HYDROLOGICAL PROCEDURE NO. 5

RATIONAL METHOD OF FLOOD ESTIMATION FOR RURAL CATCHMENTS IN PENINSULAR MALAYSIA

1989

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

Hydrological Procedure No. 5

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(REVISED AND UPDATED)
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Bahagian Pengairan dan Saliran
Kementerian Pertanian
Malaysia

RATIONAL METHOD

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FLOOD ESTIMATION FOR RURAL CATCHMENTS IN PENINSULAR MALAYSIA

(REVISED AND UPDATED)

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CONTENTS

		Page
SYPNOSIS		iii
1.	INTRODUCTION	1
2.	THE RATIONAL METHOD AS A FLOOD ESTIMATION PROCEDURE	1
2.1	General	1
2.2	Essential Features of the Rational Method	1
3.	THE INVESTIGATIONS	2
3.1	General	2
3.2	Methodology of the investigation	2
3.2.1	Design Sequence	2
3.2.2	Estimation of Time of Concentration	2
3.2.3	Estimation of the Average Intensity of the Design Storm	3
3.2.4	Estimation of Runoff Coefficient	3
3.2.5	Regional Runoff Coefficient C based in Flood Frequency Regions	3
4.	ACCURACY OF THE PROCEDURE	3
4.1	Comparison with DID HP5 (1972)	3
4.2	Comparison with the Regional Flood Frequency Analysis	5
5.	LIMITATIONS OF THE PROCEDURE	5
6.	USE OF THE PROCEDURE	5
REFERENCES		14
APPENDIX A – Multiplying Factor to take Account of Catchment Development		15
APPENDIX B – Check on Estimation of Tc Using Empirical Relationships		15

SYPNOSIS

The Rational Method of flood estimation is widely used throughout the world. Recent studies have shown that it is most useful if regarded as a statistical link between the frequency distributions of the design rainstorm and the design flood. In this procedure, the statistical approach was adopted and used to prepare a flood estimation for small rural catchments up to 100 square kilometres in Peninsular Malaysia. With the establishment of a few representative and experimental catchments and the increase in record length of some of the catchments used in the previous study, more data are available for reviewing and updating the old procedure. In this study, records from 20 small rural catchments with 5 years or more of continuous data were analysed to provide new design data. Since the methodology adopted in the new edition was basically similar to the previous edition, the presentation and arrangement are kept as similar as possible for the convenience of the users.

1. INTRODUCTION

This procedure is the result of a study into the applicability of the Rational Method of flood estimation for small rural catchments in Peninsular Malaysia.

The use of the Rational Method for urban environment has worked reasonably well in many countries. For rural catchments the use of Rational Method has received much criticism. Few overseas researchers who have studied the method as a deterministic model and tested it with observed data found that the method gave low accuracy when individual storms and resulting peak discharges were considered. However, studies by French et al. (1974) who examined the validity of the method have shown that statistically the method served the purpose of engineering practice where peak discharges of a given frequency are linked with the rainfall intensities of the same frequency.

Since the annual total expenditure on many small hydraulic structures such as bridges, culverts, diversion works and so on amounted from a hundred thousand dollars to tens of million, the need to have a procedure to guide the practitioners to arrive at a more reasonable design of such structures is both urgent and important. For this purpose DID HP No.5 (Heiler, 1974) has been published and used as a basis for the design of above structures by most practitioners.

2. THE RATIONAL METHOD AS A FLOOD ESTIMATION PROCEDURE

2.1 General

The Statistical Rational Method for peak discharges can be written as:

$$Q_T = 0.278\ C_T\ i_T\ A \ldots\ldots\ldots\ldots(1)$$

where Q_T is the peak discharge of a design flood in m^3/s with return period T years selected using any recommended design return periods applicable in Malaysia.

i_T is the average intensity of the design rainstorm of duration normally taken as being equal to time of concentration, T_c and of return period T years in mm/hr.

A is the catchment area in km^2.

C_T is a dimensionless runoff coefficient normally considered to be a function of the catchment and design storm characteristics and of return period T years.

and T_c, the so-called time of concentration referred above is defined as being the time taken for a drop of water to travel from the most remote part of the catchment to the outlet design point.

2.2 Essential features of the Rational Method

The Rational Method is generally considered to be one of the best available flood estimation procedures for small urban and rural catchment areas. However, much confusion has resulted in the past and is still common today with regard to the principles underlying the method.

The Rational Method has been criticised because of its inability to reproduce particular flood events when actual rainfall is used as the input. Such criticism implies an assumption that the method is a "deterministic" one to represent the physical operation on rainfall-runoff process. This is not the intended use of the method. It has long been recognised the most realistic way to use the Rational Method is to consider it as a "statistical" link between the frequency distributions of rainfall and runoff. As such it provides a mean of estimating the design flood of a certain return period, and of a duration equal to the time of concentration.

Rewriting equation (1) in a slightly different form, the following equation results:

$$C_T = \frac{0.278 Q_T/A}{i_T} = \frac{q_T}{i_T} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where C_T is now taken to be dimensionless statistical link between the frequency of peak discharge, q in m^3/s per km^2 and mean intensity of the design storm i_T in mm/hr. Subsequently, for a particular catchment having adequate flood and intensity data, design values of runoff coeficients, C_T can be derived by the use of the formula

$$C_T = \frac{q_T}{i_T} \quad \text{.................(3)}$$

where q_T is a peak runoff rate of return period T years derived from a frequency analysis of observed flood and i_T is the mean design storm intensity of duration equal to T_c derived from a frequency of storms of duration equal to T_c.

Using the relation in the above equation a consistent increase in C_T with increasing return period for 20 small rural catchments in Peninsular Malaysia as shown in Table 1 was found. This conforms with the investigation by French et al. (1974) on 37 rural catchments in New South Wales, Australia.

