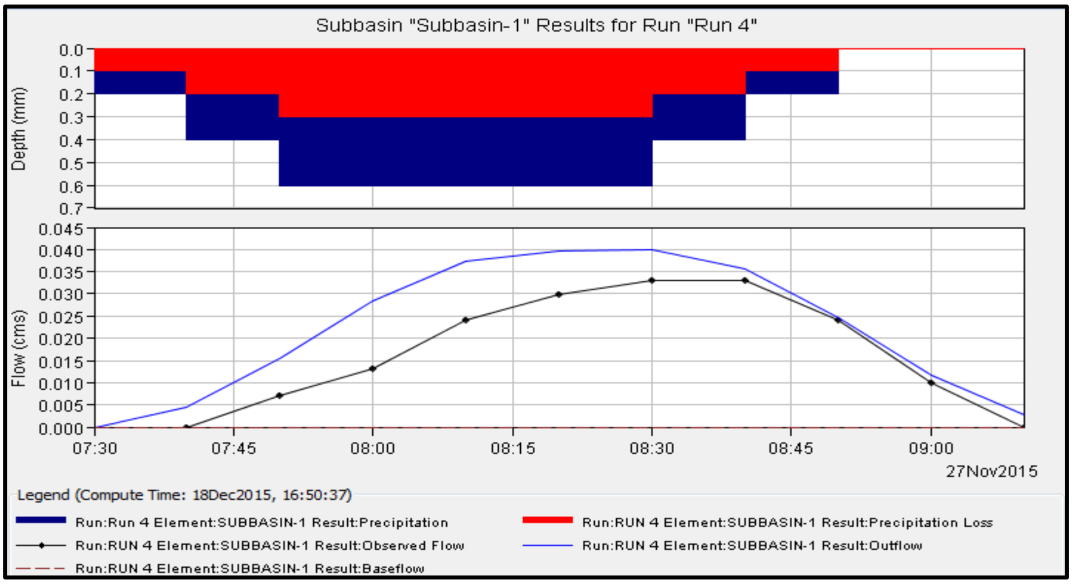


Figure 4.38: Validation Hydrograph on 27th November 2015 for Clark Time Area Method

Project: 27/11/2015
Simulation Run: Run 4 Subbasin: Subbasin-1

Start of Run:	27Nov2015, 07:30	Basin Model:	Basin 1
End of Run:	27Nov2015, 09:10	Meteorologic Model:	Met 1
Compute Time:	18Dec2015, 16:50:37	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.040 (M3/S)	Date/Time of Peak Discharge :	27Nov2015, 08:30
Total Precipitation :	3.600 (MM)	Total Direct Runoff :	1.789 (MM)
Total Loss :	1.800 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	1.800 (MM)	Discharge :	1.789 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.03 (M3/S)	Date/Time of Peak Discharge :	27Nov2015, 08:30
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.484 (MM)	Total Obs Q :	1.31 (MM)

Figure 4.39: Validation Results Summary Table of 27th November 2015 by Clark Time Area Method

From the computed results on 29th November 2015 from HEC-HMS shown in Figure 4.40, the peak discharge is 0.142 m³/s and 0.14 m³/s from the observed hydrograph at gauge shown in Figure 4.41. The peak discharges occur at 8:20 pm. The rainfall event starts from 1:00 am until 4:50 am with the 14.4 mm for the total precipitation.

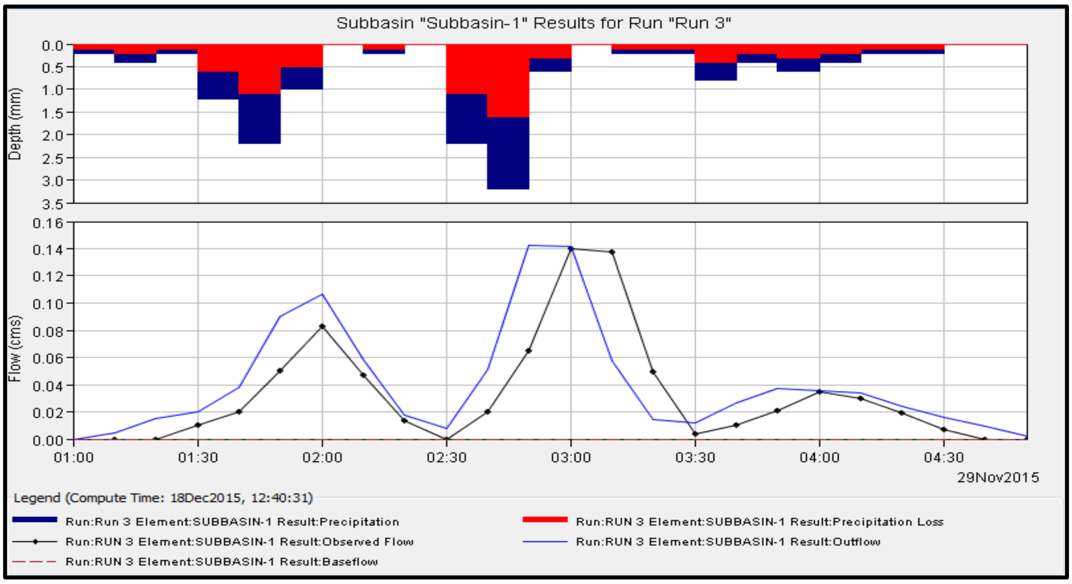


Figure 4.40: Validation Hydrograph on 29th November 2015 for Clark Time Area Method

Project: 29/11/2015
Simulation Run: Run 3 Subbasin: Subbasin-1

Start of Run:	29Nov2015, 01:00	Basin Model:	Basin 1
End of Run:	29Nov2015, 04:50	Meteorologic Model:	Met 1
Compute Time:	18Dec2015, 12:40:31	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.142 (M3/S)	Date/Time of Peak Discharge :	29Nov2015, 02:50
Total Precipitation :	14.400 (MM)	Total Direct Runoff :	7.189 (MM)
Total Loss :	7.200 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	7.200 (MM)	Discharge :	7.189 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.14 (M3/S)	Date/Time of Peak Discharge :	29Nov2015, 03:00
Avg Abs Residual :	0.02 (M3/S)		
Total Residual :	1.479 (MM)	Total Obs Q :	5.71 (MM)

Figure 4.1: Validation Results Summary Table of 29th November 2015 by Clark Time Area Method

From the computed results on 8th December 2015 from HEC-HMS shown in Figure 4.42, the peak discharge is 0.092 m³/s and 0.09 m³/s from the observed hydrograph at gauge shown in Figure 4.43. The peak discharges occur at 12:30 pm. The rainfall event starts from 12:00 am until 12:50 am with the 3.4 mm for the total precipitation

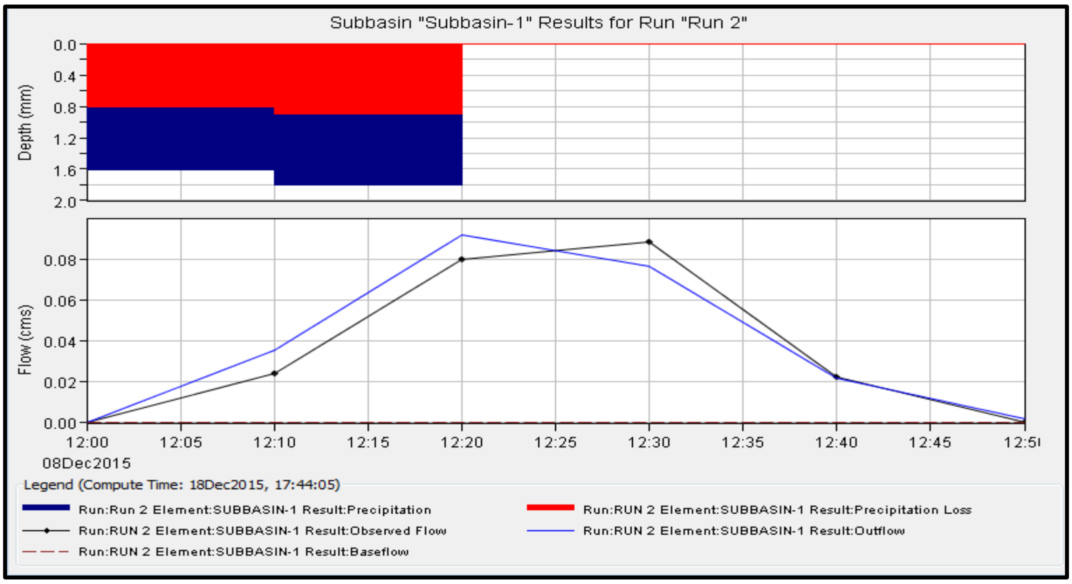


Figure 4.42: Validation Hydrograph on 8th December 2015 for Clark Time Area Method

Project: 08/12/2015
Simulation Run: Run 2 Subbasin: Subbasin-1

Start of Run:	08Dec2015, 12:00	Basin Model:	Basin 1
End of Run:	08Dec2015, 12:50	Meteorologic Model:	Met 1
Compute Time:	18Dec2015, 17:44:05	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.092 (M3/S)	Date/Time of Peak Discharge :	08Dec2015, 12:20
Total Precipitation :	3.400 (MM)	Total Direct Runoff :	1.693 (MM)
Total Loss :	1.700 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	1.700 (MM)	Discharge :	1.693 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.09 (M3/S)	Date/Time of Peak Discharge :	08Dec2015, 12:30
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.082 (MM)	Total Obs Q :	1.61 (MM)

