HYDROLOGICAL PROCEDURE NO. 4

MAGNITUDE AND FREQUENCY OF FLOODS IN PENINSULAR MALAYSIA (REVISED AND UPDATED)

1987

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

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BAHAGIAN PARIT DAN TALIAIR
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SYNOPSIS

This procedure is a revised and updated version of the Drainage and Irrigation Department Hydrological Procedure No.4 (1974) – "Magnitude and Frequency of Floods in Peninsular Malaysia". The Hydrological Procedure No. 4 which was first published in 1974 was developed based on hydrological data up to year 1970 and regional analysis was used to estimate design floods for Peninsular Malaysia.

This revised and updated version also estimates floods using the technique of regional analysis. However, an additional 10 years or more hydrological data (up to year 1982) was used to establish the new flood frequency regions for Peninsular Malaysia.

The regional analysis carried out in this procedure generally consists of the two major parts – (i) Development of a set of regional dimensionless flood frequency curves and (ii) Development of a set of regional regression equations relating mean annual flood to the catchment characteristics (catchment area and mean annual catchment rainfall).

Hence two maps are included in this procedure – Map 1 identifies the various flood frequency regions (FF regions) in Peninsular Malaysia and Map 2 identified the various mean annual flood (MAF regions) in Peninsular Malaysia. By knowing the flood frequency region and mean annual flood region a river basin of interest belongs to, the design floods of the basin can be estimated using the regional flood frequency curve and the regional MAF equation.

This procedure will be revised and updated again when an additional ten years of hydrological data is available.

CONTENTS

1. INTRODUCTION

In the planning and design of water resources projects, engineers and planners are often interested to determine the magnitude and frequency of floods that will occur at the project areas. An estimate of the magnitude of a flood of a certain recurrence interval (commonly known as the "design flood") that is likely to occur is fundamental to ensure that economic engineering design with adequate standards of safety can be achieved.

In Malaysia, streamflow records from gauged rivers offer a fairly accurate means of estimating design floods through the application of various statistical methods. However, not every river in Malaysia is gauged and moreover, gauged rivers are only gauged at certain strategic points of the rivers. If a project is located in an ungauged catchment with no streamflow records, then the design floods for the catchment will have to be estimated by other flood estimation techniques.

Hydrologists have developed numerous techniques for estimating design floods, the main ones being the rational method, unit hydrograph method, conceptual and statistical rainfall-runoff models and regional frequency analysis. This procedure describes the use of regional flood frequency analyses to estimate design floods for Peninsular Malaysia.

1.1 Regional Flood Frequency Analysis

The regional approach to flood frequency analysis has been widely used in many countries, in United Kingdom (NERC, 1975), in United States (Riggs, 1973) and in New Zealand (Beable et al, 1982). Regionalization or regional analysis is concerned with the extension of records from gauged sites of close proximity to cover that of a region: it provides a means of applying information from gauged sites in one region to ungauged sites in the same region. In regional frequency analysis, individual frequency curves from gauged sites are averaged to form a regional curve which is postulated to apply to all catchments in the region.

In this study, the regional flood frequency analysis method used by the Natural Environmental Research Council (NERC, 1975) is adopted. Basically, the method involves the development of two components:

(i) A set of dimensionless regional frequency curves relating Q_T/MAF to T where Q_T is the peak discharge of T-years recurrence interval, MAF is the mean annual flood or peak discharge and T is the recurrence interval in years.

(ii) A set of regional regression equations relating the mean annual peak discharge to the catchment characteristics of catchment area and mean annual catchment rainfall.

1.2 Frequency Distribution Used – Gumbel Type I

A probability distribution commonly used in flood frequency analysis is the Gumbel Type I distribution. This distribution has been adopted for regional flood frequency analysis in Unted Kingdom (NERC, 1975), New Zealand (Beable et al, 1982) and other countries throughout the world. The Gumbel Type I distribution was adopted for flood frequency analysis in this procedure.

The return period or recurrence interval of any ranked flood in a Gumble Type I distribution is skewed towards the mode of the theoretical distribution. The theoretical fit is then determined by the method of moments and is in the form of the following equation (Haan, 1977):

$$X_T = \overline{X} + \sigma K \quad \text{...} \quad (1)$$

where X_T is the magnitude of the event having a return period of T years.
$\overline{X}$ is the arithmetic mean value of the magnitudes of the events.
σ is the standard deviation from the mean.
K is the Chow Frequency Factor for the Extreme Value Type I distribution.

The data were also fitted using Log-Pearson III probability distribution. This distribution is recommended by the United States Water Resource Council (USWRC, 1967) for flood frequency studies in the U.S.A. However, the Log-Pearson III distribution was not adopted for this procedure because:

(i) the curvature of this distribution varies greatly from one data set to another making it difficult to obtain a regional curve.

(ii) there is a high degree of skewness in the sample distributions.

(iii) 20% of the sample data failed the Smirnov-Kolmogorov goodness-of-fit test.

2. DEVELOPMENT OF THE PROCEDURE

The method used in developing this procedure is summarized below:

(a) Selection of catchments.

(b) Extraction of annual flood flow (annual peak discharge) data.

(c) Frequency analysis of individual station flow data.

(d) Derivation of regional dimensionless flood frequency curves.

(e) Development of regional mean annual peak discharge (MAF) regression equations.

21. Selection of Catchments

Streamflow records from all river stations operated by the Drainage and Irrigation Department were investigated for the study. A total of 61 stations with lengths of records vary from 8 to 36 years in Peninsular Malaysia were selected for the analysis. The stations selected are listed in Appendix I.

The flow records from each station were assessed and selected based on the following criteria:

(i) There must be at least eight years of good quality data.

(ii) The catchment has not changed significantly over the period of records because of urbanisation, agricultural development or industrial development.

(iii) There is no substantial regulation of flow upstream of the station due to reservior storage or diversion of flow from the river.

(iv) The area of the catchment is greater than 20 square kilometres.

(v) There is no tidal influence at the station.

(vi) The catchment is predominantly rural.

2.2 Extraction of Annual Flood Data

The maximum peak discharge in each year of record is extracted from D.I.D Streamflow Record Publications (Pre-1960 to 1980). Each data sample is thoroughly investigated for incompleted data (missing record during any year). If records were missing for a particular year then they are examined to determine if the missing records occur during the dry season (when the annual peak discharge is unlikely to occur). If it is suspected that the missing records includes the annual peak discharge then that particular year's data is treated as missing.

2.3 Frequency Analysis of Individual Station Flood Data

The annual flood peaks that were collected for each station were reduced to the dimensionless form of Q_i/MAF. The MAF is defined as the arithmetic mean of the annual flood series:

$$MAF = \frac{1}{n} \sum_{i=1}^{n} Q_i \quad \text{...} (2)$$

where Q_i = annual flood peak for the i th year

n = number of records in years (number of annual flood peaks in the series)

The plotting positions of each sample is determined based on the following Gumbel criteria (Haan, 1977):

(a) The plotting position must be such that all observations can be plotted.

(b) The plotting position should lie between the observed frequencies of $(m - 1)/n$ and m/n where m is the rank of the observation beginning with m=1 for the largest value and n is the number of years of records or the number of observations.

(c) The return period of a value equal to or larger than the largest observation and the return period of a value equal to or smallest observation should converge toward n.

(d) The observations should be equally spaced on the frequency scale.

(e) The plotting position should have an intuitive meaning, be analytically simple, and be easy to use.

