HYDROLOGICAL PROCEDURE NO. 12

MAGNITUDE AND FREQUENCY OF LOW FLOWS IN PENINSULAR MALAYSIA (REVISED AD UPDATED)

1985

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

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Bahagian Parit dan Taliair
Kementerian Pertanian

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SYNOPSIS

This procedure is a revised and updated version of DID Hydrological Procedure No. 12 (1976) based on period of data available up to year 1982. Regional analysis was used to develop this procedure for estimating low flows of rivers in Peninsular Malaysia. Two maps identifying regions in Peninsular Malaysia with similar mean annual low flow and low flow frequency characteristics respectively were produced. This procedure allows the design low flow of an ungauged catchment in Peninsular Malaysia to be estimated based on the regions it is identified with, the catchment area and the mean annual rainfall over the catchment.

This procedure will be revised and updated again in the future when additional 10 years of data are collected and available for analysis.

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1. INTRODUCTION

1.1 Low flow estimation

A problem that is invariably encountered in the design of water resources projects is the determination of the reliability of water supply. When the water source is from an unregulated natural river, the reliability of the water availability is a function of the low flow characteristics. The three main characteristics of low flow which are of interest to designers are:

(i) its duration,

(ii) its magnitude and

(iii) its frequency of occurrence.

The permissible duration of low flow will reflect the tolerance of the user to periods of water deficits. The magnitude of low flow for the specified duration will determine the amount of water that is available to the user. The specified frequency of occurrence of low flow reflects the risk associated with the failure of the water supply and is dependent on the socio-economic importance of the scheme to the community.

Rapid development has placed increasing demand on water resources development and pressure to provide more information on the flow characteristics of streams and rivers, many of which have few or no streamflow data. In many cases, especially for the smaller projects, economic and social pressure do not permit a delay in project implementation pending acquisition of streamflow data.

1.2 Objective

The objective of this procedure is to provide a method of estimating the reliability of low flows of rivers in Peninsular Malaysia. The results can be used in the design of intakes, reservoirs, irrigation systems, water supply systems and hydro-electric power generation schemes, and in the management of water quality.

The durations and return periods investigated ranged between 1 and 30 days and between 1 and 50 years respectively.

1.3 Low flow frequency analysis

In low flow frequency analysis, the aim is to derive a low flow frequency curve for low flows of a specified duration (say D days) The frequency curve is derived by fitting a theoretical frequency distribution to the sample of recorded D-day low flows using either graphical or analytical means. For a selected return period T, the design discharge Q cab be read from this curve. In this study D ranges from 1 to 30 days. Each annual D-day low flow is regarded as a variable x, which is characterised by its frequency distribution. The distribution may be described as:

(a) f (x), the probability density function (pdf) which gives the probability or relative frequency of occurrence of x or

(b) F (x), the corresponding cumulative distribution function (cdf).

The two functions are related by:

$$f(x) = \frac{dF(x)}{dx} \qquad (1.1)$$

$$F(x) = f(x)\,dx \qquad (1.2)$$

where by definition

$$F(x) = \int_{-\infty}^{\infty} f(x)\,dx = 1 \qquad (1.3)$$

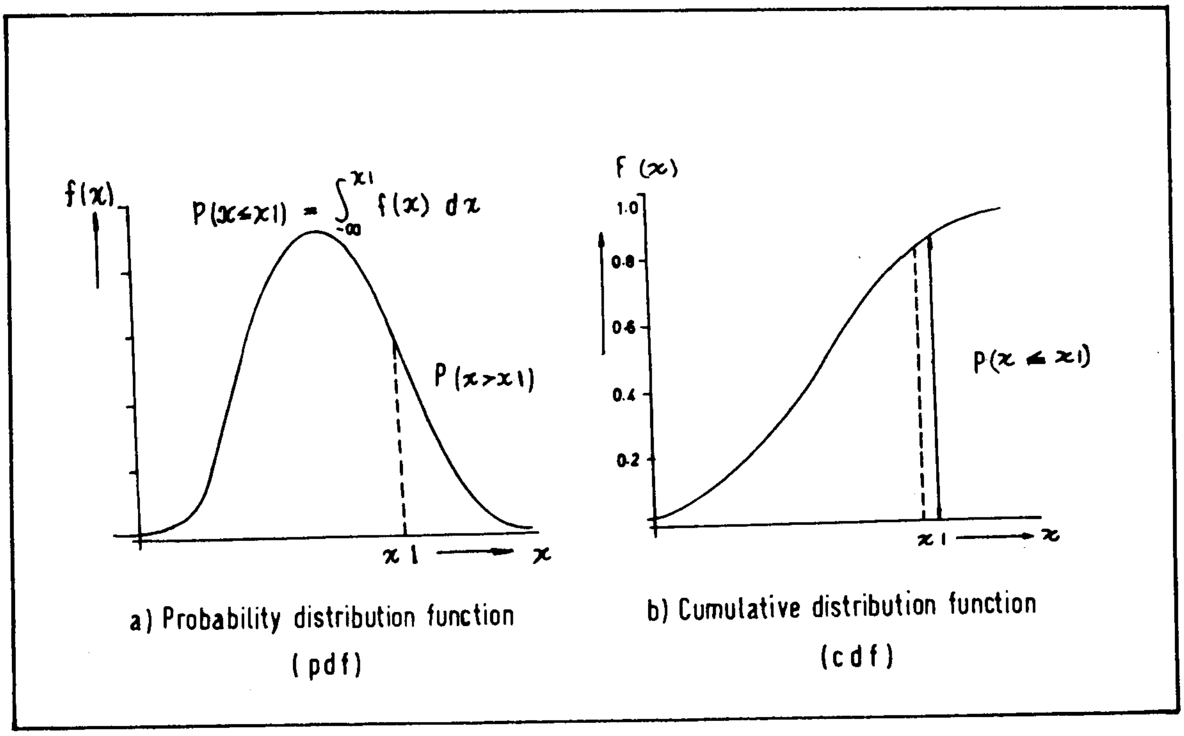

FIG 1.1:
CHARACTERISTICS OF pdf AND cdf

Fig. 1.1 illustrates the relationship between the two distribution functions. F (x1) is the probability that a random variable x is less than or equal to x1.

$$F(x1) = P(x < x1) \quad \ldots \quad (1.4)$$

where P denotes the probability

$$F(x1) = 1 - P(x > x1) \quad \ldots \quad (1.5)$$

Closely associated with this is the concept of return period (T). The return period of a low flow x1 is the average interval of time (in years) in which a low less than or equal to x1 is expected to recur. For example, if the low flow is equal to or below a certain value x1, on the average 5 times in 100 years, then:

$$F(x1) = P(x < x1) = 5/100 = 0.05$$

The return period T is then given by:

$$T = 1/F(x1) = 20 \text{ years} \quad \ldots \quad (1.6)$$

1.4 Frequency distribution

The probability distribution adopted for this investigation is the type III extreme value (EV III) distribution described by Gumbel (1954) and Jenkinson (1969). This distribution has been widely used in previous low flow studies and has been shown by Matalas (1963), Joseph (1970) and Kite (1975) to be a satisfactory model for analysing low flows. A brief mathematical description of the General Extreme Value (GEV) distribution is given in Appendix I. Certain assumptions and limitations are inherent in the use of the GEV distribution. These are as follows:

(i) The observations from which the extreme values are drawn should be independent.

(ii) The observations must be reliable and should be recorded under identical conditions (i.e. homogenous records).

(iii) The number of observations n, from which the extreme values are taken, must be large.

1.5 Regional frequency analysis

Frequency analysis at a single site was the first phase of frequency analysis to develop. Later the concept of flow frequency analysis broadened into the field of regional frequency analysis. In the latter, the low flow data over a wide region are analysed to define the common dimensionless low flow frequency curves for low flows in the region.

In this study, the regional analysis method applied by the Natural Environment Research Council of Britain (NERC) (1975) and Dryton et. a1. (1980) was adopted. The regional analysis consists basically of two components:

(i) A set of dimensionless regional frequency curves for various low flow durations relating $Q_{D,T}$/MAM to T, where $Q_{D,T}$ is the D-day duration, T-year low flow and MAM is the mean annual minimum flow (in this procedure the annual 1-day low flow is taken as the annual minimum flow)

(ii) A set of regional regression equations relating MAM to catchment characteristics.

2. DEVELOPMENT OF PROCEDURE

2.1 Methodology

The methodology adopted in developing this procedure is summarised below:

(i) Selection of catchments.
(ii) Extraction of low flow data for selected flow durations.
(iii) Frequency analysis of individual station flow data.
(iv) Derivation of demensionless regional low-flow frequency curves.
(v) Development of regional equations relating MAM to catchment characteristics.

2.2 Selection of catchments

All river stations operated by the Drainage and Irrigation Department (DID) were assessed for possible inclusion in this study. The flow stations were selected based on the followiang criteria:

(i) The catchment land use has not changed significantly over the period of record.
(ii) The low flows have not been substantially regulated or affected by the extraction, storage or diversion of water upstream.
(iii) There are 8 or more years of streamflow record available.
(iv) The catchments are predominantly rural.
(v) The catchment areas are greater than 20 km^2.

The first two conditions are consistent with the normal requirements for a homogeneous data sample. The third condition is to ensure an adequate number of data values for reliable frequency analysis. Condition (iv) is necessary because this procedure is derived for application to rural catchments and not urban catchments. Condition (v) is imposed as it was felt that the low flow characteristics of very small catchments may be significantly different from those of large catchments.

2.3 Extraction of flow data

For the post-1960 period, the annual 1-,4-,7- and 30-day low flow for each of the selected stations were extracted from DID's computer based data bank using standard retrieval programs. For the pre-1960 period, data were extracted manually.

Upstream water extraction and storage reservoirs affect the flows in some rivers. Where it was found that upstream extraction or storage significantly affected the low flow, the streamflow data were not considered in the analysis. In general, the daily flow values were not corrected for upstream water extraction. However correction to the 1-day low flow was made if the 1-day low flow was much lower than the 4-day low flow. The portion of daily discharge hydrograph which contains the 1-day low flow was plotted for visual checking. If the sudden drop in the 1-day low flow was found to be unreasonable, it was adjusted according to the general trend of the recession curve.

In cases of missing flow data during dry months, data for that year were omitted.

2.4 Frequency analysis of individual stations

The annual D-day low flow series for each station was reduced to its dimensionless form by dividing it by its corresponding MAM. The dimensionless probability plot was obtained for each series by plotting the $Q_{D,T}$/MAM ratios on log-Gumbel probability paper. The plotting position formulae used were:

(i) The Weibull formula, for record length less than 20 years

$$T = \frac{N + 1}{i} \quad \ldots \quad (2.1)$$

where T = plotting position of an annual low flow, in years
N = length of records in years
and i = rank of the annual low flow in the series
(i for the smallest, N for the largest)

(ii) The Gringorten formula, for record length greater than 20 years

$$T = \frac{N + 0.12}{i - 0.44} \quad \ldots \quad (2.2)$$

These plotting position formulae were recommended by Cunnane (1978) for the GEV distribution.

Frequency analysis on each annual low flow series was also performed by computer. The computer program SSGEV (i) fits the GEV distribution to dimensionless annual low flow series by the method of least squares. The program outputs the $Q_{D,T}$/MAM values for various return periods, T. By examining of the results of individual station frequency analysis, the low flow data of 8 stations were suspected to be inaccurate. Thus, the low flow records of these stations were not used. In all, data from only 53 catchments for period of records available up to 1982 were used in the derivation of this procedure. The 53 catchments are listed in Appendix II. The results of individual station analyses are tabulated in Appendix III.

2.5 Regional low flow frequency curves

2.5.1 Delineation of low flow frequency regions (RC Regions)

The procedure adopted for the development of the regional frequency curves is similar to that used by the NERC. First, low flow frequency regions (RC regions) were identified.

