HP 11

HYDROLOGICAL PROCEDURE

DESIGN FLOOD HYDROGRAPH ESTIMATION FOR RURAL CATCHMENTS IN MALAYSIA

(REVISED AND UPDATED 2018)

BERSEKUTU BERTAMBAH MUTU

DEPARTMENT OF IRRIGATION AND DRAINAGE MALAYSIA

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DESIGN FLOOD HYDROGRAPH ESTIMATION FOR RURAL CATCHMENTS IN MALAYSIA

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PREFACE

The design of many hydraulic structures requires a reliable and realistic estimate of the design flood hydrograph. When no streamflow records are available, as is often the case, the design flood hydrograph may be derived from a design storm.

The Hydrological Procedure No. 11: Design Flood Hydrograph Estimation for Rural Catchments in Malaysia was previously published in 1976 (HP 11, 1976). The data used were limited to up to 1973 data and it was only developed for Peninsular Malaysia and not applicable for Sabah and Sarawak. The revised and updated HP 11 (HP 11, 2018) has been developed based on data up to 2017, incorporating new rainfall and streamflow stations that have been added and the record lengths that have increased in the Peninsular Malaysia and the use of local data collected by DID Sabah and DID Sarawak. HP 11 (2018) is expected to yield better accuracy of flood estimate as more detailed data and advanced analysis method were used for its development and can be used for Peninsular Malaysia, Sabah and Sarawak.

This Procedure presents a deterministic method of estimating the design flood hydrograph for ungauged rural catchments in Malaysia. The Procedure is based on the development of three components: a design storm, a rainfall-runoff relationship and a synthetic Snyder unit hydrograph (UH). Estimation of flood peaks using the Procedure and results obtained from flood frequency analysis show that the Procedure yielded satisfactory results. The limitations of the Procedure are discussed and a number of worked examples illustrating the use of the Procedure are given.

G&P Water and Maritime Sdn Bhd (GPWM) was commissioned by the Water Resources Management and Hydrology Division of DID Malaysia to produce HP 11 (2018) through a Study named *"Revise and Update Hydrological Procedure No. 11: Design Flood Hydrograph Estimation for Rural Catchments in Malaysia bagi Program Memperkasa Data dan Rangkaian Stesen Hidrologi Nasional (RHN) Fasa 1"*, contract no. JPS/IP/C/H/22/2017.

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List of Abbreviations

ARF	Areal Reduction Factor
Bkt	Bukit (Hill)
BPSAH	Bahagian Pengurusan Sumber Air dan Hidrologi
Bt	Batu (Mile)
DID	Department of Irrigation and Drainage
IDF	Intensity-Duration-Frequency
Jam	Jambatan (Bridge)
Jln	Jalan (Road)
JPS	Jabatan Pengairan dan Saliran Malaysia (Department of Irrigation and Drainage)
K	Kuala (Confluence)
Kg	Kampung (Village)
PMP	Probable Maximum Precipitation
SCS	Soil Conservation Services
Sg	Sungai (River)
Tg	Tanjung (Headland)
Tmn	Taman (Park)
UH	Unit Hydrograph
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
USWB	United States Weather Bureau
HEC	Hydrologic Engineering Centre
HP	Hydrological Procedure
HMS	Hydrologic Modelling System

List of Symbols

A	Catchment area
C_p	Peaking coefficient
h_i	Elevation of the main stream at point i
$\bar{h}$	Average values of h_i
H	Measured water level
l_i	Length of the main stream from catchment outlet to point i
$\bar{l}$	Average values of l_i
L	Main stream length
L_c	Main stream length from catchment outlet to catchment centroid
L_g	Lag time
P	Storm rainfall depth
q_p	Peak discharge of standard UH
q_{pR}	Peak discharge of required UH
Q	Discharge or direct runoff
Q_{ave}	Average observed discharge
Q_B	Baseflow
Q_c	Computed discharge
Q_o	Observed discharge
Q_p	Peak discharge
R	Correlation coefficient
R^2	Coefficient of determination
S	Weighted slope of main stream
t_b	Time base
t_{pR}	Lag time of required UH
t_r	Rainfall duration of standard UH
t_R	Rainfall duration of required UH
T_c	Time of concentration
T_p	Time to peak
U	Unit depth of net rainfall
WT_i	Weighting factor for time index i

1. Introduction

A problem commonly encountered in the engineering field is the determination of the design flood. The design flood may be defined as the discharge magnitude of a specified protection level adopted for the design of a flood control structure taking into consideration the hydrologic and economic factors.

Design flood estimation using established methodology is relatively simple when records of streamflow and rainfall are available for the catchment concerned. The difficulties arise when no such records are available in which case the designer is faced with two alternatives:

(i) To instrument the catchment for the period required to collect the hydrological data necessary to derive the design flood.

(ii) To estimate the design flood using a flood estimation procedure.

The former approach is generally time consuming and expensive and is generally only warranted on projects involving major capital expenditure. The latter approach is undoubtedly subject to a greater degree of uncertainty, but nevertheless has to be used in the absence of the required hydrological data. Design flood estimates made using a flood estimation procedure should therefore be interpreted sensibly within the limitations of the method and where possible checked using an alternative flood estimation method available.

Four procedures for estimating the design flood of ungauged rural catchments have been adopted for use in Peninsular Malaysia – the Rational Method, Hydrological Procedure No. 5 (HP 5, 2010), the Regional Flood Frequency Method, Hydrological Procedure No. 4 (HP 4, 1987), Design Flood Hydrograph Estimation for Rural Catchments in Peninsular Malaysia, Hydrological Procedure No. 11 (HP 11, 1976) and Estimation of Design Flood Hydrograph using Clark Method for Catchments in Peninsular Malaysia, Hydrological Procedure No. 27 (HP 27, 2010). These procedures were developed from flood studies of Malaysian gauged catchments.

The Rational Method and the Regional Flood Frequency Method provide a means of estimating the design flood peak only. Although this is often sufficient, the design of many engineering works requires a consideration of storage upstream of the structure e.g. dam spillways, culverts with upstream ponding etc. The complete design flood hydrograph at the point of interest is therefore necessary.

This Procedure is a revision of the HP 11 (1976) "Design Flood Hydrograph Estimation for Rural Catchments in Peninsular Malaysia" hereby termed as HP 11 (1976) and in addition, methods for design flood hydrograph for Sabah and Sarawak were also developed and presented. The Procedure is not applicable to urban catchments.

2. Purpose of the Procedure

The purpose of this Procedure is to estimate the peak flow, the volume and time distribution of runoff for various return periods. This Procedure is developed taking into consideration:

(i) Significant differences in the catchment characteristics that affect flood.
(ii) Utilize catchment data that can be readily determined from topographical maps.
(iii) Be simple and relatively fast to apply.
(iv) Utilize advances in hydrological methods and computer modelling.

3. Development of the Procedure

3.1 General

A review by Cordery and Pilgrim (1970) shows that three common steps used in estimating design flood hydrographs are:

(i) The specification of design storm which includes the return period, the total rainfall volume, rainfall duration, the areal distribution and temporal distribution.

(ii) The estimation of runoff volume resulting from the design rainstorm.

(iii) The time distribution of runoff volume from the catchment.

Over the years, a number of techniques have been developed for estimating the components listed in the three steps above. However, the ability to develop a reliable design flood hydrograph estimation procedure depends on the availability and reliability of streamflow and rainfall data. After more than 40 years since the development of HP 11 (1976), more data especially streamflow data are available for Peninsular Malaysia. DID hydro-meteorological networks have been expanded considerably and resulting in an increase in the record lengths and number of stations in Peninsular Malaysia. The local data collected by DID Sabah and DID Sarawak are also now available. Data collection equipment has been improved thus increasing the data reliability.

3.2 The Design Storm

3.2.1 Return Period

In this Procedure, it is assumed that the return period of the design flood equals the return period of the design storm. This assumption has been adopted for most deterministic flood estimation procedures. The severity of damage caused in the event of design flood depends on the design return period adopted for a project. For large schemes, the design return period is usually based on a cost benefit analysis.

Heiler and Tan (1974) have recommended design return period for different types of water control structures in Malaysia. In cases where there is considerable risk of major damage and loss of lives in the event of design flood being exceeded, it is common practice to adopt the upper limit of the flood regime, such as a probable maximum flood (PMF) derived from probable maximum precipitation (PMP). The techniques for estimating the PMP are beyond the scope of this Procedure but can be referred to the technical guideline by WMO and NAHRIM (NAHRIM, 2009).

3.2.2 Point Rainfall Depth and Frequency

A depth–duration–frequency study of storm rainfall for Malaysia has been compiled in Hydrological Procedure No. 1, HP 1 (2015) and Hydrological Procedure No. 26, HP 26 (2018). These hydrological procedures can be used to estimate the depth of rainfall of a specified return period and duration for any location in Malaysia. Estimation of point rainfall depth using these procedures is reliable. The user may also undertake to analyse rainfall data and derive the catchment Intensity-Duration-Frequency (IDF) using up-to-date and all available data.

3.2.3 Areal Reduction Factor (ARF)

For a storm event, rainfall is usually not evenly distributed over an area with rainfall amount decreasing with distances from the storm centre. For Malaysia, large variations in rainfall amount can occur over short distances, particularly when convective thunderstorms dominate. Rainfall areal reduction factor (ARF) has been studied for Kuala Lumpur and Northern Kelantan (Water Resources Publication No. 17, WRP 17 (1986) and HP 1 (2015)). However, the areas studied are rather limited and not extensive (only up to 200 km^2) and compared to the ARF used in the earlier hydrological procedure (HP 1, 1982), the values derived are low.

In HP 11 (1976), the 24-hour ARF for the data derived in Peninsular Malaysia were plotted with the US Weather Bureau (USWB) curves. The plotted points define a typical rainfall depth-area trend with considerable scatter in the points reflecting different storm rainfall characteristics and return period. The USWB curve for 24-hour duration rainfall forms an upper envelope containing most of the study data. It is considered that this curve represents the likely upper limit of the variation of the ARF with catchment area for 24-hour rainfall typical of the more severe flood producing storms. The variation of the ARF with catchment area for 24-hour and short duration rainfall as recommended by USWB is shown in **Table 1.** For Sabah and Sarawak, the same ARF table for Peninsular Malaysia in HP 11 (1976) developed by USWB was used to convert point estimates to areal average estimates in HP 26 (1983). In this Procedure, the ARF for Peninsular Malaysia, Sabah and Sarawak can be obtained or interpolated from **Table 1**.

Table 1: ARF for Peninsular Malaysia, Sabah and Sarawak

Catchment Area (km^2)	Storm Duration (hrs)				
	0.5	1	3	6	24
0	1.00	1.00	1.00	1.00	1.00
50	0.82	0.88	0.94	0.96	0.97
100	0.73	0.82	0.91	0.94	0.96
150	0.67	0.78	0.89	0.92	0.95
200	0.63	0.75	0.87	0.90	0.93
250	0.61	0.73	0.85	0.89	0.93
300	0.59	0.71	0.84	0.88	0.93
400	0.58	0.68	0.81	0.86	0.92
500		0.67	0.80	0.85	0.92
600		0.66	0.79	0.84	0.91
800		0.65	0.78	0.83	0.91
1000			0.78	0.83	0.91

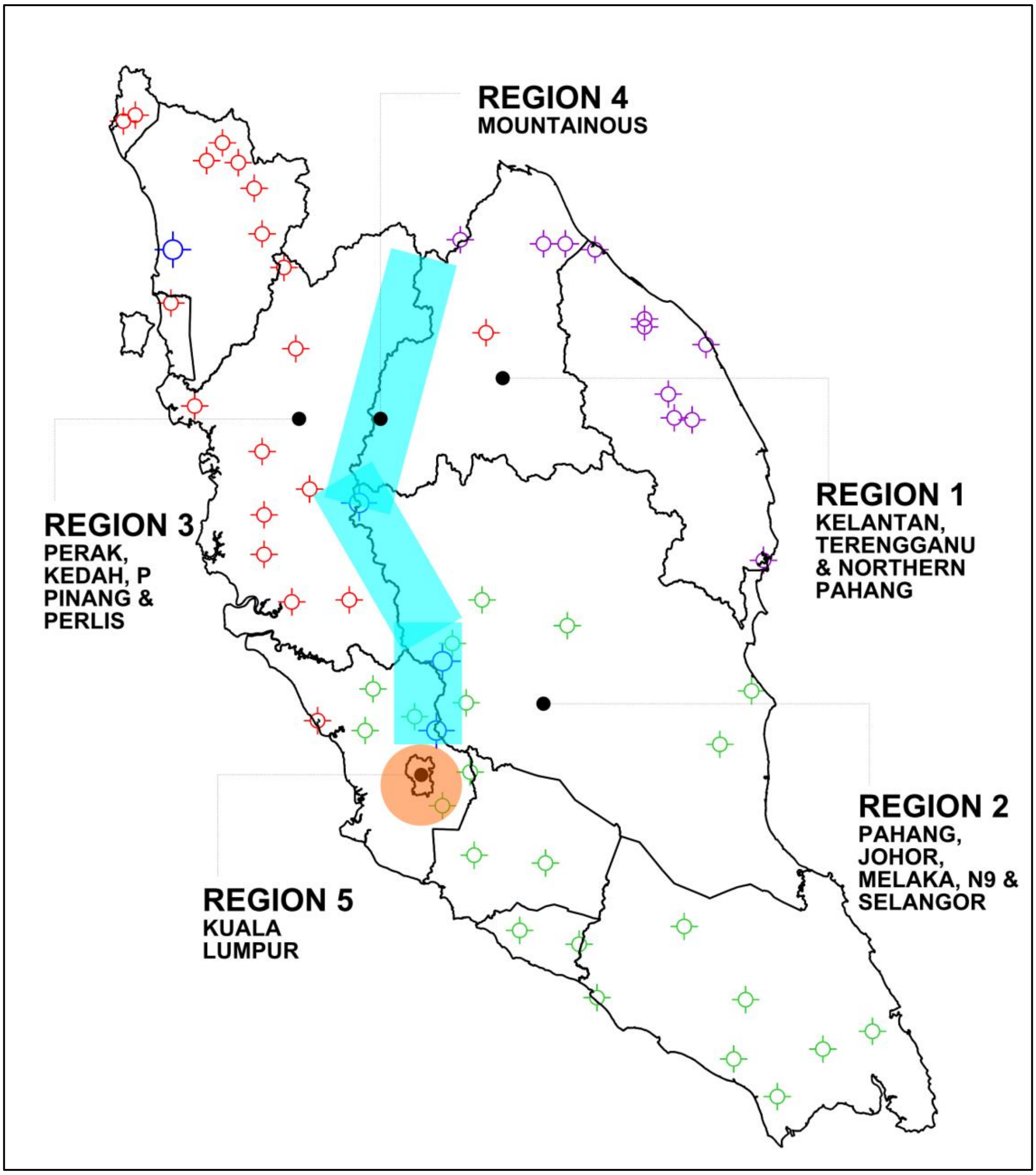
Source: USWB (1957-58)

3.2.4 Rainfall Temporal Distribution

The temporal distribution of the design storm, that is, the distribution of rainfall depth over storm duration is usually adopted from a study of the temporal distribution of the recorded storms. Design rainfall temporal pattern is a critical factor in rainfall-runoff modelling. Design temporal pattern can affect the design flood significantly.

3.2.4.1 Rainfall Temporal Distribution for Peninsular Malaysia

A study was carried out by DID (HP 1, 2015) to obtain the temporal distribution of annual maximum rainstorms for selected durations of 0.25, 0.5, 1, 3, 6, 12, 24, 48 and 72 hours for Peninsular Malaysia. Temporal distributions for 5 regions were derived as shown in **Figure 1** and these are adopted in this Procedure.



Source: HP 1 (2015)

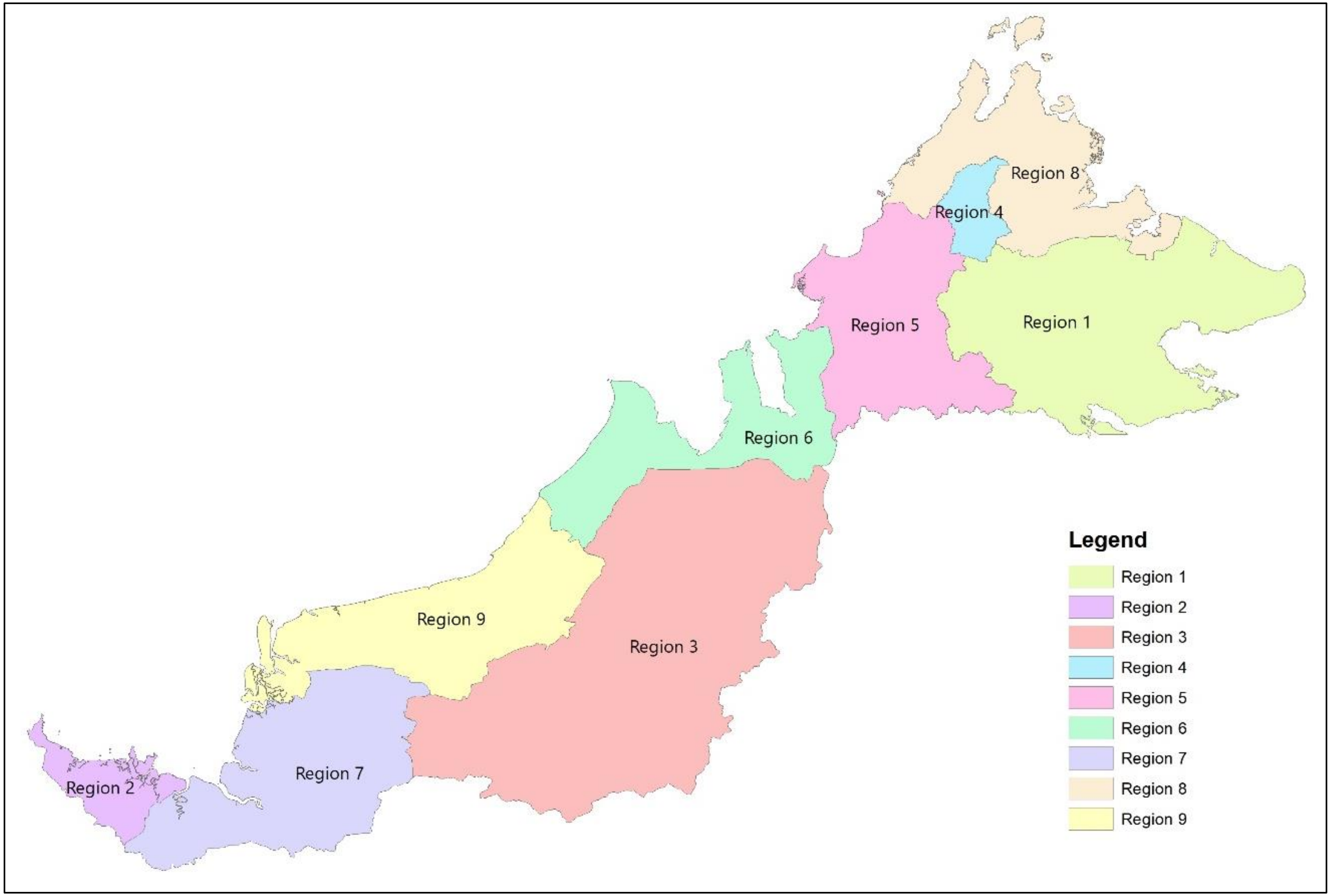
Figure 1: Rainfall Temporal Distribution Regions for Peninsular Malaysia

3.2.4.2 Rainfall Temporal Distribution for Sabah and Sarawak

The design rainfall temporal patterns for Sabah and Sarawak were derived in HP 26 (2018). The temporal patterns of durations 0.25, 0.5, 1, 3, 6, 12, 24, 48 and 72 hours were derived for 9 regions as shown in **Figure 2**. In this Procedure, the temporal patterns for Sabah and Sarawak developed in HP 26 (2018) are adopted.

3.2.5 Critical Rainfall Duration

The design storm duration for a selected return period is usually adopted as the duration which gives the maximum discharge. This critical duration can be obtained by trial and error by calculating the design flood for a range of storm durations. A similar practice has been adopted in this Procedure. The hydrograph used for design is the storm duration that gives the highest peak discharge or the highest peak after routing if outflow from storage is required.



Source: HP 26 (2018)

Figure 2: Rainfall Temporal Distribution Regions for Sabah and Sarawak

3.3 Rainfall-Runoff Relationship

In this Procedure, the method used in HP 11 (1976) was adopted to establish the rainfall-runoff relationship, that is, the total accumulated storm rainfall volume for a particular flood event and the direct runoff derived from the flood hydrograph are used to determine the rainfall-runoff relationship.

3.3.1 Peninsular Malaysia

For Peninsular Malaysia, of all the storm data analysed (for the period 1970 – 2000), 177 storms from 37 catchments out of 40 catchments were used to develop the rainfall-runoff relationship (**Table A.1**, **Appendix A**). The remaining events were not used as for these events, the rainfall records did not allow a good estimate of total storm rainfall.

The rainfall-runoff relationships so derived are shown in **Figure 3**. The scatter of points is to be expected since the volume or runoff varies with other factors in addition to rainfall amount such as the catchment moisture status prior to the storm, the surface cover, soil type and the temporal and spatial pattern as well as intensity of rainfall.

In **Figure 3**, the equation was fitted to the observed data by eye giving emphasis to the relatively few points representing the larger floods analysed. For storms smaller than 75 mm, the linear relationship shown in **Figure 3** is recommended. The equations derived for Peninsular Malaysia catchments are:

$$Q = 0.33\,P \qquad P < 75 \text{ mm} \qquad (1)$$

$$Q = \frac{P^2}{(P+150)} \qquad P > 75 \text{ mm} \qquad (2)$$

Where

P = total storm rainfall in mm

Q = direct runoff in mm

In this Procedure, no attempts were made to include the catchment antecedent moisture status in the rainfall-runoff relationship as the data were not conclusive enough to justify including an index of catchment antecedent moisture status in the rainfall-runoff relationship.

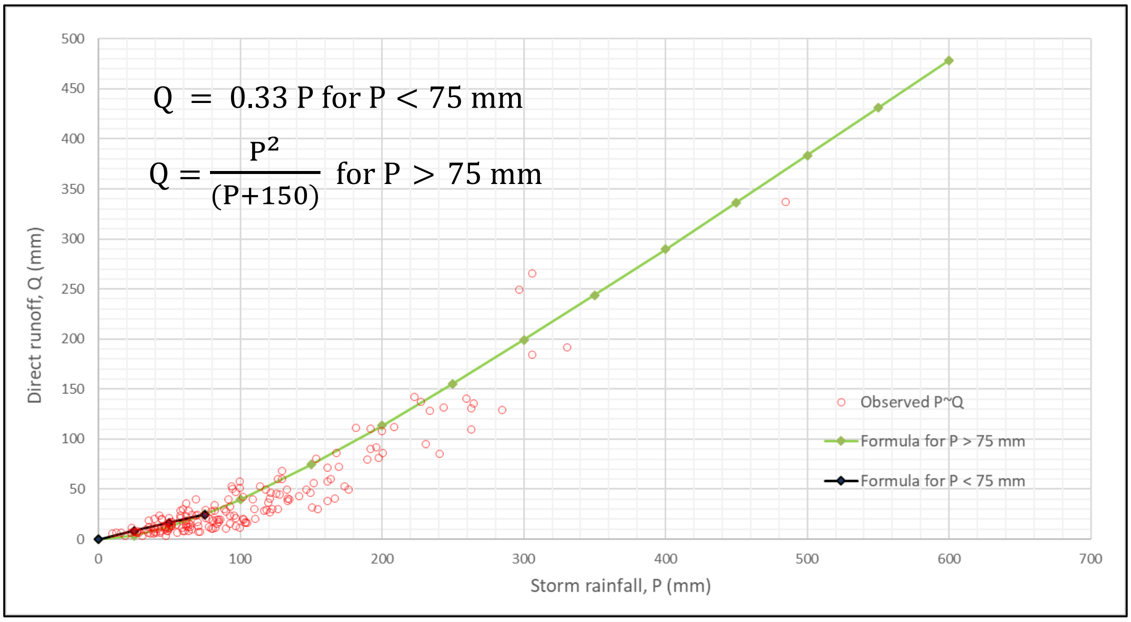


Figure 3: Rainfall-Runoff Relationship for Peninsular Malaysia Catchments

3.3.2 Sabah

For Sabah, of all the storm data analysed (for the period 1985 – 2013), 82 selected storms from 23 catchments out of 24 catchments were used to develop the rainfall-runoff relationship (**Table A.2**, **Appendix A**). The remaining events were not used as for these events, the rainfall records did not allow a good estimate of total storm rainfall.