The Weibull plotting position formula meets all the criteria stated above. Therefore, the plotting positions (recurrence interval in years) of each sample are calculated using the Weibull formula:

$$T = (n+1) / m \qquad (3)$$

where T = plotting position of the peak discharges in years

n = length of record in years

m = rank of the peak discharge in the series

The dimensionless frequency curve for each sample is obtained by plotting ratios of Q_i/MAF against the recurrence interval of Q_T using the Gumbel distribution. The Smirnov-Kolmogorov Goodness-of-Fit Test was used to test each distribution's fit to the data. Only those distribution which fit the data at 95% confidence limits were accepted.

A computer program was developed to fit the Gumbel distribution to the dimensionless annual flood series by method-of-moments. The program also calculates the 95% confidence limits and test out the goodness-of-fit. The program outputs the Q_T/MAF values where Q_T is Q_i for return period T. The results of frequency analysis carried out on individual station's data are presented in Appendix II.

2.4 Derivation of Regional Dimensionless Flood Frequency Curve

Stations which exhibited similar dimensionless frequency distribution were indentified and grouped into various groups. The grouping of stations into regions is done by superimposing the dimensionless curves together and examining the similarity of the curves. If a curve from one station lies closely to a curve from another station then the catchments of these two stations are grouped together under one region. Consideration is also given to catchments which are located closely to one another. Catchments in close proximity with one another are more likely to be classified under the same region.
Factors like climate, topography and hydrological characteristics which influence the flood flows in a river basin are also taken into consideration before finalising the regional flood frequency boundaries. The delineation of the flood frequency regions is guided by the Mean Annual Rainfall Maps (D.I.D, 1975), Hydrological Region Maps (Goh, 1974), Average Annual Water Resources Maps for Peninsular Malaysia (Teh, 1982) and topographical maps of Peninsular Malaysia published by Survey Department, Malaysia.

After the flood frequency regions has been established, the regional curve for each region is derived by averaging the dimensionless curves of stations belonging to that region. The regional curve is then the representative flood frequency curve for all rivers in that region.

A total of 6 flood frequency regions were established for Peninsular Malaysia. These regions are shown in Map 1. and the regional curves belonging to each region are shown in Figure 1.

2.5 Derivation of Regional MAF (Mean Annual Flood) Equations

The magnitude of the MAF of a river basin is affected by both the physiographical, meteorological and catchment characteristics of the basin. Catchment area, mean annual catchment rainfall, mean channel slope, mean channel length and drainage pattern are some of the easily defined characteristics that could affect the catchment's MAF.

In a study on the degree of correlation of catchment characteristics with the MAF (Nash and Shaw, 1965), it was found that a combination of the catchment area and the mean annual catchment rainfall exhibits the highest correlation with the MAF. Table 1 shows the correlation coefficient for different combination of catchment characteristics with the MAF derived from the Nash and Shaw Study.

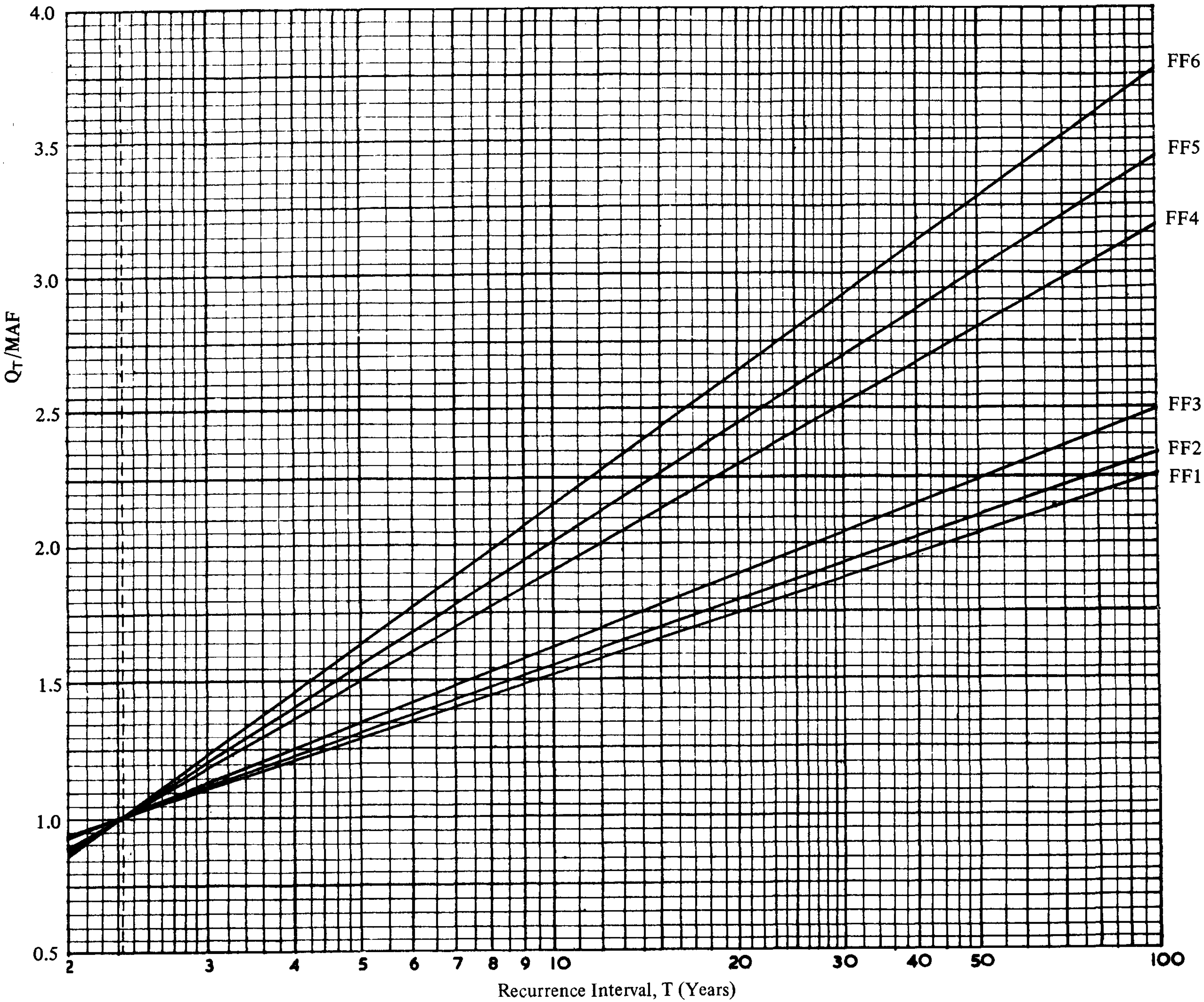

Figure 1 : Dimensionless Regional Flood Frequency Curves for Peninsular Malaysia

Table 1 : Correlation Coefficients of Catchment Characteristics with the MAF derived by Bash and Shaw

Catchment Characteristics		Coefficient of Correlation Squared
i)	ARS	0.92
ii)	AR	0.92
iii)	AS	0.87
iv)	RS	0.30
v)	A	0.60
vi)	R	0.16
vii)	S	0.28

A – catchment area

R – mean annual catchment rainfall

S – mean channel slope

In this procedure, the catchment area and mean annual catchment rainfall are the catchment characteristics chosen for the derivation of the MAF equations. These two parameters are easily available. The catchment areas of streamflow stations used in the procedure are obtained from the D.I.D Hydrological Stations Inventory (D.I.D, 1987). The mean annual catchment rainfall for catchments in Peninsular Malaysia were abstracted from the Peninsular Malaysia Mean Annual Rainfall Isohyetal Map (1950–1975) (D.I.D, 1976) by planimetering of isohyets within each catchment.