The log-Gumbel probability plots (described in section 2.4) from nearby stations were superimposed to examine the similarity of the plotted data and the fitted curve. Stations which exhibited similar dimensionless frequency distribution were lumped together and treated as belonging to one sub-region. Many sub-regions were identified in this manner and the sub-regional probability plot was derived by drawing a mean curve using all the low flow data of the stations within the sub-region. These sub-regional curves were superimposed and the process of examining the similarity of the low flow frequency curves was repeated. Adjoining sub-regions which displayed similar curves were combined to form a low flow frequency region (RC regions).

In constructing the RC regions, the many factors that could influence the low flow in the different catchments were taken into account. Attention was given to the climate, topography and soil of the catchment, the aim being to locate catchments of similar low flow frequency characteristics in the same region. The delineation was also guided by the available climatic, soil and topographical maps, for example: maps of Hydrological Regions by Goh (1974), Mean Annual Rainfall Maps by DID (1976) and Average Annual and Monthly Surface Water Resources in Penisular Malaysia by Teh (1982). Altogether four RC regions were derived and their boundaries are as shown in Map A.

2.5.2 Derivation of regional low flow frequency curves

A regional frequency curve is essentially a frequency distribution of the average $Q_{D,T}$/MAM values for a region and is assumed to be a representive frequency distribution for all the catchments in that region.

In deriving the regional frequency curve, the annual low flows of each station were assembled in the form of $Q_{D,T}$/MAM with plotting positions expressed as the reduced variate y of the Extreme Value distribution, [where $y = -\ln(-\ln(1-1/T))$]. For stations with the same record length, the i^{th} lowest low flow for each station has the same plotting position. The mean value of the ith lowest values could therefore be plotted at this plotting position. However, the selected records were not of the same length. The method used for computing the regional data points was to divide the y-variate into several class intervals. The data points that fell within a given class interval were averaged to give the regional data point (described by co-ordinates y and $Q_{D,T}$/MAM).

The equation by Jenkinson (1969) for the EV III distribution given in Eqn. 2.3 below was fitted to the regional data points.

$$X = Q_{D,T}/MAM = u + \frac{\alpha}{k}(1-e^{-ky}) \qquad (2.3)$$

where u, α and k are the 3 parameters of the GEV distribution.

A computer program was developed to compute the regional data points and fit the EV III distribution to the computed points. In fitting the equation, the program uses the Rosenbrock (1960) optimization technique. This minimizes an objective function which is the sum of squares of the actual $Q_{D,T}$/MAM values using Eqn. 2.3. The four sets of low flow frequency curves derived for durations 1, 4, 7 and 30 days are as shown in Figs. 2.1 to 2.4. The parameters of the regional frequency low flow curves and the regional $Q_{D,T}$/MAM values for selected return periods are tabulated in Table 2.1.

2.6 Regional mean annual minimum flow (MAM) equations.

2.6.1 Introduction

Having obtained the dimensionless regional frequency curves, the next step was to relate MAM to catchment characteristics so that low flow estimates can be made for ungauged catchments.

The regions for the MAM equations, may not have the same boundaries as those of the RC regions. Thus another set of regions designated as the RE regions was delineated for developing the regional MAM equations.

2.6.2 Methodology

It is assumed that the relationship between MAM and the measurable catchment characteristics is of the form:

$$MAM = a\,(X1)^{b1}(X2)^{b2}\ldots\ldots(Xn)^{bn} \qquad (2.4)$$

Where X1, X2,........, Xn are catchment characteristics and b1, b2, ..., bn are constants to be estimated.

This kind of multiplicative function had been used in hydrology by Clark (1973) and the NERC(1975). Taking the logarithms of Eqn. 2.4 results in

$$\log(MAM) = \log a + b1 \log X1 + \ldots\ldots + bn \log Xn \qquad (2.5)$$

which is a standard multiple linear regression equation.

2.6.3 Catchment characteristics

Past studies by Riggs (1973), Nash (1965) and NERC (1975) made use of many types of catchment, climatic and physical characteristics as variables in the MAM equation. In this procedure only the catchment area (AREA) and the Mean Annual catchment Rainfall (MAR) were used as variables in developing the equations. These two catchment variables have been found to be the most significant and frequently used variables in a study by Gray (1964). The other catchment variables were not used because they cannot be extracted accurately from existing maps.

The catchment areas were obtained from DID's "Hydrological Data Publication". The MARs were obtained by planimetering the 1 : 1,000,000 Peninsular Malaysia Mean Annual Rainfall Map by DID (1976).

2.6.4 Delineation of RE Regions

As a first trial, the whole of Peninsular Malaysia was considered as one RE region. Data from all the 53 selected catchments were used in establishing the following MAM equation:

$$\log(MAM) = \log a + b1 \log(AREA) + b2 \log(MAR) \qquad (2.6)$$

where MAM = mean annual minimum flow (cumecs)

AREA = area of catchment (km)

MAR = mean annual catchment rainfall (mm)

a, b1 and b2 are coefficients.

The coefficients of this equation were derived using the multiple linear regression. The MAM Equation for Peninsular Malaysia obtained by the analysis is:

$$MAM = 1.821 \times 10^{-11} \, AREA^{1.043} \, MAR^{2.533} \qquad (2.7)$$

The residuals (r) resulting from the equation are given by the following:

$$r = \log(MAM)_{obs} - \log(MAM)_{est} \qquad (2.8)$$

Where MAM_{obs} = Observed mean annual minimum flow and

MAM_{est} = Estimated mean annual minimum flow from Eqn. 2.6

These residuals are plotted on a map of Peninsular Malaysia to show their geographical distribution. Trial regions were then formed by grouping neighbouring catchments with the same residual sign (positive or negative) together. This was to ensure that for each region, the residuals resulting from the regional equation is small and distributed normally as N (0,1). Altogether three trial RE regions were delineated. Regional equations were derived for these trial regions. Residuals resulting from these trial regional equations were also plotted on a map of Peninsular Malaysia. The residuals and their geograpical positions were examined, and the final regional boundaries were derived based on the distribution of the residuals and the physical relief of the country. Those catchments with large residuals were considered as outliers and their data were excluded in the final analysis.

2.6.5 Derivation of regional MAM equations

The three final RE regions derived are as shown in Map B. For each region, the relationship given by Eqn. 2.6 was obtained. Table 2.2 below shows the coefficients of the regional MAM equations. The mean annual minimum flow for each of the catchment calculated using the derived regional equations are as shown in Appendix II.

Region	*Coefficients*			*Multiple correlation coefficient squared* R^2
	a	*b1*	*b2*	
RE 1	1.097×10^{-8}	1.092	1.663	0.97
RE 2	1.675×10^{-10}	0.920	2.387	0.96
RE 3	1.675×10^{-16}	1.197	3.856	0.99
$MAM = a\,(AREA)^{b1}\,(MAR)^{b2}$				

