HYDROLOGICAL PROCEDURE NO. 1

ESTIMATION OF THE DESIGN RAINSTORM IN PENINSULAR MALAYSIA

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

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(REVISED AND UPDATED)

Jabatan Pengairan dan Saliran
Kementerian Pertanian Malaysia

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FORWARD

Hydrological Procedure No. 1 (HP 1) for the estimation of design rainstorms, since its publication in 1973, has been very widely used by government agencies and the private sectors concerned with flood problems. More specifically the procedure has been used in conjunction with other procedures (HP 5, HP 11, HP 16 and HP 18) to arrive at design flood estimates for the purpose of determining appropriate structure type and size for proper drainage and other control measures in both urban and rural areas.

The development of the first edition of HP 1 was based on data from 80 rainfall stations with records up to 1970. Since then new rainfall stations have been added and record lengths have increased. It therefore becomes pertinent to revise and update the procedure with a view of improving its reliability in estimating the design rainstorms. This updated procedure is based on data from 210 stations with records extended to 1979.

For convenience of users, the arrangement and presentation of the new edition is kept as similar as possible to the previous edition. However, a few changes were made in respect of data treatment and isopleth constructions for short duration rainfall. These changes are discussed in the Introduction.

SYNOPSIS

This procedure has three parts. Part I describes the theory and methodology used for the frequency analysis for the 210 station records used in the study. The development of the working tools of the procedure, based on the results of Part I, is presented in Part II. The final form of the procedure is collected in Part III, with step by step instructions for the users, and some relevant comments regarding use, summarised from the more detailed aspects discussed in Parts I and II. Whilst Part III has been designed to present all the information necessary to estimate the design rainstorm, it is recommended that Part I and II be used as necessary background reading to illustrate the limitations of the method proposed.

CONTENTS

PART I

FREQUENCY ANALYSIS OF SHORT DURATION RAINFALL DATA

1. INTRODUCTION

1.1 General

This part of the procedure is intended to serve as background material for users primarily concerned with Parts II and III. Basic statistical concepts are presented for those readers with no experience in the theory and application of statistics to engineering problems, although the treatment is necessarily brief.

The methodology and results of the frequency analysis, and the inherent limitations of the procedural details as presented in Part III, are discussed in some detail. It is important for users to be aware of the problem of uncertainty in hydrological design, so that the practical implications to the design of structures can be properly appreciated.

The user accustomed to the HP 1 should note the changes made in this edition which are as listed below:–

(i) Adjustment of calendar-day multiples of rainfall.

The 24 hr. maximum rainfall based on daily data with fixed starting observation time were adjusted by factors of 1.16 (East Coast) and 1.12 (West Coast) while the 48 hr. and 72 hr. maximum rainfalls similarly obtained were adjusted by 1.08 and 1.06 respectively to approximate the true maximum rainfalls. (Please see section 4.4).

(ii) Omission of correlation study to obtain short duration rainfalls for stations with only daily rainfall records.

The number of recording raingauge stations used for obtaining the short duration rainfall (< 24 hr.) has increased from 48 in the previous edition (HP 1) to 104 in this edition. The areal coverage is considered to be sufficient for construction of the key isopleths.

(iii) Use of 3 hr. instead of 2 hr. duration rainfalls for key isopleths.

For reason of availability in the extracted data, the key isopleths for short duration rainfalls are based on ½ hr. and 3 hr. annual maximums.

(iv) Metric units are used instead of British Imperial units.

As some users of this procedure could be interested in knowing the temporal distribution of the estimated design rainstorm, a study on temporal storm pattern was carried out based on nine selected rainfall stations. The study results are attached as Appendix D for reference by interested users.

1.2 Notation

Most of the statistical terms used are defined within the context of their presentation. It is useful at this point, however, to introduce the notation used in connection with the design rainstorm:–

(i) X(T, t) is the rainfall depth (in mm) of a storm with an estimated return period of T years and having a duration of t hours. Note that return period is defined in Section 2.2.

(ii) X(20, 3) hence represents the depth of a '20 year storm' lasting for 3 hours.

(iii) X(20) denotes the '20 year' estimate of the storm whose duration is specified elsewhere (i.e. not needed in the context of the presentation).

2. OUTLINE OF THEORY

2.1 General

The use of recording raingauge data as a basis for a procedure to estimate the design rainstorm involves probability theory. The particular theory used in this study is known as the Gumbel Theory of Extreme Values, and a great deal has been written about the theory and its use for the solution of many practical problems (Gumbel, 1960). The development of this procedure follows closely the methods used in many overseas countries for the treatment of short duration rainfall data (Robertson, 1963: Reich, 1963).

In this section the theoretical aspects pertinent to the study are outlined briefly. For a more detailed treatment reference should be made to the papers given above.

2.2 Probability and Return Period

A sample of hydrological data may be a continuous records or a series of discrete events over the period of measurement. The data are termed historic data, in that they result from natural phenomena and are not repeatable, as distinct from some types of experimental data which may occur under controlled conditions and may be repeatable.

Probability theory is related to the study of the chance of occurrence of the phenomena based on the sampled data. As is probably obvious, the greater the length of a data record in time, the more confident one can be about estimates of the probability of occurrence of the phenomena, assuming that the conditions affecting the data do not change with time.

2.2.1 Probability Considerations of Hydrological Events within a Sample

If we consider a hydrological variable, such as rainfall, and denote it by X, then an individual value of X can be denoted as x(e.g. x = 50mm). The observations of X over a certain period may be regarded as statistical trials, and the values of the variable $X(= x_1, x_2, x_3, ..)$ can be considered to be random variables. Hydrological variables are both random and continuous, in that they can take "every possible" value over a certain range. The hydrological variable being considered in this study is defined for discrete time periods (e.g. ¼, 3, 24 hr. rainfall depths). Hence for each time period there is a continuous random variable X_t (t = ¼, 3, 24 etc.).

The occurrence of a value of the variable within a certain range is called an event. The number of occurrences of an event in a total population of events, is called the frequency of the event. For example, the event may be defined as the number of days in the month when the rainfall was equal to or less than 100 mm (denote this number by r). The population may be considered to be the number of days in the months, denoted by L. The probability of the event (that is of daily rainfall being equal to or less than 100 mm) is $\frac{r}{L}$

$$\text{Rewriting this } P(x) = \frac{r}{L}$$

Where P(x) is the probability that $X \leqslant x$ (in this case $X \leqslant 100$ mm).

Pursuing this aspect a little further, we can reason that the number of days in the month when the daily rainfall is either equal to or less than 100 mm, or greater than 100 mm, equals the total number of days in the month.

$$\text{i.e. } P(X \leqslant x) + P(X > x) = \frac{L}{L} = 1$$

$$\therefore P(X > x) = 1 - P(X \leqslant x) = 1 - P(x)$$

The estimates of the probability of occurrence of particular values of the phenomena can be expressed as 'return period estimates'. The return period is the average interval of time (in years) between the years that contain an event greater than or equal to the one under consideration. That is, if the return period of a 3 hr. rainstorm depth of 100 mm is 5 yrs., then this indicated that an average period of 5 yrs. will elapse between the occurrence of a 3 hr. rainstorm with depths greater than or equal to 100 mm.

The relationship between return period and probability is defined by

$$T(X) = \frac{1}{1 - P(x)} \qquad (1)$$

where $P(x)$ = probability that $X \leqslant x$ (as above) in any one year.

2.2.2 Probability Considerations of Taking Samples of Hydrological Events from the Population

For the particular record (1 month) considered above, make $r = 27$ and $L = 30$.

$$\text{Then } P(x) = \frac{27}{30} = 0.9$$

This means that if we selected one value at random from the month record (say by selecting one daily card from 30 cards), there is a $\frac{9}{10}$ chance that it would be a day with rainfall equal to or less than 100 mm.

It would be even less likely to draw 2 cards, independently, from the month and find both of them $\leqslant$ 100 mm. The probability of this event = $P(x).P(x)$

$$= \frac{9}{10} \times \frac{9}{10} = \frac{81}{100} = 0.81$$

It can be shown that, for a large population from which N independent observations are made, each with a probability of $P(x)$, the probability that they will all fail to exceed the value of x is $[P(x)]^N$ (let us call this $P_N(x)$). That is, if a sample of N values is selected from the population at random, $P_N(x)$ is the probability that the largest value in the sample $\leqslant$ x.

Hence, if we select n random samples from the population, each of size N, the series or largest values (from each sample) forms a set of random variable $x_1, x_2, \ldots x_n$ whose probability function is $P_N(x)$. The distribution of the largest values can be seen to depend upon N (the size of sample), and the form of the initial distribution $P(x)$.

2.2.3 Extreme Value Theory

It is the new population, that of the largest value in group of samples of size N drawn from the parent population, that is now our concern. Gumbel has shown that if the size of the sample, N, is very large, the distribution of the largest values in each sample is not dependent on the exact form of the initial distribution. For a large number of common initial distributions it tends towards one of three forms.

The Gumbel type I distribution has been assumed to represent the form of the distribution of the largest depth of storm rainfall of a particular duration, for each selected 12 month period. This distribution has a probability relationship of:

$$P(x) = \exp(-e^{-y}) \qquad (2)$$

$$\text{where } y = \alpha(x - \mu) \qquad (3)$$

y is known as the 'reduced variate' and α and μ are parameters which may be estimated from the observed largest values.

2.3 Application of Gumbel Theory to Short Duration Rainfall Analysis

The assumption of the mathematical form of the probability distribution of the annual maximum rainfall (Equation (2)) makes possible.

(i) Estimates of values of the variate for a particular probability of occurrence.

(ii) Assessment of the confidence that can be placed upon such estimates.

2.3.1 Gumbel Extreme Probability Paper

The method used in this study (one of several available) to estimate the parameters of the assumed probability distribution involves the the use of special probability plotting paper. Probability distributions of the Gumbel Type I, plot as straight lines on this paper. The horizontal axis of the plotting paper can be presented showing three related scales.

(i) A linear y scale (y being the reduced variate)

(ii) A probability scale on which the graduations are related to the linear y scale by Equation (2).

(iii) A return period scale related to the probability scale by equation (1). The vertical scale is a linear scale of the value of the variate. The method consists of plotting the data points on the plotting paper and of fitting a straight line to the plotted points.

2.3.2 Plotting Position

To plot data with a particular real measured value on the plotting paper, they must be assigned a return period. This is done by ranking the data in descending order (highest to lowest) and assigning each data value a rank (m), giving rank (m = 1) to the largest value, rank (m = 2) to the second largest value, and so on.

The return period estimate for plotting purposes is calculated using one of the various formulate discussed by Gumbel (1960):

$$T = \frac{n+1}{m} \qquad (4)$$

where T is the return period in years and n is the number of annual maximum values of the phenomena.

2.3.3 Fitting a Straight Line to the Plotted Points

A straight line is fitted to the plotted points by the modified least square method where both the vertical and horizontal departures are minimised. This is expected to give better fitting than the classical least square method where only vertical or horizontal departures are minimised.

2.3.4 Confidence of Estimates made from Data

The computed value of an event for a certain return periods is not the "real" value, and has a certain statistical uncertainty attached to it. This uncertainty is normally expressed by plotting two control curves on either side of the plotted line. The position of these curves is such that the vertical distance from the line to each curve is equal to the standard error of the m^{th} ranked observation, drawn from a population whose cumulative probability function is represented by the theoretical line.

If the plotted data points lie within the control curves, which are constructed from the estimated parameters of the assumed cumulative probability function, the fit of the data points to the theoretical line is considered satisfactory. The implication of the control curves can be expressed in another way. Having accepted the reasonableness of the theoretical approximation, it is useful to know the confidence that may be afforded to estimates of rainfall depth made for various return periods. A vertical line from a particular return period cuts the theoretical line and the two control curves. The estimate is then the value for the theoretical line intersection, with 2/3 probability that the confidence band contains the value.

It has been shown (Robertson, 1963) that the control curves can be constructed in the following way:–

(i) Read off X_{20} and X_2 from the fitted line (refer to Section 1.2 for a definition of these terms).

(ii) Compute $D = X_{20} - X_2$

(iii) Compute standard error (vertical distance from the fitted line to the control curves) according to the following table.

Table 1: – Data used for the Construction of Control Curves for Fitted Gumbel Type I Distribution

Return period T (yrs.)	2	5	10	20	n	50
Standard error	$\frac{0.54D}{\sqrt{n}}$	$\frac{0.86D}{\sqrt{n}}$	$\frac{1.23D}{\sqrt{n}}$	$\frac{1.73D}{\sqrt{n}}$	0.43D	0.43D

(iv) This table applies strictly only when $n \geqslant 20$.

(v) For $n < 20$, the control parallels the extrapolated section of the line at a distance equals to 0.43D after $T = n$. This applies to much of the data used for this study. Of the total of 210 stations, 128 have records less than 20 years.

3. DESCRIPTION OF RECORDING RAINGAUGE DATA

The data used in this investigation come from recording raingauges operated by the Drainage and Irrigation Department (D.I.D.) and the Malaysian Meteorological Services (M.M.S.)

3.1. D.I.D. Recording Raingauge Data

Up to the end of 1980, 268 D.I.D. recorder stations have been established in Peninsular Malaysia. Many of the recorders, especially the newly established have records too short for useful analysis. Some records of adequate length had to be discarded because of significant amount of data gaps. Overall, the areal coverage of the usable recorder stations has increased tremendously and is adequate for the study except for certain interior areas east of the Main Range.

Table 2: – Summary of D.I.D. Recording Raingauges used in the Study

Type of recorder	No. of station used in analysis
Kent Daily	7
Kent Weekly	17
Kent Monthly	1
Hattori Daily	5
Hattori Weekly	27
Hattori Long Term	17
Ota Weekly	6
Capricorder	24
Total	104

3.2 MMS Recording Raingauge Data

The MMS has the responsibility for the collection of climatic data throughout Peninsular Malaysia, and operates a number of 1st and 2nd order climate stations. Recording raingauges form part of this programme, and data from 11 such MMS stations are incorporated in this study. The stations are equipped with Dines tilting syphon recording raingauge fitted with daily charts. Full details of each station and its data are given in Appendix A.

4. DATA EXTRACTION AND GUMBEL ANALYSIS

4.1 DID Data (0–12 hrs.)

Rainfall recorded charts submitted from the field are subjected to routine checking and data extraction. For each storm that occurs the maximum depth for durations of ¼, ½, 1, 3, 6, 9 & 12 hours have been extracted. From these data, and for the period of record used in the analysis, the maximum rainfall depth for each duration was listed, for each 12 month period from 1 July to 30 June.

4.2 MMS Data (0 – 24 hrs)

Extracted data for maximum depths for each 12 month period for durations of ¼, ½, 1, 2, 3, 4, 5, 6, 12 & 24 hours was supplied by the MMS for the 11 MMS stations incorporated in this investigation.

4.3 Data Analysis

The data were analysed according to the theory outlined in Section 2. The calculations, plotting of the data and drawing of the fitted line as well as the goodness of fit test based on Chi-square and Smirnov-Kolmogorov methods for each set of data were conducted on Nova 1220 computer. The computers output consisted of plots on extreme probability paper and listings of estimated depth of storm of a certain duration for return period of 2, 5, 10, 20 and 50 years. The listings for each station record analysed are given in Appendix B.

4.4 Data for 24, 48, 72 hr. Durations

Storms with durations greater than 12 hours are of importance to flood problems of many catchments, so a special extraction operation was carried out to find the annual maximum values for these 3 durations for each station record (> 5 yrs) included in the investigation. These data were analysed and the result presented in Appendix B in an identical fashion to that described in para 4.3. Note that unlike previous edition, the 24, 48 and 72 hr annual maximums based on calendar-day rainfalls have been adjusted by certain factors to approximate the true maximums. This aspect is discussed further in Section 5.3.

5. DISCUSSION OF THE RESULTS OF DATA ANALYSIS

5.1 Errors

Recording errors resulting from partial blockage of the recorder funnel, poor syphoning and errors in the time base, are often difficult to detect. Gross errors in total volume recorded on a daily basis can be found from records of the manual check gauges used for most installations. Other errors are often obvious from the recorder trace, and can be allowed for. The errors that are present in the data due to volume recording are not serious.

A more serious and irremoveable error is introduced by poor resolution of the chart time scale, especially for short durations. Much of the data used are from Kent weekly recorders with a chart time scale of 56.5 mm/24 hr. or 2.35 mm/hr. The Hattori weekly recorders which replaced most of the Kent recorders have a chart timescale of 43.0 mm/24 hr. or 1.79 mm/hr. Depending on the rainfall intensity, errors of manual reading or of processing through digitiser can reach 15% for storm depths extracted for durations of ¼ and ½ hr. Concurrently, misalignment of the pen/float shaft can cause errors in the time scale of the record, which may not be systematic. The combined maximum likely error in depth estimates (from these two causes for short duration rainfall is not likely to exceed 20% with lesser errors for storms of longer duration.

5.2 Uncertainty

The most serious limitation to the usefulness of this investigation is still the short period of record of data available. This aspect can only be remedied with the passage of time. The treatment of the confidence limit calculations outlined in Section 2.3.4 does however, allow the goodness of fit of the sampled data to the theory to be assessed using visual criteria. The chi-square and the Smirnov-Kolmogorov tests serve further confirmation of goodness of fit. More importantly, the confidence of the estimates made from the data can be expressed quantitatively. Several examples of the scale of this uncertainty for stations used in the investigation are given in Table 3, calculated using the relationship listed in Section 2.3.4.

Table 3: – Examples of the Uncertainty of X(T, t) Values from Actual Records

Stn. No.	Years of record (n)	Storm duration (hrs.)	Computed estimates X_{20} (mm)	X_2 (mm)	D (mm)	Estimate and 2/3 probability range for return period shown (mm) 2 Yrs.	10 Yrs.	20 Yrs.
4708084	18	1	81	57	24	57± 3	74± 7	81± 10
		6	114	74	40	74± 5	103± 12	114± 17
		24	140	94	46	94± 6	127± 13	140± 20
4120064	10	1	79	56	22	56± 4	72± 9	78± 9
		6	131	82	49	82± 8	118± 19	131± 21
		24	227	123	104	123± 18	198± 41	227± 45
5105051	5	1	84	48	36	48± 9	74± 16	84± 16
		6	140	81	59	81± 14	124± 25	140± 25

The order of the uncertainty of the estimates can be appreciated from the above figures, with the effect of the period of record on confidence estimates amply demonstrated by the range for Station No. 5105051 (5 yrs. record).

5.3 Adjustment of 24, 48 and 72 hour Annual Maximums based on Calendar-day Rainfalls

As could be seen from Appendix A many of the rainfall stations used for this study are manually observed at a certain fixed time on a daily basis. Besides data from recorder stations collected in earlier years were processed into a midnight – midnight daily format. Maximum rainfalls of 24 hour or its multiples based on these calendar – day data would in most cases be less than the true maximums. For the purpose of finding out such differences, a study was carried out based on data (1970/71 – 78/79) from 25 recording raingauge stations throughout Peninsular Malaysia.

For each station and each duration (24, 48, 72 hrs.) three sets of annual maximum rainfall depths were extracted, this being 8.00 a.m. to 8.00 a.m., midnight to midnight and irrespective of the starting time, the last set representing the true annual maximums. Comparison of these three sets of data shows that the non-fixed observation time rainfall exceeds those with fixed starting time by significant amount for all the three durations concerned, whereas there is no significant difference between the two sets with fixed observation time. Further there is a significant difference (at 95% confidence level) between stations East and West of Main Range for the 24 hour maximums. The results of the study are summarised below:–

24 hr. annual maximum rainfall:

$$\frac{\text{Non-fixed starting time}}{\text{Fixed starting time}} = 1.12 \text{ (West of Main Range) and } 1.16 \text{ (East of Main Range).}$$

48 hr. annual maximum rainfall:

$$\frac{\text{Non-fixed starting time}}{\text{Fixed starting time}} = 1.08$$

72 hr. annual maximum rainfall:

$$\frac{\text{Non-fixed starting time}}{\text{Fixed starting time}} = 1.06$$

In view of the above results the rainfall data with fixed observation time used in this study are accordingly adjusted.

6. REVIEW OF ANALYSIS AND REQUIREMENTS OF A PROCEDURE

6.1 Review of Analysis

The previous Sections have dealt with the theory of extreme values used in the analysis; a description of the recording raingauge data, its extraction and analysis, the errors and uncertainties in the data and the analysis, and the results of studies carried out to derive adjustment factors for rainfall depth based on calender-day observation. All this is preliminary to the formulation of a procedure that allows the estimate of X(T, t) for any point in the country. Before outlining the development of the components of the procedure in Part II of this report, the requirements of such a procedure are discussed below.

6.2 Requirements of a Procedure

For the purposes of engineering design, the procedure must allow two distinct estimates to be made. Firstly, having specified the storm duration and return period of interest, estimates of storm intensity or total storm depth must be possible. Secondly, a pre-knowledge of storm characteristics (duration and depth) must allow an estimate of the return period of that storm.

The first situation is the most common. The critical storm duration(s) and return period(s) used as input to the procedure are discussed in detail in later publications. The second situation may arise when the return period or probability of occurrence of an important historic rainfall (of which some data is available) is required.

The procedure must allow estimates to be made based on geographic location alone (once the necessary inputs have been specified) and present little difficulty or opportunity for confusion when used by people at the sub-professional level.

There are uncertainties associated with rainfall estimates even for locations with data, because of the short period of record available compared with the longer return period estimates required for engineering design purposes. An estimation procedure should, as far as possible, preserve the reliability of estimates for locations where such data are available and indicate the likely errors in the estimate for all locations.

Finally, it should be possible to update the data-dependent aspects of the procedure as greater coverage of data are obtained in time and space.

PART II

DEVELOPMENT OF THE PROCEDURE

1. INTRODUCTION

A procedure of this type possesses two general features, regardless of the detailed methodology adopted:

(i) it presents in some form the results of the actual data analysis; and

(ii) it includes techniques to allow the reconstruction of a complete set of depth-duration-frequency estimates for any location within the area covered by the procedure.

There are several ways in which these two requirements have been met in the preparation of procedures in other countries. The type of procedure developed in this study is similar in most respects to that used in New Zealand (Robertson, 1963). Topographically there is much similarity between the Peninsular of Malaysia and the islands of New Zealand, and although the climatic regions are different, both areas are characterised by a similar coastline to land area ratio. These similarities are substantiated by the success of the application of the New Zealand procedural details to Peninsular Malaysia. The other traditional procedural forms (Reich, 1963; Institution of Engineers (Aust. 1958) have been applied to the large continental land areas with some success.

The first component in the procedure is a series of maps of Peninsular Malaysia, each one showing "key" isopleth values (particular values of X(T, t). The purpose of this component is to allow key value estimates to be made at locations away from the recording stations – it therefore represents an estimation in space.

Having the capability of estimating key values for any location, provision must be made to reconstruct the full depth – duration – frequency estimates for the location. The second component of the procedure is a depth-duration plotting diagram, which is characterised by a straight-line relationship between the key values having the same return period. That is, if all the key values are known for the same return period, estimates can be made for any duration. The duration scale of this plotting diagram is distorted, and is discussed further in Section 3.2.

All that remains to complete the estimates, is to be capable of making estimates of X(T, t) for the same duration, but different return periods. This is achieved by using the Gumbel Extreme Probability Paper described in Part I, Section 2.3.1. This component of the procedure is known as the depth-frequency plotting diagram and its use represents an estimate in time (between years).

