GOVERNMENT OF MALAYSIA
DEPARTMENT OF IRRIGATION
AND DRAINAGE

Hydrological Procedure No. 27

ESTIMATION OF DESIGN FLOOD HYDROGRAPH USING CLARK METHOD FOR RURAL CATCHMENTS IN PENINSULAR MALAYSIA

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2010

Water Resources Management and Hydrology Division
Department of Irrigation and Drainage
Ministry of Natural Resources and Environment Malaysia

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SYNOPSIS

The design of many engineering works requires the consideration of storage upstream of the structure, examples are dam spillways, retention ponds and for such cases, a complete design flood hydrograph is therefore necessary to determine the inflow/outflow and storage relationships for the site concerned. A sound and reliable estimate of the design flood hydrograph at the site is necessary considering the cost of the structure. However, there are usually no streamflow records at the point of interest and the design hydrograph may have to be derived from a design storm.

This procedure gives a method for the estimation of design flood hydrographs for rural catchments in Peninsular Malaysia. The procedure uses three components; the design storm, the rainfall-runoff relationship and the equations for Clark parameters in the development of design flood hydrographs, the reliability and limitation of the procedure are discussed and worked examples using a computer programme illustrating the use of the procedure are also presented.

In this study, 530 storms from catchments less than 5,000 km^2 throughout Peninsular Malaysia were analyzed. Of these, 422 storms were taken from the period 1970 - 2000 and also from 2001 - 2009. The records prior to 2001 were used for calibrating Clark model and to establish the rainfall-runoff relationships. Records of 2001-2009 were mainly used to verify the equations derived relating Clark parameters to catchment characteristics.

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1. INTRODUCTION

Engineers and water resources planners are often encountering problems in the determination of a design flood as the accuracy of the flood adopted for the design of a water control structure will affect its cost and safety.

For a site of concern where a streamflow record with sufficient length is available, it is rather a relatively simple job in design flood estimation using the readily available methodology. However, for most of the sites where a structure is to be constructed, there are no streamflow or rainfall records available and the designer has to recourse to alternative methods in estimating the design flood.

It is considered not appropriate to instrument the catchment for the period required to collect the hydrological data necessary to derive the design flood. This is time consuming and expensive and is generally warranted when it involves projects with major capital expenditure. An acceptable way is to estimate the design flood using a flood estimation procedure in the absence of hydrological data even though the approach is subject to a greater degree of uncertainty.

Design flood estimates made using a flood estimation procedure should therefore be interpreted sensibly within the limitations of the method, and checked using other flood estimation methods available if possible.

Three flood estimation procedures have been published by JPS and adopted for use in Peninsular Malaysia. The Rational Method (Azmi & Zahari, 1989) and the Regional Flood Frequency Method (Ong, 1987) have been compiled for flood peak estimation on rural Malaysian catchments. Hydrological Procedure No. 11 (Taylor, 1976) has been designed to estimate triangular flood hydrographs for ungauged catchments.

This procedure is developed to complement the procedures mentioned above to provide an option of estimating the flood hydrograph for ungauged rural catchments. The procedure is not applicable to urban catchments.

2. SPECIFICATION FOR PROCEDURE

It is considered that the procedure needs to be able to:

a) Estimate the peak flow, the volume and time distribution of runoff for various return periods.
b) Account for the significance differences in the catchment characteristics that affect floods.
c) Utilise catchment data that can be readily determined from topographical maps.
d) Be simple and relatively fast to apply.

3. DEVELOPMENT OF PROCEDURE

3.1 General

Synthetic procedures for design flood hydrographs are mainly deterministic, that is, the design flood is derived from a hypothetical design storm. A review by Cordery and Pilgrim (1970) shows that three common steps are used in estimating design flood hydrographs:

a) The specifications of design storm which includes the return period, the total rainfall volume, the areal distribution of rainfall and the rainfall temporal distribution and its duration.
b) The estimation of runoff volume resulting from the design storm
c) The time distribution of runoff 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. In this respect, the problem is that there are very few major floods for which reliable rainfall and streamflow data are available for the catchments. Any relationships developed are therefore based on relatively limited records and the flood estimates are made from extrapolated relationships.

The techniques used in the development of this procedure are therefore adopted primarily to retain a degree of simplicity commensurate with the data records available.

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 is exceeded depends on the design return period adopted for a project. On large schemes, the design return period is usually based on a cost benefit analysis. For smaller schemes, it is difficult to quantify the costs pertaining to flood damage and the design return period is chosen quite arbitrary. Heiler and Tan (1974) have recommended design return period for difference types of water control structures in Malaysia.

In cases where there is considerable risk of major damage and loss of live 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 derived from probable maximum storm. The techniques for estimating the probable maximum storm are beyond the scope of this procedure.

3.2.2 Point Rainfall Depth and Frequency

A depth – duration – frequency study of storm rainfall for Peninsular Malaysia has been compiled in Hydrological Procedure No.1 (1982). Hydrological Procedure No. 1 can be used to estimate the depth of rainfall of a specified return period and duration for any point in Peninsular Malaysia. It is considered that the procedure can be used to estimate the point rainfall depth with reasonably reliability. The user may also undertake to analyse rainfall data and derive the catchment IDF using the most recent available data.

3.2.3 Areal Reduction Factor

For a storm event, rainfall is usually not evenly distributed over an area with rainfall amount decreasing with distances from the storm centre. For Peninsular Malaysia large variations in rainfall amount can occur over short distances, particularly when thunderstorms dominate. Rainfall areal reduction factors have been studied for Kuala Lumpur and Kelantan (Water Resources Publication No. 17, 1986). However, the areas studied are rather limited and not extensive. As such, the areal reduction factors of Hydrological Procedure No.1 (1982) are adopted for this study. The areal reduction factors proposed are reproduced as Table 1.

Table 1: Areal Reduction Factors

Catchment Area (km^2)	**Storm Duration (hrs)**				
	1/2	**1**	**3**	**6**	**24**
0	1	1	1	1	1
50	0.845	0.900	0.952	0.968	0.958
100	0.737	0.828	0.914	0.941	0.958
150	0.668	0.776	0.884	0.919	0.943
200	0.629	0.740	0.861	0.901	0.933
250	0.609	0.717	0.843	0.886	0.925
300	0.598	0.702	0.831	0.873	0.919
350	0.588	0.693	0.821	0.863	0.915
400	0.580	0.686	0.814	0.854	0.913
500		0.663	0.801	0.841	0.909
600		0.660	0.790	0.840	0.910
700		0.482	0.750	0.818	0.892
800		0.650	0.780	0.830	0.910
1000			0.780	0.830	0.910

3.2.4 Temporal Distribution

A study was carried out by JPS (1982, Hydrological Procedure No.1) to find the temporal distribution of annual maximum rainstorms for selected durations of ½, 3, 6, 24 and 72 hours. Nine rainfall stations located at different parts of Peninsular Malaysia were selected for this purpose. The average temporal distributions over the years of record were computed. The temporal distributions of east and west coast Peninsular Malaysia for the various durations are presented in the Procedure (HP1). These temporal patterns were used for this study.

3.2.5 Rainfall Duration

The design storm duration is usually adopted as the duration which gives the maximum discharge. This critical duration can be found by trial and error by calculating the design flood for a range of storm durations. A similar practice will be adopted in this procedure. As there is no known method of determining the correct critical duration of rainfall that should be used to estimate the design hydrograph, a number of storms of selected return period and different durations should be applied to the unit hydrograph. The hydrograph used for design is that giving the highest peak discharge, or the highest peak after routing if outflow from storage is required.”

3.3 Rainfall Runoff Relationship

In this procedure, the method used in Hydrological Procedure No. 11 is adopted to establish the rainfall runoff relationship, that is, a rainfall runoff relationship is developed so that the volume of runoff can be estimated from the design storm volume. It is important for rainfall runoff relationship to be compatible with the design storm as estimated from the procedures such as those presented in Hydrological Procedure No. 1. As the storm rainfall recorded in any period of a particular duration is accumulated and used to compute the design storm volume for that particular duration in deriving the design rainfall, 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

There are hundred and one (101) automatic water level recording stations operated by JPS in Peninsular Malaysia. Water level data obtained from these stations may be used to compute streamflows. As some of the catchments are larger than 5000 km^2, exceeding the limit as mentioned by Linsley et al. (1975) for unit hydrograph estimation and there are no continuous and complete records for a number of other stations, storms from 57 catchments were used for analysis. Some of the gauging stations selected were operated by other agencies such as JKR Selangor.

In this study, 530 storms from catchments less than 5000 km^2 throughout Peninsular Malaysia were analyzed. Of these, 422 storms were taken from the period 1970 - 2000 and the rest from 2001 - 2009. The records prior to 2001 were used for calibrating Clark model and to establish the rainfall-runoff relationships. Records of 2001-2009 were mainly used to verify the equations derived relating Clark parameters to catchment characteristics.

For each storm, the volume of direct runoff, total storm rainfall volume were calculated using the records of JPS. Of the data analysed for the period 1970 – 2000, 228 storms from 41 catchments were used to develop the rainfall runoff relationships. These data are listed in Appendix A. The remaining events are not used as for these events the rainfall records sometimes do not allow a good estimate of total storm rainfall.

In this procedure, rainfall runoff relationships for East Coast and West Coast are derived separately as storm rainfall and direct runoff of West Coast are found to be different from those of East Coast. The rainfall runoff relationships are shown in Figure 1 and Figure 2. 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 intensity of rainfall. In this study, no attempts were made to include the catchment antecedent moisture status in the rainfall runoff relationship as has been shown in Hydrological Procedure No. 11, rainfall and baseflow indices were not conclusive enough to justify including as index of catchment antecedent moisture status in the rainfall-runoff relationship. It was also shown in Flood Runoff Analysis (1994) that antecedent moisture index is a poor indicator of antecedent moisture condition.

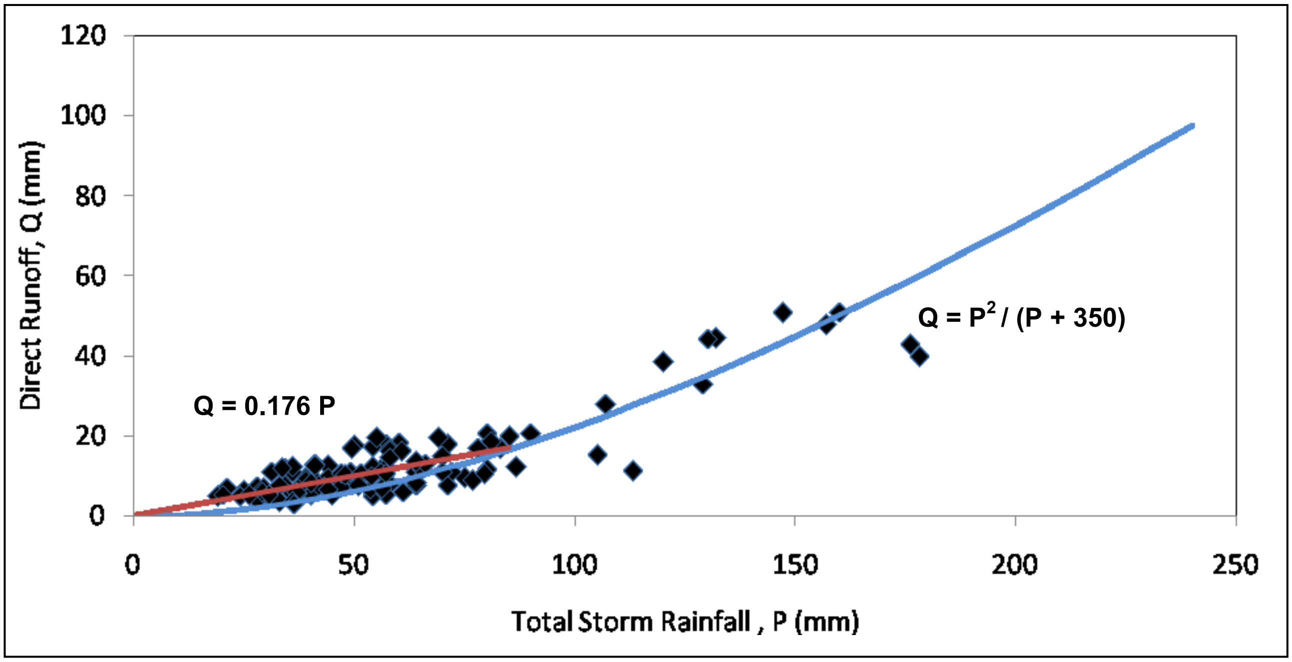

Figure 1: Rainfall – Runoff Relationship for West Coast Catchments of Peninsular Malaysia

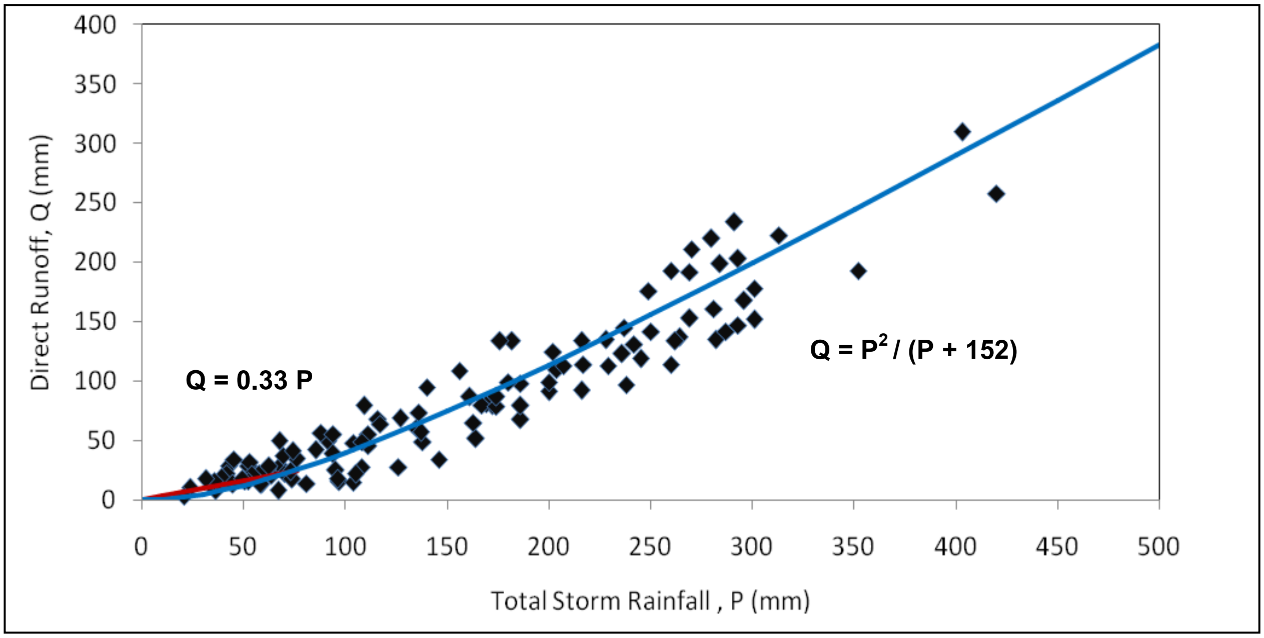

Figure 2: Rainfall – Runoff Relationship for East Coast Catchments of Peninsular Malaysia

It can be seen from figure 2 that the equations of Hydrological Procedure No. 11 are applicable to the east coast and Johor catchments. The equations are:

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

$$Q = \frac{P^2}{P + 52} \qquad P > 75 \text{ mm} \qquad (2)$$

Where P = total storm rainfall in mm

Q = direct runoff in mm

To establish the rainfall runoff relationships of west coast catchments, we follow the procedures used in Hydrological Procedure No. 11. In Figure 1, the equation was fitted to the observed data by eye giving emphasis to the relatively few points representing the larger floods analysed. The fitted curve does not match the observed data for the smaller storms and for storms below 75 mm, the linear relationship shown in Figure 1 is recommended.