Figure 4.43: Validation Results Summary Table of 8th December 2015 by Clark Time Area Method

From the computed results on 9th December 2015 from HEC-HMS shown in Figure 4.44, the peak discharge is 0.153 m³/s and 0.14 m³/s from the observed hydrograph at gauge shown in Figure 4.45. The peak discharges occur at 5:30 pm. The rainfall event starts from 4:30 am until 6:40 am with the 12.8 mm for the total precipitation

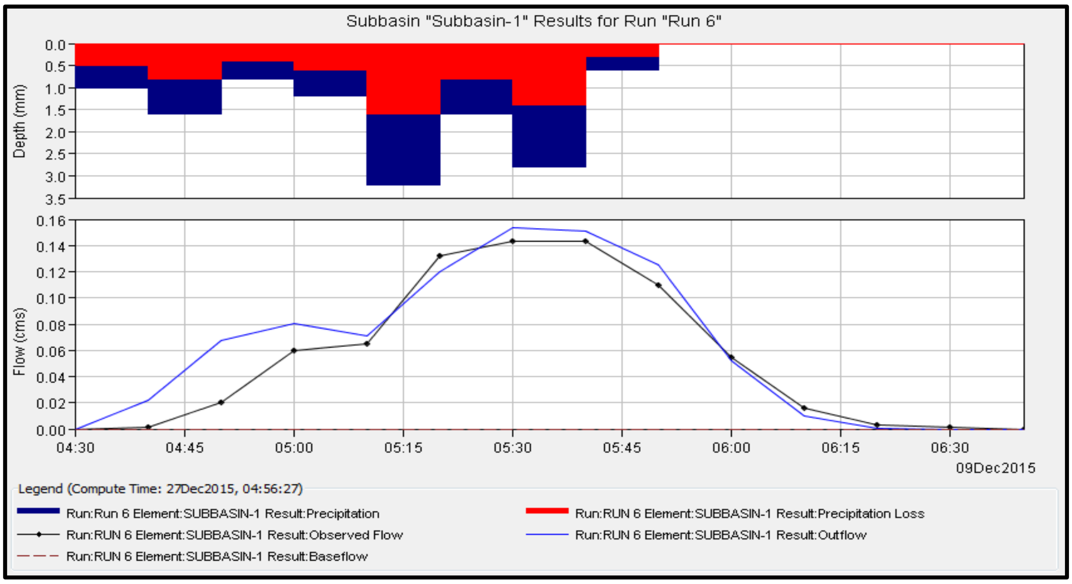
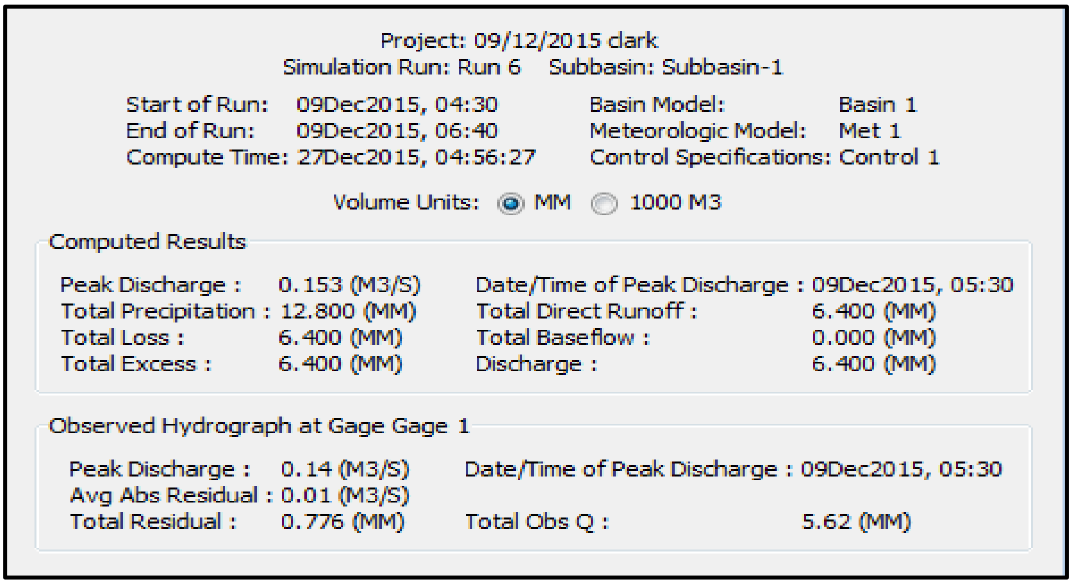


Figure 4.44: Validation Hydrograph on 9th December 2015 for Clark Time Area Method


Project: 09/12/2015 clark
Simulation Run: Run 6 Subbasin: Subbasin-1

Start of Run:	09Dec2015, 04:30	Basin Model:	Basin 1
End of Run:	09Dec2015, 06:40	Meteorologic Model:	Met 1
Compute Time:	27Dec2015, 04:56:27	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	0.153 (M3/S)	Date/Time of Peak Discharge :	09Dec2015, 05:30
Total Precipitation :	12.800 (MM)	Total Direct Runoff :	6.400 (MM)
Total Loss :	6.400 (MM)	Total Baseflow :	0.000 (MM)
Total Excess :	6.400 (MM)	Discharge :	6.400 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge :	0.14 (M3/S)	Date/Time of Peak Discharge :	09Dec2015, 05:30
Avg Abs Residual :	0.01 (M3/S)		
Total Residual :	0.776 (MM)	Total Obs Q :	5.62 (MM)

Figure 4.45: Validation Results Summary Table of 9th December 2015 by Clark Time Area Method

4.4 EFFICIENCY INDEX

The accuracy of results computed by HEC-HMS is determined by using one of the statistics methods which is the Efficiency Index. Efficiency Index can be defined as below:

$$\text{Efficiency Index} = \frac{SS_{Total} - SS_{Error}}{SS_{Total}} \qquad (4.1)$$

SS_{Total}, the total sum of squared error is the sum of squared error when predicting using the mean; the sum of the squared products of all the actual values minus the mean. The formula of SS_{Total} is as follows:

$$SS_{Total} = \sum (Q_i - Q_{ag})^2 \qquad (4.2)$$

SS_{Error}, the sum of squared error is the sum of squared error when using the prediction model; the sum of squared products of all the actual values minus their predicted values. The formula of SS_{Error} is as below:

$$SS_{Error} = \sum (Q_i - F_i)^2 \qquad (4.3)$$

Where,

Q_i	= Observed Discharge at Time *i*
Q_{ag}	= Mean of Observed Discharge, $Q_{ag} = \sum \frac{Q_i}{N}$
N	= Number of Discharge Data
F_i	= Simulated Discharge at Time *i*

With a good prediction, the SS_{Error} should be less than the SS_{Total}. This comparison is an indicator of the accuracy of this prediction model and is called the proportionate reduction in error, $(R)^2$. This proportion is the percentage of variance. With a higher accuracy of the model can be achieved (Wong, 2005).

4.4.1 Efficiency Index for Calibration Process

4.4.1.1 Snyder

Table 4.5 shows the data of Efficiency Index of Calibration Process for Snyder method for 20th November 2015. The same procedure and formula are also used on 24th November 2015 and 25th November 2015. Refer appendix D.

Table 4.5: Data of Efficiency Index of Calibration process for Snyder Method on 20th November 2015

Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
12:20 PM	0.000	0.000	0.000	0.000	0.069	-0.069	0.005
12:30 PM	0.000	0.000	0.000	0.000	0.069	-0.069	0.005
12:40 PM	0.051	0.040	0.011	0.000	0.069	-0.018	0.000
12:50 PM	0.195	0.160	0.035	0.001	0.069	0.126	0.016
1:00 PM	0.234	0.234	0.000	0.000	0.069	0.165	0.027
1:10 PM	0.052	0.120	-0.068	0.005	0.069	-0.017	0.000
1:20 PM	0.000	0.029	-0.029	0.001	0.069	-0.069	0.005
1:30 PM	0.045	0.078	-0.033	0.001	0.069	-0.024	0.001
1:40 PM	0.152	0.200	-0.048	0.002	0.069	0.083	0.007
1:50 PM	0.100	0.175	-0.075	0.006	0.069	0.031	0.001
2:00 PM	0.000	0.030	-0.030	0.001	0.069	-0.069	0.005
2:10 PM	0.000	0.000	0.000	0.000	0.069	-0.069	0.005
$\Sigma Q_i =$	0.829	$\Sigma(Q_i - F_i)^2 =$		0.017	$\Sigma(Q_i - Q_{ag})^2 =$		0.076

Calculation of Efficiency Index for 20th November 2015:

Mean of Observed discharge, $Q_{ag} = \sum \frac{Q_i}{N}$

$$= \frac{0.829}{12} = 0.069 \text{ m}^3/\text{s}$$

$$Efficiency\ Index = \frac{SS_{Total} - SS_{Error}}{SS_{Total}}$$

$$= \frac{0.076 - 0.017}{0.076} \times 100\%$$

$$= 77.63\%$$

4.4.1.2 Clark Time Area

Table 4.6 shows the data of Efficiency Index of calibration process for Clark Time Area method for 20th November 2015. Refer appendix E.