2. COMPONENT ONE – THE ISOPLETH MAPS

2.1 Description

The key values of X(T, t) defined in the procedure are:

(i) X(2, ½)
(ii) X(20, ½)
(iii) X(2, 3)
(iv) X(20, 3)
(v) X(2, 24)
(vi) X(20, 24)
(vii) X(2, 72)
(viii) X(20, 72)

The key value estimates were plotted initially for each location on a 1:500,000 map of Peninsular Malaysia. Isopleths were drawn using linear interpolation between the plotted points. For the purpose of presentation the 8 isopleth maps have been reduced to scale of 1:2,650,000.

These maps allow key values to be estimated at any location, and are reproduced as Figure 1 – 8 in Part III.

2.2 Discussion

The west coast is reasonably well covered by rainfall recording stations for elevation below 150 metres. The errors introduced by linear interpolation would appear to be no greater than the uncertainties inherent in the data, except where steep isopleth gradients are indicated. Areal coverage on the east coast is not as dense, with very little recording raingauge data away from the lowland coastal areas. This sparse coverage forces isopleth construction to extend the influence of actual data for long distances, and errors are very likely. The magnitude of the errors in the coastal regions, especially for durations less than 5 hours, should not be serious, as gradients of isopleths are not steep.

3. COMPONENT TWO – RAINFALL DEPTH-DURATION PLOTTING DIAGRAM

3.1 Description

It is necessary to allow the depth of storm of the same return period (2 or 20 yrs.) to be estimated for durations other than those of the key values. From overseas studies (Reich, 1963; Robertson, 1963) it seemed likely that a special duration scale could be computed to linearise the relationship of depth-duration scale between the key values. For such a solution to be satisfactory, the same duration scale must be suitable for linearising depth-duration relations for all return periods.

From the Gumbel analysis results in Appendix B, all the 5 yr. return period estimates of storm depth for the computed durations were listed, using stations with records > 5 years. For each duration (t), period of record (n), and for each station, a weighted storm depth was calculated as follows:

Weighted value of $X(5, t) = n\ [x(5, t)]$ (11)

The weighted values for each duration were computed, summed for all stations, and divided by the sum of all the recora years for the stations used, to find the average depth for each duration.

The average depth-duration values for a storm with a return period of 5 years so calculated are shown in Table 4:–

Table 4: Weighted Average Depth – Duration Pattern for X(5, t)

		key			key			key		key
Duration (hr)	¼	½	1	2	3	6	12	24	48	72
Depth (mm)	34.9	52.2	73.0	94.5	102.0	119.6	146.0	186.4	238.0	273.8

This average 5 yr. storm pattern was used to compute the distorted storm duration scale so that all the points calculated would plot as a straight line between the key values.

The dimensionless duration scales for the linearisation of these depth-duration values between the key values are shown in Table 5:–

Table 5:– Scale Factors for the Construction of the Depth-Duration Plotting Diagram

Duration (hr.)	¼	½	1	2	3	6	12	24	48	72
Scale Factors (0–3) hr range	0	0.26	0.57	0.89	1.00					
Scale Factors (3–24) hr range					0	0.21	0.52	1.00		
Scale Factors (24–72) hr range								0	0.59	1.00

3.2 **Discussion**

The final form of a depth-duration plotting diagram constructed according to the scale factors shown in 3.1 is given in Appendix E. An assessment of the reliability of the diagram for return periods other than 5 years, using 2 yr and 20 yr data, was carried out.

For all the stations used in the preparation of the diagram, the key values for 2 yr, and 20 yr, return periods were plotted on the diagram and straight lines drawn between them. The computed values for intermediate durations were plotted on the same diagram, and the goodness of fit for each plot assessed. A summary of the errors associated with this diagram is shown in Appendix C. The results are encouraging, especially in view of the length of the period of record used to construct and check the duration scale distortion. The errors involved are within the order of those associated with other aspects of this investigation, and are acceptable. Considerable improvement could be expected when the details of the diagram are recomputed in the light of new data.

4. COMPONENT THREE – RAINFALL DEPTH – FREQUENCY PLOTTING DIAGRAM

4.1 **Description**

The extreme probability paper used in the analysis of the data is presented as Appendix F. This becomes the third component of the procedure for presenting depth-frequency or depth return period relationship of storms of the same duration.

4.2 **Discussion**

The use of the Gumbel Type I distribution to represent the depth-frequency relationship of annual maximum storm events is well established. Studies carried out in Malaysia (Lockwood, 1967) and overseas (Reich, 1963) have reported good agreement between recorded phenomena and the theory.

PART III

THE PROCEDURE AND ITS USE

1. INTRODUCTION

Part III of this procedure contains the results of the studies outlined in Parts I and II, presented in a form amenable to everyday use. Included also in Part III are sections dealing with the more important findings documented previously, especially in connection with the errors, in accuracies and confidence estimates of the results.

2. COLLECTION OF THE COMPONENTS OF THE PROCEDURE

2.1 **Conversion of Point Estimates to Areal Average Estimates**

Whilst a limited study of storm rainfall variation with area has been carried out (D.I.D., 1970), based on daily raingauge totals in Selangor, the results are not complete enough for use in a generalised design procedure.

The conversion of point rainfall estimates to average catchment rainfall estimates should therefore be based on data shown in Table 6 (U.S.W.B., 1957 – 58):

Table 6:– Value of Areal Average Rainfall – Point Rainfall

Catchment Area (km^2)	Storm Duration (hrs.)				
	½	1	3	6	24
0	1.0	1.0	1.0	1.0	1.0
50	0.82	0.88	0.94	0.96	0.97
100	0.73	0.82	0.91	0.94	0.96
150	0.67	0.78	0.89	0.92	0.95
200	0.63	0.75	0.87	0.90	0.93
250	0.61	0.73	0.85	0.89	0.93
300	0.59	0.71	0.84	0.88	0.93
400	0.58	0.68	0.81	0.86	0.92
500		0.67	0.80	0.85	0.92
600		0.66	0.79	0.84	0.91
800		0.65	0.78	0.83	0.91
1000			0.78	0.83	0.91

2.2 **Summary**

The results of the data analysis and presentation in a form for use in the procedure has resulted in the following figures, these figures and Table 6 form the working tools for the procedure, and are presented in this Section.

(i) Isopleth maps of storm duration of ½, 3, 24, 72 hours for return periods of 2 and 20 years. Figures 1 – 8.

(ii) Plotting diagram of storm depth (X) versus storm duration (t) for a constant return period (T). Appendix E.

(iii) Plotting diagram of storm depth (X) versus return period (T) for constant storm duration (t). Appendix F.

(iv) Table 6 presents the recommended values of the ratio $\frac{\text{catchment average rainfall}}{\text{point rainfall estimate}}$ to be used in the procedure.

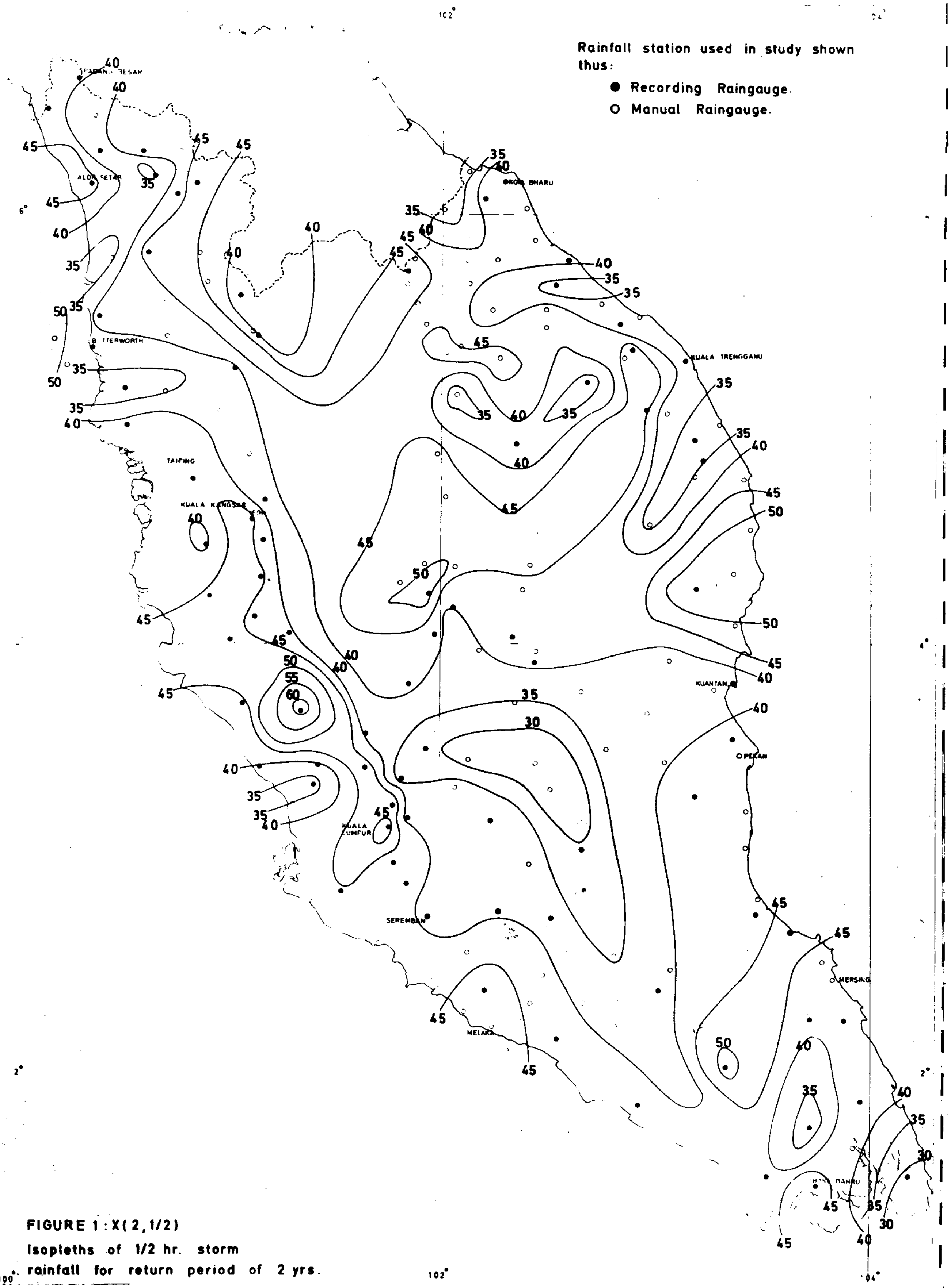


FIGURE 1 : X(2, 1/2)
Isopleths of 1/2 hr. storm rainfall for return period of 2 yrs.

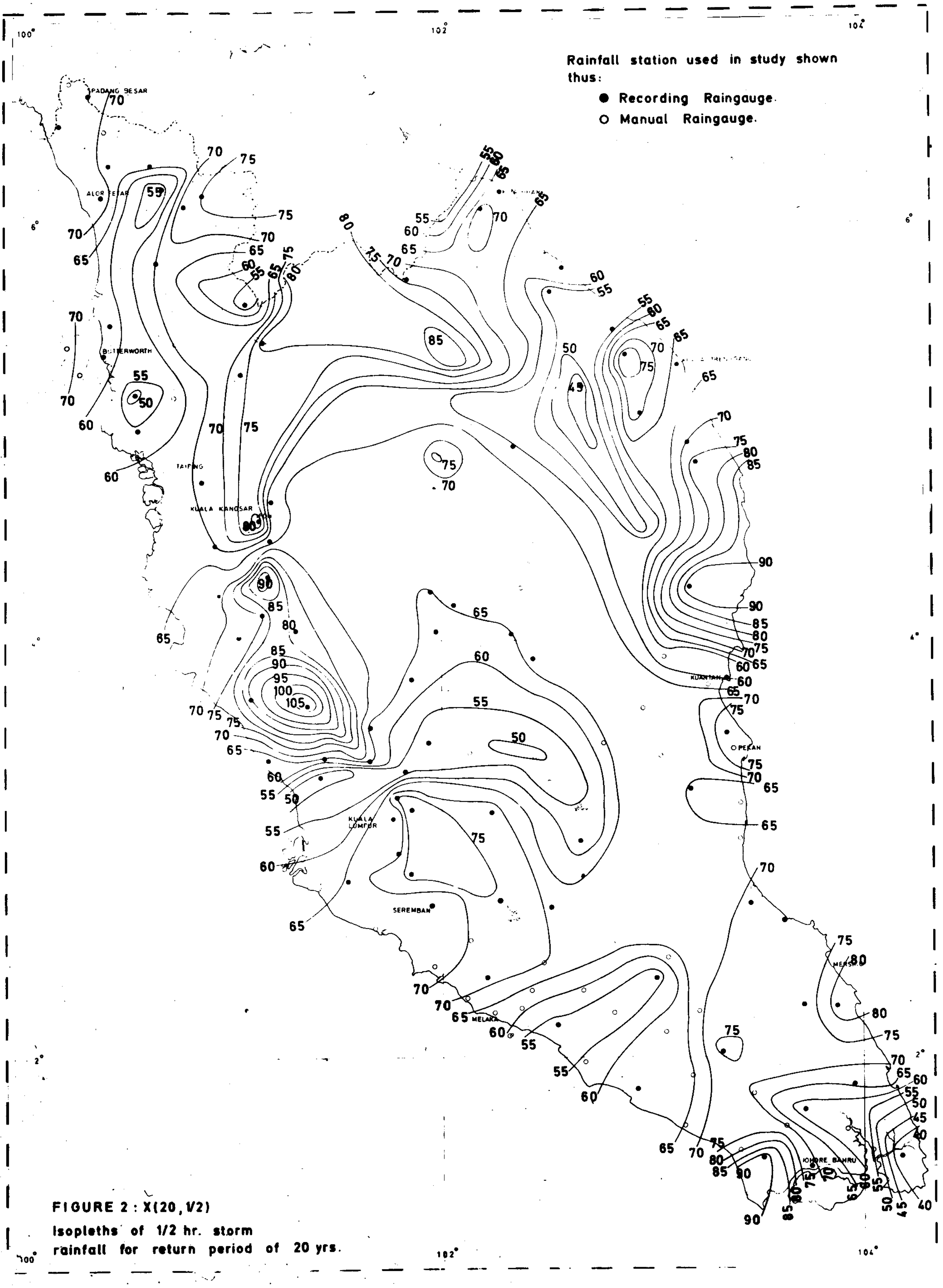


FIGURE 2 : X(20, 1/2)
Isopleths of 1/2 hr. storm rainfall for return period of 20 yrs.

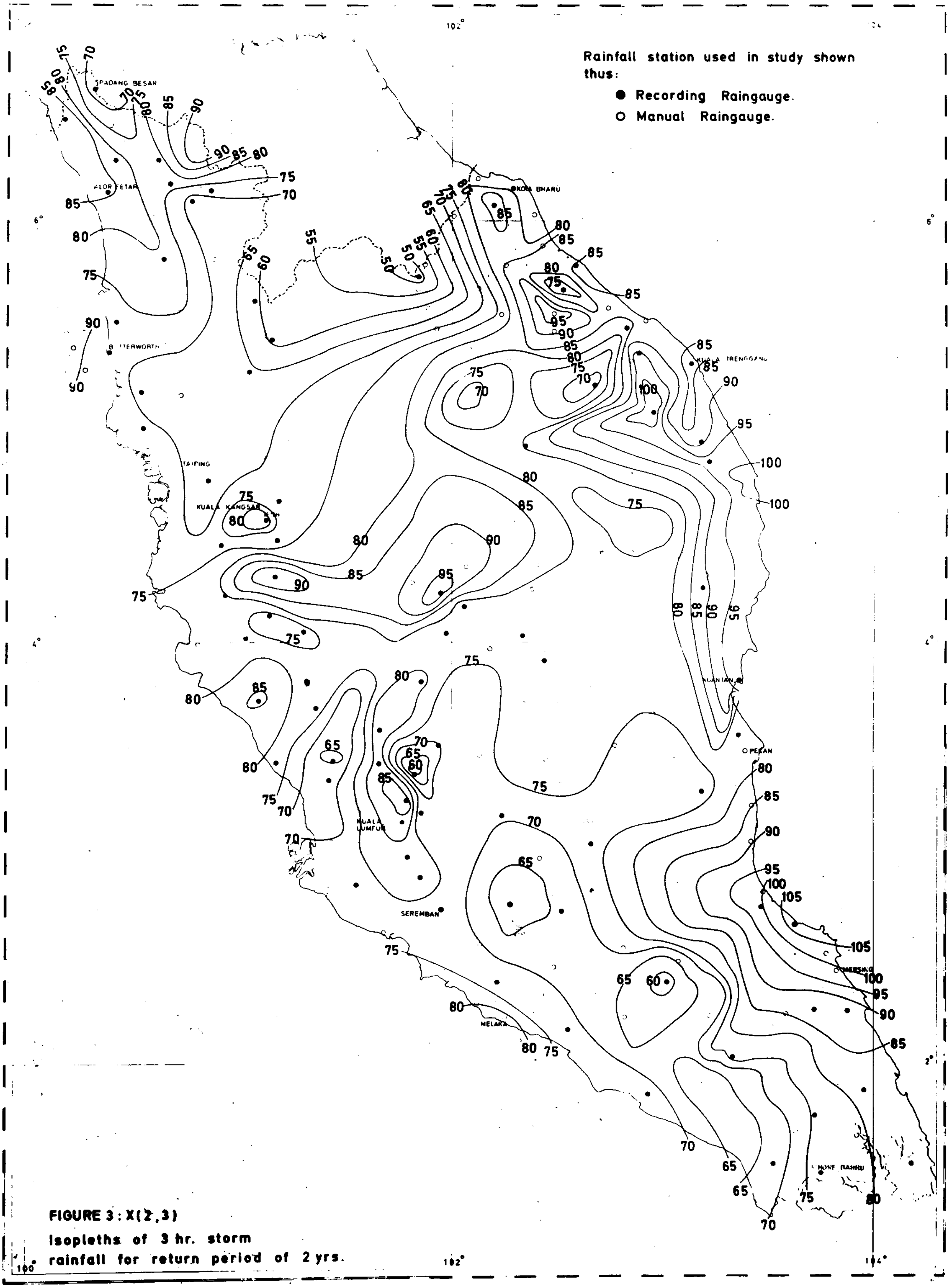


FIGURE 3 : X(2,3)
Isopleths of 3 hr. storm rainfall for return period of 2 yrs.

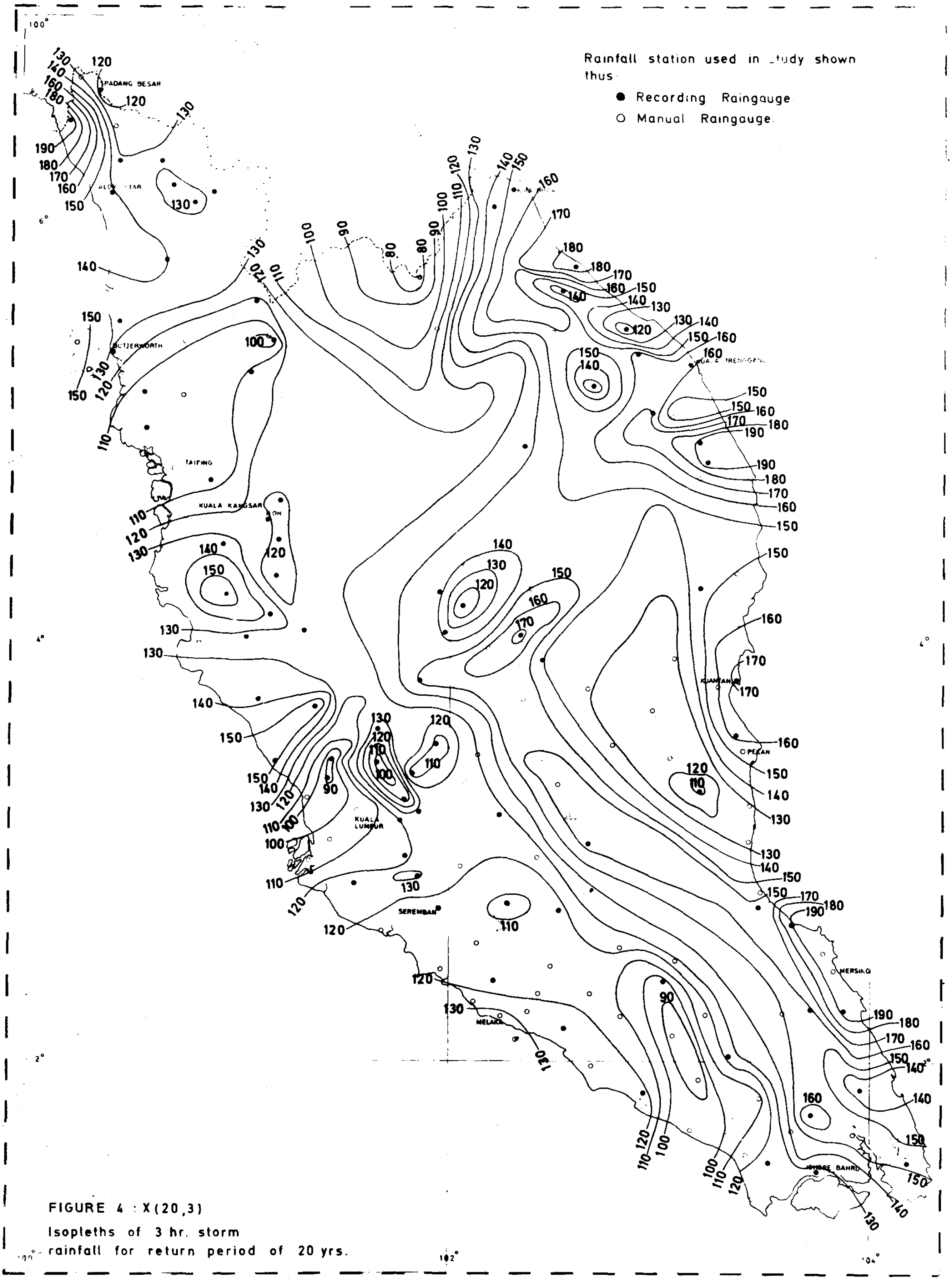


FIGURE 4 : X(20,3)
Isopleths of 3 hr. storm rainfall for return period of 20 yrs.