In **Figure 4**, the equation was fitted to the observed data by eye giving emphasis to the relatively few points representing the larger floods analysed. For storms smaller than 100 mm, the linear relationship shown in **Figure 4** is recommended. The equations derived for Sabah catchments are:

$$Q = 0.25\,P \qquad P < 100 \text{ mm} \qquad (3)$$

$$Q = \frac{P^2}{(P+300)} \qquad P > 100 \text{ mm} \qquad (4)$$

Where

P = total storm rainfall in mm

Q = direct runoff in mm

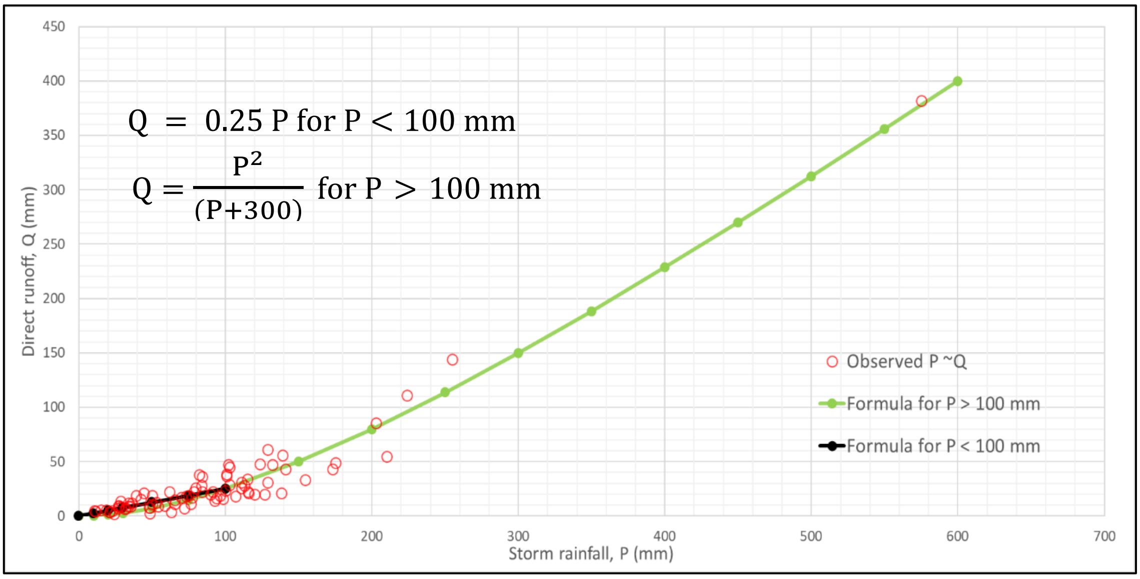


Figure 4: Rainfall-Runoff Relationship for Sabah Catchments

3.3.3 Sarawak

For Sarawak, of all the storm data analysed (for the period 1985 – 2016), 215 selected storms from 19 catchments were used to develop the rainfall-runoff relationship (**Table A.3**, **Appendix A**). The remaining events were not used as for these events, the rainfall records did not allow a good estimate of total storm rainfall.

In **Figure 5**, the equation was fitted to the observed data by eye giving emphasis to the relatively few points representing the larger floods analysed. For storms smaller than 100 mm, the linear relationship shown in **Figure 5** is recommended. The equations derived for Sarawak catchments are:

$$Q = 0.38\,P \qquad P < 100 \text{ mm} \qquad (5)$$

$$Q = \frac{P^2}{P+160} \qquad P > 100 \text{ mm} \qquad (6)$$

Where

P = total storm rainfall in mm

Q = direct runoff in mm

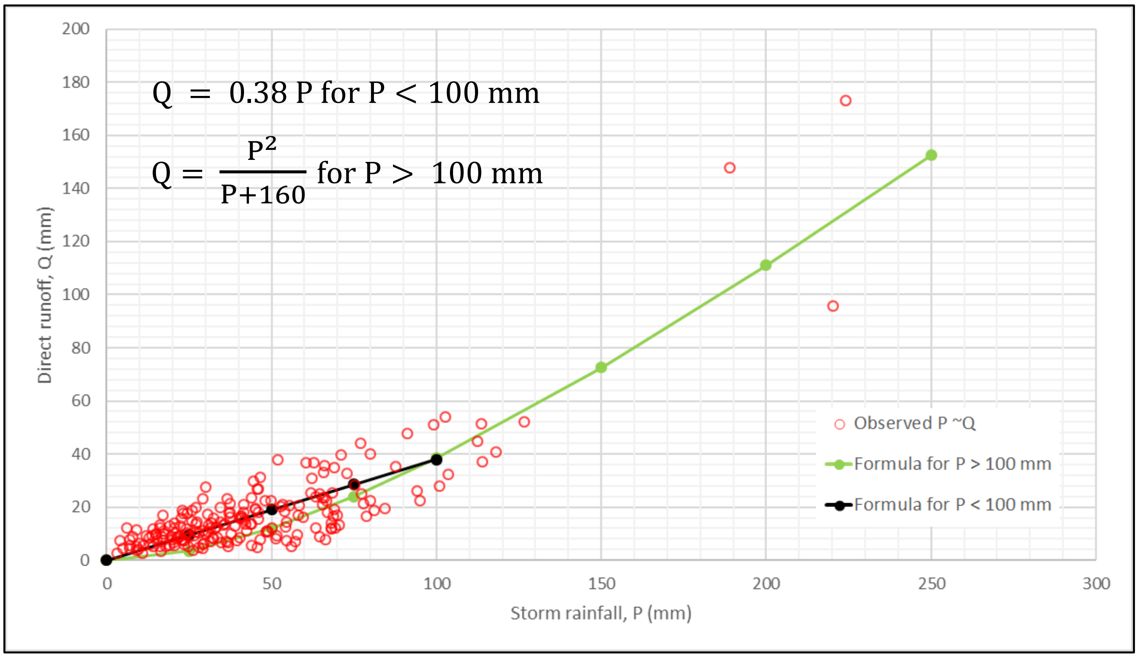


Figure 5: Rainfall-Runoff Relationship for Sarawak Catchments

3.4 The Time Distribution of Runoff

3.4.1 General

There are several methods of distributing the runoff volume with time of which the best known is probably the Unit Hydrograph (UH). The synthetic UH methods have been utilized to describe the entire UH for a gauged catchment with only a few parameters. The hydrograph parameters can be related to catchment characteristics from which the parameters are derived. These methods can be applied to ungauged catchments with similar hydrologic conditions. Many synthetics UH methods have been proposed but the Snyder UH is used in this Procedure because it has been widely used in many countries.

3.4.2 Snyder Unit Hydrograph (UH)

Time parameters such as lag time and time of concentration are essential inputs to common flood discharge models. These parameters of stream flow response time are related to physical features of the catchment such as drainage area, stream length and slope. An estimated catchment lag time is needed to develop a synthetic UH by the methods of Snyder and the Natural Resources Conservation Services (formerly known as Soil Conservation Services (SCS)), whereas the calculation of design discharges by the rational method requires an estimation of the time of concentration.

The concept of catchment lag or lag time is central to the development of unit hydrograph theory. Catchment lag is a global measure of response time, encompassing hydraulic length, catchment gradient and other related factors. Lag time ($\mathrm{L_g}$) has been defined in several different ways. In this Procedure, lag time is defined as the time difference from the centroid of the net rainfall to the peak discharge at the catchment outlet. This definition is the one used in Snyder and SCS synthetic UH models. Another definition adopted by United States Bureau of Reclamation (USBR, 1978) for lag time is the time difference from the centroid of the net rainfall to the mid volume of direct runoff (see **Figure 6**).

There are several definitions of lag time, depending on what particular instant is taken to describe the occurrences of either unit rainfall or runoff. Ponce (1989) documented several definitions of lag time (see **Figure 6**). In **Figure 6**, T1 is defined as the lag time from the beginning of continuous excess rainfall to the centroid of direct runoff. T2 is the lag time from centroid of excess rainfall to the peak of direct runoff hydrograph. T3 is the lag time from centroid of excess rainfall to the centroid of direct runoff. T4 is the lag time from centroid of total rainfall to centroid of direct runoff. T5 is the lag time from the beginning of continuous rainfall to the peak of direct runoff hydrograph. T6 is the lag time from end of rainfall to the point of inflection on direct runoff recession. T7 is the lag time from centroid of total rainfall to the peak of direct runoff hydrograph. In this Procedure, T2 is adopted as it is consistent with the definitions of Snyder and HEC-HMS. T3 was used in HP 11 (1976).

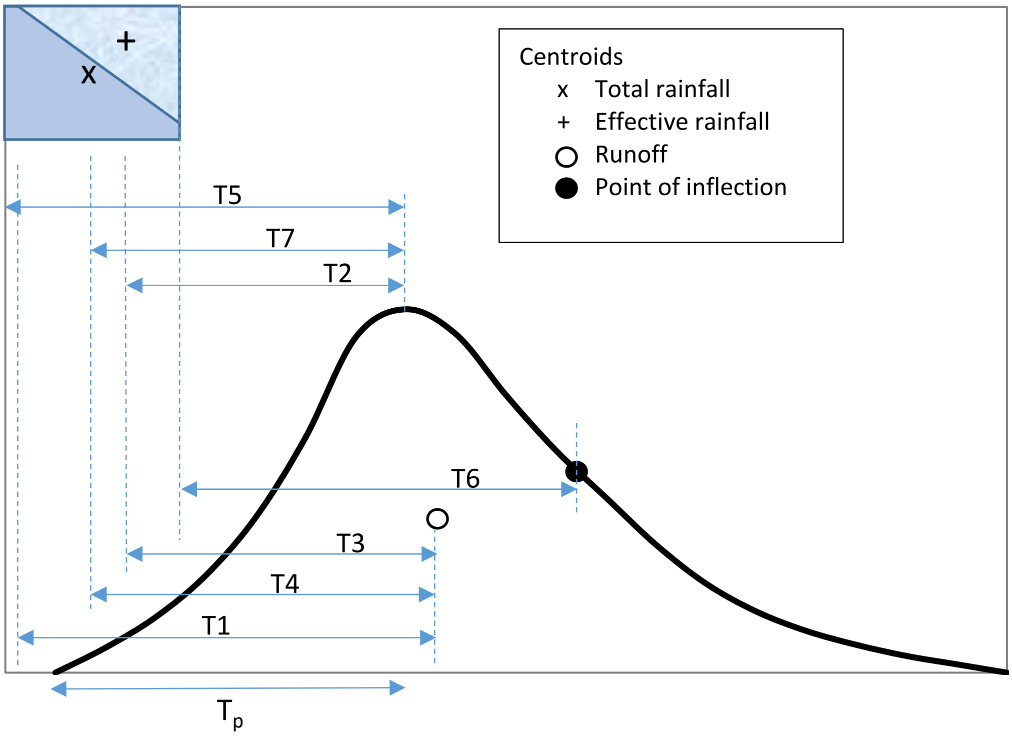


Figure 6: Alternative Definition of Catchment Lag (Ponce)

3.4.3 Snyder UH Peaking Coefficient

A common descriptor of the shape of the Snyder UH is the peaking coefficient (C_p). The peaking coefficient is a dimensionless parameter represented by the formula:

$$Q_p = \frac{C_p\ U\ A}{L_g} \tag{7}$$

In which Q_p is the peak discharge, U is the unit depth of net rainfall, A is the catchment area and L_g is the lag time.

In Flood Runoff Analysis (USACE, 1994), it was stated that the original development of Snyder method and values for C_p were made with data from the Appalachian Mountain region. Subsequent applications in other regions produced values for the coefficients that were substantially different. The coefficients should be calibrated with data from the region in which they were applied. Indeed, it is not necessary to adopt the form of the original equation for L_g. Regression analysis can be used to develop expressions for L_g and C_p that consider measurable catchment characteristics. According to a number of studies, C_p tends to be fairly constant but is weakly correlated to the catchment parameters such as catchment area, stream length and stream slope. Therefore, regional average values were adopted for particular area studied. Some ranges and regional average values of C_p are listed in **Table 2**.

Table 2: Ranges and Regional Average Values of C_p

Location	*Range of C_p	Regional Average C_p Value	Source
Kansas	0.46 to 0.77	0.62	McEnroe and Zhao, 1999
Appalachian Mountain	0.56 to 0.69	0.60	Ponce, 1989
Central Texas and Central Nebraska	-	0.80	Viessman and Lewis, 1995
Southern California	-	0.90	Viessman and Lewis, 1995
Montana	0.2 to 0.8	0.52	USGS, 1996
Experimental catchments New Zealand	0.4 to 0.88	0.64	Hoffmeister and Weisman, 1977
Kum river Korea	0.31 to 0.8	0.60	Jeong et. al, 2001
Ethopia	0.063 to 0.344	-	Azeze, 2004
Attanagalu Oya river India	0.25 to 0.44	0.38	Halwatura and Najim, 2013; Thapa and Wijesekera, 2017

*Remarks: *Values derived from individual catchment*

The average value of C_p is between 0.46 and 0.77 (McEnroe and Zhao, 1999). In the SCS synthetic UH method, C_p is assigned with a constant value of 0.75. Snyder gave C_p value in the range 0.56 to 0.69 (Ponce, 1989). The Snyder synthetic UH method requires C_p as an input. The peak discharge of the synthetic UH is directly proportional to C_p.

3.4.4 Snyder UH Parameter Determination

3.4.4.1 Selection of Rainfall-Runoff Events

Due to the limitations of streamflow data, stations with reasonable flow records for various catchment sizes where data were available for deriving the Snyder UH were used. In Peninsular Malaysia, data were more complete for catchments less than 2,000 km^2. However, in Sabah and Sarawak, there were fewer gauged catchments smaller than 2,000 km^2. In order to have more data for model calibration, record of some catchments with area greater than 2,000 km^2 were also used.

In the development of this Procedure, rainfall-runoff events were discarded if:

(i) The hydrographs were multi-peaked.
(ii) The hydrographs started before the hyetographs, indicating inconsistency in the timing of rainfall and runoff.
(iii) The hydrographs started after the hyetograph ended, indicating inconsistency in the rainfall runoff records.
(iv) The centroid of effective rainfall occurring after the centroid of runoff, indicating inconsistency in the timing of rainfall and runoff.
(v) Direct runoff greater than total rainfall for a storm event, indicating inconsistency in rainfall runoff record.

3.4.4.2 Snyder UH Modelling Using HEC-HMS

HP 11 (1976) has been developed using the Snyder UH method. Snyder UH is a synthetic and parametric UH method. UH defines all pertinent properties with one or more equations, each of which has one or more parameters. When the parameters are specified, the equations can be solved, yielding the UH ordinates.

The Hydrologic Modelling System (HEC-HMS) program of Hydrologic Engineering Centre has been developed to derive flood hydrographs (historical and design) using UH method including the Snyder UH. It can also be used to obtain the Snyder parameter values i.e. the lag time and peaking coefficient, via calibration with storm rainfall runoff data. The HEC-HMS model has a calibration module with optimisation algorithm to facilitate the derivation of the UH parameters.

The runoff volume of the UH is one-unit rainfall excess depth multiplied by the catchment area. Therefore, for a triangular UH, once the UH peak and the time to UH peak are known, the UH time base and all the ordinates of the UH can be calculated.

A synthetic UH relates the parameters of a parametric UH to catchment characteristics. Using the relationships, it is possible to develop a UH for catchments other than the catchment originally used to derive the UH.

For a standard UH of a catchment, the average catchment lag time derived using several recorded rainfall-runoff events through calibration is usually adopted as the catchment lag time for gauged catchment. For ungauged catchment, the catchment lag time can be estimated using a regional formula relating catchment lag of gauged catchment to catchment characteristics such as catchment area, main stream length and stream slope.

Snyder provided the relationships for estimating the UH parameters from catchment characteristics. Snyder selected the lag, peak flow and total time base as the critical characteristics of a UH. Herein the lag is the difference in the time of the UH peak and the time associated with the centroid of the excess rainfall hyetograph (**Figure 6**).

Snyder defined the standard UH as one whose rainfall duration, $\mathrm{t_r}$ (in hr), is related to the catchment lag time, $\mathrm{L_g}$ (in hr), by:

$$\mathrm{L_g} = 5.5\ \mathrm{t_r} \tag{8}$$

Thus, if the catchment lag time is known, rainfall duration of the standard Snyder UH can be obtained. If the rainfall duration of the required UH is different from the rainfall duration of the standard UH specified in **Equation 8** (for example, unit hydrographs are normally derived for durations at multiple of minutes or multiple of hours depending on the catchment time of response and the rainfall temporal pattern and duration), the following relationship can be used to define UH lag time and required UH duration:

$$t_{pR} = L_g - \frac{t_r - t_R}{4} \tag{9}$$

Where

t_R is the rainfall duration of required UH in hr

t_{pR} is the lag time of required UH in hr

The required duration is determined based on the catchment time of response and catchment rainfall duration and temporal pattern.

For the standard UH, the peak discharge per unit of excess rainfall per unit area of the catchment is:

$$q_p = \frac{C\,C_p}{L_g} \tag{10}$$

Where

q_p is peak discharge of standard UH in m^3/s/km^2/mm

C_p is UH peaking coefficient

C is conversion factor (0.275 for 1 mm standard UH)

For other required durations, the UH peak discharge, q_{pR} is:

$$q_{pR} = \frac{C\,C_p}{t_{pR}} \tag{11}$$

Where

q_{pR} is peak discharge of required UH in m^3/s/km^2/mm

C_p is UH peaking coefficient

C is conversion factor (0.275 for 1 mm standard UH)

t_{pR} is lag time of required UH in hr

The time base, t_b of the UH can be determined using the fact that the area under the UH is equivalent to a direct runoff of 1 mm. Assuming a triangular shape for the UH, the base time may be estimated by:

$$t_b = \frac{0.556}{q_{pR}} \tag{12}$$

Where

t_b is time base in hr

q_{pR} is peak discharge of required UH in m^3/s/km^2/mm

The time to peak, T_p of the UH can be calculated using:

$$T_p = t_{pR} + \frac{t_R}{2} \tag{13}$$

Where

T_p is time to peak in hr

t_{pR} is lag time of required UH in hr

t_R is the rainfall duration of required UH in hr

3.4.4.3 Computation of Lag Time and Peaking Coefficient

The calibration feature in the HEC-HMS flood hydrograph program was used to determine the lag time and peaking coefficient for the individual event. Each catchment was modelled as a single basin. Catchment rainfall was estimated using records from the catchments. The computation of lag times from rainfall and flow data requires the separation of baseflow and the computation of net or excess rainfall.

For this Procedure, the exponential recession module of HEC-HMS to calculate baseflow and direct runoff of the catchments was used. The effect of baseflow on the streamflow hydrograph are defined by three parameters:

(i) the discharge at the start of the storm
(ii) the discharge below which baseflow recession occurs and
(iii) the ratio of recession discharge

The parameters were estimated by inspection of recorded hydrographs and input as initial values. Final values were estimated by the program using calibration and optimization facilities of the program. Baseflow calculated was subtracted from the total storm hydrograph to obtain the direct runoff hydrograph.

The initial and uniform loss model was used to compute the excess rainfall. In the initial and uniform loss model, all rainfall is lost until the initial loss is satisfied. After the initial loss is satisfied, rainfall is lost at a specified constant rate. The initial loss and constant loss rate for each event were determined by calibration within HEC-HMS.

In HEC-HMS, a synthetic UH can be generated by several different models, including the Snyder model. The Snyder model in HEC-HMS has two parameters: the catchment lag time and the peaking coefficient. The values of the synthetic UH can be determined by the calibration module within HEC-HMS.

3.4.4.4 Parameter Estimation in HEC-HMS

HEC-HMS used a numerical index to measure the closeness of fit of the computed and observed hydrographs. The objective function that is minimized by optimization routine is a discharge weighted root-mean square error. This objective function is:

$$\mathrm{STDER} = \sqrt{\frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{Q_o} - \mathrm{Q_c})^2 \, \mathrm{WT_i}} \tag{14}$$

In which $\mathrm{Q_o}$ and $\mathrm{Q_c}$ are observed and computed discharges at time index i, $\mathrm{WT_i}$ is the weighting factor for time index i, and n is the number of ordinates of the hydrograph. The weighting factor, $\mathrm{WT_i}=\frac{\mathrm{Q_o}+\mathrm{Q_c}}{2\,\mathrm{Q_{ave}}}$, in which $\mathrm{Q_{ave}}$ is the average of observed discharge. This objective function provides an index of how closely the observed hydrograph is replicated. It is weighted to emphasize the closeness of fit at the high flows. An improvement in the fit at the highest flows yields the greatest reduction in the objective function (HEC, 2016). This emphasis on high flows is appropriate for flood hydrograph analysis.

HEC-HMS uses a univariate gradient search procedure to determine the optimal parameter estimates. This search procedure minimizes the partial derivatives of the objective function with respect to the unknown parameters. A single parameter is varied in each iteration. The derivatives are estimated numerically, and Newton's technique is used to improve parameter estimates. The optimization does not guarantee a global optimum solution of the objective function. Different initial values can result in different optimal values.

3.4.4.5 Model Calibration

The main aim of this Procedure was to use gauged data to derive the Snyder UH parameters and these established Snyder UH parameters would be adopted for ungauged catchments on a regional basis. Hence the availability, coverage and quality of storm data were among the important factors in the selection of catchments to be used in this Procedure. The criteria for selection of storm events and catchments for Snyder UH parameterisation were as follows:

(i) Catchment area not exceedingly large

(ii) Continuous and complete records

(i) Calibration for Peninsular Malaysia

727 storm events from 40 selected catchments throughout Peninsular Malaysia were used to estimate the Snyder parameters by employing the HEC-HMS Calibration Module. As recorded rainfall and streamflow data were available since 1970, Snyder UH parameters ($\mathrm{L_g}$ and $\mathrm{C_p}$) derived from 581 storms (mainly from the period 1970 – 2000) were subsequently used to derive the coefficient values in the lag ($\mathrm{L_g}$) equation (see **Equation 17**). The remaining 146 events (mainly 2001 – 2017) were used to verify the derived coefficient values. This was to ensure that sufficient data were available for both derivation and verification of the parameter values.

(ii) Calibration for Sabah

371 storm events from 24 selected catchments throughout Sabah were used to estimate the Snyder parameters by employing the HEC-HMS Calibration Module. As recorded rainfall and streamflow data were available since 1985, Snyder UH parameters ($\mathrm{L_g}$ and $\mathrm{C_p}$) derived from 253 storms (mainly from the period 1985 – 2000) were subsequently used to derive the coefficient values in the lag ($\mathrm{L_g}$) equation (see **Equation 19**). The remaining 118 events (mainly 2001 – 2016) were used to verify the derived coefficient values. This was to ensure that sufficient data were available for both derivation and verification of the parameter values.

(iii) Calibration for Sarawak

377 storm events from 19 selected catchments throughout Sarawak were used to estimate the Snyder parameters by employing the HEC-HMS Calibration Module. As recorded rainfall and streamflow data were available since 1977, Snyder UH parameters ($\mathrm{L_g}$ and $\mathrm{C_p}$) derived from 272 storms (mainly from the period 1985 – 2000) were subsequently used to derive the coefficient values in the lag ($\mathrm{L_g}$) equation (see **Equation 20**). The remaining 105 events (mainly 2001 – 2016) were used to verify the derived coefficient values. This was to ensure that sufficient data were available for both derivation and verification of the parameter values.

Some observed and simulated hydrographs from Peninsular Malaysia, Sabah and Sarawak are shown in **Appendix B** for illustration purpose.

3.5 Average Lag Time ($\mathrm{L_g}$) for Gauged Catchments

From all the selected individual storm events which yielded individual $\mathrm{L_g}$ and $\mathrm{C_p}$ values, single $\mathrm{L_g}$ and $\mathrm{C_p}$ for each catchment were derived by averaging.

(i) Peninsular Malaysia

Table C.1 (Appendix C) shows the average lag time and peaking coefficient for the 40 selected catchments in Peninsular Malaysia. The averaged values of $\mathrm{L_g}$ and $\mathrm{C_p}$ for each catchment were used in the regression analysis to derive the regression coefficients of the lag equation to be used for ungauged catchments.