Table 4.6: Data of Efficiency Index of Calibration process for Clark Time Area Method on 20th November 2015.

Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
12:20 PM	0.000	0.000	0.000	0.000	0.069	-0.069	0.005
12:30 PM	0.000	0.000	0.000	0.000	0.069	-0.069	0.005
12:40 PM	0.051	0.040	0.011	0.000	0.069	-0.018	0.000
12:50 PM	0.195	0.170	0.025	0.001	0.069	0.126	0.016
1:00 PM	0.234	0.220	0.014	0.000	0.069	0.165	0.027
1:10 PM	0.052	0.100	-0.048	0.002	0.069	-0.017	0.000
1:20 PM	0.000	0.030	-0.030	0.001	0.069	-0.069	0.005
1:30 PM	0.045	0.100	-0.055	0.003	0.069	-0.024	0.001
1:40 PM	0.152	0.210	-0.058	0.003	0.069	0.083	0.007
1:50 PM	0.100	0.150	-0.050	0.003	0.069	0.031	0.001
2:00 PM	0.000	0.050	-0.050	0.003	0.069	-0.069	0.005
2:10 PM	0.000	0.000	0.000	0.000	0.069	-0.069	0.005
$\Sigma Q_i =$	0.829	$\Sigma(Q_i - F_i)^2 =$		0.016	$\Sigma(Q_i - Q_{ag})^2 =$		0.076

Calculation of Efficiency Index for 20th November 2015:

Mean of Observed discharge, $Q_{ag} = \sum \frac{Q_i}{N}$

$$= \frac{0.829}{12}$$

$$= 0.069 \text{ m}^3/\text{s}$$

$$\textit{Efficiency Index} = \frac{SS_{Total} - SS_{Error}}{SS_{Total}}$$

$$= \frac{0.076 - 0.016}{0.076} \times 100\%$$

$$= 78.95\ \%$$

4.4.2 Efficiency Index for Validation Process

4.4.2.1 Snyder

Figure 4.7 shows the table of calculation for validation process on 29th November 2015. The same procedure and formula are also used on 25th November 2015, 26th November 2015, 27th November 2015, 8nd December 2015 and 9th December 2015. Refer appendix D.

Table 4.7: Data of Efficiency Index of Validation process for Snyder Method on 29th November 2015.

Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
1:00 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
1:10 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
1:20 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
1:30 AM	0.010	0.020	-0.010	0.000	0.032	-0.022	0.000
1:40 AM	0.020	0.035	-0.015	0.000	0.032	-0.012	0.000
1:50 AM	0.050	0.083	-0.033	0.001	0.032	0.018	0.000
2:00 AM	0.083	0.110	-0.027	0.001	0.032	0.051	0.003
2:10 AM	0.047	0.067	-0.020	0.000	0.032	0.016	0.000
2:20 AM	0.013	0.020	-0.007	0.000	0.032	-0.018	0.000
2:30 AM	0.000	0.015	-0.015	0.000	0.032	-0.032	0.001
2:40 AM	0.020	0.040	-0.020	0.000	0.032	-0.012	0.000
2:50 AM	0.065	0.134	-0.069	0.005	0.032	0.033	0.001
3:00 AM	0.140	0.150	-0.010	0.000	0.032	0.108	0.012
3:10 AM	0.137	0.060	0.077	0.006	0.032	0.106	0.011
3:20 AM	0.050	0.010	0.040	0.002	0.032	0.018	0.000
3:30 AM	0.004	0.012	-0.008	0.000	0.032	-0.028	0.001
3:40 AM	0.010	0.024	-0.014	0.000	0.032	-0.022	0.000
3:50 AM	0.021	0.038	-0.017	0.000	0.032	-0.011	0.000
4:00 AM	0.035	0.039	-0.004	0.000	0.032	0.003	0.000
4:10 AM	0.030	0.030	0.000	0.000	0.032	-0.002	0.000
4:20 AM	0.019	0.020	-0.001	0.000	0.032	-0.012	0.000
4:30 AM	0.007	0.020	-0.013	0.000	0.032	-0.025	0.001
4:40 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
4:50 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
$\Sigma Q_i =$	0.761	$\Sigma(Q_i - F_i)^2 =$		0.016	$\Sigma(Q_i - Q_{ag})^2 =$		0.037

Calculation of Efficiency Index for 25th November 2015:

Mean of Observed discharge, $Q_{ag} = \sum \frac{Q_i}{N}$

$= \frac{0.761}{24}$

$= 0.032$ m³/s

Efficiency Index $= \frac{SS_{Total} - SS_{Error}}{SS_{Total}}$

$= \frac{0.037 - 0.016}{0.037}$ x 100%

=56.76 %

4.4.2.2 Clark Time Area

Figure 4.8 shows the example of the validation process for Clark Time Area methods. Five events are using the same procedures and formula to determine the Efficiency Index for the accuracy of Clark Time Area method. Refer appendix E.

Table 4.8: Data of Efficiency Index of Validation process for Clark Time Area Method on 29th November 2015

Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
1:00 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
1:10 AM	0.000	0.005	-0.005	0.000	0.032	-0.032	0.001
1:20 AM	0.000	0.018	-0.018	0.000	0.032	-0.032	0.001
1:30 AM	0.010	0.020	-0.010	0.000	0.032	-0.022	0.000
1:40 AM	0.020	0.040	-0.020	0.000	0.032	-0.012	0.000
1:50 AM	0.050	0.090	-0.040	0.002	0.032	0.018	0.000
2:00 AM	0.083	0.112	-0.029	0.001	0.032	0.051	0.003
2:10 AM	0.047	0.060	-0.013	0.000	0.032	0.016	0.000
2:20 AM	0.013	0.016	-0.003	0.000	0.032	-0.018	0.000
2:30 AM	0.000	0.010	-0.010	0.000	0.032	-0.032	0.001
2:40 AM	0.020	0.050	-0.030	0.001	0.032	-0.012	0.000
2:50 AM	0.065	0.143	-0.078	0.006	0.032	0.033	0.001
3:00 AM	0.140	0.141	-0.001	0.000	0.032	0.108	0.012
3:10 AM	0.137	0.060	0.077	0.006	0.032	0.106	0.011
3:20 AM	0.050	0.014	0.036	0.001	0.032	0.018	0.000
3:30 AM	0.004	0.013	-0.009	0.000	0.032	-0.028	0.001
3:40 AM	0.010	0.030	-0.020	0.000	0.032	-0.022	0.000
3:50 AM	0.021	0.040	-0.019	0.000	0.032	-0.011	0.000
4:00 AM	0.035	0.035	0.000	0.000	0.032	0.003	0.000
4:10 AM	0.030	0.035	-0.005	0.000	0.032	-0.002	0.000
4:20 AM	0.019	0.023	-0.004	0.000	0.032	-0.012	0.000
4:30 AM	0.007	0.019	-0.012	0.000	0.032	-0.025	0.001
4:40 AM	0.000	0.010	-0.010	0.000	0.032	-0.032	0.001
4:50 AM	0.000	0.000	0.000	0.000	0.032	-0.032	0.001
$\Sigma Q_i =$	0.761	$\Sigma(Q_i - F_i)^2 =$		0.019	$\Sigma(Q_i - Q_{ag})^2 =$		0.037

Calculation of Efficiency Index for 25th November 2015:

Mean of Observed discharge, $Q_{ag} = \sum \frac{Q_i}{N}$

$= \frac{0.761}{24}$

$= 0.032$ m³/s

Efficiency Index$= \frac{SS_{Total} - SS_{Error}}{SS_{Total}}$

$= \frac{0.037 - 0.019}{0.037}$ x 100%

= 48.65 %

4.4.2.3 Summary of Efficiency Index

Summary of Efficiency Index for all nine rainfall events are shown in Table 4.9 for both Snyder and Clark Time Area method. From Table 4.9, the average Efficiency Index for both Snyder and Clark Time Area methods are 75.09% and 71.22%. By using HEC-HMS analysis and simulation, it can conclude that Snyder method is the most appropriate method for UMP to design drainage system because Snyder methods have highest Efficiency Index.

Table 4.9: Summary of Efficiency Index

Events	**Date**	**Method**	
		Snyder (%)	**Clark Time Area (%)**
1	20th November 2015	78.00	79.58
2	22nd November 2015	80.25	85.09
3	24th November 2015	40.94	34.99
4	25th November 2015	78.57	71.43
5	26th November 2015	92.69	94.23
6	27th November 2015	66.67	61.11
7	29th November 2015	55.43	48.37
8	08th December 2015	97.83	95.65
9	09th December 2015	85.42	70.50
	AVERAGE	**75.09**	**71.22**

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

After the simulation and comparison of the rainfall and runoff by using HEC-HMS program, the most appropriate method to be used in UMP Gambang Campus can be determine. To achieve that, the data from October until December need to be collected every 10 minute by using flow meter and rain gauge. The equipment must be placed at the outlet of the sub-catchment area which is near to the main gate UMP.