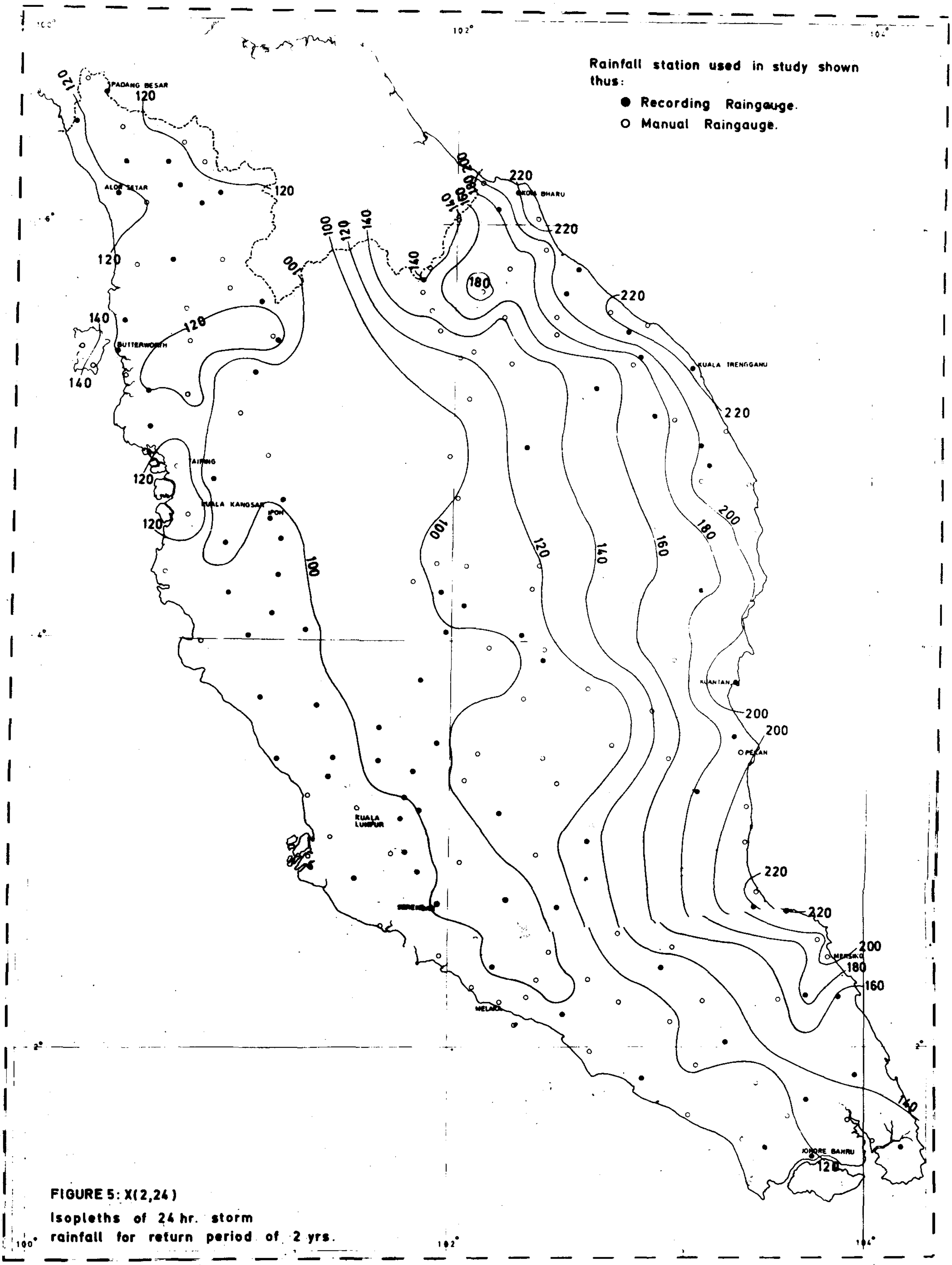


FIGURE 5: X(2,24)

Isopleths of 24 hr. storm rainfall for return period of 2 yrs.

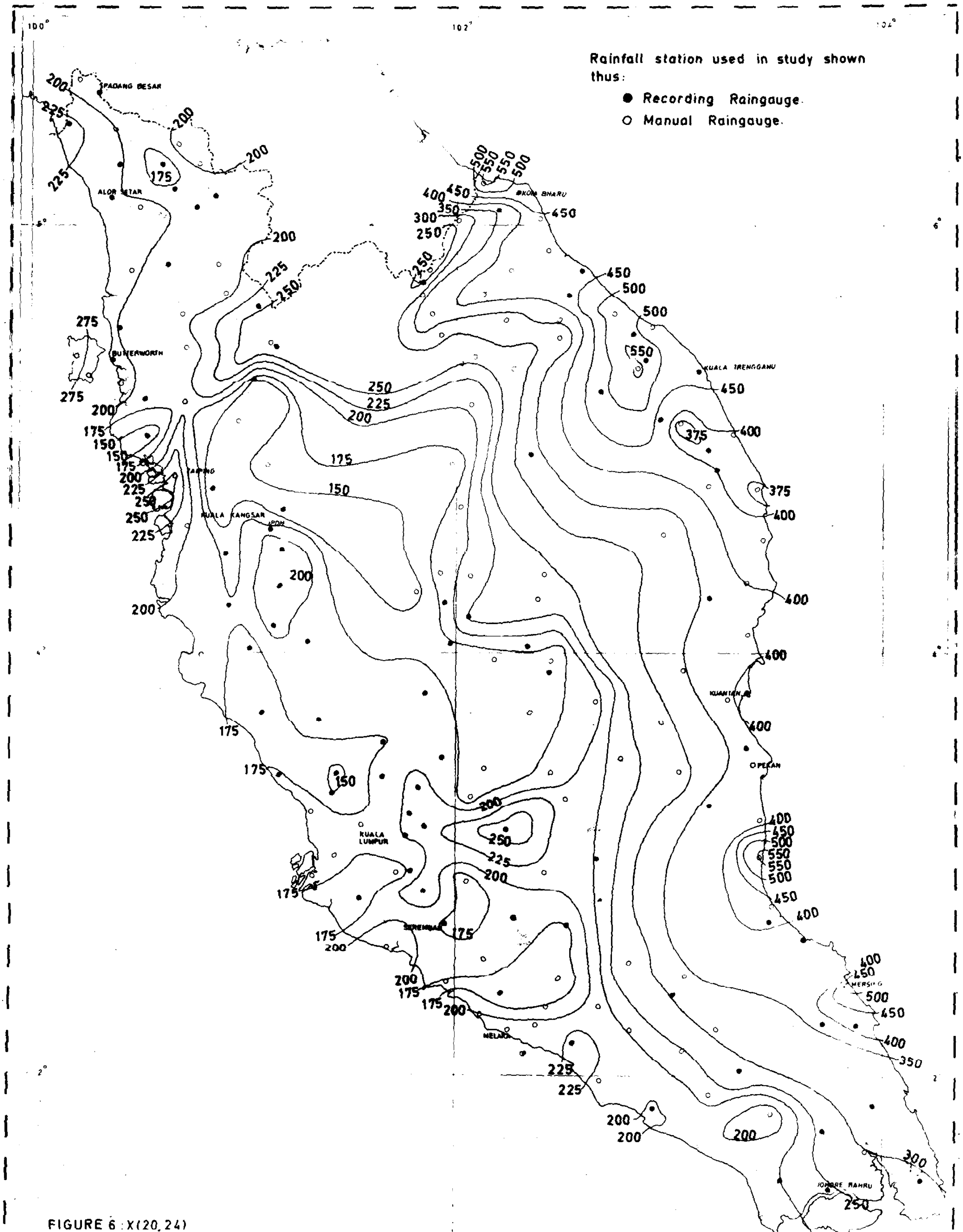


FIGURE 6 : X(20, 24)
Isopleths of 24 hr. storm rainfall for return period of 20 yrs.

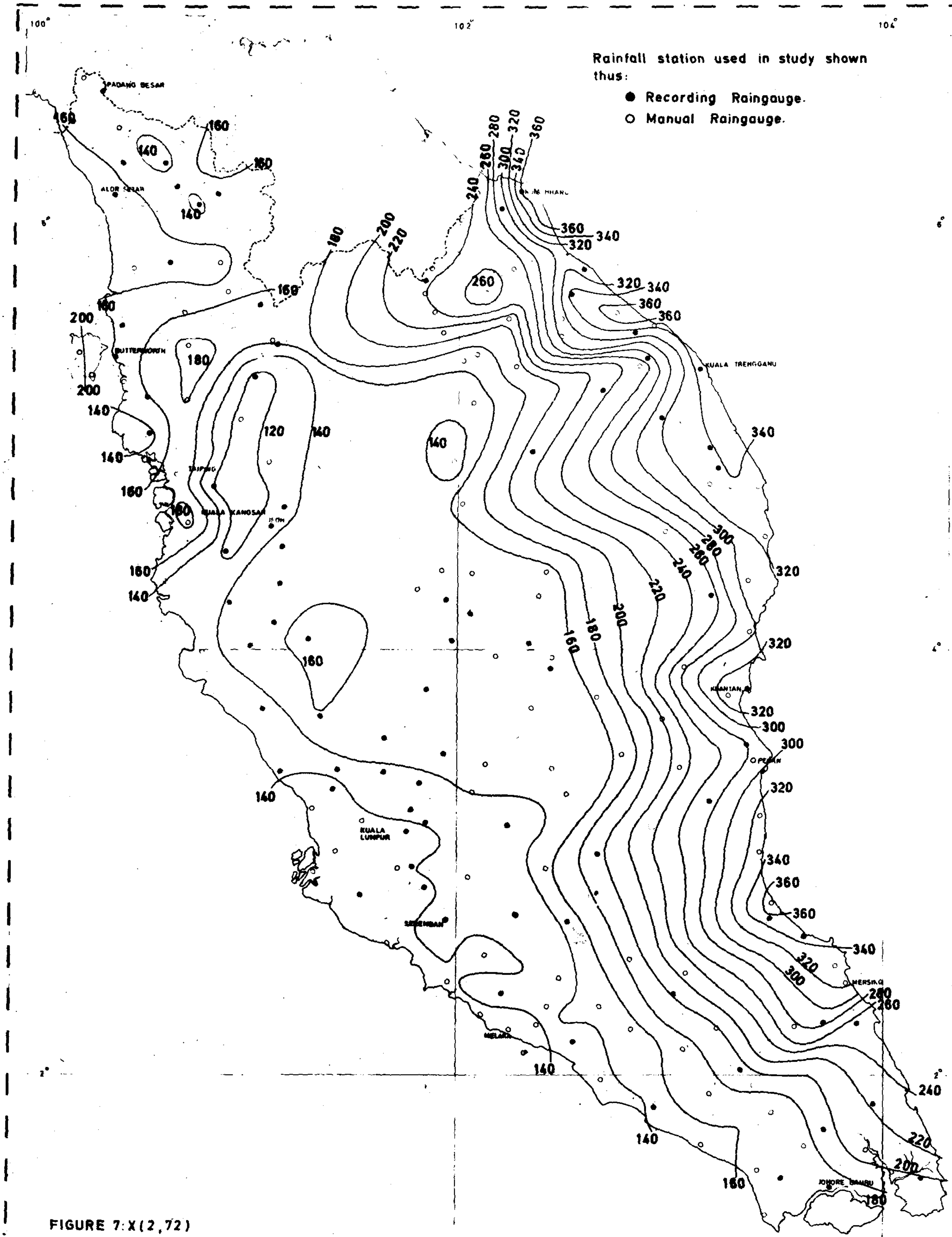


FIGURE 7: X (2, 72)
Isopleths of 72 hr. storm rainfall for return period of 2 yrs.

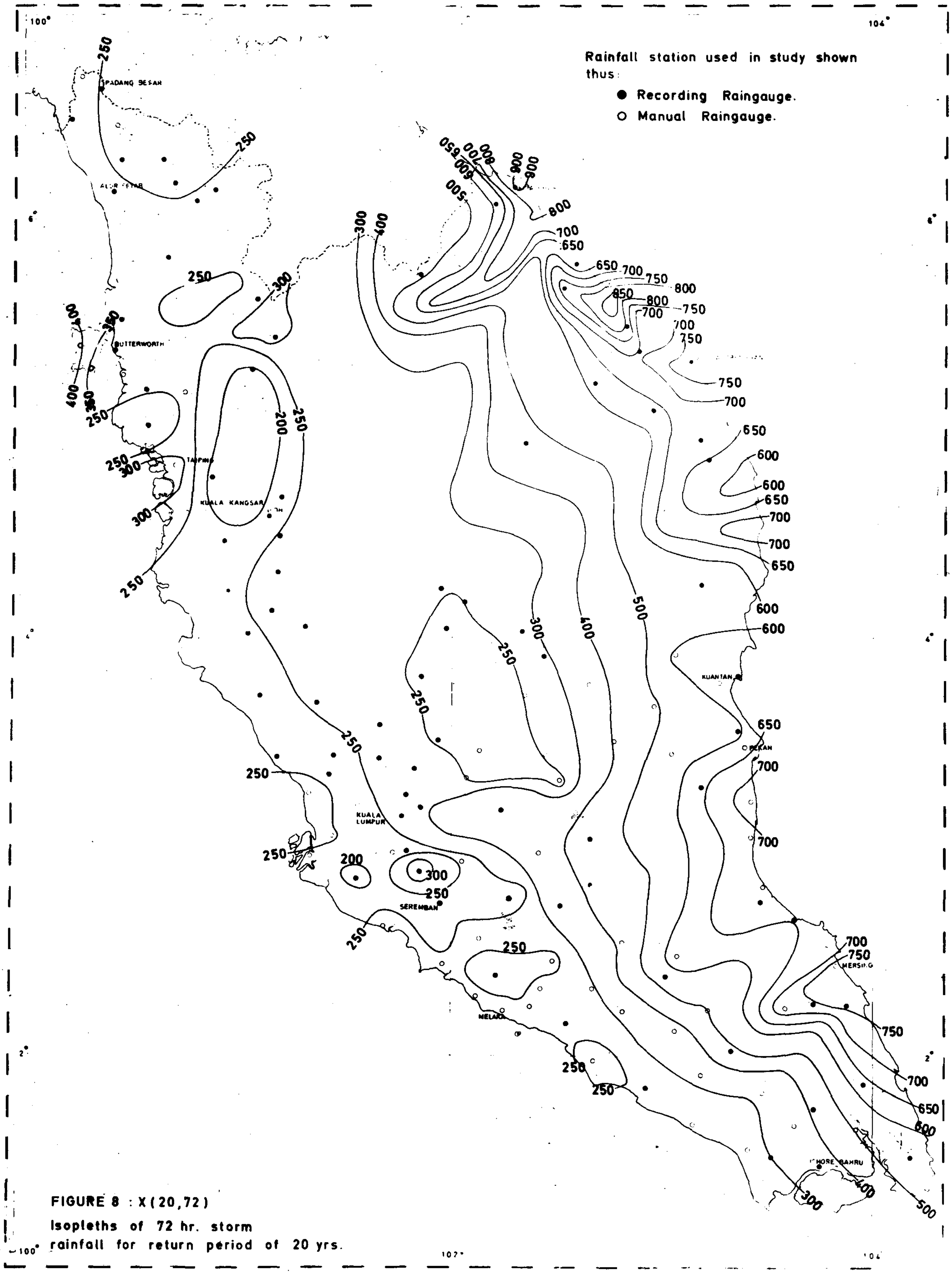


FIGURE 8 : X(20,72)
Isopleths of 72 hr. storm rainfall for return period of 20 yrs.

3. USE OF THE PROCEDURE FOR THE ESTIMATION OF X(T, t) FOR ANY LOCATION IN PENINSULAR MALAYSIA

The use of the procedure is illustrated by two worked examples.

Example One: Find the storm intensity (mm/hour) for a storm with a return period of 25 years for a point lat. 4° 00'N, long. 102° 00'E, for storm durations of 1, 10 and 48 hours, over a catchment area of 100 km^2.

(NB: X(T, t) refers to the depth (in mm) of a rainstorm with a return period of T years and duration of t hours).

Solution:–

1. Read values of X(T, t) for T = 2, 20 and t = ½, 3, 24, 72 from Figures 1 – 8.

$X(2, \frac{1}{2})$ =	40	(Fig. 1)
$X(20, \frac{1}{2})$ =	62	(Fig. 2)
$X(2, 3)$ =	78	(Fig.3)
$X(20, 3)$ =	140	(Fig. 4)
$X(2, 24)$ =	100	(Fig. 5)
$X(20, 24)$ =	175	(Fig. 6)
$X(2, 72)$ =	152	(Fig. 7)
$X(20, 72)$ =	250	(Fig. 8)

2. Set a suitable ordinate scale on Fig. 10 and plot the 8 values of X(T, t) above.

3. Draw straight lines between points representing the same duration (½, 3, 24 and 72 hours).

4. Read off the 4 lines on Fig. 10 the depth values corresponding to a return period of 25 years.

$X(25, \frac{1}{2}) = 64$
$X(25, 3) = 145$
$X(25, 24) = 181$
$X(25, 72) = 259$

5. Plot these four values on figure 9 setting a suitable ordinate scale, and join them with straight lines.

6. The required 25 yr. storm depth can now be read off the plot of the durations required.

$X(25, 1) = 98$ mm
$X(25, 10) = 161$ mm
$X(25, 48) = 226$ mm

7. Storm intensities (i) are found by dividing the total depth estimate by the storm durations

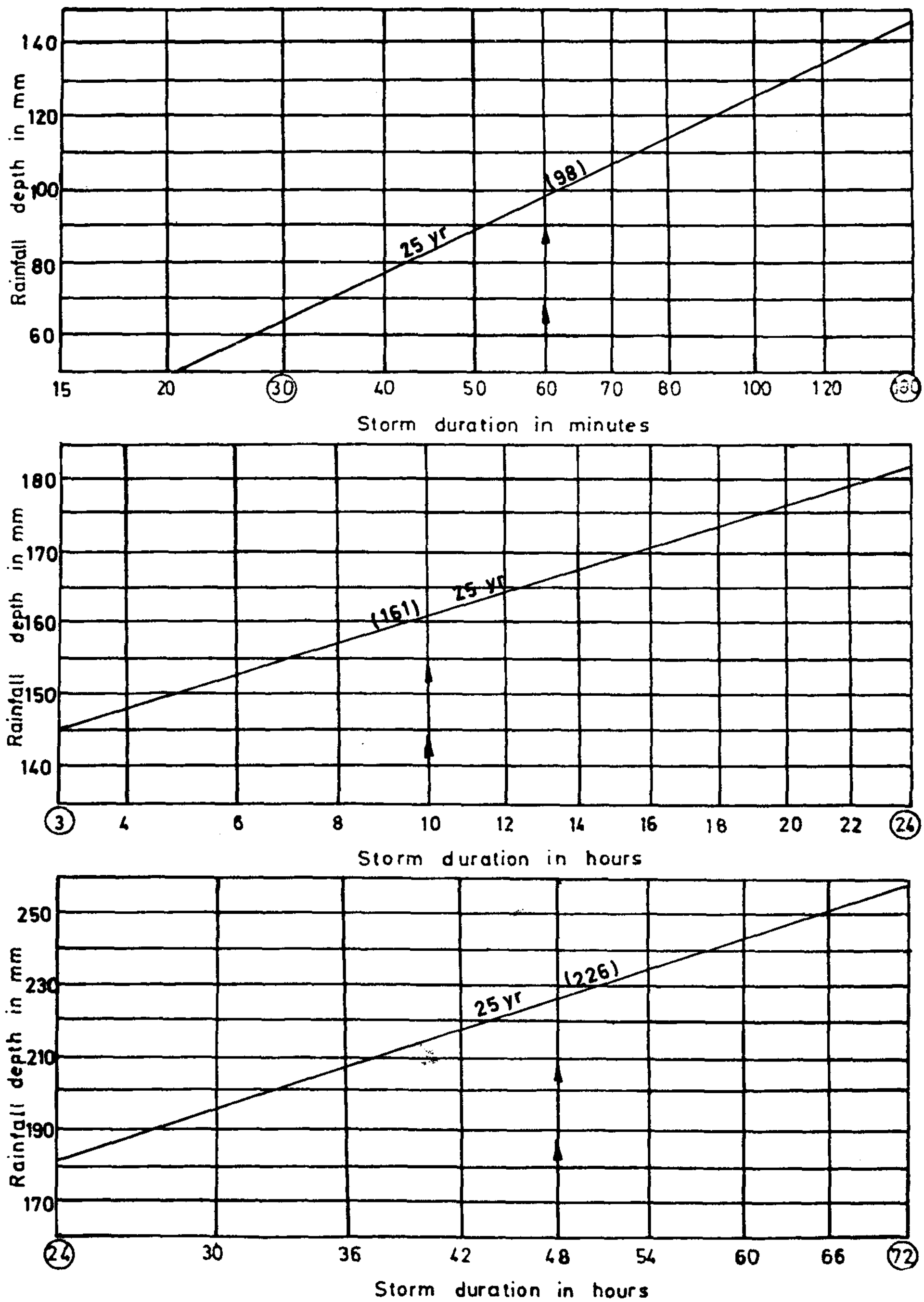
(point estimates of) $i(25, 1) = \frac{X(25, 1)}{1} = 98.0$ mm/hr

– do – $i(25, 10) = \frac{x(25, 10)}{10} = 16.1$ mm/hr

– do – $i(25, 48) = \frac{X(25, 10)}{48} = 4.7$ mm/hr

8. The estimate for the intensity to be used for catchment average is found by multiplying the above figures by the factor for an area of 100 km^2 and the particular storm duration from Table 6.