(ii) Sabah

Table C.2 (Appendix C) shows the average lag time and peaking coefficient for the 24 selected catchments Sabah. The averaged values of $\mathrm{L_g}$ and $\mathrm{C_p}$ for 22 out of 24 catchments were used in the regression analysis to derive the regression coefficients of the lag equation to be used for ungauged catchments.

(iii) Sarawak

Table C.3 (Appendix C) shows the average lag time and peaking coefficient for the 19 selected catchments in Sarawak. The averaged values of $\mathrm{L_g}$ and $\mathrm{C_p}$ for 14 out of 19 catchments were used in the regression analysis to derive the regression coefficients of the lag equation to be used for ungauged catchments.

3.6 Lag Time ($\mathrm{L_g}$) Equation Development

Equations relating $\mathrm{L_g}$ and catchment characteristics are required to estimate $\mathrm{L_g}$ for ungauged catchments. For example, $\mathrm{L_g}$ is related to main stream length and slope according to Carter (1961), McEnroe and Zhao (1999) and Jeong et al. (2001). $\mathrm{L_g}$ equation developed by Snyder (1938) included a coefficient that varies geographically ($\mathrm{C_t}$), main stream length (L) and distance along the main stream from the outlet to the point nearest to the centroid of the catchment ($\mathrm{L_c}$). Simple and multiple linear regressions were used to determine the mathematical relationships of $\mathrm{L_g}$ and catchment characteristics such as area, main stream length and slope for the catchments with lag times calibrated using recorded storm events. Generally, $\mathrm{L_g}$ is more correlated to catchment area, main stream length and slope.

The accuracy of regression analysis (regression equations) are expressed by the two standard statistical measures R, the coefficient of correlation and R^2 the coefficient of determination. R indicates the correlation between the dependent and independent variables. R^2 shows how much variation in the dependent variable can be accounted for by the independent variables. For example, an R^2 of 0.94 indicates that 94% of the variation is accounted for by the independent variables and that 6% is due to other factors. A higher R^2 means the regression line (equation) fits the data better.

The simple linear equation is of the form:

$$y = a + bx1 + cx2 + dx3 + \dots \tag{15}$$

Where y is the dependent variable, x1, x2, x3… are independent variables and a, b, c... are coefficients.

The multiple linear regression formula is:

$$y = ax1^{b}\, x2^{c}\, x3^{d} \dots \tag{16}$$

Logarithmic transformation of **Equation 16** results in a linear equation with respect to the logarithms of the variables.

(i) Lag Equation for Peninsular Malaysia

The best fit lag equation for Peninsular Malaysia is:

$$L_g = 0.639\ A^{0.4143}\ L^{0.1403}\ S^{-0.4321} \tag{17}$$

Where

L_g is the lag time in hr

A is the catchment area in km²

L is the main stream length from catchment divide to catchment outlet in km

S is the weighted slope of main stream in %

R = 0.93, R^2 = 0.86

To calculate the weighted slope of the catchment main stream, the main stream was divided into a number of points. The elevation and distance at point i were measured and the weighted slope was then calculated using the Excel slope equation:

$$S = \frac{\sum(l_i - \bar{l})(h_i - \bar{h})}{\sum(l_i - \bar{l})^2} 100 \tag{18}$$

Where

S is the weighted slope of main stream in %

l_i is the length of the main stream from catchment outlet to point i in m

h_i is the elevation of the main stream at point i in m

$\bar{h}$ and $\bar{l}$ are the average values of h_i and l_i

(ii) Lag Equation for Sabah

The best fit lag equation for Sabah is:

$$L_g = 5.145\ A^{-0.1174}\ L^{0.2417}\ S^{-0.7157} \tag{19}$$

Where

L_g is the lag time in hr

A is the catchment area in km²

L is the main stream length from catchment divide to catchment outlet in km

S is the weighted slope of main stream in %

$R = 0.94$, $R^2 = 0.88$

(iii) Lag Equation for Sarawak

The best fit lag equation for Sarawak is:

$$L_g = 2.701\ A^{-0.2954}\ L^{0.6795}\ S^{-0.3737} \tag{20}$$

Where

L_g is the lag time in hr

A is the catchment area in km²

L is the main stream length from catchment divide to catchment outlet in km

S is the weighted slope of main stream in %

$R = 0.91$, $R^2 = 0.83$

3.7 Peaking Coefficients (C_p)

Correlation analysis showed that C_p is not strongly related to any catchment characteristics. When C_p is plotted against A, L, L_c, S and L_g, a flat slope exists and shows only a small amount of scatter for the regression line due to weak correlation between C_p and the catchment parameters. Therefore, the use of an average value for C_p may be just as reliable as the use of a regression equation.

Average catchment C_p are normally obtained by calibrating several recorded storm runoff events from the catchment and average the C_p values derived from these events. C_p values vary from storm to storm for a catchment and it is not correlated to the storm or flood magnitude. A range of C_p values was obtained from studies throughout the world using recorded events, examples are shown in **Section 3.4.3**. The recommended range of C_p and regional average C_p for Peninsular Malaysia, Sabah and Sarawak are shown in **Table 3**.

Table 3: The Recommended Range of C_p and Regional Average C_p for Peninsular Malaysia, Sabah and Sarawak

Location	Range of C_p	Regional Average C_p
Peninsular Malaysia	0.34 to 0.72	0.55
Sabah	0.33 to 0.72	0.54
Sarawak	0.42 to 0.78	0.64

3.8 Design Baseflow (Q_B)

A baseflow is required to derive the total design hydrograph. It is difficult to predict the statistical characteristics of baseflow prior to a major flood. For this Procedure, baseflows of the recorded hydrographs for the catchments before the occurrence of the floods were averaged. Baseflows were taken from flood events with rather dry and moderately wet antecedent conditions as observed on the catchment studied.

(i) Peninsular Malaysia

The average baseflows for the catchments in Peninsular Malaysia were plotted against the catchment area as shown in **Figure 7.** A best fit equation was derived for general use. The equation is:

$$Q_B = 0.11\ A^{0.8589} \tag{21}$$

Where

Q_B is the baseflow in m^3/s

A is the catchment area in km^2

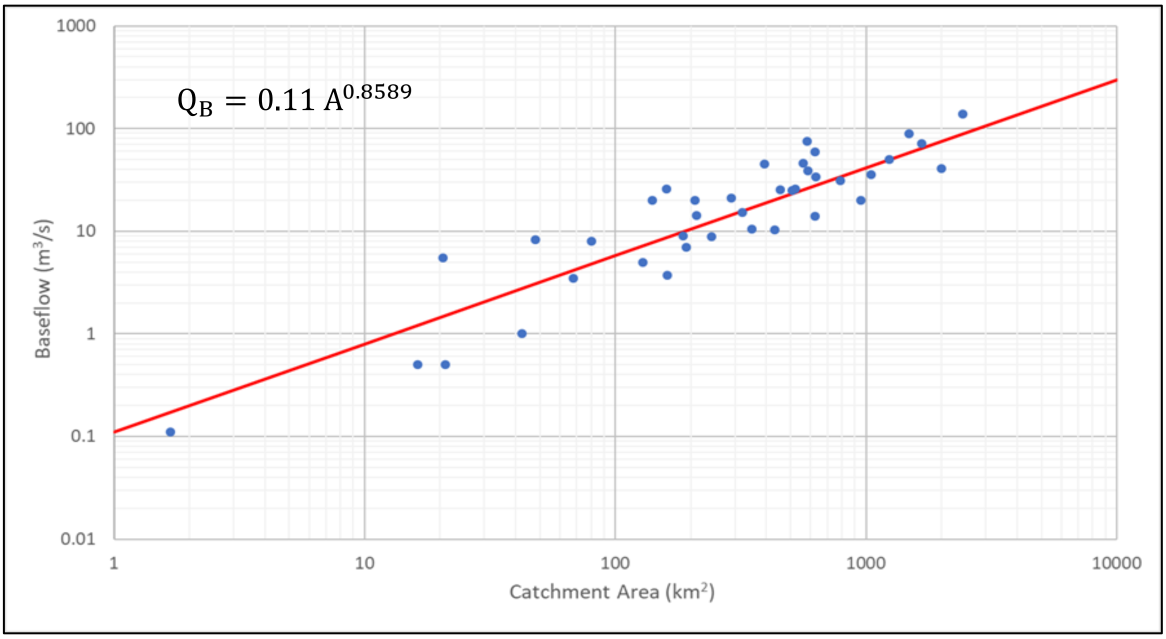


Figure 7: Baseflow and Catchment Area Relationship for Peninsular Malaysia

(ii) Sabah

The average baseflows for the catchments in Sabah were plotted against the catchment area as shown in **Figure 8.** A best fit equation was derived for general use. The equation is:

$$Q_B = 0.0783\ A^{0.8653} \tag{22}$$

Where

Q_B is the baseflow in m^3/s

A is the catchment area in km^2

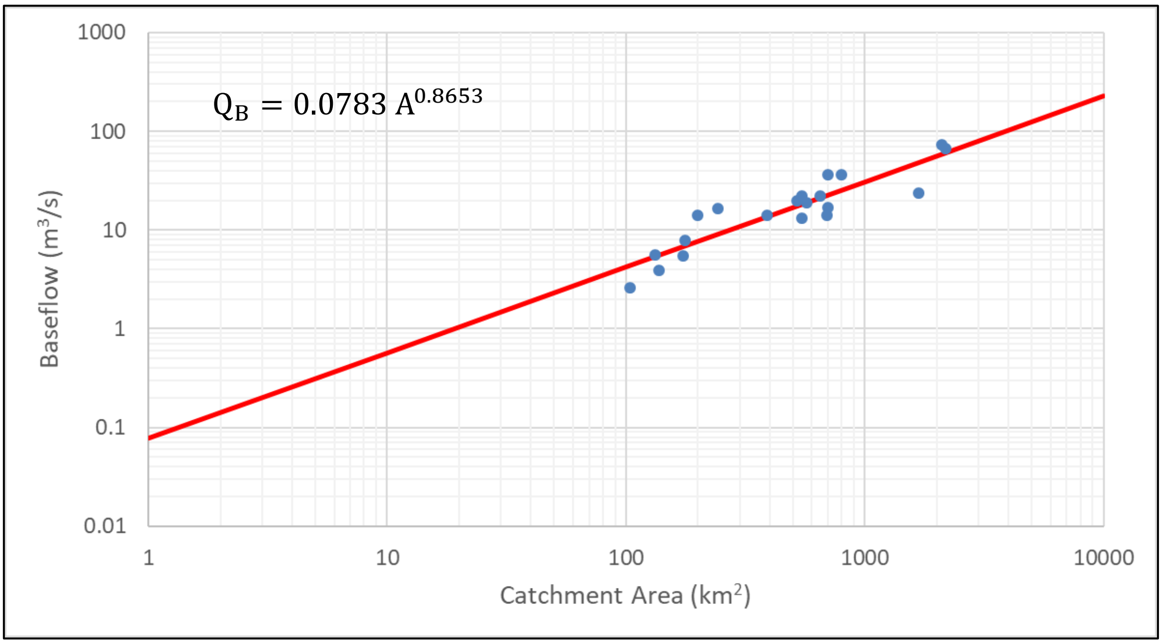


Figure 8: Baseflow and Catchment Area Relationship for Sabah

(iii) Sarawak

The average baseflows for the catchments in Sarawak were plotted against the catchment area as shown in **Figure 9.** A best fit equation was derived for general use. The equation is:

$$Q_B = 0.0111\ A^{1.1682} \tag{23}$$

Where

Q_B is the baseflow in m^3/s

A is the catchment area in km^2

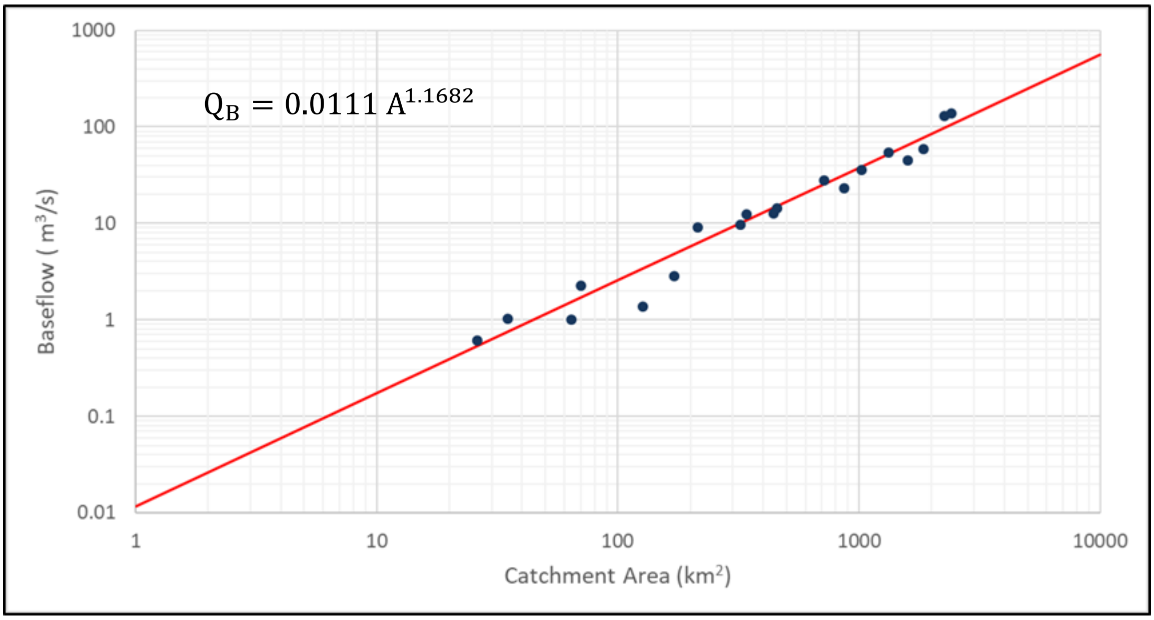


Figure 9: Baseflow and Catchment Area Relationship for Sarawak

3.9 Derivation of the Design Flood Hydrograph using Computer Program

A computer program in MS Excel was developed for use in estimating the design flood for ungauged catchments for this Procedure. This is a simple and easy to use program and needs only minimum input. The equations related to storm duration, peak discharge, time to peak and time base of the Snyder UH are embedded in the computer program (See **Section 3.4.4.2** for more information of the Snyder method).

A triangular UH can be derived using Snyder method and input of catchment data. With the rainfall data input and the calculation of runoff using the rainfall-runoff relationship derived for this Procedure, a convolution algorithm transforms the direct runoff into flood discharge. The rainfall temporal patterns were incorporated into the program thus making input into the program simple.

The user needs to input only catchment data such as catchment area, main stream length, stream slope and the Snyder peaking coefficient for the program to estimate catchment lag and Snyder UH. Design rainfall, ARF and rainfall pattern region also need to be input to estimate the direct runoff from the catchment. A baseflow is calculated using the built-in formula. The program will display the UH, direct runoff and total runoff hydrographs in tabular form and the total runoff hydrograph in graphical form. The computer program in excel sheet is shown in **Appendix D**.

4. Application of the Procedure

4.1 Application of the Procedure using Manual Calculation

Snyder UH method is used for calculation of design hydrograph. Method of application for manual calculation is shown below:

Step 1: Determine the catchment area, main stream length and weighted stream slope from the topographical map, manually or using the GIS tools.

Step 2: Obtain the design rainfall for the specified return period using HP 1 (2015) for Peninsular Malaysia and HP 26 (2018) for Sabah and Sarawak or perform a frequency analysis using DID data for rainfall stations in or near the catchment.

Step 3: Obtain or interpolate the ARF from **Table 1** for Peninsular Malaysia, Sabah and Sarawak.

Step 4: Determine the rainfall temporal pattern region from **Figure 1** for Peninsular Malaysia and **Figure 2** for Sabah and Sarawak.

Step 5: Calculate the lag time, $\mathrm{L_g}$ (using **Equation 17**, **Equation 19** or **Equation 20**).

Step 6: Calculate the rainfall duration of standard UH, $\mathrm{t_r}$ (using **Equation 8**).

Step 7: Determine the required rainfall duration of the derived UH, $\mathrm{t_R}$ (depending on rainfall temporal pattern and catchment response time).

Step 8: Calculate the required catchment lag time (time difference between the centroid of excess rainfall hyetograph and UH peak), t_{pR} (using **Equation 9**).

Step 9: Calculate the peak discharge per unit catchment area of the standard UH, q_p using **Equation 10**.

Step 10: Calculate the peak discharge per unit of catchment area of the required UH, q_{pR} using **Equation 11**.

Step 11: Calculate the catchment peak discharge of UH, Q_p.

Step 12: Calculate the time base of UH, t_b using **Equation 12**.

Step 13: Calculate the time to peak of UH, T_p using **Equation 13**.

Step 14: Calculate the number of intervals in t_b, assuming triangular UH.

Step 15: Calculate the number of intervals in T_p.

Step 16: Calculate and check the volume of UH runoff.

Step 17: Calculate the UH ordinates using similar triangle.

Step 18: Determine the catchment rainfall.

Step 19: Determine the direct runoff (using **Equation 1** to **Equation 6** depending on the location and total rainfall amount).

Step 20: Calculate the baseflow (using **Equation 21, Equation 22** or **Equation 23** for Peninsular Malaysia, Sabah and Sarawak respectively).

Step 21: Perform the UH Convolution.

Step 22: Calculate and plot the total runoff hydrograph.

4.2 Application of the Procedure using Computer Program

The Excel program has been developed to estimate the design flood hydrograph for any catchment located in the Peninsular Malaysia, Sabah and Sarawak using the Snyder method. The user only needs to enter the catchment properties data such as catchment size, main stream length and stream slope. Design rainfall and ARF are also required as inputs to the computer program. Rainfall temporal patterns for Peninsular Malaysia, Sabah and Sarawak are embedded in the computer program. The outputs of this program are the total hydrograph and peak discharge.

The method of application is as follows:

Step 1: Determine the catchment area, main stream length and weighted stream slope from the topographical map, manually or using the GIS tools.

Step 2: Obtain the design rainfall for the specified return period using HP 1 (2015) for Peninsular Malaysia and HP 26 (2018) for Sabah and Sarawak or perform a frequency analysis using DID data for rainfall stations in or near the catchment.

Step 3: Obtain or interpolate the ARF from **Table 1** for Peninsular Malaysia, Sabah and Sarawak.

Step 4: Determine the rainfall temporal pattern region from **Figure 1** for Peninsular Malaysia and **Figure 2** for Sabah and Sarawak.

Step 5: Enter the data into the Excel program. Results will be displayed in Excel worksheet.

4.3 Worked Examples

Example 1: Flood Hydrograph for Peninsular Malaysia

Problem:

It is proposed to construct a small weir across Sg Sungkai located in Kg Gajah. Estimate the 20-year design flood hydrograph using Snyder UH method. Calculate the total hydrograph for a 6-hour storm.

Solution using manual calculation:

Step 1: Determine the catchment area, main stream length and weighted stream slope from the topographical map, manually or using the GIS tools.

Catchment Area, A: 289 km^2

River length, L: 45 km

Weighted slope of main stream, S: 2.95 %

Peaking Coefficient, C_p: 0.55 from **Table 3**

Step 2: Obtain the design rainfall for the specified return period using HP 1 (2015).

Design rainfall of 20-year ARI (6 hours) is 132 mm.

Step 3: Interpolate the ARF from **Table 1**.

The ARF value is 0.88.

Step 4: Determine the rainfall temporal pattern region from **Figure 1** for Peninsular Malaysia.

Rainfall temporal pattern for Region 3:

Time (hrs)	0.5	1.0	1.5	2	2.5	3
Proportion of total rainfall	0.045	0.070	0.078	0.099	0.113	0.129

Time (hrs)	3.5	4	4.5	5	5.5	6
Proportion of total rainfall	0.121	0.099	0.081	0.076	0.047	0.041

Step 5: Calculate the lag time, $\mathrm{L_g}$ (using **Equation 17**).

$$\mathrm{L_g} = 0.639\ \mathrm{A}^{0.4143}\ \mathrm{L}^{0.1403}\ \mathrm{S}^{-0.4321}$$

$$= 0.639\ \mathrm{x}\ 289^{0.4143}\ \mathrm{x}\ 45^{0.1403}\ \mathrm{x}\ 2.95^{-0.4321}$$

$$= 7.14\ \mathrm{hrs}$$

Step 6: Calculate the rainfall duration of standard UH, $\mathrm{t_r}$ (using **Equation 8**).

$$\mathrm{t_r} = \frac{\mathrm{L_g}}{5.5} = \frac{7.14}{5.5} = 1.3\ \mathrm{hrs}$$

Step 7: Determine the required rainfall duration of the derived unit hydrograph, $\mathrm{t_R}$ (depending on rainfall temporal pattern and catchment response time).

$\mathrm{t_R} = 0.5\ \mathrm{hr}$ for a 0.5 hr UH (time interval used for a 6-hour storm)

This is set according to the rainfall temporal pattern. Normally $\mathrm{t_R} \leq \frac{\mathrm{L_g}}{5}$.

Step 8: Calculate the required catchment lag time (time difference between the centroid of excess rainfall hyetograph and unit hydrograph peak), $\mathrm{t_{pR}}$ (using **Equation 9**).

$$\mathrm{t_{pR}} = \mathrm{L_g} - \frac{\mathrm{t_r} - \mathrm{t_R}}{4} = 7.14 - \frac{(1.3 - 0.5)}{4} = 6.94\ \mathrm{hr}$$

Step 9: Calculate the peak discharge per unit catchment area of the standard UH, $\mathrm{q_p}$ using **Equation 10**.

$$\mathrm{q_p} = \frac{\mathrm{C\ C_p}}{\mathrm{L_g}} = \frac{0.275\ \mathrm{x}\ 0.55}{7.14} = 0.021\ \mathrm{m^3/s/km^2/mm}$$

Step 10: Calculate the peak discharge per unit of catchment area of the required UH, $\mathrm{q_{pR}}$ using **Equation 11**.

$$\mathrm{q_{pR}} = \frac{\mathrm{C\ C_p}}{\mathrm{t_{pR}}} = \frac{0.275\ \mathrm{x}\ 0.55}{6.94} = 0.022\ \mathrm{m^3/s/km^2/mm}$$

Step 11: Calculate the catchment peak discharge of UH, Q_p.

$$Q_p = q_{pR} \text{ x } A = 0.022 \text{ x } 289 = 6.36 \text{ m}^3/\text{s}/\text{mm}$$

Step 12: Calculate the time base of UH, t_b using **Equation 12**.

$$t_b = \frac{0.556}{q_{pR}} = \frac{0.556}{0.022} = 25.27 \text{ hr}$$

Step 13: Calculate the time to peak of UH, T_p using **Equation 13**.

$$T_p = t_{pR} + \frac{t_R}{2} = 6.94 + \frac{0.5}{2} = 7.19 \text{ hr}$$

Step 14: Calculate the number of intervals in t_b, assuming triangular UH.

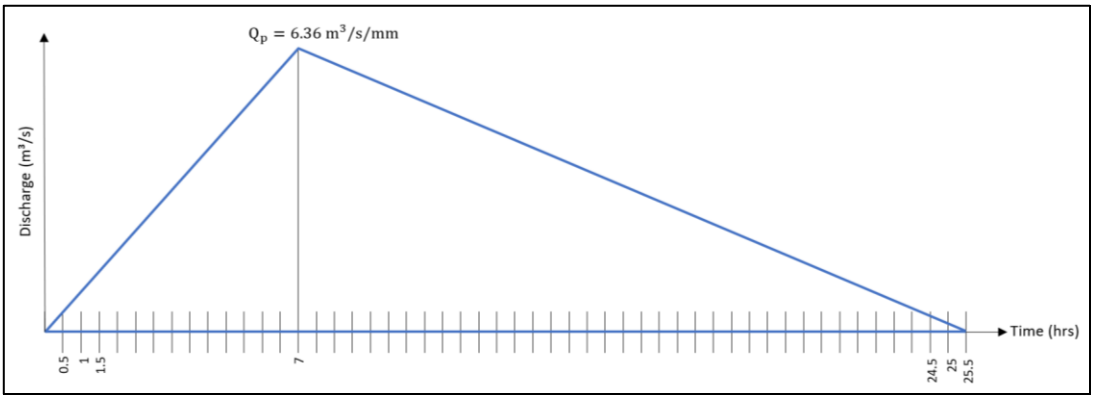
$$N3B = \frac{t_b}{t_R} = \frac{25.27}{0.5} = 50.5\ (\approx 51)$$ Round to integer for ease of calculation

Step 15: Calculate the number of intervals in T_p.

$$N3A = \frac{T_p}{t_R} = \frac{7.19}{0.5} = 14.3\ (\approx 14)$$ Round to integer for ease of calculation

Step 16: Calculate and check the volume of UH runoff.