The relationship existing between catchment characteristics and its MAF is assumed to be in the form of:

$$MAF = c\ A^{a}\ R^{b} \qquad (4)$$

Where MAF is the mean annual flood

A is the catchment area

R is the mean annual catchment rainfall

c,a,b are catchment characteristics constants to be estimated

The MAF equation is reduced to a multiple linear regression by transforming Equation (4) into its logarithmic form:

$$\text{Log MAF} = \log c + a \log A + b \log R \qquad (5)$$

The residual r, from the equation (5) is defined as:

$$r = \log(\text{MAF obs.}) - \log(\text{MAF est.}) \qquad (6)$$

where r is the log residual of the MAF equation

MAF obs. is the observed MAF

MAF est.. is the estimated MAF

The MAF regions are established using the same method adopted in D.I.D Hydrological Procedure No. 12 – "Magnitude and Frequency of Low Flows in Peninsular Malaysia". (Toong, 1985). Grouping of catchments into regions is done by separating the residuals into positive and negative residuals. Catchments with positive residuals formed one region and catchments with negative residuals formed another region. Refinement is carried out by repeating the grouping in each region until an ideal number of MAF regions is attained. Six final MAF regions are established and these regions are shown in Map 2. The MAF equations with the catchment characteristic constants and the correlation coefficients squared derived for each region are listed in Table 2.

Table 2 : Regional Mean Annual Flood (MAF) Equations

Region	MAF Equation	Catchment Characteristics Constants			Multiple Coefficient of Correlation Squared
		c	a	b	
MAF 1	$MAF = 0.6582\ A^{0.7901} R^{0.1980}$	0.6582	0.7901	0.1980	0.99
MAF 2	$MAF = 0.9630\ A^{0.6541} R^{0.8093}$	0.9630	0.6541	0.8093	0.88
MAF 3	$MAF = 0.1192\ A^{0.6175} R^{3.0571}$	0.1192	0.6175	3.0571	0.99
MAF 4	$MAF = 0.1048\ A^{0.7177} R^{3.0224}$	0.1048	0.7177	3.0224	0.89
MAF 5	$MAF = 0.0140\ A^{0.7954} R^{5.0354}$	0.0140	0.7954	5.0354	0.98
MAF 6	$MAF = 0.4783\ A^{0.9066} R^{0.9463}$	0.4783	0.9066	0.9463	0.99

A – Catchment Area in km.

R – Mean Annual Catchment Rainfall in metres.

NOTE : R is measured in metres.

3. APPLICATION OF PROCEDURE

In the development of this procedure, many constraints were set by the nature of the hydrological data used in deriving the regional flood frequency curves and the MAF equations. Therefore in the application of this procedure, the catchment of interest should also satisfy the following criteria:

(i) The catchment must not be significantly regulated (by reservoir, diversion, etc).

(ii) The catchment must not be influenced by tidal effects.

(iii) The catchment area must be greater then 20 square kilometres.

(iv) The catchment is predominantly rural.

3.1 Method of Application

The method of application of this procedure to estimate design floods for an ungauged catchment involves the following steps:

Step 1 – Determine the catchment area A in square kilometres.

Step 2 – Estimate the mean annual catchment rainfall R in metres (1000 x millimetres).

- i) The catchment mean annual rainfall can be estimated from available rainfall records of D.I.D. rainfall stations within or near the catchment.
- ii) If no rainfall records are available, R can be estimated from the 1:1,000,000 Mean Annual Rainfall Isohyetal Map (1950–1975) for Peninsular Malaysia (D.I.D, 1976).

Note : The unit for R used in the MAF regression analysis is in metres.

Step 3 – Determine the MAF region of the catchment from Map 2.

Step 4 – Compute the MAF from the appropriate regional MAF equation.

Step 5 – Determine the flood frequency (FF region) region of the catchment from Map 1.

Step 6 – Obtain the dimensionless ordinates Q_T/MAF from the appropriate regional flood frequency curves for the return periods required.

Step 7 – Determine Q_T for the various return periods by multiplying the Q_T/MAF factor by the MAF obtain in Step 4.

3.2 Worked Examples

Example 1 – Determine the 30-year design discharge for an ungauged site on Sg. Batang Kali located at Lat.3° 23' N, Long. 101° 38' E.

Step 1 : Catchment area A = 88 km^2.

Step 2 : Mean annual catchment rainfall R = 2.550m (2550mm).

Step 3 : From Map 2, the site is located in mean annual flood region MAF 3.

Step 4 : The MAF equation for region MAF 3 is

$$MAF = 0.1192\ A^{0.6175}\ R^{3.0571}$$

$$MAF = 0.1192\ (88^{0.6175})(2.550^{3.0571})$$

$$MAF = 33.10\ m^3/s.$$

Step 5 : From Map 1, the site is located in flood frequency region FF2.

Step 6 : The Q_T/MAF value for the 30-year return period of region FF2. is obtained from the flood frequency curve in Figure 1:–

$$Q_{30}/MAF = 1.94.$$

Step 7 . $Q_{30} = Q_{30}/MAF \times MAF$

$Q_{30} = 1.94 \times 33.10$

$Q_{30} = 64.21\ m^3/s.$

Example 2 – Derive the mean annual flood and flood frequency curve for Sg. Langat at Kajang (DID Stn. no. 2917442) with a catchment area of 380 km and a mean annual catchment rainfall of 2675mm (2.675m).

Results : From Map 1 and Map 2, the site is located in mean annual flood region MAF 3 and flood frequency region FF3. Following the steps in section 3.1, the results obtained from regional analysis are presented in Table 3. For comparison purposes, the results of the single station analysis are also presented in Table 3.

Table 3 : Results of design peak discharges derived from regional analysis and single station analysis for stn. no. 2917442

Method of Analysis	MAF (m^3/s)	Q_T for T-year recurrence interval (m^3/s)					
		T=2	T=5	T=10	T=20	T=50	T=100
Regional	94.59	88.91	127.20	153.24	177.83	210.00	233.64
Single Station	99.61	94.62	131.49	155.39	178.30	208.18	231.10

4. ACCURACY OF PROCEDURE

Three different comparisons are made to assess the accuracy of the procedure. The first comparison gives an indication of how the 10-year design peak discharges estimated from regional analysis (using this procedure) vary with the 10-year peak discharges recorded by river stations throughout Peninsular Malaysia. The second comparison shows the differences between design peak discharges derived from this procedure HP4 (1987) and design peak discharges derived from the old procedure, HP4(1974). The last comparison gauges the accuracy of regional analysis used in the procedure as compared to other methods of design flood estimation used in flood studies for rivers in Peninsular Malaysia.

4.1 Comparison with Observed Data

In this comparison, the observed 10-year peak discharges from all the sixty one river stations and the 10-year peak discharges estimated using regional analysis in this procedure are plotted in the form of a scatter diagram in Figure 2. It can be seen that no major discrepancies exist between the peak discharges derived by regional analysis and that derived from single station frequency analysis. However, the scatter diagram shows that 54.1 percent of the flood estimates made using this procedure tends to be overestimated. 77.0 percent of the 10-year peak discharges estimated from this procedure are within the range of 0.67 to 1.50 times the recorded values.