3. THE INVESTIGATION

3.1 General

It is the intention of this section to outline the general methodology employed for the interest of the general user, rather than to describe in detail the development of the procedure. The frequency analysis of the annual maximum flood data from the catchments are not covered. Interested readers should refer to the revised and updated editions of DID Hydrological Procedure No. 1 and No. 4 for details.

3.2 Methodology of the investigation

3.2.1 Design Sequence

In using the Rational Method for flood estimation the usual design sequence is as follows:

(a) estimate the critical duration of the design storm (made equal to T_c),
(b) compute the various values of mean intensity (i_T) for duration $= T_c$
(c) estimate the values of C_T from storm and flood frequency regions,
(d) compute the estimates of peak discharge (Q_T) for various values of T_c using equation (1).

3.2.2 Estimation of time of concentration

An essential part of the Rational Method is the estimation of the time of concentration, T_c previously defined in para 2.1. While this is an unrealistic physical concept in a natural catchment, there is little doubt that some "characteristic time" exists that is critical for particular catchment. This cannot be defined precisely, and probably varies from season to season and from storm to storm. Various practical methods were proposed by previous researchers to estimate time of concentration. At the initial stage of the study, average time lags between centroids of rainfall hyetographs to the peak of corresponding hydrographs as proposed by Schaake et al. (1967) was attempted to estimate T_c. Due to inadequate rainfall data for several catchments used in the study, derivation of T_c by this method was abandoned. The minimum time of rise of a flood hydrograph that reflects total catchment contribution as proposed by Pilgrim et al. (1974) was selected for this study. The minimum time of rise against duration of storm was studied for 20 small rural catchments in Peninsular Malaysia. A typical plot of the relationship is shown in Figure 1 where the typical time of rise was adopted as the time of rise for that particular catchment. In order to establish a relationship between the time of concentration and the physiographic characteristics of the catchments, a multiple linear regression analysis was carried out by presupposing a relation of the form

$$T_c/L = K A^a S^b \quad \text{.................... (4)}$$

where T_c is the time of concentration in hours
L is the length of the main stream in kilometres.
S is the slope in percent from the main stream catchment boundry intersection to the design point, measured along the main stream.
k, a and b are constants.

Transforming equation (4) into logarithmic form the equation which resulted from the regression analysis was

$$Tc = \frac{1.286\ L}{A^{0.223}\ S^{0.263}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

with a multiple coefficient of correlation = 0.87 between the observed and estimated values of T_c. The graphical solution to this equation is presented in Figure 2.

3.2.3 Estimation of the average intensity of the design storm, i_T

The method of estimating the design rainstorm contained in the revised and updated DID Hydrological Procedure No. 1 (Fadhlillah et al. 1982) has been used through out this investigation for computing the characteristics of the design storm for each of the study catchments. The only input for using this procedure is the duration of the storm, which is made equal to T_c found from equation (4), and the geographical location of the design point. Note that the design intensity should be adjusted to take account of the reduction in storm intensity with catchment area according to Table 6, page 12 of the above procedure or Figure 6 page 10 of DID Water Resources Publication No 17.

3.2.4 Estimation of runoff coefficient, C

The runoff coefficient C in the Rational Method which is often regarded as a simple parameter is complex and affected by various factors and processes. Several factors affecting runoff coefficients C are infiltration losses, variation of rainfall intensities, catchment storage, antecedent wetness and physical characteristic of the drainage area. Various approaches have been made available to present design runoff coefficient, C in tabular selection tables, graphical relations and simple recommended values which can be found in various reference books. Most of these approaches have been based on engineering judgement and experience rather than values derived from observed flood data. In this procedure, the approach used was to derive C for various return periods from frequency analysis of observed flood data and design rainfall intensities for 20 small rural catchments in Peninsular Malaysia.

3.2.5 Regional Runoff coefficient, C based on Flood Frequency Regions

Mean values of runoff coefficient for a return period of 10 years, C_{10} were computed for each region. For the application of this procedure, Peninsular Malaysia was divided into 4 regions (Figure 3). These are Flood Frequency Regions based on DID HP No. 4 (Ong, 1987) where runoff coefficients C within the same region would not be much affected by the frequency distribution of flood peaks and the flood producing rainstorms. Mean values of C_T/C_{10} where C_T are runoff coefficients of return period T years were computed. A family of curves representing different regions was established as shown in Figure 4. Knowing the region in which a particular project lies and using the appropriate regional runoff coefficient curve, the factor C_T/C_{10} is obtained for any particular return period and hence C_T can be obtained.

4. ACCURACY OF THE PROCEDURE

Three methods were employed to assess the accuracy of the new procedure. One method was the scatter diagram (as shown in Figure 5) which compared the 10 years design peak discharges estimated using the new procedure with the 10 years peak discharges of single station frequency analysis of observed data.

Another method was the comparison between the design peak discharges derived using the new procedure and the design peak discharges derived using the previous procedure (DID HP5, 1974). The third comparison checked the accuracy of the procedure by comparing it with the regional flood frequency analysis (DID HP4, 1987).

4.1 Comparison with HP5 (1972)

Table 1 compared the results obtained from DID HP5 (1988) and DID HP5 (1974) for two single stations which are Sg. Durian Tunggal at Batu 11, Air Resam and Sg. Chalok at Jambatan Chalok. Although the values estimated using HP5 (1974) gave higher value, the accuracy of the new procedure (HP5, 1988) should have been improved for the following reasons:

(i) Additional streamflow and rainfall data up to the latest record (1986) have been used wherever possible.