(catchment average estimate of)	i(25, 1)	= 98.0 x 0.82 = 80.4 mm/hr
– do –	i(25, 10)	= 16.1 x 0.95 = 15.3 mm/hr
– do –	i(25, 48)	= 4.7 x 0.96 = 4.5 mm/hr



Legend
③ one of the cardinal storm duration

FIGURE 9: EXAMPLE 1

Depth-Duration Plotting Diagram for a constant Return Period

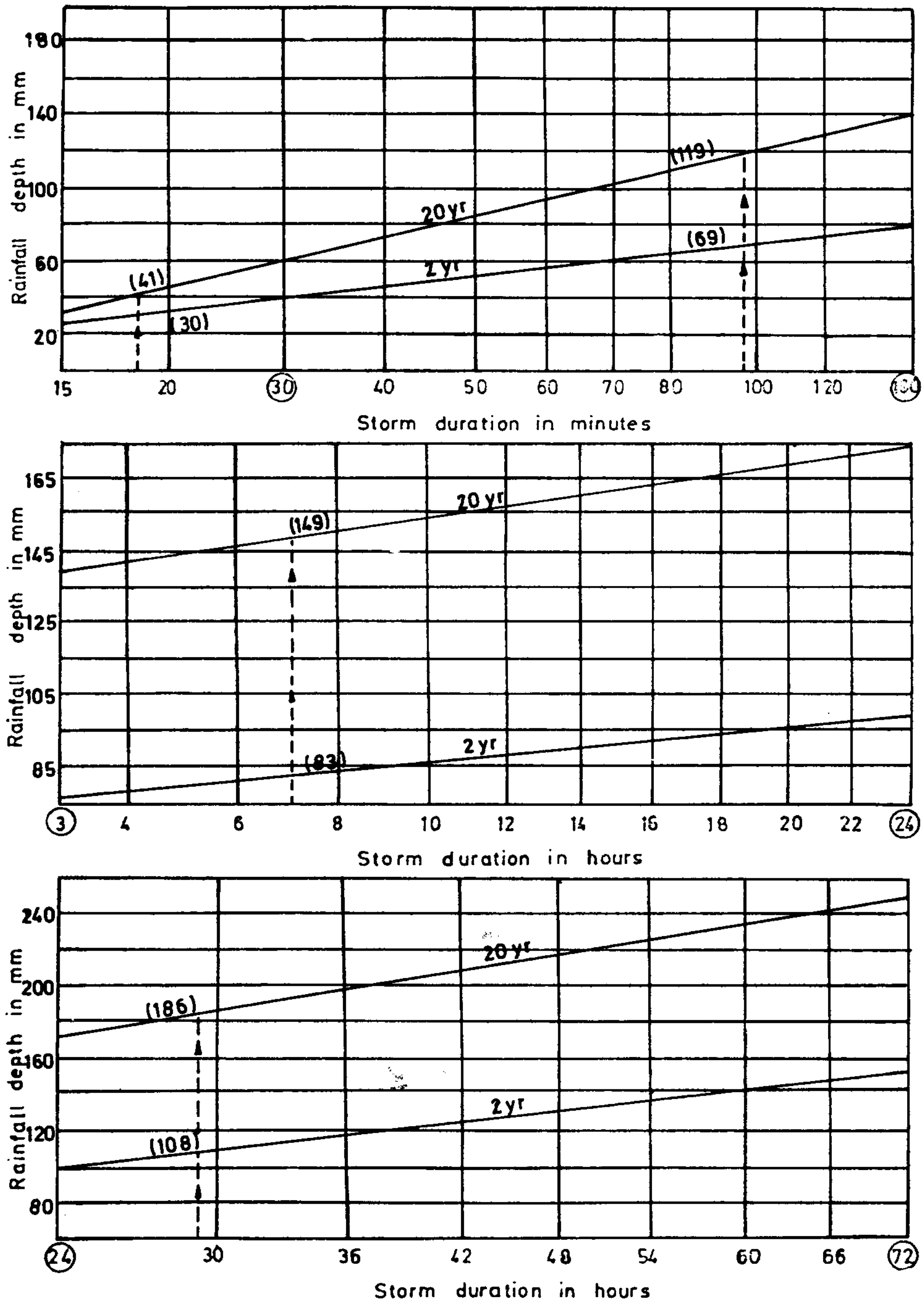


FIGURE 9: EXAMPLE 2

Depth–Duration Plottion Diagram for a constant Return Period

Legend

③ one of the cardinal storm duration

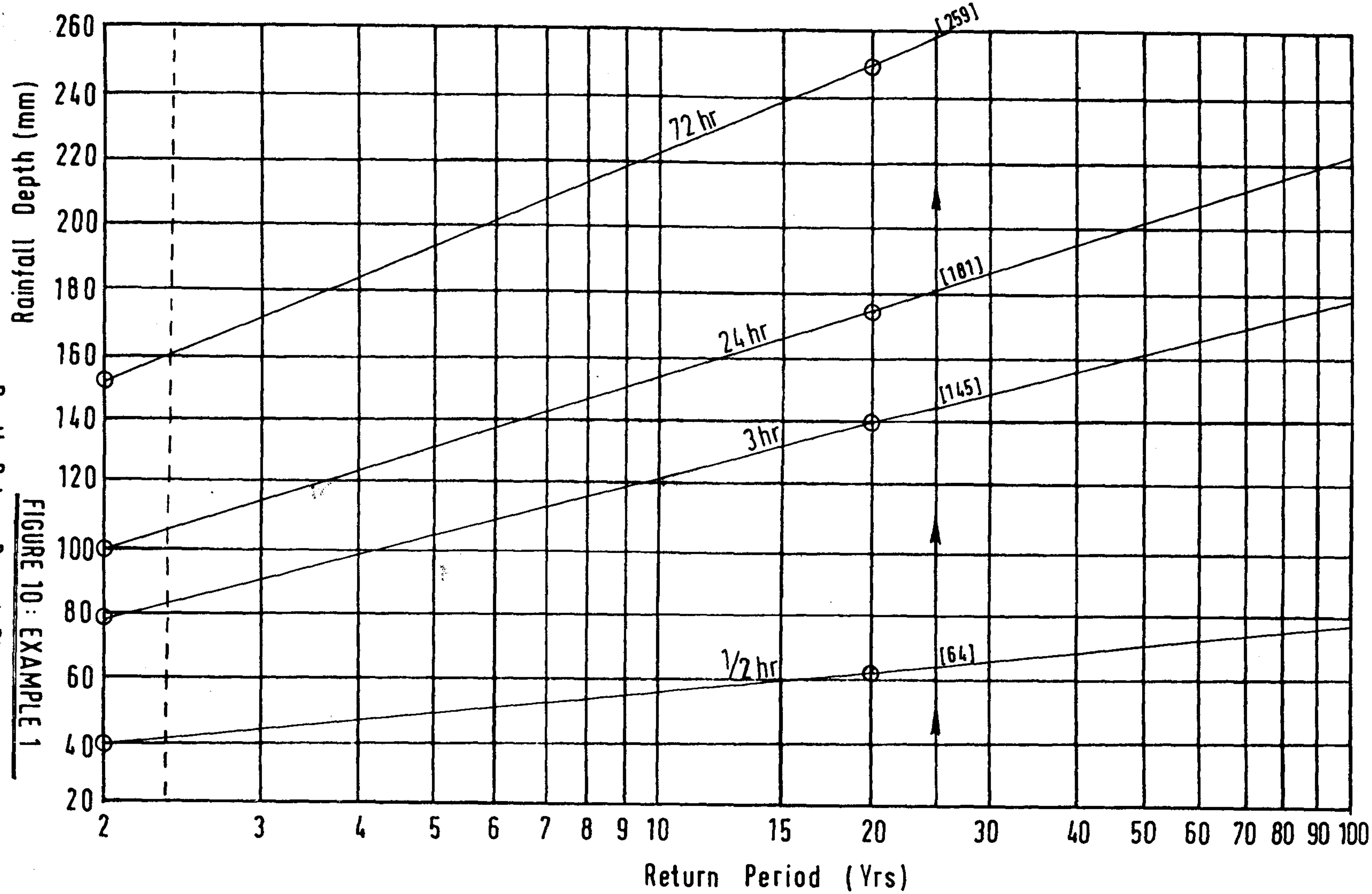


FIGURE 10: EXAMPLE 1

Depth-Return Period Plotting Diagram for a Constant Storm Duration

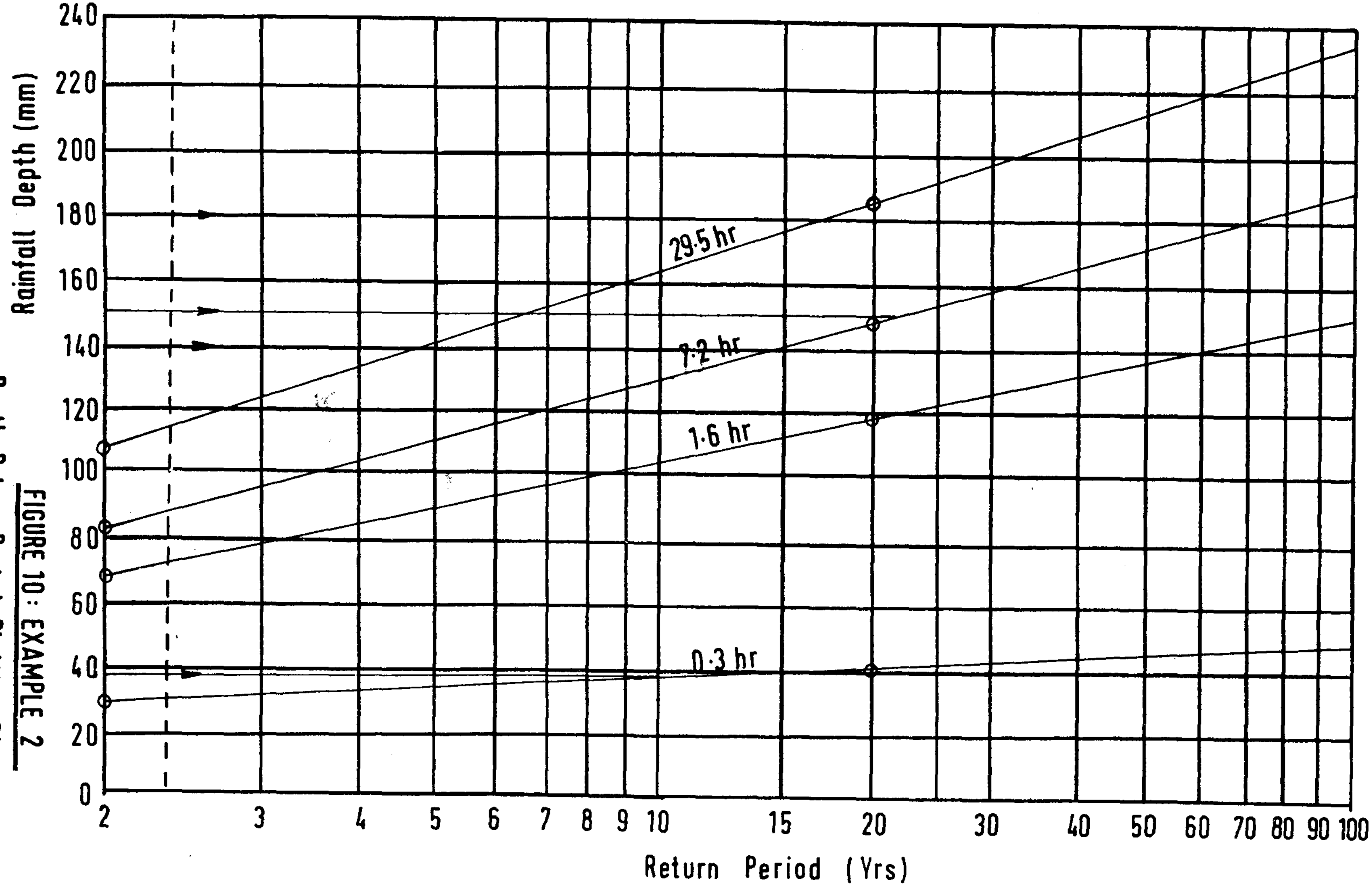


FIGURE 10 : EXAMPLE 2

Depth-Return Period Plotting Diagram for a Constant Storm Duration

Example Two: Find the return period of the following storms recorded at a location lat 4° 00'N long 102° 00'E.

Storm No.	Storm Depth (mm)	Storm Duration (hrs)
1	38	0.3
2	140	1.6
3	150	7.2
4	180	29.5

Solution:–

1. Repeat Step 1 as for Example One.

2. Set suitable ordinate scales for Figure 9 and plot the 8 values from (1) above.

3. Join all the points representing the same return period (2 and 20 yrs) by straight lines.

4. Read off the plot of the 2 yr. and 20 yr. storm depths for the durations considered.

   X(2, 0.3) = 30 mm
   X(20, 0.3) = 41 mm
   X(2, 1.6) = 69 mm
   X(20, 1.6) = 119 mm
   X(2, 7.2) = 83 mm
   X(20, 7.2) = 149 mm
   X(2, 29.5) = 108 mm
   X(20, 29.5) = 186 mm

5. Plot the two values associated with each storm duration (0.3, 1.6, 7.2, 29.5) and join by straight lines on Figure 10.

6. The return period of the particular storm depth for each duration can now be read off the plotted lines on Figure 10.

Storm No.	Return Period (Yr.)
1	10
2	55
3	21
4	17

4. SOURCES OF ERROR

A detailed discussion of the sources of error contained in the original data; analysis and method of presentation in the procedure are contained in Parts I and II. It is useful to indicate the implication of maximum likely errors in using this procedure for estimating the design rainstorm.

4.1 Uncertainty in Analysis where data exists

The computed values of X(T, t) for locations where data is available are only "estimates" of the "real" X(T, t) values. The longer the period of record, the more reliable is the estimate. The period of record for the data used in the preparation of this procedure ranged from 5 to 43 years. An example of the uncertainty involved for estimates of X(T, t) for a station with 10 years of data is given below.

Example

Station No. 4120064 — Name: Kuala Lipis Hospital
Period of record used: 10 years
Estimate of X(20, 6) = 131.6 mm
Reliability: 2/3 probability that X(20, 6) lies in the range (152.8 – 110.4) mm
Reliability: 2/3 probability that a storm X(T, 6) = 131.6 mm has a return period of between 7 and 62 years.

It can be seen therefore that a large uncertainty exists when dealing with estimated values of X (T, t), even when records are available. This is largely a direct result of the short period of record available for analysis. (See Section 2.3.4 for calculation of confidence limits).

4.2 Estimation of X(T, t) for Locations where no data are available.

Linear interpolation has been used to draw isopleths of key duration and frequency combinations between the locations where computed values are available. The confidence placed on the location of isopleths depends upon the areal coverage of computed values. The errors introduced by using linear interpolation are liable to be larger for areas poorly covered by recording raingauges and for elevations above 150 metres.

As far as longer duration (⩾ 24 hr.) rainfalls are concerned, the error arising from extrapolation to locations with no data should not be serious as the areal coverage of rainfall stations with daily data is quite intensive with an average distance of about 25 km between stations. The influence of local topography within such short distances is unlikely to be critical.

However, for shorter duration (< 24 hr.) rainfall, the local topographical influence is greater. Furthermore, with fewer stations of recording type the average distance between stations has increased to 35 km.

Nevertheless, the errors should be within acceptable limits when compared with other form of errors (depth estimates, assumed probability distribution function, generalised depth-duration plotting diagram etc.). For this reason the areal coverage of the recording raingauge stations was considered to be adequate and that it was deemed not necessary to carry out the correlation study for estimating short duration rainfall at non recording stations.

As a general guide, the error introduced by using the isopleths to estimate key values of X(T, t) is likely to be not more than about 10%.

4.3 Use of Plotting Diagrams for Interpolation of X(T, t) Values other than those defined by isopleths.

It has been necessary to incorporate plotting diagrams for depth-duration and depth-frequency interpolation in the procedure. These diagrams are for linearising the relationship between the key values of X(T, t) and are obtained by averaging the weighted 5 year storm. Thus the rainfall depth estimate obtained for these diagram may have some errors in it. The magnitude of this error is however within acceptable limits for procedures of this type. For order of likely errors, reference should be made to Appendix C.

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APPENDIX A
SUMMARY OF DATA USED IN THE STUDY

(a) Recording Raingauge Data – D.I.D. – Data used for duration up to 72 hours.

Station No.	Period of Record	No. Yrs. Used	Type of Recorder	Approx. Height above M.S.L.(M)
1437116	1960/61 – 78/79 1948/49 – 78/79	19 31	Hattori Daily	15
1829078	1960/61 – 78/79 1945/46 – 78/79	19 33	Hattori Weekly	15
2033153	1960/61 – 75/76 1954/55 – 78/79	13 22	Hattori Daily	30
2125042	1962/63 – 73/74 1959/60 – 73/74	12 14	Kent Daily	15
2237164	1962/63 – 76/77 1962/63 – 76/77	11 11	Capricorder	15
2238188	1965/66 – 75/76 1965/66 – 75/76	11 11	Hattori Weekly	30
2322004	1960/61 – 74/75 1948/49 – 78/79	14 30	Kent Daily	15
2636170	1960/61 – 78/79 1947/48 – 78/79	19 32	Hattori Weekly	15
2719001	1960/61 – 78/79 1960/61 – 78/79	18 18	Capricorder	60
2722002	1961/62 – 78/79 1961/62 – 78/79	18 18	Kent Weekly	75
2725083	1965/66 – 78/79 1923/24 – 78/79	13 47	Hattori Long Term	45
2815001	1960/61 – 78/79 1947/48 – 78/79	17 29	Hattori Long Term	15
2818110	1965/66 – 78/79 1964/65 – 78/79	13 14	Capricorder	30
3117070	1952/53 – 78/79 1952/53 – 78/79	27 27	Hattori Daily	75
3122001	1964/65 – 73/74 1959/60 – 73/74	10 15	Kent Weekly	50

(a) Recording Raingauge Data – D.I.D. – Data used for duration up to 72 hours.

Station No.	Period of Record	No. Yrs. Used	Type of Recorder	Approx. Height above M.S.L.(M)
3318126	1965/66 – 76/77 1965/66 – 76/77	12 12	Kent Weekly	305
3411017	1961/62 –78/79 1945/46 – 78/79	17 33	Hattori Long Term	15
3414031	1965/66 – 72/73 1947/48 – 72/73	8 26	Kent Weekly	16
3516022	1965/66 – 78/79 1953/54 – 78/79	14 26	Capricorder	60
3533102	1962/63 – 77/78 1948/49 – 77/78	14 29	Hattori Weekly	15
3613004	1965/66 – 77/78 1958/59 – 77/78	13 20	Hattori Long Term	15
3710006	1965/66 – 78/79 1963/64 – 78/79	14 16	Capricorder	15
3818054	1965/66 – 73/74 1947/48 – 73/74	9 25	Capricorder	150
4010001	1960/61 – 78/79 1947/48 – 78/79	19 32	Capricorder	15
4012143	1964/65 – 76/77 1947/48 – 76/77	13 30	Capricorder	30
4019061	1965/66 – 75/76 1951/52 – 78/79	11 27	Hattori Weekly	120
4111137	1965/66 – 76/77 1953/54 – 76/77	12 24	Kent Daily	15
4120064	1965/66 – 74/75 1947/48 – 74/75	10 28	Kent Weekly	75
4209093	1961/62 – 78/79 1953/54 – 78/79	14 22	Ota Weekly	15
4231103	1965/66 – 72/73 1957/58 – 72/73	8 16	Capricorder	30
4409091	1965/66 – 78/79 1965/66 – 78/79	14 14	Hattori Weekly	30
4411001	1961/62 – 75/76 1947/48 – 75/76	15 28	Kent Weekly	30

(a) Recording Raingauge Data – D.I.D. – Data used for duration up to 72 hours.

Station No.	Period of Record	No. Yrs. Used	Type of Recorder	Approx, Height above M.S.L.(M)
4611114	1964/65 – 74/75	11	Kent Weekly	30
	1945/46 – 74/75	29		
4788084	1959/60 – 78/79	18	Hattori Weekly	45
	1959/60 – 78/79	18		
5005001	1960/61 – 73/74	14	Kent Daily	15
	1960/61 – 73/74	14		
5210069	1965/66 – 77/78	13	Hattori Weekly	120
	1965/66 – 77/78	13		
5331048	1961/62 – 78/79	17	Kent Weekly	15
	1954/55 – 78/79			
5504035	1960/61 – 74/75	15	Ota Weekly	30
	1960/61 – 74/75	10		
5625004	1961/62 – 75/76	15	Kent Weekly	15
	1948/49 – 75/76	28		
5725006	1961/62 – 78/79	18	Hattori Weekly	15
	1948/49 – 78/79	31		
5806066	1957/58 – 77/78	21	Kent Weekly	30
	1952/53 – 77/78	25		
6007063	1965/66 – 76/77	12	Kent Weekly	60
	1965/66– 76/77	12		
6021061	1961/62 – 74/75	14	Kent Daily	15
	1948/49 – 74/75	27		
6103047	1965/66 – 77/78	13	Hattori Daily	15
	1946/47 – 77/78	31		
6122064	1957/58 – 78/79	22	Hattori Daily	15
	1948/49 – 78/79	31		
6204023	1965/66 – 76/77	12	Hattori Weekly	30
	1965/66 – 76/77	12		
6206035	1957/58 – 78/79	22	Hattori Weekly	30
	1952/53 – 78/79	26		
6401001	1960/61 – 74/75	11	Kent Daily	15
	1952/53 – 74/75	18		

Note: + Short duration rainfall depths (<24 hrs) were obtained from the top period while long duration rainfall depths (≥24 hrs) were obtained from the bottom period.

(b) Recording Raingauge Data – D.I.D. – Data used for duration up to 12 hours.

Station No.	Period of Record	No. Yrs. Used	Type of Recorder	Approx. Height above M.S.L.(M)
1535107	1971/72 – 77/78	7	Hatori Weekly	15
1541139	1974/75 – 78/79	5	Capricorder	15
1737001	1970/71 – 74/75	5	Hatori Weekly	30
1834124	1970/71 – 78/79	9	Hatori Weekly	45
1839196	1970/71 – 78/79	9	Hatori Weekly	15
1931001	1970/71 – 75/76	6	Ota Weekly	15
2330009	1970/71 – 78/79	9	Hatori Weekly	45
2528012	1970/71 – 78/79	9	Capricorder	30
2734183	1970/71 – 78/79	9	Hatori Weekly	15
2917001	1970/71 – 78/79	9	Hatori Weekly	15
3026156	1970/71 – 75/76	5	Capricorder	45
3118102	1970/71 – 78/79	8	Capricorder	75
3217002	1972/73 – 78/79	7	Hatori Weekly	75
3231163	1974/75 – 78/79	5	Hatori Long Term	15
3314001	1974/75 – 78/79	5	Capricorder	15
3416002	1974/75 – 78/79	5	Ota Weekly	30
3424081	1970/71 – 77/78	7	Capricorder	30
3519125	1970/71 – 78/79	9	Capricorder	90
3615003	1971/72 – 78/79	8	Capricorder	45
3833001	1970/71 – 78/79	9	Hatori Weekly	15
3924072	1970/71 – 78/79	9	Hatori Weekly	40
3930012	1971/72 – 77/78	6	Capricorder	45
4023001	1973/74 – 78/79	5	Hatori Long Term	80
4219001	1974/75 – 78/79	5	Hatori Long Term	75
4311001	1974/75 – 78/79	5	Hatori Weekly	40
4511111	1970/71 – 78/79	9	Ota Weekly	45
4529071	1974/75 – 78/79	5	Capricorder	20
4734079	1970/71 – 78/79	9	Hatori Weekly	15
4819027	1971/72 – 78/79	8	Hatori Long Term	120
4832077	1970/71 – 78/79	9	Capricorder	15
4923001	1974/75 – 78/79	5	Hatori Long Term	60
4931067	1970/71 – 76/77	7	Kent Weekly	15
5029034	1971/72 – 78/79	8	Hatori Long Term	30
5030039	1970/71 – 76/77	7	Kent Weekly	25
5105051	1970/71 – 74/75	5	Kent Weekly	30
5120025	1970/71 – 78/79	9	Capricorder	105
5226001	1974/75 – 78/79	5	Capricorder	150
5303053	1970/71 – 75/76	6	Kent Daily	15
5320038	1971/72 – 78/79	8	Hatori Long Term	115
5322044	1971/72 – 78/79	8	Hatori Long Term	15
5328044	1973/74 – 78/79	6	Hatori Long Term	30
5411066	1972/73 – 78/79	6	Hatori Long Term	165
5412067	1970/71 – 74/75	5	Kent Monthly	280
5428025	1970/71 – 76/77	7	Kent Weekly	30
5522047	1970/71 – 78/79	5	Capricorder	30
5524002	1971/72 – 78/79	8	Hatori Long Term	15
5610063	1971/72 – 78/79	8	Hatori Long Term	275
5718033	1971/72 – 78/79	8	Hatori Long Term	70
5722057	1970/71 – 78/79	8	Hatori Weekly	30
5804035	1971/72 – 77/78	5	Kent Weekly	15
6019004	1970/71 – 78/79	8	Capricorder	15
6106034	1970/71 – 78/79	7	Kent Weekly	25
6108001	1973/74 – 78/79	5	Hatori Weekly	120
6121015	1970/71 – 74/75	5	Kent Weekly	15
6207032	1970/71 – 78/79	9	Hatori Weekly	90
6603002	1970/71 – 78/79	8	Ota Weekly	60

(c) Recording Raingauge Data – M.M.S. – Data used for duration up to 24 hours.