The percentage breakdown of the 10-year peak discharges for all the river stations derived from regional analysis as compared to the 10-year peak discharges derived from single station frequency analysis is presented in Figure 3.

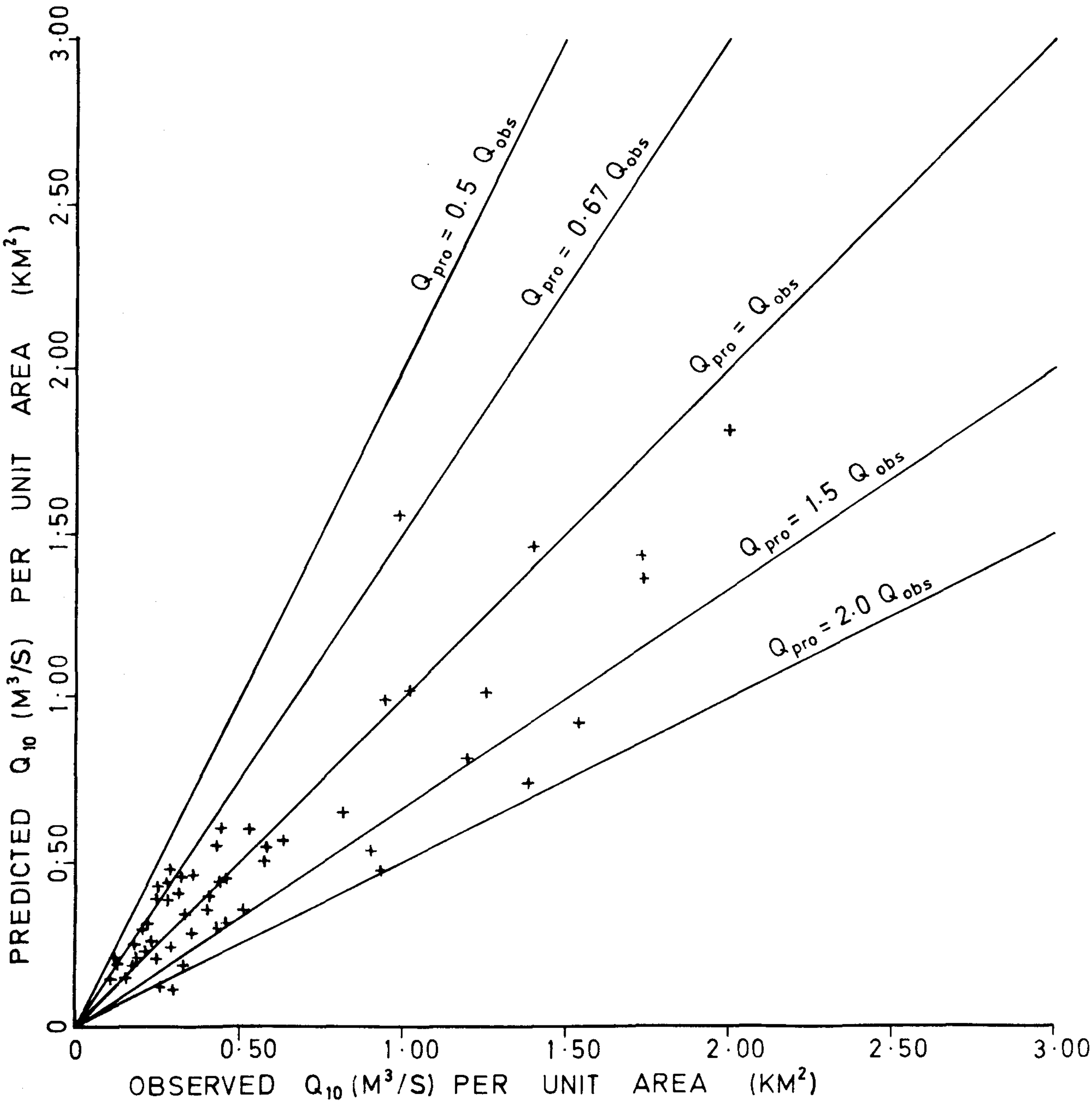

Figure 2 : Scatter diagram comparing Q_{10} values obtained from this procedure HP4 (1987), Q_{pro} and Q_{10} values obtained from single station frequency analysis of observed data (Q_{obs}).

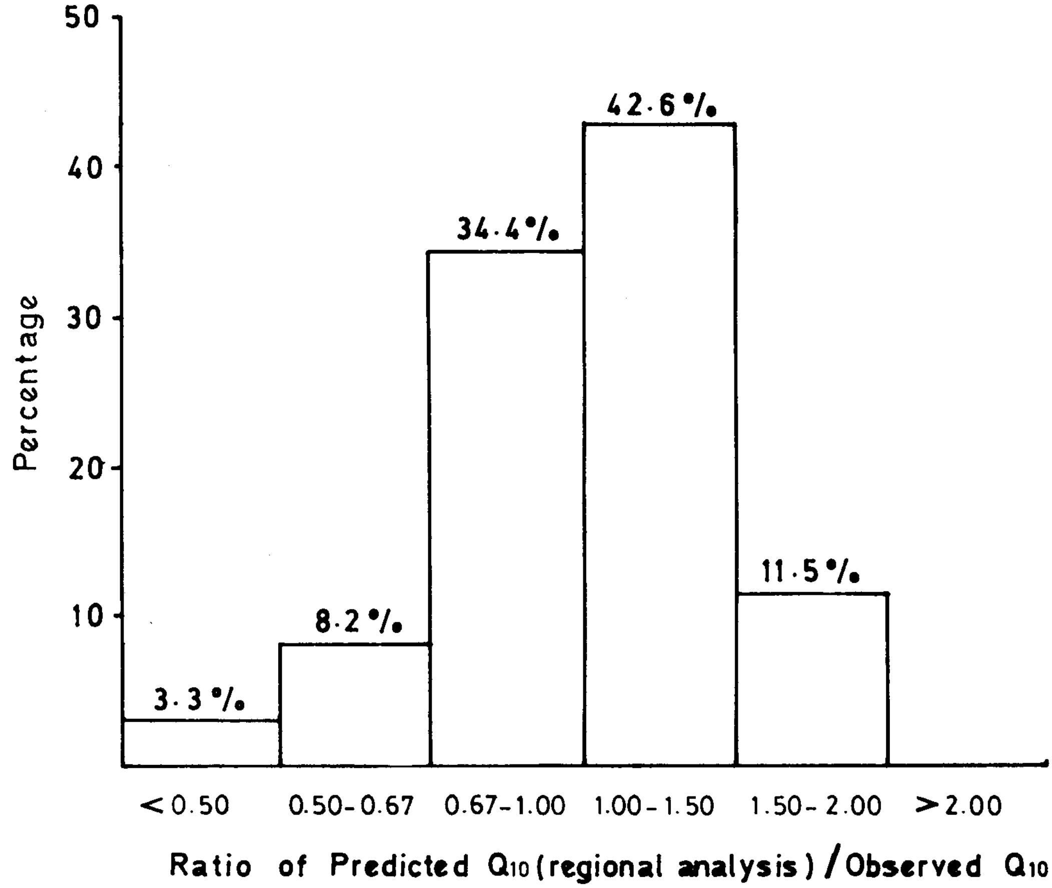

Figure 3 : Frequency diagram showing the percentage breakdown of the ratios of Q_{10} values from regional analysis to Q_{10} values from observed records.