During the period of time, nine events of rainfall are selected to analyze and simulated using HEC-HMS software. Three events of rainfall are used to calibrate and another six events are used to validate by using Snyder and Clark Time Area method. After that, statistics method which is Efficiency Index is used to determine the accuracy of results computed by HEC-HMS software. The result from Efficiency Index is important to determine either Snyder or Clark Time Area method is the most appropriate method to be used.

5.2 CONCLUSION

As a conclusion, the objectives of this study are achieved. There are to determine the rainfall-runoff relationship and to compare the rainfall-runoff analysis using Snyder and Clark Time Area method.

Based on hydrograph of nine rainfall event simulated form HEC-HMS, after five minutes to ten minutes of the maximum rainfall arise then the peak flow rate occurred. When the rate of rainfall exceeds the infiltration capacity of the soil, after which runoff is generated. It shows that when the rainfall increases, the flow rate also increase and when the rainfall decreases, the flow rate also decreases.

By using HEC-HMS analysis and simulation, it can conclude that the Snyder method is the best method for UMP Gambang Campus drainage system. This is because Snyder method has the highest average Efficiency Index compare to Clark Time Area method. From the calculation of Efficiency Index, the average Efficiency Index for both Snyder and Clark Time Area are 75.09% and 71.22%.

However, HEC-HMS is still crucial in simulating the runoff process although it still has its own weakness. In UMP, Snyder method from this research can help to predict future flood problem and settle other matters involving the water resources management system.

5.2 RECOMMENDATION

Based on the results and conclusions of the study that has been made, HEC-HMS is software that is able to predict the accuracy of the actual parameter for UMP campus Gambang. However, there are still needs to improve to get better result by using this software.

i. The layout of UMP’s drainage system must be detail enough to get the best result for upcoming research. It is recommended to use more method such as SCS method, ModClark method, Kinematic Wave method and User Specific UH method from the HEC-HMS.

ii. The rainfall data and the flow rate data should be taken throughout the whole year so that sufficient data can be taken to analyze the rainfall-runoff relationship. More events can be selected to obtain more accurate result for the study.

iii. The flow rate must be taken more than several point of outlet of the drainage. This is because different points of outlets have various flow rate and many point of outlet may give variety of data.

iv. The equipment such as flow meter must be test before install at site to avoid the technical problem especially the sensor that is placed in the drainage. The rain gauge also should be checked frequently especially the battery to avoid any missing data. This problem may cause reduce the number of events that can be selected and may reduce the accuracy of the data.

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Appendix A: Rainfall Data

Appendix A: Rainfall Data

Site Name	UMP
Isco Quantity	Rainfall
Label	Rainfall
Units	mm
Resolution	0.2
Significant Digits	7

Event 1	
Date and Time	**Rainfall (mm)**
11/20/2015 12:20 PM	0.0000
11/20/2015 12:30 PM	0.0000
11/20/2015 12:40 PM	1.8000
11/20/2015 12:50 PM	5.6000
11/20/2015 1:00 PM	1.2000
11/20/2015 1:10 PM	0.0000
11/20/2015 1:20 PM	0.0000
11/20/2015 1:30 PM	4.4000
11/20/2015 1:40 PM	3.0000
11/20/2015 1:50 PM	0.2000
11/20/2015 2:00 PM	0.0000
11/20/2015 2:10 PM	0.0000
Event 2	
Date and Time	**Rainfall(mm)**
11/22/2015 11:00 AM	0.0000
11/22/2015 11:10 AM	0.0000
11/22/2015 11:20 AM	1.0000
11/22/2015 11:30 AM	2.6000
11/22/2015 11:40 AM	2.0000
11/22/2015 11:50 AM	0.0000
11/22/2015 12:00 PM	0.0000
11/22/2015 12:10 PM	0.0000
11/22/2015 12:20 PM	0.0000
11/22/2015 12:30 PM	0.0000

Event 3	
Date and Time	**Rainfall(mm)**
11/24/2015 5:00 PM	0.0000
11/24/2015 5:10 PM	0.0000
11/24/2015 5:20 PM	7.0000
11/24/2015 5:30 PM	9.0000
11/24/2015 5:40 PM	3.6000
11/24/2015 5:50 PM	1.6000
11/24/2015 6:00 PM	0.0000
11/24/2015 6:10 PM	0.0000
11/24/2015 6:20 PM	0.0000
11/24/2015 6:30 PM	0.0000
11/24/2015 6:40 PM	0.0000
11/24/2015 6:50 PM	0.0000
Event 4	
Date and Time	**Rainfall(mm)**
11/25/2015 3:00 PM	0.0000
11/25/2015 3:10 PM	0.0000
11/25/2015 3:20 PM	0.4000
11/25/2015 3:30 PM	1.2000
11/25/2015 3:40 PM	0.0000
11/25/2015 3:50 PM	0.0000
11/25/2015 4:00 PM	0.0000
11/25/2015 4:10 PM	0.0000
11/25/2015 4:20 PM	0.0000

Event 5	
Date and Time	**Rainfall(mm)**
11/26/2015 2:20 PM	0.0000
11/26/2015 2:30 PM	0.0000
11/26/2015 2:40 PM	3.2000
11/26/2015 2:50 PM	2.4000
11/26/2015 3:00 PM	0.6000
11/26/2015 3:10 PM	0.0000
11/26/2015 3:20 PM	1.4000
11/26/2015 3:30 PM	0.6000
11/26/2015 3:40 PM	0.0000
11/26/2015 3:50 PM	0.0000
11/26/2015 4:00 PM	0.0000
Event 6	
Date and Time	**Rainfall(mm)**
11/27/2015 7:30 AM	0.0000
11/27/2015 7:40 AM	0.2000
11/27/2015 7:50 AM	0.4000
11/27/2015 8:00 AM	0.6000
11/27/2015 8:10 AM	0.6000
11/27/2015 8:20 AM	0.6000
11/27/2015 8:30 AM	0.6000
11/27/2015 8:40 AM	0.4000
11/27/2015 8:50 AM	0.2000
11/27/2015 9:00 AM	0.0000
11/27/2015 9:10 AM	0.0000

Event 7	
Date and Time	**Rainfall(mm)**
11/29/2015 1:00 AM	0.0000
11/29/2015 1:10 AM	0.2000
11/29/2015 1:20 AM	0.4000
11/29/2015 1:30 AM	0.2000
11/29/2015 1:40 AM	1.2000
11/29/2015 1:50 AM	2.2000
11/29/2015 2:00 AM	1.0000
11/29/2015 2:10 AM	0.0000
11/29/2015 2:20 AM	0.2000
11/29/2015 2:30 AM	0.0000
11/29/2015 2:40 AM	2.2000
11/29/2015 2:50 AM	3.2000
11/29/2015 3:00 AM	0.6000
11/29/2015 3:10 AM	0.0000
11/29/2015 3:20 AM	0.2000
11/29/2015 3:30 AM	0.2000
11/29/2015 3:40 AM	0.8000
11/29/2015 3:50 AM	0.4000
11/29/2015 4:00 AM	0.6000
11/29/2015 4:10 AM	0.4000
11/29/2015 4:20 AM	0.2000
11/29/2015 4:30 AM	0.2000
11/29/2015 4:40 AM	0.0000
11/29/2015 4:50 AM	0.0000

Event 8	
Date and Time	**Rainfall(mm)**
12/08/2015 11:50 PM	0.0000
12/08/2015 12:00 PM	6.2000
12/08/2015 12:10 PM	1.6000
12/08/2015 12:20 PM	1.8000
12/08/2015 12:30 PM	0.0000
12/08/2015 12:40 PM	0.0000
12/08/2015 12:50 PM	0.0000
Event 9	
Date and Time	**Rainfall(mm)**
12/09/2015 04:30 PM	0.0000
12/09/2015 04:40 PM	1.0000
12/09/2015 04:50 PM	1.6000
12/09/2015 05:00 PM	0.8000
12/09/2015 05:10 PM	1.2000
12/09/2015 05:20 PM	3.2000
12/09/2015 05:30 PM	1.6000
12/09/2015 05:40 PM	2.8000
12/09/2015 05:50 PM	0.6000
12/09/2015 06:00 PM	0.0000
12/09/2015 06:10 PM	0.0000
12/09/2015 06:20 PM	0.0000
12/09/2015 06:30 PM	0.2000
12/09/2015 06:40 PM	0.0000

Appendix B: Flow Rate Data

Appendix B: Flow Rate Data

Site Name	UMP
Isco Quantity	Flow Rate
Label	Flow Rate
Units	m^3/s
Resolution	0.0001
Significant Digits	7