TABLE 2.2: COEFFICIENTS OF REGIONAL MAM EQUATIONS

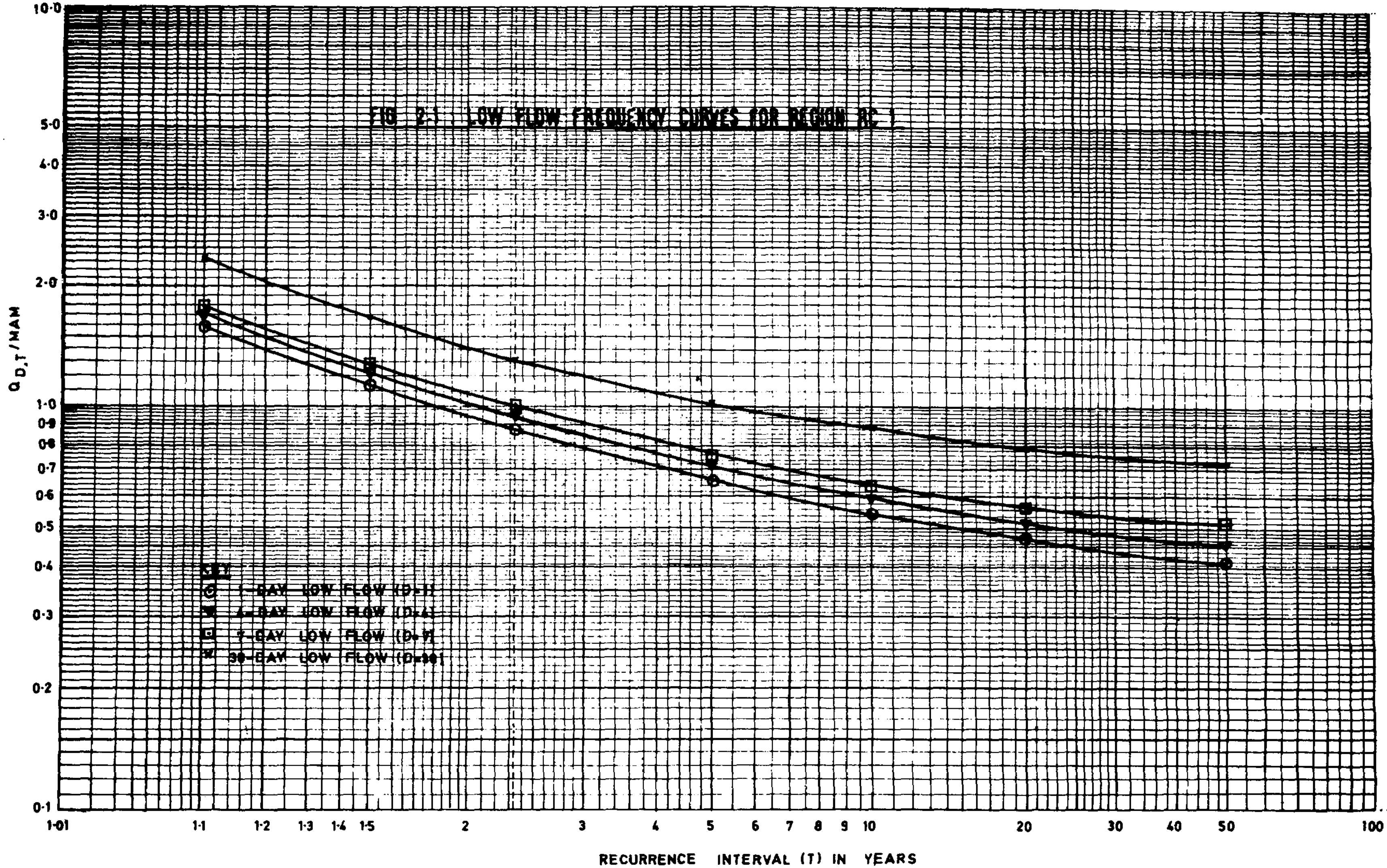

FIG 2.1 : LOW FLOW FREQUENCY CURVES FOR REGION RC 1

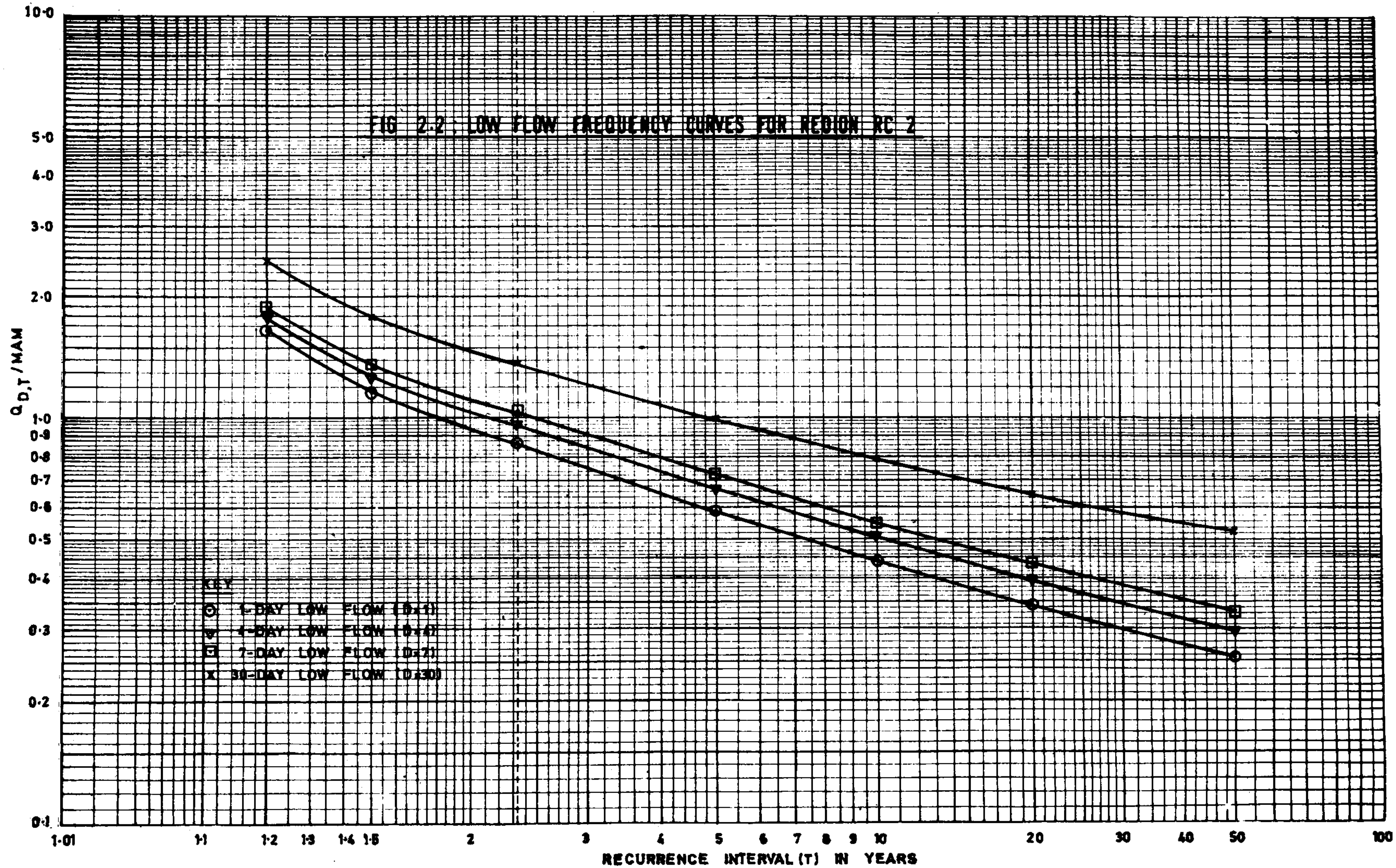

FIG 2.2: LOW FLOW FREQUENCY CURVES FOR REGION RC 2

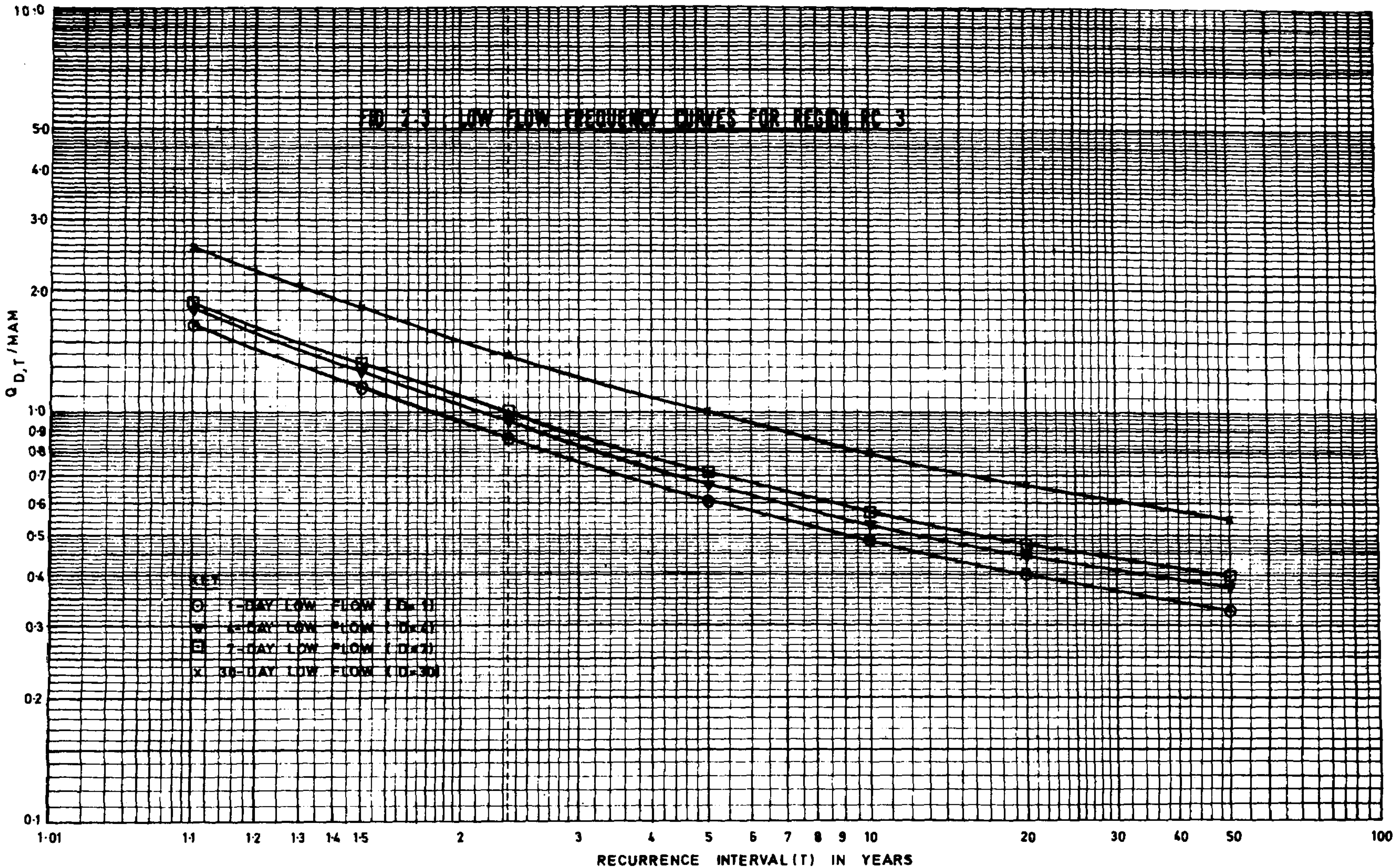
FIG 2.3 : LOW FLOW FREQUENCY CURVES FOR REGION RC 3
KEY
1-DAY LOW FLOW (D=1)
4-DAY LOW FLOW (D=4)
7-DAY LOW FLOW (D=7)
30-DAY LOW FLOW (D=30)
$Q_{D,T}$/MAM
10·0
5·0
4·0
3·0
2·0
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
1·01
1·1
1·2
1·3
1·4
1·5
2
3
4
5
6
7
8
9
10
20
30
40
50
100
RECURRENCE INTERVAL (T) IN YEARS

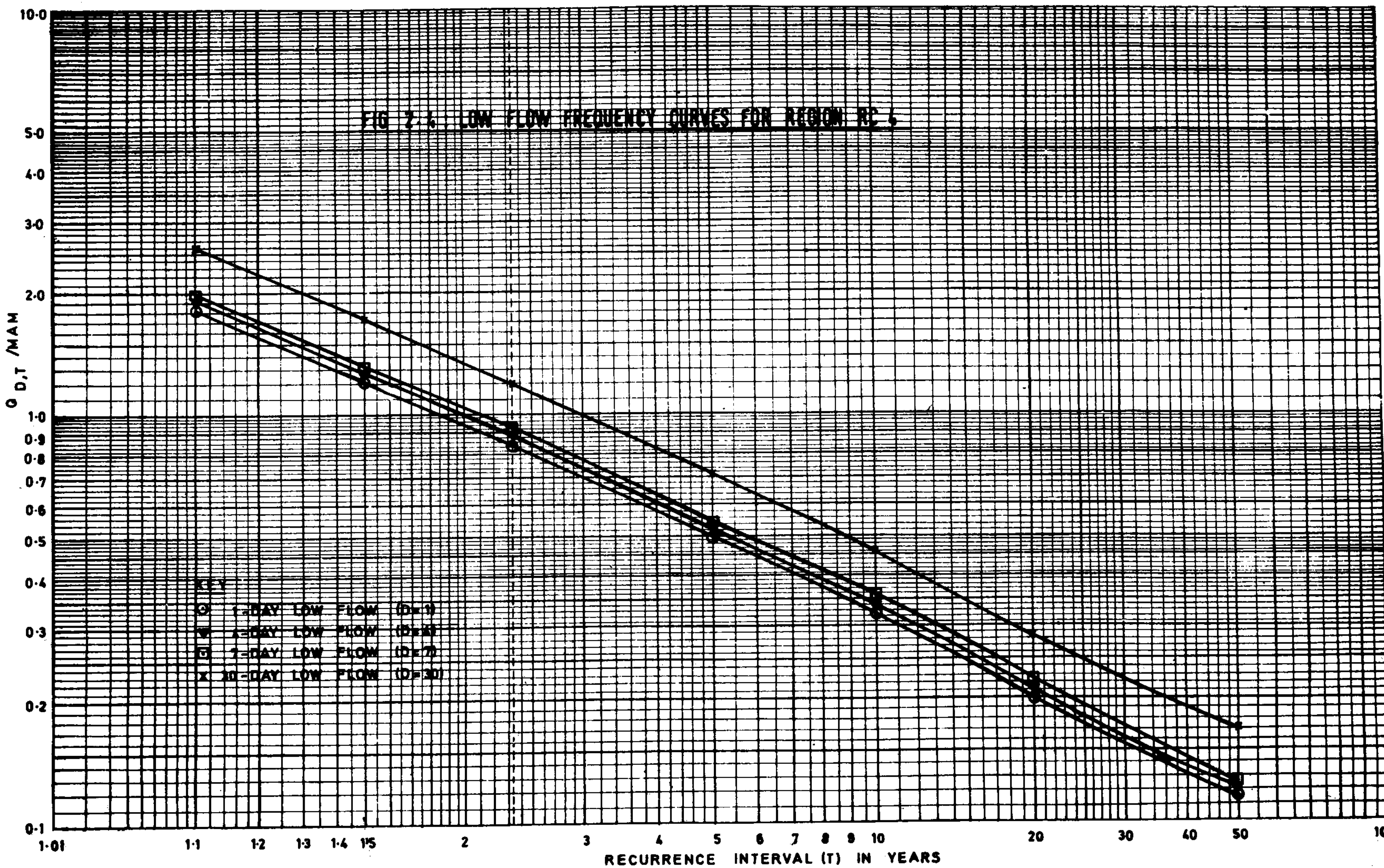
FIG 2.4 LOW FLOW FREQUENCY CURVES FOR REGION RC 4
KEY
1-DAY LOW FLOW (D=1)
4-DAY LOW FLOW (D=4)
7-DAY LOW FLOW (D=7)
30-DAY LOW FLOW (D=30)
Q D,T /MAM
10·0
5·0
4·0
3·0
2·0
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
1·01
1·1
1·2
1·3
1·4
1·5
2
3
4
5
6
7
8
9
10
20
30
40
50
100
RECURRENCE INTERVAL (T) IN YEARS

REGION	DURATION (DAYS)	$Q_{D,T}$/MAM FOR VARIOUS RETURN PERIOD T (years)							TYPE III EXTREME VALUE DISTRIBUTION PARAMETERS		
		1.1	1.5	2.33	5	10	20	50	u	α	k
RC1	1	1.592	1.136	0.878	0.656	0.545	0.476	0.420	1.093	- 0.437	0.583
	4	1.701	1.220	0.949	0.712	0.594	0.520	0.460	1.176	- 0.462	0.577
	7	1.792	1.288	1.006	0.765	0.645	0.571	0.512	1.241	- 0.480	0.594
	30	2.336	1.679	1.322	1.025	0.883	0.797	0.731	1.619	- 0.614	0.632
RC2	1	1.664	1.169	0.870	0.593	0.444	0.344	0.257	1.121	- 0.497	0.492
	4	1.777	1.272	0.962	0.668	0.506	0.396	0.298	1.222	- 0.514	0.465
	7	1.887	1.361	1.037	0.728	0.556	0.439	0.335	1.310	- 0.536	0.458
	30	2.459	1.790	1.384	1.000	0.790	0.648	0.523	1.726	- 0.676	0.474
RC3	1	1.653	1.160	0.874	0.618	0.486	0.400	0.329	1.114	- 0.482	0.540
	4	1.802	1.262	0.952	0.677	0.536	0.446	0.373	1.212	- 0.525	0.553
	7	1.865	1.317	0.999	0.716	0.569	0.475	0.397	1.265	- 0.535	0.543
	30	2.543	1.818	1.396	1.601	0.796	0.662	0.548	1.749	- 0.718	0.519
RC4	1	1.818	1.212	0.847	0.507	0.323	0.201	0.116	1.154	- 0.609	0.490
	4	1.903	1.268	0.885	0.530	0.339	0.211	0.123	1.206	- 0.637	0.492
	7	1.994	1.328	0.925	0.554	0.355	0.226	0.132	1.261	- 0.669	0.497
	30	2.595	1.716	1.193	0.712	0.456	0.286	0.171	1.632	- 0.876	0.506

TABLE 2.1 : RESULT OF DIMENSIONLESS REGIONAL FREQUENCY ANALYSIS FOR REGIONS RC1, RC2, RC3 AND RC4.