The equations for estimating direct runoff Q from total storm P are:

$$Q = 0.176\,P \qquad P < 75 \text{ m} \qquad (3)$$

$$Q = \frac{P^2}{P + 50} \qquad P > 75 \text{ mm} \qquad (4)$$

Figure 3 shows the approximate boundary of the East Coast and West Coast 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. The synthetic unit hydrograph methods have been utilized to describe the entire unit hydrograph 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 synthetic unit hydrograph methods have been proposed but the Clark unit hydrograph is used in this study because it has been widely used in countries like USA and Australia.

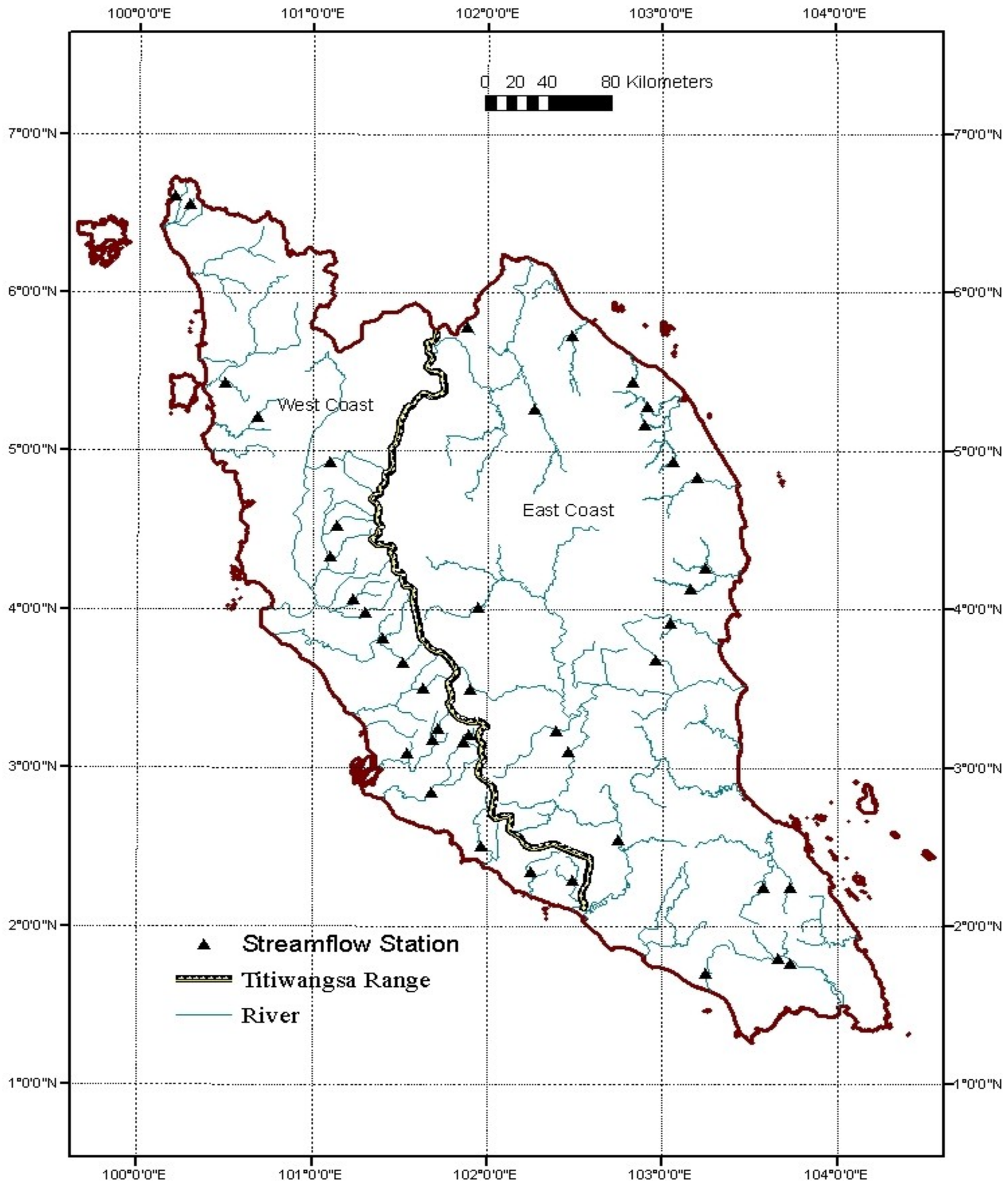

Figure 3: Approximate Boundary of West Coast and East Coast Catchments

3.4.2 Clark Unit Hydrograph

The movement of water through a catchment is dominated by the process of translation and attenuation. Translation is a movement of water through the catchment because of gravity force. Attenuation is the result on friction force and channel storage effect. Clark (1945) pointed out that the translation of flow could be described by the time area curve. This time area curve shows the fraction of catchment area contributing runoff to the catchment outlet as a fraction of time since the start of effective rainfall. Effective rainfall is the rainfall that is not lost through infiltration or retained on the land surface. i.e. it represents the direct runoff. The time area curve is bounded by the time of concentration, Tc of a catchment, which is a parameter of the Clark unit hydrograph. Clark used a simple linear reservoir for which storage is related to inflow to describe attenuation as:

$$S = RO \qquad (5)$$

Where S = the catchment storage

R = catchment storage coefficient and

O = outflow from the catchment

Clark stated that a synthetic unit hydrograph could be obtained by routing 1 unit of direct runoff to the channel in proportion to the time area curve and routing the runoff entering the channel through a simple linear reservoir.

Research has found that determining the time area curve for the catchment was not needed to obtain a reasonable unit hydrograph. Experience with the Clark unit hydrograph method at Hydrologic Engineering Centre shows that a detailed time – area curve is not necessary for accurate synthetic unit hydrograph estimation. The typical time area relationship which is used in Hydrologic Engineering Centre is:

$$\frac{A_t}{A} = \begin{cases} 1.414\left(\frac{t}{T_c}\right)^{\cdot .5} & for \quad t \leq \frac{T_c}{2} \\ -\ .414\left(-\ \frac{t}{T_c}\right)^{\cdot .5} & for \quad t \geq \frac{T_c}{2} \end{cases} \qquad (6)$$

Where A_t= cumulative catchment area contributing at time t

A = total catchment area

T_c = time of concentration of catchment

T_c and R can be obtained via calibration using computer program such as HEC-HMS.

3.4.3 Determining and Evaluating Clark Unit Hydrograph Parameters

Selected storms were calibrated using HEC-HMS to obtain optimal Tc and R values for the Clark unit hydrograph. Tc and R values determined in this study are evaluated by comparing the values obtained using additional hydrographs for the period 2001 – 2009 and the values derived using the equations of this study.

3.4.4 Storm Selection

Storms for determining parameters for synthetic unit hydrographs should be selected to conform closely to the definition of a unit hydrograph. The storm should be of simple storm, resulting in well defined hydrographs with distinct peaks. The rainfall should be uniformly distributed throughout the period of effective precipitation and preferred to be uniformly distributed over the catchment.

3.4.5 Clark Parameter Determination

The Tc and R values for the Clark unit hydrograph method were determined by calibrating HEC-HMS model (2009). The 228 storms used in deriving the rainfall runoff relationships for the 41 catchments were used to estimate Tc and R. In the calibration runs, a loss model is required for HEC-HMS to estimate direct runoff from catchment rainfall, and as HEC-HMS does not include a loss model allowing the deduction of a proportion of rainfall to estimate direct runoff, the initial loss – continuing loss model is adopted for calibration purposes. The Tc and R for Sg. Damansara and Sg. Langat at Mile 10 were obtained from the paper by Hong (1990).

The rainfall data, basin model, discharge data, meteorological model and control model were input to HEC-HMS for calibrating the Clark and loss parameters. To optimize the observed hydrographs using the Clark method, optimization run configurations were specified. The optimization process was:

a) Run configuration was formed for each event by defining the basin model, the meteorological model and the control model.

b) Parameters to be optimized using Clark method were initial loss, constant loss, the time of concentration and the storage coefficient, the recession constant and initial flow.

c) Initial estimates of the parameters were input into the optimization manager.

These parameters were optimized until the optimized hydrograph closely matched the observed hydrograph.

Some of the observed and predicted hydrographs are shown in Appendix B.

Average Tc and R of Clark method obtained together with the catchment characteristics are presented in Appendix C.

3.4.6 Equation Development

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

For simplicity and consistency, equations relating Tc and R and catchment area, stream slope, and main stream length are used to estimate Tc and R for this procedure. Results are:

$$Tc = 2.32\,A^{-0.1188}\,L^{0.9573}\,S^{-0.5074} \qquad (7)$$

R^2 = 0.7883

SE = 0.2116

$$R = 2.976\,A^{-0.1943}\,L^{0.9995}\,S^{-0.4588} \qquad (8)$$

R^2 = 0.7656

SE = 0.2024

Where A = catchment area in km^2

L = main stream length in km

S = weighted slope of main stream in m/km

Where

$$S = \left[\frac{\sum l_i \sqrt{S_i}}{\sum l_i}\right]^2 \qquad (9)$$

and l_i = incremental stream length

S_i = incremental slope

as defined in Hydrological Procedure No. 11

R^2 = coefficient of determination

SE = standard error or the root mean square error

The catchments were subdivided into east and West Coast catchments and the same multiple linear correlations carried out to derive Tc and R on a regional basis, it was found that no better correlations can be obtained. Attempts to obtain better correlations by further dividing the catchments into smaller regional groups for regression analysis are not successful. Equations (7) and (8) are used to estimate Tc and R for this procedure.

3.4.7 Equation Verification

In this study, 125 storms from 26 catchments, mainly obtained for the period 2001-2009, were used to calibrate the HEC-HMS model to optimize the Tc and R values. The average Tc and R values (here termed as measured values) together with those calculated using equations (7) and (8) are presented in Appendix D. Results are plotted in Figure 4 and Figure 5. In the figures, Tc and R from both the calibration and verification storms are plotted against those derived from the equations and it can be seen from the figures that for most of the catchments, the difference between the points plotted using verification storms and the equation and that plotted using calibration storms and the equation is not significant.

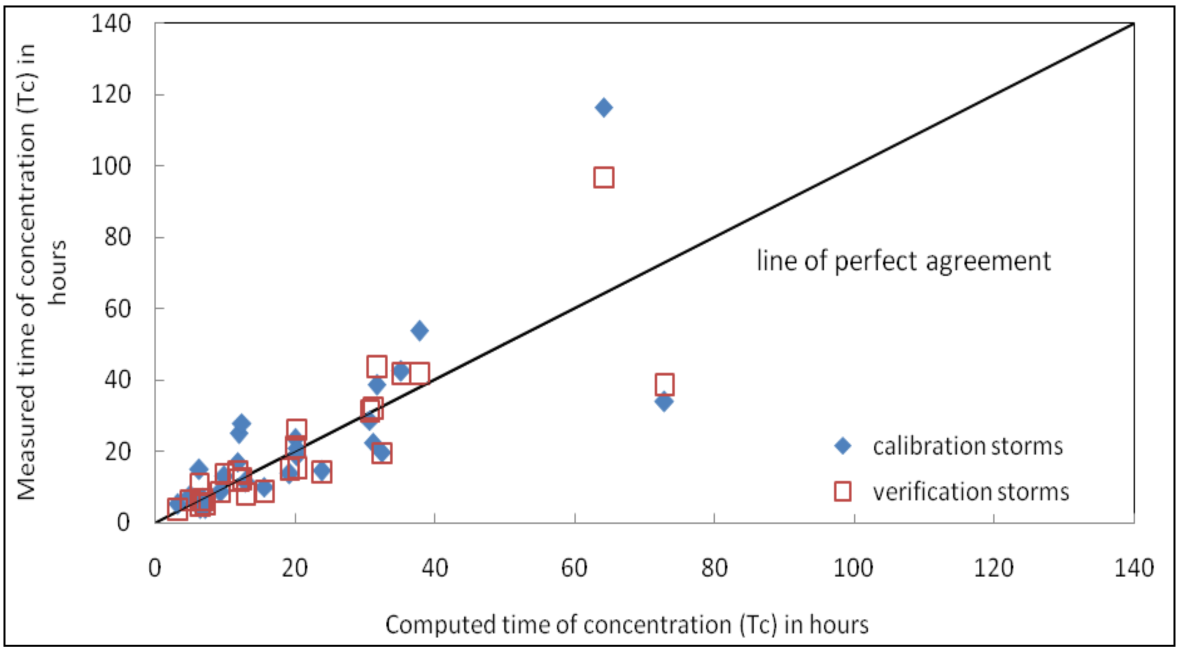

Figure 4: Time of Concentration for Storms of 26 Catchments for Clark Unit Hydrograph Method Measured (average) and as a Function of Catchment Characteristics