Event 1	
Date and Time	**Flowrate (m^3/s)**
11/20/2015 12:20 PM	0.0000
11/20/2015 12:30 PM	0.0000
11/20/2015 12:40 PM	0.0510
11/20/2015 12:50 PM	0.1949
11/20/2015 1:00 PM	0.2342
11/20/2015 1:10 PM	0.0524
11/20/2015 1:20 PM	0.0000
11/20/2015 1:30 PM	0.0450
11/20/2015 1:40 PM	0.1517
11/20/2015 1:50 PM	0.1000
11/20/2015 2:00 PM	0.0000
11/20/2015 2:10 PM	0.0000
Event 2	
Date and Time	**Flowrate (m^3/s)**
11/22/2015 11:00 AM	0.0000
11/22/2015 11:10 AM	0.0000
11/22/2015 11:20 AM	0.0007
11/22/2015 11:30 AM	0.0605
11/22/2015 11:40 AM	0.1200
11/22/2015 11:50 AM	0.0635
11/22/2015 12:00 PM	0.0039
11/22/2015 12:10 PM	0.0000
11/22/2015 12:20 PM	0.0000
11/22/2015 12:30 PM	0.0000

Event 3	
Date and Time	**Flowrate (m^3/s)**
11/24/2015 5:00 PM	0.0000
11/24/2015 5:10 PM	0.0000
11/24/2015 5:20 PM	0.0460
11/24/2015 5:30 PM	0.2090
11/24/2015 5:40 PM	0.2930
11/24/2015 5:50 PM	0.2800
11/24/2015 6:00 PM	0.1770
11/24/2015 6:10 PM	0.0800
11/24/2015 6:20 PM	0.0180
11/24/2015 6:30 PM	0.0030
11/24/2015 6:40 PM	0.0030
11/24/2015 6:50 PM	0.0030
Event 4	
Date and Time	**Flowrate (m^3/s)**
11/25/2015 3:00 PM	0.0000
11/25/2015 3:10 PM	0.0000
11/25/2015 3:20 PM	0.0075
11/25/2015 3:30 PM	0.0286
11/25/2015 3:40 PM	0.0332
11/25/2015 3:50 PM	0.0050
11/25/2015 4:00 PM	0.0000
11/25/2015 4:10 PM	0.0000
11/25/2015 4:20 PM	0.0000

Event 5	
Date and Time	**Flowrate (m^3/s)**
11/26/2015 2:20 PM	0.0000
11/26/2015 2:30 PM	0.0000
11/26/2015 2:40 PM	0.0600
11/26/2015 2:50 PM	0.1470
11/26/2015 3:00 PM	0.1220
11/26/2015 3:10 PM	0.0400
11/26/2015 3:20 PM	0.0350
11/26/2015 3:30 PM	0.0510
11/26/2015 3:40 PM	0.0100
11/26/2015 3:50 PM	0.0000
11/26/2015 4:00 PM	0.0000
Event 6	
Date and Time	**Flowrate (m^3/s)**
11/27/2015 7:30 AM	0.0000
11/27/2015 7:40 AM	0.0000
11/27/2015 7:50 AM	0.0070
11/27/2015 8:00 AM	0.0130
11/27/2015 8:10 AM	0.0240
11/27/2015 8:20 AM	0.0300
11/27/2015 8:30 AM	0.0330
11/27/2015 8:40 AM	0.0330
11/27/2015 8:50 AM	0.0240
11/27/2015 9:00 AM	0.0100
11/27/2015 9:10 AM	0.0000

Event 7	
Date and Time	**Flowrate (m^3/s)**
11/29/2015 1:00 AM	0.0000
11/29/2015 1:10 AM	0.0000
11/29/2015 1:20 AM	0.0000
11/29/2015 1:30 AM	0.0100
11/29/2015 1:40 AM	0.0200
11/29/2015 1:50 AM	0.0500
11/29/2015 2:00 AM	0.0829
11/29/2015 2:10 AM	0.0473
11/29/2015 2:20 AM	0.0134
11/29/2015 2:30 AM	0.0000
11/29/2015 2:40 AM	0.0200
11/29/2015 2:50 AM	0.0647
11/29/2015 3:00 AM	0.1401
11/29/2015 3:10 AM	0.1373
11/29/2015 3:20 AM	0.0496
11/29/2015 3:30 AM	0.0040
11/29/2015 3:40 AM	0.0100
11/29/2015 3:50 AM	0.0210
11/29/2015 4:00 AM	0.0350
11/29/2015 4:10 AM	0.0300
11/29/2015 4:20 AM	0.0194
11/29/2015 4:30 AM	0.0067
11/29/2015 4:40 AM	0.0000
11/29/2015 4:50 AM	0.0000

Event 8	
Date and Time	**Flowrate (m^3/s)**
12/08/2015 11:50 PM	0.0000
12/08/2015 12:00 PM	0.0001
12/08/2015 12:10 PM	0.0240
12/08/2015 12:20 PM	0.0800
12/08/2015 12:30 PM	0.0883
12/08/2015 12:40 PM	0.0225
12/08/2015 12:50 PM	0.0000
Event 9	
Date and Time	**Flowrate (m^3/s)**
12/09/2015 04:30 PM	0.0000
12/09/2015 04:40 PM	0.0013
12/09/2015 04:50 PM	0.0200
12/09/2015 05:00 PM	0.0602
12/09/2015 05:10 PM	0.0650
12/09/2015 05:20 PM	0.1317
12/09/2015 05:30 PM	0.1433
12/09/2015 05:40 PM	0.1429
12/09/2015 05:50 PM	0.1101
12/09/2015 06:00 PM	0.0547
12/09/2015 06:10 PM	0.0160
12/09/2015 06:20 PM	0.0032
12/09/2015 06:30 PM	0.0013
12/09/2015 06:40 PM	0.0000

Appendix C: Water Level Data

Appendix C: Water Level Data

Site Name	UMP
Isco Quantity	Water Level
Label	Water Level
Units	m
Resolution	0.001
Significant Digits	5

Event 1	
Date and Time	**Water Level (m)**
11/20/2015 12:20 PM	0.0000
11/20/2015 12:30 PM	0.0010
11/20/2015 12:40 PM	0.0010
11/20/2015 12:50 PM	0.0010
11/20/2015 1:00 PM	0.0670
11/20/2015 1:10 PM	0.0880
11/20/2015 1:20 PM	0.0220
11/20/2015 1:30 PM	0.0010
11/20/2015 1:40 PM	0.0900
11/20/2015 1:50 PM	0.1470
11/20/2015 2:00 PM	0.0460
11/20/2015 2:10 PM	0.0060
Event 2	
Date and Time	**Water Level (m)**
11/22/2015 11:00 AM	0.0010
11/22/2015 11:10 AM	0.0010
11/22/2015 11:20 AM	0.0010
11/22/2015 11:30 AM	0.0020
11/22/2015 11:40 AM	0.0640
11/22/2015 11:50 AM	0.0730
11/22/2015 12:00 PM	0.0630
11/22/2015 12:10 PM	0.0110
11/22/2015 12:20 PM	0.0000
11/22/2015 12:30 PM	0.0020

Event 3	
Date and Time	**Water Level (m)**
11/24/2015 5:00 PM	0.1540
11/24/2015 5:10 PM	0.1880
11/24/2015 5:20 PM	0.1820
11/24/2015 5:30 PM	0.1180
11/24/2015 5:40 PM	0.0540
11/24/2015 5:50 PM	0.0090
11/24/2015 6:00 PM	0.0090
11/24/2015 6:10 PM	0.0100
11/24/2015 6:20 PM	0.0100
11/24/2015 6:30 PM	0.0100
11/24/2015 6:40 PM	0.0100
11/24/2015 6:50 PM	0.0100
Event 4	
Date and Time	**Water Level (m)**
11/25/2015 3:00 PM	0.0000
11/25/2015 3:10 PM	0.0000
11/25/2015 3:20 PM	0.0000
11/25/2015 3:30 PM	0.0030
11/25/2015 3:40 PM	0.0820
11/25/2015 3:50 PM	0.0810
11/25/2015 4:00 PM	0.0110
11/25/2015 4:10 PM	0.0000
11/25/2015 4:20 PM	0.0000

Event 5	
Date and Time	**Water Level (m)**
11/26/2015 2:20 PM	0.0020
11/26/2015 2:30 PM	0.0020
11/26/2015 2:40 PM	0.0050
11/26/2015 2:50 PM	0.0950
11/26/2015 3:00 PM	0.0620
11/26/2015 3:10 PM	0.0250
11/26/2015 3:20 PM	0.0130
11/26/2015 3:30 PM	0.0570
11/26/2015 3:40 PM	0.0150
11/26/2015 3:50 PM	0.0030
11/26/2015 4:00 PM	0.0010
Event 6	
Date and Time	**Water Level (m)**
11/27/2015 7:30 AM	0.0040
11/27/2015 7:40 AM	0.0040
11/27/2015 7:50 AM	0.0040
11/27/2015 8:00 AM	0.0050
11/27/2015 8:10 AM	0.0050
11/27/2015 8:20 AM	0.0080
11/27/2015 8:30 AM	0.0170
11/27/2015 8:40 AM	0.0170
11/27/2015 8:50 AM	0.0210
11/27/2015 9:00 AM	0.0050
11/27/2015 9:10 AM	0.0000