4.2 Comparison with HP4(1974)

This procedure, HP4(1987) is developed totally independent of the old procedure, the first edition of the D.I.D Hydrological Procedure No. 4 "Magnitude and Frequency of Floods in Peninsular Malaysia" (Heiler and Chew, 1974). The old procedure was developed based on streamflow data from year 1948 to 1970. Since then, an additional ten years or more data has been collected and made available for analysis. Hence, this procedure utilizes a longer period of data (up to year 1982) in its analysis. Also, a different approach in the method of analysis has been adopted to improve the accuracy and performance of the procedure.

The major difference of this procedure HP4(1987) compared to the old procedure HP4(1974) are summarized below:

(i) Additional Streamflow Data Used

An additional ten to twelve years of streamflow data (up to year 1982) is used to derive the dimensionless flood frequency curves and the mean annual flood regression equations in this procedure.

(ii) Two Regional Maps

In this procedure, two regional maps are developed: one for the flood frequency regions (Map 1) and the other for the mean annual flood regions (Map 2). The flood frequency regions are demarcated for areas in which the set of dimensionless flood frequency curves (see Figure 1) applies whereas the mean annual flood regions are demarcated for areas which share the same mean annual flood regression equations coefficients (see Table 2).

(iii) **Additional Characteristic of Mean Annual Catchment Rainfall used to derive the Mean Annual Flood Regression (MAF) Equations**

Other than catchment area, an additional characteristic, the mean annual catchment rainfall is used to derive the regional mean annual flood regression equations in this procedure. Unlike the old procedure (HP4 1974) where only catchment areas is correlated with mean annual floods to derive the regression equations coefficients, this procedure used both the characteristics of catchment area and catchment mean annual rainfall to derive the mean annual flood regression equations coefficients.

(iv) **Streamflow data from different gauging stations used**

Streamflow data from gauging stations used in this procedure are not all from the same stations used in the old procedure, HP4 (1974). Streamflow data from stations that do not fit into the Gumbel Type I Distribution and data from stations that exhibited great changes since 1970 (usually from catchments of non-homogeneous nature) are not included in the analysis of this procedure.

4.2.1 Comparison of Results using HP4(1987) and HP4(1974)

The mean design peak discharge estimated for three ungauged catchments at Sg. Batang Kali, Sg. Setiu and Sg. Lipis using this procedure HP4(1987) and the old procedure HP4(1974) are listed below:

(i) Site: Sg. Batang Kali at Lat. 3° 23' N, Long. 101° 38' E

Catchment area A: 88 km^2 (34 $mile^2$)

Mean annual catchment rainfall R = 2.550m (2550mm)

HP4(1987): Flood Frequency Region FF2

Mean Annual Flood Region MAF 5

$$MAF = 0.1192\,(88^{0.6175})\,(2.550^{3.0571})$$
$$= 33.10\ m^3/s.$$

HP4(1974): Flood Frequency Region F4

$$Q_{2.33} = 104\,A^{0.693}$$
$$= 104\,(34^{0.693})$$
$$= 1197.70\ ft^3/sec$$
$$= 33.94\ m^3/s.$$

Table 4 : Comparison for results obtained from HP4(1987) and HP4(1974) for Sg. Batang Kali at Lat. 3° 23' N, Long. 101° 38' E

Hydrological Procedure Used	Region		Q_T for T-year recurrence interval (m^3/s)					
	FF	MAF	2.33	5	10	20	50	100
HP4(1987)	FF2	MAF3	33.10	43.36	51.31	62.31	59.58	77.45
HP4(1974)	F4	–	33.94	39.03	43.44	46.84	51.59	55.32

(ii) Site: Sg. Setiu at Lat. 5° 31' N, Long. 102° 44' E

Catchment Area A: 161 km^2 (62 $mile^2$)

Mean annual catchment rainfall R = 3490 mm

HP4 (1987): Flood Frequency Region FF5

Mean Annual Flood Region MAF6

$$MAF = 0.4783\,A^{0.9066}R^{0.9463}$$
$$= 0.4783\,(161^{0.9066})\,(3.490^{0.9463})$$
$$= 156.35\ m^3/s.$$

HP4(1974): Flood Frequency Region F4

$$Q_{2.33} = 218\ A^{0.883}$$
$$= 218(62^{0.883})$$
$$= 8339.47\ ft^3/s$$
$$= 236.33\ m^3/s.$$

Table 5 : Comparison of results obtained from HP4(1987) andHP4(1974) for Sg. Setiu at Lat. 5° 31' N, Long. 102° 44'E

Hydrological Procedure Used	Region		Q_T for T-year recurrence interval (m^3/s)					
	FF	MAF	2.33	5	10	20	50	100
HP4(1987)	FF5	MAF6	156.35	243.91	312.70	383.06	469.05	537.84
HP4(1974)	F8	–	236.33	271.78	302.50	326.14	359.22	385.22

(iii) Site: Sg. Lipis at Lat. 4° 00' N, Long. 101° 40' E

Catchment area A: 130 Km^2 (50 $mile^2$)

Mean annual catchment rainfall R = 2.200m (2200mm)

HP4 (1987): Flood Frequency Region FF1

Mean Annual Flood Region MAF5

$$MAF = 0.0140\ (130^{0.7954})\ (2.200^{5.0354})$$
$$= 35.63\ m^3/s.$$

HP4 (1974): Flood Frequency Region F10

$$Q_{2.33} = 1250\ A^{0.3860}$$
$$= 1250\ (50^{0.3860})$$
$$= 5658.64\ ft^3/sec$$
$$= 160.30\ m^3/s.$$

Table 6 : Comparison of results obtained from HP4(1987) and HP4(1974) for Sg. Lipis at Lat.4° 00' N, Long. 101° 40' E

Hydrological Procedure Used	Region		Q_T for T-year recurrence interval (m^3/s)					
	FF	MAF	2.33	5	10	20	50	100
HP4(1987)	FF1	MAF5	35.63	45.96	54.16	62,35	72,69	80.52
HP4(1974)	F10	–	160.30	203.58	242.05	275.72	323.87	354.26

5. RELIABILITY OF PROCEDURE

In statistical studies, error analyses are usually carried out to determine the reliability of data and methods used. Hence, in this procedure, it is also essential that the statistical reliability of the estimated design peak discharges be considered. Due to the complex nature of the errors involved in this procedure, no theoretical expression for the standard error is derived. For users to subjectively evaluate the accuracy of any design floods estimated using this procedure, the various sources and causes of errors are discussed below:

(i) Lower peak discharge record from stick gauges

The present automatic recorder stations (used in this procedure) that were established prior to 1960 were all operated by stick gauges before being upgraded to the automatic recorder system. 23% of streamflow stations presently used in this procedure are still being operated solely by stick gauges.

For stick gauges, the water level is read manually twice a day (8 a.m. and 8 p.m. daily). During flood times, the peak water-level could happen at any time between 8 a.m. and 8 p.m. causing the peak level to be missed and not recorded. A lower peak water-level would be recorded. This error will eventually result in the underestimation of the design flood estimated using this procedure.

(ii) Poor quality rating curve and peak discharge records

River cross-sections frequently change in urbanised catchments where rivers have been canalised and widened. Other changes in river cross-section also happened, especially in rivers that are subseptible to scouring and silting. When a river has changed its cross-section, then the records will be rendered non-homogenous.