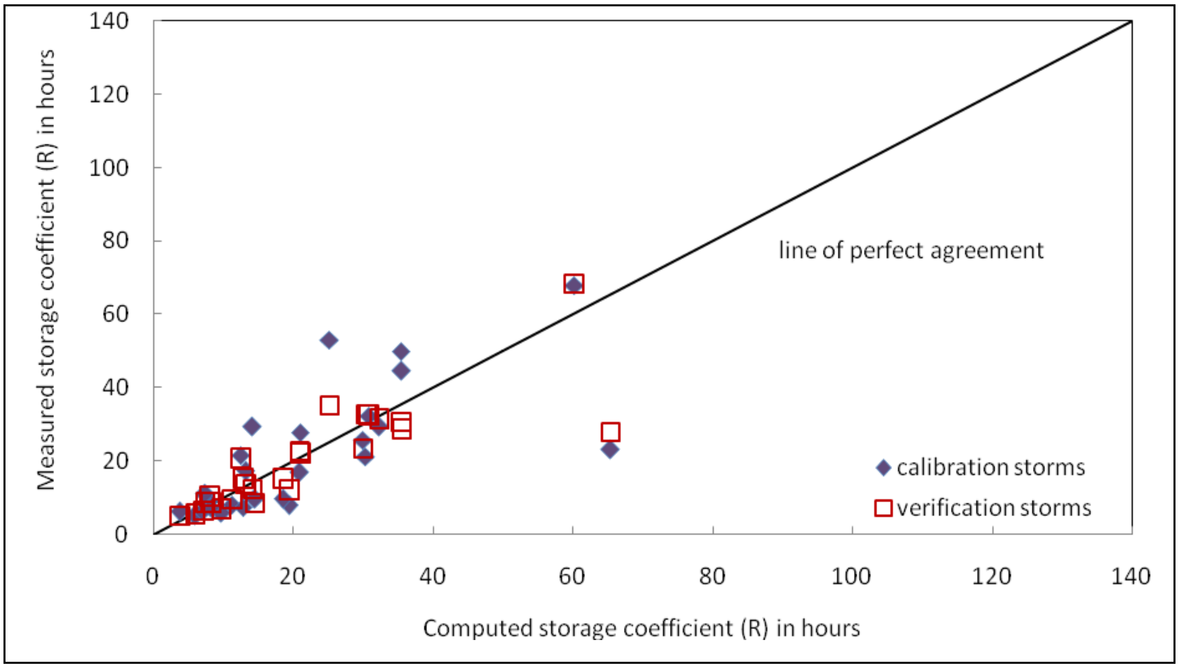

Figure 5: Storage Coefficient for Storms of 26 Catchments for Clark Unit Hydrograph Method Measured (average) and as a Function of Catchment Characteristics

The Multiple Linear Regression Program is used to correlate the measured Tc and R from verifications storms to those obtained using equations (7) and (8) and the results are:

For Tc calculated using equation (7)

R^2 = 0.8145

SE = 0.149

For R calculated using equation (8)

R^2 = 0.7829

SE = 0.1354

As the differences between the coefficient of determination and the standard error for the calibration and verification storms are small, the equations are valid for use to estimate Tc and R for the regions where these parameters are derived.

3.4.8 Design Baseflow

A baseflow is required to derive the total design hydrograph. It is difficult to predict the statistical characteristics of baseflow prior to a major flood. For this study, baseflows of the recorded hydrographs for the catchments before the occurrence of the floods were averaged and plotted as shown in Figure 6. Baseflows were taken for rather dry and moderate wet antecedent catchment conditions. A best fit equation was derived for general use. The equation is:

$$Q_B = 0.11\ A^{0.85889} \qquad (10)$$

Where Q_B is the baseflow in m^3/s

A is the catchment area in km^2

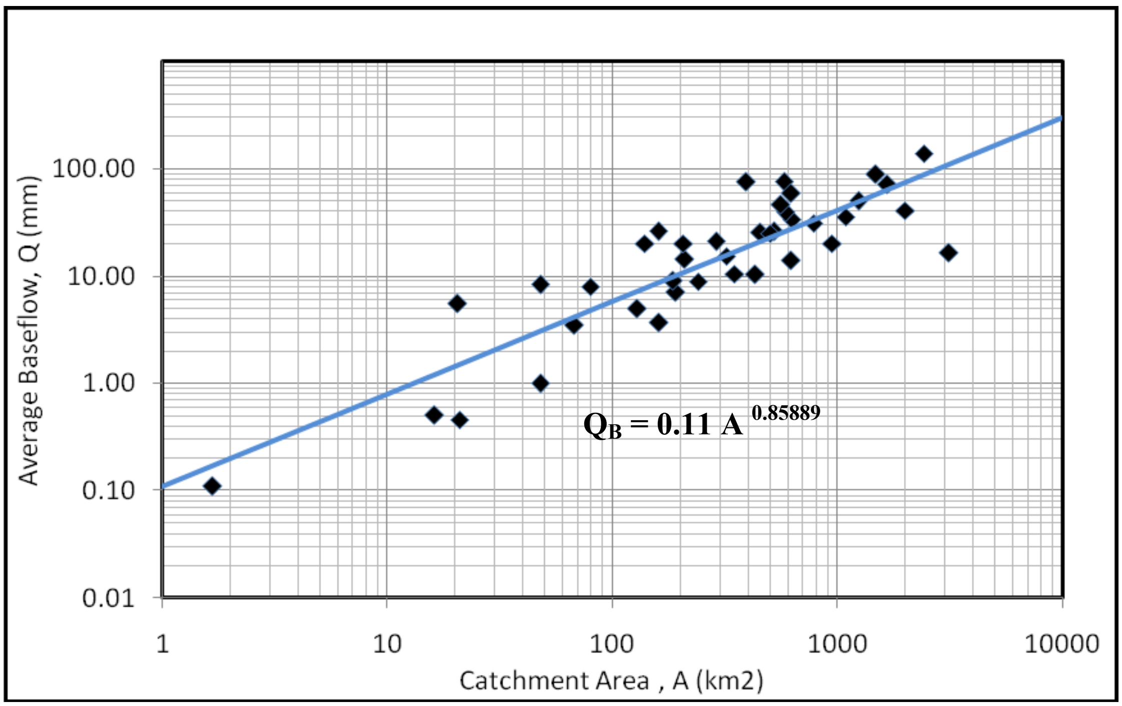

Figure 6: Relationship of Baseflow and Catchment Area

4. RELIABILITY OF THE PROCEDURE

One way of showing the reliability of the procedure for reconstituting the flood with a return period of T years is a scatter diagram. In this study, a number of 30 catchments with sufficient length of rainfall and streamflow records (over 20 years) are selected and the records are used to derive the 50 year rainfall depth and the flood magnitude for the catchments. The method used in JPS Hydrological Procedure No. 1 (1982) is adopted to fit the rainfall and flood data analytically. This method uses the modified leas squares to fit the Gumbel distribution to minimize the sum of squares of the departures of the plotted points. The time series data were scanned for outliers using the median rule of Seo (2006). This method is applicable to moderately skewed distributions as it uses the median value as an estimation of location. Outliers detected are excluded from further analysis only when there are strong belief and statistical evidence that the values are outliers. A computer program is developed to calculate the 50 year flood hydrographs for the 30 catchments. Results estimated using Clark method and frequency analysis are presented in Appendix E.

Figure 7 shows the scatter diagram of peak discharges obtained from frequency analysis and the Clark method. It can be seen from the figure that most of the points lie between the curves representing 70% and 130% of the qp = qo line. Where qp = predicted peak discharge using Clark method and qo=observed peak discharge from frequency analysis.

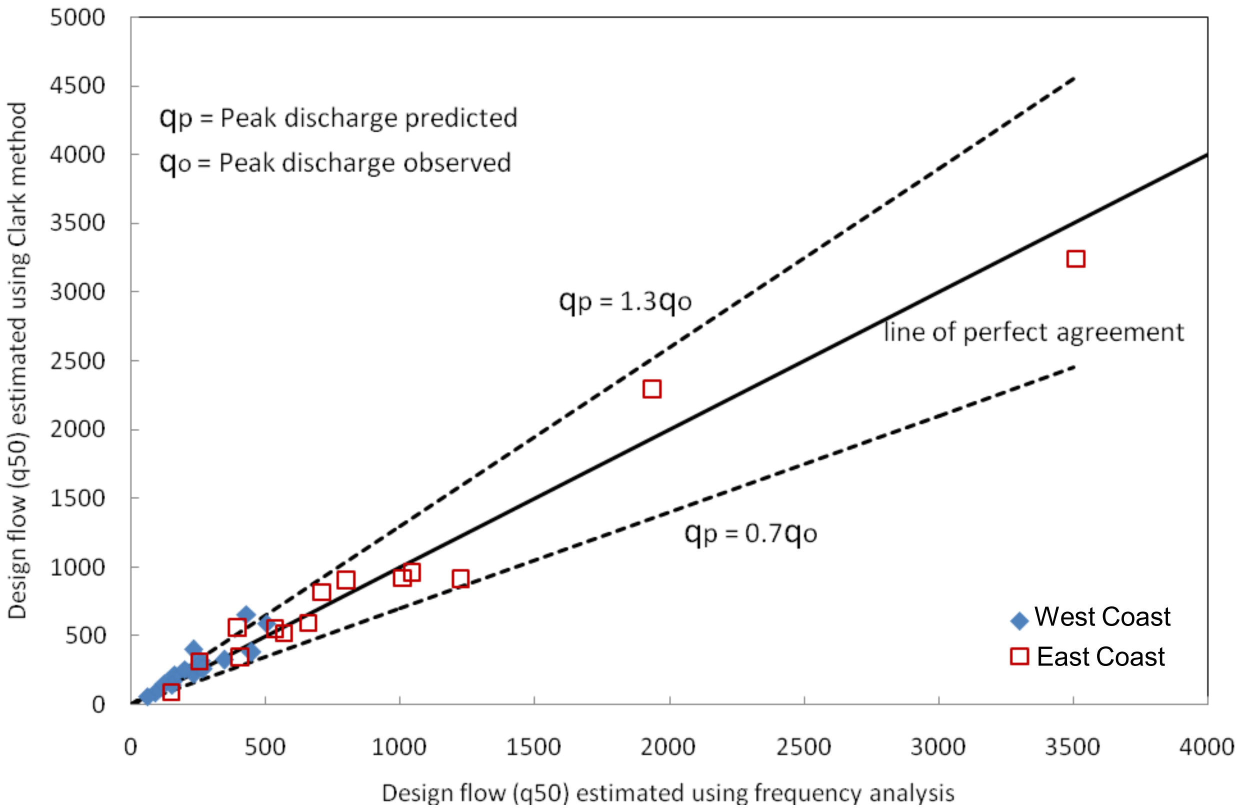

Figure 7: Peak Discharge Estimated using Clark Method and Frequency Analysis

5. LIMITATION OF PROCEDURE

This procedure has been prepared mainly for the estimation of reasonable flood hydrographs where hydrological data for the catchment is sparse or nonexistent. The main limiting assumption inherent is that the T year flood is caused by the storm of T year return period. Generally, the proportion of direct runoff relative to rainfall is greater when the antecedent moisture is high. The rainfall-runoff relationships are derived for design purposes and they are based on average conditions. The same applies to the Tc and R values derived. The areal variability of catchment rainfall during a storm causes the time of concentration of a catchment to vary from storm to storm. This makes the assumption of uniform areal distribution of design storm invalid.

Some unaccounted 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.

6. APPLICATION OF PROCEDURE

6.1 Method of Application

A web based program is developed to estimate the design flood hydrograph for any catchment located in the Peninsular Malaysia. The user needs only to enter data such as catchment size, stream slope and main stream length and rainfall data which can be obtained from HP 1.The Clark unit hydrograph and total hydrograph are printed and shown on the computer screen.

6.1.1 Manual

The method of application is shown below:

Step 1: Determine the catchment area, weighted stream slope and main stream length from the topographical map.

Step 2: Estimate the design rainfall for the specified return period.

Design rainfall for various durations can be obtained using DID H.P. 1 or performing a frequency analysis using the data of DID data bank for rainfall stations in or near the catchment.

Step 3: Find ARF from Table 1.

Step 4: Determine the flood region, East or West.

Step 5: From the rainfall temporal pattern of HP 1, determine the fraction of total rainfall in each interval.

Step 6: Enter the data into the Web based program.

6.1.2 Web Based Programme

The details for the use of web based program is explained in The User‘s Manual for HP 27 (refer to **Appendix F**)

7. WORKED EXAMPLES

7.1 Example 1

Calculate the 1 in 20 year design flood hydrograph for the following West Coast catchment;

Area = 321 km^2

Stream length = 37.8 km

Weighted stream slope = 23.9 m/km

Solution:

Analysis of the rainfall data of an autographic station near the catchment shows that the 1 in 20 year rainfall is:

Rainfall duration (hrs)	Rainfall depth (mm)
3	132
4	139
6	144
9	145
12	146

Areal reduction factors (from Table 1) are:

Rainfall duration (hrs)	Areal reduction factor
3	0.84
4	0.85
6	0.88
9	0.89
12	0.90

Calculate direct runoff using equation (4)

Using equation (7) Tc = 7.56 hrs

Equation (8) gives R = 8.53 hrs

Baseflow is 15.64 m^3/s using equation (10)

Use West Coast rainfall temporal patterns of Hydrological Procedure No. 1 (HP1)

The computer programme gives the following results:

Rainfall duration (hrs)	3	4	6	9	12
Peak discharge (m^3/s)	198.6	218.1	231.3	227.1	213.9

The 6 hour storm gives the highest peak discharge of 231.3 m3/s.

Figure 8 and Figure 9 show the 1mm unit hydrographs and the total design flood hydrographs respectively.