Table 1 – Details of Study Catchments

ITEM	STATION NO.	STATION NAME	CATCHMENT AREA	MAINSTREAM LENGTH	SLOPE AT SOURCE	Tc	DERIVED RUNOFF COEFFICIENTS(C)				
			KM^2	KM	%	(hrs.)	C_2	C_5	C_{10}	C_{20}	C_{50}
1	1732401	Parit Madirono	1.9	1.96	0.50	2.62	0.17	0.20	0.21	0.23	0.25
2	1739457	Sg. Permandi at Bt. 27 J.B./Mersing	23.0	6.44	0.90	4.23	0.045	0.056	0.061	0.056	0.064
3	1839462	Sg. Mupor at Bt. 32 Jalan J.B.	21.8	6.44	0.87	4.32	0.04	0.05	0.06	–	–
4	2034473	Sg. Kahang at Ulu Kahang	69.9	21.6	3.30	7.87	0.01	0.02	0.03	0.04	0.05
5	2322415	Sg. Durian Tunggal at Bt. 11 Air Resam	72.5	14.48	1.50	6.44	0.04	0.06	0.07	0.08	0.09
6	2619424	Sg. Mantau at Kg. Mantau	13.0	6.4	3.40	3.37	0.034	0.043	0.045	0.047	0.051
7	2723401	Sg. Kepis at Jam. Kayu Lama	21.0	11.0	1.49	6.46	0.078	0.098	0.112	0.134	0.14
8	2734401	Sg. Pontian at Jam. Balak	62.9	11.9	0.47	7.41	0.073	0.094	0.103	0.109	0.125
9	3118445	Sg. Lui at Kg. Lui	68.1	15.2	4.03	5.29	0.06	0.065	0.067	0.069	0.07
10	3216439	Sg. Batu at Kg. Sg. Tua	55.7	14.48	7.98	4.40	0.05	0.054	0.06	0.065	0.07
11	3231493	Sg. Serai at Kg. Unchang	58.3	12.07	0.20	9.57	0.09	0.104	0.113	0.115	0.127
12	3925401	Sg. Tekam, Site A	0.374	0.99	0.013	4.97	0.13	0.26	0.37	0.44	0.46
13	3925403	Sg. Tekam, Site C	0.56	1.34	0.80	2.08	0.16	0.24	0.30	0.33	0.39
14	4112459	Sg. Gedong at Bidor	108.0	24.0	4.99	7.12	0.112	0.134	0.152	0.162	0.174
15	4212467	Sg. Cendriang at Bt. 32 Jln. Tapah	119.0	10.1	2.07	3.70	0.071	0.073	0.076	0.078	0.079
16	5428401	Sg. Chalok at Jam. Chalok	20.5	7.0	0.83	4.82	0.45	0.47	0.49	0.51	0.53
17	5718401	Sg. Lanas at Air Lanas	80.0	15.2	3.80	5.18	0.24	0.27	0.28	0.29	0.32
18	6022421	Sg. Kemasin at Peringat	47.9	17.4	0.06	19.79	0.38	0.44	0.47	0.49	0.53
19	6502431	Sg. Pelarit at Titi Konkrit	48.0	10.8	1.52	6.96	0.05	0.055	0.06	0.062	0.65
20	6502402	Sg. Buloh at Batu Tangkup	6.2	6.17	0.60	6.04	0.21	0.23	0.25	0.27	0.30

(ii) The rainfall regions have been divided into four as compared to only two in the previous study (HP5, 1974). Further subdivision of rainfall regions is not possible due to the lack of small catchment data.
(iii) Streamflow stations other than the stations used in the previous procedure (HP5, 1974) have been included. Most of the stations in this study (HP5, 1988) are recorder stations. These stations provided continuous recorded data which should be more accurate in term of reliability than manual stations.
(iv) Most of the streamflow stations in this study have more gentle slopes compared to the stations used in the previous study. This will be more representative of most of the practical river catchments in Malaysia and the steeper slopes in the previous study may have contributed to higher flows.

Table 2 — Comparison of Results by Various Methods

Method	Q_{10} value for Sg. Durian Tunggal at Bt. 11 Air Resam (m^3/s)	Q_{10} value for Sg. Serai at Kg. Unchang (m^3/s)
Rational Method (1974)	36	49
Rational Method (1988)	27	32
Frequency Analysis Of Observed Data	26	28
Regional Flood Frequency Analysis HP4, 1987	28	58

4.2 Comparison with the regional flood frequency analysis DID (HP4, 1987)

The comparison of DID HP5 (1988) to DID HP4 (1987) in Table 2 showed that DID HP4 (1987) estimated a higher value. It should be noted that DID HP4 (1987) used the extension of records and other informations from gauged sites of close proximity to cover a region to get a regional mean annual flood equation.

5. LIMITATIONS OF THE PROCEDURE

From the theoretical basis of the Rational Method, two important factors are neglected. These are the effects of channel storage and temporal and spatial variations of rainfall intensities. Due to such limitations and also that the procedure was derived utilizing data from rural catchments with areas ranging from 0.3 — 100 km^2, the use of the procedure to estimate the runoff for larger areas is not recommended. Multiplying factors to take account of catchment development (Appendix A) should serve as a general guide to arrive at a reasonable estimate although there has been no study to substantiate this recommendation. The procedure may not be reliable to estimate the runoff for areas with steeper slope. For general guidence the limit is approximately from 0.01 — 8 percent; the slope values of which this procedure was developed. Like any other flood estimation procedures, the design flood obtained from this procedure should be checked with other available procedures and the decision to adopt the estimated design values should be complemented by a sound engineering judgement.

6. USE OF THE PROCEDURE

6.1 Component of the procedure

The following items are required to use this flood estimation procedure:

(i) Figure 3, showing the general disposition of four regions proposed for application of Figure 3,
(ii) Figure 2, being a graphical solution to the Tc formula presented as equation (5),
(iii) Figure 4, showing the relationship of mean frequency factor C_T/C_{10} for different regions and
(iv) D.I.D Hydrological Procedure No. 1 (1982) "Estimation of the Design Rainfall in Peninsular Malaysia".