Synthetic triangular UH:



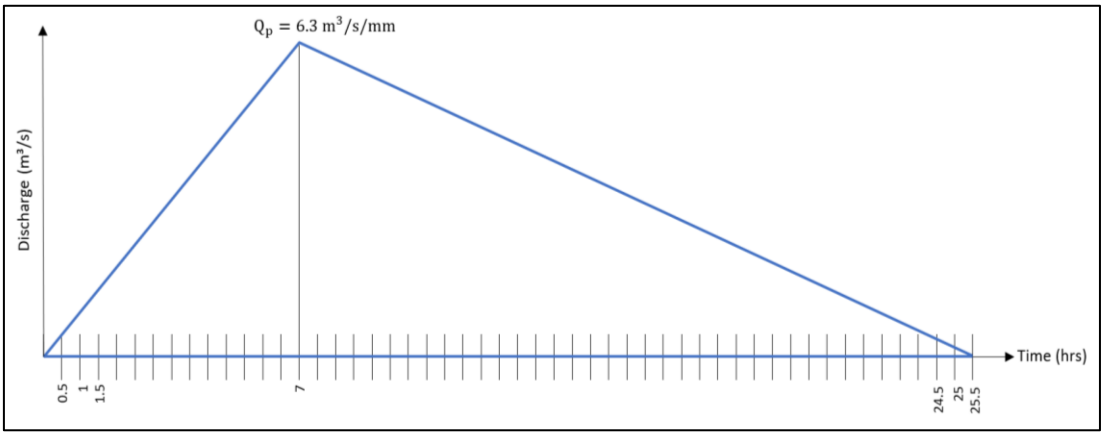
$$\text{Volume} = \frac{\frac{1}{2} \text{ x } t_b \text{ x } Q_p}{A} = \frac{\frac{1}{2} \text{ x } 0.5 \text{ x } 51 \text{x } 6.36 \text{ x } 3600 \text{ x } 1000}{289 \text{ x } 1000 \text{ x } 1000} = 1.01 \text{ mm}$$

$$\text{Revised } Q_p = \frac{Q_p}{\text{Volume}} = \frac{6.36}{1.01} = 6.3 \text{ m}^3/\text{s}$$

Re-calculate the volume using the revised Q_p:

$$\text{Volume} = \frac{\frac{1}{2} \text{ x } t_b \text{ x } Q_p}{A} = \frac{\frac{1}{2} \text{ x } 0.5 \text{ x } 51 \text{x } 6.3 \text{ x } 3600 \text{ x } 1000}{289 \text{ x } 1000 \text{ x } 1000} = 1 \text{ mm OK}$$

Adjusted UH is plotted as shown below:



Step 17: Calculate the UH ordinates using similar triangle.

Time interval	Discharge (m³/s)
1 (0.5 hr)	0.45
2 (1 hr)	0.90
3 (1.5 hr)	1.35
4 (2 hr)	1.80
5 (2.5 hr)	2.25
.	.
.	.
.	.
50 (25 hr)	0.17

Step 18: Determine the catchment rainfall.

Design rainfall for 6-hour duration = 132 mm

ARF = 0.88

Catchment rainfall = 0.88 x 132 = 116 mm

Step 19: Determine the direct runoff (using **Equation 2**).

$$\text{Direct runoff, Q} = \frac{P^2}{(P+150)} = \frac{116^2}{(116+150)} = 50.6 \text{ mm}$$

Distribution of direct runoff based on proportion of total rainfall.

Time (hrs)	0.5	1.0	1.5	2	2.5	3
Runoff (mm)	2.28	3.54	3.95	5.01	5.72	6.53

Time (hrs)	3.5	4	4.5	5	5.5	6
Runoff (mm)	6.12	5.01	4.10	3.84	2.38	2.07

Step 20: Calculate the baseflow (using **Equation 21** for Peninsular Malaysia).

$$Q_B = 0.11\ A^{0.8589} = 0.11 \text{ x } 289^{0.8589} = 14.3 \text{ m}^3/\text{s}$$

Step 21: Perform the UH Convolution.

Refer to **Table A**.

Step 22: Calculate and plot the total runoff hydrograph.

Interval No	**Total runoff**
0	14.3
1	15.3
2	17.9
3	22.3
4	29.0
5	38.2
.	.
.	.
.	.
55	31.0
56	25.9
57	21.9
58	18.9
59	16.8
60	15.4
61	14.6

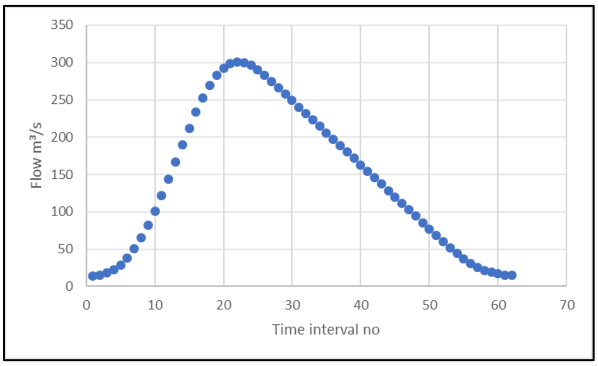


Table A: UH Convolution for Example 1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	UH ordinates																							
2	Time Interval	Discharge (m^3/s)				Rainfall data input				Incremental rainfall , expressed as proportion of total storm rainfall														
3						P	ARF	Region		Interval	1	2	3	4	5	6	7	8	9	10	11	12		
4	0	0				132	0.88	3		12	0.045	0.07	0.078	0.099	0.113	0.129	0.121	0.099	0.081	0.076	0.047	0.041		
5	1	0.45				Catchment rainfall		Incremental rainfall excess																
6	2	0.90				Catchment rainfall	Total Excess RF	RE1	RE2	RE3	RE4	RE5	RE6	RE7	RE8	RE9	RE10	RE11	RE12					
7	3	1.35				116	50.6	2.28	3.54	3.95	5.01	5.72	6.53	6.12	5.01	4.10	3.84	2.38	2.07					
8	4	1.80										Sum of direct runoff					8114		m^3/s.hr					
9	5	2.25	Q_B									Direct runoff volume					50.54		mm					
10	6	2.70	14.3		Rainfall excess for time interval																			
11	7	3.15	Time Interval	Discharge (m^3/s)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Direct runoff	Total runoff
12	8	3.60	0		2.28	3.54	3.95	5.01	5.72	6.53	6.12	5.01	4.10	3.84	2.38	2.07							0.00	14.3
13	9	4.05	1	0.45	1.02																		1.02	15.3
14	10	4.50	2	0.90	2.05	1.59																	3.64	17.9
15	11	4.95	3	1.35	3.07	3.19	1.77																8.03	22.3
16	12	5.40	4	1.80	4.10	4.78	3.55	2.25															14.67	29.0
17	13	5.85	5	2.25	5.12	6.37	5.32	4.50	2.57														23.89	38.2
18	14	6.30	6	2.70	6.14	7.96	7.10	6.76	5.14	2.93													36.04	50.3
19	15	6.13	7	3.15	7.17	9.56	8.87	9.01	7.71	5.87	2.75												50.94	65.2
20	16	5.96	8	3.60	8.19	11.15	10.65	11.26	10.28	8.80	5.51	2.25											68.09	82.4
21	17	5.79	9	4.05	9.21	12.74	12.42	13.51	12.85	11.74	8.26	4.50	1.84										87.09	101.4
22	18	5.62	10	4.50	10.24	14.33	14.20	15.77	15.42	14.67	11.01	6.76	3.69	1.73									107.81	122.1
23	19	5.45	11	4.95	11.26	15.93	15.97	18.02	18.00	17.61	13.76	9.01	5.53	3.46	1.07								129.61	143.9
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							.	.
44	40	1.87	32	3.23	7.36	12.05	14.10	18.75	22.37	26.65	26.04	22.16	18.83	18.32	11.73	10.59							208.95	223.2
45	41	1.70	33	3.06	6.97	11.45	13.43	17.90	21.40	25.54	25.00	21.31	18.13	17.66	11.33	10.24							200.35	214.6
46	42	1.53	34	2.89	6.59	10.85	12.76	17.04	20.43	24.43	23.96	20.45	17.43	17.01	10.92	9.88							191.75	206.0
47	43	1.36	35	2.72	6.20	10.24	12.09	16.19	19.45	23.32	22.92	19.60	16.73	16.36	10.52	9.53							183.15	197.4
48	44	1.19	36	2.55	5.81	9.64	11.41	15.34	18.48	22.21	21.87	18.75	16.04	15.70	10.11	9.18							174.55	188.8
49	45	1.02	37	2.38	5.42	9.04	10.74	14.49	17.51	21.10	20.83	17.90	15.34	15.05	9.71	8.82							165.95	180.2
50	46	0.85	38	2.21	5.04	8.44	10.07	13.64	16.54	19.99	19.79	17.04	14.64	14.39	9.31	8.47							157.35	171.6
51	47	0.68	39	2.04	4.65	7.83	9.40	12.78	15.56	18.88	18.75	16.19	13.95	13.74	8.90	8.12							148.75	163.0
52	48	0.51	40	1.87	4.26	7.23	8.73	11.93	14.59	17.77	17.71	15.34	13.25	13.08	8.50	7.76							140.15	154.4
53	49	0.34	41	1.70	3.87	6.63	8.06	11.08	13.62	16.66	16.67	14.49	12.55	12.43	8.09	7.41							131.55	145.8
54	50	0.17	42	1.53	3.49	6.03	7.39	10.23	12.65	15.55	15.62	13.64	11.85	11.78	7.69	7.06							122.95	137.2
55			43	1.36	3.10	5.42	6.71	9.37	11.67	14.44	14.58	12.78	11.16	11.12	7.28	6.71							114.35	128.6
56			44	1.19	2.71	4.82	6.04	8.52	10.70	13.33	13.54	11.93	10.46	10.47	6.88	6.35							105.75	120.0
57			45	1.02	2.32	4.22	5.37	7.67	9.73	12.22	12.50	11.08	9.76	9.81	6.47	6.00							97.15	111.4
58			46	0.85	1.94	3.62	4.70	6.82	8.75	11.10	11.46	10.23	9.06	9.16	6.07	5.65							88.55	102.8
59			47	0.68	1.55	3.01	4.03	5.97	7.78	9.99	10.42	9.37	8.37	8.51	5.66	5.29							79.95	94.2
60			48	0.51	1.16	2.41	3.36	5.11	6.81	8.88	9.37	8.52	7.67	7.85	5.26	4.94							71.35	85.6
61			49	0.34	0.77	1.81	2.69	4.26	5.84	7.77	8.33	7.67	6.97	7.20	4.86	4.59							62.75	77.0
62			50	0.17	0.39	1.21	2.01	3.41	4.86	6.66	7.29	6.82	6.28	6.54	4.45	4.24							54.15	68.4
63			51			0.60	1.34	2.56	3.89	5.55	6.25	5.97	5.58	5.89	4.05	3.88							45.56	59.8
64			52				0.67	1.70	2.92	4.44	5.21	5.11	4.88	5.23	3.64	3.53							37.34	51.6
65			53					0.85	1.95	3.33	4.17	4.26	4.18	4.58	3.24	3.18							29.73	44.0
66			54						0.97	2.22	3.12	3.41	3.49	3.93	2.83	2.82							22.79	37.1
67			55							1.11	2.08	2.56	2.79	3.27	2.43	2.47							16.71	31.0
68			56								1.04	1.70	2.09	2.62	2.02	2.12							11.60	25.9
69			57									0.85	1.39	1.96	1.62	1.76							7.59	21.9
70			58										0.70	1.31	1.21	1.41							4.63	18.9
71			59											0.65	0.81	1.06							2.52	16.8
72			60												0.40	0.71							1.11	15.4
73			61													0.35							0.35	14.6

Explanation of the table:

- Column A contains the intervals where the total equals to N3B calculated in Step 14.
- Column B contains the UH ordinates from 1 to 50 calculated in Step 17.
- Cell G7 is the direct runoff calculated from Step 19.
- Cells K4 to V4 are obtained from rainfall temporal pattern (Refer to Step 4).
- Cells H7 to S7 are the rainfall excess which is calculated using the rainfall-runoff relationship.

  H7 = G7 x K4 = 50.6 x 0.045 = 2.28
- Column E is calculated by multiplying the incremental rainfall excess in cells E12 to P12 and the discharge of UH ordinates in Column D.

  For interval 1: E13 = E12 x D13 = 2.28 x 0.45 = 1.02

  For interval 50: E62 = E12 x D62 = 2.28 x 0.17 = 0.39
- In Column F, the direct runoff starts by a lag of 1 time interval, i. e. starts from second interval

  For interval 2: F14 = F12 x D13 = 3.54 x 0.45 = 1.59

  For interval 51: F63 = F12 x D62 = 3.54 x 0.17 = 0.6
- In Column G, the direct runoff starts by a lag of 2 time interval, starts from third interval

  For interval 3: G15 = G12 x D13 = 3.95 x 0.45 = 1.77

  For interval 52: G64 = G12 x D62 = 3.95 x 0.17 = 0.67
- The direct runoff is calculated in Column W

  W13 = E13 = 1.02

  W14 = E14 + F14 = 2.05 + 1.59 = 3.64

  W73 = P73 = 0.35
- Total runoff in Column X is calculated by adding baseflow (cell C10 calculated in **Step 20**) to the direct runoff (Column W)

  X12 = W12 + C10 = 0 + 14.3 =14.3

  X13 = W13 + C10 = 1.02 + 14.3 = 15.3

  X73 = W73 + C10 = 0.35 + 14.3 = 14.6

  From the Column X, the peak discharge is 301.6 m^3/s.

Solution using computer program:

Area, A: 289 km^2

River Length, L: 45 km

Slope: 2.95 %

Peaking Coefficient, C_p: 0.55 from **Table 3**

Calculate lag time

$$L_g = 0.639\ A^{0.4143}\ L^{0.1403}\ S^{-0.4321}$$

$$= 0.639\ \text{x}\ 289^{0.4143}\ \text{x}\ 45^{0.1403}\ \text{x}\ 2.95^{-0.4321}$$

$$= 7.14\ \text{hrs}$$

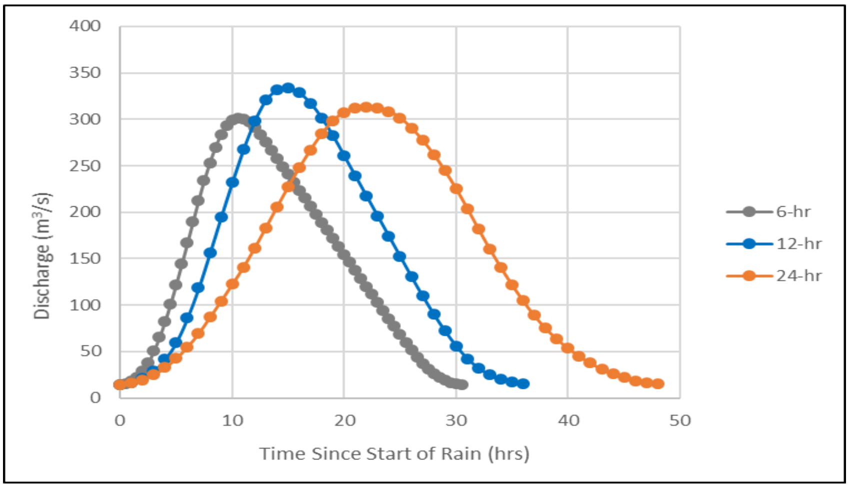
Design rainfall of 20-year ARI obtained from HP 1 (2015):

Durations (hrs)	6	12	24
Rainfall (mm)	132	149	169
ARF	0.88	0.90	0.93

Peak discharge computed using the computer program:

Rainfall Durations (hrs)	6	12	24
Peak Discharge (m^3/s)	302	334	313

Derived hydrographs: The critical storm is 12 hours



Example 2: Flood Hydrograph for Sabah

Problem:

It is proposed to construct a small weir across Sg Papar located in Kg Kogopon. Estimate the 50-year design flood hydrograph using Snyder UH method. Calculate the total hydrograph for a 24-hour storm.

Solution using Manual Calculation:

Step 1: Determine the catchment area, main stream length and weighted stream slope from the topographical map, manually or using the GIS tools.

Catchment Area, A: 546 km^2

River length, L: 65.5 km

Weighted slope of main stream, S: 1.37 %

Peaking Coefficient, C_p: 0.54 from **Table 3**

Step 2: Obtain the design rainfall for the specified return period using HP 26 (2018).

Design rainfall of 50-year ARI (24 hours) is 296 mm.

Step 3: Interpolate the ARF from **Table 1**.

The ARF value is 0.92.

Step 4: Determine the rainfall temporal pattern region **Figure 2** for Sabah.

Rainfall temporal pattern for Region 5:

Time (hrs)	1	2	3	4	5	6
Proportion of total rainfall	0.01	0.017	0.025	0.025	0.03	0.035

Time (hrs)	7	8	9	10	11	12
Proportion of total rainfall	0.046	0.05	0.058	0.058	0.062	0.069

Time (hrs)	13	14	15	16	17	18
Proportion of total rainfall	0.07	0.064	0.06	0.058	0.052	0.049

Time (hrs)	19	20	21	22	23	24
Proportion of total rainfall	0.043	0.034	0.028	0.025	0.019	0.014

Step 5: Calculate the lag time, L_g (using **Equation 19**).

$$
\begin{aligned}
L_g &= 5.145\ A^{-0.1174}\ L^{0.2417}\ S^{-0.7157} \\
&= 5.145 \text{ x } 546^{-0.1174} \text{ x } 65.5^{\ 0.2417} \text{ x } 1.37^{-0.7157} \\
&= 5.38 \text{ hrs}
\end{aligned}
$$

Step 6: Calculate the rainfall duration of standard UH, t_r (using **Equation 8**).

$$t_r = \frac{L_g}{5.5} = \frac{5.38}{5.5} = 0.98 \text{ hrs}$$

Step 7: Determine the required rainfall duration of the derived unit hydrograph, t_R (depending on rainfall temporal pattern and catchment response time).

$t_R = 1 \text{ hr}$ for a 1 hr UH (time interval used for a 24-hour storm)

This is set according to the rainfall temporal pattern. Normally $t_R \leq \frac{L_g}{5}$.

Step 8: Calculate the required catchment lag time (time difference between the centroid of excess rainfall hyetograph and unit hydrograph peak), t_{pR} (using **Equation 9**).

$$t_{pR} = L_g - \frac{t_r - t_R}{4} = 5.38 - \frac{(0.98 - 1)}{4} = 5.39 \text{ hr}$$

Step 9: Calculate the peak discharge per unit catchment area of the standard UH, q_p using **Equation 10**.

$$q_p = \frac{C\ C_p}{L_g} = \frac{0.275 \text{ x } 0.54}{5.38} = 0.028 \text{ m}^3/\text{s}/\text{km}^2/\text{mm}$$

Step 10: Calculate the peak discharge per unit of catchment area of the required UH, q_{pR} using **Equation 11**.

$$q_{pR} = \frac{C\ C_p}{t_{pR}} = \frac{0.275 \text{ x } 0.54}{5.39} = 0.028 \text{ m}^3/\text{s}/\text{km}^2/\text{mm}$$

Step 11: Calculate the catchment peak discharge of UH, $\mathrm{Q_p}$.

$$\mathrm{Q_p = \ q_{pR}\ x\ A = 0.028\ x\ 546 = 15.29\ m^3/s/mm}$$

Step 12: Calculate the time base of UH, $\mathrm{t_b}$ using **Equation 12.**

$$\mathrm{t_b = \frac{0.556}{q_{pR}} = \frac{0.556}{0.028} = 19.86\ hr}$$

Step 13: Calculate the time to peak of UH, $\mathrm{T_p}$ using **Equation 13**.

$$\mathrm{T_p = \ t_{pR} + \frac{t_R}{2} = 5.39 + \frac{1}{2} = 5.89\ hr}$$

Step 14: Calculate the number of intervals in $\mathrm{t_b}$, assuming triangular UH.

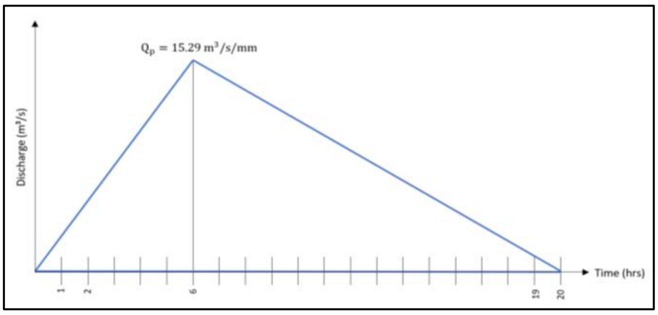
$$\mathrm{N3B = \frac{t_b}{t_R} = \frac{19.86}{1} = 19.86\ (\approx 20)}$$ Round to integer for ease of calculation

Step 15: Calculate the number of intervals in $\mathrm{T_p}$.

$$\mathrm{N3A = \frac{T_p}{t_R} = \frac{5.89}{1} = 5.89\ (\approx 6)}$$ Round to integer for ease of calculation

Step 16: Calculate and check the volume of UH runoff.

Synthetic triangular UH:



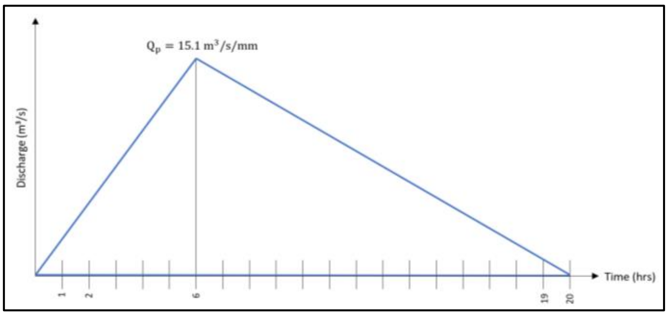
$$\mathrm{Volume = \frac{\frac{1}{2}\ x\ t_b\ x\ Q_p}{A} = \frac{\frac{1}{2}\ x\ 1\ x\ 20\ x\ 15.29\ x\ 3600\ x\ 1000}{546\ x\ 1000\ x\ 1000} = 1.01\ mm}$$

$$\text{Revised } Q_p = \frac{Q_p}{\text{Volume}} = \frac{15.29}{1.01} = 15.1 \text{ m}^3/\text{s}$$

Re-calculate the volume using the revised Q_p:

$$\text{Volume} = \frac{\frac{1}{2} \text{ x } t_b \text{ x } Q_p}{A} = \frac{\frac{1}{2} \text{ x } 1 \text{ x } 20 \text{ x } 15.1 \text{ x } 3600 \text{ x } 1000}{546 \text{ x } 1000 \text{ x } 1000} = 1 \text{ mm OK}$$

Adjusted UH is plotted as shown below:



Step 17: Calculate the UH ordinates using similar triangle.

Time interval	Discharge (m^3/s)
1 (1 hr)	2.53
2 (2 hr)	5.06
3 (3 hr)	7.58
.	.
.	.
.	.
19 (19 hr)	1.08

Step 18: Determine the catchment rainfall.

Design rainfall for 24-hour duration = 296 mm

ARF = 0.92

Catchment rainfall = 0.92 x 296 = 272 mm

Step 19: Determine the direct runoff (using **Equation 4**).

$$\text{Direct runoff, } Q = \frac{P^2}{(P+300)} = \frac{272^2}{(272+300)} = 129.3 \text{ mm}$$

Distribution of direct runoff based on proportion of total rainfall.

Time (hrs)	1	2	3	4	5	6
Runoff (mm)	1.29	2.20	3.23	3.23	3.88	4.53

Time (hrs)	7	8	9	10	11	12
Runoff (mm)	5.95	6.47	7.50	7.50	8.02	8.92

Time (hrs)	13	14	15	16	17	18
Runoff (mm)	9.05	8.28	7.76	7.50	6.72	6.34

Time (hrs)	19	20	21	22	23	24
Runoff (mm)	5.56	4.40	3.62	3.23	2.46	1.81

Step 20: Calculate the baseflow (using **Equation 22** for Sabah).