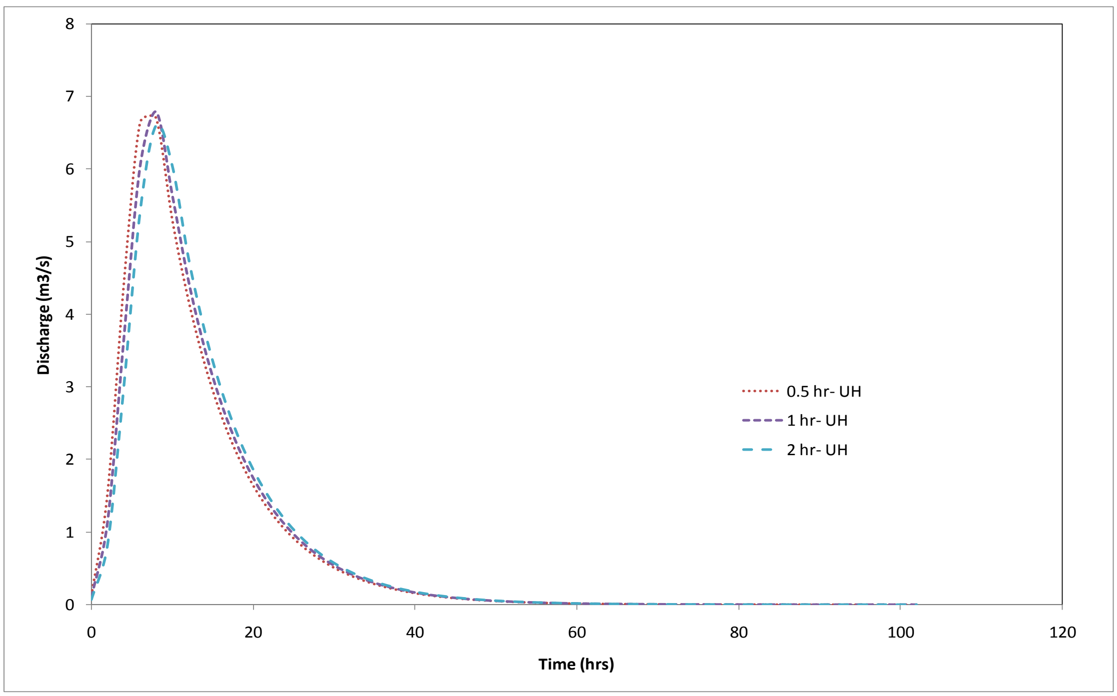

Figure 8: ½ Hour, 1 Hour and 2 Hour Unit Hydrograph

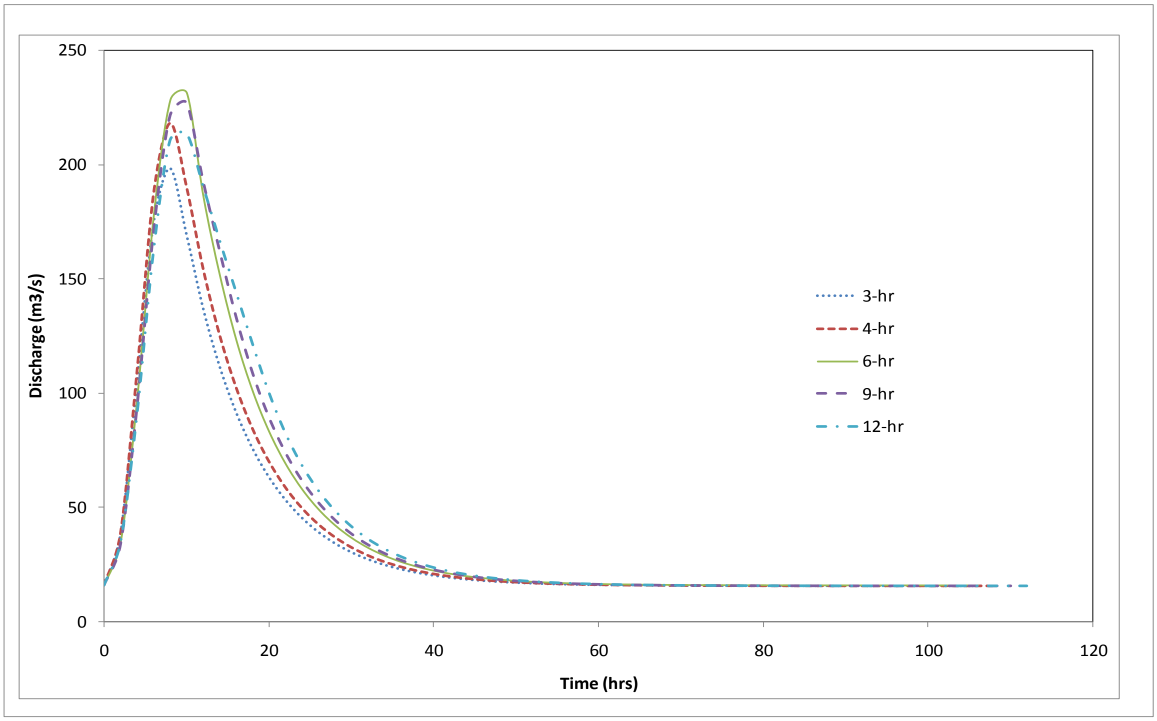

Figure 9: Total Design Flood Hydrographs for Various Storm Durations

7.2 Example 2

Find the 50 year design flood hydrograph for the East Coast catchment with the following characteristics;

Area = 587 km^2

Stream length = 58.8 km

Stream slope = 3.6 m/km

Solution:

The 50 year rainfall for the automatic station near the gauging station is:

Duration (hrs)	Rainfall depth (mm)
6	231
9	266
12	306
18	366
24	408
30	446
36	472
42	497

Areal reduction factors (from Table 1) for the various rainfall durations are:

Rainfall duration (hrs)	Areal reduction factor
6	0.84
9	0.847
12	0.86
18	0.89
24	0.91
30	0.91
36	0.91
42	0.91

Use equation (2) to compute direct runoff.

Equation (10) gives a baseflow of 26.26 m^3/s

From equation (7) Tc = 28.07 hrs

Equation (8) gives R = 28.11 hrs

Use the east coast rainfall temporal patterns (HP1).

The Clark hydrograph programme gives :

Duration (hrs)	Peak flow (m^3/s)
6	428.4
9	519.0
12	622.4
18	788.4
24	852.5
30	905.7
36	922.5
42	917.5

The 50 year peak flow is 922.5 m^3/s and the critical storm is 36 hours.

Figure 10 shows the hydrographs computed.

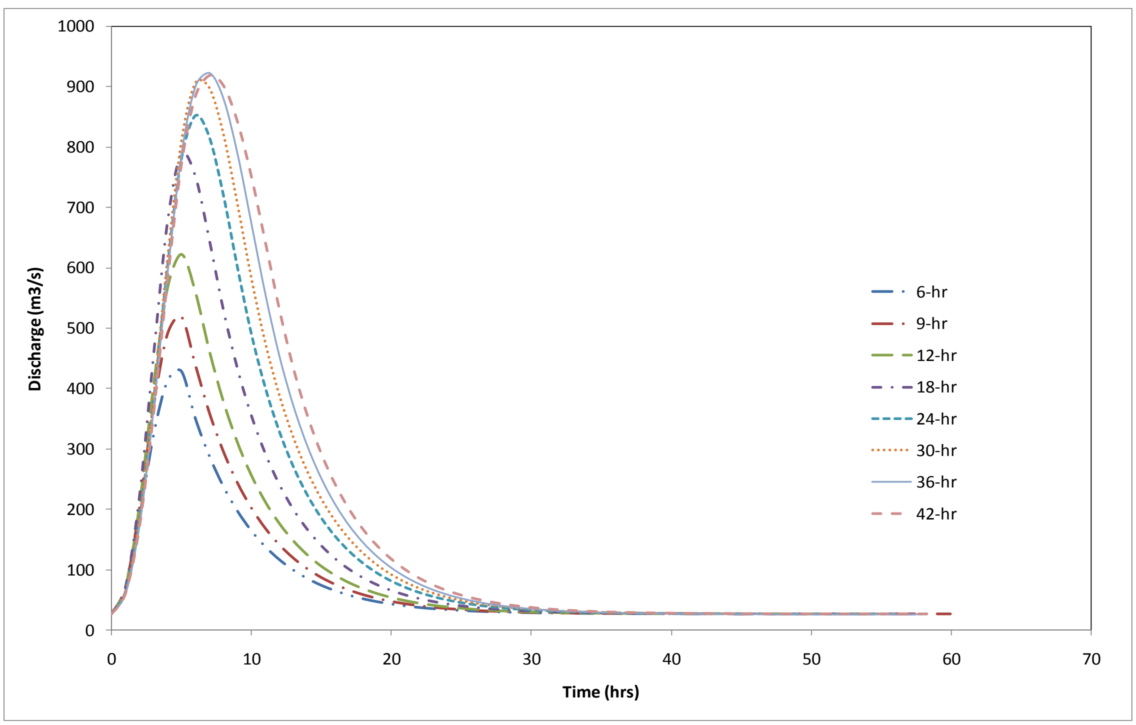

Figure 10: Computed Total Design Flood Hydrographs for Various Storm Durations

7.3 Example 3

Find the 10 year design flood hydrograph for the following east coast catchment:

Area = 20.5 km^2

Main stream length= 7.1 km

Weighted stream slope = 2.2 m/km

Solution:

The average 10 year rainfall for two autographic stations near the catchment is:

Duration (hrs)	Rainfall depth (mm)
6	221
9	265
12	290

ARF is 0.98 for the rainfall durations above

Use Equation (2) to compute direct runoff

Equation (10) gives a baseflow of 1.47 m^3/s

Tc = 7.09 hrs [Equation (7)]

R = 8.18 hrs [Equation (8)]

Use the rainfall temporal patterns of east coast. The results are:

Duration (hrs)	Peak flow (m^3/s)
6	53.5
9	62.2
12	60

Figure 11 shows the total hydrographs computed.

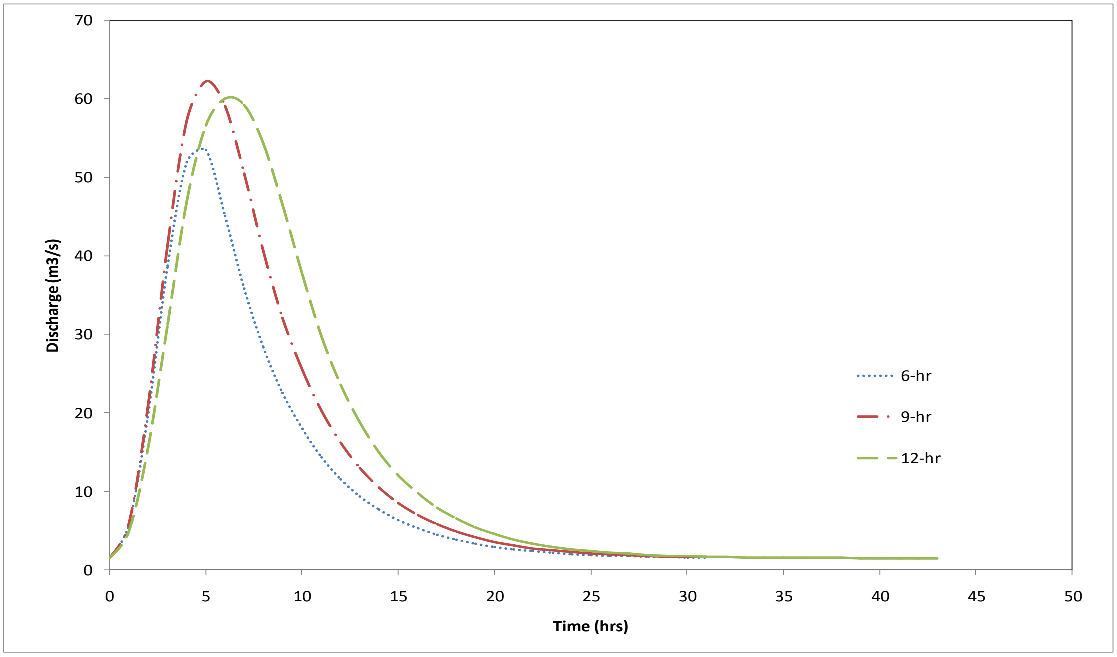

Figure 11: Computed Total Design Flood Hydrographs for Various Storm Durations

7.4 Example 4

Use HEC-HMS to find the 20 year 6 hour flood hydrograph of Example 1.

Using Equation (7) Tc = 7.56 hrs

Equation (8) gives R = 8.53 hrs

The 6 hr point rainfall = 144 mm

ARF for 6 hr duration = 0.88

Catchment rainfall = 144 x 0.88

= 126.72 mm

Direct runoff $= \dfrac{126.7^2}{126.7+350}$ [Equation (4)]

= 33.69 mm

Calculate the 1 hour incremental runoff proportional to the rainfall temporal pattern of west coast.

Time Interval	Runoff (mm)
0 - 1 hr	14.15
1 – 2 hr	11.12
2 – 3 hr	4.04
3 – 4 hr	2.36
4 – 5 hr	1.35
5 – 6 hr	0.67
Total	33.69

One way to use a constant runoff coefficient in HEC-HMS is to input the direct runoff and take initial loss and constant loss equal to zero.