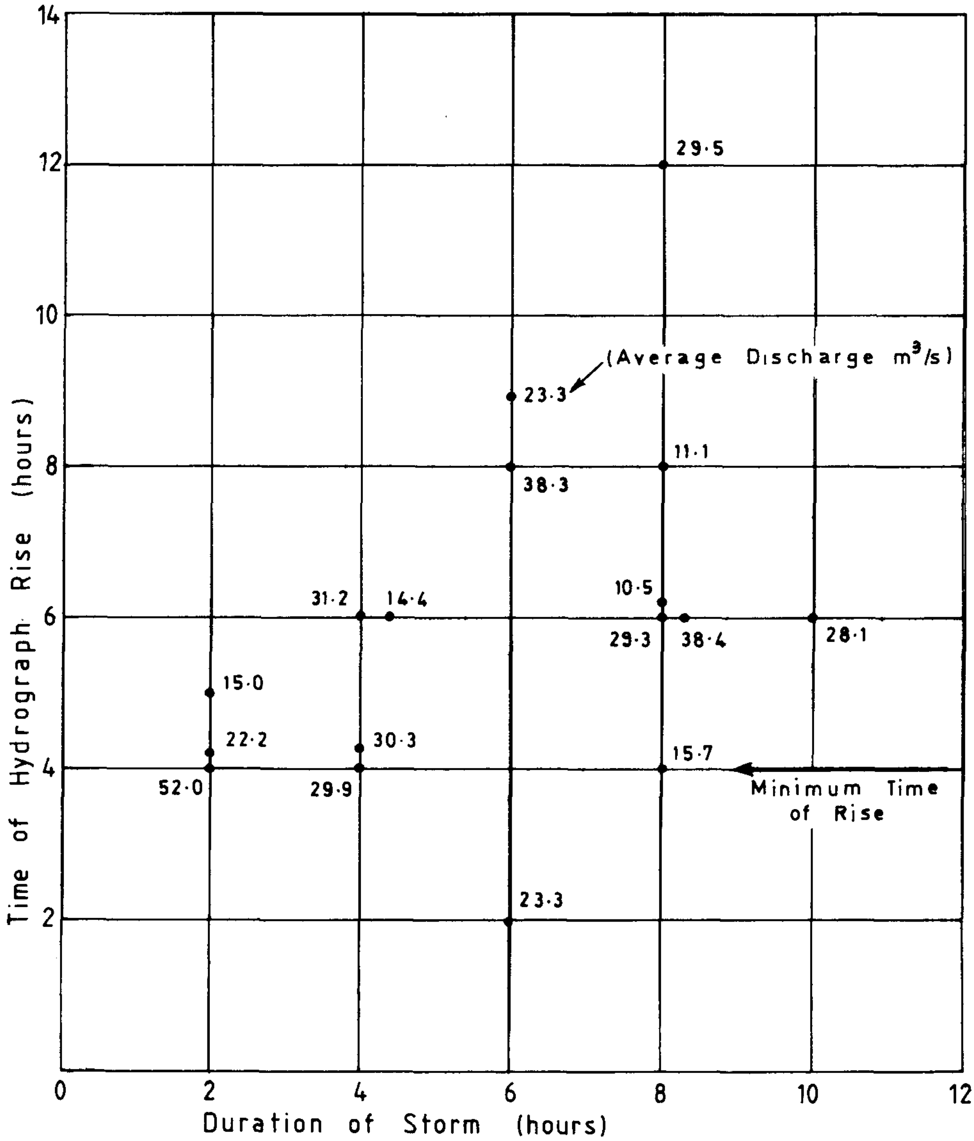

Figure 1 - Relationship Between Time of Hydrograph Rise and Duration of Storm For Sungai Gedong at Bidor.