Event 7	
Date and Time	**Water Level (m)**
11/29/2015 1:00 AM	0.0000
11/29/2015 1:10 AM	0.0000
11/29/2015 1:20 AM	0.0000
11/29/2015 1:30 AM	0.0000
11/29/2015 1:40 AM	0.0000
11/29/2015 1:50 AM	0.0000
11/29/2015 2:00 AM	0.0240
11/29/2015 2:10 AM	0.0570
11/29/2015 2:20 AM	0.0240
11/29/2015 2:30 AM	0.0000
11/29/2015 2:40 AM	0.0000
11/29/2015 2:50 AM	0.0060
11/29/2015 3:00 AM	0.1160
11/29/2015 3:10 AM	0.0910
11/29/2015 3:20 AM	0.0350
11/29/2015 3:30 AM	0.0100
11/29/2015 3:40 AM	0.0000
11/29/2015 3:50 AM	0.0040
11/29/2015 4:00 AM	0.0017
11/29/2015 4:10 AM	0.0000
11/29/2015 4:20 AM	0.0060
11/29/2015 4:30 AM	0.0130
11/29/2015 4:40 AM	0.0000
11/29/2015 4:50 AM	0.0000

Event 8	
Date and Time	**Water Level (mm)**
12/08/2015 11:50 PM	0.0000
12/08/2015 12:00 PM	0.0000
12/08/2015 12:10 PM	0.0350
12/08/2015 12:20 PM	0.0570
12/08/2015 12:30 PM	0.0830
12/08/2015 12:40 PM	0.0340
12/08/2015 12:50 PM	0.0000
Event 9	
Date and Time	**Water Level (mm)**
12/09/2015 04:30 PM	0.0010
12/09/2015 04:40 PM	0.0020
12/09/2015 04:50 PM	0.0020
12/09/2015 05:00 PM	0.0020
12/09/2015 05:10 PM	0.0750
12/09/2015 05:20 PM	0.0520
12/09/2015 05:30 PM	0.0230
12/09/2015 05:40 PM	0.0000
12/09/2015 05:50 PM	0.0000
12/09/2015 06:00 PM	0.0020
12/09/2015 06:10 PM	0.0040
12/09/2015 06:20 PM	0.0070
12/09/2015 06:30 PM	0.0030
12/09/2015 06:40 PM	0.0010

Appendix D:

Efficiency Index Data

(Snyder Method)

Appendix D: Efficiency Index Data (Snyder Method)

20/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
12:20 PM	0.0000	0.0000	0.0000	0.0000	0.0691	-0.0691	0.0048
12:30 PM	0.0000	0.0000	0.0000	0.0000	0.0691	-0.0691	0.0048
12:40 PM	0.0510	0.0400	0.0110	0.0001	0.0691	-0.0181	0.0003
12:50 PM	0.1949	0.1600	0.0349	0.0012	0.0691	0.1258	0.0158
1:00 PM	0.2342	0.2340	0.0002	0.0000	0.0691	0.1651	0.0273
1:10 PM	0.0524	0.1200	-0.0676	0.0046	0.0691	-0.0167	0.0003
1:20 PM	0.0000	0.0290	-0.0290	0.0008	0.0691	-0.0691	0.0048
1:30 PM	0.0450	0.0780	-0.0330	0.0011	0.0691	-0.0241	0.0006
1:40 PM	0.1517	0.2000	-0.0483	0.0023	0.0691	0.0826	0.0068
1:50 PM	0.1000	0.1750	-0.0750	0.0056	0.0691	0.0309	0.0010
2:00 PM	0.0000	0.0300	-0.0300	0.0009	0.0691	-0.0691	0.0048
2:10 PM	0.0000	0.0000	0.0000	0.0000	0.0691	-0.0691	0.0048
$\Sigma Q_i =$	0.8292	$\Sigma(Q_i - F_i)^2 =$		0.0167	$\Sigma(Q_i - Q_{ag})^2 =$		0.0759

22/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
11:00 AM	0.0000	0.0000	0.0000	0.0000	0.0300	-0.0300	0.0009
11:10 AM	0.0000	0.0000	0.0000	0.0000	0.0300	-0.0300	0.0009
11:20 AM	0.0007	0.0200	-0.0193	0.0004	0.0300	-0.0293	0.0009
11:30 AM	0.0605	0.0800	-0.0195	0.0004	0.0300	0.0305	0.0009
11:40 AM	0.1200	0.1400	-0.0200	0.0004	0.0300	0.0900	0.0081
11:50 AM	0.0635	0.1000	-0.0365	0.0013	0.0300	0.0335	0.0011
12:00 PM	0.0039	0.0300	-0.0261	0.0007	0.0300	-0.0261	0.0007
12:10 PM	0.0000	0.0000	0.0000	0.0000	0.0300	-0.0300	0.0009
12:20 PM	0.0000	0.0000	0.0000	0.0000	0.0300	-0.0300	0.0009
12:30 PM	0.0000	0.0000	0.0000	0.0000	0.0300	-0.0300	0.0009
$\Sigma Q_i =$	0.2486	$\Sigma(Q_i - F_i)^2 =$		0.0032	$\Sigma(Q_i - Q_{ag})^2 =$		0.0162

24/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
5:00 PM	0.0000	0.0000	0.0000	0.0000	0.0927	-0.0927	0.0086
5:10 PM	0.0000	0.0000	0.0000	0.0000	0.0927	-0.0927	0.0086
5:20 PM	0.0460	0.1200	-0.0740	0.0055	0.0927	-0.0467	0.0022
5:30 PM	0.2090	0.4000	-0.1910	0.0365	0.0927	0.1163	0.0135
5:40 PM	0.2930	0.4800	-0.1870	0.0350	0.0927	0.2003	0.0401
5:50 PM	0.2800	0.2800	0.0000	0.0000	0.0927	0.1873	0.0351
6:00 PM	0.1770	0.1000	0.0770	0.0059	0.0927	0.0843	0.0071
6:10 PM	0.0800	0.0300	0.0500	0.0025	0.0927	-0.0127	0.0002
6:20 PM	0.0180	0.0000	0.0180	0.0003	0.0927	-0.0747	0.0056
6:30 PM	0.0030	0.0000	0.0030	0.0000	0.0927	-0.0897	0.0080
6:40 PM	0.0030	0.0000	0.0030	0.0000	0.0927	-0.0897	0.0080
6:50 PM	0.0030	0.0000	0.0030	0.0000	0.0927	-0.0897	0.0080
$\Sigma Q_i =$	1.1120	$\Sigma(Q_i - F_i)^2 =$		0.0857	$\Sigma(Q_i - Q_{ag})^2 =$		0.1451

25/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
3:00 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.000
3:10 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.000
3:20 PM	0.0075	0.010	-0.003	0.0000	0.008	-0.001	0.000
3:30 PM	0.0286	0.037	-0.008	0.0001	0.008	0.020	0.000
3:40 PM	0.0332	0.045	-0.012	0.0001	0.008	0.025	0.001
3:50 PM	0.0050	0.016	-0.011	0.0001	0.008	-0.003	0.000
4:00 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.000
4:10 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.000
4:20 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.000
$\Sigma Q_i =$	0.0743	$\Sigma(Q_i - F_i)^2 =$		0.0003	$\Sigma(Q_i - Q_{ag})^2 =$		0.0014

26/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
2:20 PM	0.0000	0.0000	0.0000	0.0000	0.0423	-0.0423	0.0018
2:30 PM	0.0000	0.0000	0.0000	0.0000	0.0423	-0.0423	0.0018
2:40 PM	0.0600	0.0600	0.0000	0.0000	0.0423	0.0177	0.0003
2:50 PM	0.1470	0.1500	-0.0030	0.0000	0.0423	0.1047	0.0110
3:00 PM	0.1220	0.1400	-0.0180	0.0003	0.0423	0.0797	0.0064
3:10 PM	0.0400	0.0600	-0.0200	0.0004	0.0423	-0.0023	0.0000
3:20 PM	0.0350	0.0350	0.0000	0.0000	0.0423	-0.0073	0.0001
3:30 PM	0.0510	0.0600	-0.0090	0.0001	0.0423	0.0087	0.0001
3:40 PM	0.0100	0.0400	-0.0300	0.0009	0.0423	-0.0323	0.0010
3:50 PM	0.0000	0.0150	-0.0150	0.0002	0.0423	-0.0423	0.0018
4:00 PM	0.0000	0.0000	0.0000	0.0000	0.0423	-0.0423	0.0018
$\Sigma Q_i =$	0.4650	$\Sigma(Q_i - F_i)^2 =$		0.0019	$\Sigma(Q_i - Q_{ag})^2 =$		0.0260

27/12/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
7:30 PM	0.0000	0.0000	0.0000	0.0000	0.0158	-0.0158	0.0003
7:40 PM	0.0000	0.0040	-0.0040	0.0000	0.0158	-0.0158	0.0003
7:50 PM	0.0070	0.0150	-0.0080	0.0001	0.0158	-0.0088	0.0001
8:00 PM	0.0130	0.0270	-0.0140	0.0002	0.0158	-0.0028	0.0000
8:10 PM	0.0240	0.0370	-0.0130	0.0002	0.0158	0.0082	0.0001
8:20 PM	0.0300	0.0400	-0.0100	0.0001	0.0158	0.0142	0.0002
8:30 PM	0.0330	0.0400	-0.0070	0.0000	0.0158	0.0172	0.0003
8:40 PM	0.0330	0.0350	-0.0020	0.0000	0.0158	0.0172	0.0003
8:50 PM	0.0240	0.0250	-0.0010	0.0000	0.0158	0.0082	0.0001
9:00 PM	0.0100	0.0120	-0.0020	0.0000	0.0158	-0.0058	0.0000
9:10 PM	0.0000	0.0030	-0.0030	0.0000	0.0158	-0.0158	0.0003
$\Sigma Q_i =$	0.1740	$\Sigma(Q_i - F_i)^2 =$		0.0006	$\Sigma(Q_i - Q_{ag})^2 =$		0.0018