3. USE OF THE PROCEDURE

3.1 Introduction

The application of this procedure is constrained by the nature of the data used in deriving it. Its application should therefore be confined to catchments that satisfy the following criteria:

(i) The catchment must be rural.

(ii) The catchment must not have significant storages (swamps and lakes), or regulations (reservoirs).

Caution must be exercised in applying this procedure to small catchments (areas below 20 sq. km.) and also to catchments located in areas where the density of river stations used in deriving the regional curve is sparse.

3.2 Method of application

The general procedure for the estimation of low flow frequency of rivers in Peninsular Malaysia is as shown in the flow chart in Fig. 3.1 The steps involved in the application of this procedure for the estimation of low flow frequency of an ungauged catchment are as follows:

STEP 1

Determine the area (AREA) of the catchment in km^2.

STEP 2

Estimate the mean annual rainfall (MAR) in mm for the catchment from available rainfall racords. If no rainfall records are available, the MAR could be estimated from the 1: 1,000,000 Peninsular Malaysia Mean Annual Rainfall Map by DID (1976).

STEP 3

Determine the RE region of the catchment from the MAP B.

STEP 4

Compute the mean annual minimum flow (MAM) from the appropriate regional MAM equation.

STEP 5

Determine the RC region of the catchment from MAP A.

STEP 6

Obtain the various dimensionless ordinates $Q_{D,,T}$/MAM from the regional curves of the RC region determined in STEP 5.

STEP 7

Determine $Q_{D,T}$ by multiplying $Q_{D,T}$/MAM obtained in STEP 6 by the MAM computed in STEP 4.

3.3 Worked examples

3.3.1 Example 1

Derive the 7-day low flow frequency curve for an ungauged site on Sg. Lipis given the following information:

Catchment Mean Annual Rainfall = 2200 mm

Location of site: $4^0\ 00'$ N, $101^0\ 40'$ E

STEP 1

AREA = 130 km^2

STEP 2

MAR = 2200 mm

STEP 3

From MAP B, the site in located in RE 3.

STEP 4

Using regional MAM equation of RE 3

$$\begin{aligned} MAM &= 1.675 \times 10^{-16} (AREA)^{1.197} (MAR)^{3.856} \\ &= 1.675 \times 10^{-16} (130)^{1.197} (2200)^{3.856} \\ &= 0.439 \text{ cumecs} \end{aligned}$$

STEP 5

From MAP A, the site is located in RC 3

STEP 6

The $Q_{D,T}$/MAM values for RC 3 are given in Table 1.1 or Fig. 2.3

STEP 7

The 7-day low flow frequency curve at the Sg. Lipis station was computed by multiplying $Q_{D,T}$/MAM values obtained in STEP 6 by 0.439 (the MAM of this station). The ordinates of the derived curve are tabulated below:

Return Period T (years)	*7-day low flow, $Q_{7,T}$ (cumecs)*
1.5	0.58
2.33	0.44
5.0	0.31
10.0	0.25
20.0	0.21
50.0	0.17

TABLE 3.1: 7-DAY LOW FLOW ESTIMATES FOR SG. LIPIS AT 4^0 00'N $101^0$40'E

3.3.2 Example 2

Derive the annual D—day low flow frequency curve for Sungai Langat at Dengkil. (DID station no. 2816441).

In this case, 20 years of low flow records were available. The MAM computed from the records was 10.99 cumecs. The site is located in region RC 3. The annual D—day low flow frequency curve was developed from the dimensionless frequency curve of region RC 3 (see Fig. 2.3).

As a comparision, the individual station frequency analysis was also performed. The result of the two methods of analysis are summarised in Table 3.2 below.

Method of Analysis	*Duration D (days)*	*$Q_{D,T}$ (Cumecs) for return periods T years*					
		1.50	2.33	5.00	10.00	20.00	25.00
Regional Frequency Analysis	1	12.75	9.60	6.79	5.34	4.40	4.17
	4	13.87	10.46	7.44	5.89	4.90	4.67
	7	14.47	10.98	7.87	6.22	5.22	4.95
	30	19.98	15.34	11.00	8.75	7.28	6.81
Single Station Frequency Analysis	1	11.39	8.79	6.54	5.41	4.71	4.55
	4	12.10	9.58	7.27	6.08	5.32	5.10
	7	12.90	10.23	7.85	6.63	5.84	5.65
	30	18.21	15.15	11.68	9.37	7.50	6.97

TABLE 3.2: COMPARISON OF LOW FLOWS DERIVED BY REGIONAL FREQUENCY ANALYSIS AND LOW FLOWS DERIVED BY SINGLE STATION FREQUENCY ANALYSIS FOR STATION NO. 2816441

4. RELIABILITY OF THE PROCEDURE

4.1 General

In applying this procedure, it is important to consider the statistical reliability of the estimated low flows. Because of the complex nature of errors involved, a theoretical derivation of an expression for the standard error was not carried out here. However it is useful to discuss the various sources of errors and the likely magnitude of errors associated with them, so that users can subjectively evaluate the accuracy of any low flow estimates made. The sources of errors are discussed below.

4.2 Streamflow data errors

Uncertainties in the streamflow data are due to the following:

(i) Errors in measuring amd determining discharge.

This arises because of inaccuracies in gauging measurements, errors in calculations, unstable gauging control sections, etc. Such errors may be as large as 20 per cent or more. For most stations there are very few or no low flow gauging carried out. Thus, at low stages the rating curves are derived by extrapolation and this is subjected to large errors. The magnitude of the errors involved may be as large as 30 per cent.

(ii) Errors caused by upstream water abstraction.

Stations with considerable water abstraction in relation to the normal low flow revealed very erratic daily discharge hydrograph patterns. Since it was not possible to correct the measured flows for abstractions, data from stations with significant upstream draw-off, were excluded from the analysis.

4.3 Errors in discharge frequency analysis

In this study the type III extreme value distribution was used to represent the frequency distribution of low flows. The probability curves were fitted by the method of least squares. In each case, the goodness-of-fit of the theoretical distribution to the low flow data was inspected by eye. The error associated with the choice of the probability distribution and the method of fitting the distribution to the data is considered to be small.

According to Taylor and Goh (1976): "The length of records used in the frequency analysis has a significant effect on the accuracy of the derived low flow frequency curves in that there is some uncertainty associated with assigning recurrence intervals (or cumulative probabilities) to recorded data; the degree of uncertainty depending on the length of the records being analysed. The shorter the period of the record the greater the range of recurrence intervals which could be assigned to a particular low flow event."

Fig. 4.1 shows the variation in confidence limits of the assigned recurrence interval of a 15-year low flow as a function of record length. The limits shown on Fig. 4.1 define the range within which there is 67% probability that the true recurrence interval will lie. It is assumed that the possible recurrence intervals for a particular low flow event are normally distributed.

Since the station records used in this study were between 8 and 35 years, it can be seen that the possible error in the low flow frequency curves is considerable.

4.4 Errors in regionalization

The accuracy with which the low flow regions are defined depends largely on the density of gauged catchment over the area. Within a region any local variations in climate and geology will result in the true low flow charactertistics differing from those estimated from the regional relationship. The precision of the regression equations for estimating MAM can be judged by the correlation between the observed and predicted values of MAM in Table 4.1.

RE Region	*Correlation Coefficient Squared (R^2)*
RE 1	0.97
RE 2	0.96
RE 3	0.99

TABLE 4.1: CORRELATION BETWEEN OBSERVED AND PREDICTED MAM

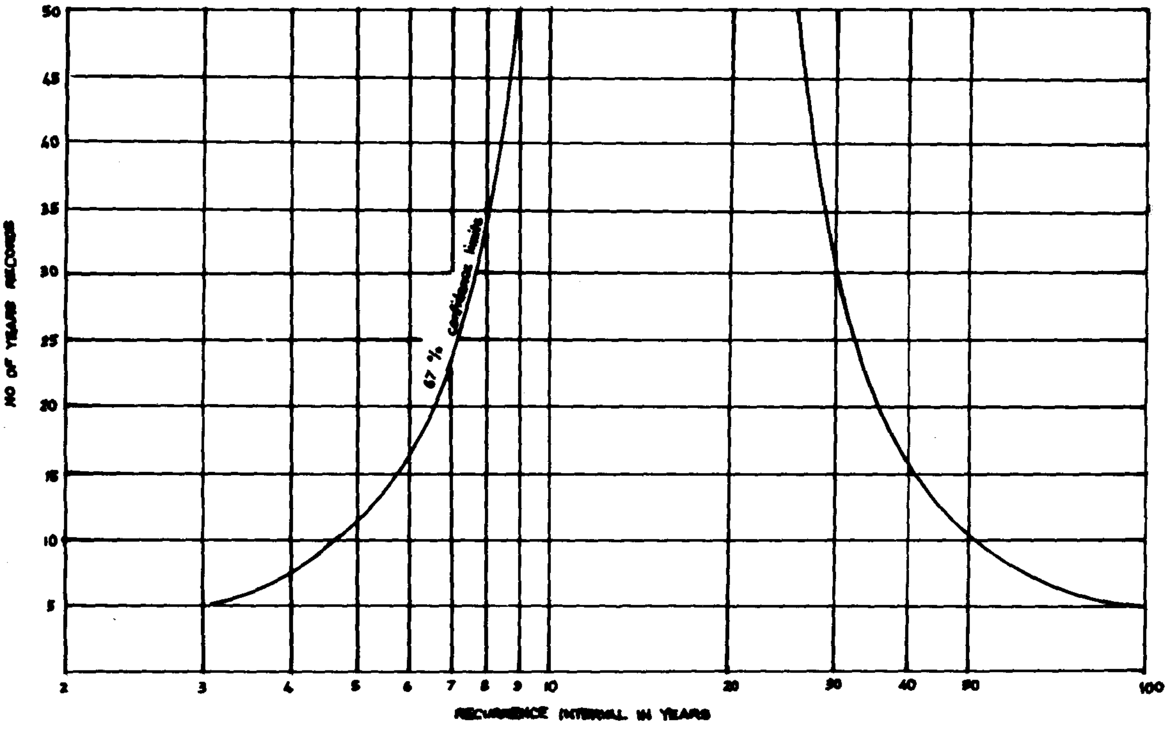

FIG. 4.1: CONFIDENCE LIMITS FOR 15-YEAR LOW FLOW

5. COMPARISON OF THIS PROCEDURE WITH OTHER LOW FLOW STUDIES IN PENINSULAR MALAYSIA

5.1 Comparison with HP 12 (1976)

The first edition of DID Hydrological Procedure No. 12—"Magnitude and Frequency of Low Flows in Peninsular Malaysia" by Taylor and Goh (1976) was developed based on streamflow data over the period 1948-1970. Since then more data have been collected and are available for analysis and hence the decision to review the procedure, In an attempt to improve upon it, a slightly different approach was adopted. This revised procedure therefore not only uses more data (i.e. data after 1970), but also contain some changes in its approach and analysis. Major differences in both procedures are highlighted as follows:

(i) **MORE STREAMFLOW DATA USED**

Additional data for the period 1971 to 1982 were used in the derivation of this procedure.