Click HEC-HMS to start the program

Click File menu and then New

When create New Project appears

Name: type *Example 4*

Description: type *20 yr 6 hour*

Location: type *f:/Example4HMS*

Default unit system: type *metric*

Click create

Click tools; Click program setting; Click default

Choose initial loss - constant loss

Choose Clark unit hydrograph

Choose gage wts

Click OK

Go to tool menu

Click components → time series data manager

When time Series Data Manager appears

Data type: choose Precipitation gage

Choose New

When Create a new Precipitation gage appears

Name: type *Design 20 yr storm*

Description: type *6 hour*

Click create

Then Close time series data manager

On the watershed explorer, Click on the + sign of Time series data

Click on + Sign of Precipitation gauge

Click on + Sign of Design 20 yr storm

Click on time window default 01Jan2000 00:00; 02Jan2000 00:00

Click on Time series gauge

Time interval: Choose 1 hour

Click time window

Start Date: Type *01Jan2000*

Start time: *00:00*

End Date: *01Jan2000*

End time: *06:00*

This is to input rainfall / direct runoff 0 ~ 6 hours at 1 hour interval

Click Table

Fill in Precipitation amount for each interval

01Jan2000 00:00 : No value entered

01Jan2000 01:00 : 14:15

01Jan2000 02:00 : 11.12

01Jan2000 06:00 : 0.67

Click Graph to choose the plot of precipitation values

Click components → Basin model manager

When Basin model manager appears

Click New

When Create a new Basin Model appears

Name: Type *Example 4*

Description: Type *20yr 6hr*

Click create

Close Basin model manager

On the watershed explorer

Click + sign of Basin model

Under Basin models

Click Example 4

Choose subbasin symbol and click on graph

Basin model (Example 4) left click

When create a new subbasin element appears

Name: type *Example 4*

Description: type *20yr 6hr*

Click create

Close Basin model (Example 4)

On watershed explorer

Click + sign of example 4

Click + sign of subbasin example 4

Click loss

For Initial loss : type *0*

Constant rate : type *0* $\Big\}$ 100% runoff

Impervious : type *0*

Click example 4 when table appears, fill in area 321

Click transform

Time of concentration Type *7.56*

Storage coefficient Type *8.53*

Click baseflow

Initial Discharge Type *15.6* [baseflow]

Recession constant Type *1*

Ratio tp peak

Ratio: type *0* [independent of peak flow]

Click Components tool bar → meteorological model manager - New

Name: type *gage wts*

Description: type *20 yr 6 hr*

Click create

Close meteorological model manager

On the watershed explorer

Click on + sign of meteorological models

Click gage wts

On the table at the bottom, Click Basins in the Basin model

Include subbasins

Choose Yes

Go back to meteorological models at the bottom of precipitation

Click + sign on Example 4

Click gauge weights

At the bottom table

Right column shows use gauge

Choose Yes

When table appears, Click gage weights

Depth weight: type *1* Time weight : type *1*

Click components → Control specification manager → New

When create a new control specifications appears

Name: type *Control Example 4*

Description: Type *20 year 6 hr*

Clicks create and close the control specification

On watershed explorer Click + sign control specification

Click on control example 4

When the table appears

Start Date: type *01Jan2000*

Start Time: *00:00*

End Date: *04Jan2000*

End Time: *24:00*

Time interval: *1 hr*

Choose 1 hour time interval

The duration of simulation runs must be chosen long enough so that the whole Direct Runoff Hydrograph is covered.

i.e. start from baseflow and end at baseflow

Here we choose 4 days, if not long enough, extend the time

Click file → save to save all data input

Click compute → create a simulation and when create a simulation run appears

Click next, next, next, finish

Click compute at toolbar

Click compute run 1

When the run is finished

Click close

Click Results

Click + sign of simulation runs

Click run 1

Click example 4

Click Graph to see hydrograph

Click Summary to see results

Peak is 234.5 m^3/s

Total excess = 33.69 mm

Total direct runoff = 33.69 mm

Click Time Series Table to see the full hydrograph

Click file → Save to save all data

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APPENDIX A:

DATA USED TO DERIVE RAINFALL – RUNOFF RELATIONSHIP

WEST COAST CATCHMENTS

No.	Station ID	River	Event	Total Storm Precipitation P (mm)	Total Direct Runoff Q (mm)
1	6502431	Sg. Pelarit at Titi Baru	Sep-87	107.0	28.0
			Jul-91	129.0	33.0
2	6502402	Sg. Buloh at Kg. Batu Tangkup	May-96	44.0	12.6
			Oct-95	80.0	20.7
3	5405421	Sg. Kulim at Ara Kuda	Sep-75	48.0	10.0
			Oct-74	28.0	7.4
			Apr-73	49.0	10.0
			Dec-72	21.0	7.0
			Sep-72a	39.0	8.0
			Sep-72b	50.0	17.5
			Dec-75	41.0	9.0
			Feb-71	39.0	9.7
			Dec-70	34.0	12.0
4	5206432	Sg. Krian at Selama	Sep-99	176.0	42.8
			Sep-95	147.0	50.8
			Oct-94	71.0	10.0
			May-81	51.0	9.6
			Nov-80	57.0	18.0
5	4911445	Sg. Plus at Kg. Lintang	Dec-99	35.0	10.5
			Aug-97	40.0	5.2
			Feb-97	28.0	4.7
			Dec-96	34.0	7.5
			Jan-80	28.0	4.1
			Oct-76	40.0	5.5
6	4511468	Sg. Raia at Keramat Pulai	Sep-79	58.0	8.0
			Oct-81	36.0	5.7
			Jul-83	45.0	5.3
7	4311464	Sg. Kampar at Kg. Lanjut	Jan-85	54.0	5.0
			Oct-83	54.0	10.6
			Jul-82	54.0	10.4
			May-82	71.0	17.8
			Apr-82	19.0	4.8
			Apr-81	113.0	11.3
			Sep-75	61.0	6.0

No.	Station ID	River	Event	Total Storm Precipitation P (mm)	Total Direct Runoff Q (mm)
8	4012401	Sg. Bidor at Malayan Tin Bhd	Oct-96	49.2	16.8
			Jun-87	130.0	44.3
			Nov-86	178.0	39.8
			Nov-82	64.0	10.9
9	3913458	Sg. Sungkai at Sungkai	Dec-99	41.0	13.0
			Sep-99	60.0	18.4
			Mar-97	54.0	17.3
			Dec96a	83.0	16.8
			Dec96b	56.0	11.6
			May-91	57.0	12.4
			Oct-90	51.0	9.5
			Sep-89	58.0	17.0
			Apr-86	29.5	6.9
			Sep-83	75.0	9.6
			Oct-76	64.0	7.7
			Oct-73	46.0	9.3
10	3814416	Sg. Slim at Slim River	Feb-00	72.0	11.0
			Jun-98	20.0	5.4
			Sep-96	70.0	14.8
			Sep-94	37.0	5.5
			Dec-86	58.0	16.2
			Nov-81	105.0	15.2
			Sep-80	39.0	9.0
			May-79	33.0	7.7
			May-78	44.0	9.7
			Apr-78	80.0	11.6
			Jan-75	41.0	12.6
			Jan-74	25.0	6.2
			Apr-74	24.0	5.0
			Feb-74	43.0	7.2
			Apr-73	37.0	7.0
			Oct-72	54.0	12.2
			Oct-71	57.0	5.4
			Sep-71	47.0	7.2
			May-71	33.0	3.5
			Oct70a	24.0	5.0
			Oct70b	42.0	7.5
11	3615412	Sg. Bernam at Tg. Malim	Apr-96a	85.0	19.9
			Apr-96b	90.0	20.7
			Jun-91	70.0	11.0
			Apr-87	64.0	8.2
			Dec-84	58.0	14.7
			Jun-80	29.0	5.9
			May-80	44.0	6.7
			Apr-78	47.0	10.7
			Aug-76	65.0	11.5

No.	Station ID	River	Event	Total Storm Precipitation P (mm)	Total Direct Runoff Q (mm)
12	3516422	Sg. Selangor at Rasa	Sep-73	40.0	8.3
			Oct-72	56.0	11.0
			Dec-91	49.0	11.0
			Jan-71	160.0	51.0
			Dec-86	55.0	19.5
			Sep-85	35.8	10.8
			Sep-82	36.0	12.2
15	3217401	Sg. Gombak at Dam Site	May-90	26.1	5.2
			Aug-87	53.6	6.7
			Feb-86	36.8	3.7
			Oct-85	36.8	5.9
			Jun-83	56.2	6.9
16	3216439	Sg. Batu at Sungai Tua	Jun-74	30.5	5.2
			0ct78	35.9	3.5
			Mar-76	76.9	8.8
			May-83	66.0	13.0
			Jul-73	53.9	10.1
			May-74	50.9	7.6
			Nov-82	36.2	3.0
13	3118445	Sg. Lui at Kg. Lui	Apr-79	48.0	10.2
			Nov-82	71.0	7.7
			Jan-76	51.5	10.7
14	2816441	Sg. Langat at Dengkil	Oct-97	69.0	19.5
			Nov-82	60.6	16.2
17	2519421	Sg. Linggi at Sua Betong	May-72	79.4	10.5
			Sep-96	86.7	12.2
18	2322413	Sg. Melaka at Pantai Belimbing	Nov-81	31.3	11.0
			Mar-95	81.0	18.5
			Nov-82	64.0	13.5
19	2224432	Sg. Kesang at Kg. Chin Chin	May-78	33.5	11.8
			Oct-96	78.0	17.0
			Dec-00	57.0	10.7

EAST COAST CATCHMENTS

No.	Station ID	River	Event	Total Storm Precipitation P (mm)	Total Direct Runoff Q (mm)
20	1732401	Parit Madirono	May-82	67.5	49.5
			Jan-87	42.6	28.6
			Jul-88	91.4	49.5
21	1737451	Sg. Johor at Rantau Panjang	Nov-79	182.0	134.0
			Dec-81	176.0	134.0
			Dec-92	140.0	94.8
22	1836402	Sg. Sayong at Jamb. Johor Tenggara	Dec-84	69.7	25.0
			Feb-96	94.0	39.0
			Jan-99	88.0	56.4
			Feb-00	52.5	29.0
23	2235401	Sg. Kahang at Jln Kluang	Dec-81	293.0	203.0
			Dec-83a	313.0	223.0
			Dec-83b	216.0	134.0
24	2237471	Sg. Lenggor at Bt. 42	Jan-79	217.0	114.0
			Jan-95	293.0	147.0
25	2527411	Sg. Muar at Buloh Kasap	Feb-77	76.0	35.0
			Dec-85	161.0	87.0
			Dec-87	67.5	29.0
			Mar-88	94.0	55.3
			Dec-90	104.0	48.0
			Nov-92	135.0	61.0
26	3024443	Sg. Serting at Padang Gudang	Dec-99	103.7	14.8
			Nov-81	109.0	79.8
			Jan-76	108.0	27.7
			Oct-77	58.2	13.6
			Nov-75	73.8	17.8
27	3224433	Sg. Triang at Jambatan Keretapi	Nov-88	111.0	46.0
			Mar-89	39.4	15.7
			Dec-90	85.3	42.0
			Dec-85	136.0	73.5
28	3519426	Sg. Bentong at Kuala Marong	May-81	20.5	3.2
			Nov-79	62.0	26.0
			Jan-80	35.6	16.0
			Jan-00	31.4	17.4
			Sep-99	57.7	22.6
			Apr-97	50.5	16.3
29	3629403	Sg. Lepar at Gelugor	Dec-90	111.0	55.5
			Jan-84	186.0	98.0
			Dec-83	186.0	68.0
			Dec-95	180.0	99.4
			Dec-91	296.0	168.0
			Jan-00	216.0	92.0

No.	Station ID	River	Event	Total Storm Precipitation	Total Direct Runoff
				P	Q
				(mm)	*(mm)*
30	3930401	Sg. Kuantan at Bukit Kenau	Dec-98	260.0	193.0
			Nov-97	63.5	21.0
			Feb-96	23.6	10.0
			Jan-84	172.0	79.8
			Dec-81	69.4	37.3
31	4019462	Sg. Lipis at Benta	Dec-99	116.0	68.4
			Feb-84	41.7	22.3
			Nov-83	97.0	15.6
			Apr-81	39.0	18.7
			Nov-78	44.5	13.7
			Nov-75	70.0	22.3
			Mar-74	58.6	13.7
			Mar-94	36.0	13.8
			Jan-92	36.4	7.8
			May-88	67.0	7.9
			Mar-85	95.0	25.0
32	4131453	Sg. Cherul at Kg. Banho	Dec-97a	108.3	49.0
			Dec-97b	200.0	91.0
			Mar-88	352.0	193.0
			Sep-97	105.0	21.7
33	4232452	Sg. Kemaman at Rantau Panjang	Dec-93	169.0	81.0
			Dec-78	62.5	28.4
			Nov-92	72.9	23.8
			Dec-89	53.0	32.0
			Dec-80	301.0	152.0
			Dec-87	260.0	114.0
34	4832441	Sg. Dungun at Jamb. Jerangau	Nov-89	117.0	64.0
			Jan-93	54.0	21.0
			Jan-95	138.0	49.0
			Dec-77	146.0	34.0
			Dec-78	237.0	145.0
35	4930401	Sg. Berang	Dec-96	186.0	79.6
			Dec-98	74.0	41.0
			Jan-95	264.0	137.0
36	5129437	Sg. Telemong at Paya Rapoh	Jan-84	126.0	28.0
			Jan-95	45.2	34.0
			Dec-87	200.0	99.0
			Nov-94	156.0	109.0

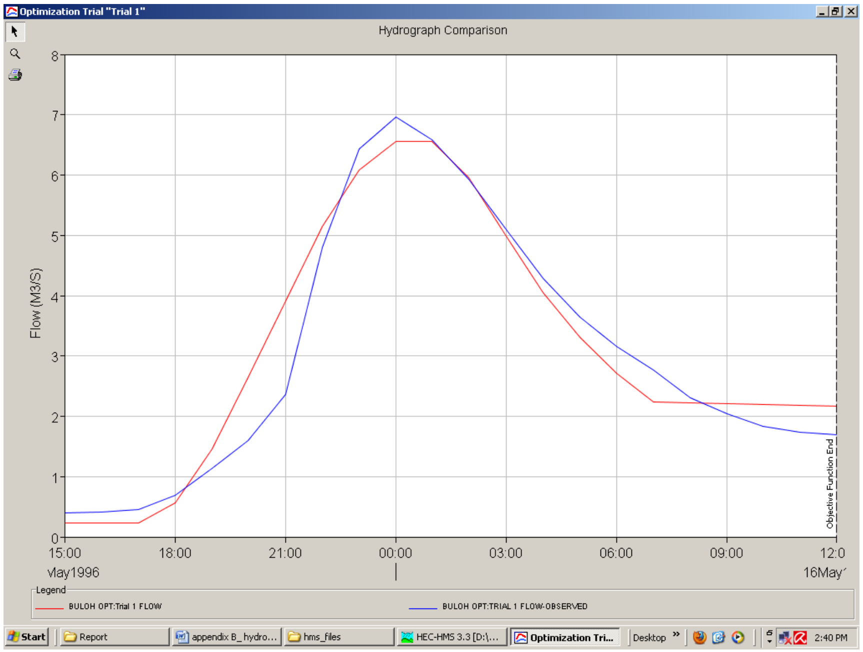
No.	Station ID	River	Event	Total Storm Precipitation P (mm)	Total Direct Runoff Q (mm)
37	5222452	Sg. Lebir at Kg. Tualang	Nov-90	249.0	176.0
			Dec-92	281.0	161.0
			Jan-90	242.0	131.0
			Dec-97	52.0	16.0
			Nov-87	81.0	13.9
			Dec-91	269.0	192.0
			Nov-92	250.0	142.0
			Dec-78	174.0	79.0
			Nov-79	403.0	310.0
38	5229436	Sg. Nerus at Kg. Bukit	Dec-97	270.0	211.0
			Nov-00	291.0	234.0
			Jan-91	280.0	220.0
			Dec-81	204.0	110.0
			Dec-87	202.0	125.0
			Nov-90	207.0	113.0
39	5428401	Sg. Chalok at Jamb. Chalok	Dec-97	164.0	52.0
			Dec-98	137.0	57.0
			Dec-99	167.0	80.0
			Dec-83	238.0	97.0
			Dec-84	228.0	135.0
			Nov-91	284.0	199.0
			Nov-92	163.0	65.0
			Nov-79	269.0	153.0
40	5718401	Sg. Lanas at Air Lanas	Nov-81	287.0	142.0
			Nov-86	245.0	119.0
			Nov-94	96.0	17.6
			Jan-95	49.0	18.2
			Dec-84	420.0	258.0
			Mar-85	174.0	87.0
41	5724411	Sg. Besut at Jamb. Jerteh	Dec-96	127.0	69.0
			Nov-81	301.0	178.0
			Nov-92	282.0	135.0
			Nov-94	262.0	134.0
			Dec-97	229.0	113.0
			Feb-00	236.0	123.0