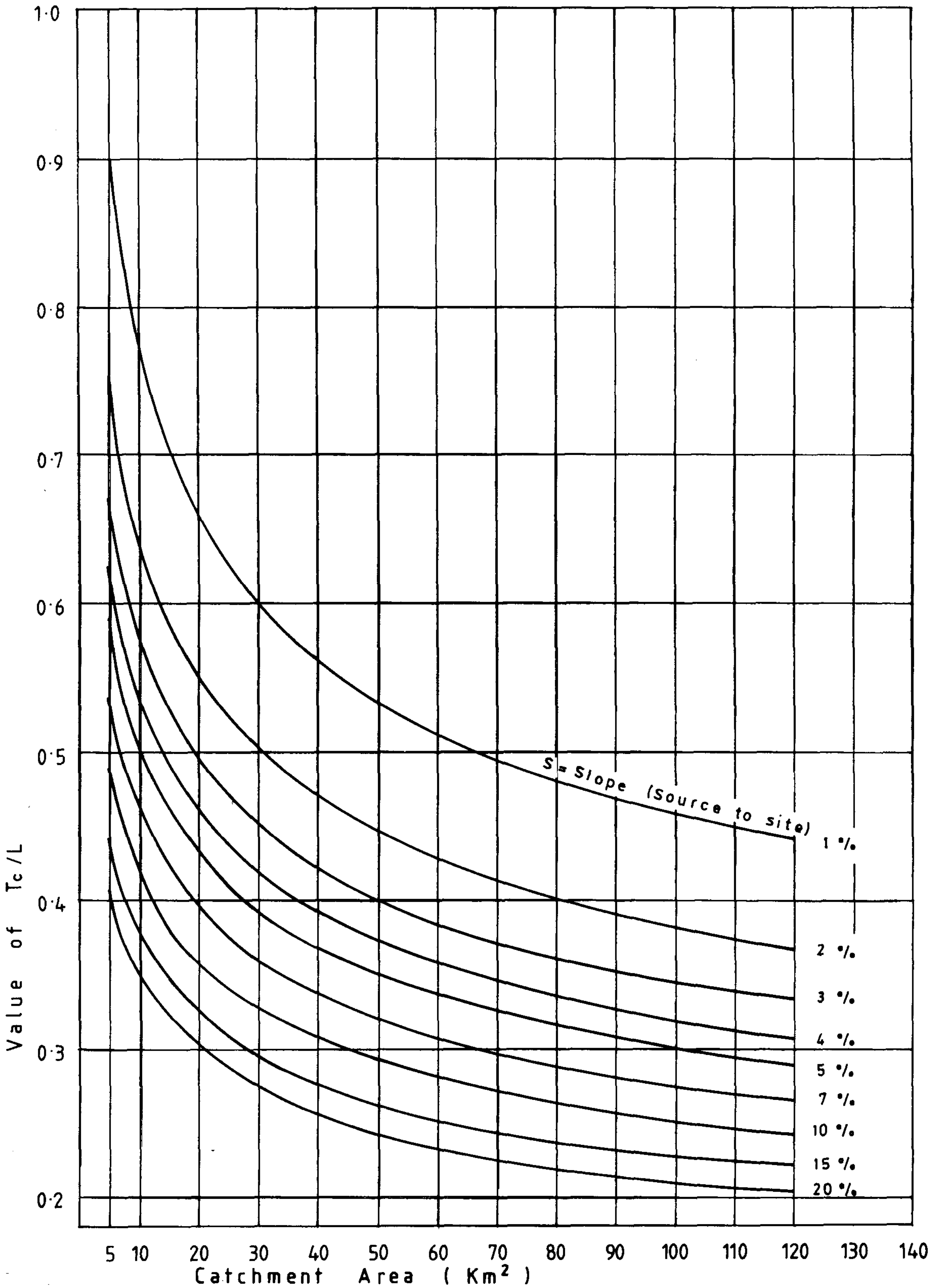

Figure 2 - Time of Concentration Graph
Graphical Solution of $Tc = \frac{1 \cdot 286\ L}{A^{0 \cdot 223}\ S^{0 \cdot 263}}$

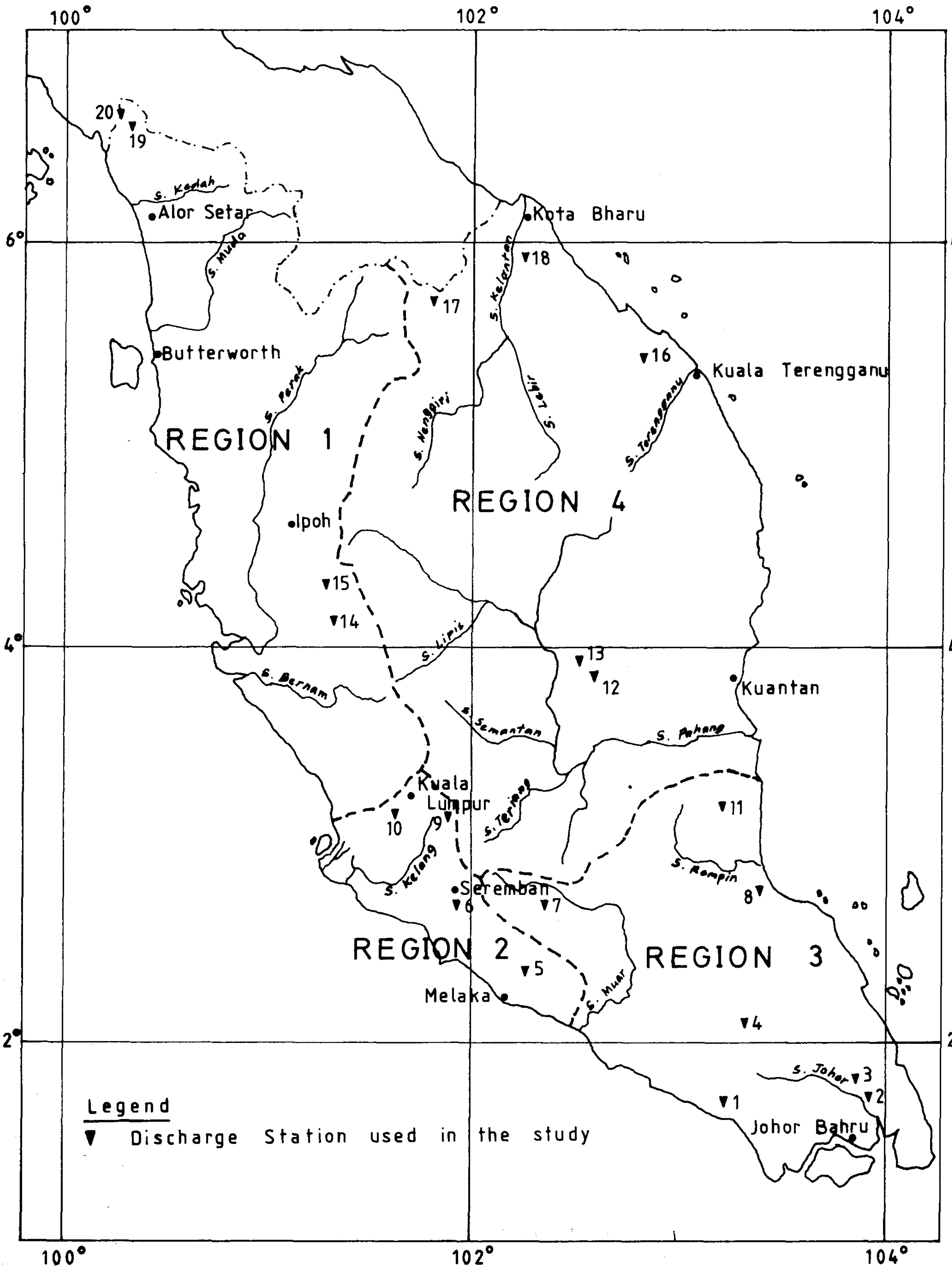

Figure 3 – Location of study catchments and Regional Applicability of the procedure.