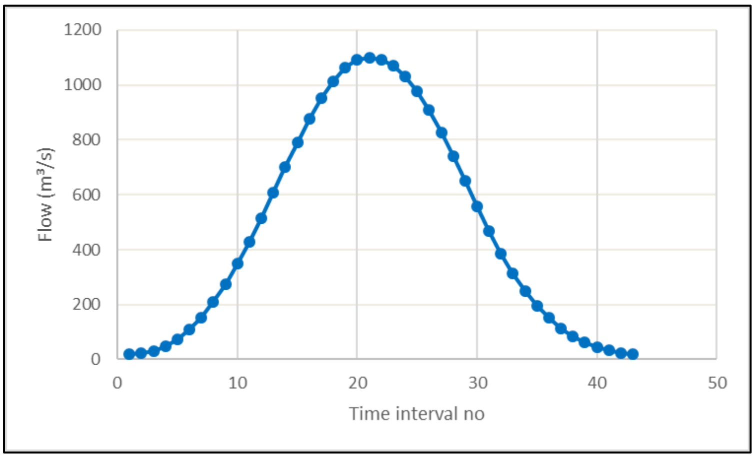
$$Q_B = 0.0783\ A^{0.8653} = 0.0783 \text{ x } 546^{0.8653} = 18.3\ m^3/s$$

Step 21: Perform the UH Convolution.

Refer to **Table B**.

Step 22: Calculate and plot the total runoff hydrograph.

Interval No	**Total runoff**
0	18.3
1	21.6
2	30.4
3	47.4
4	72.6
5	107.6
.	.
.	.
.	.
38	61.9
39	45.1
40	33.0
41	24.9
42	20.3



Explanation of **Table B** is similar to Example 1 above.

Table B: UH Convolution for Example 2

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T			AB	AC	AD	AE	AF	AG	AH
1	UH ordinates																												
2	Time Interval	Discharge (m^3/s)				Rainfall data input				Incremental rainfall , expressed as proportion of total storm rainfall																			
3						P	ARF	Region		Interval	1	2	3	4	5	6	7	8	9	10	.	.	18	19	20	21	22	23	24
4	0	0				296	0.92	5		24	0.01	0.017	0.025	0.025	0.03	0.035	0.046	0.05	0.058	0.058	.	.	0.049	0.043	0.034	0.028	0.025	0.019	0.014
5	1	2.53				Catchment rainfall		Incremental rainfall excess																					
6	2	5.06				Catchment rainfall	Total Excess RF	RE1	RE2	RE3	RE4	RE5	RE6	RE7	RE8	RE9	RE10	RE11	RE12	RE13	.	.	RE21	RE22	RE23	RE24			
7	3	7.58				272	129.3	1.29	2.20	3.23	3.23	3.88	4.53	5.95	6.47	7.50	7.50	8.02	8.92	9.05	.	.	3.62	3.23	2.46	1.81			
8	4	10.11										Sum of direct runoff					19636.59		m^3/s.hr										
9	5	12.64	Q_B									Direct runoff volume					129.47		mm										
10	6	15.17	18.3		Rainfall excess for time interval																								
11	7	14.08	Time Interval	Discharge (m^3/s)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	.	.	24	Direct runoff	Total runoff				
12	8	13.00	0		1.29	2.20	3.23	3.23	3.88	4.53	5.95	6.47	7.50	7.50	8.02	8.92	9.05	8.28	7.76	7.50	.	.	1.81	0.00	18.3				
13	9	11.92	1	2.53	3.27																.	.		3.27	21.6				
14	10	10.83	2	5.06	6.54	5.56															.	.		12.10	30.4				
15	11	9.75	3	7.58	9.81	11.12	8.17														.	.		29.10	47.4				
16	12	8.67	4	10.11	13.08	16.67	16.35	8.17													.	.		54.27	72.6				
17	13	7.58	5	12.64	16.35	22.23	24.52	16.35	9.81												.	.		89.26	107.6				
18	14	6.50	6	15.17	19.62	27.79	32.69	24.52	19.62	11.44											.	.		135.68	154.0				
19	15	5.42	7	14.08	18.22	33.35	40.87	32.69	29.43	22.89	15.04										.	.		192.48	210.8				
20	16	4.33	8	13.00	16.81	30.97	49.04	40.87	39.23	34.33	30.08	16.35									.	.		257.68	276.0				
21	17	3.25	9	11.92	15.41	28.58	45.54	49.04	49.04	45.77	45.12	32.69	18.96								.	.		330.17	348.5				
22	18	2.17	10	10.83	14.01	26.20	42.04	45.54	58.85	57.22	60.16	49.04	37.93	18.96							.	.		409.95	428.3				
23	19	1.08	11	9.75	12.61	23.82	38.53	42.04	54.65	68.66	75.20	65.39	56.89	37.93	20.27						.	.		495.98	514.3				
24			12	8.67	11.21	21.44	35.03	38.53	50.44	63.76	90.24	81.74	75.85	56.89	40.54	22.56					.	.		588.23	606.5				
25			13	7.58	9.81	19.06	31.53	35.03	46.24	58.85	83.79	98.08	94.82	75.85	60.81	45.12	22.89				.	.		681.88	700.2				
26			14	6.50	8.41	16.67	28.02	31.53	42.04	53.95	77.35	91.08	113.78	94.82	81.08	67.68	45.77	20.92			.	.		773.10	791.4				
27			15	5.42	7.01	14.29	24.52	28.02	37.83	49.04	70.90	84.07	105.65	113.78	101.35	90.24	68.66	41.85	19.62		.	.		856.84	875.1				
28			16	4.33	5.60	11.91	21.02	24.52	33.63	44.14	64.46	77.07	97.52	105.65	121.63	112.80	91.55	62.77	39.23	18.96	.	.		932.46	950.8				
29			17	3.25	4.20	9.53	17.52	21.02	29.43	39.23	58.01	70.06	89.40	97.52	112.94	135.36	114.43	83.70	58.85	37.93	.	.		996.12	1014.4				
30			18	2.17	2.80	7.15	14.01	17.52	25.22	34.33	51.56	63.05	81.27	89.40	104.25	125.69	137.32	104.62	78.47	56.89	.	.		1043.58	1061.9				
31			19	1.08	1.40	4.76	10.51	14.01	21.02	29.43	45.12	56.05	73.14	81.27	95.56	116.02	127.51	125.55	98.08	75.85	.	.		1072.39	1090.7				
32			20			2.38	7.01	10.51	16.81	24.52	38.67	49.04	65.02	73.14	86.88	106.35	117.70	116.58	117.70	94.82	.	.		1082.44	1100.7				
33			21				3.50	7.01	12.61	19.62	32.23	42.04	56.89	65.02	78.19	96.68	107.89	107.61	109.29	113.78	.	.		1075.01	1093.3				
34			22					3.50	8.41	14.71	25.78	35.03	48.76	56.89	69.50	87.02	98.08	98.65	100.89	105.65	.	.		1051.05	1069.4				
35			23						4.20	9.81	19.34	28.02	40.64	48.76	60.81	77.35	88.28	89.68	92.48	97.52	.	.		1012.52	1030.8				
36			24							4.90	12.89	21.02	32.51	40.64	52.13	67.68	78.47	80.71	84.07	89.40	.	.	4.58	959.18	977.5				
37			25								6.45	14.01	24.38	32.51	43.44	58.01	68.66	71.74	75.67	81.27	.	.	9.15	889.96	908.3				
38			26									7.01	16.25	24.38	34.75	48.34	58.85	62.77	67.26	73.14	.	.	13.73	809.76	828.1				
39			27										8.13	16.25	26.06	38.67	49.04	53.81	58.85	65.02	.	.	18.31	722.93	741.2				
40			28											8.13	17.38	29.01	39.23	44.84	50.44	56.89	.	.	22.89	631.43	649.7				
41			29												8.69	19.34	29.43	35.87	42.04	48.76	.	.	27.46	539.19	557.5				
42			30													9.67	19.62	26.90	33.63	40.64	.	.	25.50	448.53	466.8				
43			31														9.81	17.94	25.22	32.51	.	.	23.54	366.56	384.9				
44			32															8.97	16.81	24.38	.	.	21.58	294.25	312.6				
45			33																8.41	16.25	.	.	19.62	231.76	250.1				
46			34																	8.13	.	.	17.66	178.23	196.5				
47			35																		.	.	15.69	133.12	151.4				
48			36																		.	.	13.73	96.12	114.4				
49			37																		.	.	11.77	66.42	84.7				
50			38																		.	.	9.81	43.58	61.9				
51			39																		.	.	7.85	26.76	45.1				
52			40																		.	.	5.89	14.71	33.0				
53			41																		.	.	3.92	6.59	24.9				

Solution using computer program:

Area, A: 546 km^2

River Length, L: 65.5 km

Slope: 1.37%

Rainfall Temporal Region: 5

Peaking Coefficient, C_p: 0.54 from **Table 3**

Calculate lag time

$$L_g = 5.145\ A^{-0.1174}\ L^{0.2417}\ S^{-0.7157}$$

$$= 5.145 \text{ x } 546^{-0.1174} \text{ x } 65.5^{\ 0.2417} \text{ x } 1.37^{-0.7157}$$

$$= 5.38 \text{ hrs}$$

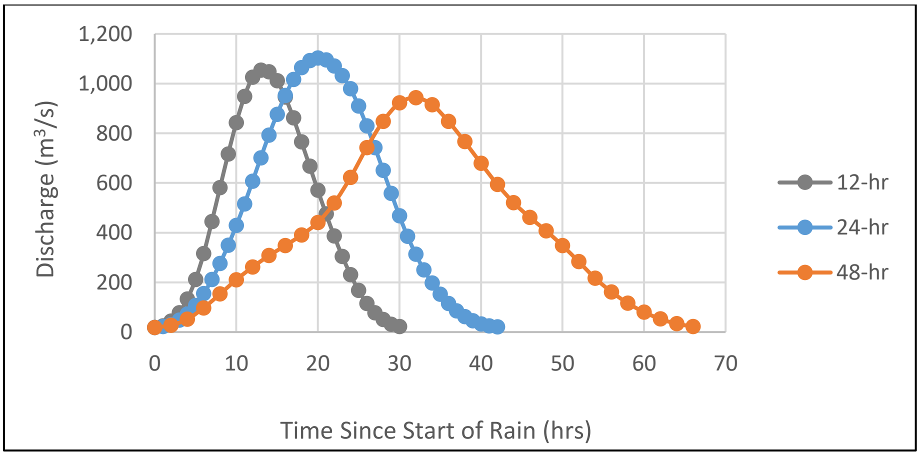
Rainfall: 50 years ARI

Durations (hrs)	**12**	**24**	**48**
Rainfall (mm)	247	296	353
ARF	0.87	0.92	0.92

Peak discharge computed using the computer program:

Rainfall Durations (hrs)	**12**	**24**	**48**
Peak Discharge (m^3/s)	1,054	1,103	943

Derived hydrographs: The critical storm is 24 hours



Example 3: Flood Hydrograph for Sarawak

Problem:

It is proposed to construct a small weir across Sg Sekerang located in Entaban. Estimate the 20-year design flood hydrograph using Snyder UH method. Calculate the total hydrograph for a 24-hour storm.

Solution using Manual Calculation:

Step 1: Determine the catchment area, main stream length and weighted stream slope from the topographical map, manually or using the GIS tools.

Catchment Area, A: 715 km^2

River length, L: 114 km

Weighted slope of main stream, S: 0.5 %

Peaking Coefficient, C_p: 0.64 from **Table 3**

Step 2: Obtain the design rainfall for the specified return period using HP 26 (2018).

Design rainfall of 20-year ARI (24 hours) is 207 mm.

Step 3: Interpolate the ARF from **Table 1**.

The ARF value is 0.91.

Step 4: Determine the rainfall temporal pattern region from **Figure 2** for Sarawak.

Rainfall temporal pattern for Region 7:

Time (hrs)	1	2	3	4	5	6
Proportion of total rainfall	0.014	0.025	0.029	0.033	0.035	0.036

Time (hrs)	7	8	9	10	11	12
Proportion of total rainfall	0.037	0.039	0.04	0.042	0.05	0.081

Time (hrs)	13	14	15	16	17	18
Proportion of total rainfall	0.112	0.072	0.05	0.042	0.04	0.038

Time (hrs)	19	20	21	22	23	24
Proportion of total rainfall	0.036	0.035	0.034	0.032	0.028	0.022

Step 5: Calculate the lag time, L_g (using **Equation 20**).

$$L_g = 2.701\ A^{-0.2954}\ L^{0.6795}\ S^{-0.3737}$$
$$= 2.701 \text{ x } 715^{-0.2954} \text{ x } 114^{0.6795} \text{ x } 0.5^{-0.3737}$$
$$= 12.55 \text{ hrs}$$

Step 6: Calculate the rainfall duration of standard UH, t_r (using **Equation 8**).

$$t_r = \frac{L_g}{5.5} = \frac{12.55}{5.5} = 2.28 \text{ hrs}$$

Step 7: Determine the required rainfall of the derived unit hydrograph, t_R (depending on rainfall temporal pattern and catchment response time).

$t_R = 1$ hr   for a 1 hr UH (time interval used for a 24-hour storm)

This is set according to the rainfall temporal pattern. Normally $t_R \leq \frac{L_g}{5}$.

Step 8: Calculate the required catchment lag time (time difference between the centroid of excess rainfall hyetograph and unit hydrograph peak), t_{pR} (using **Equation 9**).

$$t_{pR} = L_g - \frac{t_r - t_R}{4} = 12.55 - \frac{(2.28 - 1)}{4} = 12.23 \text{ hr}$$

Step 9: Calculate the peak discharge per unit catchment area of the standard UH, q_p using **Equation 10**.

$$q_p = \frac{C\ C_p}{L_g} = \frac{0.275 \text{ x } 0.64}{12.55} = 0.014 \text{ m}^3/\text{s}/\text{km}^2/\text{mm}$$

Step 10: Calculate the peak discharge per unit of catchment area of the required UH, q_{pR} using **Equation 11**.

$$q_{pR} = \frac{C\ C_p}{t_{pR}} = \frac{0.275 \text{ x } 0.64}{12.23} = 0.0144 \text{ m}^3/\text{s}/\text{km}^2/\text{mm}$$

Step 11: Calculate the catchment peak discharge of UH, Q_p.

$$Q_p = q_{pR} \text{ x } A = 0.0144 \text{ x } 715 = 10.3 \text{ m}^3/\text{s/mm}$$

Step 12: Calculate the time base of UH, t_b using **Equation 12**.

$$t_b = \frac{0.556}{q_{pR}} = \frac{0.556}{0.0144} = 38.61 \text{ hr}$$

Step 13: Calculate the time to peak of UH, T_p using **Equation 13**.

$$T_p = t_{pR} + \frac{t_R}{2} = 12.23 + \frac{1}{2} = 12.73 \text{ hr}$$

Step 14: Calculate the number of intervals in t_b, assuming triangular UH.

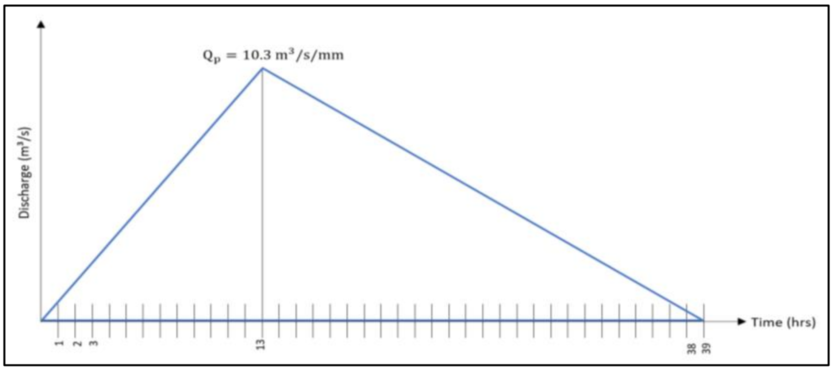
$$N3B = \frac{t_b}{t_R} = \frac{38.61}{1} = 38.61 \ (\approx 39)$$ Round to integer for ease of calculation

Step 15: Calculate the number of intervals in T_p.

$$N3A = \frac{T_p}{t_R} = \frac{12.73}{1} = 12.73 \ (\approx 13)$$ Round to integer for ease of calculation

Step 16: Calculate and check the volume of UH runoff.

Synthetic triangular UH:



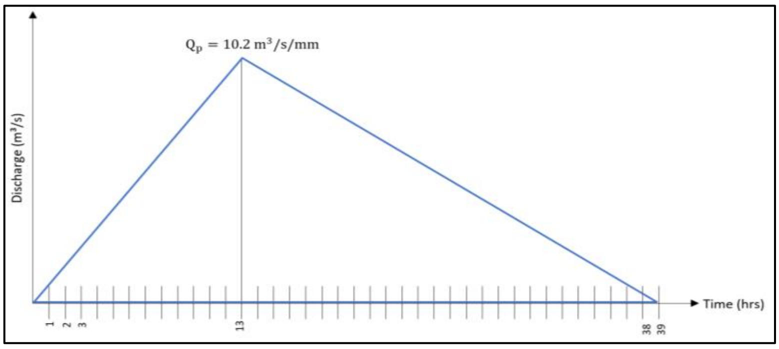
$$\text{Volume} = \frac{\frac{1}{2} \text{ x } t_b \text{ x } Q_p}{A} = \frac{\frac{1}{2} \text{ x } 1 \text{ x } 39 \text{ x } 10.3 \text{ x } 3600 \text{ x } 1000}{715 \text{ x } 1000 \text{ x } 1000} = 1.01 \text{ mm}$$

$$\text{Revised } Q_p = \frac{Q_p}{\text{Volume}} = \frac{10.3}{1.01} = 10.2 \text{ m}^3/\text{s}$$

Re-calculate the volume using the revised Q_p:

$$\text{Volume} = \frac{\frac{1}{2} \text{ x } t_b \text{ x } Q_p}{A} = \frac{\frac{1}{2} \text{ x 1 x 39 x 10.2 x 3600 x 1000}}{\text{715 x 1000 x 1000}} = 1 \text{ mm OK}$$

Adjusted UH is plotted as shown below:



Step 17: Calculate the UH ordinates using similar triangle.

Time interval	Discharge (m^3/s)
1 (1 hr)	0.78
2 (2 hr)	1.57
3 (3 hr)	2.35
.	.
.	.
.	.
37 (37 hr)	0.78
38 (38 hr)	0.39

Step 18: Determine the catchment rainfall.

Design rainfall for 24-hour duration = 207 mm

ARF = 0.91

Catchment rainfall = 0.91 x 207 = 188 mm

Step 19: Determine the direct runoff (using **Equation 6**).

$$\text{Direct runoff, } Q = \frac{P^2}{(P+160)} = \frac{188^2}{(188+160)} = 101.6 \text{ mm}$$

Distribution of direct runoff based on proportion of total rainfall.

Time (hrs)	1	2	3	4	5	6
Runoff (mm)	1.42	2.54	2.95	3.35	3.56	3.66

Time (hrs)	7	8	9	10	11	12
Runoff (mm)	3.76	3.96	4.06	4.27	5.08	8.23

Time (hrs)	13	14	15	16	17	18
Runoff (mm)	11.38	7.32	5.08	4.27	4.06	3.86

Time (hrs)	19	20	21	22	23	24
Runoff (mm)	3.66	3.56	3.45	3.25	2.84	2.24

Step 20: Calculate the baseflow (using **Equation 23** for Sarawak).

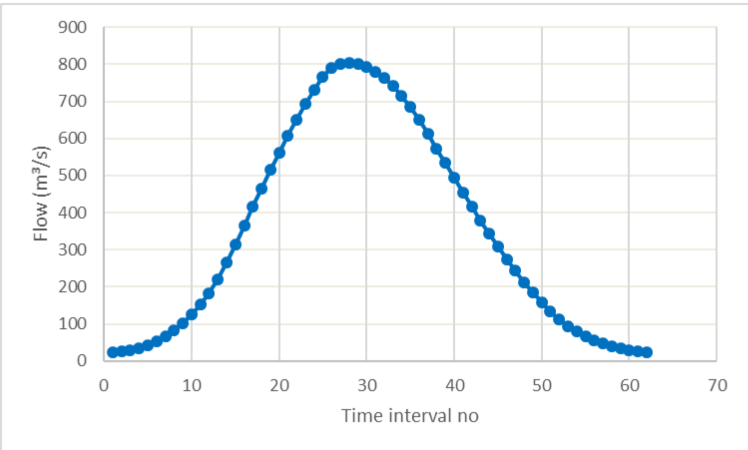
$$Q_B = 0.0111\ A^{1.1682} = 0.0111 \text{ x } 715^{1.1682} = 23.9\ m^3/s$$

Step 21: Perform the UH Convolution.

Refer to **Table C**.

Step 22: Calculate and plot the total runoff hydrograph.

Interval No	**Total runoff**
0	23.9
1	25.01
2	28.11
3	33.53
4	41.57
5	52.42
.	.
.	.
.	.
57	40.67
58	34.66
59	30.03
60	26.76
61	24.77



Explanation of **Table C** is similar to Example 1 above.