29/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
1:00 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
1:10 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
1:20 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
1:30 AM	0.0100	0.0200	-0.0100	0.0001	0.0317	-0.0217	0.0005
1:40 AM	0.0200	0.0350	-0.0150	0.0002	0.0317	-0.0117	0.0001
1:50 AM	0.0500	0.0830	-0.0330	0.0011	0.0317	0.0183	0.0003
2:00 AM	0.0829	0.1100	-0.0271	0.0007	0.0317	0.0512	0.0026
2:10 AM	0.0473	0.0670	-0.0197	0.0004	0.0317	0.0156	0.0002
2:20 AM	0.0134	0.0200	-0.0066	0.0000	0.0317	-0.0183	0.0003
2:30 AM	0.0000	0.0150	-0.0150	0.0002	0.0317	-0.0317	0.0010
2:40 AM	0.0200	0.0400	-0.0200	0.0004	0.0317	-0.0117	0.0001
2:50 AM	0.0647	0.1340	-0.0693	0.0048	0.0317	0.0330	0.0011
3:00 AM	0.1401	0.1500	-0.0099	0.0001	0.0317	0.1084	0.0117
3:10 AM	0.1373	0.0600	0.0773	0.0060	0.0317	0.1056	0.0111
3:20 AM	0.0496	0.0100	0.0396	0.0016	0.0317	0.0179	0.0003
3:30 AM	0.0040	0.0120	-0.0080	0.0001	0.0317	-0.0277	0.0008
3:40 AM	0.0100	0.0240	-0.0140	0.0002	0.0317	-0.0217	0.0005
3:50 AM	0.0210	0.0380	-0.0170	0.0003	0.0317	-0.0107	0.0001
4:00 AM	0.0350	0.0390	-0.0040	0.0000	0.0317	0.0033	0.0000
4:10 AM	0.0300	0.0300	0.0000	0.0000	0.0317	-0.0017	0.0000
4:20 AM	0.0194	0.0200	-0.0006	0.0000	0.0317	-0.0123	0.0002
4:30 AM	0.0067	0.0200	-0.0133	0.0002	0.0317	-0.0250	0.0006
4:40 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
4:50 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
$\Sigma Q_i =$	0.7614	$\Sigma(Q_i - F_i)^2 =$		0.0164	$\Sigma(Q_i - Q_{ag})^2 =$		0.0368

8/12/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
12:00 PM	0.0001	0.0000	0.0001	0.0000	0.0195	-0.0194	0.0004
12:10 PM	0.0240	0.0300	-0.0060	0.0000	0.0195	0.0045	0.0000
12:20 PM	0.0800	0.0880	-0.0080	0.0001	0.0195	0.0605	0.0037
12:30 PM	0.0883	0.0820	0.0063	0.0000	0.0195	0.0688	0.0047
12:40 PM	0.0225	0.0260	-0.0035	0.0000	0.0195	0.0030	0.0000
12:50 PM	0.0000	0.0000	0.0000	0.0000	0.0195	-0.0195	0.0004
$\Sigma Q_i =$	0.2149	$\Sigma(Q_i - F_i)^2 =$		0.0164	$\Sigma(Q_i - Q_{ag})^2 =$		0.0368

9/12/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
4:40 PM	0.0013	0.0000	0.0013	0.0000	0.0580	-0.0567	0.0032
4:50 PM	0.0200	0.0300	-0.0100	0.0001	0.0580	-0.0380	0.0014
5:00 PM	0.0852	0.0700	0.0152	0.0002	0.0580	0.0272	0.0007
5:10 PM	0.0982	0.0750	0.0232	0.0005	0.0580	0.0402	0.0016
5:20 PM	0.1317	0.1100	0.0217	0.0005	0.0580	0.0737	0.0054
5:30 PM	0.1263	0.1580	-0.0317	0.0010	0.0580	0.0683	0.0047
5:40 PM	0.1160	0.1560	-0.0400	0.0016	0.0580	0.0580	0.0034
5:50 PM	0.1001	0.1300	-0.0299	0.0009	0.0580	0.0421	0.0018
6:00 PM	0.0547	0.0600	-0.0053	0.0000	0.0580	-0.0033	0.0000
6:10 PM	0.0160	0.0100	0.0060	0.0000	0.0580	-0.0420	0.0018
6:20 PM	0.0032	0.0000	0.0032	0.0000	0.0580	-0.0548	0.0030
6:30 PM	0.0013	0.0000	0.0013	0.0000	0.0580	-0.0567	0.0032
6:40 PM	0.0000	0.0000	0.0000	0.0000	0.0580	-0.0580	0.0034
$\Sigma Q_i =$	0.7540	$\Sigma(Q_i - F_i)^2 =$		0.0049	$\Sigma(Q_i - Q_{ag})^2 =$		0.0336

Appendix E:

Efficiency Index Data

(Clark Time Area Method)

Appendix E: Efficiency Index Data (Clark Time Area Method)

20/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
12:20 PM	0.0000	0.0000	0.0000	0.0000	0.0691	-0.0691	0.0048
12:30 PM	0.0000	0.0000	0.0000	0.0000	0.0691	-0.0691	0.0048
12:40 PM	0.0510	0.0400	0.0110	0.0001	0.0691	-0.0181	0.0003
12:50 PM	0.1949	0.1700	0.0249	0.0006	0.0691	0.1258	0.0158
1:00 PM	0.2342	0.2200	0.0142	0.0002	0.0691	0.1651	0.0273
1:10 PM	0.0524	0.1000	-0.0476	0.0023	0.0691	-0.0167	0.0003
1:20 PM	0.0000	0.0300	-0.0300	0.0009	0.0691	-0.0691	0.0048
1:30 PM	0.0450	0.1000	-0.0550	0.0030	0.0691	-0.0241	0.0006
1:40 PM	0.1517	0.2100	-0.0583	0.0034	0.0691	0.0826	0.0068
1:50 PM	0.1000	0.1500	-0.0500	0.0025	0.0691	0.0309	0.0010
2:00 PM	0.0000	0.0500	-0.0500	0.0025	0.0691	-0.0691	0.0048
2:10 PM	0.0000	0.0000	0.0000	0.0000	0.0691	-0.0691	0.0048
$\Sigma Q_i =$	0.8292	$\Sigma(Q_i - F_i)^2 =$		0.0155	$\Sigma(Q_i - Q_{ag})^2 =$		0.0759

22/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
11:00 AM	0.0000	0.0000	0.0000	0.0000	0.0254	-0.0254	0.0006
11:10 AM	0.0000	0.0000	0.0000	0.0000	0.0254	-0.0254	0.0006
11:20 AM	0.0000	0.0200	-0.0200	0.0004	0.0254	-0.0254	0.0006
11:30 AM	0.0600	0.0900	-0.0300	0.0009	0.0254	0.0346	0.0012
11:40 AM	0.1200	0.1400	-0.0200	0.0004	0.0254	0.0946	0.0089
11:50 AM	0.0670	0.0900	-0.0230	0.0005	0.0254	0.0416	0.0017
12:00 PM	0.0070	0.0200	-0.0130	0.0002	0.0254	-0.0184	0.0003
12:10 PM	0.0000	0.0020	-0.0020	0.0000	0.0254	-0.0254	0.0006
12:20 PM	0.0000	0.0000	0.0000	0.0000	0.0254	-0.0254	0.0006
12:30 PM	0.0000	0.0000	0.0000	0.0000	0.0254	-0.0254	0.0006
$\Sigma Q_i =$	0.2540	$\Sigma(Q_i - F_i)^2 =$		0.0024	$\Sigma(Q_i - Q_{ag})^2 =$		0.0161

24/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
5:00 PM	0.0000	0.0000	0.0000	0.0000	0.0917	-0.0917	0.0084
5:10 PM	0.0000	0.0000	0.0000	0.0000	0.0917	-0.0917	0.0084
5:20 PM	0.0000	0.2000	-0.2000	0.0400	0.0917	-0.0917	0.0084
5:30 PM	0.2000	0.4000	-0.2000	0.0400	0.0917	0.1083	0.0117
5:40 PM	0.3000	0.4000	-0.1000	0.0100	0.0917	0.2083	0.0434
5:50 PM	0.3000	0.3000	0.0000	0.0000	0.0917	0.2083	0.0434
6:00 PM	0.2000	0.1000	0.1000	0.0100	0.0917	0.1083	0.0117
6:10 PM	0.1000	0.0000	0.1000	0.0100	0.0917	0.0083	0.0001
6:20 PM	0.0000	0.0000	0.0000	0.0000	0.0917	-0.0917	0.0084
6:30 PM	0.0000	0.0000	0.0000	0.0000	0.0917	-0.0917	0.0084
6:40 PM	0.0000	0.0000	0.0000	0.0000	0.0917	-0.0917	0.0084
6:50 PM	0.0000	0.0000	0.0000	0.0000	0.0917	-0.0917	0.0084
$\Sigma Q_i =$	1.1000	$\Sigma(Q_i - F_i)^2 =$		0.1100	$\Sigma(Q_i - Q_{ag})^2 =$		0.1692