Station Name	Period of Record	No, Yrs. Used	Type of Recorder	Approx. Height above M.S.L. (M)
Mersing	1951/52 – 77/78	27	Dines Tilting Syphon daily	45
Alor Setar	1951/52 – 77/78	27	"	6
Bayan Lepas	1951/52 – 77/78	27	"	4
Ipoh	1951/52 – 77/78	27	"	39
Sitiawan	1951/52 – 77/78	27	"	7
Subang (KL)	1951/52 – 77/78	27	"	16
Melaka	1951/52 – 77/78	27	"	7
Cameron Highland	1964/65 – 77/78	14	"	1448
Kuantan	1951/52 – 77/78	27	"	15
Kuala Trengganu	1951/52 – 77/78	27	"	32
Kota Bahru	1951/52 – 77/78	27	"	5

(d) Daily Rainfall Data – D.I.D.

Station No.	Period of Record	No. Yrs. Used	Type of Gauge	Elevation above MSL (m)
1334106	1947/48 – 78/79	32	M8	15
1534104	1945/46 – 78/79	34	M8	15
1540135	1949/50 – 78/79	29	M8	15
1631084	1950/51 – 78/79	29	M8	15
1636109	1947/48 – 78/79	32	M8	70
1639132	1947/48 – 78/79	32	M8	15
1834124	1947/48 – 78/79	32	M8	45
1926051	1961/62 – 78/79	18	M8	30
1931072	1946/47 – 78/79	33	M8	15
2123024	1970/71 – 78/79	9	M8	20
2130068	1947/48 – 78/79	30	M8	15
2221008	1953/54 – 78/79	26	M8	75
2222011	1947/48 – 78/79	32	M8	15
2223022	1953/54 – 78/79	26	M8	40
2228016	1959/60 – 79/80	21	M8	15
2232158	1945/46 – 78/79	33	M8	45
2235163	1949/50 – 79/80	30	M8	15
2324033	1953/54 – 78/79	26	M8	20
2326022	1947/48 – 78/79	32	M8	40
2419054	1946/47 – 78/79	33	M8	15
2424087	1930/31 – 78/79	43	M8	70
2430008	1958/59 – 74/75	17	M8	60
2438185	1960/61 – 78/79	19	M5	15
2521050	1959/60 – 78/79	20	M8	40
2528012	1945/46 – 78/79	33	M8	15
2537183	1949/50 – 78/79	29	M8	15
2616135	1930/31 –78/79	42	M8	15
2834181	1960/61 – 78/79	19	M8	15
2913122	1942/43 – 78/79	28	M8	15
2917106	1930/31 – 78/79	41	M8	55
2920012	1936/37 – 78/79	29	M8	110
2924096	1947/48 – 78/79	31	M8	80
3014084	1943/44 – 78/79	28	M8	15
3034168	1960/61 – 78/79	19	M8	15
3115079	1942/43 – 78/79	34	M8	15
3213057	1939/40 – 78/79	37	M8	15
3234162	1960/61 – 78/79	18	M8	15
3320130	1947/48 – 78/79	32	M8	150
3325085	1960/61 – 78/79	19	M8	30
3421134	1947/48 – 78/79	32	M8	60
3424081	1946/47 – 78/79	30	S8	30
3430097	1960/61 – 78/79	19	M8	15
3527092	1931/32 – 78/79	35	M8	60
3629098	1932/33 – 78/79	31	M8	60
3723077	1962/63 – 78/79	17	M8	45
3726073	1947/48 – 78/79	29	M8	45
3833022	1947/48 – 74/75	28	M8	15
3907103	1953/54 – 78/79	21	M8	15
3921068	1951/52 – 78/79	28	M8	100
3924071	1946/47 – 78/79	19	M8	60
3930012	1946/47 – 78/79	33	M8	60
4033001	1947/48 – 78/79	29	M8	15
4218042	1969/70 – 78/69	9	M8	85

(d) Daily Rainfall Data – D.I.D.

Station No.	Period of Record	No. Yrs. Used	Type of Gauge	Elevation above MSL (m)
4223115	1948/49 – 77/78	28	M8	60
4306042	1935/36 – 78/79	31	M8	15
4319048	1966/67 – 78/79	13	M8	18
4320066	1965/66 – 74/75	10	M8	100
4324113	1947/48 – 78/79	30	M8	60
4333096	1956/57 – 78/79	21	M8	15
4507036	1953/54 – 78/79	27	M8	15
4529071	1966/67 – 78/79	11	S5	15
4534092	1957/58 – 78/79	22	M8	15
4620045	1948/49 – 78/79	31	M8	150
4731083	1957/58 – 78/79	22	M8	45
4734079	1948/49 – 78/79	29	M8	15
4806032	1953/54 – 78/79	26	M8	15
4811078	1935/36 – 78/79	33	M8	55
4819001	1959/60 – 70/71	9	M8	90
5009071	1936/37 – 78/79	30	M8	85
5030039	1948/49 – 78/79	31	M8	15
5033069	1952/53 – 78/79	26	M8	15
5107007	1936/37 – 78/79	35	M8	20
5120025	1951/52 – 78/79	28	M8	75
5204049	1947/48 – 78/79	32	M8	15
5302001	1953/54 – 78/79	24	M8	30
5320038	1952/53 – 78/79	15	S5	90
5320039	1952/53 – 78/79	21	M8	15
5322044	1972/73 – 78/79	7	S5	45
5328043	1959/60 – 78/79	14	M8	15
5407080	1959/60 – 78/79	20	M8	50
5411068	1947/48 – 76/77	29	M8	70
5419036	1952/53 – 78/79	26	M8	60
5424001	1966/67 – 78/79	13	M8	15
5507076	1963/64 – 78/79	16	M8	25
5518035	1956/57 – 78/79	23	M8	60
5522047	1948/49 – 78/79	29	M8	30
5524002	1957/58 – 78/79	12	S5	20
5527021	1960/61 – 78/79	19	M8	15
5529027	1967/68 – 78/79	12	M8	15
5609072	1945/46 – 78/79	32	M5	520
5618033	1956/57 – 71/72	13	M8	80
5621052	1956/57 – 78/79	23	M8	20
5704055	1950/51 – 78/79	29	M8	990
5718001	1956/57 – 78/79	23	M8	45
5722057	1951/52 – 77/78	27	M8	30
5808070	1959/60 – 78/79	20	M8	60
5824079	1956/57 – 78/79	23	M8	15
6005044	1959/60 – 75/76	17	M8	15
6019004	1946/47 – 73/74	26	M8	15
6023072	1959/60 – 78/79	16	M8	30
6121015	1967/68 – 78/79	9	M8	15
6207032	1970/71 – 78/79	9	M8	90
6306031	1970/71 – 78/79	9	M8	30
6397111	1963/64 – 78/79	16	M8	15
6403025	1965/66 – 78/79	14	M8	40
6602002	1953/54 – 78/79	26	M8	30

Note:- M8 = Manual 8" diameter raingauge
M5 = Manual 5" diameter raingauge

APPENDIX B

RESULTS OF GUMBEL FREQUENCY ANALYSIS – VALUES OF X(T, t)

(a) Recording Raingauge Data – DID – Duration ≤ 72 hours

Station No.	Return (T) Period (yrs.)	Storm Duration (t) (hrs.)								
		¼	½	1	3	6	12	24	48	72
1437116	2	31	48	64	80	92	105	128	156	177
	5	39	60	80	101	121	149	189	233	261
	10	44	68	91	115	140	178	230	283	317
	20	48	76	102	128	158	206	269	331	371
	50	54	85	116	145	182	243	319	394	440
1829078	2	27	44	55	73	79	84	116	138	154
	5	33	53	65	94	111	116	152	181	200
	10	37	59	72	109	132	137	176	209	231
	20	40	64	78	122	152	157	199	237	260
	50	45	72	87	140	179	183	229	272	298
2033153	2	33	52	68	76	80	91	133	173	199
	5	42	62	86	98	103	142	203	282	321
	10	48	69	99	113	118	175	249	354	402
	20	54	76	110	127	133	207	293	423	480
	50	61	85	126	146	153	249	351	513	580
2125042	2	28	43	57	72	75	76	107	119	127
	5	36	48	69	96	105	106	164	180	193
	10	41	51	78	112	125	125	201	221	237
	20	46	53	86	127	144	144	237	261	279
	50	52	57	97	147	169	169	284	312	333
2237164	2	27	41	61	88	104	124	238	294	311
	5	37	55	79	119	145	195	428	568	659
	10	43	64	91	140	173	242	554	749	890
	20	49	72	102	160	199	287	674	923	1111
	50	57	83	117	185	233	346	870	1149	1398
2238188	2	33	45	63	89	108	136	200	233	267
	5	43	62	94	134	157	192	342	418	508
	10	50	73	115	163	189	229	436	540	668
	20	56	84	135	192	220	265	527	657	821
	50	65	98	161	229	260	312	644	809	1019
2322004	2	32	48	64	73	78	80	95	111	121
	5	39	59	76	91	100	103	122	138	153
	10	43	66	83	103	115	118	140	156	175
	20	48	73	90	115	129	133	157	174	195
	50	53	81	99	129	147	153	178	196	221
2636170	2	31	47	65	108	138	163	232	314	358
	5	38	57	79	145	183	213	307	414	498
	10	42	64	87	169	213	245	357	480	590
	20	47	70	96	192	241	276	405	544	680
	50	53	78	107	222	278	317	466	626	794

Station No.	Return (T) Period (yrs.)	Storm Duration (t) (hrs.)								
		¼	½	1	3	6	12	24	48	72
2719001	2	25	35	49	67	74	78	101	116	130
	5	34	48	68	88	98	105	141	152	169
	10	40	57	81	101	114	123	167	177	194
	20	46	66	93	115	129	140	192	200	219
	50	53	77	109	132	149	163	224	230	251
2722002	2	25	40	53	61	64	67	97	107	114
	5	33	55	72	81	85	87	134	146	152
	10	39	65	84	95	99	100	159	171	178
	20	45	75	96	108	113	113	182	196	202
	50	52	88	111	125	130	130	213	227	233
2725083	2	25	38	52	67	72	80	106	129	151
	5	34	52	73	87	91	104	137	195	242
	10	40	61	87	100	103	120	157	239	302
	20	46	69	101	112	115	136	176	281	359
	50	53	81	118	128	130	156	201	335	434
2815001	2	30	45	60	74	78	79	98	109	122
	5	36	54	73	97	102	102	123	131	143
	10	40	60	81	113	117	117	139	146	157
	20	44	66	89	128	133	133	154	159	171
	50	49	74	99	148	152	152	174	177	189
2818110	2	29	43	62	82	86	92	113	139	156
	5	42	58	85	103	109	127	161	211	236
	10	50	68	110	117	123	150	193	259	289
	20	58	78	115	131	137	172	224	305	340
	50	69	91	133	149	156	200	264	365	406
3117070	2	32	52	68	84	90	93	119	137	155
	5	38	59	81	100	112	117	157	185	206
	10	42	64	90	111	126	132	182	216	239
	20	46	68	98	121	140	147	206	247	271
	50	51	75	109	134	159	167	238	286	312
3122001	2	28	40	56	72	83	90	115	126	135
	5	38	53	74	96	118	150	182	220	244
	10	46	62	86	112	142	190	226	282	316
	20	53	70	98	127	165	228	268	342	385
	50	62	81	112	146	194	278	323	420	475
3318126	2	23	32	45	57	65	70	96	109	118
	5	26	41	56	77	90	106	159	182	207
	10	29	46	64	91	106	130	201	230	266
	20	31	51	71	103	122	153	240	276	322
	50	34	58	80	120	143	183	292	335	395
3411017	2	26	40	56	79	88	89	112	127	139
	5	34	50	74	113	124	125	142	162	178
	10	40	56	85	135	147	148	162	186	204
	20	45	62	96	156	170	171	181	208	228
	50	52	69	110	184	199	200	206	237	260

Station No.	Return (T) Period (yrs)	Storm Duration (t) (hrs)								
		¼	½	1	3	6	12	24	48	72
3414031	2	28	40	52	62	66	72	99	122	141
	5	34	52	66	75	79	89	123	147	177
	10	38	60	75	84	88	100	138	164	210
	20	42	67	84	92	97	110	154	180	223
	50	47	77	96	103	108	124	173	201	253
3516022	2	23	39	61	86	89	93	109	139	161
	5	32	50	76	107	109	112	141	187	214
	10	38	57	85	121	122	126	162	219	250
	20	43	64	95	135	135	138	183	249	285
	50	50	73	107	152	152	154	209	288	329
3533102	2	29	41	55	72	87	103	191	243	278
	5	47	58	78	112	131	149	271	352	407
	10	58	68	93	139	161	180	323	424	493
	20	70	79	108	164	189	209	373	494	574
	50	84	92	127	197	226	247	439	583	580
3613004	2	31	47	63	84	89	95	117	142	163
	5	43	60	83	117	122	129	152	180	211
	10	51	69	97	139	145	151	175	206	243
	20	59	77	110	160	166	173	198	230	274
	50	69	88	127	187	193	200	227	262	314
3710006	2	31	45	65	87	91	93	108	119	130
	5	52	66	82	109	115	116	130	146	159
	10	66	80	93	124	130	131	144	165	178
	20	80	93	104	138	145	145	158	183	196
	50	97	110	118	156	164	164	176	205	219
3818054	2	26	42	55	81	90	96	100	128	141
	5	31	51	72	113	120	128	138	169	183
	10	34	58	83	133	142	154	163	196	210
	20	37	64	94	153	158	166	187	223	236
	50	40	72	108	179	186	194	217	257	270
4010001	2	29	47	66	77	79	82	108	128	148
	5	37	58	81	98	103	105	133	163	184
	10	43	65	92	112	118	121	150	186	209
	20	48	72	101	126	133	136	166	209	232
	50	55	81	114	114	152	155	187	238	262
4012143	2	25	40	54	72	76	77	116	152	175
	5	36	57	70	95	100	101	145	192	227
	10	44	68	80	110	116	117	164	219	261
	20	51	79	90	124	131	133	182	245	294
	50	60	93	103	142	151	153	206	279	337
4019061	2	28	41	56	72	77	85	105	127	146
	5	36	52	71	102	106	113	138	165	191
	10	41	59	81	121	125	132	159	189	220
	20	46	66	91	139	143	151	180	213	249
	50	53	75	103	164	167	174	207	243	285

Station No.	Return (T) Period (yrs)	Storm Duration (t) (hrs)								
		¼	½	1	3	6	12	24	48	72
4111137	2	29	43	59	74	83	86	112	135	154
	5	34	57	81	102	120	128	153	187	213
	10	38	65	95	121	126	152	180	221	252
	20	42	74	109	139	160	188	206	253	289
	50	47	85	128	162	190	210	240	296	337
4120064	2	28	40	56	72	82	85	123	136	159
	5	39	52	66	89	104	109	168	177	199
	10	46	61	72	100	118	125	198	204	225
	20	53	69	78	111	131	140	227	230	250
	50	61	80	86	125	149	160	264	264	282
4209093	2	32	45	63	79	83	86	109	127	142
	5	40	55	83	114	118	119	139	161	179
	10	45	61	96	136	140	141	159	183	204
	20	50	67	108	158	162	162	178	204	227
	50	57	75	124	187	191	191	203	232	258
4231103	2	41	56	72	88	103	112	160	207	247
	5	52	71	94	113	153	172	253	321	385
	10	60	81	108	129	186	211	315	396	476
	20	67	91	121	144	218	248	374	469	564
	50	76	104	139	164	260	297	451	562	677
4409091	2	27	39	59	72	77	78	96	113	124
	5	35	50	73	99	106	108	128	151	167
	10	40	57	84	117	126	128	149	176	195
	20	45	64	94	134	145	147	169	200	222
	50	51	73	108	156	169	172	196	232	258
4411001	2	25	40	55	68	72	75	111	138	154
	5	31	49	70	90	95	96	159	181	197
	10	35	55	80	104	109	111	192	210	225
	20	39	61	89	118	124	125	222	237	253
	50	44	68	101	135	142	142	262	273	288
4611114	2	23	35	48	65	71	72	92	110	122
	5	31	47	62	84	89	90	108	136	155
	10	36	55	71	97	101	101	118	154	177
	20	41	62	80	110	113	113	128	170	198
	50	47	72	91	126	127	127	141	191	225
4708084	2	27	42	57	69	74	77	94	106	119
	5	33	53	67	85	92	96	114	127	137
	10	38	61	74	96	103	108	127	140	149
	20	42	68	81	107	114	121	140	153	161
	50	47	77	90	121	129	136	157	169	176
5005001	2	27	41	59	73	77	81	101	124	136
	5	31	47	68	87	95	98	127	155	168
	10	34	51	74	96	106	108	143	175	189
	20	37	56	80	104	117	119	160	194	209
	50	41	61	88	115	131	132	180	219	236

Station No.	Return (T) Period (yrs)	Storm Duration (t) (hrs								
		¼	½	1	3	6	12	24	48	72
5210069	2	27	38	53	67	73	79	97	113	120
	5	38	53	70	87	91	99	118	144	158
	10	45	63	81	100	103	112	132	165	183
	20	52	72	92	113	114	125	146	186	207
	50	61	85	106	129	129	142	163	212	238
5331048	2	23	36	55	83	108	151	243	313	361
	5	32	48	71	118	157	229	359	474	548
	10	39	56	81	142	190	281	435	581	671
	20	44	63	92	164	221	330	509	683	789
	50	52	73	105	193	261	394	604	815	943
5504035	2	26	42	59	74	82	90	127	145	153
	5	32	50	78	100	116	130	188	211	217
	10	36	56	90	117	139	157	228	255	259
	20	40	62	102	133	161	183	266	296	299
	50	45	69	118	154	189	217	316	351	352
5625004	2	21	33	47	71	98	143	222	300	360
	5	30	42	58	98	141	211	330	450	551
	10	36	48	65	116	170	257	401	549	678
	20	42	54	72	133	198	300	470	645	799
	50	49	61	81	155	233	356	558	768	956
5725006	2	26	41	56	88	123	159	180	236	284
	5	33	51	76	131	195	252	297	361	420
	10	38	57	88	159	243	313	374	444	510
	20	43	63	101	186	289	372	448	523	597
	50	49	71	117	221	349	448	544	626	709
5806066	2	29	47	65	79	83	88	116	144	166
	5	36	55	81	105	108	111	147	196	221
	10	40	61	92	122	124	127	168	230	257
	20	44	66	102	134	140	142	188	263	292
	50	49	73	115	160	160	161	214	305	337
6007063	2	29	43	56	68	76	80	115	132	145
	5	41	57	74	92	105	116	169	190	205
	10	48	67	86	107	124	139	205	229	244
	20	56	76	97	123	142	162	240	266	282
	50	65	88	112	142	166	191	284	314	332
6021061	2	29	44	64	89	109	140	185	241	295
	5	34	56	80	113	150	201	226	356	436
	10	38	64	90	128	178	241	320	432	529
	20	42	71	101	143	204	280	372	506	619
	50	46	80	114	162	239	330	439	601	735
6103047	2	29	47	67	87	95	106	130	160	177
	5	36	59	82	110	121	134	169	204	220
	10	41	66	92	126	138	152	195	233	248
	20	45	74	102	141	154	169	220	260	276
	50	51	83	114	161	176	192	252	296	311

Station No.	Return (T) Period (Yrs)	Storm Duration (t) (hrs)								
		¼	½	1	3	6	12	24	48	72
6122064	2	27	40	56	80	104	144	229	301	348
	5	33	52	73	112	156	232	345	481	570
	10	37	60	85	133	190	290	421	600	718
	20	41	67	96	153	223	346	495	714	859
	50	46	77	110	179	266	418	590	862	1042
6204023	2	23	37	54	82	90	94	119	135	150
	5	31	50	67	104	120	131	158	174	185
	10	37	59	75	119	140	156	184	200	208
	20	42	68	83	133	160	179	208	225	230
	50	49	69	93	151	185	210	240	257	258
6206035	2	29	44	59	78	84	87	103	124	138
	5	37	57	74	101	110	111	128	151	167
	10	42	65	85	117	127	127	145	168	186
	20	47	73	95	132	143	143	161	185	205
	50	53	84	108	152	164	164	181	207	229
6401001	2	28	43	63	89	102	112	124	139	155
	5	38	56	84	136	154	168	174	189	215
	10	44	65	98	167	188	200	208	222	254
	20	51	74	112	197	222	230	239	253	292
	50	59	85	129	235	265	275	280	294	341

APPENDIX B (Cont.)