Table C: UH Convolution for Example 3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	.	.	AB	AC	AD	AE	AF	AG	AH
1	UH ordinates																												
2	Time Interval	Discharge (m^3/s)				Rainfall data input				Incremental rainfall , expressed as proportion of total storm rainfall																			
3						P	ARF	Region		Interval	1	2	3	4	5	6	7	8	9	10	.	.	18	19	20	21	22	23	24
4	0	0				207	0.91	7		24	0.014	0.025	0.029	0.033	0.035	0.036	0.037	0.039	0.04	0.042	.	.	0.038	0.036	0.035	0.034	0.032	0.028	0.022
5	1	0.78				Catchment rainfall		Incremental rainfall excess																					
6	2	1.57				Catchment rainfall	Total Excess RF	RE1	RE2	RE3	RE4	RE5	RE6	RE7	RE8	RE9	RE10	RE11	RE12	RE13	.	.	RE21	RE22	RE23	RE24			
7	3	2.35				188	101.6	1.42	2.54	2.95	3.35	3.56	3.66	3.76	3.96	4.06	4.27	5.08	8.23	11.38	.	.	3.45	3.25	2.84	2.24			
8	4	3.14										Sum of direct runoff					20250.14		m^3/s.hr										
9	5	3.92	Q_B									Direct runoff volume					101.96		mm										
10	6	4.71	23.9		Rainfall excess for time interval																								
11	7	5.49	Time Interval	Discharge (m^3/s)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	.	.	24	Direct runoff	Total runoff				
12	8	6.28	0		1.42	2.54	2.95	3.35	3.56	3.66	3.76	3.96	4.06	4.27	5.08	8.23	11.38	7.32	5.08	4.27	.	.	2.24	0	23.9				
13	9	7.06	1	0.78	1.11																.	.		1.11	25.0				
14	10	7.85	2	1.57	2.23	1.98															.	.		4.21	28.1				
15	11	8.63	3	2.35	3.34	3.99	2.30														.	.		9.63	33.5				
16	12	9.42	4	3.14	4.46	5.97	4.63	2.61													.	.		17.67	41.6				
17	13	10.20	5	3.92	5.57	7.98	6.93	5.26	2.78												.	.		28.52	52.4				
18	14	9.81	6	4.71	6.69	9.96	9.26	7.87	5.59	2.85											.	.		42.22	66.1				
19	15	9.42	7	5.49	7.80	11.96	11.56	10.52	8.37	5.75	2.93										.	.		58.89	82.8				
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.				
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.				
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.				
38	34	1.96	26	5.10	7.24	13.94	17.35	21.04	23.75	25.84	28.01	31.09	33.45	36.85	45.82	77.53	111.64	74.66	47.85	36.85	.	.	5.26	777.72	801.6				
39	35	1.57	27	4.71	6.69	12.95	16.20	19.70	22.36	24.41	26.55	29.50	31.87	35.18	43.84	74.23	107.20	71.81	51.82	40.22	.	.	7.03	780.48	804.4				
40	36	1.18	28	4.32	6.13	11.96	15.05	18.39	20.93	22.98	25.08	27.96	30.25	33.52	41.86	71.02	102.65	68.95	49.83	43.55	.	.	8.78	777.20	801.1				
41	37	0.78	29	3.92	5.57	10.97	13.89	17.09	19.54	21.52	23.61	26.41	28.66	31.81	39.88	67.82	98.21	66.03	47.85	41.89	.	.	10.55	768.97	792.9				
42	38	0.39	30	3.53	5.01	9.96	12.74	15.78	18.16	20.09	22.11	24.87	27.08	30.15	37.85	64.61	93.77	63.17	45.82	40.22	.	.	12.30	755.96	779.9				
43			31	3.14	4.46	8.97	11.56	14.47	16.77	18.67	20.64	23.28	25.50	28.48	35.86	61.31	89.33	60.32	43.84	38.52	.	.	14.07	738.37	762.3				
44			32	2.75	3.91	7.98	10.41	13.13	15.38	17.24	19.18	21.74	23.87	26.82	33.88	58.10	84.78	57.46	41.86	36.85	.	.	15.81	716.43	740.3				
45			33	2.35	3.34	6.99	9.26	11.83	13.96	15.81	17.71	20.20	22.29	25.11	31.90	54.89	80.34	54.53	39.88	35.18	.	.	17.58	690.38	714.3				
46			34	1.96	2.78	5.97	8.11	10.52	12.57	14.35	16.24	18.65	20.71	23.44	29.87	51.68	75.90	51.68	37.85	33.52	.	.	19.33	660.22	684.1				
47			35	1.57	2.23	4.98	6.93	9.21	11.18	12.92	14.74	17.11	19.12	21.78	27.89	48.39	71.47	48.82	35.86	31.81	.	.	21.10	626.27	650.2				
48			36	1.18	1.68	3.99	5.78	7.87	9.79	11.49	13.27	15.52	17.54	20.11	25.91	45.18	66.91	45.97	33.88	30.15	.	.	22.85	588.92	612.8				
49			37	0.78	1.11	3.00	4.63	6.57	8.37	10.07	11.81	13.98	15.92	18.45	23.93	41.97	62.48	43.04	31.90	28.48	.	.	21.97	549.00	572.9				
50			38	0.39	0.55	1.98	3.48	5.26	6.98	8.60	10.34	12.43	14.33	16.74	21.95	38.76	58.04	40.19	29.87	26.82	.	.	21.10	509.07	533.0				
51			39			0.99	2.30	3.95	5.59	7.17	8.84	10.89	12.75	15.07	19.91	35.55	53.60	37.33	27.89	25.11	.	.	20.20	469.12	493.0				
52			40				1.15	2.61	4.20	5.75	7.37	9.31	11.17	13.41	17.93	32.26	49.16	34.48	25.91	23.44	.	.	19.33	429.74	453.6				
53			41					1.31	2.78	4.32	5.90	7.76	9.54	11.74	15.95	29.05	44.61	31.62	23.93	21.78	.	.	18.46	391.33	415.2				
54			42						1.39	2.85	4.44	6.22	7.96	10.03	13.97	25.84	40.17	28.69	21.95	20.11	.	.	17.58	354.10	378.0				
55			43							1.43	2.93	4.67	6.37	8.37	11.94	22.63	35.73	25.84	19.91	18.45	.	.	16.69	318.19	342.09				
56			44								1.47	3.09	4.79	6.70	9.96	19.34	31.30	22.98	17.93	16.74	.	.	15.81	283.68	307.58				
57			45									1.54	3.17	5.04	7.98	16.13	26.74	20.13	15.95	15.07	.	.	14.94	250.58	274.48				
58			46										1.58	3.33	5.99	12.92	22.30	17.20	13.97	13.41	.	.	14.07	218.95	242.85				
59			47											1.67	3.96	9.71	17.87	14.35	11.94	11.74	.	.	13.17	188.94	212.84				
60			48												1.98	6.42	13.43	11.49	9.96	10.03	.	.	12.30	160.47	184.37				
61			49													3.21	8.88	8.64	7.98	8.37	.	.	11.42	133.66	157.56				
62			50														4.44	5.71	5.99	6.70	.	.	10.55	108.86	132.76				
63			51															2.85	3.96	5.04	.	.	9.68	87.29	111.19				
64			52																1.98	3.33	.	.	8.78	70.21	94.11				
65			53																	1.67	.	.	7.91	56.00	79.90				
66			54																		.	.	7.03	43.74	67.64				
67			55																		.	.	6.16	33.18	57.08				
68			56																		.	.	5.26	24.21	48.11				
69			57																		.	.	4.39	16.77	40.67				
70			58																		.	.	3.52	10.76	34.66				
71			59																		.	.	2.64	6.13	30.03				
72			60																		.	.	1.75	2.86	26.76				
73			61																		.	.	0.87	0.87	24.77				

Solution using Computer Program:

Area, A: 715 km^2

River Length, L: 114 km

Slope: 0.5%

Rainfall Temporal Region: 7

Peaking Coefficient, C_p: 0.64 from **Table 3**

Calculate lag time

$$L_g = 2.701\ A^{-0.2954}\ L^{0.6795}\ S^{-0.3737}$$

$$= 2.701 \text{ x } 715^{-0.2954} \text{ x } 114^{0.6795} \text{ x } 0.5^{-0.3737}$$

$$= 12.55 \text{ hrs}$$

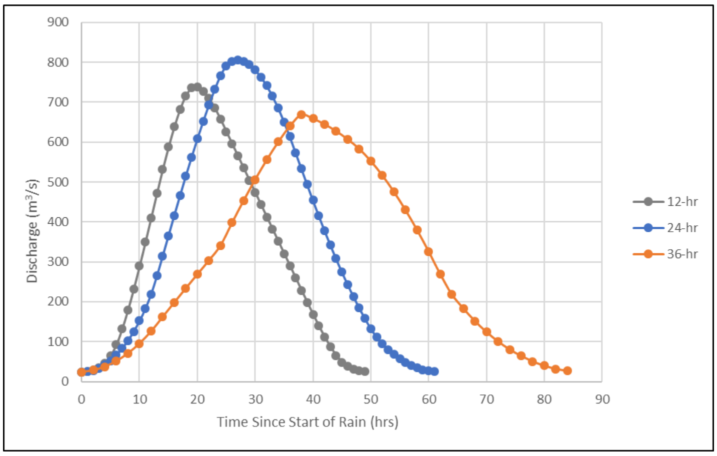
Rainfall: 20 years ARI

Durations (hrs)	12	24	48
Rainfall (mm)	183	207	231
ARF	0.86	0.91	0.91

Peak discharge computed using the computer program:

Rainfall Durations (hrs)	12	24	48
Peak Discharge (m^3/s)	738	805	668

Derived hydrographs: The critical storm is 24 hours



5. Limitations of the Procedure

The Snyder method for this Procedure has been prepared mainly for the estimation of reasonable flood hydrographs where hydrological data for the catchment is sparse or non-existent. The current Procedure although has made significant improvements as compared to HP 11 (1976), there are still some limitations as follows:

- Assumption of T-year ARI flood is caused by the storm of T-year ARI
- Antecedent moisture of catchment was not considered in the derivation of rainfall-runoff relationship
- The rainfall-runoff coefficients showed large variability despite the large number of storm events evaluated. The adopted coefficients are slightly larger than the mean values to avoid under-estimation of the design flood, erring on the conservative side
- The areal variability of catchment rainfall during a storm causes the lag time of a catchment to vary from storm to storm. This makes the assumption of uniform areal distribution of design storm invalid.
- Some un-accounted for storage depression (e.g wetland, extremely flat catchment slopes) could lead to the overestimation of the peak discharge and the underestimation of the time to peak when using the equations. The equations developed are applicable for catchment with size used for the development of these equations.

It is recommended that the design flood estimation using this Procedure should:

(i) Not be used on catchment less than 20 km^2 and larger than 2,000 km^2 for Peninsular Malaysia, less than 100 km^2 and larger than 3,000 km^2 for Sabah and less than 20 km^2 and larger than 2,500 km^2 for Sarawak.

(ii) Not be used as a design basis when serious consequences such as major damage and loss of lives would result from the design flood being exceeded. In this case the PMP and PMF method should be used in preference to the design storm. The temporal and areal pattern of the PMP should be determined from an analysis of extreme flood producing storms in the area. The PMP should be estimated from meteorological data using WMO or NAHRIM procedure.

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APPENDICES

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.1: Data Used to Derive Rainfall-Runoff Relationship for Peninsular Malaysia

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
1	0340211SF (1931423)	Sg Sembrong di Bt 2 Air Hitam, Yong Peng	21 Sep 1970	223	142
			29 Dec 1970	485	337
			17 Feb 1973	100	57
			14 May 1973	62	35
			6 Jan 1978	182	111
2	0320191SF (2528414)	Sg Segamat di Segamat	5 Mar 1974	28	8
			2 Dec 1978	121	40
3	0430271SF (1836402)	Sg Sayong di Johor Tenggara	30 Mar 1979	47	9
			9 Aug 1980	102	42
			17 Dec 1980	93	32
			22 Dec 1984	130	68
			6 Mar 1988	128	44
			18 Nov 1988	122	46
			27 May 1993	65	12
			2 Feb 1996	82	28
			27 Dec 1998	120	36
4	0320381SF (2625412)	Sg Muar di Bt 57 Jln Gemas-Rompin	14 Dec 1972	52	17
			18 Nov 1974	29	6
			25 Sep 1976	36	12
			7 Feb 1984	95	50
			14 Mar 1984	109	39
			9 Mar 1988	35	6
5	0551181SF (3629403)	Sg Lepar di Jam Gelugor	17 Dec 1976	100	51
			8 Jan 1978	65	14
			14 Dec 1982	58	28
			24 Nov 1990	130	60
			15 Dec 1997	80	27
6	0500141SF (2237471)	Sg Lenggor di Bt 42 Kluang-Mersing	2 Dec 1977	192	110
			18 Dec 1983	94	52
			6 Dec 1987	201	86
7	0570121SF (3930401)	Sg Kuantan di Bkt Kenau	16 Jun 1975	27	6
			6 Sep 1977	52	13
			10 Oct 1977	58	21
			12 Dec 1981	55	14
			29 Jan 1984	154	80
			14 Mar 1985	228	137
			2 Nov 1993	209	112

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.1: Data Used to Derive Rainfall-Runoff Relationship for Peninsular Malaysia

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
			2 Feb 1996	24	11
			12 Nov 1997	64	28
8	0320551SF (2723401)	Sg Kepis di Jam Kayu Lama	20 Mar 1980	40	10
			28 Nov 1980	70	17
			12 Nov 1981	50	10
			18 Sep 1999	45	20
9	0600111SF (4232452)	Sg Kemaman di Rantau Panjang	29 Nov 1989	58	23
			8 Jan 1990	150	46
10	0551481SF (4320401)	Sg Kecau di Kg Dusun	19 Dec 1986	82	34
			8 Dec 1987	43	23
			25 Jun 1994	40	20
			22 Dec 1995	36	18
			20 Jul 1997	66	24
			9 Nov 1998	50	16
			23 Nov 1999	48	12
11	0500281SF (2235401)	Sg Kahang di Bt 26 Jln Kluang	2 Jan 1979	285	129
			5 Jan 1980	134	40
			29 Dec 1980	97	47
			25 Dec 1983	244	131
			8 Mar 1986	192	90
			24 Jan 1987	168	86
			28 Nov 1989	331	191
			27 Dec 1998	170	72
12	0430121SF (1737451)	Sg Johor di Rantau Panjang	13 Oct 1975	93	23
			23 Feb 1977	60	30
			17 Jan 1980	135	39
			22 Sep 1980	70	24
			10 Dec 1981	260	140
			16 Dec 1982	297	249
			23 Dec 1984	200	108
			13 Jan 1990	152	56
13	0600101SF (4131453)	Sg Cherul di Ban Ho	30 Nov 1986	164	60
			25 Jan 1987	90	27
			7 Mar 1988	306	184
			11 Dec 1997	198	81
			18 Dec 1997	92	39
			29 Dec 1997	162	71

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.1: Data Used to Derive Rainfall-Runoff Relationship for Peninsular Malaysia

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
14	0670011SF (4930401)	Sg Berang di Menerong	25 Jan 1995	265	135
			12 Dec 1996	190	79
			18 Dec 1997	306	265
15	0551041SF (3519426)	Sg Bentong di Jam K Marong	17 Feb 1974	50	21
			7 Jan 1975	78	12
			5 Nov 1979	62	22
16	0340231SF (2130422)	Sg Bekok di Bt 77 Jln Yong Peng/Labis	17 Feb 1973	69	39
			14 Jun 1973	76	29
			23 Nov 1975	69	23
			27 Dec 1976	127	60
			5 Jan 1979	234	128
			14 Oct 1980	89	30
			2 Mar 1984	114	52
			8 Mar 1986	196	91
			7 Dec 1987	142	43
17	0180311SF (3913458)	Sg Sungkai di Sungkai	6 Oct 1985	134	38
			4 Dec 1996	167	40
			18 Jan 1997	16	6
			13 Feb 1997	97	13
			22 Mar 1997	63	12
			29 Apr 1997	28	6
			11 Nov 1997	50	11
			27 Sep 1999	96	23
18	0180761SF (4511468)	Sg Raia di Keramat Pulai	28 May 1986	39	5
			7 Nov 1986	23	6
			4 Aug 1987	31	3
			7 Aug 1987	41	6
			5 May 1988	13	6
			1 Sep 1989	47	12
			12 Oct 1989	10	5
			12 Mar 1993	34	9
			10 Apr 1993	72	7
			6 Jun 1993	49	8
			5 Dec 1993	49	8

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.1: Data Used to Derive Rainfall-Runoff Relationship for Peninsular Malaysia

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
19	0180131SF (4610466)	Sg Pari di Jln Silibin, Ipoh	21 May 1994	62	13
20	0240511SF (2918401)	Sg Semenyih di Sg Rinching	7 Oct 1977	48	3
			10 Apr 1979	19	3
21	0210311SF (3516422)	Sg Selangor di Rasa	5 Nov 1971	71	13
			3 Dec 1980	84	19
			2 Oct 1988	64	16
			2 Nov 1988	40	7
			17 Jan 1997	62	15
			11 Aug 1998	62	18
22	0180361SF (4911445)	Sg Plus di Kg Lintang	29 Oct 1976	64	8
			30 Oct 1995	76	21
			20 Dec 1999	42	10
			24 Mar 2000	100	11
23	0010331SF (6602401)	Sg Pelarit di Wang Mu	23 Aug 1985	45	12
			20 Sep 1989	39	12
			19 Sep 1995	45	19
24	0290131SF (2322413)	Sg Melaka di Pantai Belimbing	15 Feb 1981	52	14
25	0240441SF (3118445)	Sg Lui di Kg Lui	27 Nov 1974	81	10
			18 Apr 1979	48	11
26	0270081SF (2519421)	Sg Linggi di Sua Betong	7 Jul 1973	84	15
			12 Sep 1974	44	8
			13 Nov 1974	97	21
			18 Nov 1980	102	20
			1 Jan 1981	37	5
			13 Jul 1983	80	10
27	0240341SF (2816441)	Sg Langat di Dengkil	21 Sep 1970	60	8
			9 Nov 1973	66	9
			9 Mar 1974	83	11
			24 Nov 1974	44	6
			4 Jan 1977	52	13
28	0100041SF (5007421)	Sg Kurau di Pondok Tg	3 Sep 1979	162	57
			17 Sep 1995	118	49
			29 Oct 1995	263	130

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.1: Data Used to Derive Rainfall-Runoff Relationship for Peninsular Malaysia

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
29	0060071SF (5405421)	Sg Kulim di Ara Kuda	13 Sep 1972	85	19
			27 Apr 1984	127	30
			8 Nov 1987	119	29
30	0090141SF (5206432)	Sg Kerian di Selama	7 May 1986	105	16
			18 Sep 1987	81	18
			17 Sep 1995	177	49
			3 Sep 1999	126	45
31	0180801SF (4310401)	Sg Kinta di Weir G, Tg Tualang	6 Oct 1985	133	49
			14 Nov 1987	104	17
			22 Sep 1989	241	85
			26 May 1993	111	20
			8 Nov 1993	93	15
32	0310061SF (2224432)	Sg Kesang di Chin Chin	20 Nov 1970	104	16
			1 Jan 1971	174	52
			10 Oct 1976	147	49
			11 Oct 1979	71	7
			12 Jul 1983	26	7
			17 Nov 1996	25	7
33	0290141SF (2322415)	Sg Durian Tunggal di Bt 11 Air Resam	16 Sep 1998	56	6
34	0180641SF (4212467)	Sg Cenderiang di Bt 32 Jln Tapah	31 Oct 1984	90	10
			22 Nov 1984	59	11
35	0180861SF (4012401)	Sg Bidor di Bidor Malayan Tin Bhd	3 Jul 1982	123	30
			14 Sep 1983	110	30
			11 Apr 1984	85	17
			2 Jun 1987	162	38
36	0190131SF (3615412)	Sg Bernam di Tg Malim	5 May 1992	155	30
			21 Nov 1992	121	26
			11 Jun 1997	86	19
37	0210201SF (3414421)	Sg Selangor di Rantau Panjang	1 Jan 1971	263	109
			3 May 1976	151	31
			6 Feb 1985	117	28
			16 Apr 1985	78	20
			2 Dec 1985	52	17
			11 Feb 1987	61	8
			11 Aug 1987	103	19
			30 Oct 1991	231	95

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.2: Data Used to Derive Rainfall-Runoff Relationship for Sabah

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
1	0850041WL (4278402)	Sg Tawau di Kuhara	16 Apr 1985	32.3	7.2
			1 May 1985	65.3	11.5
2	0790021WL (4474401)	Sg Kalabakan di Kalabakan	28 Mar 1988	26.8	7.0
			12 Jun 1988	63.0	4.0
			24 May 1989	33.9	11.9
			1 Sep 1989	69.8	17.0
			3 Dec 1993	28.4	13.3
3	0880011WL (4581401)	Sg Kalumpang di Mostyn Bridge	30 Apr 1986	53.9	8.8
			4 Mar 1988	82.0	38.0
4	0750041WL (4764402)	Sg Talangkai di Lotong	5 Feb 1999	111.0	31.0
5	1490031WL (4955403)	Sg Mengalong di Sindumin	7 Jan 2000	27.3	9.6
			21 Mar 2001	76.5	11.0
			27 Nov 2002	26.7	8.9
			2 Oct 2004	35.5	8.8
6	1040031WL (5074401)	Sg Kuamut di Ulu Kuamut	29 Apr 1985	154.6	33.2
7	1480021WL (5156401)	Sg Lakutan di Mesapol Quarry	3 Nov 2011	129.0	31.0
8	1010031WL (5181401)	Sg Segama di Limkabong	25 Nov 1988	39.0	19.0
			2 Dec 1994	102.7	44.8
			12 May 1996	44.5	21.4
9	1460121WL (5261402)	Sg Sook di Biah	27 Feb 2008	138.0	21.0
10	1460211WL (5461401)	Sg Baiayo di Bandukan	7 May 1994	31.5	6.5
			5 Jun 1995	48.4	2.7
			24 Dec 1999	20.7	3.8
			10 May 2000	11.5	4.4
			31 May 2002	22.9	4.8
			31 Mar 2005	24.0	1.9
11	1460221WL (5462402)	Sg Apin-Apin di Waterworks	3 Nov 1997	18.8	5.2
			20 Jul 1998	33.7	9.2
			4 Feb 2000	21.2	3.5
			6 Feb 2000	15.2	5.7
			12 Apr 2000	10.5	4.9
12	1460251WL (5668401)	Sg Kegibangan di Tampias P.H.	17 Feb 1999	96.4	18.7
			20 Mar 1999	98.2	15.9
			10 May 2005	120.0	20.0

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.2: Data Used to Derive Rainfall-Runoff Relationship for Sabah

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
13	1400021WL (5760401)	Sg Papar di Kaiduan	19 May 1985	72.0	7.0
			5 Jun 1985	48.5	8.0
			3 Oct 1985	50.2	18.8
			12 Jun 1988	42.3	15.4
			11 Sep 1991	28.8	8.3
			11 Sep 1991	83.6	28.2
			9 Nov 1991	99.8	23.6
			20 Jun 1992	115.8	21.0
			20 Jun 1992	115.3	22.0
			7 Jul 1993	202.7	85.77
			22 Jun 1995	77.4	16.8
			18 Sep 1995	50.0	10.9
			15 Feb 1996	62.0	22.0
14	1400041WL (5760402)	Sg Papar di Kogopon	8 Sep 2013	132.0	47.0
15	1160151WL (5768401)	Sg Labuk di Tampias	6 Mar 1986	48.0	7.6
			21 Feb 1989	84.0	22.0
			20 Jan 1991	102.8	28.8
			5 Mar 1994	58.4	9.3
16	1390021WL (5961401)	Sg Moyog di Penampang	23 Nov 1990	111.0	26.0
			23 Sep 1993	141.0	43.0
17	1160031WL (6073401)	Sg Tungud di Basai	13 Dec 1987	93.7	16.6
			20 Feb 1988	173.0	43.0
			25 Jan 1989	36.0	11.7
			30 Sep 1989	52.9	12.6
			12 Jan 1993	127.0	20.0
			16 Jan 1993	115.0	34.0
			24 Dec 1993	575.0	382.0
			24 Oct 1998	84.0	36.0
			23 Dec 1999	255.0	144.0
			27 Jan 1992	139.0	56.0
18	1360041WL (6162403)	Sg Tuaran di Pump House 1	10 Dec 1991	101.0	37.0
			13 Mar 1994	101.0	38.6
19	1200011WL (6172401)	Sg Sugut di Bukit Mondou	12 Dec 1987	129.0	61.0
			1 Mar 1989	92.7	14.3
			6 Jun 1994	89.7	20.0

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.2: Data Used to Derive Rainfall-Runoff Relationship for Sabah

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
20	1340021WL (6264401)	Sg Kadamaian di Tamu Darat	6 Nov 1989	107.0	18.0
			7 Jun 1992	65.6	14.8
			14 Jul 1996	113.2	28.0
			27 May 1999	123.5	48.0
21	1340031WL (6364401)	Sg Wariu di Bridge No.2	26 Dec 1996	102.2	47.0
22	1280011WL (6468402)	Sg Bongan di Timbang Batu Sabah	12 Nov 1987	79.5	26.0
			31 Jul 1995	91.5	22.3
23	1260011WL (6670401)	Sg Bengkoka di Kobon	7 Dec 1987	175.0	49.0
			15 Aug 1988	78.5	22.0
			7 Jan 1991	74.6	19.0
			11 Feb 1994	73.0	18.0
			22 Feb 1999	210.0	55.0
			2 Jan 2003	224.0	111.0

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
1	1790041WL (1004438)	Sg Kayan di Krusen	3 Dec 1985	16.0	5.0
			28 Sep 1986	19.6	9.0
			23 Jan 1987	15.3	7.3
			11 Oct 1987	41.9	15.3
			16 Jan 1990	36.7	6.7
			1 Feb 1990	17.2	11.0
			22 Nov 1991	58.4	20.5
			4 Mar 1995	65.8	33.2
			30 Apr 1995	46.4	31.3
			3 Jan 1996	33.2	12.5
			2 Feb 1996	21.5	8.1
			3 Feb 2003	118.0	40.7
			29 Aug 2007	43.9	23.4
			8 Jun 2008	224.0	173.0
			9 Jan 2009	189.0	148.0
			18 Jun 2016	102.8	54.0

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
2	1790051WL (1005447)	Sg Kedup di New Meringgu	19 Aug 1998	70.0	16.9
			21 May 2000	46.7	7.9
			15 Feb 2001	100.2	57.9
			15 Feb 2001	113.6	51.5
			17 Sep 2001	95.0	22.4
			2 Oct 2001	107.0	22.6
			15 Jan 2003	113.9	37.1
			17 Jun 2005	30.7	10.8
			26 Jul 2005	27.2	13.6
			16 Aug 2005	40.9	16.6
			2 Oct 2005	220.3	95.8
			11 Jun 2006	21.5	8.7
			29 Jan 2007	49.9	22.5
			22 Nov 2012	69.4	12.1
3	1770061WL (1015401)	Sg Entebar di Entebar	22 Jan 2000	46.1	26.7
4	1770021WL (1018401)	Sg Ai di Lubok Antu	5 Nov 1978	48.9	10.7
			4 Dec 1978	22.2	12.9
			13 Feb 1979	64.7	25.0
			20 Jan 1980	20.5	12.2
			3 Mar 1980	17.4	10.0
			30 Mar 1980	68.1	12.0
			3 Apr 1980	24.4	10.3
			13 Aug 1980	40.7	16.4
			19 Nov 1980	48.6	11.2
			23 Oct 1997	60.5	12.3
			12 Jul 1998	20.5	14.1
5	1790031WL (1108401)	Sg Sabal Kruin di Sabal Kruin	8 Oct 1988	42.7	28.1
			10 May 1989	37.6	9.8
			9 Jul 1989	22.6	15.8
			8 Aug 1991	43.9	5.4
			1 Jul 1994	64.5	8.7
			28 Aug 1994	31.4	7.2
			1 Jul 1995	95.9	59.4
			18 Jul 1997	9.2	3.9
			13 Jun 1999	66.8	18.2