APPENDIX B:

PREDICTED AND OBSERVED HYDROGRAPHS

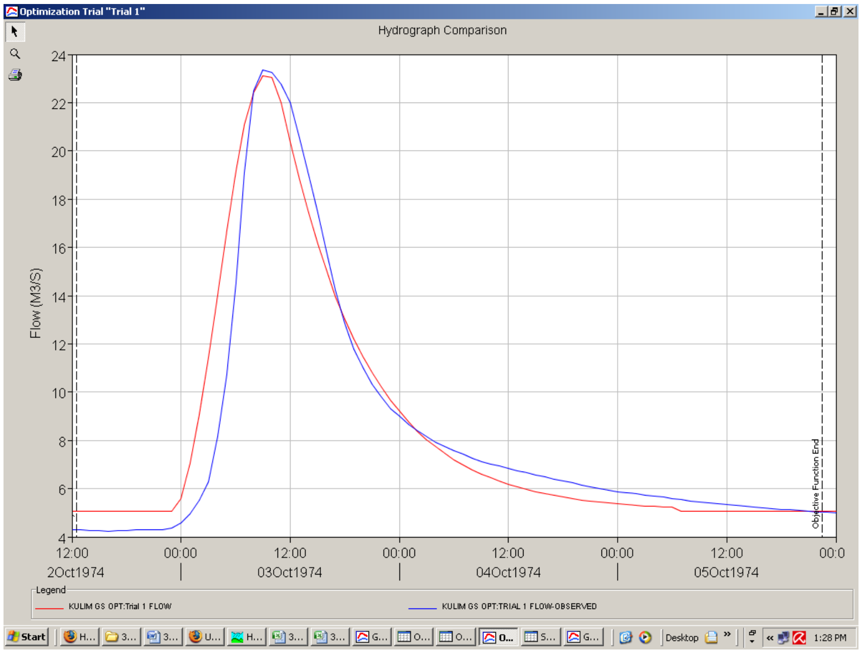
1. SG. BULOH AT KG. BATU TANGKUP – 6502402

<u>16 May 1996</u>



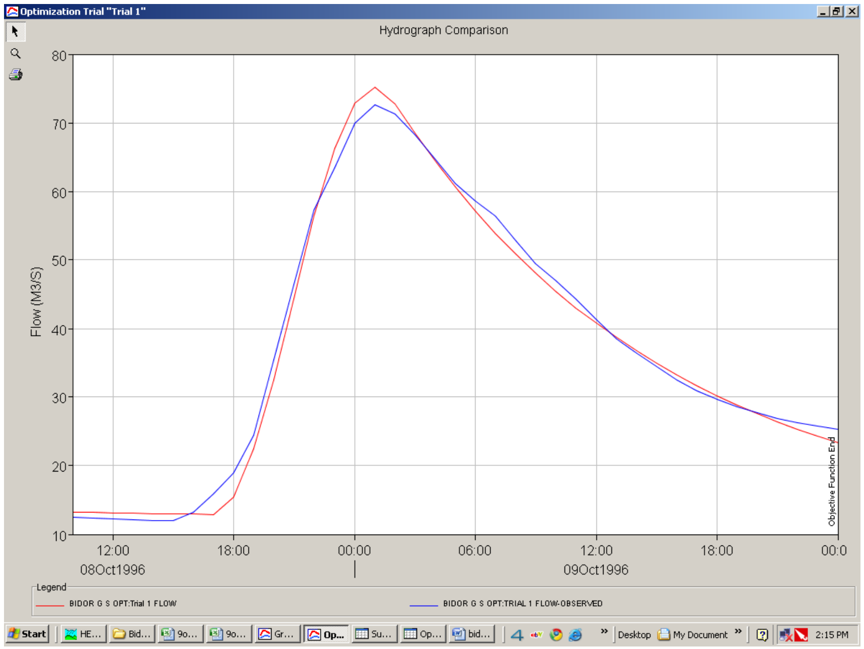
2. SG. KULIM AT ARA KUDA – 5405421

<u>3 October 1974</u>



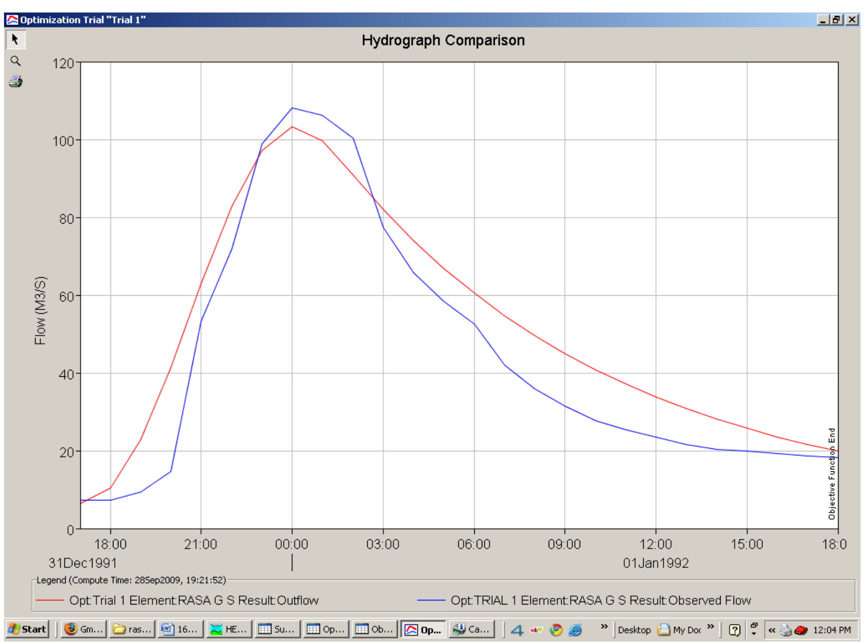
3. SG. BIDOR AT MALAYAN TIN BHD – 4012401

9 October 1996



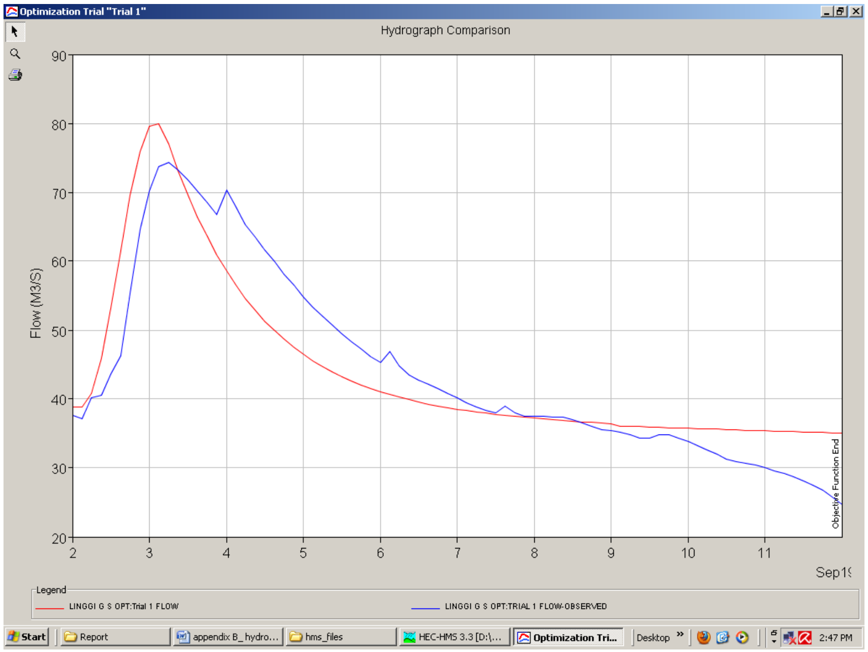
4. SG. SELANGOR AT RASA – 3516422

31 December 1991



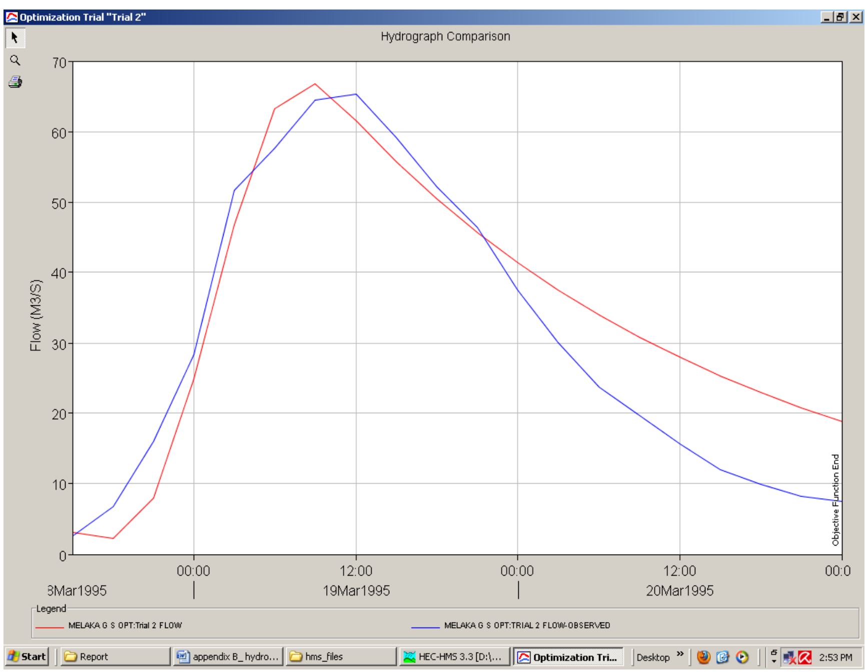
5. SG. LINGGI AT SUA BETONG – 2519421

3 September 1996



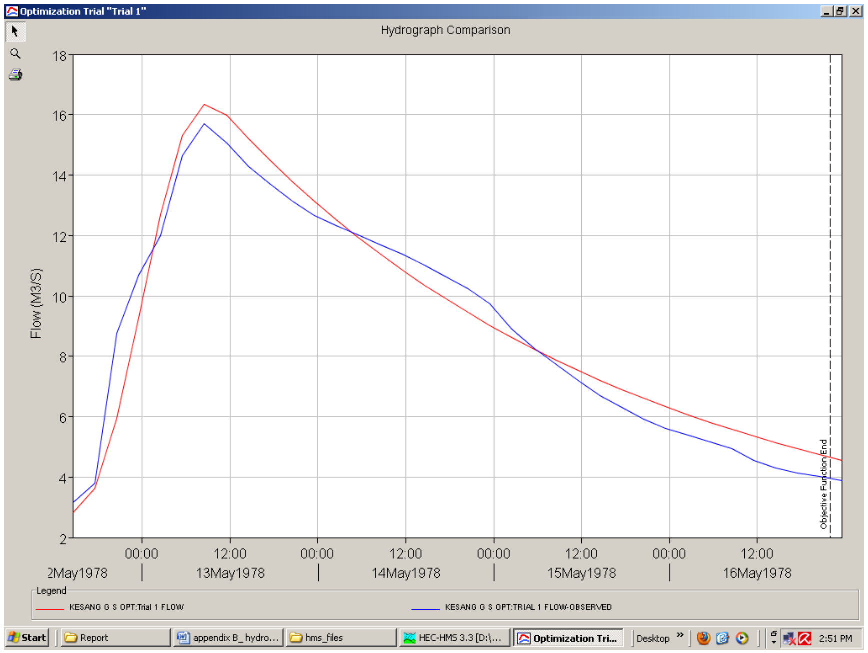
6. SG. MELAKA AT PANTAI BELIMBING – 2322413