(b) Recording Raingauge Data–DID–Duration ≤ 12 hours. – Values of X(T, t)

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
1535107	2	29	42	56	66	74	85
	5	40	64	80	92	102	112
	10	48	79	95	108	121	130
	20	55	93	110	124	139	148
	50	65	111	129	145	162	170
1541139	2	16	35	60	85	103	120
	5	17	38	69	115	147	184
	10	18	40	74	136	176	227
	20	19	43	80	155	204	268
	50	21	45	86	180	241	321
1737001	2	24	35	50	75	79	85
	5	28	46	80	117	120	134
	10	31	54	98	144	148	166
	20	34	61	116	171	174	197
	50	38	70	140	205	209	236
1834124	2	31	45	58	71	74	76
	5	42	56	70	86	92	94
	10	50	63	78	96	104	106
	20	57	70	85	106	115	118
	50	67	79	95	119	130	133
1839196	2	30	45	63	82	98	106
	5	40	54	78	105	143	163
	10	46	60	89	120	173	201
	20	52	66	99	134	201	237
	50	60	73	111	152	238	284
1931001	2	27	38	48	60	65	74
	5	36	48	61	69	77	98
	10	42	55	69	75	85	114
	20	48	62	77	80	93	129
	50	56	71	87	87	103	149
2330009	2	27	36	46	58	69	81
	5	32	43	58	73	102	129
	10	36	48	66	84	124	161
	20	39	52	73	93	145	191
	50	43	58	83	106	172	230
2528012	2	21	35	55	73	80	85
	5	36	49	70	95	103	114
	10	46	58	80	110	118	134
	20	56	67	89	124	133	153
	50	68	79	101	142	152	178

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
2734163	2	29	43	60	100	140	183
	5	38	55	74	127	190	281
	10	43	63	84	144	223	345
	20	49	70	93	161	255	407
	50	56	80	105	182	296	487
2917001	2	27	41	62	77	82	89
	5	37	53	77	94	103	122
	10	43	61	87	103	117	144
	20	49	69	96	116	130	165
	50	57	78	109	130	147	193
3026156	2	20	31	46	74	83	105
	5	31	42	61	114	143	222
	10	38	49	70	140	183	300
	20	45	57	79	166	222	374
	50	54	66	91	199	272	471
3118102	2	24	38	57	71	78	80
	5	38	56	68	96	104	110
	10	48	68	78	112	121	129
	20	58	80	88	128	137	148
	50	70	95	101	149	159	172
3217002	2	37	53	75	101	111	116
	5	49	88	132	150	178	203
	10	57	111	170	182	222	261
	20	65	133	207	212	265	317
	50	75	162	254	254	320	389
3231163	2	30	45	59	71	81	96
	5	37	53	73	87	96	121
	10	42	58	82	98	105	135
	20	46	63	91	106	114	153
	50	52	69	102	122	126	174
3314001	2	20	33	54	66	77	86
	5	24	39	69	80	105	124
	10	26	44	79	86	123	149
	20	28	48	89	93	140	173
	50	31	53	101	101	163	204
3416002	2	34	49	63	61	86	92
	5	41	57	83	118	133	134
	10	45	62	97	142	165	165
	20	49	67	110	165	195	195
	50	55	73	127	195	233	233
3424081	2	24	41	62	81	87	90
	5	35	59	84	120	130	133
	10	42	70	98	146	158	162
	20	49	82	112	171	186	190
	50	57	96	130	203	221	226

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
3519125	2	17	31	50	70	77	80
	5	24	40	61	86	101	110
	10	29	45	69	97	116	130
	20	33	51	76	107	131	149
	50	39	58	85	120	151	174
3615003	2	15	29	46	65	67	70
	5	18	35	57	86	87	92
	10	20	39	64	99	100	106
	20	22	43	71	112	112	120
	50	25	48	80	129	129	137
3833001	2	25	36	58	101	148	196
	5	30	44	68	132	225	312
	10	34	50	75	152	276	389
	20	37	55	82	173	325	462
	50	41	61	90	199	389	558
3924072	2	28	41	58	76	87	92
	5	40	52	76	104	120	125
	10	49	60	88	122	142	147
	20	57	67	100	140	164	169
	50	67	76	114	164	191	196
3930012	2	20	35	56	77	97	138
	5	27	44	70	99	141	231
	10	31	50	80	113	170	293
	20	35	56	89	127	198	352
	50	41	63	100	145	234	429
4023001	2	28	44	59	82	92	95
	5	33	53	67	121	135	142
	10	36	59	72	147	163	173
	20	39	64	77	172	189	202
	50	43	72	84	204	224	241
4219001	2	34	53	79	97	100	106
	5	46	58	95	119	123	128
	10	54	61	105	134	138	143
	20	61	64	114	148	153	157
	50	71	67	127	167	171	175
4311001	2	30	48	72	97	105	112
	5	44	69	96	105	130	143
	10	54	83	112	115	147	163
	20	63	96	127	126	163	183
	50	75	113	146	150	184	208
4511111	2	31	49	64	85	88	90
	5	41	63	85	103	108	113
	10	48	73	98	115	122	127
	20	54	82	111	127	134	141
	50	62	94	128	142	151	160

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
4529071	2	16	31	50	71	93	118
	5	19	39	57	98	123	170
	10	22	44	62	115	143	204
	20	24	49	66	132	162	236
	50	27	56	72	154	187	279
4734079	2	29	43	63	103	127	169
	5	40	62	95	137	165	225
	10	47	74	116	159	190	262
	20	55	86	136	181	214	298
	50	64	101	162	208	245	344
4819027	2	30	46	62	83	87	91
	5	37	59	86	101	104	107
	10	41	67	102	113	115	117
	20	45	76	117	124	126	127
	50	50	86	136	138	140	140
4832077	2	21	35	59	97	131	170
	5	33	53	80	140	197	260
	10	41	65	94	169	240	320
	20	49	77	108	196	281	377
	50	59	92	125	232	335	452
4923001	2	24	38	62	80	83	91
	5	34	48	75	104	109	124
	10	40	54	85	119	126	146
	20	46	60	94	134	142	167
	50	53	68	105	153	163	194
4931067	2	20	34	49	89	133	176
	5	28	50	70	134	224	273
	10	32	60	84	163	285	337
	20	37	70	98	192	343	399
	50	43	83	115	229	417	479
5029034	2	44	59	80	105	133	172
	5	88	114	129	153	194	249
	10	118	150	161	184	233	301
	20	146	184	192	214	272	350
	50	183	229	232	254	321	415
5030039	2	24	37	53	82	114	159
	5	34	49	68	108	152	211
	10	40	57	78	125	178	246
	20	47	65	88	142	203	278
	50	55	75	100	163	235	321

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
5105051	2	21	31	48	67	81	83
	5	25	39	64	85	107	112
	10	28	44	74	97	124	130
	20	30	49	84	108	140	148
	50	34	55	97	123	161	171
5120025	2	19	32	49	68	78	88
	5	30	43	60	89	101	108
	10	37	50	67	104	117	121
	20	44	57	74	118	132	134
	50	53	66	82	136	151	154
5226001	2	16	31	51	66	94	124
	5	18	35	63	92	126	184
	10	20	38	72	110	147	225
	20	22	40	80	126	167	263
	50	24	45	90	148	193	313
5303053	2	26	40	55	74	87	100
	5	37	58	71	124	132	149
	10	45	70	81	151	162	182
	20	52	81	91	189	191	213
	50	61	96	103	230	230	254
5320038	2	30	47	67	84	90	103
	5	40	67	84	107	120	147
	10	47	79	96	121	140	176
	20	53	92	107	135	159	204
	50	62	107	122	154	184	240
5322044	2	30	48	64	76	83	94
	5	36	60	84	96	104	124
	10	40	67	97	110	118	145
	20	44	75	109	123	131	164
	50	49	84	125	140	148	189
5328044	2	31	49	68	96	137	196
	5	42	63	85	126	199	262
	10	50	71	96	145	240	305
	20	57	80	107	164	280	347
	50	66	91	121	188	331	401
5411066	2	29	45	60	70	72	73
	5	51	61	72	82	83	83
	10	66	72	80	90	91	91
	20	79	82	89	97	99	99
	50	97	97	100	107	108	108
5412067	2	24	37	46	56	64	71
	5	36	57	72	84	96	98
	10	45	70	89	103	117	117
	20	53	83	105	121	138	138
	50	63	99	126	145	165	166

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
5428025	2	24	36	53	81	116	170
	5	30	43	60	95	150	226
	10	34	48	65	104	172	264
	20	38	52	70	112	194	300
	50	43	58	76	123	221	346
5522047	2	24	36	57	76	109	162
	5	30	50	73	115	200	317
	10	34	60	84	141	260	420
	20	38	68	94	166	317	519
	50	43	80	107	199	392	647
5524002	2	29	44	61	100	130	190
	5	35	51	76	130	167	254
	10	40	56	86	151	191	297
	20	44	60	95	170	214	339
	50	50	66	107	195	243	392
5610063	2	31	47	59	71	77	86
	5	54	94	114	125	134	138
	10	69	125	149	161	173	173
	20	84	155	184	195	209	209
	50	103	194	228	240	257	260
5718033	2	29	49	76	104	120	154
	5	34	60	99	137	173	243
	10	38	67	115	159	208	301
	20	41	74	130	181	242	358
	50	46	83	149	208	286	431
5722057	2	27	43	58	87	114	167
	5	37	54	71	121	181	272
	10	43	61	80	144	226	342
	20	49	68	88	166	269	408
	50	57	77	99	194	325	495
5804035	2	24	25	52	79	87	88
	5	37	43	69	106	108	113
	10	44	50	81	127	127	129
	20	52	57	92	145	145	145
	50	61	65	107	168	168	168
6019004	2	22	32	50	73	88	126
	5	30	42	66	86	104	181
	10	35	48	77	95	115	218
	20	40	55	87	104	126	252
	50	46	63	100	115	140	298
6106034	2	23	34	53	76	82	89
	5	28	42	68	98	109	115
	10	31	46	78	112	127	132
	20	35	51	87	126	144	148
	50	39	57	100	144	165	169

Station No.	Return Period (T) (yrs)	Storm Duration (t) (hrs)					
		¼	½	1	3	6	12
6108001	2	31	47	59	72	76	80
	5	45	72	86	100	109	110
	10	54	89	103	118	130	130
	20	63	105	120	135	151	151
	50	74	125	142	158	178	180
6121015	2	20	33	52	83	101	132
	5	25	41	68	104	149	228
	10	28	46	78	118	180	296
	20	31	51	88	131	210	354
	50	34	57	101	149	249	434
6207031	2	32	44	67	93	101	111
	5	42	53	84	114	131	140
	10	48	60	95	128	152	159
	20	55	66	105	142	171	177
	50	63	75	119	159	196	201
6603002	2	30	40	57	68	76	94
	5	37	54	77	89	97	113
	10	41	64	91	103	111	126
	20	46	73	104	117	124	138
	50	51	84	120	135	141	153

APPENDIX B (CONTINUED)

(c) Recording Raingauge Data–MMS–Duration ≤ 24 hrs. – Values of X(T, t)

Station Name	Return Period (T) (yrs)	Storm Duration (t) (hrs)						
		¼	½	1	3	6	12	24
Bayan Lepas	2	31	49	69	91	104	116	136
	5	37	56	84	114	127	148	181
	10	41	61	94	130	141	170	211
	20	45	66	104	145	156	191	240
	50	49	72	116	164	174	217	278
Kuala Lumpur	2	37	55	70	81	85	90	106
	5	43	64	78	93	102	111	135
	10	48	70	83	101	114	124	154
	20	52	75	89	109	125	137	173
	50	58	82	96	119	139	155	196
Kuantan	2	31	49	70	100	125	166	211
	5	38	60	86	124	163	238	324
	10	42	67	97	139	188	285	399
	20	46	74	107	154	212	331	470
	50	51	83	120	174	243	390	563
Melaka	2	30	47	65	83	91	98	108
	5	47	59	84	104	117	126	139
	10	42	66	97	118	134	144	159
	20	46	74	110	132	150	161	178
	50	52	83	126	150	171	184	204
Alor Setar	2	33	49	63	81	94	100	.112
	5	39	58	79	101	117	123	139
	10	44	64	89	114	132	139	156
	20	48	70	99	127	146	153	173
	50	53	78	111	144	165	172	194
Kota Bahru	2	31	47	64	101	138	186	236
	5	35	56	80	135	184	271	362
	10	39	62	90	157	214	328	446
	20	42	68	100	179	243	383	527
	50	46	75	113	207	281	453	631
Sitiawan	2	31	46	63	83	89	93	97
	5	38	56	79	109	121	125	133
	10	43	63	89	126	142	146	156
	20	47	69	98	142	162	167	179
	50	53	77	111	164	188	193	209
Kuala Trengganu	2	27	43	61	91	126	171	220
	5	34	52	76	117	176	249	338
	10	38	59	86	134	209	300	416
	20	41	65	96	151	241	349	491
	50	46	72	109	172	282	413	589

Station Name	Return Period (T) (yrs)	Storm Duration (t) (hrs)						
		¼	½	1	3	6	12	24
Cameron Highland	2	24	37	51	63	73	77	87
	5	29	42	62	83	94	97	115
	10	32	46	69	97	107	110	133
	20	35	50	76	110	120	123	150
	50	39	55	85	126	137	139	173
Ipoh	2	36	52	68	83	90	92	101
	5	42	60	79	100	111	112	128
	10	47	66	87	112	125	125	145
	20	51	71	94	124	138	140	162
	50	56	78	103	138	156	160	184
MERSING	2	31	48	70	103	132	165	204
	5	37	56	81	136	188	242	313
	10	41	62	89	158	224	292	386
	20	44	68	96	179	259	341	455
	50	49	75	106	206	305	403	545

APPENDIX B (Cont.)

(d) Daily Rainfall Data–DID–Values of X(T, t)

Station No.	Storm Duration (t) (hrs)	Return Period (T) (Yrs)				
		2	5	10	20	50
1334108	24	114	156	183	210	244
	48	142	188	219	248	285
	72	164	210	240	270	307
1534104	24	116	160	189	217	253
	48	145	195	228	260	301
	72	170	223	259	293	337
1540135	24	124	169	198	226	263
	48	167	243	294	343	405
	72	196	303	374	441	529
1631084	24	117	158	185	211	244
	48	130	183	218	251	294
	72	151	215	257	298	351
1636109	24	117	172	208	243	288
	48	155	223	269	313	370
	72	176	256	309	359	425
1639132	24	149	226	278	328	392
	48	187	302	377	450	544
	72	219	352	441	526	636
1834124	24	108	139	160	180	206
	48	146	205	245	283	332
	72	162	223	264	303	354
1926051	24	108	130	145	159	178
	48	122	151	170	188	211
	72	135	166	186	206	231
1931072	24	124	170	200	228	265
	48	153	219	262	304	358
	72	173	240	285	328	384
2123024	24	66	98	120	141	167
	48	98	123	144	163	189
	72	113	156	184	211	246
2130068	24	117	172	208	243	288
	48	151	230	282	332	397
	72	169	260	319	377	451
2221008	24	119	156	180	203	233
	48	144	198	234	268	312
	72	160	212	247	280	323
2222011	24	116	162	193	222	260
	48	136	187	220	252	294
	72	152	209	247	284	331

Station No.	Storm Duration (t) (hrs)	Return Period (T) (yrs)				
		2	5	10	20	50
2223022	24	108	154	185	214	252
	48	130	180	213	245	285
	72	140	192	227	260	303
2228016	24	107	142	165	187	215
	48	140	198	237	274	321
	72	155	221	265	306	361
2232158	24	129	206	256	305	368
	48	175	291	368	441	536
	72	198	325	410	491	596
2235163	24	154	231	282	331	395
	48	211	330	409	485	583
	72	278	477	610	737	850
2324022	24	91	128	152	175	205
	48	121	169	201	232	271
	72	131	186	222	257	302
2326022	24	109	155	185	214	251
	48	131	186	222	257	302
	72	152	213	253	291	341
2419054	24	110	138	156	174	197
	48	131	170	197	222	254
	72	145	194	226	257	297
2424087	24	95	122	140	157	178
	48	116	153	178	202	233
	72	128	174	205	234	272
2430008	24	145	235	295	352	426
	48	195	342	440	533	654
	72	225	408	530	646	797
2438185	24	212	335	416	494	596
	48	282	441	546	647	778
	72	325	529	663	793	960
2521050	24	104	139	162	184	213
	48	135	190	226	260	305
	72	154	210	247	282	328
2528012	24	134	195	236	275	325
	48	166	248	303	354	422
	72	185	283	349	411	492
2537183	24	183	263	315	365	430
	48	235	336	404	469	552
	72	280	390	462	532	621
2616135	24	118	166	198	229	269
	48	137	189	223	255	297
	72	153	206	240	273	316

Station No.	Storm Duration (t) (hrs)	Return Period (t) (yrs)				
		2	5	10	20	50
2834181	24	228	313	369	423	492
	48	309	471	579	681	816
	72	371	593	740	881	1063
2913122	24	101	134	156	177	204
	48	123	163	190	216	250
	72	141	188	220	250	289
2917106	24	105	132	150	167	189
	48	125	157	179	200	226
	72	148	184	208	232	262
2920012	24	81	115	136	157	184
	48	97	142	171	199	235
	72	113	167	202	236	280
2924096	24	109	153	182	209	245
	48	130	202	249	295	354
	72	156	241	297	351	421
301484	24	106	141	164	186	215
	48	136	173	198	221	252
	72	153	196	225	252	287
3034168	24	189	260	306	351	408
	48	276	385	457	526	616
	72	331	482	583	679	803
3115079	24	106	140	163	185	213
	48	131	167	190	212	241
	72	146	185	211	235	267
3213057	24	119	162	191	219	254
	48	135	177	205	232	267
	72	153	203	236	268	310
3234162	24	207	288	342	393	459
	48	282	427	523	615	734
	72	326	503	619	732	877
3320130	24	111	136	153	169	190
	48	137	172	196	219	248
	72	156	197	224	250	283
3325085	24	88	143	180	215	260
	48	111	161	194	225	267
	72	123	173	206	238	279
3421134	24	108	134	151	167	188
	48	127	154	172	189	210
	72	144	176	197	217	244

Station No.	Storm Duration (t) (hrs)	Return Period (t) (yrs)				
		2	5	10	20	50
3424081	24	108	142	165	186	215
	48	130	172	201	228	263
	72	145	193	226	257	297
3430097	24	155	213	251	288	336
	48	207	324	401	476	572
	72	234	383	481	576	698
3527092	24	106	157	192	225	267
	48	139	220	274	326	392
	72	166	271	341	407	494
3629098	24	139	206	250	292	347
	48	189	285	349	410	489
	72	219	337	415	490	587
3723077	24	104	132	151	169	192
	48	128	168	194	220	152
	72	140	192	227	260	302
3726073	24	101	141	167	192	225
	48	134	192	230	267	314
	72	159	233	281	327	387
3833022	24	211	287	337	385	447
	48	297	436	5261	618	733
	72	335	470	559	645	756
3907103	24	108	147	165	187	215
	48	130	167	192	215	245
	72	143	181	207	231	262
3921068	24	90	121	142	161	187
	48	108	139	160	180	206
	72	130	176	207	236	274
3924071	24	110	134	149	164	183
	48	135	179	208	236	272
	72	159	223	265	305	357
3930012	24	178	256	308	358	422
	48	237	352	427	500	594
	72	288	434	531	624	744
4033001	24	199	275	326	374	437
	48	258	355	419	480	560
	72	298	423	505	584	686
4218042	24	79	108	127	145	169
	48	117	167	200	231	272
	72	149	207	246	284	332
4223115	24	120	176	213	249	295
	48	144	231	288	343	415
	72	167	267	333	397	479

Station No.	Storm Duration (t) (hrs)	Return Period (t) (yrs)				
		2	5	10	20	50
4306042	24	110	153	182	209	244
	48	122	166	194	222	258
	72	137	182	212	240	277
4319048	24	116	147	167	187	213
	48	133	1.66	188	209	237
	72	152	184	206	226	252
4320066	24	110	155	184	212	248
	48	128	167	193	218	251
	72	142	190	221	252	291
4324113	24	120	166	197	226	264
	48	136	180	210	238	275
	72	153	202	234	265	304
4333096	24	199	287	345	401	474
	48	267	389	469	547	647
	72	303	427	510	589	692
4507036	24	129	166	190	213	243
	48	159	198	224	249	281
	72	184	219	243	265	294
4529071	24	163	324	431	533	666
	48	221	504	691	871	1104
	72	253	544	736	920	1159
4534092	24	208	312	381	447	532
	48	274	417	512	603	720
	72	326	501	617	728	872
4620045	24	101	138	163	186	217
	48	140	195	232	267	312
	72	166	239	287	333	392
4731083	24	207	301	364	424	502
	48	140	195	232	267	312
	72	348	477	562	645	751
4734079	24	198	275	326	375	438
	48	249	346	410	471	550
	72	298	412	487	559	653
4806032	24	121	181	220	258	307
	48	151	207	244	280	326
	72	180	243	284	324	376
4811078	24	102	130	148	162	189
	48	123	151	170	187	211
	72	141	170	189	207	230
4819001	24	88	121	142	163	189
	48	114	161	192	222	260
	72	131	188	226	262	309

Station No.	Storm Duration (t) (hrs)	Return Period (t) (yrs)				
		2	5	10	20	50
5009071	24	77	98	112	125	143
	48	93	116	131	146	165
	72	109	133	149	165	184
5030039	24	181	265	320	373	442
	48	274	402	487	568	674
	72	337	479	574	665	782
5033069	24	215	297	351	402	470
	48	285	403	482	557	654
	72	333	488	590	689	816
5101007	24	124	153	172	191	214
	48	157	198	225	251	285
	72	182	221	247	272	304
5120025	24	114	153	179	204	237
	48	135	185	215	246	285
	72	149	203	239	273	317
5204049	24	119	165	195	225	262
	48	135	185	218	250	291
	72	149	205	241	276	321
5302001	24	168	243	292	339	400
	48	210	285	335	382	444
	72	239	315	365	414	476
5320038	24	121	173	207	239	281
	48	144	196	230	263	305
	72	165	226	266	304	354
5320039	24	105	135	155	174	199
	48	145	194	227	259	300
	72	174	240	284	326	380
5322044	24	126	192	235	276	329
	48	165	276	350	421	513
	72	195	345	445	540	664
5328043	24	164	338	453	564	707
	48	210	381	493	602	742
	72	249	440	566	688	845
5407080	24	123	152	171	189	212
	48	164	199	223	245	274
	72	188	226	252	276	308
5411068	24	124	203	255	305	370
	48	147	226	278	328	392
	72	162	238	288	336	398
5419036	24	136	211	261	309	371
	48	181	275	338	397	474
	72	209	310	377	442	525

Station No.	Storm Duration (t) (hrs)	Return Period (t) (yrs)				
		2	5	10	20	50
5424001	24	176	231	268	303	349
	48	257	346	405	461	534
	72	311	424	498	569	662
5507076	24	113	144	163	183	207
	48	139	179	206	230	260
	72	151	185	207	230	260
5518035	24	146	248	316	381	465
	48	203	371	483	590	729
	72	238	425	549	668	821
5522047	24	142	222	275	327	393
	48	180	284	353	420	505
	72	203	325	406	484	585
5524002	24	168	230	270	309	360
	48	224	312	369	425	497
	72	261	389	474	556	661
5527021	24	221	359	450	537	650
	48	305	516	657	791	965
	72	372	598	747	890	1075
5529027	24	247	345	410	472	552
	48	315	459	555	647	765
	72	345	504	610	711	841
5609072	24	115	150	174	196	225
	48	133	166	187	208	234
	72	147	185	210	234	266
5618033	24	157	239	294	346	414
	48	210	327	405	479	575
	72	253	380	464	545	649
5621052	24	192	294	362	428	552
	48	260	408	505	599	720
	72	299	473	589	700	843
5704055	24	206	275	321	364	421
	48	259	334	384	432	494
	72	291	375	431	484	553
5718001	24	103	142	168	192	224
	48	146	216	263	308	366
	72	174	251	302	350	413
5722057	24	156	285	369	451	556
	48	212	431	566	695	862
	72	249	507	661	809	1000
5808070	24	110	147	171	194	224
	48	146	189	218	246	281
	72	172	223	257	290	332

Station No.	Storm Duration (t) (hrs)	Return Period (t) (yrs)				
		2	5	10	20	50
5824079	24	192	285	347	406	483
	48	248	365	442	516	611
	72	301	438	528	615	727
6005044	24	121	159	185	209	241
	48	146	188	215	241	275
	72	164	216	251	284	327
6019004	24	139	194	231	267	313
	48	187	258	305	350	408
	72	227	317	377	434	508
6023072	24	237	328	388	446	521
	48	323	478	580	678	805
	72	380	567	691	811	965
6121015	24	204	357	458	555	681
	48	229	398	509	616	754
	72	257	424	534	641	778
6207032	24	131	161	181	200	225
	48	157	182	198	213	233
	72	164	188	205	220	240
6306031	24	129	167	192	216	248
	48	142	175	197	218	245
	72	147	183	207	230	260
6397111	24	136	182	213	242	280
	48	171	218	249	278	317
	72	199	254	291	326	371
6403025	24	112	150	176	200	232
	48	133	167	190	212	240
	72	148	179	199	219	244
6602002	24	103	136	158	180	207
	48	132	167	190	212	241
	72	153	193	220	246	279