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

No.	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
			7 Aug 1999	36.1	7.2
			08 Sep 1999	33.1	12.0
6	1810061WL (1301427)	Sg Sarawak Kanan di Pk Buan Bidi	19 Nov 1997	28.0	4.8
			22 Dec 1997	9.5	4.3
			29 Dec 1997	45.0	19.2
			3 Feb 1998	23.5	5.9
			3 Apr 1998	87.5	35.1
			10 Aug 1998	14.0	5.3
			2 Sep 1998	39.5	7.5
			27 Sep 1998	32.0	8.5
			27 Oct 1998	94.0	26.2
			29 Oct 1998	78.0	21.3
			16 Dec 1998	26.0	14.8
			27 Dec 1998	103.5	32.2
			4 Jan 1999	50.0	12.0
			25 Jan 1999	54.5	7.3
			20 Jun 1999	80.0	22.5
			9 Jul 1999	19.0	5.4
			14 Jul 1999	37.5	18.0
			21 Sep 1999	66.5	7.8
			4 Oct 1999	112.5	44.7
			17 Oct 1999	36.0	13.8
			10 Nov 1999	48.0	22.6
			4 Dec 1999	32.5	15.8
			24 Feb 2000	29.5	6.2
			10 Apr 2000	26.5	9.4
			25 May 2000	37.5	21.3
			30 May 2000	101.0	28.1
			21 Sep 2000	81.0	18.8
			5 Feb 2001	69.0	35.0
			28 Feb 2001	42.0	13.7
			3 Mar 2001	34.5	14.3
7	1810141WL (1302428)	Sg Sarawak Kiri di Kg Git	26 Oct 1997	43.8	13.0
			30 Oct 1997	9.4	2.8
			9 Nov 1997	30.0	7.3
			19 Nov 1997	31.5	4.6
			19 Dec 1997	74.3	12.3
			21 Dec 1997	47.2	7.6
			22 Dec 1997	17.3	8.9

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
			2 Feb 1998	27.9	11.5
			3 Feb 1998	10.4	6.3
			4 Feb 1998	16.9	5.4
			21 Feb 1998	23.5	9.4
			2 Apr 1998	38.4	8.5
			13 Apr 1998	28.8	11.8
			1 Jun 1998	26.4	9.8
			24 Jun 1998	59.8	13.3
			08 Jul 1998	46.4	16.8
			23 Jul 1998	34.8	5.3
			25 Aug 1998	23.4	13.0
			03 Sep 1998	29.4	7.8
			1 Oct 1998	44.4	10.2
			13 Oct 1998	31.4	8.8
			31 Oct 1998	35.2	18.8
			28 Nov 1998	17.7	11.8
			22 Dec 1998	41.2	9.0
			20 Jan 1999	43.5	18.9
			25 Jan 1999	44.8	10.6
			15 May 1999	19.2	10.3
			25 May 1999	29.4	11.1
			26 Jun 1999	54.0	27.5
8	180021WL (1304439)	Sg Tuang di Kg Batu Gong	25 Aug 1985	60.4	36.9
			6 Nov 1985	62.1	31.0
			8 Feb 1986	62.8	36.6
			5 Mar 1987	75.3	28.4
			9 Jul 1988	53.5	21.0
			25 Jun 1990	70.6	13.3
			26 Sep 1990	62.0	25.5
			6 Jul 1991	29.2	4.4
			23 Nov 1991	76.7	46.0
			16 Jul 1992	51.4	8.2
			21 Aug 1993	23.1	7.4
			1 Jul 1994	20.6	5.7
			02 Dec 1994	31.0	13.2
			1 Jul 1995	72.8	32.8
			31 Mar 1996	66.6	22.4
			12 Jul 1996	45.8	4.9

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
			28 Sep 1996	9.0	5.2
			26 Oct 1997	56.0	5.2
			4 May 1998	38.8	12.9
			13 Feb 1999	65.4	23.7
9	1770051WL (1316401)	Sg Sekerang di Entaban	30 Jan 1996	26.3	3.9
			1 Feb 1996	77.3	25.1
			2 Feb 1996	91.3	47.6
			18 Feb 1996	52.7	20.4
			1 Oct 1997	13.7	9.3
			23 Dec 1997	7.0	4.5
			29 Dec 1997	24.6	5.2
			6 Jan 1998	68.7	16.7
			15 Apr 1998	68.4	25.2
10	1750021WL (1415401)	Sg Layar di Ng Lubau	6 Jan 1990	54.4	14.3
			25 Nov 1990	59.5	16.3
			23 Apr 1991	71.0	39.6
			23 Nov 1992	36.5	23.2
			12 Apr 1993	99.2	50.9
			4 Feb 1994	56.0	41.0
			22 Dec 1994	47.3	34.5
			3 Mar 1995	66.5	44.2
			4 May 1997	44.5	29.9
			25 Aug 1998	52.0	38.0
			28 Oct 1999	68.5	56.3
11	1740031WL (1813401)	Sg Sebatan di Sebatan	22 Dec 1997	37.5	16.1
			11 Apr 1998	16.0	12.0
			3 Jun 1998	58.0	17.0
			29 Aug 1998	23.5	7.5
			23 Sep 1998	80.0	40.2
			26 Mar 1999	32.5	8.3
			1 Oct 1999	43.5	13.6
			5 Oct 1999	31.5	12.2
			3 Dec 1999	27.5	14.2
			6 Jan 2000	63.5	12.3
			26 Feb 2000	10.9	2.6
			13 Sep 2000	44.0	13.7
			26 Sep 2000	23.0	7.8
			1 Oct 2000	69.0	19.0
			12 Apr 2001	29.0	23.3

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	Rainfall, P (mm)	Runoff, Q (mm)
12	1730431WL (1826401)	Sg Katibas di Ng Mukeh	19 Jan 1993	29.1	6.0
			9 Dec 1993	34.8	6.7
			17 Jun 1996	34.6	20.0
			4 Feb 2000	68.1	11.7
			4 May 2000	16.5	3.5
13	1730131WL (1915401)	Sg Sarikei di Ambas	6 Dec 1997	68.0	14.0
			4 Jan 1998	40.5	15.7
			5 Jan 1998	46.0	15.6
			04 Apr 1998	41.0	15.8
			27 Aug 1998	45.0	19.4
			1 Oct 1998	66.0	35.5
			11 Nov 1998	55.5	20.6
			14 Feb 2000	54.0	18.3
			22 Mar 2000	46.0	18.0
			13 Sep 2000	63.5	24.0
14	1730451WL (1918401)	Btg Rajang di Ng Ayam	3 Jun 1994	126.5	52.2
			4 Jul 1995	45.8	26.7
			12 Oct 1995	41.5	20.8
			13 Aug 1996	65.6	20.8
			19 Jan 1998	23.2	17.8
			14 Sep 1999	33.6	8.5
			5 Dec 1999	51.6	9.3
15	1710011WL (2421401)	Sg Oya di Setapang	3 Oct 1991	14.9	9.5
			25 Sep 1993	84.3	19.6
			4 Jun 1995	78.8	16.7
			6 Oct 1995	41.6	17.9
			7 Jun 1996	36.7	5.3
			9 Jul 1996	7.0	5.6
			16 Jul 1998	48.3	10.8
16	1700031WL (2523401)	Btg Mukah di Selangau	31 May 1983	57.9	9.8
17	1640021WL (3231401)	Sg Sibiu di Sibiu (Atc)	30 Apr 1988	20.2	6.6
			24 May 1988	13.2	6.1
			5 Jun 1990	29.9	10.1
			17 Feb 1991	57.2	7.1
			7 Feb 2000	35.4	13.1

Appendix A: Data Used to Derive Rainfall-Runoff Relationship

Table A.3: Data Used to Derive Rainfall-Runoff Relationship for Sarawak

	Station ID	Station Name	Rainfall-Runoff Data		
			Event Date	**Rainfall, P (mm)**	**Runoff, Q (mm)**
18	1540061WL (4448420)	Sg Limbang di Insungai	16 Feb 1984	37.1	17.8
			23 Feb 1984	24.4	17.5
			19 Sep 1984	40.3	8.6
			21 Jan 1985	54.2	12.5
			7 May 1985	77.1	44.0
			14 Feb 1987	31.7	14.0
			29 Oct 1989	27.1	20.0
19	1520011WL (4553401	Sg Trusan di Long Tengoa D	1 Oct 1991	42.4	11.1
			5 May 1995	66.0	23.4
			11 Feb 1997	17.0	7.4
			26 Sep 1997	30.7	17.3
			10 Oct 1997	24.0	9.7
			26 Sep 1998	16.7	8.8

Appendix B: Comparison between Simulated and Observed Hydrographs

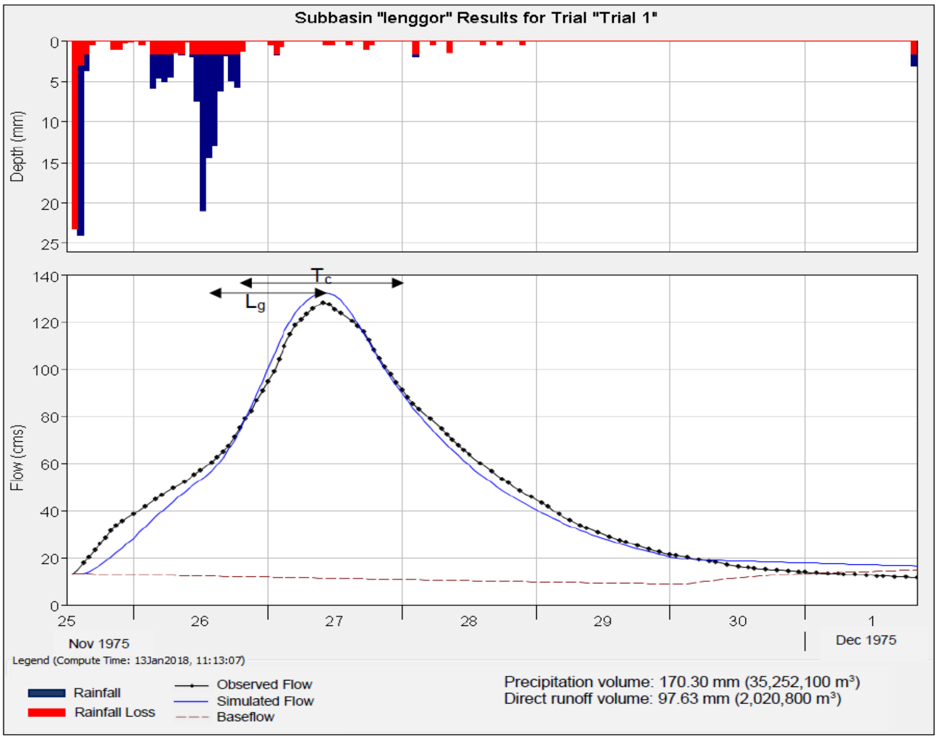


Figure B.1: Simulated and Observed Hydrograph of Sg Lenggor di Bt 42 Kluang/Mersing (Event Nov 1975)

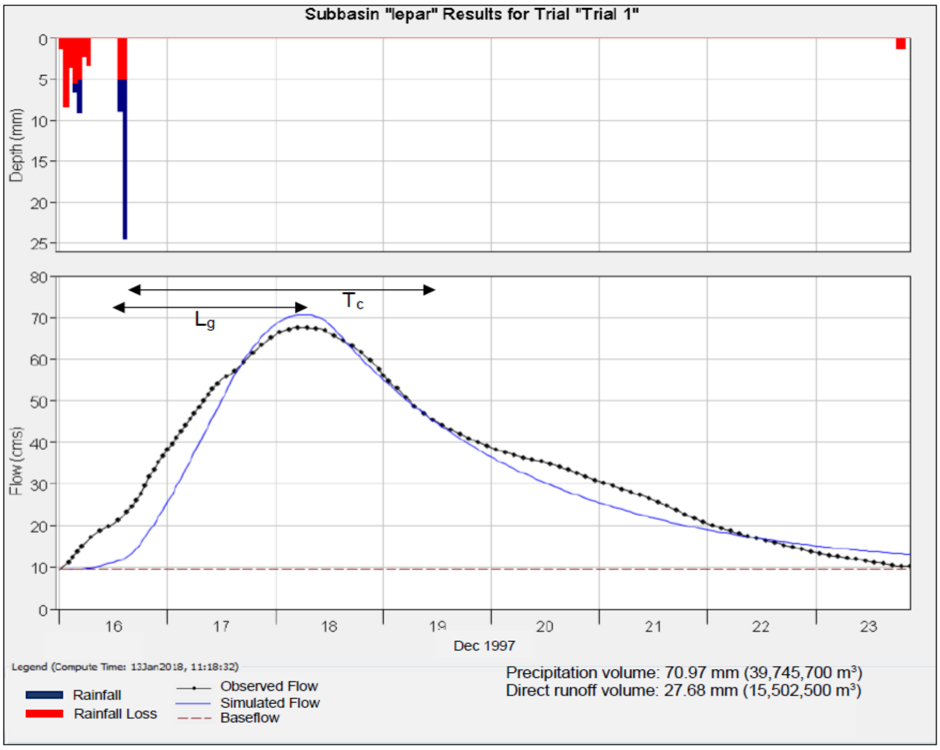


Figure B.2: Simulated and Observed Hydrograph of Sg Lepar di Jam Gelugor (Event Dec 1997)

Appendix B: Comparison between Simulated and Observed Hydrographs

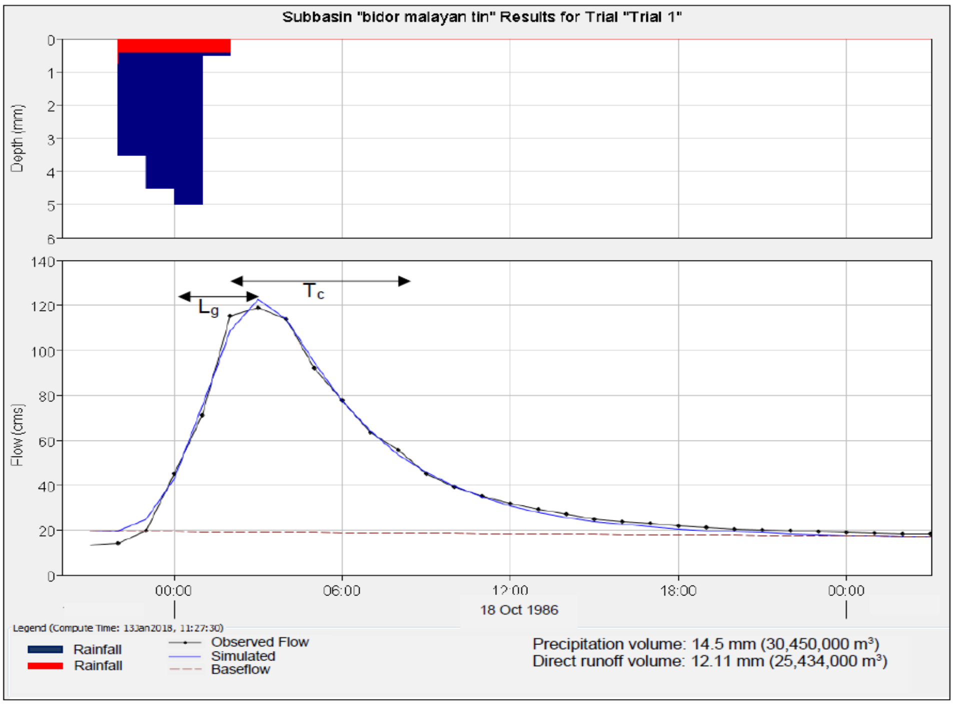


Figure B.3: Simulated and Observed Hydrograph of Sg Bidor di Malayan Tin (Event Oct 1986)

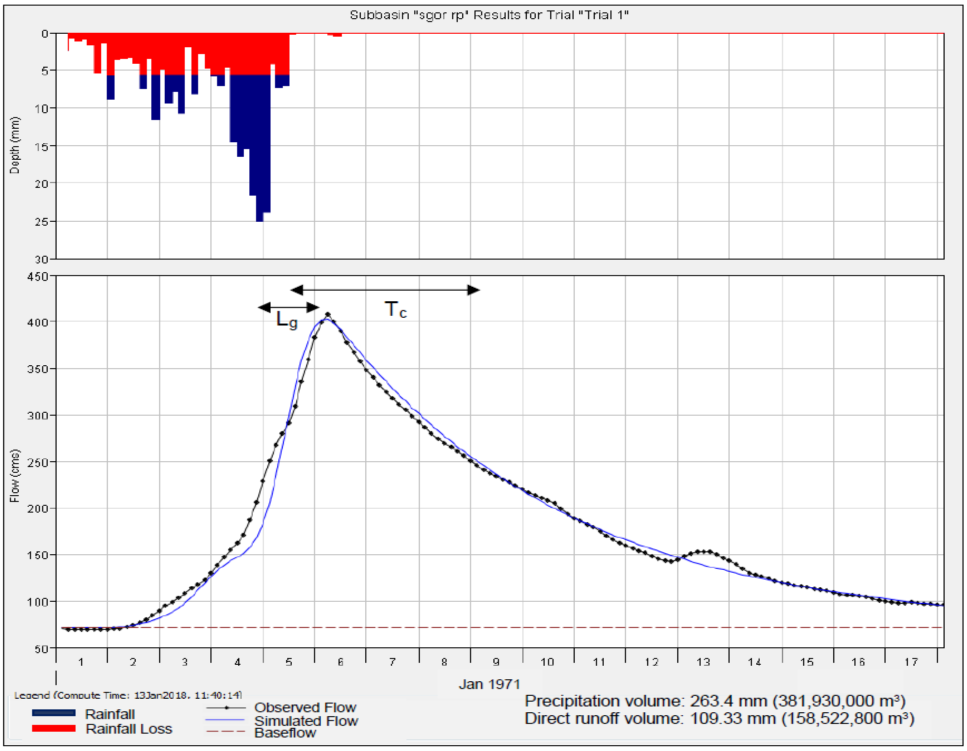


Figure B.4: Simulated and Observed Hydrograph of Sg Selangor di Rantau Panjang (Event Jan 1971)

Appendix B: Comparison between Simulated and Observed Hydrographs

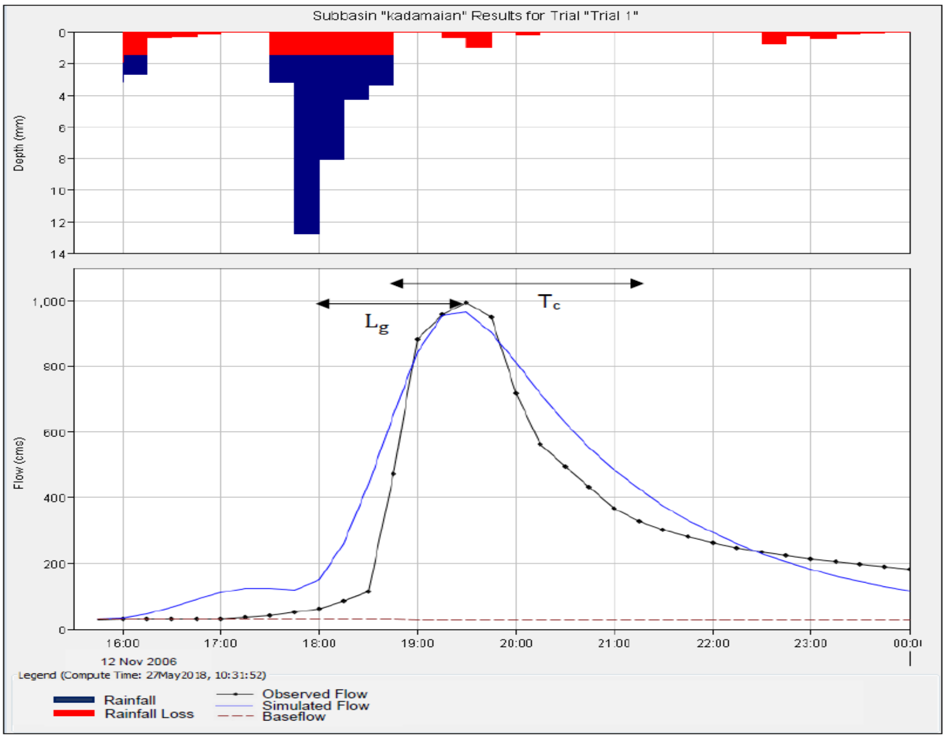


Figure B.5: Simulated and Observed Hydrograph of Sg Kadamaian di Tamu Darat (Event Nov 2006)

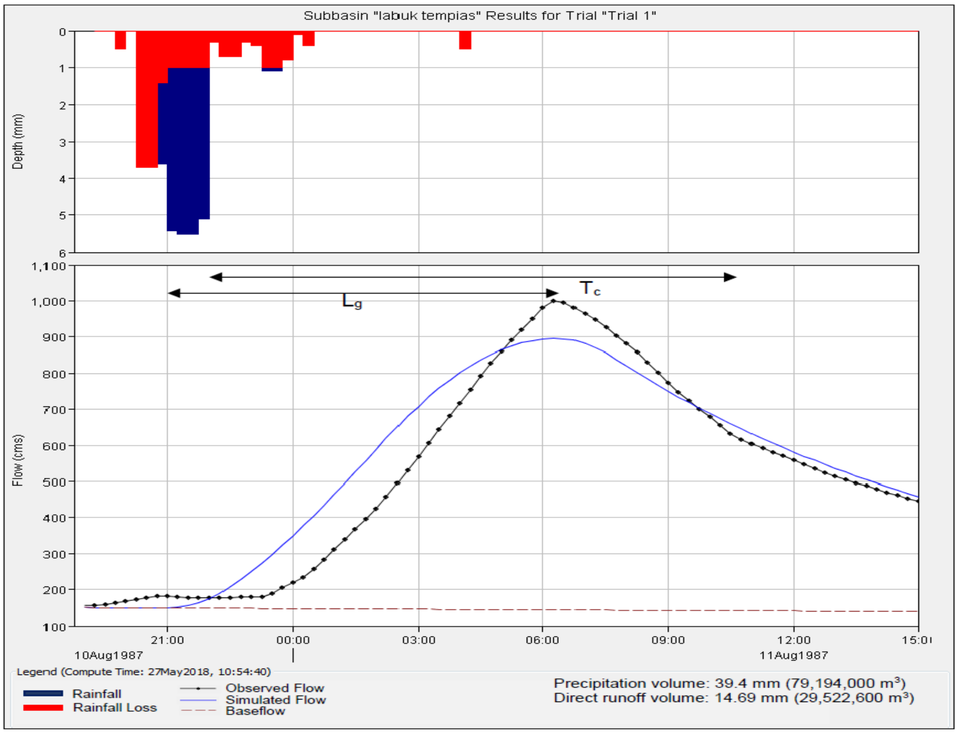


Figure B.6: Simulated and Observed Hydrograph of Sg Labuk di Tampias (Event Aug 1987)