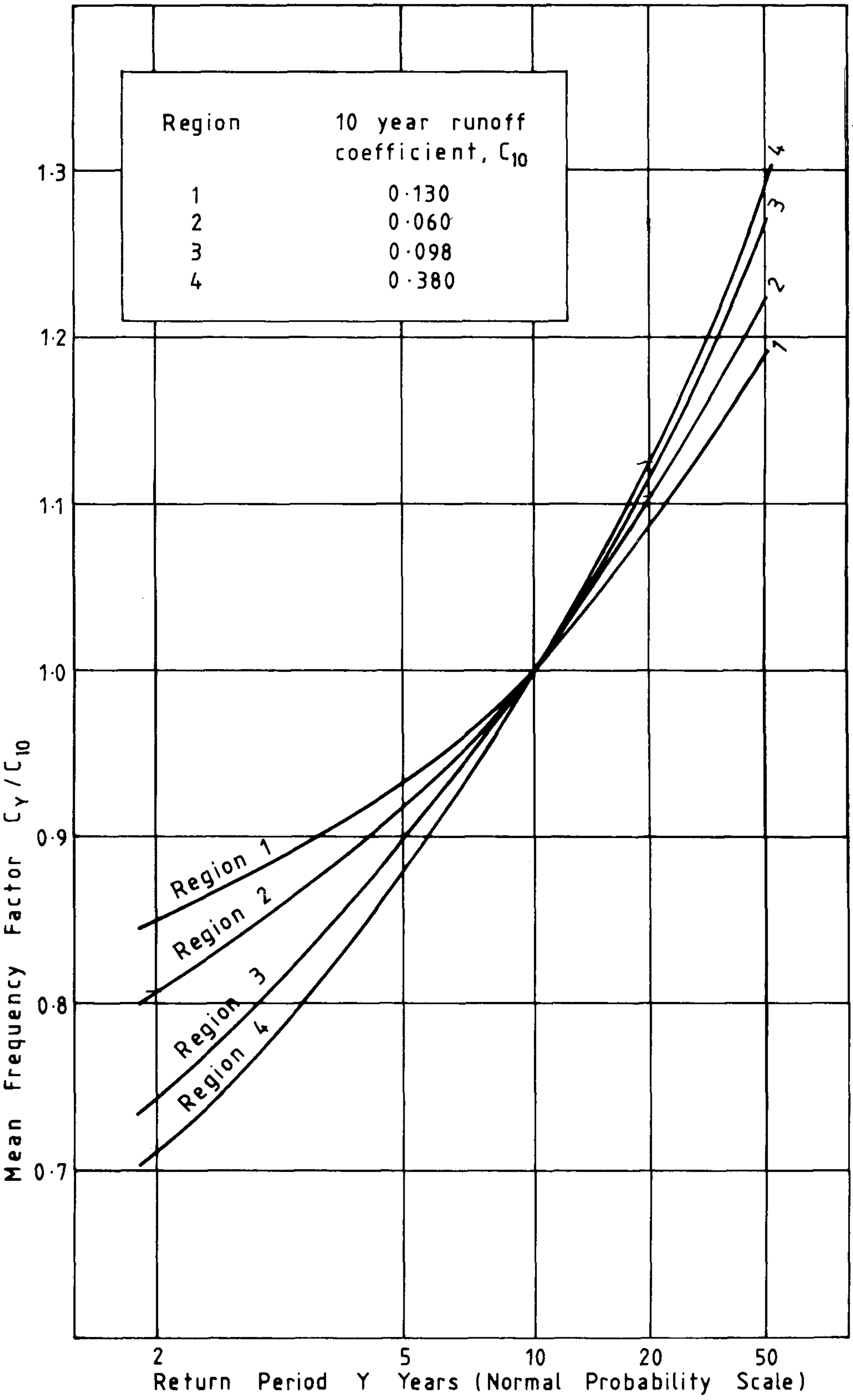

Figure 4 - Relation of mean frequency factor C_Y/C_{10} for different regions.