The other factor that causes inacurrate peak discharge data is the extrapolation of rating curves. For certain flood events, the peak water-levels recorded are beyond the range of the stage-discharge rating curves. Hence, the rating curves would have to be extrapolated in order that the peak water-levels recorded can be converted to peak discharge value.

Other factors like errors in data collection, errors in data analysis, non-functioning of water-level recorders and inaccurate gauging measurements also attribute to the poor quality of peak discharge records of a streamflow station.

(iii) Different length of records

It is recommended in the U.S.G.S "Flood Frequency Analysis" (Dalyrmple, 1960) that all period of records be adjusted to a common base period. The common base period, derived from the longest available records, is necessary because storms and floods of one period of time are different in magnitude and distribution to those of another period. Hence, for different length of records, missing years may be filled in by correlation techniques. The estimated peaks are not used directly but serve the purpose of allowing the correct recurrence interval to be assigned to the recorded peak discharge data in order that the records can be compared or combined.

In this procedure, no adjustment of the length of records to a common base period was carried out because the variation in the lengths of records of streamflow stations used in this procedure is not high enough to justify for the adjustment of a common base period. The average length of record for the streamflow stations used is 23.2 years, the shortest period being 8 years and the longest period is 36 years. 46% of the length of records is between 20 to 30 years. Hence the error attributed by the different length of records is relatively small.

6. REFERENCES

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APPENDIX I

List of Catchments and Catchment Characteristics

Station No.	Catchment	Length of Records (Years)	Catchment Area (km²)	Catchment Mean Annual Rainfall mm	Observed MAF (m³/s)	Predicted MAF (m³/s)	Region FF	Region MAF
1737451	Sg Johor at Rantau Panjang	17	1130	2455	208.82	245.62	FF4	MAF4
1931423	Sg Sembrong at Brizay Bridge	22	186	2350	51.85	58.96	FF4	MAF4
2130422	Sg Bekok at Jln. Yong Peng – Air Hitam	11	350	2250	53.76	81.38	FF4	MAF4
2224432	Sg Kesang at Chin Chin	22	161	1750	13.63	21.81	FF4	MAF4
2237471	Sg Lenggor at Bt. 42 Kluang – Mersing	22	207	2815	150.80	109.87	FF4	MAF4
2322413	Sg Melaka at Pantai Belimbing	22	350	1940	47.56	51.99	FF3	MAF4
2519421	Sg Linggi at Sua Betong	34	523	2175	77.43	97.99	FF3	MAF4
2520423	Sg Pedas at Kg. Pilin	34	111	2000	28.79	25.00	FF3	MAF4
2525415	Sg Gemencheh at Jln. Gemas – Rompin	20	453	1750	72.61	45.82	FF4	MAF4
2527411	Sg Muar at Buluh Kasap	22	3130	1895	228.66	233.33	FF4	MAF4
2625412	Sg Muar at Bt. 57 Jln. Gemas – Rompin	23	1210	1990	159.05	136.76	FF4	MAF4
2719422	Sg Linggi at Rahang	29	189	2100	50.22	42.45	FF3	MAF4
2722413	Sg Muar at Kuala Pilah	25	370	2000	76.88	59.32	FF4	MAF4
2816441	Sg Langat at Dengkil	33	1240	2455	128.03	151.03	FF3	MAF3
2917442	Sg Langat at Kajang	22	380	2675	99.61	94.59	FF3	MAF3
2918443	Sg Semenyih at Semenyih	27	210	2565	53.38	57.68	FF3	MAF3
3022431	Sg Triang at Juntai	33	904	2200	94.35	88.86	FF3	MAF3
3116433	Sg Gombak at Jln. Tun Razak	21	122	2600	48.49	42.99	FF3	MAF3
3116434	Sg Batu at Sentul	20	145	2625	51.84	49.25	FF3	MAF3
3224433	Sg Triang at Jln. Keretapi	12	1870	2000	144.20	184.26	FF1	MAF5
3414421	Sg Selangor at Rantau Panjang	33	1450	2680	223.66	217.50	FF2	MAF3
3423421	Sg Semantan At Jam. Keretapi	8	2490	2250	316.59	418.71	FF1	MAF5
3424411	Sg Pahang at Temerloh	19	19000	2100	3046.04	1489.43	FF1	MAF5
3519426	Sg Bentong at Jam. K. Marong	13	241	2375	141.41	85.80	FF1	MAF5
3615412	Sg Bernam at Tanjung Malim	33	186	2750	54.96	66.21	FF2	MAF3
3813411	Sg Bernam at Jam. SKC	24	1090	2770	223.80	201.73	FF2	MAF3
3813414	Sg Trolak at Trolak	29	66	2800	43.59	34.33	FF2	MAF2
3814415	Sg Bil at Jln. Tg. Malim – Slim	30	41	2665	32.17	24.16	FF2	MAF2
3814416	Sg Slim at Pekan Slim	14	455	2650	88.14	116.09	FF2	MAF2
3913458	Sg Sungkai at Sungkai	34	289	2625	62.06	85.61	FF2	MAF2
4011451	Sg Bidor at Bt. 9 Jln. Anson	28	373	3000	86.74	112.70	FF2	MAF2
4012452	Sg Bidor at Bt. 18 Jln. Anson	20	339	3000	74.74	105.87	FF2	MAF2
4019462	Sg Lipis at Benta	18	1670	2290	257.06	333.02	FF1	MAF5
4111455	Sg Batang Padang at T. Keramat	30	445	2900	89.11	123.07	FF2	MAF2
4112456	Sg Batang Padang at Tapah	27	376	3100	176.03	116.34	FF2	MAF2
4112459	Sg Gedong at Bidor	17	108	3100	82.08	51.45	FF2	MAF2
4121413	Sg Jelai at Jam. Bunggor	12	6030	2350	860.56	1053.27	FF1	MAF5
4131453	Sg Cherul at Ban Ho	8	505	2875	332.20	366.75	FF5	MAF6
4223450	Sg Tembeling at Merting	14	5010	2200	435.31	652.05	FF1	MAF5
4232452	Sg Kemaman at Ran. Panjang	13	626	3150	316.28	485.83	FF5	MAF6
4311464	Sg Kampar at Kg. Lanjut	35	432	2525	89.55	107.91	FF2	MAF2
4410461	Sg Kinta at Bt. Gajah	29	1054	2305	170.39	179.64	FF2	MAF2
4410465	Sg Kinta at Kellas	18	251	2375	46.22	71.99	FF2	MAF2
4809443	Sg Perak at Jam. Iskandar	34	7770	2120	1116.78	620.12	FF2	MAF2
4832441	Sg Dungun at Jam. Jerangau	17	1410	2960	1226.06	956.33	FF5	MAF6
4911445	Sg Plus at Kg. Lintang	26	1090	2300	177.31	183.31	FF2	MAF2
5007423	Sg Ara at Bt. 20 Jln. Taiping	35	140	3000	80.22	59.37	FF2	MAF2
5106431	Sg Krian at Dusun Rimau	14	694	3000	112.85	143.83	FF2	MAF1
5106433	Sg Ijok at Titi Ijok	35	216	3210	71.36	71.36	FF2	MAF2
5130432	Sg Terengganu at Kg. Tanggol	35	2690	3340	2264.51	1925.59	FF5	MAF6
5206432	Sg Krian at Selama	19	629	2800	170.81	131.27	FF2	MAF1
5320443	Sg Galas at Dabong	10	7770	2400	3682.40	3684.33	FF6	MAF6
5405421	Sg Kulim at Ara Kuda	30	129	2800	39.58	37.54	FF2	MAF1
5505412	Sg Muda at Victoria Estate	18	4010	2300	483.44	545.64	FF2	MAF1
5506413	Sg Muda at Batu Pekaka	26	3340	2200	506.39	468.11	FF2	MAF1