Appendix B: Comparison between Simulated and Observed Hydrographs

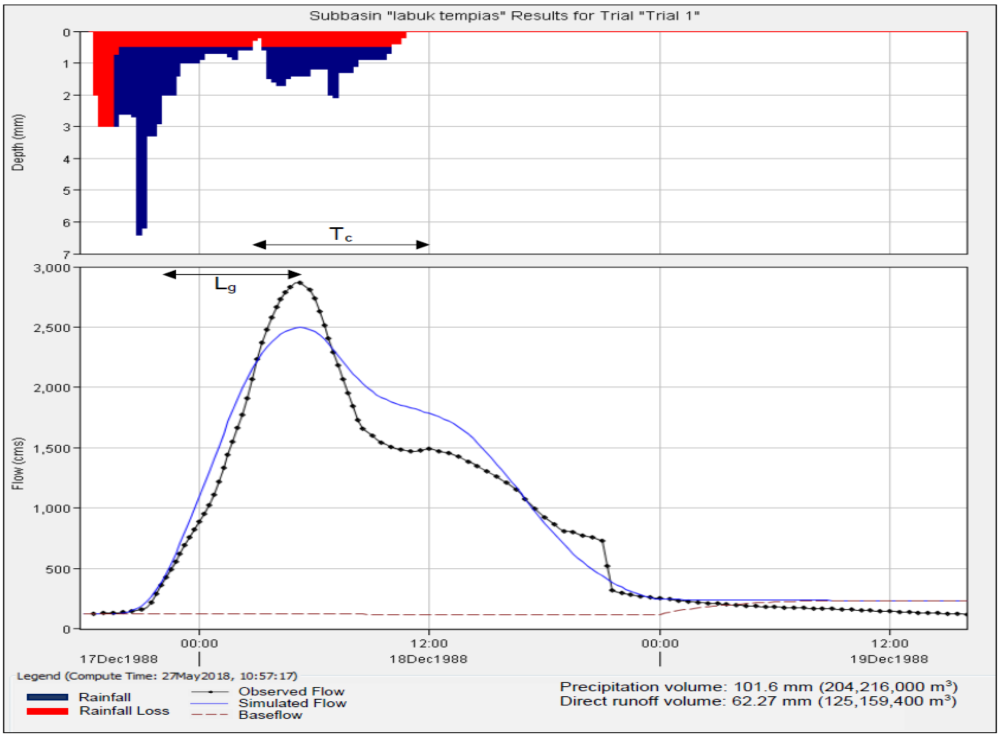


Figure B.7: Simulated and Observed Hydrograph of Sg Labuk at Tampias (Event Dec 1988)

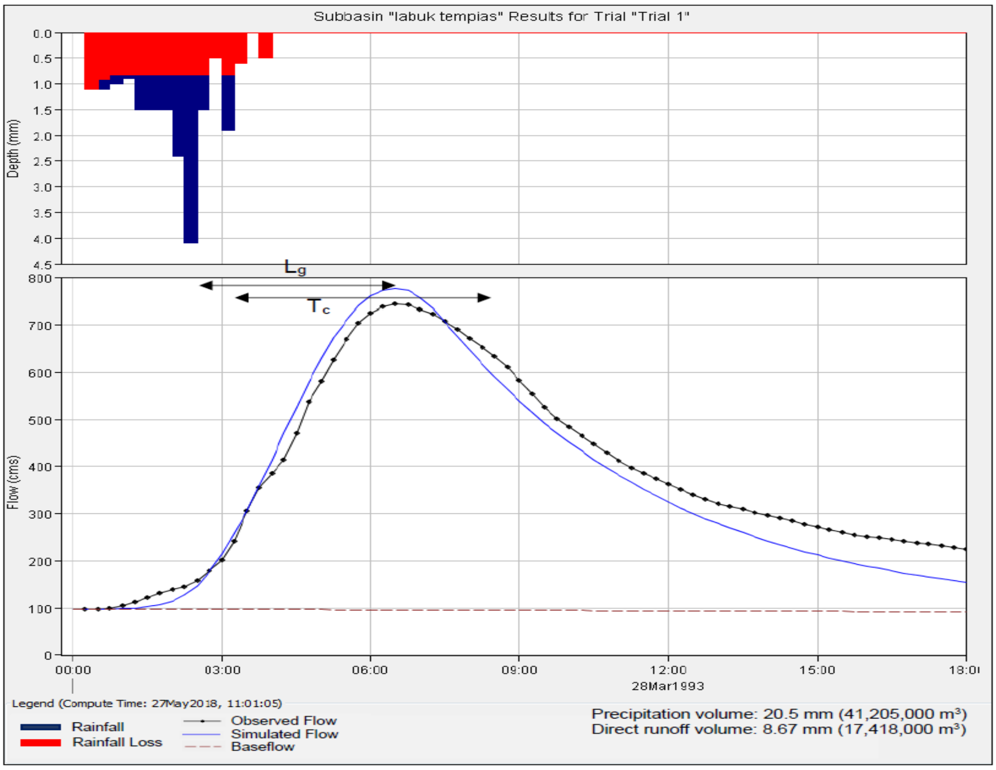


Figure B.8: Simulated and Observed Hydrograph of Sg Labuk at Tampias (Event March 1993)

Appendix B: Comparison between Simulated and Observed Hydrographs

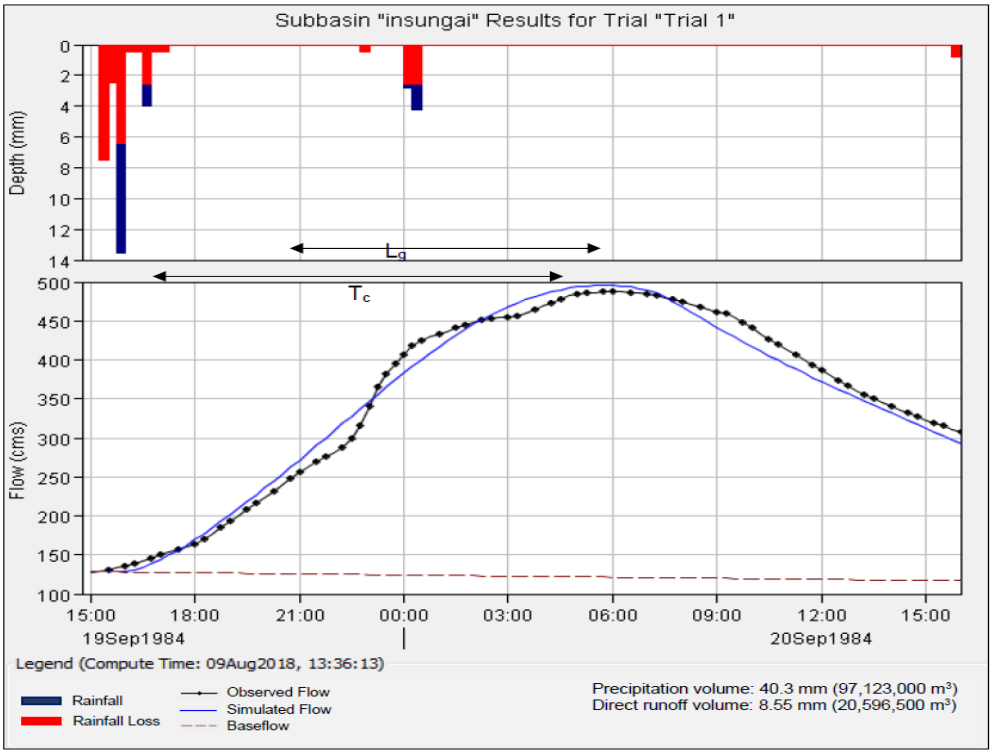


Figure B.9: Simulated and Observed Hydrograph of Sg Limbang di Insungai (Event Sep 1984)

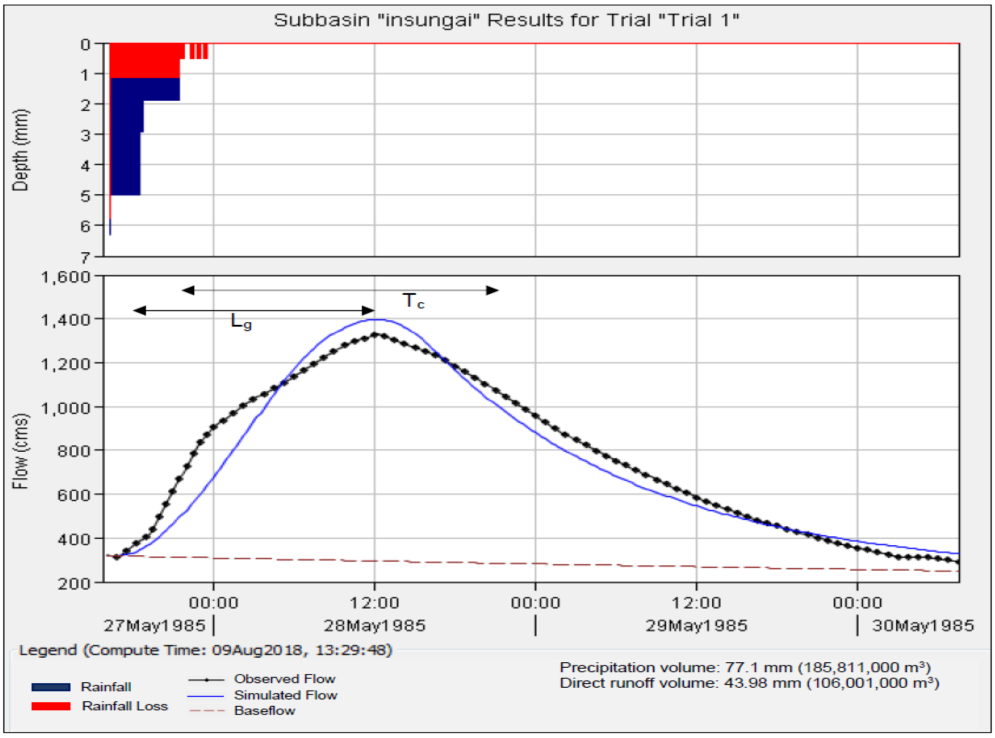


Figure B.10: Simulated and Observed Hydrograph of Sg Limbang di Insungai (Event May 1985)

Appendix C: Average Catchment Lag Times and Peaking Coefficients

Table C.1 Average Catchment Lag Times (L_g) and Peaking Coefficients (C_p) for Peninsular Malaysia

No.	Station ID	Station Name	A (km^2)	L (km)	L_c (km)	S (%)	L_g * (hr)	C_p
1	0010291SF (6503401)	Sg Arau di Ladang Tebu Felda	21	9.26	5.05	0.45	3.35	0.34
2	0060071SF (5405421)	Sg Kulim di Ara Kuda	129	30.66	15.49	0.63	9.58	0.57
3	0180311SF (3913458)	Sg Sungkai di Sungkai	289	45.02	25.74	2.95	10.00	0.51
4	0180861SF (4012401)	Sg Bidor di Malayan Bidor	210	34.41	21.62	2.53	6.85	0.51
5	0180641SF (4212467)	Sg Cenderiang di Batu 32 Jalan Tapah	119	16.68	9.10	0.54	6.89	0.50
6	0180801SF (4310401)	Sg Kinta di Weir Tg Tualang	1,700	83.33	41.47	1.20	19.00	0.44
7	0180761SF (4511468)	Sg Raia di Keramat Pulai	192	37.89	19.35	4.19	4.04	0.48
8	0180131SF (4610466)	Sg Pari di Jalan Silibin	245	38.96	16.53	1.22	13.10	0.45
9	0180291SF (4611463)	Sg Kinta di Tg Rambutan	246	33.77	19.93	3.70	3.63	0.50
10	0180361SF (4911445)	Sg Plus di Kg Lintang	1,090	78.75	48.88	1.58	12.50	0.65
11	0090141SF (5206432)	Sg Kerian di Selama	629	46.44	27.39	2.08	18.10	0.51
12	0240441SF (3118445)	Sg Lui di Kg Lui	68	16.18	8.17	3.16	6.74	0.63
13	0190131SF (3615412)	Sg Bernam di Tanjung Malim	186	25.50	17.20	3.98	3.88	0.53
14	0320551SF (2723401)	Sg Kepis di Jam Kayu Lama	21	10.28	5.15	0.78	3.92	0.52
15	0310061SF (2224432)	Sg Kesang di Chin Chin	161	33.97	15.83	0.22	19.40	0.46
16	0290131SF (2322413)	Sg Melaka di Pantai Belimbing	350	43.23	23.18	0.17	17.10	0.59
17	0290141SF (2322415)	Sg Durian Tunggal di Batu 11 Air Resam	73	14.58	5.92	0.44	7.10	0.59
18	0430271SF (1836402)	Sg Sayong di Johor Tenggara	624	48.03	23.55	0.09	58.70	0.62
19	0500281SF (2235401)	Sg Kahang di Batu 26 Jalan Kluang	587	58.07	24.86	0.27	40.00	0.52
20	0500141SF (2237471)	Sg Lenggor di Batu 42 Kluang/Mersing	207	26.70	10.79	0.34	21.40	0.46
21	0551041SF (3519426)	Sg Bentong di Jam Kuala Marong	241	29.48	11.90	4.53	5.13	0.51

Remarks: *Optimized L_g from HEC-HMS

Appendix C: Average Catchment Lag Times and Peaking Coefficients

Table C.1 Average Catchment Lag Times (L_g) and Peaking Coefficients (C_p) for Peninsular Malaysia

No.	Station ID	Station Name	A (km^2)	L (km)	L_c (km)	S (%)	L_g * (hr)	C_p
22	0551181SF (3629403)	Sg Lepar di Jam Gelugor	560	69.35	25.38	0.32	39.10	0.63
23	0551481SF (4320401)	Sg Kecau di Kg Dusun	497	56.57	30.48	0.58	11.10	0.70
24	0600101SF (4131453)	Sg Cherul di Ban Ho	505	59.18	28.35	0.57	21.30	0.67
25	0600111SF (4232452)	Sg Kemaman di Rantau Panjang	626	59.42	30.34	0.58	18.70	0.48
26	0670011SF (4930401)	Sg Berang di Menerong	140	29.98	19.19	2.46	6.10	0.59
27	0670261SF (5129437)	Sg Telemong di Paya Rapat	160	41.04	18.52	1.10	8.35	0.59
28	0670221SF (5229436)	Sg Nerus di Kg Bukit	393	49.58	24.83	0.32	27.70	0.62
29	0680111SF (5428401)	Sg Chalok di Jam Chalok	21	7.21	3.20	0.17	5.70	0.54
30	0740231SF (5718401)	Sg Lanas di Air Lanas	80	17.35	8.39	0.26	11.60	0.57
31	0240341SF (2816441)	Sg Langat di Dengkil	1,240	70.32	23.14	0.48	21.70	0.47
32	0240511SF (2918401)	Sg Semenyih di Kg Rinching	225	35.79	17.03	1.21	8.19	0.49
33	0210311SF (3516422)	Sg Selangor di Rasa	321	36.23	17.51	2.60	5.87	0.50
34	0210201SF (3414421)	Sg Selangor di Rantau Panjang	1,450	74.32	33.88	0.93	38.69	0.53
35	0230391SF (3116434)	Sg Batu di Sentul	145	28.43	12.23	1.98	5.88	0.60
36	0230401SF (3116433)	Sg Gombak di Jalan Tun Razak	122	30.86	16.74	2.05	3.27	0.49
37	0320381SF (2625412)	Sg Muar di Batu 57 Jalan Gemas-Rompin	1,210	90.46	62.85	0.13	32.00	0.72
38	0270081SF (2519421)	Sg Linggi di Sua Betong	523	59.58	28.56	0.93	26.40	0.46
39	0430121SF (1737451)	Sg Johor di Rantau Panjang	1,130	61.34	25.57	0.06	69.20	0.65
40	0720051SF (6022421)	Sg Kemasin di Peringat	48	25.86	14.54	0.03	22.70	0.62

Remarks: *Optimized L_g from HEC-HMS

Appendix C: Average Catchment Lag Times and Peaking Coefficients

Table C.2: Average Catchment Lag Times (L_g) and Peaking Coefficients (C_p) for Sabah

No.	Station ID	Station Name	A (km^2)	L (km)	L_c (km)	S (%)	L_{g*} (hr)	C_p
1	0850041WL (4278402)	Sg Tawau di Kuhara	104	37.64	26.27	1.67	8.10	0.52
2	0870011WL (4381401)	Sg Balung di Balung Bridge	137	38.22	23.89	0.98	4.80	0.62
3	0790021WL (4474401)	Sg Kalabakan di Kalabakan	1,150	77.39	36.03	0.47	12.10	0.72
4	0880011WL (4581401)	Sg Kalumpang di Mostyn Bridge	544	67.08	28.51	0.59	7.80	0.60
5	0750041WL (4764402)	Sg Talangkai di Lotong	652	60.36	31.13	0.38	4.30	0.43
6	1490031WL (4955403)	Sg Mengalong di Sindumin	522	61.07	31.43	0.92	7.80	0.54
7	1040031WL (5074401)	Sg Kuamut di Ulu Kuamut	2,950	166.23	67.77	0.21	8.50	0.53
8	1480021WL (5156401)	Sg Lakutan di Mesapol Quarry	173	33.62	14.88	0.98	8.50	0.53
9	1010031WL (5181401)	Sg Segama di Limkabong	2,175	186.80	108.34	0.29	18.10	0.71
10	1460121WL (5261402)	Sg Sook di Biah	1,684	120.87	48.74	0.14	31.50	0.52
11	1460211WL (5461401)	Sg Baiayo di Bandukan	176	31.53	16.76	2.59	2.90	0.40
12	1460221WL (5462402)	Sg Apin-Apin di Waterworks	113	37.91	20.94	2.37	4.00	0.55
13	1460251WL (5668401)	Sg Kegibangan di Tampias P.H.	800	54.23	28.45	1.49	3.90	0.49
14	1400021WL (5760401)	Sg Papar di Kaiduan	365	48.82	27.69	1.80	3.70	0.52
15	1400041WL (5760402)	Sg Papar di Kogopon	546	65.46	36.60	1.37	4.00	0.55
16	1160151WL (5768401)	Sg Labuk di Tampias	2,010	89.11	42.33	1.18	5.90	0.58
17	1390021WL (5961401)	Sg Moyog di Penampang	200	28.81	14.53	1.98	4.20	0.41
18	1160031WL (6073401)	Sg Tungud di Basai	700	87.06	46.92	0.43	10.90	0.64
19	1360041WL (6162403)	Sg Tuaran di Pump House 1	695	57.06	33.95	1.61	6.10	0.42
20	1200011WL (6172401)	Sg Sugut di Bukit Mondou	2,101	124.47	70.75	0.77	11.20	0.59
21	1340021WL (6264401)	Sg Kadamaian di Tamu Darat	388	46.99	21.61	3.64	2.40	0.52

Remarks: *Optimized L_g from HEC-HMS

Appendix C: Average Catchment Lag Times and Peaking Coefficients

Table C.2: Average Catchment Lag Times (L_g) and Peaking Coefficients (C_p) for Sabah

No.	Station ID	Station Name	A (km^2)	L (km)	L_c (km)	S (%)	L_g* (hr)	C_p
22	1340031WL (6364401)	Sg Wariu di Bridge No.2	243	31.25	18.12	4.65	2.40	0.59
23	1280011WL (6468402)	Sg Bongan di Timbang Batu Sabah	470	57.62	26.92	0.98	5.40	0.57
24	1260011WL (6670401)	Sg Bengkoka di Kobon	700	64.69	28.90	1.58	3.60	0.33

Appendix C: Average Catchment Lag Times and Peaking Coefficients

Table C.3: Average Catchment Lag Times (L_g) and Peaking Coefficients (C_p) for Sarawak

No.	Station ID	Station Name	A (km^2)	L (km)	L_c (km)	S (%)	L_g (hr)	C_p
1	1790041WL (1004438)	Sg Kayan di Krusen	456	56.87	23.89	0.47	10.31	0.64
2	1790051WL (1005447)	Sg Kedup di New Meringgu	342	50.61	29.42	0.16	41.38	0.63
3	1770061WL (1015401)	Sg Entebar di Entebar	26	7.93	3.98	0.46	5.21	0.61
4	1770021WL (1018401)	Sg Ai di Lubok Antu	1,326	110.09	60.74	0.32	10.84	0.66
5	1790031WL (1108401)	Sg Sabal Kruin di Sabal Kruin	127	24.14	13.20	0.61	29.99	0.67
6	1810061WL (1301427)	Sg Sarawak Kanan di Pk Buan Bidi	215	43.87	17.94	0.69	7.97	0.67
7	1810141WL (1302428)	Sg Sarawak Kiri di Kg Git	442	44.44	22.91	0.22	8.64	0.75
8	180021WL (1304439)	Sg Tuang di Kg Batu Gong	64	23.42	13.22	0.21	28.84	0.66
9	1770051WL (1316401)	Sg Sekerang di Entaban	715	114.07	46.82	0.50	10.36	0.59
10	1750021WL (1415401)	Sg Layar di Ng Lubau	321	50.62	22.20	0.37	6.67	0.76
11	1740031WL (1813401)	Sg Sebatan di Sebatan	35	13.45	4.89	0.46	8.59	0.42
12	1730431WL (1826401)	Sg Katibas di Ng Mukeh	2,257	137.15	47.45	0.29	10.96	0.58
13	1730131WL (1915401)	Sg Sarikei di Ambas	70	12.54	9.35	0.35	6.58	0.72
14	1730451WL (1918401)	Btg Rajang di Ng Ayam	1,588	97.05	45.71	0.10	17.18	0.73

Remarks: *Optimized L_g from HEC-HMS

Appendix C: Average Catchment Lag Times and Peaking Coefficients

Table C.3: Average Catchment Lag Times (L_g) and Peaking Coefficients (C_p) for Sarawak

No.	Station ID	Station Name	A (km^2)	L (km)	L_c (km)	S (%)	L_g (hr)	C_p
15	1710011WL (2421401)	Sg Oya di Setapang	869	94.47	45.59	0.23	20.40	0.66
16	1700031WL (2523401)	Btg Mukah di Selangau	1,021	90.47	44.20	0.12	19.63	0.78
17	1640021WL (3231401)	Sg Sibiu di Sibiu (Atc)	171	40.54	20.73	0.13	15.30	0.59
18	1540061WL (4448420)	Sg Limbang di Insungai	2,410	177.26	90.03	0.91	13.03	0.62
19	1520011WL (4553401)	Sg Trusan di Long Tengoa D	1,849	131.77	67.64	0.96	7.09	0.63

Remarks: *Optimized L_g from HEC-HMS

Appendix D: Computer Program for Unit Hydrograph Computation

Hydrological Procedure No 11:
Design Flood Hydrograph Estimation for Rural Catchments in Malaysia

This program is designed to use for rural catchments in: **Peninsular Malaysia**

Input: *(Please input the parameter in blue colour cell)*

Example for: Sg Sungkai

Catchment Data

1)	Catchment Area, A:	289	km^2
2)	Main Stream Length, L:	45	km
3)	Weighted Slope (of the main stream), S:	2.95	%
4)	Snyder Peaking Coefficient, Cp:	0.55	

Rainfall Data

1)	Rainfall Duration, RD:	6	hrs
2)	Design Rainfall, P:	132	mm
3)	No of Time Interval:	12	(Automatically update based on rainfall duration)
4)	Area Reduction Factor:	0.88	(Refer Reference)
5)	Temporal Pattern Region:	3	(Refer Reference)

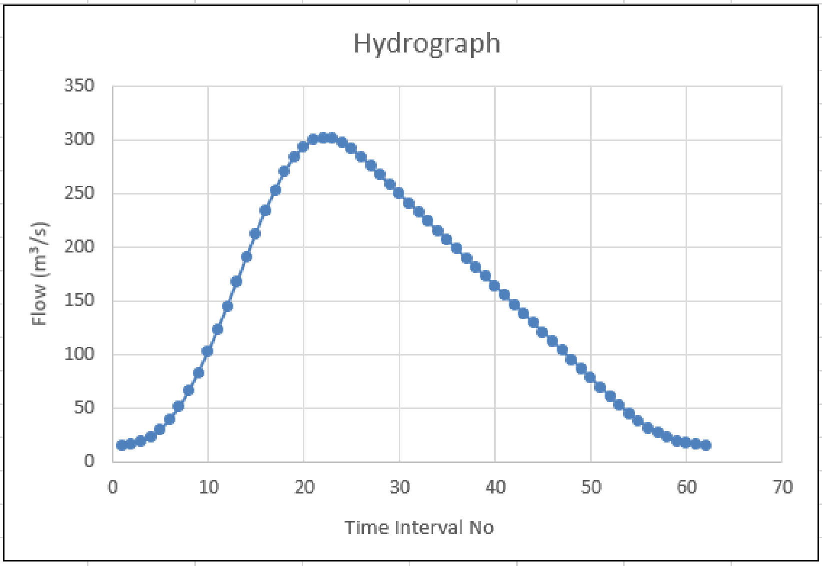
Appendix D: Computer Program for Unit Hydrograph Computation

Hydrological Procedure No 11:
Design Flood Hydrograph Estimation for Rural Catchments in Malaysia

This program is designed to use for rural catchments in: **Peninsular Malaysia**

Output: *(Results of the hydrograph are presented in green colour cell)*

INTV No	Runoff (m^3/s)
0	14.29
1	15.32
2	17.94
3	22.34
4	29.00
5	38.23
6	50.40
7	65.34
8	82.53
9	101.57
10	122.34
11	144.18
12	166.96
13	189.73
14	212.51
15	233.87
16	253.04
17	269.75
18	283.35
19	293.40
[illegible]	[illegible]



Peak Flow, Qp: 302 m^3/s

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