(ii) **DATA FROM SOME STATIONS USED IN HP 12 (1976) NOT INCLUDED IN THIS STUDY**

Difficulty was encountered in fitting the EVIII distribution to data from twelve stations used in HP 12 (1976). These twelve stations were not included in the derivation of this procedure.

(iii) **TWO REGIONAL MAPS**

In this procedure two maps were produced; one for the MAM equations, the other for the low flow frequency curves. The RE region demarcates areas which share the same MAM equation coefficients while the RC region demarcates areas in which a particular set of dimensionless flow frequency curves apply.

(iv) **LOW FLOWS OF MORE THAN 1 DAY WERE EXTRACTED AND ANALYSED**

In HP 12 (1976) low flows of more then 1 day duration were derived by extrapolating from regional recession curves. In this procedure, actual annual low flow data of various durations were analysed and frequency curves for low flows of various durations derived.

5.2 Comparison of results obtained using HP 12 (1985) and HP 12 (1976)

Listed below are the low flows estimated for some rivers in Peninsular Malaysia derived using both procedures.

(i) Site: Sg. Lipis at 4^0 00′ N, 101^0 40′ E

Catchment Area (AREA) = 130 km.^{2} (50 sq. mile).

Mean annual rainfall (MAR) = 2,200 mm. (86.6 in.)

HP 12 (1985): Regions RC 3 and RE 3

HP 12 (1976): Region R3.

$$MAM = 1.675 \times 10^{-16} (130)^{1.197} (2200)^{3.856}$$
$$= 0.439 \text{ cumecs}$$

From HP 12 (1976) the characteristic value, v (the 1.5 year return period minimum flow) is:

$$V = 9.9 \times 10^{-5} (50)^{0.93} (86.6)^{2.05}$$
$$= 35.28 \text{ cusecs } (1.00 \text{ cumecs})$$

The low flows computed are as follows:

Return Period	*7-day low flow, $Q_{7,T}$ (cumecs)*	
(years)	*HP 12 (1985)*	*HP 12 (1976)*
1.5	0.58	1.56
5.0	0.31	0.87
10.0	0.25	0.68
20.0	0.21	0.56

(ii) Site: Sg. Muda at DID station No. 6007415

Catchment area (AREA) = 1220 km^2 (476 sq. miles).

Mean annual rainfall (MAR) = 2145 mm (84 inches)

HP 12 (1985): Regions RC 1 and RE 1

HP 12 (1976): Region R3

$$MAM = 1.097 \times 10^{-8}(1220)^{1.092}(2145)^{1.663}$$
$$= 8.926 \text{ cumecs.}$$
$$V = 9.9 \times 10^{-5}(476)^{0.93}(84)^{2.05}$$
$$= 272.5 \text{ cusecs } (7.72 \text{ cumecs})$$

The low flows computed are as follows:

Return Period	*7-day low flow, $Q_{7,T}$ (cumecs)*	
(years)	*HP 12 (1985)*	*HP 12 (1976)*
1.5	11.36	9.65
5.0	6.75	3.83
10.0	5.69	2.46
20.0	5.04	1.73

(iii) Site: Sg. Batang Padang at DID station No. 4112456
Catchment area (AREA) = 375 km.^{2} (146 sq. miles).
Mean annual rainfall (MAR) = 2800 mm (110 inches)
HP 12 (1985): Region; RC 2 and RE 2
HP 12 (1976): Region; R2

$$MAM = 1.675 \times 10^{-10} (376)^{0.92} (2800)^{2.387}$$
$$= 6.631 \text{ cumecs}$$
$$V = 5.3 \times 10^{-2} (146)^{1.06} (110)^{0.56}$$
$$= 145.1 \text{ cusecs } (4.11 \text{ cumecs})$$

The low flows computed are as follows:

Return Period (years)	*7-day low flow, $Q_{7,T}$ (cumecs)*	
	HP 12 (1985)	*HP 12 (1976)*
1.5	9.02	4.91
5.0	4.82	2.69
10.0	3.69	2.12
20.0	2.91	1.74

5.3 Comparison with other low flow studies in Peninsular Malaysia.

Scarf (1977) in his study "Water Resources for Irrigation of Upland Areas in South Kelantan" derived the low flow characteristics of several rivers in South Kelantan. The 30-day low flows for rivers in Pasir Puteh-Besut region estimated by Scarf are given in Table 5.1. As a comparison, the 30-day low flows for these rivers were also estimated using this procedure. All the rivers are located in RE region 1 and RC region 1. The results are tabulated in Table 5.2. and it shows that the values obtained using this procedure are fairly close to the values obtained by Scarf.

River	*Tributary*	*Site*	*Area (km^2)*	*Average 30 consecutive day low flow m^3/sec for return period 1:T years*					*Remarks*
				1:2.33	*1:5*	*1:10*	*1:50*	*1:100*	
Besut		Jerteh[1]	790	11.9	9.2	7.6	4.9	4.1	(1) Based on extremal analyses of low flow records.
	Angga	Headworks	77	1.16	0.90	0.74	0.48	0.40	(2) Excludes flow from Sg. Angga.
	Besut	Rantau Panjang[2]	640	9.64	7.45	6.15	3.97	3.32	(3) Accurate estimation difficult because of continual padi usage and accuracy probably not better than ± 30%.
	Pelagat	Rawang Panjang	57	0.86	0.66	0.55	0.35	0.30	
Yong		Pulau Lima[3]	54	0.81	0.63	0.52	0.34	0.28	
	Yong	Bt. Yong	28	0.42	0.33	0.27	0.17	0.15	
	Gaal	Gaal[3]	12	0.18	0.14	0.11	0.08	0.06	
Rasau		Pasir Puteh	83	1.25	0.97	0.80	0.52	0.43	
	Taweh	Taweh	25	0.38	0.29	0.24	0.16	0.13	
	Jeram	Jeram	15	0.23	0.17	0.14	0.09	0.08	
	Telosan	Gong Kelih	13	0.20	0.15	0.13	0.08	0.07	
Semerak		Pasir Puteh[3]	220	1.2	1.0	0.8	0.5	0.4	

TABLE 5.1: AVERAGE 30 CONSECUTIVE DAY LOW FLOW FOR RIVERS IN THE PASIR PUTEH—BESUT REGION SOURCE: SCARF (1977)

River	Tributary	Site	Area (km^2)	MAR (mm)	MAM (cumecs)	Average 30—day low flow for Return Period 1: T years (cumecs)			
						1:2.33	1:5	1:10	1:50
Besut		Jerteh	790	3135	9.87	12.59	9.95	8.20	5.77
	Angga	Headworks	77	3250	0.87	1.15	0.89	0.77	0.64
	Besut	Rantau Panjang	640	3000	7.71	10.19	7.90	6.81	5.64
	Pelagat	Rawang Panjang	57	3200	0.61	0.81	0.63	0.54	0.45
Yong		Pulau Lima	54	3150	0.56	0.74	0.58	0.50	0.41
	Yong	Bt. Yong	28	3000	0.25	0.33	0.26	0.22	0.18
	Gaal	Gaal	12	3000	0.10	0.13	0.10	0.09	0.07
Rasau		Pasir Puteh	83	3050	0.85	1.13	0.87	0.75	0.62
	Taweh	Jeram	25	3000	0.22	0.30	0.23	0.20	0.16
	Jeram	Jeram	15	3100	0.14	0.18	0.14	0.12	0.10
	Telosan	Gong Kelih	13	3050	0.11	0.15	0.12	0.10	0.08
Semerak		Pasir Puteh	220	3050	2.47	3.26	2.53	2.18	1.80

TABLE 5.2: THE MAM AND THE 30—DAY LOW FLOWS DERIVED USING THIS PROCEDURE

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APPENDIX I

The general extreme value distribution

The pdf of the general extreme value (GEV) distribution may be written as:

$$f(x) = (1/x)\,[1-k(x-u)/x]^{1/k-1}\, e^{-[1-k\,(x-u)/x]^{1/k}}$$

where u = location parameter
x = scale parameter
k = shape parameter

The corresponding cdf is given by

$$f(x) = e^{-(1-k[x-u]/x)^{1/k}}$$

There ia a family of GEV distributions, each characterized by the value of the shape parameter k. The family can be divided into three classes, corresponding to different ranges of the k value.

(i) $k = O$ corresponds to the type I extreme value distribution (EVI)

(ii) $k < O$ corresponds to the type II extreme value distribution (EVII)

(iii) $k > O$ corresponds to the type III extreme value distribution (EVIII)

FIG I.1 shows how the three types of extreme value distributions are related to one another.

As can be seen from Fig. I.1, EVIII has a lower bound but no upper bound, EVIII has a upper bound but no lower bound, while EVI is a straight line and unbounded. EVI and EVII are usually used for the analysis of flood flow while EVIII is used for low flow frequency analysis.

Using the Jenkinson equation, the low flow for return period T, Q_T is given by:

$$Q_T = u + wx$$

where $W = 1\,[I - \exp(-\,ky_T)]$ = modified frequency factor.