19 March 1995



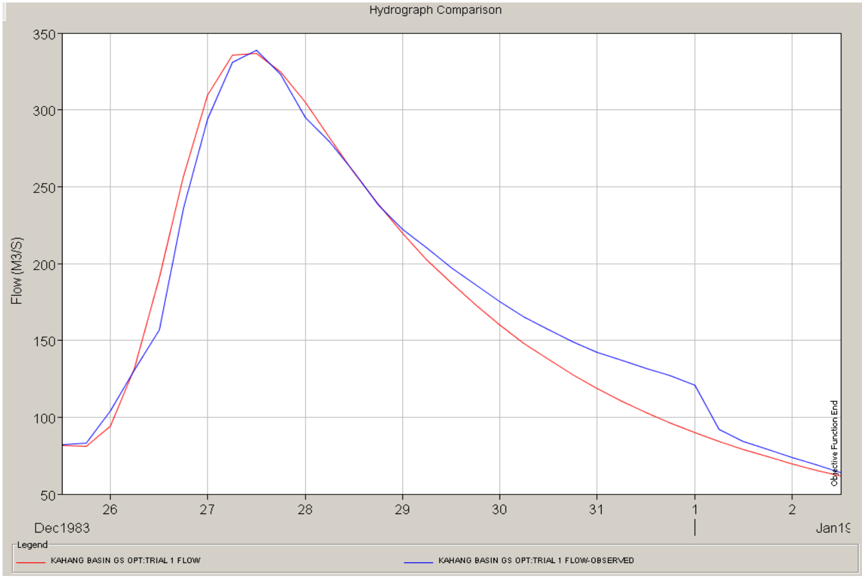
7. SG. KESANG AT CHIN CHIN – 2224432

13 May 1978



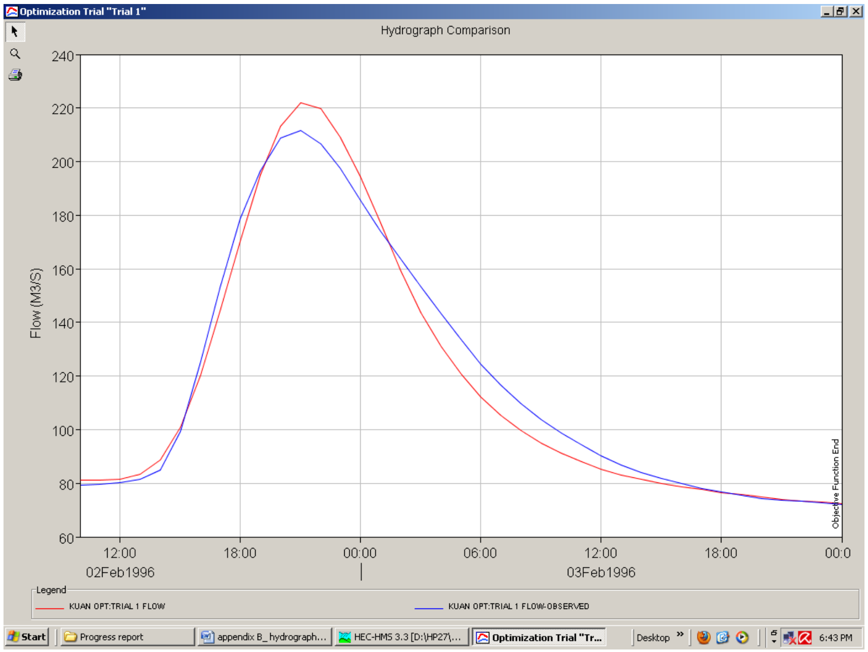
8. SG. KAHANG AT JLN KLUANG / MERSING – 2235401

27 December 1983



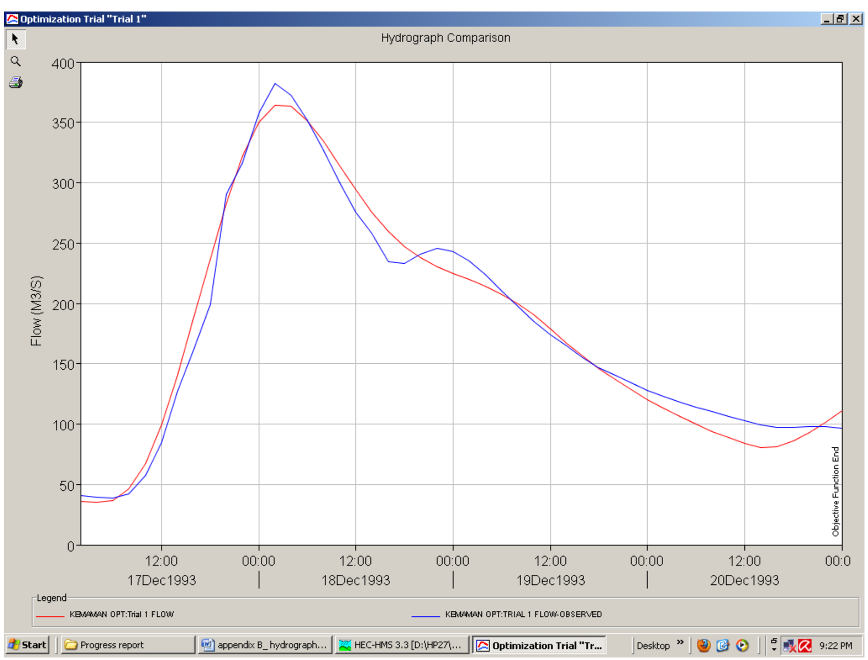
9. SG. KUANTAN AT BUKIT KENAU – 3930401

2 February 1996



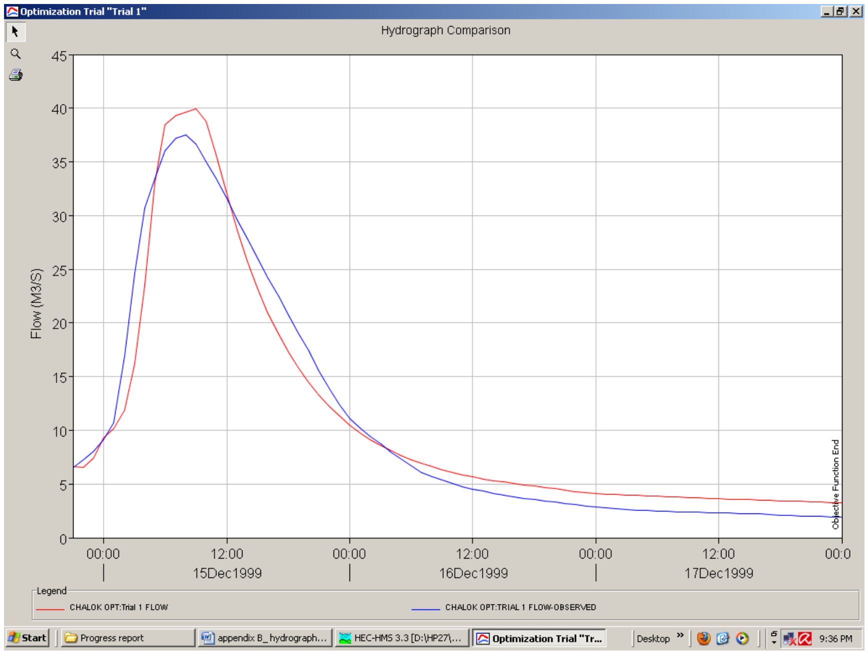
10. SG. KEMAMAN AT RANTAU PANJANG – 4232452

18 December 1993



11. SG. CHALOK AT JAMB. CHALOK – 5428401

15 December 1999



APPENDIX C:

AVERAGE Tc, R AND CATCHMENT CHARACTERISTICS

No.	Station ID	Station Name	Time of Concentration	Storage Coefficient	Catchment Area	Main River Length	Main River Slope
			Tc	R	A	L	S
			(hrs)	*(hrs)*	*km²*	*km*	*m/km*
1	1732401	Parit Madirono	6.2	7.0	1.7	2.8	2.0
2	1737451	Sg. Johor at Rantau Panjang	54.3	61.6	1,130.0	61.4	1.2
3	1836402	Sg. Sayong at Jamb. Johor Tenggara	53.8	44.6	624.0	47.1	1.3
4	2224432	Sg. Kesang at Kg. Chin Chin	14.5	53.0	161.0	34.0	3.4
5	2235401	Sg. Kahang at Jln Kluang	58.7	39.0	587.0	58.8	3.6
6	2237471	Sg. Lenggor at Bt. 42	28.0	17.3	207.0	26.7	5.2
7	2322413	Sg. Melaka at Pantai Belimbing	15.7	36.2	350.0	43.8	2.1
8	2519421	Sg. Linggi at Sua Betong	23.4	27.9	523.0	59.7	7.4
9	2527411	Sg. Muar at Buloh Kasap	150.0	109.0	3,130.0	165.4	1.9
10	2816441	Sg. Langat at Dengkil	18.9	29.3	1,240.0	49.0	7.7
11	3024443	Sg. Serting at Padang Gudang	64.9	131.5	950.0	92.8	1.1
12	3118445	Sg. Lui at Kg. Lui	7.6	5.1	68.1	15.5	14.4
13	3216439	Sg. Batu at Sg. Tua	1.1	2.9	55.7	14.8	64.5
14	3217401	Sg. Gombak at Dam Site	2.2	4.0	84.7	20.2	49.0
15	3224433	Sg. Triang at Jln. Keretapi	116.5	68.0	2,000.0	144.7	2.9
16	3516422	Sg. Selangor at Rasa	6.0	14.1	321.0	37.8	23.9
17	3519426	Sg. Bentong at Kuala Marong	4.1	6.4	241.0	25.0	16.2
18	3615412	Sg. Bernam at Tg. Malim	5.2	6.3	186.0	20.2	45.8
19	3629403	Sg. Lepar at Gelugor	42.5	50.0	560.0	69.5	3.2
20	3814416	Sg. Slim at Slim River	17.0	7.5	455.0	51.0	16.1
21	3913458	Sg. Sungkai at Sungkai	13.0	8.2	289.0	44.6	19.7
22	3930401	Sg. Kuantan at Bukit Kenau	8.6	5.9	582.0	36.2	12.7
23	4012401	Sg. Bidor at Malayan Tin Bhd	7.5	9.4	210.0	34.9	21.1
24	4019462	Sg. Lipis at Benta	38.6	21.2	1670	89.6	4.9
25	4131453	Sg. Cherul at Kg. Banho	20.9	17.0	505.0	53.6	6.0
26	4232452	Sg. Kemaman at Rantau Panjang	19.8	29.4	626.0	64.7	3.2
27	4311464	Sg. Kampar at Kg. Lanjut	9.3	17.7	432.0	54.7	18.9
28	4511468	Sg. Raia at Keramat Pulai	6.0	7.5	192.0	37.8	33.8
29	4832441	Sg. Dungun at Jamb. Jerangau	22.5	25.8	1,480.0	88.3	5.1
30	4911445	Sg. Plus at Kg. Lintang	13.7	7.9	1,090.0	71.4	9.5
31	4930401	Sg. Berang at Kg. Menerong	6.7	8.9	140.0	30.0	23.7
32	5129437	Sg. Telemong at Paya Rapat	10.1	9.6	160.0	42.4	9.3

No.	Station ID	Station Name	Time of Concentration	Storage Coefficient	Catchment Area	Main River Length	Main River Slope
			Tc	**R**	**A**	**L**	**S**
			(hrs)	***(hrs)***	***Km^2***	***km***	***m/km***
33	5206432	Sg. Krian at Selama	25.1	21.6	629.0	46.7	12.4
34	5222452	Sg. Lebir at Kg. Tualang	33.9	23.2	2,430.0	128.7	1.7
35	5229436	Sg. Nerus at Kg. Bukit	28.7	32.4	393.0	48.5	2.3
36	5405421	Sg. Kulim at Ara Kuda	11.3	9.7	129.0	30.0	6.7
37	5428401	Sg. Chalok at Jam. Chalok	4.0	7.2	20.5	7.1	2.2
38	5718401	Sg. Lanas at Air Lanas	15.0	11.0	80.0	18.5	12.3
39	5724411	Sg. Besut at Jamb. Jerteh	17.8	20.6	787.0	63.1	2.1
40	6502402	Sg. Buloh at Kg. Batu Tangkup	8.9	4.4	16.3	7.7	4.3
41	6502431	Sg. Pelarit at Titi Baru	13.9	16.6	48.0	23.6	12.8
42	JKR	Sg. Damansara at Bt. 41.5	7.0	5.1	97.0	16.0	2.2
43	JKR	Sg. Langat at Bt.10	1.5	2.8	76.0	13.5	44.6
44	2918443*	Sg. Semenyih at Semenyih	-	-	212	29.8	13.7

*Records not used for calibration

APPENDIX D:

MEASURED AND COMPUTED Tc AND R

No.	Station ID	Catchment	Mean Tc from verfication storm	Tc from equation (7)	Mean R from verification storm	R from equation (8)
1	1836402	Sg. Sayong at Jamb. Johor Tenggara	42.00	37.80	28.80	35.50
2	2224432	Sg. Kesang at Kg. Chin Chin	14.40	23.80	35.30	25.20
3	2237471	Sg. Lenggor at Bt. 42	12.30	12.40	13.80	13.20
4	2519421	Sg. Linggi at Sua Betong	21.40	20.03	22.30	20.98
5	2816441	Sg. Langat at Dengkil	15.50	20.30	12.40	14.20
6	3118445	Sg. Lui at Kg. Lui	6.40	5.00	5.80	5.97
7	3224433	Sg. Triang at Jln. Keretapi	96.80	64.10	68.40	60.20
8	3519426	Sg. Bentong at Kuala Marong	5.00	6.40	6.60	7.10
9	3615412	Sg. Bernam at Tg. Malim	3.90	3.18	5.20	3.76
10	3629403	Sg. Lepar at Gelugor	42.00	35.20	30.80	35.40
11	3814416	Sg. Slim at Slim River	14.40	11.76	15.30	12.84
12	3913458	Sg. Sungkai at Sungkai	13.70	9.90	9.70	11.20
13	3930401	Sg. Kuantan at Bukit Kenau	8.70	9.30	7.00	9.73
14	4019462	Sg. Lipis at Benta	43.90	31.70	32.90	30.40
15	4131453	Sg. Cherul at Kg. Ban Ho	26.20	20.20	22.80	20.90
16	4232452	Sg. Kemaman at Rantau Panjang	19.50	32.40	31.70	32.30
17	4832441	Sg. Dungun at Jam. Jerangau	32.20	31.10	23.50	30.00
18	4911445	Sg. Plus at Kg. Lintang	15.00	19.20	12.20	19.40
19	4930401	Sg. Berang at Kg. Menerong	6.60	6.72	10.50	7.99
20	5129437	Sg. Telemong at Paya Rapat	8.90	15.60	15.40	18.50
21	5206432	Sg. Krian at Selama	11.90	11.92	20.90	12.50
22	5222452	Sg. Lebir at Kg. Tualang	38.80	72.80	28.00	65.40
23	5229436	Sg. Nerus at Kg. Bukit	31.50	30.70	32.70	30.80
24	5405421	Sg. Kulim at Ara Kuda	8.00	12.90	8.70	14.50
25	5428401	Sg. Chalok at Jamb. Chalok	5.50	7.10	8.90	8.20
26	5718401	Sg. Lanas at Air Lanas	11.00	6.30	8.90	7.40

APPENDIX E:

CALCULATED AND OBSERVED PEAK DISCHARGES

No.	Station ID	Station Name	Catchment Area (km^2)	50 ARI peak discharge	
				Clark method (m3/s)	Frequency analysis (m3/s)
1	1836402	Sg. Sayong at Jamb. Johor Tenggara	624.0	566.3	395.0
2	2224432	Sg. Kesang at Kg. Chin Chin	161.0	60.7	60.8
3	2235401	Sg. Kahang at Jln Kluang	587.0	922.5	1008.0
4	2237471	Sg. Lenggor at Bt. 42	207.0	522.7	568.8
5	2322413	Sg. Melaka at Pantai Belimbing	350.0	146.7	154.0
6	2519421	Sg. Linggi at Sua Betong	523.0	263.3	268.3
7	2918443	Sg. Semenyih at Semenyih	212.0	152.8	125.8
8	3118445	Sg. Lui at Kg. Lui	68.1	89.7	93.3
9	3516422	Sg. Selangor at Rasa	321.0	285.4	246.0
10	3519426	Sg. Bentong at Kuala Marong	241.0	347.4	403.0
11	3615412	Sg. Bernam at Tg. Malim	186.0	401.5	233.0
12	3629403	Sg. Lepar at Gelugor	560.0	556.9	535.0
13	3813411	Sg. Bernam at SKC	1090	657.4	429.4
14	3814416	Sg. Slim at Slim River	455.0	323.7	260.0
15	3913458	Sg. Sungkai at Sungkai	289.0	256.7	202.0
16	4012401	Sg. Bidor at Malayan Tin Bhd	210.0	226.0	235.1
17	4019462	Sg. Lipis at Benta	1670.0	820.6	708.0
18	4232452	Sg. Kemaman at Rantau Panjang	626.0	919.2	1225.0
19	4311464	Sg. Kampar at Kg. Lanjut	432.0	218.9	162.4
20	4611463	Sg. Kinta at Tg. Rambutan	246.0	380.1	448.0
21	4832441	Sg. Dungun at Jamb. Jerangau	1480.0	3245.7	3509.0
22	4911445	Sg. Plus at Kg. Lintang	1090.0	593.2	503.0
23	4930401	Sg. Berang at Kg. Menerong	140.0	907.0	798.0
24	5129437	Sg. Telemong at Paya Rapat	160.0	598.0	657.0
25	5206432	Sg. Krian at Selama	629.0	329.1	346.3
26	5229436	Sg. Nerus at Kg. Bukit	393.0	963.0	1043.0
27	5405421	Sg. Kulim at Ara Kuda	129.0	167.8	1563.0
28	5428401	Sg. Chalok at Jamb. Chalok	20.5	94.7	148.9
29	5718401	Sg. Lanas at Air Lanas	80.0	316.8	253.0
30	5724411	Sg. Besut at Jamb. Jerteh	787.0	2300.4	1936.0

APPENDIX F:

USER'S MANUAL

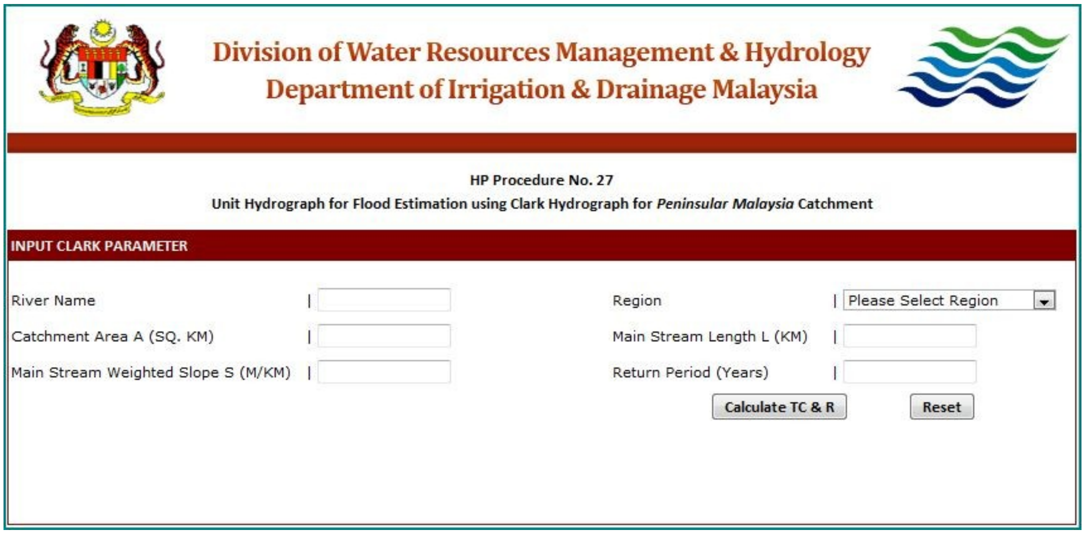
HP No. 27

Unit Hydrograph for Flood Estimation using Clark Hydrograph for Rural Catchments in Peninsular Malaysia

1. Input Parameter

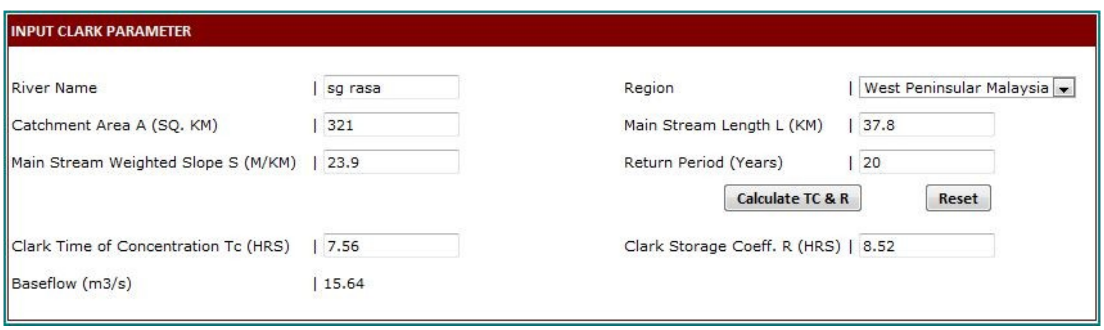
a) Open web browser and enter the URL: http:// h2o.water.gov.my

- Click **HP 27** Unit Hydrograph for Flood Estimation of Design Flood Hydrograph Using Clark Method for Rural Catchments in Peninsular Malaysia.
- User will be redirected to the input parameter page.



b) Enter data for Clark Parameter. Click **Calculate TC & R**.

- Value for TC & R will be calculated by the application.



c) Enter data for Design Parameter. Click **Calculate**.

- User will be redirected to result page.

INPUT DESIGN PARAMETER

Temporal Pattern Type	User Defined		
Storm Duration (HRS)	Please Select	Time Interval (HRS)	Please Select
Catchment Area	Please Select	Rainfall Depth (MM)	132
Fraction of Temporal Pattern *(separate each value with a comma)*	0.29,0.31,0.2,0.12,0.05,0.03		

Calculate Reset

1 Output Parameter

a) Outputs are in as graphs and data file.

Hydrological Procedure No. 27
CLARK Unit Hydrology

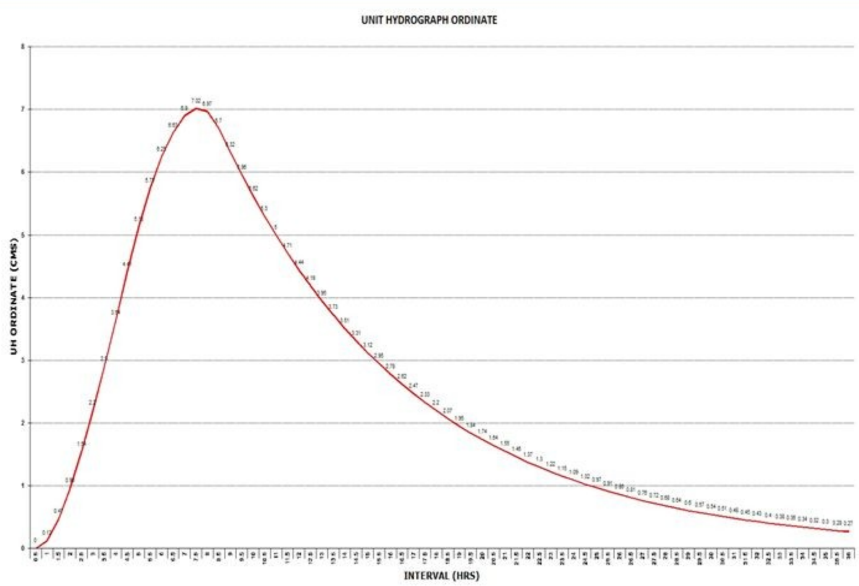
UNIT HYDROGRAPH AND TOTAL RUNOFF HYDROGRAPH FOR SG RASA2

River Name	: sg rasa2	Region	: West Peninsular Malaysia
Catchment Area A (SQ. KM)	: 321	Main Stream Length L (KM)	: 37.8
Main Stream Slope S (M/KM)	: 23.9	Return Period (Years)	: 20
Clark Time of Concentration Tc (HRS)	: 7.56	Clark Storage Coeff. R (HRS)	: 8.52
Storm Duration (HRS)	: 3	IUH UH Time Interval (HRS)	: 0.5
Return Period (Years)	: 20	Storm Depth (MM)	: 132
No. of Time Int for IUH and UH	: 15	Actual TC used in IUH, UH (HRS)	: 7.5
Areal Reduction Factor	: 0.6		

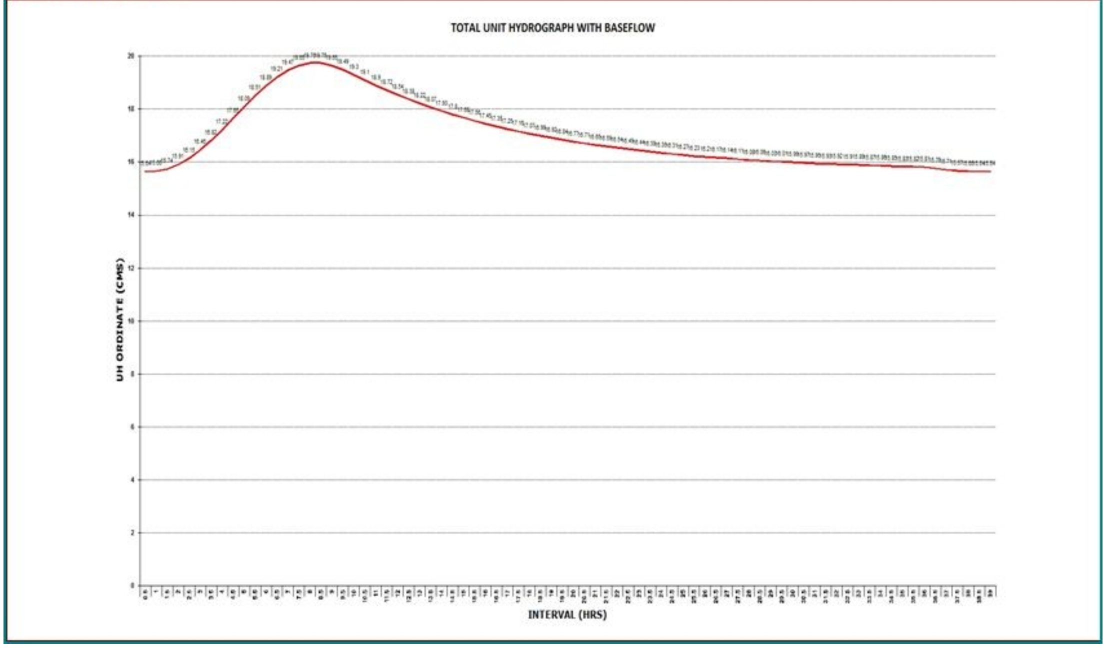
OUTPUT DATA

View Catchment Data **View UH Ordinate Data**

Unit Hydrograph Ordinate



Design Flood Hydrograph



HYDROLOGICAL PROCEDURES PUBLISHED

No. 1	-	Estimation of the Design Rainstorm in Peninsular Malaysia (Revised and updated, 2010).
No. 2	-	Water Quality Sampling for Surfaces Water (1973).
No. 3	-	A General Purpose Event Water Level Recorder Capricorder Model 1598 (1973).
No. 4	-	Magnitude and frequency of floods in Peninsular Malaysia (1974).
No. 5	-	Rational method of flood estimation for rural catchments in Peninsular Malaysia (Revised and updated, 2010).
No. 6	-	Hydrological Station numbering system (1974).
No. 7	-	Hydrological Station Registers (1974).
No. 8	-	Field Installation and Maintenance of Capricorder 1599 (1974).
No. 9	-	Field Installation and Maintenance of Caprocorder 1598 Digital Event Water Level Recorder (1974).
No. 10	-	Stage-Discharge Curves (1977).
No. 11	-	Design Flood Hydrograph Estimation for Rural Catchments in Peninsular Malaysia (1976).
No. 12	-	Magnitude and Frequency of Low Flows in Peninsular Malaysia (1976).
No. 13	-	The Estimation of Storage – Draft Rate Characteristics for Rivers in Peninsular Malaysia (1976).
No. 14	-	Graphical Recorders Instruction for Chart Changing and Annotation (1976).
No. 15	-	River Discharges Measurement by Current Meter (1976).
No. 16	-	Flood Estimation for Urban Areas in Peninsular Malaysia (1976).
No. 17	-	Estimation Potential Evapotranspiration Using the Penman Procedure (1977).
No. 18	-	Hydrological Design of Agriculture Drainage Systems (1977).
No. 19	-	The Determination of Suspended Sediment Discharges (1977).
No. 20	-	Hydrological Aspects of Agriculture Planning and Irrigation Design (1977).
No. 21	-	Evaporation Data Collection Using U.S Class “A” Aluminum Pan (1981).

No. 22 - River Water Quality Sampling (1981).

No. 23 - Operation and Maintenance of Cableways Installation (1981).

No. 24 - Establishment of Agro-hydrological Stations (1982).

No. 25 - Standard Stick Gauge of River Station (1982).

No. 26 - Estimation of Design Rainstorm in Sabah and Sarawak (1983).

No. 27 - Estimation of Design Flood Hydrograph Using Clark Method For Rural Catchments in Peninsular Malaysia (2010).

BAHAGIAN PENGURUSAN SUMBER AIR DAN HIDROLOGI

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