APPENDIX C

CHECK ON VALIDITY OF DEPTH – DURATION PLOTTING DIAGRAM

Station No.	Return Period (T) (yrs)	% Errors in X(T, t) for the Duration(t) (hrs) shown				
		¼	1	6	12	48
1437116	2	– 19	+ 3	+ 2	0	– 1
	20	– 58	+ 4	– 1	+ 1	+ 1
1829078	2	– 19	– 4	– 4	– 14	0
	20	– 10	– 13	+ 11	– 3	+ 1
2033153	2	– 30	+ 9	– 8	– 14	+ 1
	20	+ 20	+ 11	– 20	– 1	+ 5
2125042	2	+ 14	+ 4	– 4	– 18	0
	20	– 35	+ 2	– 4	– 27	0
2238188	2	+ 9	0	– 6	– 6	– 3
	20	+ 16	+ 5	– 18	– 36	– 4
2322004	2	– 22	+ 8	– 1	– 5	+ 1
	20	– 21	– 1	0	– 3	– 3
2636170	2	+ 13	– 11	+ 4	– 6	+ 4
	20	+ 40	– 25	0	– 20	– 5
2719001	2	+ 4	+ 2	0	– 9	– 1
	20	– 4	+ 6	– 1	– 5	– 4
2722002	2	– 28	+ 9	– 14	– 24	– 1
	20	– 51	+ 8	– 8	– 29	+ 1
2725083	2	– 12	+ 4	– 4	– 4	– 3
	20	– 17	+ 14	– 8	– 7	– 9
2815001	2	– 17	+ 5	– 1	– 10	– 3
	20	0	– 3	+ 3	– 5	+ 3
2818110	2	0	+ 5	– 2	– 7	0
	20	– 2	+ 13	– 9	– 6	+ 4
3117070	2	– 30	+ 3	– 1	– 10	– 1
	20	– 7	+ 8	+ 1	– 11	+ 1
3122001	2	+ 4	+ 16	+ 4	– 4	– 1
	20	+ 6	+ 4	+ 5	+ 12	– 1

Station No.	Return Period (T) (yrs)	% Errors in X(T, t) for the Duration(t) (hrs) shown				
		¼	1	6	12	48
3318126	2	0	+ 17	+ 5	− 8	0
	20	− 6	+ 13	− 15	− 12	− 4
3411017	2	0	0	+ 3	− 8	− 1
	20	33	− 4	+ 5	+ 1	0
3414031	2	− 14	+ 6	− 5	− 12	− 2
	20	− 36	− 8	− 5	− 13	− 8
3516022	2	− 4	+ 5	− 2	− 3	+ 2
	20	+ 12	+ 1	− 7	− 16	+ 4
353102	2	− 3	+ 4	− 6	− 26	0
	20	+ 17	− 6	− 10	− 29	+ 3
3613004	2	− 10	0	− 1	− 6	− 1
	20	+ 17	− 2	− 1	− 4	− 5
3710006	2	0	+ 3	− 1	− 5	− 2
	20	+ 3	− 8	+ 2	+ 3	+ 2
3818054	2	− 8	− 5	+ 7	+ 5	+ 3
	20	+ 14	− 7	+ 25	+ 23	+ 3
4019061	2	− 7	+ 4	− 3	− 9	− 2
	20	+ 13	− 5	− 3	− 7	− 4
4111137	2	− 7	+ 5	+ 1	− 9	− 1
	20	− 19	+ 8	+ 23	+ 21	0
4120064	2	− 4	− 2	− 1	− 15	− 6
	20	− 4	− 6	− 5	− 21	− 5
4209093	2	− 3	+ 6	− 2	− 9	0
	20	+ 20	+ 4	0	− 3	− 1
4231103	2	− 10	+ 3	0	− 13	− 2
	20	− 6	+ 7	+ 9	− 7	− 2
4409091	2	0	+ 9	0	− 9	+ 1
	20	+ 11	+ 1	+ 3	− 3	0
4411001	2	− 16	+ 5	− 6	− 20	+ 1
	20	− 8	+ 3	− 12	− 40	− 1

Station No.	Return Period (T) (yrs)	% Errors in X(T, t) for the Duration(t) (hrs) shown				
		¼	1	6	12	48
4611114	2	– 9	0	0	– 10	+ 5
	20	– 12	– 3	– 1	– 5	+ 1
4708084	2	– 19	+ 7	0	– 6	– 1
	20	– 29	– 4	0	– 2	0
5005051	2	– 11	+ 8	0	– 7	+ 2
	20	+ 5	+ 5	0	+ 8	+ 3
5210069	2	0	+ 6	– 3	+ 1	+ 2
	20	– 8	+ 9	– 5	– 4	+ 2
5331048	2	+ 17	0	– 2	– 9	0
	20	+ 32	– 13	+ 1	– 3	+ 2
5504035	2	– 19	+ 7	– 2	– 13	+ 2
	20	0	+ 10	+ 1	– 4	+ 4
5625004	2	+ 5	– 4	– 4	– 6	– 1
	20	+ 4	– 22	+ 6	– 3	– 1
5725006	2	+ 4	– 7	+ 13	+ 14	– 2
	20	+ 53	– 11	+ 19	+ 14	– 2
5806066	2	– 21	+ 6	– 5	– 14	0
	20	+ 18	+ 1	– 16	– 22	+ 6
6007063	2	– 17	+ 5	– 1	– 15	0
	20	+ 20	+ 1	– 4	– 18	+ 1
6021061	2	0	0	0	0	– 3
	20	– 10	0	+ 7	+ 4	– 2
6103047	2	– 10	+ 4	– 3	– 3	+ 1
	20	– 9	0	– 3	– 8	+ 3
6122064	2	0	– 2	– 4	– 8	0
	20	+ 12	– 6	– 2	+ 2	1
6204023	2	+ 9	– 2	– 6	– 9	– 1
	20	– 7	– 16	+ 8	+ 4	+ 2
6206035	2	+ 9	– 2	0	– 6	+ 1
	20	– 15	– 3	+ 7	– 1	+ 1
6401001	2	0	+ 16	+ 18	– 8	– 2
	20	+ 5	– 26	– 20	– 24	– 7

APPENDIX D

Temporal Distribution of Annual Maximum Rainstorms in Peninsular Malaysia

1. Introduction

Hydrological Procedure No. 1 enables an estimation of the design rainfall depths in Peninsular Malaysia. As an extension, a study was carried out to find out the temporal distribution of annual maximum rainstorms for a few selected durations namely ½, 3, 6, 12, 24 and 72 hours.

Nine rainfall stations located at different parts of the Peninsular Malaysia were selected for this purpose (see Fig. D.1). The data used cover nine water years from July 1970 to June 1979.

2. Analysis and Results

It was decided to distribute the rainfall within the six selected durations as follows:–

½ hour – 3 time periods of 10 minutes each
3 hours – 6 time periods of ½ hour each
6 hours – 6 time periods of 1 hour each
12 hours – 6 time periods of 2 hours each
24 hours – 4 time periods of 6 hours each
72 hours – 6 time periods of 12 hours each

From each year of record, the storm producing the annual maximum rainfall depth for each of the above six durations was noted. The annual maximum rainfall depths were then sub-divided into the respective time periods. The amount of rain falling in each of these periods was then expressed in percentage of the whole maximum rainfall depth for the respective duration. Note that the starting time of the annual maximum rainfall depth need not coincide with the starting time of the rainstorm as the annual maximum values are usually part of the total storms.

For each station, the average temporal distributions over the nine year period were computed. As there were noticeable difference between the West Coast and East Coast values (except for ½ hour storms) the nine rainfall stations were accordingly grouped and the mean temporal distributions for each group were then computed.

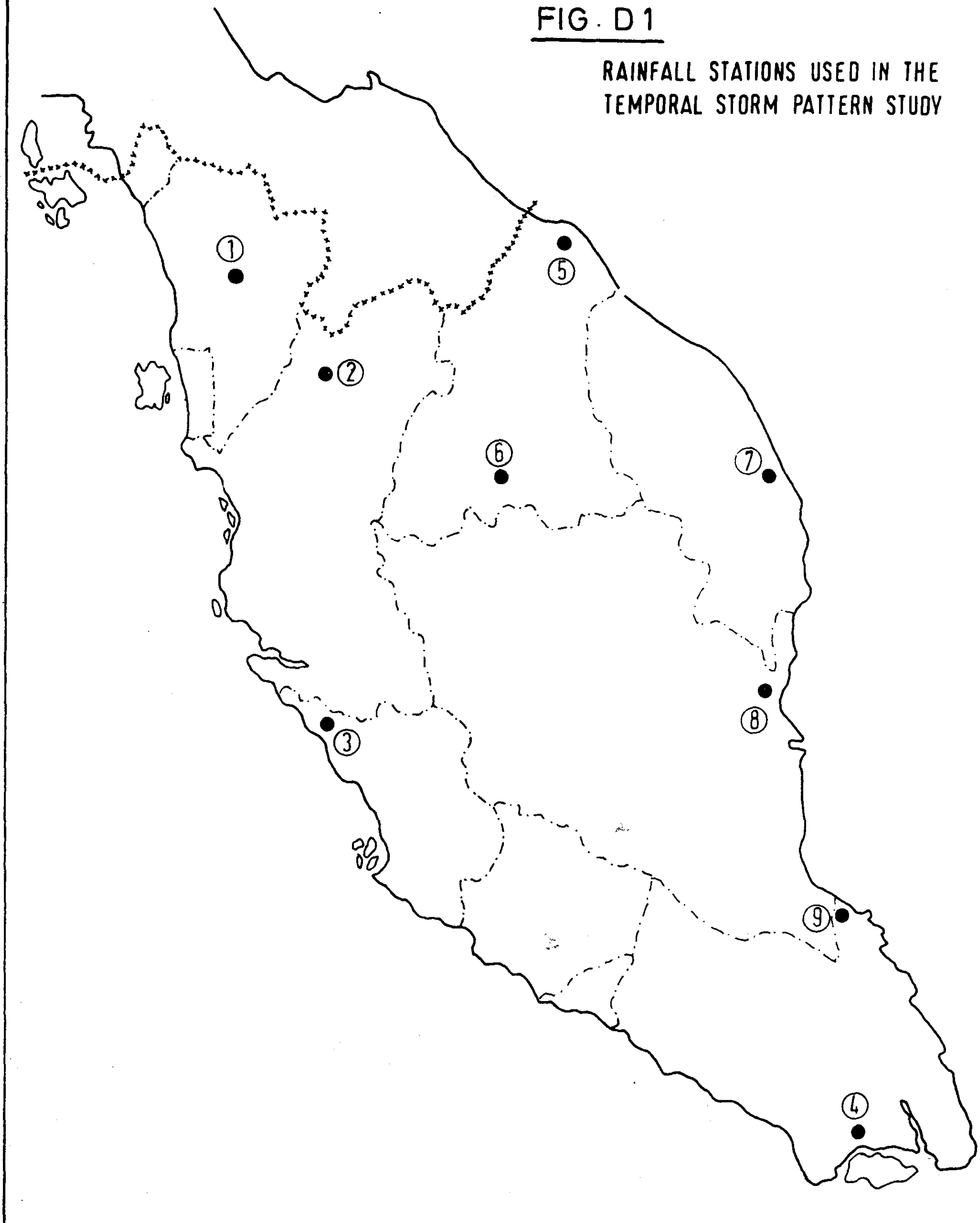
The results are presented as shown in Fig. D.2 to Fig. D.7 for temporal distributions at individual stations, and Fig. D.8 to Fig. D.13 for the mean temporal distributions for each group of West Coast and East Coast stations.

3. Comment

From Fig. D.2 to D.7 it can be seen that within each group, the temporal distributions of the storm are quite consistent except for isolated cases such as in Fig. D.4, Fig. D.5 (East Coast – 6 and 12 hours respectively) and Fig. D.7 (West Coast – 72 hours). However, the results presented here should only be used as a guide in the temporal distribution of any design rainstorm, especially for cases where the durations concerned are different from those used in the study. It should be recognised that the study deals with only the annual rainfall maximums which are in general of a burst type of event for short duration rainstorms and a summation of storm events for longer duration rainstorms.

FIG. D1

RAINFALL STATIONS USED IN THE TEMPORAL STORM PATTERN STUDY



NOTE

FIGURES SHOWING THE TEMPORAL DISTRIBUTIONS FOR THE SELECTED STATIONS

FIG D.2 : 1/2 HOUR MEAN AT 10 MIN. INTERVAL
FIG D.3 : 3 HOUR AT 1/2 HOURLY INTERVAL
FIG D.4 : 6 HOUR AT 1 HOURLY INTERVAL
FIG D.5 : 12 HOUR AT 2 HOURLY INTERVAL
FIG D.6 : 24 HOUR AT 6 HOURLY INTERVAL
FIG D.7 : 72 HOUR AT 12 HOURLY INTERVAL

FIG. D.2

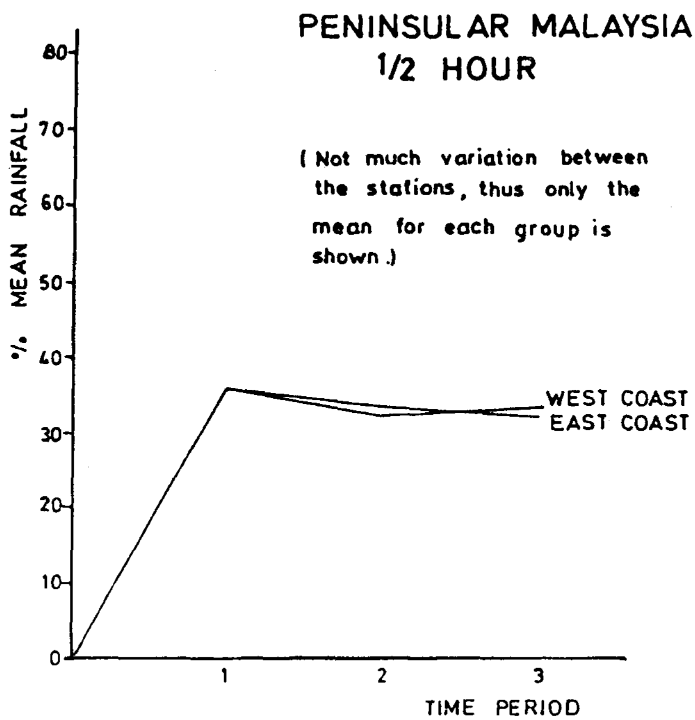


FIG. D.3

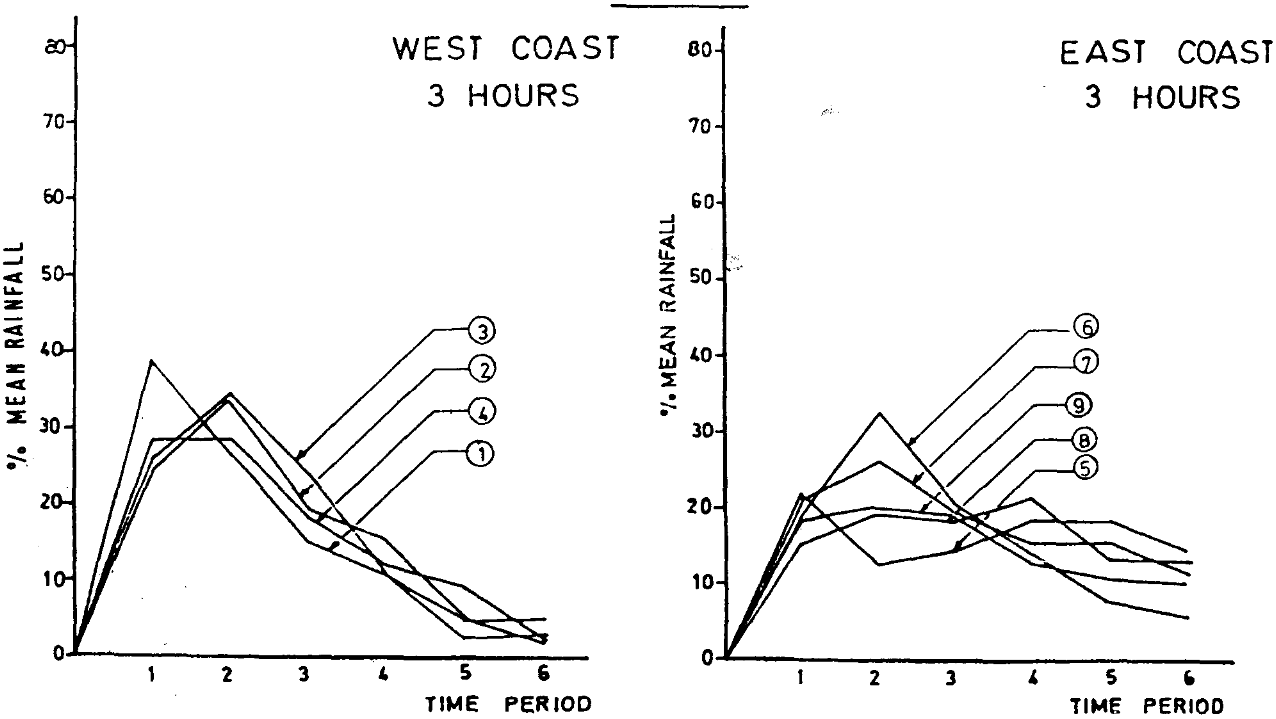


FIG. D.4

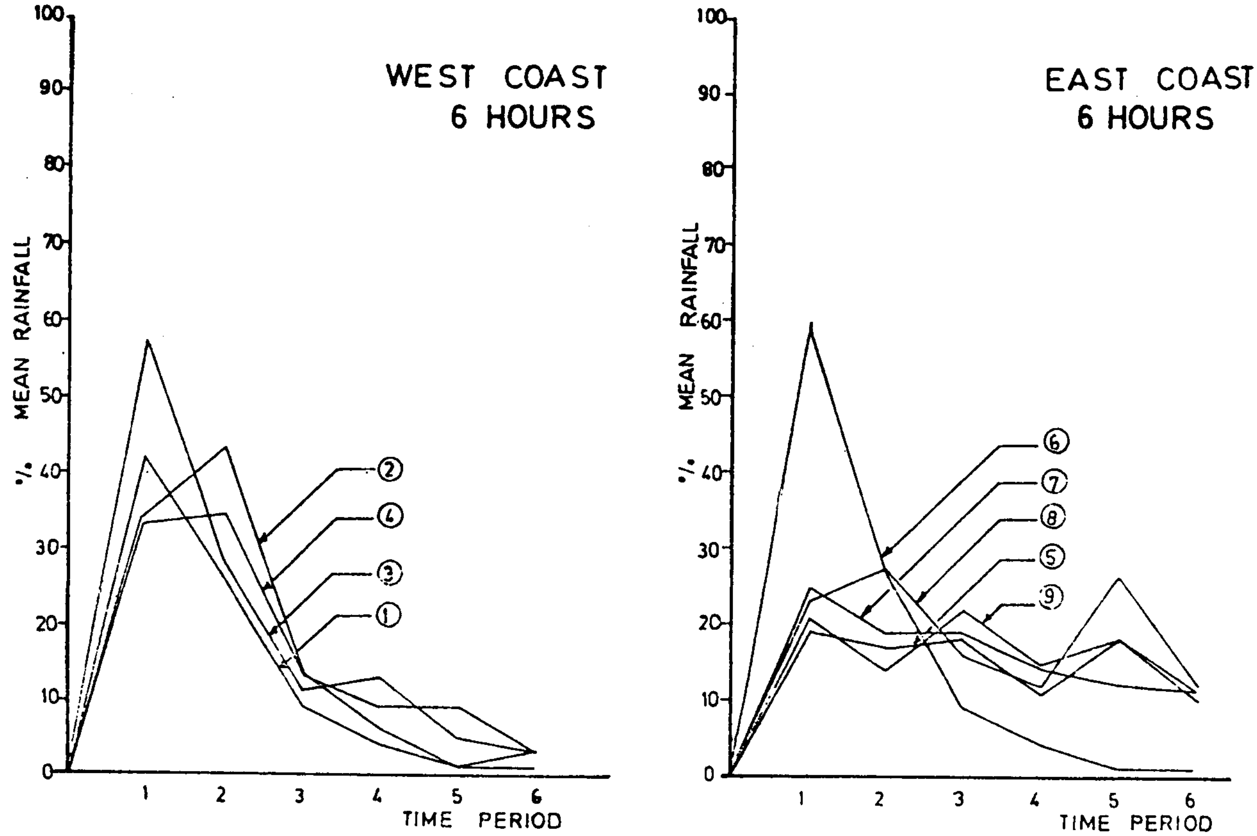

WEST COAST
6 HOURS
EAST COAST
6 HOURS
% MEAN RAINFALL
TIME PERIOD
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
①
②
③
④
⑤
⑥
⑦
⑧
⑨

FIG. D.5

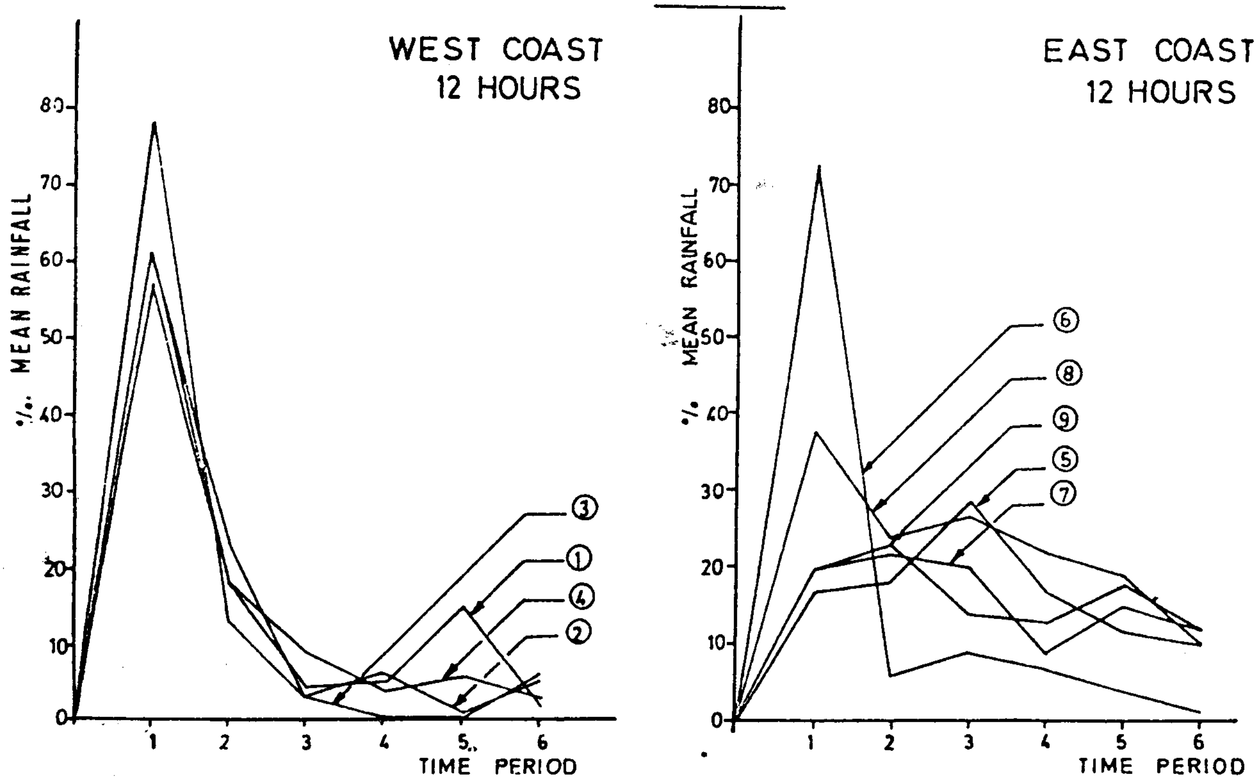

WEST COAST
12 HOURS
EAST COAST
12 HOURS
% MEAN RAINFALL
TIME PERIOD
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
①
②
③
④
⑤
⑥
⑦
⑧
⑨