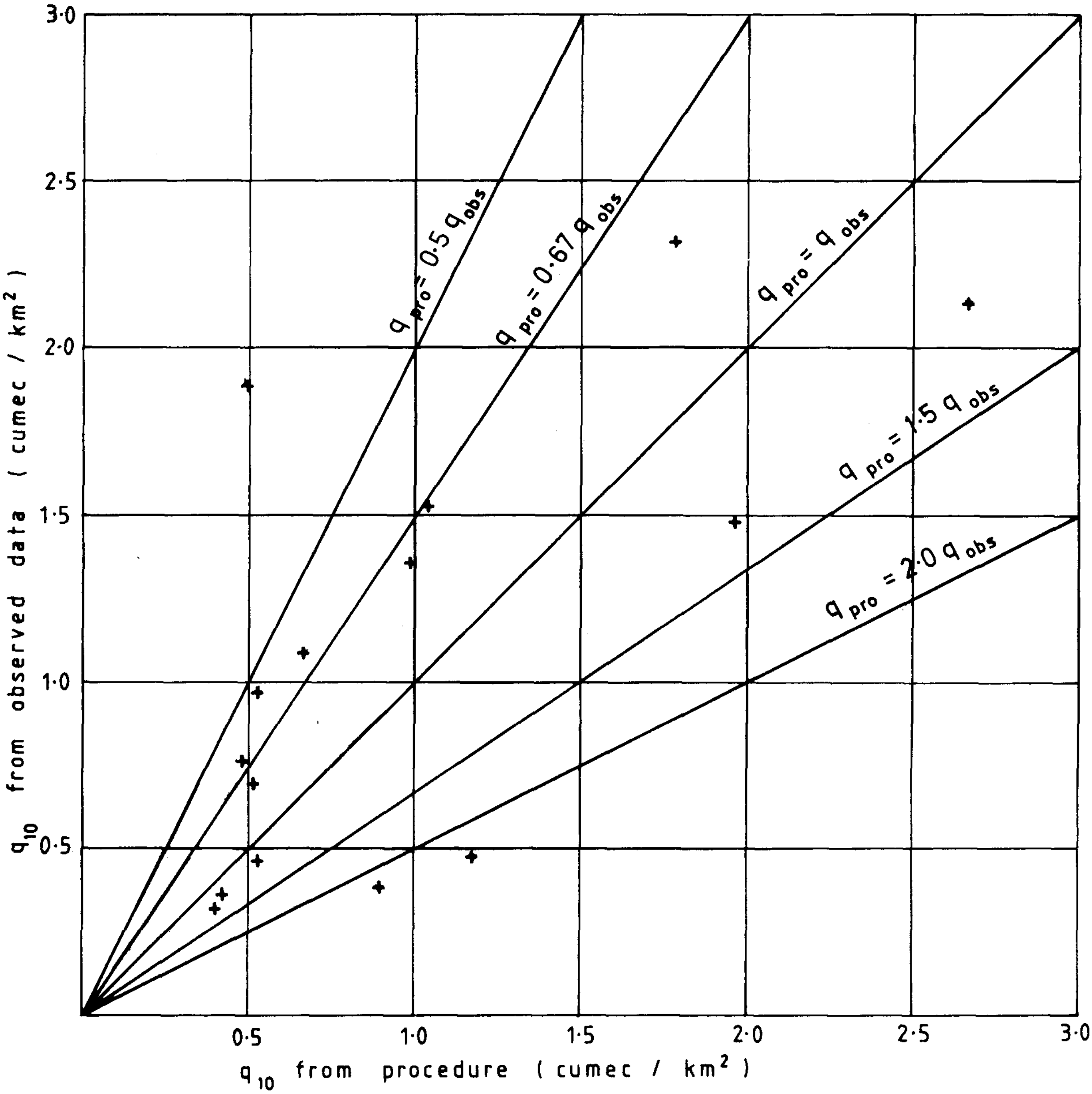

Figure 5 -Scatter diagram comparing q_{10} values obtained from this procedure HP 5(1988) q_{pro} and q_{10} values obtained from frequency analysis of observed data, q_{obs} .

6.2 **Design Sequence**

The detailed design sequence for using this procedure is as follows:

Step 1 For the design situation being considered select a design return period (T_1).

Step 2 Estimate the critical storm duration, T_c from catchment characteristics from Figure 2.

Step 3 Compute the depth of design storm of duration, T_c for following return period T_1, 2, 10, 20 years (Note that estimates for return periods of 2 and 20 years are required to make confidence limit estimates of the design rainstorm).

Step 4 Compute the confidence limits of $X(T_1, T_c)$ estimate using $X(2, T_c)$ and $X(20, T_c)$ values, (See pp. 4—5 in DID Hydrological Procedure No. 1 1982).

Step 5 Estimate the value of C from Figure 4.

Step 6 Compute the estimate of design discharge Q_T together with confidence limits of the estimates, using equation (1).

Step 7 Adjust Q_T estimate according to future land use development using factor (F) shown in Appendix A.

6.3 **Worked examples**

Example 1:

A flood estimate is required for a point latitude 4°00′ N and longitude 102°00′ E for a catchment possessing the following characteristics:

Area	=	25.90 sq.km.
Slope	=	3%
Length of mainstream	=	6.44 km
Development from jungle	=	40%

Solutions:

Step 1 From any recommended hydrological procedure, choose
T = 10 years

Step 2 From

$$T_C = \frac{1.286 \times L}{A^{0.223} \times S^{0.263}} = \frac{1.286 \times 6.44}{25.9^{0.223} \times 3^{0.263}} = 3 \text{ hrs.}$$

Step 3 From DID HP No. 1, find
$X(2,3) = 78$ mm
$X(10,3) = 122$ mm
$X(20,3) = 140$ mm

Step 4 Confidence interval = 0.43 D
$D = X(20) - X(2) = 140 - 78 \text{ mm} = 62 \text{ mm}$
$0.43D = 0.43 \times 62 = 26$ mm

Step 5 $i_{10} = \frac{X(10)}{3} = \frac{122 \pm 26:7}{3} = 40.7 \pm 8.9$ mm/hr

Step 6 From the curve frequency factor C_T/C_{10} for different regions, find for region 4
$C_{10} = 0.38$

Step 7 $Q_{10} = 0.278 \times C_{10} \times i_{10} \times A$
$= 111.36 \pm 24.35$ m^3/s

Step 8 From Appendix A multiplying factor for development
F = 1.05
$Q_{10} = (111.36 \times 1.05) \pm (24.35 \times 1.05)$
$= 116.92 \pm 25.57$ m^3/s

Example 2:

A flood estimate is required for a point latitude 4°00′ N and longitude 102°00′ E for a catchment possessing the following characteristics:

Area	=	25.90 sq. km
Slope	=	1%
Length of mainstream	=	6.44 km
Development for jungle	=	40%

Solutions:

Step 1 $T = 10$ years

Step 2 From Tc

$$= \frac{1.286 \times L}{A^{0.223} \times S^{0.263}}$$

$$= \frac{1.286 \times 6.44}{25.9^{0.223} \times 1^{0.263}}$$

$$= 4.0 \text{ hrs.}$$

Step 3 From DID HP No. 1, find

$X(2,4) = 80$ mm

$X(10,4) = 98$ mm

$X(20,4) = 105$ mm

Step 4 Confidence Interval $= 0.43$ D

$D = X(20) - X(2) = 105 - 80 = 25$ mm

$0.43D = 0.43 \times 25 = 10.7$ mm

Step 5 $i_{10} = \frac{X(10)}{4} = \frac{98 \pm 10.7}{4}$

$= 24.5 \pm 2.7$ mm/hr

Step 6 From the curve frequency factor C_T/C_{10} for different regions, find for region 4