5506416	Sg Sedim at Merbau Pulas	26	440	2835	101.97	99.22	FF2	MAF1
5506417	Sg Karangan at Titi Karangan	10	83	3100	24.75	27.04	FF2	MAF1
5721442	Sg Kelantan at Jam. Guillermard	25	11900	2430	5236.86	5486.45	FF6	MAF6
5806414	Sg Muda at Jeniang	36	1710	2185	310.26	275.44	FF2	MAF1
6022421	Sg Kemasin at Peringat	20	48	2875	49.69	43.43	FF5	MAF6
6204421	Sg Padang Terap at Lengkuas	22	1270	1830	185.69	210.23	FF2	MAF1

APPENDIX II

Results of Individual Station Frequency Analysis.

Station No.	Q_T, Peak Discharge for T – years recurrence interval (m^3/s)					
	T = 2	T = 5	T = 10	T = 20	T = 50	T = 100
1737451	196.29	292.35	357.08	419.73	499.08	559.64
1931423	47.70	78.81	99.03	119.26	144.66	163.85
2130422	50.53	77.95	95.69	112.90	135.48	152.14
2224432	13.08	17.17	19.76	22.35	25.76	28.21
2237471	137.23	232.23	295.57	335.89	432.80	491.61
2322413	45.18	61.35	71.82	81.80	95.12	105.11
2519421	73.56	100.66	118.47	135.50	157.96	174.22
2520423	27.06	37.71	44.91	51.53	60.46	67.08
2525415	65.35	116.18	149.58	181.53	222.91	254.14
2527411	208.08	349.85	443.60	532.78	647.11	734.00
2625412	146.33	240.17	302.20	362.63	440.57	497.83
2719422	45.70	76.84	97.43	117.01	142.62	161.71
2722413	69.19	123.01	158.37	192.97	237.56	269.85
2816441	119.07	117.96	217.65	254.78	304.71	340.56
2917442	94.62	131.49	155.39	178.30	208.18	231.10
2918443	49.64	75.80	92.88	109.43	130.78	146.80
3022431	89.63	120.77	140.58	160.40	184.93	204.74
3116433	46.07	64.98	77.58	89.71	105.71	117.35
3116434	49.77	70.50	85.02	98.50	116.64	129.60
3224433	139.87	178.81	203.32	227.84	261.00	284.07
3414421	216.95	266.16	299.70	331.02	373.51	404.82
3423421	303.93	395.74	455.89	512.88	585.69	639.51
3424411	2832.82	4538.60	5665.63	6762.21	8163.37	9229.50
3519426	135.75	185.25	217.77	248.88	289.89	321.00
2615412	52.21	69.25	80.24	90.68	104.42	114.87
3813411	208.13	315.56	387.17	456.55	543.83	610.97
3813414	40.10	63.64	79.33	94.59	113.77	128.59
3814415	28.95	49.54	63.37	76.24	93.29	106.16
3814416	86.38	101.36	111.94	121.63	134.85	144.55
3913458	58.96	80.68	94.95	108.61	126.60	140.26
4011451	82.40	113.63	135.31	155.26	182.15	201.24
4012452	72.50	88.19	98.66	108.37	121.08	130.80
4019462	249.35	313.61	357.31	401.01	455.00	496.13
4111455	87.33	101.59	111.39	120.30	132.77	141.68
4112456	158.43	276.37	352.06	425.99	522.81	593.22
4112459	76.33	120.66	150.21	178.11	215.05	242.14
4121413	826.14	1135.94	1333.87	1531.80	1789.96	1979.29
4131453	295.66	544.81	707.59	867.04	1069.68	1222.50
4223450	417.90	548.49	635.55	718.26	822.74	905.44
4232452	290.98	487.07	616.75	740.10	901.40	1021.58
4311464	85.97	107.46	120.89	134.33	152.24	164.77
4410461	163.57	211.83	243.66	274.33	315.22	344.19
4410465	42.98	64.25	78.57	91.98	109.54	122.48
4809443	1027.44	1619.33	2021.37	2401.08	2892.46	3261.00
4832441	1114.80	1923.34	2450.12	2964.65	3613.93	4116.20
4911445	170.22	219.86	251.78	283.70	322.70	352.85
5007423	77.01	99.47	114.71	129.96	148.41	162.85
5106431	109.40	136.55	154.60	171.53	194.10	211.03

5106433	68.51	85.63	96.34	107.04	120.60	131.30
5130432	2015.41	3623.23	4664.89	5683.92	6997.34	7971.08
5206432	160.56	237.43	288.67	336.50	401.40	447.52
5320443	3350.98	6149.61	7953.98	9721.54	12004.62	13698.53
5405421	37.60	51.06	59.77	68.08	79.16	87.08
5505412	464.10	618.80	725.16	826.68	952.38	1053.90
5505413	476.01	693.75	835.54	972.27	1154.57	1286.23
5506416	97.89	126.44	145.82	164.17	188.64	205.98
5506417	23.02	38.12	48.26	57.92	70.29	79.70
5721412	4660.81	8640.82	11259.25	13720.57	17019.80	19428.75
5724413	148.23	245.96	309.49	371.39	451.21	511.47
5806414	291.64	415.75	499.52	577.08	679.47	750.83
6022421	45.71	76.03	95.90	115.28	140.13	158.51
6204421	180.12	215.40	237.68	258.11	285.96	306.39