Y = reduced variate at return period T

X = scale parameter

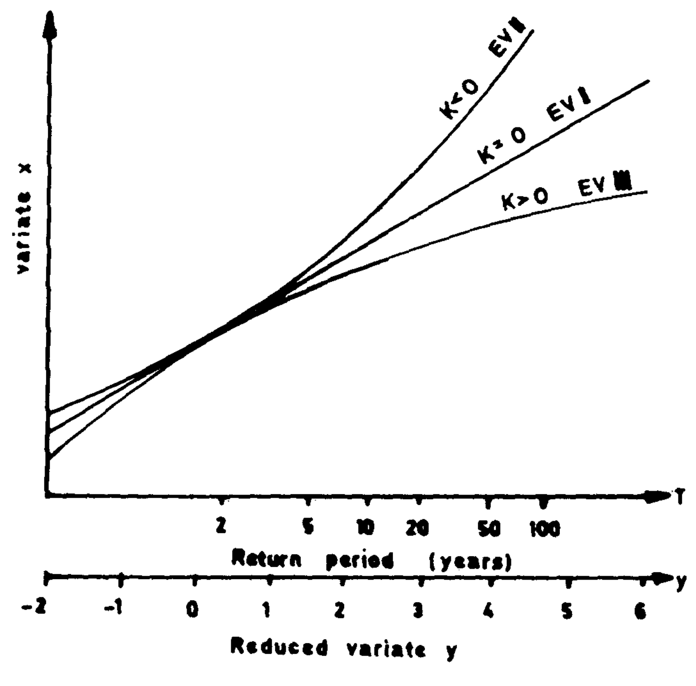

FIG. I·1: EXTREME VALUE DISTRIBUTIONS

APPENDIX II

List of Catchments and Catchment Characteristics

Station No.	River	Station	Length of records (years)	Catchment Area (km^2)	Catchment Mean Annual Rainfall (mm)	Observed MAM (cumecs)	Predicted MAM (cumecs)	Region RE	Region RC	Upstream water Extraction
1737451	Sg. Johor	Rantau Panjang	19	1130	2455	8.791	8.893	3	1	Negligible
2224432	Sg. Kesang	Chin Chin	20	161	1875	0.257	0.306	3	3	Considerable
2237471	Sg. Lenggor	Bt. 42 Kluang-Mersing	17	207	2815	1.581	1.978	3	3	Negligible
2322415	Sg. Durian Tunggal	Bt. 11 Air Resam	8	73	1900	0.104	0.124	3	3	Nil
2519421	Sg. Linggi	Sua Betong	32	523	2175	3.720	2.218	3	3	Some
2528414	Sg. Segamat	Segamat	11	658	1990	8.417	2.979	3	3	Considerable
2816441	Sg. Langat	Dengkil	20	1240	2455	10.990	9.877	3	3	Considerable
2917442	Sg. Langat	Kajang	21	380	2675	6.364	6.025	2	2	Considerable
2918443	Sg. Semenyih	Semenyih	27	210	2565	3.616	3.158	2	2	Nil
2920432	Sg. Triang	Kg. Chenor	22	228	1875	1.305	1.612	2	3	Some
3022431	Sg. Triang	Juntai	25	904	2200	7.447	8.387	2	3	Some
3116433	Sg. Gombak	Jln. Pekeliling	21	122	2600	1.304	1.979	2	2	Negligible
3116434	Sg. Batu	Sentol	14	145	2625	1.955	2.373	2	2	Negligible
3414421	Sg. Selangor	Rantau Panjang	32	1450	2680	17.907	20.752	2	1	Negligible
3424411	Sg. Pahang	Temerloh	16	19000	2250	133.534	179.742	3	3	Negligible
3519426	Sg. Bentong	Jam. Kuala Marong	11	241	2375	4.130	2.983	2	3	Nil
3615412	Sg. Bernam	Tanjong Malim	30	186	2750	3.426	3.335	2	1	Negligible
3813411	Sg. Bernam	Jambatan SKC	15	1090	2770	17.287	17.268	2	1	Negligible
3813414	Sg. Trolak	Trolak	26	66	2800	1.205	1.338	2	2	Negligible
3814413	Sg. Slim	Kg. Slim	17	314	2610	4.690	4.767	2	2	Nil
3814415	Sg. Bil	Jln. Tg. Malim-Slim	33	41	2665	0.937	0.769	2	1	Negligible
3911457	Sg. Sungkai	Jln. Anson-Kampar	24	479	2875	6.789	8.856	2	1	Negligible
3913456	Sg. Sungkai	Sungkai	30	289	2685	4,985	4.725	2	2	Negligible
4012452	Sg. Bidor	Bt. 18, Jln. Anson	30	339	3000	5.641	7.132	2	2	Negligible
4019462	Sg. Lipis	Benta	15	1670	2290	13.795	10.870	3	3	Some
4111455	Sg. Batang-Padang	Tg. Keramat	12	445	2900	10.18	8.419	2	2	Diversion of water into river
4112456	Sg. Batang-Padang	Tapah	27	376	2800	8.965	6.630	2	2	Diversion of water into river
4121413	Sg. Jelai	Stn. Tele Jeram Bungor	8	7320	2390	75.000	74.996	3	3	Negligible
4311464	Sg. Kampar	Kg. Lanjut	34	432	2525	2.449	5.887	2	2	Negligible
4324454	Sg. Tembeling	Stn. Tele K. Tahan	11	2700	2165	17.068	15.530	3	3	Negligible
4410461	Sg. Kinta	Batu Gajah	24	1054	2305	12.256	10.797	1	2	Some
4410465	Sg. Raja	Ldg. Kinta Kellas	24	251	2375	3.573	3.097	2	2	Negligible

List of Catchments and Catchment Characteristics—(Continued)

Station No.	River	Station	Length of records (years)	Catchment Area (km²)	Catchment Mean Annual Rainfall (mm)	Observed MAM (cumecs)	Predicted MAM (cumecs)	Region RE	Region RC	Upstream water Extraction
4510462	Sg. Kinta	Ipoh	21	313	2375	2.361	2.384	1	2	Negligible
4610466	Sg. Pari	Jln. Silibin Ipoh	15	245	2315	2.109	1.748	1	1	Some
4611463	Sg. Kinta	Tg. Rambutan	33	246	2305	1.640	1.750	1	2	Negligible
4809443	Sg. Perak	Stn. Tele Jam. Iskandar	26	7770	2120	71.878	66.110	1	1	Considerable
4907422	Sg. Kurau	Bt. 14, Jln. Taiping	35	80	3000	0.721	0.796	1	1	Some
4911445	Sg. Plus	Kg. Lintang	26	1090	2300	11.277	8.825	1	1	Nil
5007421	Sg. Kurau	Pondok Tanjong	34	337	3150	3.141	4.132	1	1	Some
5007423	Sg. Ara	Bt. 20, Jln. Taiping	28	140	3000	2.195	1.460	1	1	Some
5106431	Sg. Krian	Dusun Rimau	14	694	3000	9.997	8.385	1	1	Negligible
5106433	Sg. Ijok	Titi Ijok	15	216	3210	1.793	2.624	1	1	Considerable
5130432	Sg. Terengganu	Kg. Tanggol	18	3340	2690	46.248	38.888	1	1	Negligible
5206432	Sg. Krian	Selama	15	629	2930	11.546	7.270	1	1	Negligible
5402421	Sg. Kulim	Ara Kuda	26	129	2800	2.558	1.195	1	1	Nil
5505412	Sg. Muda	Ladang Victoria	9	4010	2300	22.447	36.593	1	1	Considerable
5506416	Sg. Sedim	Merbau Pulas	25	440	2835	4.601	4.641	1	1	Negligible
5506417	Sg. Karangan	Titi Karangan	11	83	3100	1.271	0.871	1	1	Nil
5721442	Sg. Kelantan	Stn. Tele Guillemard	24	11900	2430	151.249	131.487	1	1	Negligible
5724411	Sg. Besut	Jambatan Jerteh	20	787	3135	9.868	10.350	1	1	Negligible
5806414	Sg. Muda	Jeniang	22	1710	2185	11.218	13.250	1	1	Considerable
6019411	Sg. Golok	Rantau Panjang	17	761	2875	6.022	8.639	1	4	Negligible
6022421	Sg. Kemasin	Peringat	17	48	2875	0.321	0.423	1	4	Nil

APPENDIX III

Results of Individual Station Frequency Analysis

STATION No.	DURATION (D) (DAYS)	$Q_{D,T}$ (CUMECS) T = 1.1	T = 1.5	T = 2.33	T = 5.0	T = 10.0	T = 20.0	T = 50.0
1737451	1	17.610	9.6788	6.5601	4.7045	4.0946	3.8286	3.6841
	4	19.763	11.150	7.5997	5.3824	4.6130	4.2612	4.0601
	7	20.977	11.978	8.2178	5.8357	4.9955	4.6062	4.3802
	30	30.531	15.358	11.085	9.2742	8.8711	8.7448	8.6966
2224432	1	.53116	.28640	.18045	.11048	.08499	.07252	.06516
	4	.69037	.35326	.21161	.12181	.08980	.07507	.06629
	7	.62040	.32606	.20142	.12096	.09235	.07875	.07082
	30	.87394	.49830	.30963	.16431	.10085	.06516	.03994
2237471	1	2.2824	1.8453	1.5125	1.1139	.83229	.59377	.32521
	4	2.3575	1.9802	1.6649	1.2462	.91671	.60992	.22606
	7	2.5397	2.1187	1.7725	1.3215	.97337	.65439	.26289
	30	4.1065	3.0578	2.4467	1.8983	1.6139	1.4300	1.2765
2322415	1	.20085	.12493	.08640	.05609	.04278	.03513	.02975
	4	.22748	.14703	.10368	.06799	.05099	.04079	.03314
	7	.24448	.16686	.12040	.07734	.05439	.03909	.02606
	30	.43938	.31076	.24221	.18612	.15977	.14419	.13229
2519421	1	5.5331	4.2598	3.4252	2.5754	2.0703	1.7025	1.3530
	4	6.0023	4.5856	3.6626	2.7292	2.1785	1.7802	1.4037
	7	6.5632	4.8802	3.8363	2.8346	2.2762	1.8918	1.5479
	30	9.8569	7.2249	5.5555	3.9147	2.9765	2.3156	1.7096
2528414	1	11.980	9.9246	8.1904	5.8694	4.0244	2.2924	.10340
	4	12.442	10.343	8.7901	6.9904	5.7612	4.7510	3.6513
	7	12.563	10.534	9.0136	7.2244	5.9830	4.9490	3.8059
	30	13.521	11.575	10.031	8.0969	6.6643	5.3994	3.9082
2816441	1	16.543	12.415	9.9663	7.7246	6.5374	5.7558	5.0901
	4	17.308	13.243	10.766	8.4337	7.1601	6.2986	5.5431
	7	18.062	13.997	11.452	8.9867	7.5977	6.6331	5.7609
	30	22.467	18.229	15.164	11.695	9.3856	7.5297	5.5586
2917442	1	9.7578	7.2867	5.7473	4.2635	3.4320	2.8572	2.3405
	4	10.152	7.7997	6.2255	4.5861	3.5881	2.8465	2.1241
	7	10.790	8.1759	6.5028	4.8425	3.8830	3.2008	2.5691
	30	13.858	9.5241	7.5020	6.0649	5.4890	5.1907	4.9958
2918443	1	5.8504	4.3334	3.2958	2.1898	1.4994	.97507	.45184
	4	6.3521	4.9484	3.9164	2.7275	1.9210	1.2620	.54929
	7	6.6592	5.1932	4.1190	2.8856	2.0521	1.3734	.64193
	30	7.5802	6.0431	4.9312	3.6720	2.8334	2.1595	1.4433
2920432	1	2.1912	1.4422	1.0768	.80482	.69008	.62805	.58527
	4	2.2907	1.5091	1.1535	.90708	.81133	.76289	.73201
	7	2.4218	1.6224	1.2357	.95014	.83088	.76686	.72323
	30	3.1564	2.3108	1.8068	1.3433	1.0966	.93314	.79348
3022431	1	10.469	8.7609	7.3425	5.4762	4.0193	2.6728	1.0011
	4	10.879	9.2249	7.8360	5.9870	4.5255	3.1601	1.4445
	7	11.524	9.7178	8.2428	6.3377	4.8793	3.5547	1.9414
	30	14.8	12.478	10.679	8.4841	6.9023	5.5397	3.9759
3116433	1	2.2235	1.4966	1.0969	.75921	.59547	.49575	.41728
	4	2.3657	1.6292	1.2170	.86204	.68612	.57705	.48980
	7	2.4459	1.7343	1.3263	.96601	.78272	.66629	.57054
	30	3.0793	2.2975	1.8025	1.3170	1.0399	.84504	.66686
3116434	1	2.9941	2.3552	1.8586	1.2510	.81133	.43144	—
	4	3.3306	2.6212	2.0586	1.3547	.83371	.37394	—
	7	3.5960	2.8130	2.2008	1.4470	.89802	.42068	—
	30	4.3688	3.4915	2.7909	1.9082	1.2496	.66487	—