25/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
3:00 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.0001
3:10 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.0001
3:20 PM	0.0075	0.009	-0.002	0.0000	0.008	-0.001	0.0000
3:30 PM	0.0286	0.040	-0.011	0.0002	0.008	0.020	0.0004
3:40 PM	0.0332	0.043	-0.010	0.0001	0.008	0.025	0.0006
3:50 PM	0.0050	0.015	-0.010	0.0001	0.008	-0.003	0.0000
4:00 PM	0.0000	0.002	-0.002	0.0000	0.008	-0.008	0.0001
4:10 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.0001
4:20 PM	0.0000	0.000	0.000	0.0000	0.008	-0.008	0.0001
$\Sigma Q_i =$	0.0743	$\Sigma(Q_i - F_i)^2 =$		0.0004	$\Sigma(Q_i - Q_{ag})^2 =$		0.0014

26/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
2:20 PM	0.0000	0.0000	0.0000	0.0000	0.0423	-0.0423	0.0018
2:30 PM	0.0000	0.0000	0.0000	0.0000	0.0423	-0.0423	0.0018
2:40 PM	0.0600	0.0700	-0.0100	0.0001	0.0423	0.0177	0.0003
2:50 PM	0.1470	0.1580	-0.0110	0.0001	0.0423	0.1047	0.0110
3:00 PM	0.1220	0.1280	-0.0060	0.0000	0.0423	0.0797	0.0064
3:10 PM	0.0400	0.0500	-0.0100	0.0001	0.0423	-0.0023	0.0000
3:20 PM	0.0350	0.0400	-0.0050	0.0000	0.0423	-0.0073	0.0001
3:30 PM	0.0510	0.0600	-0.0090	0.0001	0.0423	0.0087	0.0001
3:40 PM	0.0100	0.0400	-0.0300	0.0009	0.0423	-0.0323	0.0010
3:50 PM	0.0000	0.0100	-0.0100	0.0001	0.0423	-0.0423	0.0018
4:00 PM	0.0000	0.0000	0.0000	0.0000	0.0423	-0.0423	0.0018
$\Sigma Q_i =$	0.4650	$\Sigma(Q_i - F_i)^2 =$		0.0015	$\Sigma(Q_i - Q_{ag})^2 =$		0.0260

27/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
7:30 PM	0.0000	0.0000	0.0000	0.0000	0.0158	-0.0158	0.0003
7:40 PM	0.0000	0.0050	-0.0050	0.0000	0.0158	-0.0158	0.0003
7:50 PM	0.0070	0.0150	-0.0080	0.0001	0.0158	-0.0088	0.0001
8:00 PM	0.0130	0.0280	-0.0150	0.0002	0.0158	-0.0028	0.0000
8:10 PM	0.0240	0.0370	-0.0130	0.0002	0.0158	0.0082	0.0001
8:20 PM	0.0300	0.0400	-0.0100	0.0001	0.0158	0.0142	0.0002
8:30 PM	0.0330	0.0400	-0.0070	0.0000	0.0158	0.0172	0.0003
8:40 PM	0.0330	0.0370	-0.0040	0.0000	0.0158	0.0172	0.0003
8:50 PM	0.0240	0.0250	-0.0010	0.0000	0.0158	0.0082	0.0001
9:00 PM	0.0100	0.0120	-0.0020	0.0000	0.0158	-0.0058	0.0000
9:10 PM	0.0000	0.0030	-0.0030	0.0000	0.0158	-0.0158	0.0003
$\Sigma Q_i =$	0.1740	$\Sigma(Q_i - F_i)^2 =$		0.0007	$\Sigma(Q_i - Q_{ag})^2 =$		0.0018

29/11/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
1:00 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
1:10 AM	0.0000	0.0050	-0.0050	0.0000	0.0317	-0.0317	0.0010
1:20 AM	0.0000	0.0180	-0.0180	0.0003	0.0317	-0.0317	0.0010
1:30 AM	0.0100	0.0200	-0.0100	0.0001	0.0317	-0.0217	0.0005
1:40 AM	0.0200	0.0400	-0.0200	0.0004	0.0317	-0.0117	0.0001
1:50 AM	0.0500	0.0900	-0.0400	0.0016	0.0317	0.0183	0.0003
2:00 AM	0.0829	0.1120	-0.0291	0.0008	0.0317	0.0512	0.0026
2:10 AM	0.0473	0.0600	-0.0127	0.0002	0.0317	0.0156	0.0002
2:20 AM	0.0134	0.0160	-0.0026	0.0000	0.0317	-0.0183	0.0003
2:30 AM	0.0000	0.0100	-0.0100	0.0001	0.0317	-0.0317	0.0010
2:40 AM	0.0200	0.0500	-0.0300	0.0009	0.0317	-0.0117	0.0001
2:50 AM	0.0647	0.1430	-0.0783	0.0061	0.0317	0.0330	0.0011
3:00 AM	0.1401	0.1410	-0.0009	0.0000	0.0317	0.1084	0.0117
3:10 AM	0.1373	0.0600	0.0773	0.0060	0.0317	0.1056	0.0111
3:20 AM	0.0496	0.0140	0.0356	0.0013	0.0317	0.0179	0.0003
3:30 AM	0.0040	0.0130	-0.0090	0.0001	0.0317	-0.0277	0.0008
3:40 AM	0.0100	0.0300	-0.0200	0.0004	0.0317	-0.0217	0.0005
3:50 AM	0.0210	0.0400	-0.0190	0.0004	0.0317	-0.0107	0.0001
4:00 AM	0.0350	0.0350	0.0000	0.0000	0.0317	0.0033	0.0000
4:10 AM	0.0300	0.0350	-0.0050	0.0000	0.0317	-0.0017	0.0000
4:20 AM	0.0194	0.0230	-0.0036	0.0000	0.0317	-0.0123	0.0002
4:30 AM	0.0067	0.0190	-0.0123	0.0002	0.0317	-0.0250	0.0006
4:40 AM	0.0000	0.0100	-0.0100	0.0001	0.0317	-0.0317	0.0010
4:50 AM	0.0000	0.0000	0.0000	0.0000	0.0317	-0.0317	0.0010
$\Sigma Q_i =$	0.7614	$\Sigma(Q_i - F_i)^2 =$		0.0190	$\Sigma(Q_i - Q_{ag})^2 =$		0.0368

8/12/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
12:00 PM	0.0001	0.0000	0.0001	0.0000	0.0195	-0.0194	0.0004
12:10 PM	0.0240	0.0350	-0.0110	0.0001	0.0195	0.0045	0.0000
12:20 PM	0.0800	0.0850	-0.0050	0.0000	0.0195	0.0605	0.0037
12:30 PM	0.0883	0.0730	0.0153	0.0002	0.0195	0.0688	0.0047
12:40 PM	0.0225	0.0225	0.0000	0.0000	0.0195	0.0030	0.0000
12:50 PM	0.0000	0.0000	0.0000	0.0000	0.0195	-0.0195	0.0004
$\Sigma Q_i =$	0.2149	$\Sigma(Q_i - F_i)^2 =$		0.0004	$\Sigma(Q_i - Q_{ag})^2 =$		0.0092

9/12/2015							
Time	Q_i	F_i	$(Q_i - F_i)$	$(Q_i - F_i)^2$	Q_{ag}	$Q_i - Q_{ag}$	$(Q_i - Q_{ag})^2$
4:40 PM	0.0000	0.0000	0.0000	0.0000	0.0588	-0.0588	0.0035
4:50 PM	0.0200	0.0300	-0.0100	0.0001	0.0588	-0.0388	0.0015
5:00 PM	0.0890	0.0500	0.0390	0.0015	0.0588	0.0302	0.0009
5:10 PM	0.1000	0.0500	0.0500	0.0025	0.0588	0.0412	0.0017
5:20 PM	0.1300	0.1200	0.0100	0.0001	0.0588	0.0712	0.0051
5:30 PM	0.1270	0.1500	-0.0230	0.0005	0.0588	0.0682	0.0046
5:40 PM	0.1180	0.1500	-0.0320	0.0010	0.0588	0.0592	0.0035
5:50 PM	0.1000	0.1300	-0.0300	0.0009	0.0588	0.0412	0.0017
6:00 PM	0.0570	0.0570	0.0000	0.0000	0.0588	-0.0018	0.0000
6:10 PM	0.0180	0.0110	0.0070	0.0000	0.0588	-0.0408	0.0017
6:20 PM	0.0050	0.0000	0.0050	0.0000	0.0588	-0.0538	0.0029
6:30 PM	0.0010	0.0050	-0.0040	0.0000	0.0588	-0.0578	0.0033
6:40 PM	0.0000	0.0570	-0.0570	0.0032	0.0588	-0.0588	0.0035
$\Sigma Q_i =$	0.7650	$\Sigma(Q_i - F_i)^2 =$		0.0100	$\Sigma(Q_i - Q_{ag})^2 =$		0.0339