$C_{10} = 0.38$

Step 7 $Q_{10} = 0.278 \times C_{10} \times i_{10} \times A$

$= 0.278 \times 0.38 \times (24.5 \pm 2.7) \times 25.9$

$= 67.03 \pm 7.39$ m^3/s

Example 3:
Obtain a flood estimate for a culvert on a main trunk road at location latitude 5°00′ N and longitude 103°00′ E on a catchment possesing the following characteristics:

Area	=	5.18 sq.km
Slope	=	5%
Length of mainstream	=	2.41 km
Development for natural vegetation	=	zero

Solutions:

Step 1 From any recommended hydrological procedure choose T = 20 years

Step 2 From Tc

$$= \frac{1.286 \times L}{A^{0.233} \times S^{0.263}}$$

$$= \frac{1.286 \times 2.41}{5.18^{0.233} \times 5^{0.263}}$$

$$= 1.406 \text{ hrs.}$$

Step 3 From DID HP No. 1, find

X(2, 1.406) = 75 mm
X(10, 1.406) = 118 mm
X(20, 1.406) = 135 mm

Step 4 Confidence Interval = 0.43D

D = X(20) − X(2) = 135 − 75 = 60 mm
0.43 D = 0.43 × 60 = 25.80 mm

Step 5 $i_{10} = X(10) = \frac{118 \pm 25.80}{1.4} = 83.0 \pm 18.4$ mm/hr

$i_{20} = X(20) = \frac{135 \pm 25.80}{1.4} = 96.0 \pm 18.4$ mm/hr

Step 6 From the curve of frequency factors C_T/C_{10} for different regions, find for regions 4

$C_{10} = 0.38$
$C_{20} = 0.429$

Step 7 $Q_{10} = C_{10} \times i_{10} \times A$

$= 0.278 \times 0.38 \times (83 \pm 18.4) \times 5.18$
$= 45.42 \pm 10.06$ m^3/s

$Q_{20} = 0.278 \times C_{20} \times i_{20} \times A$

$= 0.278 \times 0.429 \times (96.0 \pm 18.4) \times 5.18$
$= 59.30 \pm 11.36$ m^3/s

REFERENCES

1. Chee Yan, Ong "Magnitude and Frequency of Floods in Peninsular Malaysia" *Ministry of Agriculture Malaysia, Kuala Lumpur, 1987*
2. French, et al. "Experimental Examination of the Rational Method for Small Rural Catchments" *Civil Eng Transactions, Institution of Engineer, Australia,* Month Vol. CE 16, 1974, pp. 95-102.
3. Heiler, T.D "Rational Method of flood Estimation for Rural Catchments in Peninsular Malaysia" *Ministry of Agriculture Malaysia,* Kuala Lumpur, 1974.
4. Institution of Engineers, Australia "Australian Rainfall and Runoff", 1977.
5. Mahmood, Fadhlillah "Estimation of the Design Rainstorm, D.I.D. Hydrological Procedure No. 1" *Ministry of Agriculture Malaysia, Kuala Lumpur, 1982.*
6. *Schaake, John C "Experimental Examination of the Rational Method" Journal of the Hydraulic Division,* ASCE, Nov. 1967, pp. 353-359.

APPENDIX A

MULTIPLYING FACTORS TO TAKE ACCOUNT OF CATCHMENT DEVELOPMENT

Development to Agriculture from jungle in percent	Multiplying Q_T estimates from undeveloped area by factor shown (F)
0—25	1.00
25—50	1.05
50—75	1.15
75—100	1.20

Source: DID HP5 (1974) page 7.

APPENDIX B

CHECK ON ESTIMATION OF Tc USING EMPIRICAL RELATIONSHIPS

STATION NO.	Catchment Area km^2	Measured Time of Rise in hour	T_c (in hours) using Bransby Williams Formula	T_c (in hours) using D.I.D. Formula (1974)	T_c (in hours) using D.I.D. Formula (1988)
1732401	1.9	4	1.30	0.71	2.62
1739457	23	6	2.96	2.36	4.23
1839462	21.8	12	2.99	2.36	4.32
2034473	69.9	4	6.84	4.89	7.87
2322415	72.5	6.5	5.35	4.78	6.44
2619424	13	3	2.39	1.18	3.37
2723401	21	6	4.61	3.17	6.46
2734401	62.9	21	5.63	6.64	7.41
3118445	68.1	6	4.64	3.14	5.29
3216439	55.7	2	3.93	2.12	4.40
3231493	58.3	12	6.82	9.97	9.57
3925401	0.374	2	1.60	1.66	4.97
3925403	0.56	6	0.91	0.34	2.08
4112459	108	4	6.70	4.73	7.12
4212467	119	5	3.33	3.04	3.70
5428401	20.5	12	3.30	2.61	4.82
5718401	80	4	4.62	3.26	5.18
6022421	47.9	15	12.76	24.50	19.79
6502431	48	6	5.14	5.55	6.96
6502402	6.2	9	3.50	2.34	6.04

NOTE 1 — The Bransby-Williams Formula is widely used in Australia and Papua New Guinea for estimating T_c from catchment characteristics, and was the most successful of the overseas relationships tried in matching observed T_c of Malaysian catchments. It is included in this appendix for comparison purposes.

NOTE 2 — Bransby-Williams (Australian Rainfall and Runoff, 1977)

$$Tc = \frac{58.5\ L}{A^{0.1}\ S^{0.2}} \quad \text{(minutes)}$$

L = Length of mainstream in km
A = Area in km^2
S = Slope in m/km.

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