Results of Individual Station Frequency Analysis—*(Continued)*

STATION No.	*DURATION (D) (DAYS)*	$Q_{D,T}$ *(CUMECS)*						
		T = 1.1	*T = 1.5*	*T = 2.33*	*T = 5.0*	*T = 10.0*	*T = 20.0*	*T = 50.0*
3414421	1	23.015	19.878	17.482	14.607	12.569	10.840	8.8878
	4	23.274	20.699	18.373	15.015	12.125	9.2170	5.2425
	7	23.966	21.270	18.883	15.514	12.683	9.8924	6.1663
	30	32.466	26.580	22.920	19.397	17.427	16.067	14.846
3424411	1	256.24	157.21	107.12	68.399	51.356	41.797	34.967
	4	266.08	174.67	122.45	76.525	53.247	38.492	26.437
	7	276.46	180.52	127.64	82.896	61.142	47.845	37.404
	30	390.75	217.99	154.19	118.61	107.74	103.29	101.03
3519426	1	6.5116	4.7448	3.7079	2.7703	2.2799	1.9606	1.6921
	4	6.7020	5.0419	3.9867	2.9476	2.3516	1.9312	1.5445
	7	7.0068	5.2215	4.1164	3.0589	2.4711	2.0671	1.7068
	30	8.0235	6.1411	4.9428	3.7598	3.0802	2.5997	2.1572
3615412	1	5.0062	3.9329	3.1994	2.4190	1.9329	1.5637	1.1960
	4	5.3326	4.1989	3.4864	2.7929	2.4003	2.1266	1.8779
	7	5.5623	4.4711	3.7773	3.0938	2.7014	2.4246	2.1703
	30	6.7816	5.5079	4.6385	3.7136	3.1377	2.7011	2.2663
3813411	1	23.025	19.384	16.672	13.506	11.327	9.5235	7.5450
	4	23.924	19.821	16.956	13.834	11.839	10.291	8.7110
	7	25.122	20.490	17.428	14.280	12.392	11.004	9.6720
	30	32.545	25.1	20.991	17.507	15.811	14.772	13.955
3813414	1	2.1059	1.3751	.98980	.67847	.53484	.45099	.38810
	4	2.2839	1.5416	1.1181	.74618	.55807	.43881	.34164
	7	2.3609	1.5955	1.1686	.80255	.62181	.50992	.42096
	30	2.6629	1.9028	1.4431	1.0133	.78074	.62465	.48867
3814413	1	8.1201	5.6870	4.1331	2.5943	1.7071	1.0779	.49660
	4	8.2853	5.9153	4.3708	2.8079	1.8856	1.2181	.58697
	7	8.5340	6.1057	4.5249	2.9278	1.9864	1.3062	.66402
	30	9.6569	7.7414	6.2637	4.4703	3.1847	2.0819	.82295
3814415	1	1.3436	1.0459	.86147	.68499	.58669	.51926	.45892
	4	1.3870	1.0918	.90822	.73173	.63314	.56516	.50397
	7	1.4572	1.1263	.93173	.75439	.66147	.60057	.54929
	30	1.5731	1.2677	1.0864	.92040	.83258	.77450	.72521
3911457	1	11.090	5.8635	5.0751	4.8943	4.8751	4.8717	4.8711
	4	11.454	6.2388	5.4649	5.2901	5.2717	5.2686	5.2680
	7	12.190	6.9686	6.1244	5.9173	5.8932	5.8890	5.8878
	30	16.760	10.544	8.4309	7.3479	7.0476	6.9343	6.8816
3913458	1	7.4119	5.7504	4.6255	3.4405	2.7096	2.1603	1.6190
	4	7.8059	6.0422	4.9156	3.8006	3.1578	2.7020	2.2807
	7	8.3765	6.4496	5.2578	4.1178	3.4847	3.0499	2.6623
	30	9.8575	7.7898	6.5340	5.3561	4.7153	4.2833	3.9059
4012453	1	8.7405	6.7462	5.2941	3.6388	2.5283	1.6300	.66856
	4	8.9935	7.1102	5.6768	3.9618	2.7510	1.7266	.57394
	7	9.2771	7.4405	6.0031	4.2309	2.9391	1.8150	.51048
	30	11.723	9.7816	8.1717	6.0572	4.4099	2.8898	1.0062
4019462	1	22.346	16.249	12.399	8.6309	6.4861	4.9824	3.6096
	4	23.907	17.095	12.903	8.9147	6.7116	5.2071	3.8725
	7	25.047	17.644	13.198	9.0751	6.8606	5.3847	4.1102
	30	29.416	21.761	16.844	11.948	9.1057	7.0793	5.1949
4111455	1	13.857	11.626	9.8966	7.7870	6.2663	4.9561	3.4524
	4	15.654	13.141	11.349	9.3521	8.0445	7.0088	5.9261
	7	17.223	14.315	12.307	10.146	8.7824	7.7368	6.6830
	30	19.435	16.020	14.026	12.230	11.296	10.691	10.184

Results of Individual Station Frequency Analysis—*(Continued)*

STATION No.	DURATION (D) (DAYS)	$Q_{D,T}$ (CUMECS) T = 1.1	T = 1.5	T = 2.33	T = 5.0	T = 10.0	T = 20.0	T = 50.0
4112456	1	14.256	10.440	8.0278	5.6666	4.3215	3.3779	2.5161
	4	15.175	11.288	8.7921	6.3079	4.8669	3.8399	2.8853
	7	16.063	12.003	9.3870	6.7725	5.2496	4.1601	3.1433
	30	18.561	14.242	11.350	8.3380	6.5034	5.1391	3.8096
4121413	1	88.908	77.712	68.085	54.931	44.243	34.011	20.802
	4	95.684	83.346	72.979	59.165	48.236	38.016	25.162
	7	102.93	86.496	74.132	59.523	49.345	40.830	31.378
	30	131.78	103.09	84.461	65.677	54.633	46.670	39.171
4311464	1	4.3076	2.8490	2.0694	1.4303	1.1303	.95241	.81728
	4	4.9575	3.2813	2.4110	1.7201	1.4065	1.2261	1.0935
	7	5.5003	3.7975	2.8470	2.0320	1.6300	1.3810	1.1830
	30	8.5530	6.0042	4.6796	3.6258	3.1470	2.8708	2.6677
4324454	1	43.054	18.310	11.097	7.9343	7.2006	6.9632	6.8694
	4	44.885	19.217	12.098	9.1278	8.4776	8.2773	8.2023
	7	48.440	23.501	14.790	10.200	8.8861	8.3771	8.1331
	30	60.918	32.816	21.850	15.377	13.268	12.356	11.863
4410461	1	20.701	13.386	9.9827	7.5714	6.6079	6.1108	5.7864
	4	22.293	14.263	10.537	7.9045	6.8561	6.3164	5.9654
	7	23.569	14.912	11.004	8.3204	7.2850	6.7666	6.4394
	30	30.425	19.592	14.464	10.766	9.2589	8.4677	7.9419
4410465	1	6.4034	4.2238	2.9731	1.8683	1.3054	.94674	.65269
	4	7.1269	4.6388	3.2127	1.9550	1.3150	.90822	.57479
	7	7.8017	5.0493	3.4595	2.0453	1.3193	.85411	.46941
	30	10.137	6.3890	4.3646	2.6875	1.8907	1.4133	1.0467
4510462	1	4.1278	2.7773	1.9938	1.2938	.93286	.70057	.50737
	4	4.1759	2.8666	2.1082	1.4312	1.0824	.85836	.67252
	7	4.3071	2.9586	2.1938	1.5269	1.1918	.98102	.81020
	30	6.3465	4.0700	2.9074	1.9994	1.5952	1.3663	1.2008
4610466	1	4.2975	2.1295	1.5309	1.2822	1.2280	1.2116	1.2054
	4	4.4130	2.3025	1.6555	1.3567	1.2833	1.2581	1.2479
	7	4.6147	2.5309	1.8105	1.4348	1.3283	1.2878	1.2683
	30	5.7666	3.3898	2.4824	1.9589	1.7926	1.7221	1.6850
4611463	1	3.0357	1.9360	1.3246	.80227	.54589	.38754	.26204
	4	3.2011	2.1320	1.5059	.94108	.64646	.45496	.29433
	7	3.4422	2.3266	1.6697	1.0737	.76091	.55666	.38414
	30	5.0068	3.3088	2.3586	1.5416	1.1374	.88640	.68612
4809443	1	107.18	81.645	65.572	49.904	41.020	34.813	29.168
	4	116.52	87.974	72.050	58.400	51.669	47.503	44.189
	7	123.59	92.712	76.577	63.671	57.773	54.356	51.825
	30	148.53	117.67	95.365	70.151	53.385	39.925	25.645
4907422	1	1.2986	.82096	.57649	.38499	.29972	.25127	.21615
	4	1.4496	.91331	.64476	.43966	.35042	.30085	.26572
	7	1.5728	.99773	.70793	.48442	.38640	.33173	.29263
	30	2.3660	1.5977	1.1839	.84164	.67960	.58272	.50850
4911445	1	16.742	12.868	10.362	7.8459	6.3734	5.3159	4.3241
	4	17.539	13.665	11.144	8.5949	7.0921	6.0057	4.9799
	7	18.249	14.454	11.907	9.2465	7.6212	6.4096	5.2258
	30	24.786	19.034	15.410	11.873	9.8663	8.4623	7.1844

Results of Individual Station Frequency Analysis—*(Continued)*

STATION No.	DURATION (D) (DAYS)	$Q_{D,T}$ (CUMECS) T = 1.1	T = 1.5	T = 2.33	T = 5.0	T = 10.0	T = 20.0	T = 50.0
5007421	1	4.8496	3.5289	2.7734	2.1076	1.7697	1.5552	1.3796
	4	5.4017	4.0425	3.2156	2.4380	2.0142	1.7278	1.4771
	7	6.0433	4.3487	3.4190	2.6354	2.2561	2.0252	1.8450
	30	9.2416	6.9856	5.5476	4.1272	3.3102	2.7323	2.1994
5007423	1	3.7493	2.4289	1.7887	1.3150	1.1164	1.0096	.93683
	4	4.3034	2.6620	1.9278	1.4283	1.2377	1.1431	1.0839
	7	4.2606	2.7071	2.0261	1.5728	1.4037	1.3212	1.2711
	30	5.6178	3.8688	3.0340	2.4263	2.1762	2.0439	1.9550
5106431	1	15.282	11.346	9.0425	6.9652	5.8822	5.1790	4.5892
	4	15.705	11.893	9.6312	7.5601	6.4626	5.7399	5.1241
	7	16.322	12.507	10.279	8.2742	7.2320	6.5567	5.9915
	30	24.959	16.569	13.181	11.108	10.405	10.090	9.9142
5106433	1	3.4592	1.8382	1.3748	1.1754	1.1300	1.1156	1.1099
	4	3.9720	1.9541	1.5212	1.3816	1.3589	1.3533	1.3518
	7	4.5414	2.2688	1.7229	1.5255	1.4890	1.4793	1.4759
	30	8.5898	4.1890	2.8895	2.3119	2.1759	2.1314	2.1136
5130432	1	76.288	49.663	38.830	32.154	29.872	28.842	28.261
	4	78.794	54.272	42.928	34.940	31.769	30.143	29.089
	7	82.536	58.346	46.134	36.713	32.575	30.258	28.606
	30	105.29	75.386	58.876	44.879	38.061	33.886	30.601
5206432	1	16.343	13.293	11.025	8.3807	6.5646	5.0640	3.4207
	4	16.940	13.718	11.352	8.6297	6.7864	5.2824	3.6578
	7	18.274	14.244	11.638	9.0212	7.4901	6.3904	5.3595
	30	25.449	18.310	14.550	11.516	10.116	9.2989	8.6881
5405421	1	4.3598	2.7079	2.0275	1.6025	1.4552	1.3878	1.3493
	4	4.4674	2.8173	2.1170	1.6663	1.5045	1.4283	1.3836
	7	4.5844	2.9153	2.2008	1.7365	1.5683	1.4884	1.4408
	30	5.0380	3.4292	2.7011	2.2003	2.0065	1.9091	1.8476
5505412	1	42.478	25.833	18.361	13.262	11.308	10.335	9.7244
	4	44.519	27.078	19.124	13.607	11.454	10.365	9.6697
	7	46.163	28.527	20.075	13.899	11.344	9.9873	9.0728
	30	60.193	34.622	23.442	16.019	13.260	11.922	11.107
5506416	1	6.9725	5.2541	4.1754	3.1269	2.5340	2.1210	1.7462
	4	7.2853	5.4550	4.3198	3.2309	2.6241	2.2065	1.8331
	7	7.7892	5.6550	4.4176	3.3127	2.7431	2.3768	2.0725
	30	9.9198	7.1691	5.5989	4.2195	3.5210	3.0788	2.7176
5506417	1	1.9754	1.5045	1.1768	.82125	.59518	.42040	.24278
	4	2.0176	1.5224	1.2079	.89802	.72011	.59490	.47960
	7	2.0482	1.5717	1.2725	.98187	.81756	.70340	.59972
	30	2.3178	1.8671	1.5652	1.2501	1.0584	.91558	.77620
5721442	1	230.04	175.74	139.30	101.27	78.059	60.764	43.877
	4	243.57	182.86	144.51	106.97	85.597	70.607	56.919
	7	253.49	191.12	151.76	113.28	91.403	76.076	62.097
	30	316.73	234.08	185.14	140.43	116.81	101.29	88.092
5724411	1	13.240	10.933	9.3745	7.7340	6.7241	5.9663	5.2198
	4	13.861	11.493	9.8365	8.0280	6.8694	5.9691	5.0482
	7	14.407	12.059	10.358	8.4292	7.1422	6.1062	5.0037
	30	17.561	14.491	12.311	9.8901	8.3119	7.0663	5.7700

Results of Individual Station Frequency Analysis—(*Continued*)