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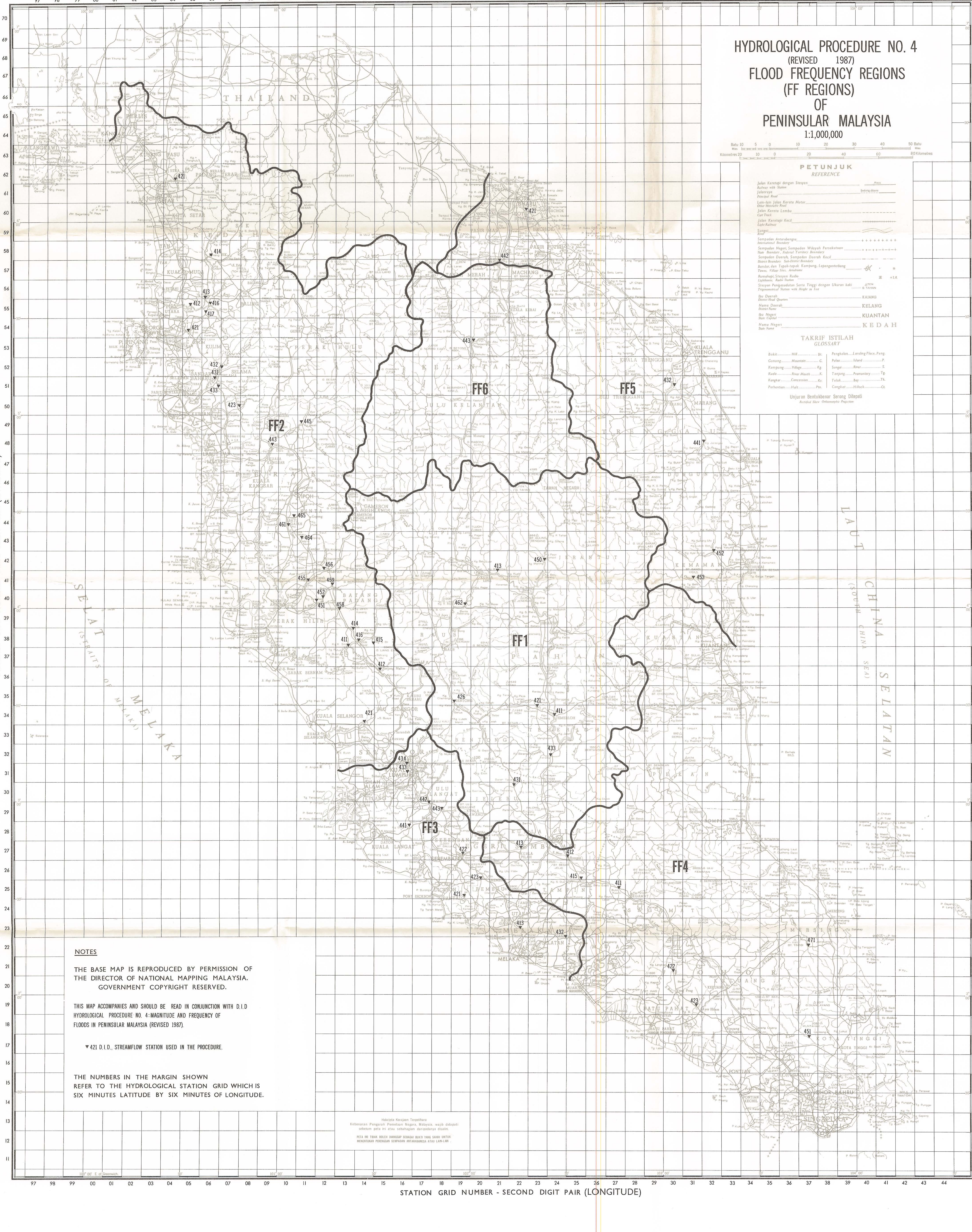
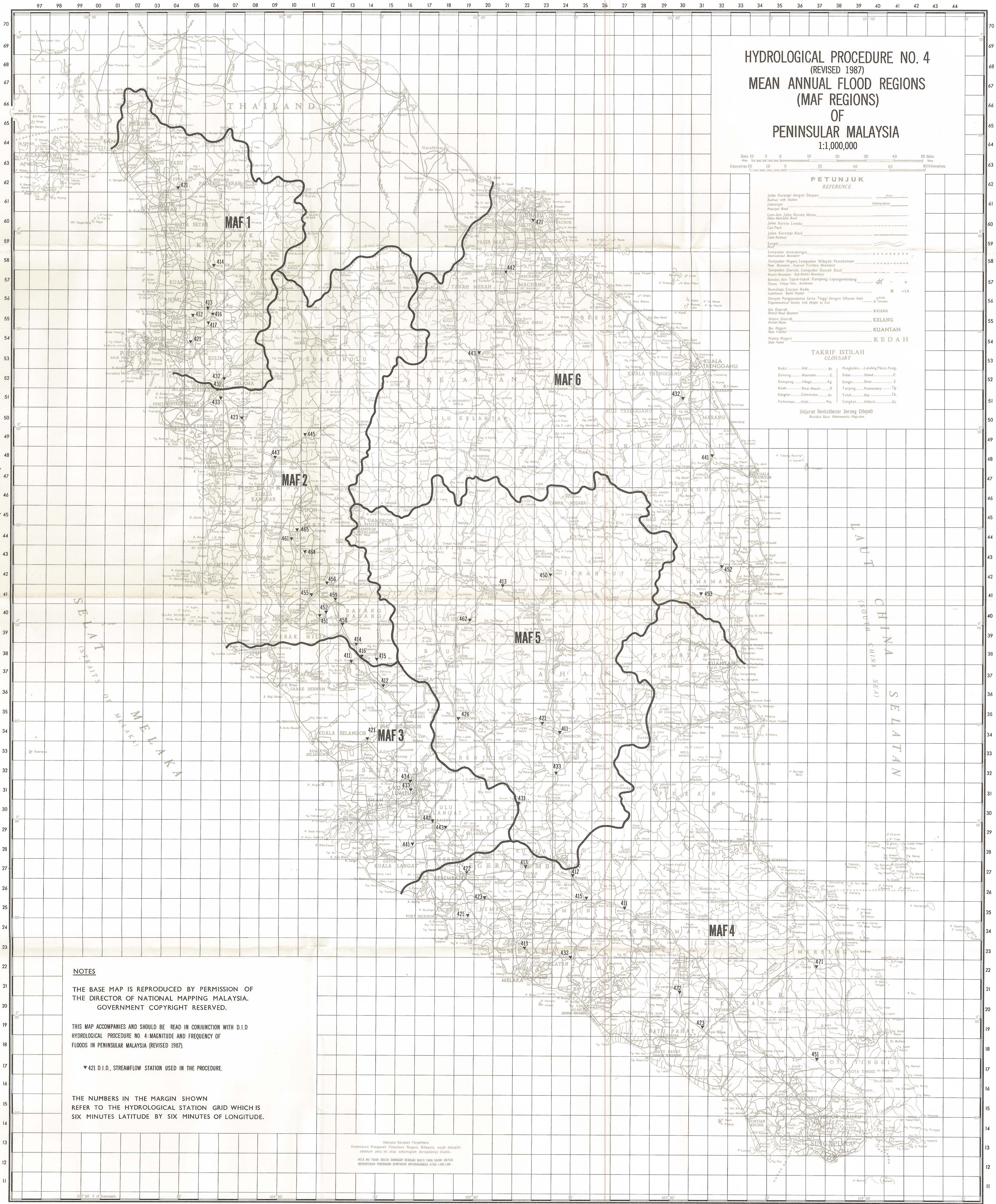
MAP 1



STATION GRID NUMBER - FIRST DIGIT PAIR (LATITUDE)

STATION GRID NUMBER - SECOND DIGIT PAIR (LONGITUDE)

MAP 2


HYDROLOGICAL PROCEDURE NO. 4
(REVISED 1987)
MEAN ANNUAL FLOOD REGIONS
(MAF REGIONS)
OF
PENINSULAR MALAYSIA
1:1,000,000
PETUNJUK
REFERENCE
TAKRIF ISTILAH
GLOSSARY
Unjuran Bentukbenar Serong Ditepati
MAF 1
MAF 2
MAF 3
MAF 4
MAF 5
MAF 6
THAILAND
SELAT MELAKA
LAUT CHINA SELATAN
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▼421 D.I.D., STREAMFLOW STATION USED IN THE PROCEDURE.
THE NUMBERS IN THE MARGIN SHOWN REFER TO THE HYDROLOGICAL STATION GRID WHICH IS SIX MINUTES LATITUDE BY SIX MINUTES OF LONGITUDE.
STATION GRID NUMBER - FIRST DIGIT PAIR (LATITUDE)
STATION GRID NUMBER - SECOND DIGIT PAIR (LONGITUDE)