STATION No.	*DURATION (D) (DAYS)*	$Q_{D,T}$ *(CUMECS)*						
		T = 1.1	*T = 1.5*	*T = 2.33*	*T = 5.0*	*T = 10.0*	*T = 20.0*	*T = 50.0*
5806414	1	16.710	12.769	10.263	7.7935	6.3768	5.3768	4.4569
	4	17.188	13.152	10.557	7.9697	6.4666	5.3938	4.3952
	7	17.653	13.553	10.913	8.2771	6.7428	5.6459	4.6229
	30	21.278	16.397	13.245	10.086	8.2411	6.9181	5.6796
6019411	1	10.908	7.3309	5.1584	3.1207	2.0122	1.2654	.61275
	4	11.533	7.6538	5.3538	3.2504	2.1374	1.4051	.78187
	7	12.073	7.9994	5.5983	3.4161	2.2691	1.5193	.88499
	30	16.664	10.769	7.3201	4.2110	2.5915	1.5402	.65892
6022421	1	.60935	.39518	.26827	.15212	.09065	.05014	.01586
	4	.62663	.41275	.28357	.16261	.09745	.05354	.01530
	7	.65467	.43144	.29660	.17025	.10170	.05581	.01586
	30	.81133	.53881	.37479	.22181	.13909	.08385	.03598

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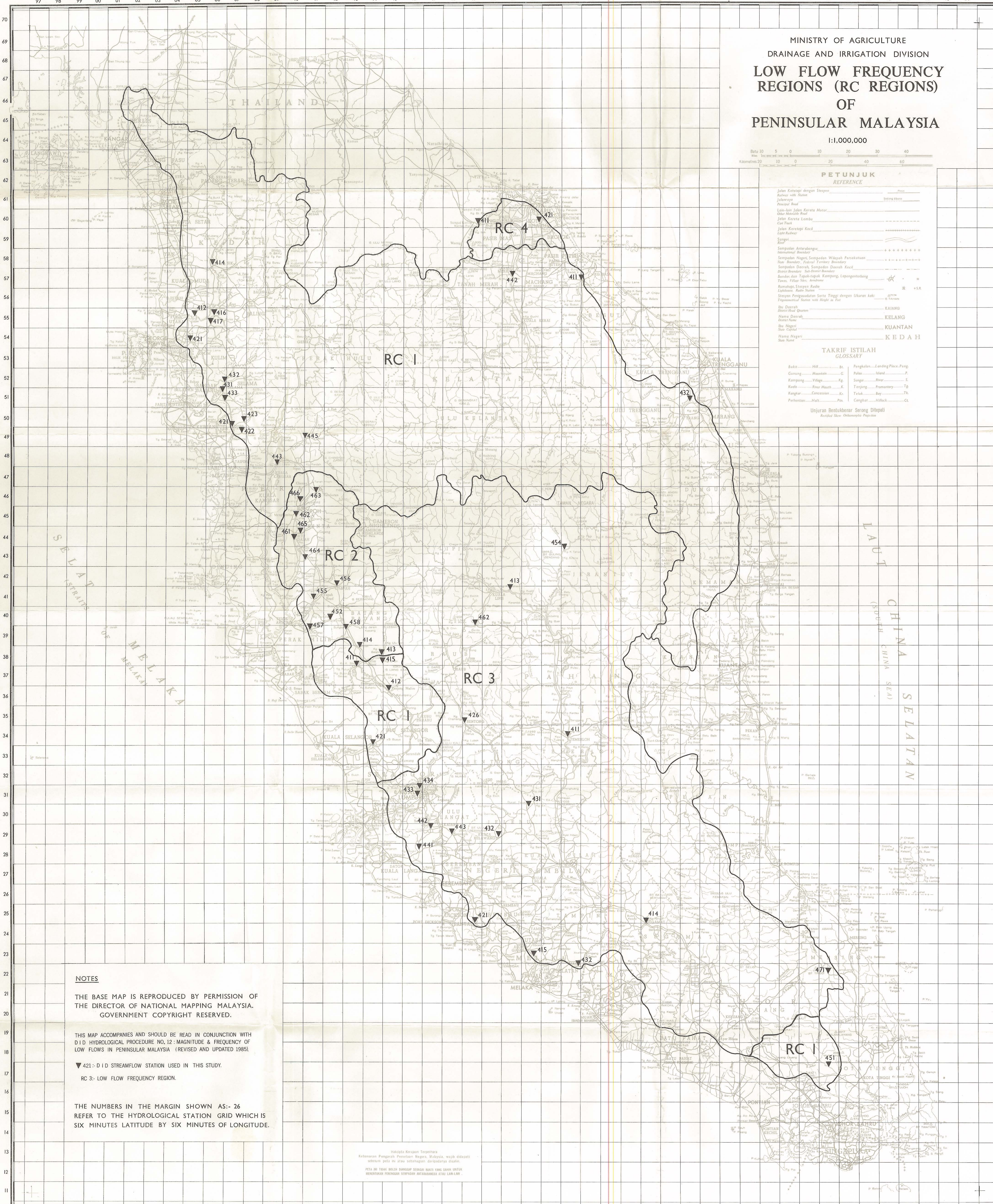
L—78835.

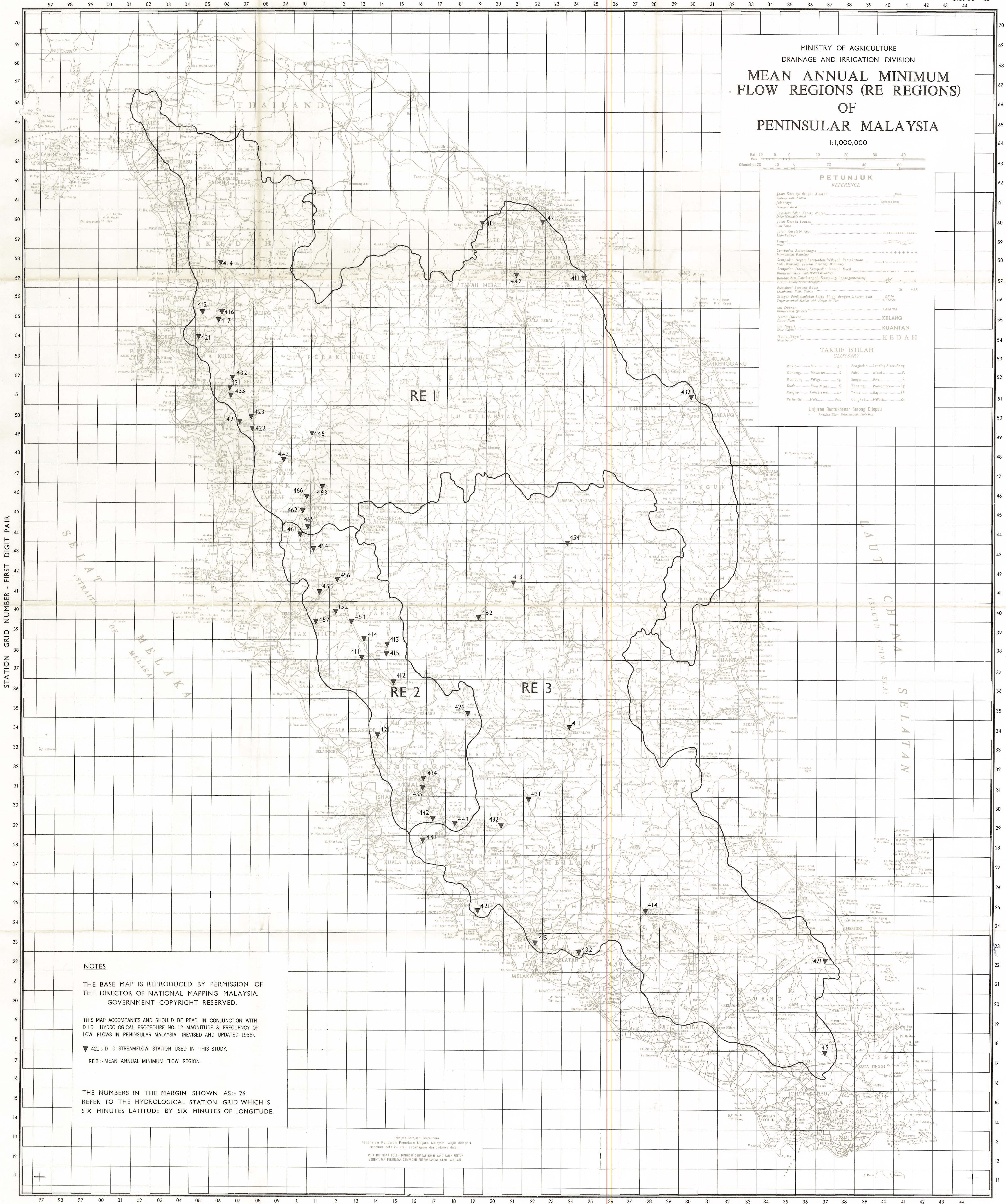
MAP A



STATION GRID NUMBER - SECOND DIGIT PAIR

Dicetak oleh Direktorat Pemetaan Negara, Malaysia No. 220-85.

MAP B



MINISTRY OF AGRICULTURE
DRAINAGE AND IRRIGATION DIVISION
MEAN ANNUAL MINIMUM FLOW REGIONS (RE REGIONS) OF PENINSULAR MALAYSIA
1:1,000,000
Batu Miles
Kilometres
PETUNJUK
REFERENCE
Jalan Keretapi dengan Stesyen / Railway with Station
Jalanraya / Principal Road
Lain-lain Jalan Kereta Motor / Other Motorable Road
Jalan Kereta Lembu / Cart Track
Jalan Keretapi Kecil / Light Railway
Sungai / River
Sempadan Antarabangsa / International Boundary
Sempadan Negeri, Sempadan Wilayah Persekutuan / State Boundary, Federal Territory Boundary
Sempadan Daerah, Sempadan Daerah Kecil / District Boundary Sub-District Boundary
Bandar dan Tapak-tapak Kampung, Lapanganterbang / Towns, Village Sites, Aerodrome
Rumahapi, Stesyen Radio / Lighthouse, Radio Station
Stesyen Penigasudutan Serta Tinggi dengan Ukuran kaki / Trigonometrical Station with Height in Feet
Ibu Daerah / District Head Quarters ... KAJANG
Nama Daerah / District Name ... KELANG
Ibu Negeri / State Capital ... KUANTAN
Nama Negeri / State Name ... KEDAH
TAKRIF ISTILAH
GLOSSARY
Bukit ... Hill ... Bt.
Gunung ... Mountain ... G.
Kampung ... Village ... Kg.
Kuala ... River Mouth ... K.
Kangkar ... Concession ... Kr.
Perhentian ... Halt ... Ptn.
Pengkalan ... Landing Place ... Peng.
Pulau ... Island ... P.
Sungai ... River ... S.
Tanjung ... Promontory ... Tg.
Teluk ... Bay ... Tk.
Cangkat ... Hillock ... Ct.
Unjuran Bentukbenar Serong Ditepati
Rectified Skew Orthomorphic Projection
THAILAND
RE 1
RE 2
RE 3
SELAT MELAKA (STRAITS OF MELAKA)
LAUT CHINA SELATAN (SOUTH CHINA SEA)
NOTES
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THIS MAP ACCOMPANIES AND SHOULD BE READ IN CONJUNCTION WITH DID HYDROLOGICAL PROCEDURE NO. 12: MAGNITUDE & FREQUENCY OF LOW FLOWS IN PENINSULAR MALAYSIA (REVISED AND UPDATED 1985).
▼ 421 :- DID STREAMFLOW STATION USED IN THIS STUDY.
RE 3 :- MEAN ANNUAL MINIMUM FLOW REGION.
THE NUMBERS IN THE MARGIN SHOWN AS:- 26 REFER TO THE HYDROLOGICAL STATION GRID WHICH IS SIX MINUTES LATITUDE BY SIX MINUTES OF LONGITUDE.
STATION GRID NUMBER - FIRST DIGIT PAIR
STATION GRID NUMBER - SECOND DIGIT PAIR