FIG. D.6

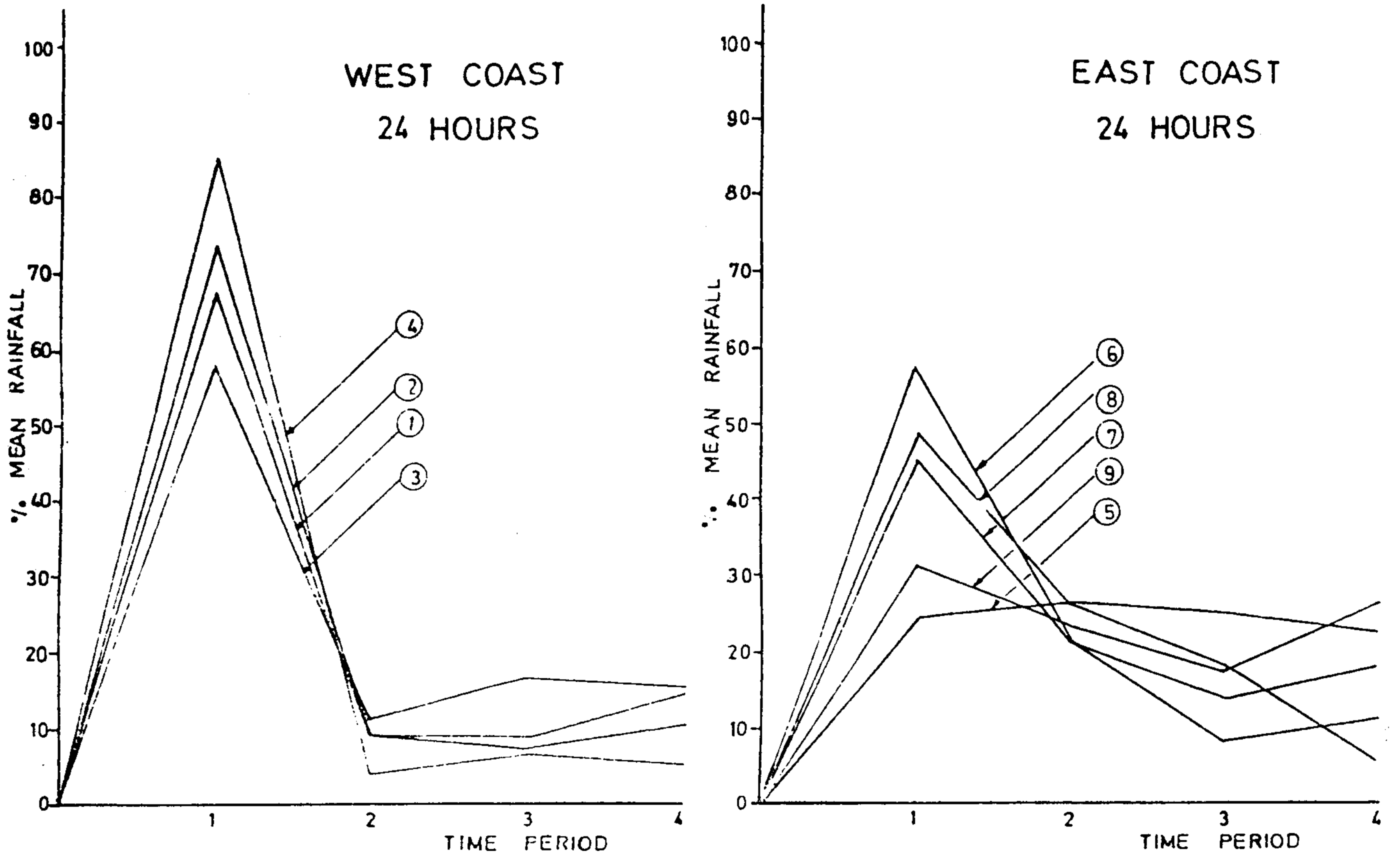
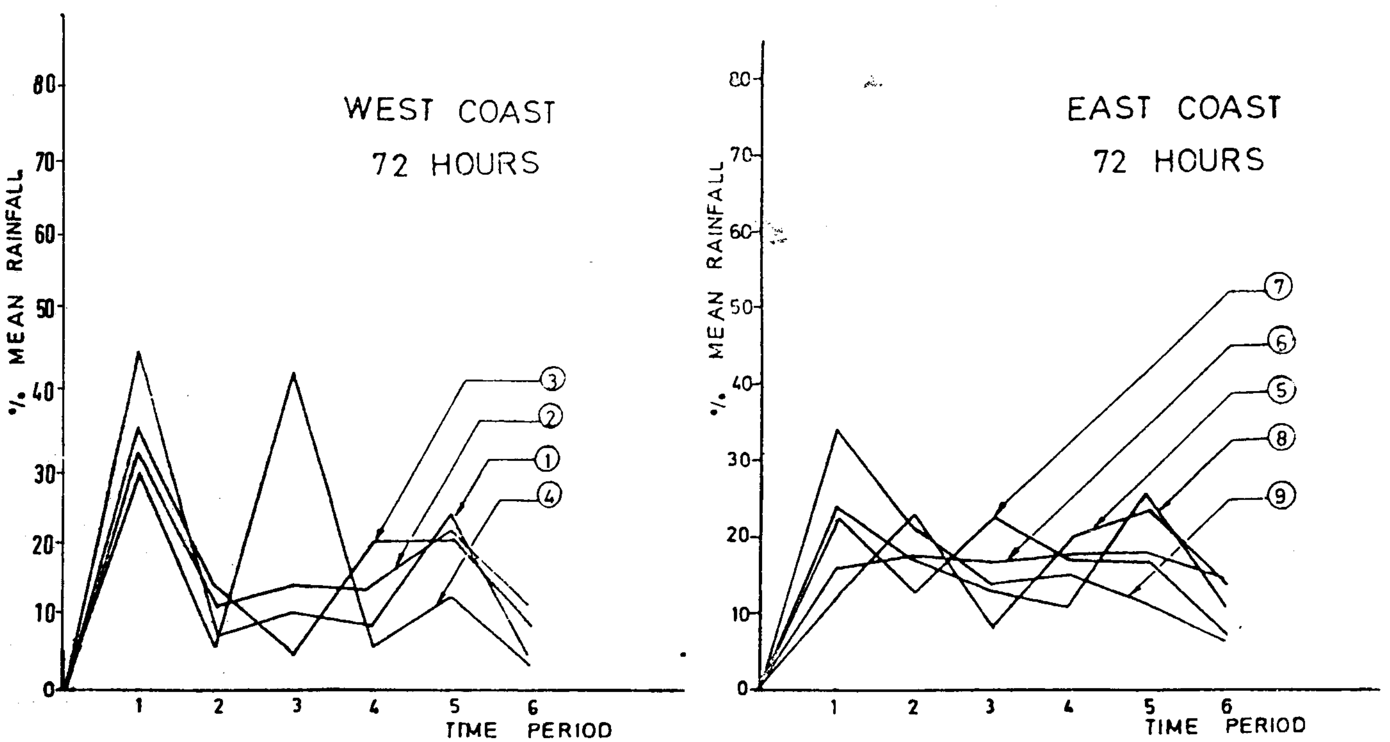

WEST COAST
24 HOURS
% MEAN RAINFALL
TIME PERIOD
EAST COAST
24 HOURS
% MEAN RAINFALL
TIME PERIOD

FIG. D.7


WEST COAST
72 HOURS
% MEAN RAINFALL
TIME PERIOD
EAST COAST
72 HOURS
% MEAN RAINFALL
TIME PERIOD

NOTE

FIGURES SHOWING THE TEMPORAL DISTRIBUTIONS FOR EACH GROUPING OF STATIONS

FIG. D.8

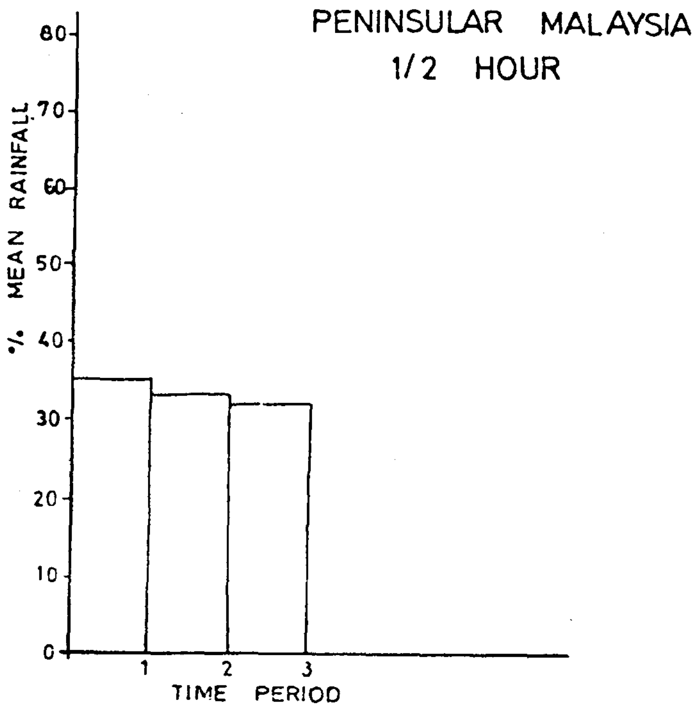
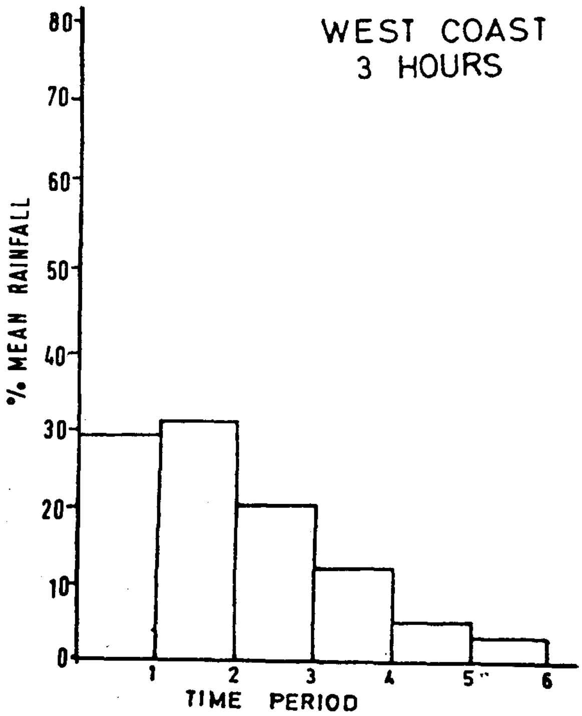


FIG. D.9



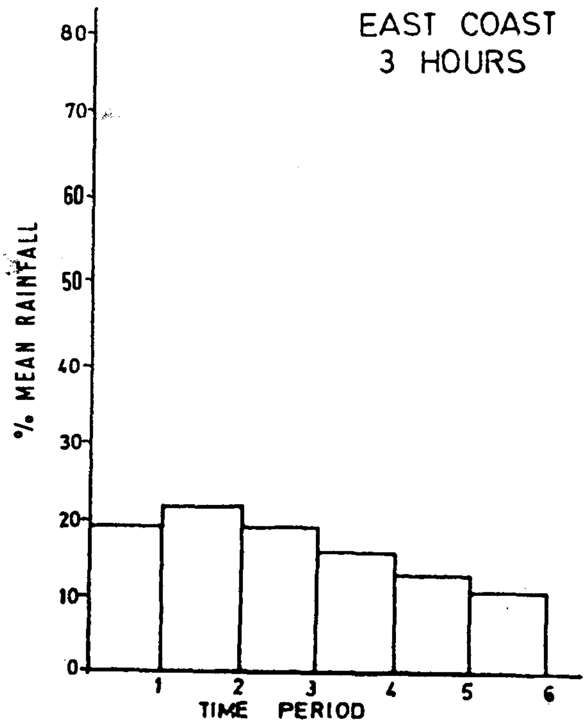


FIG. D.10

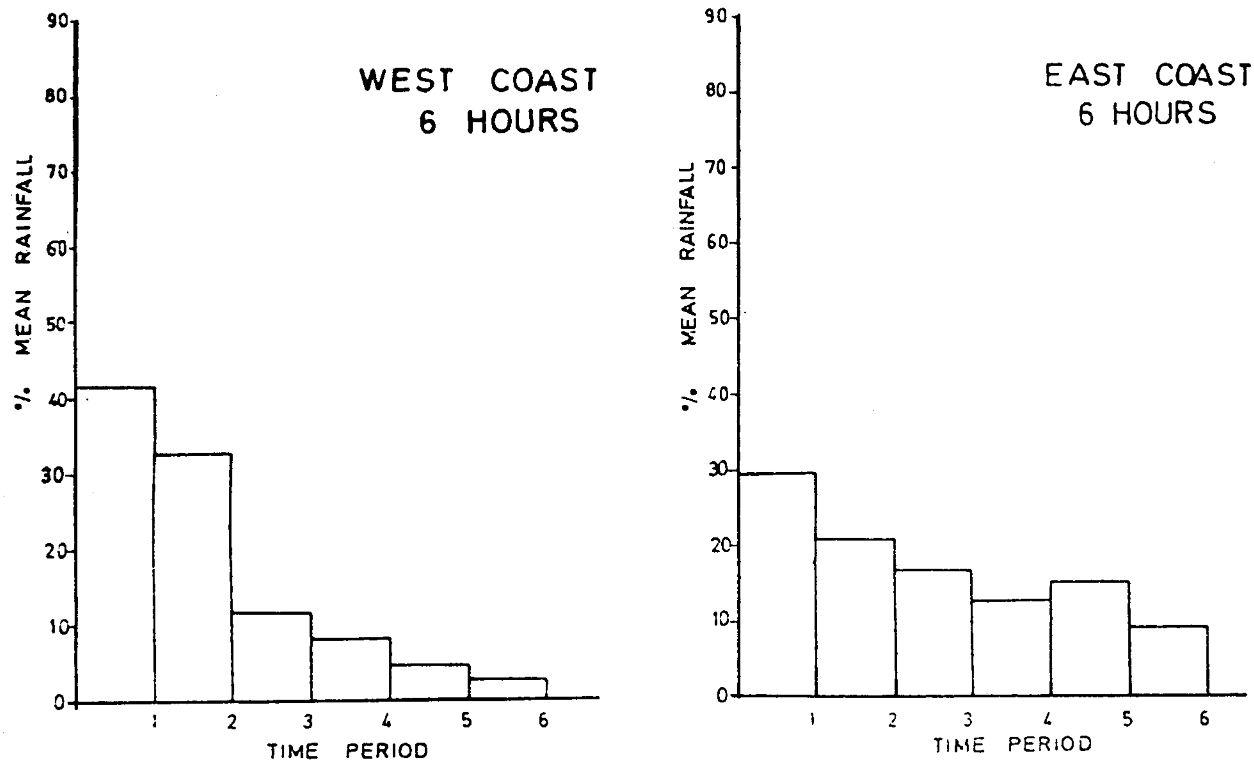


FIG. D.11

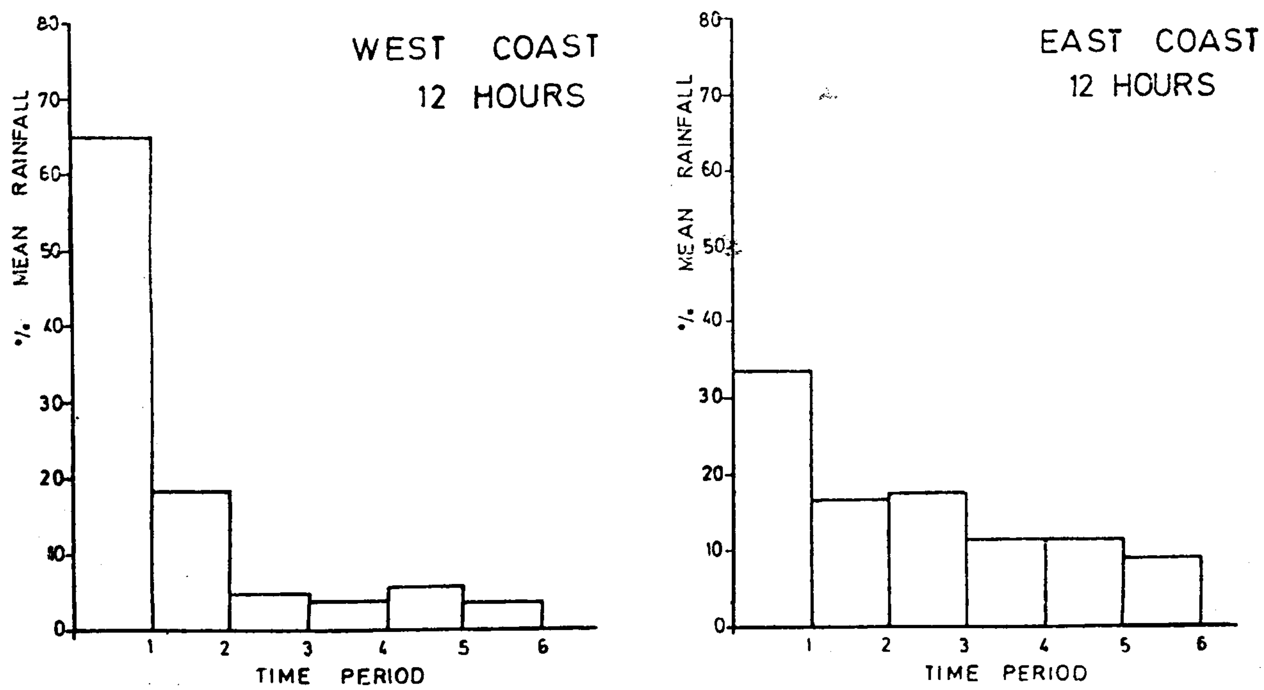


FIG. D.12

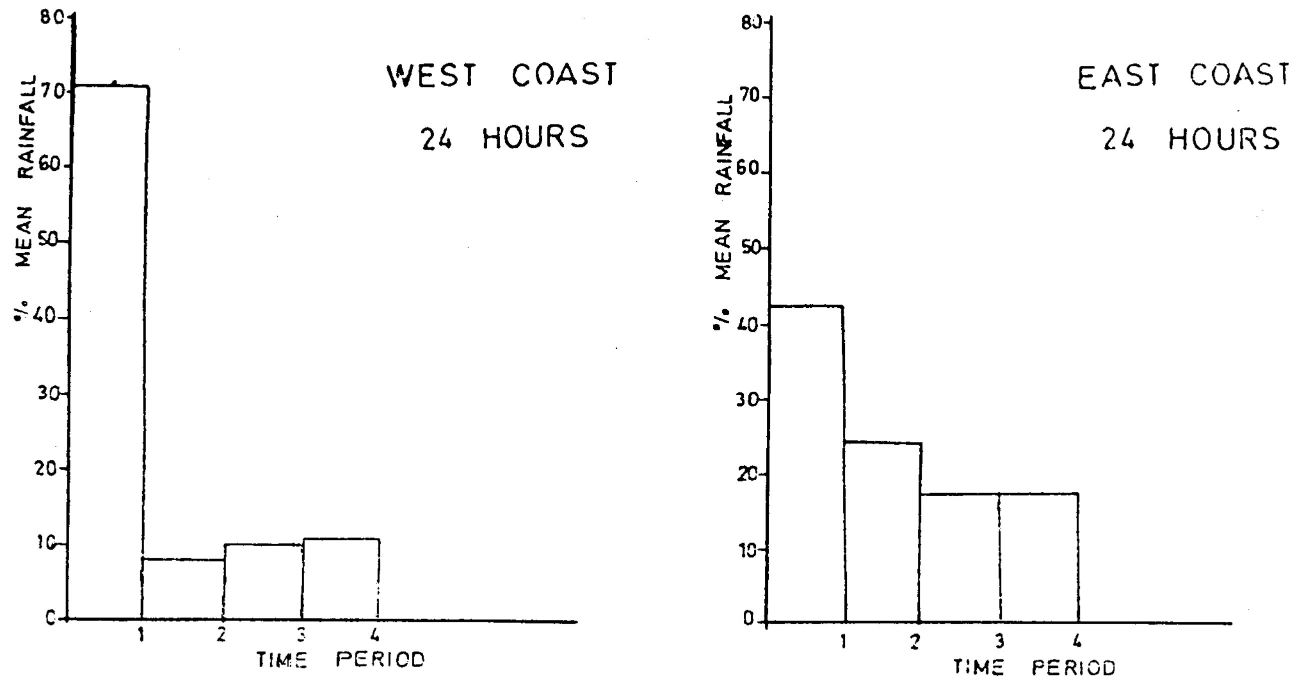
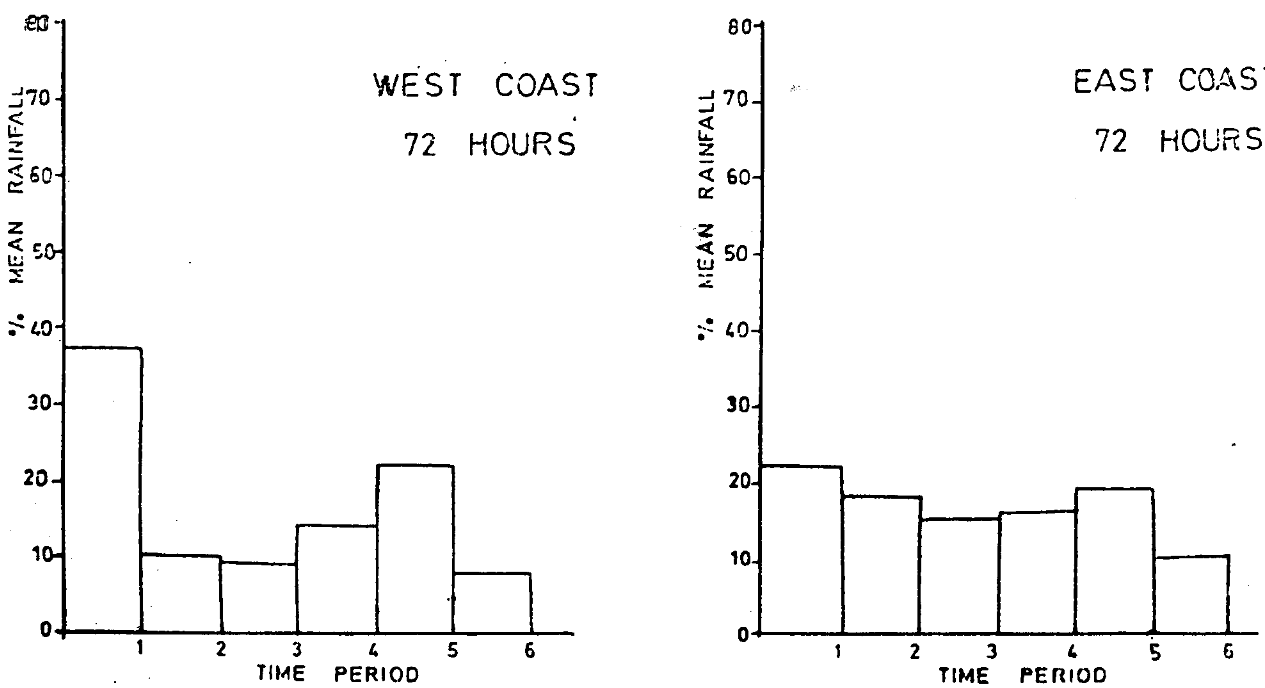
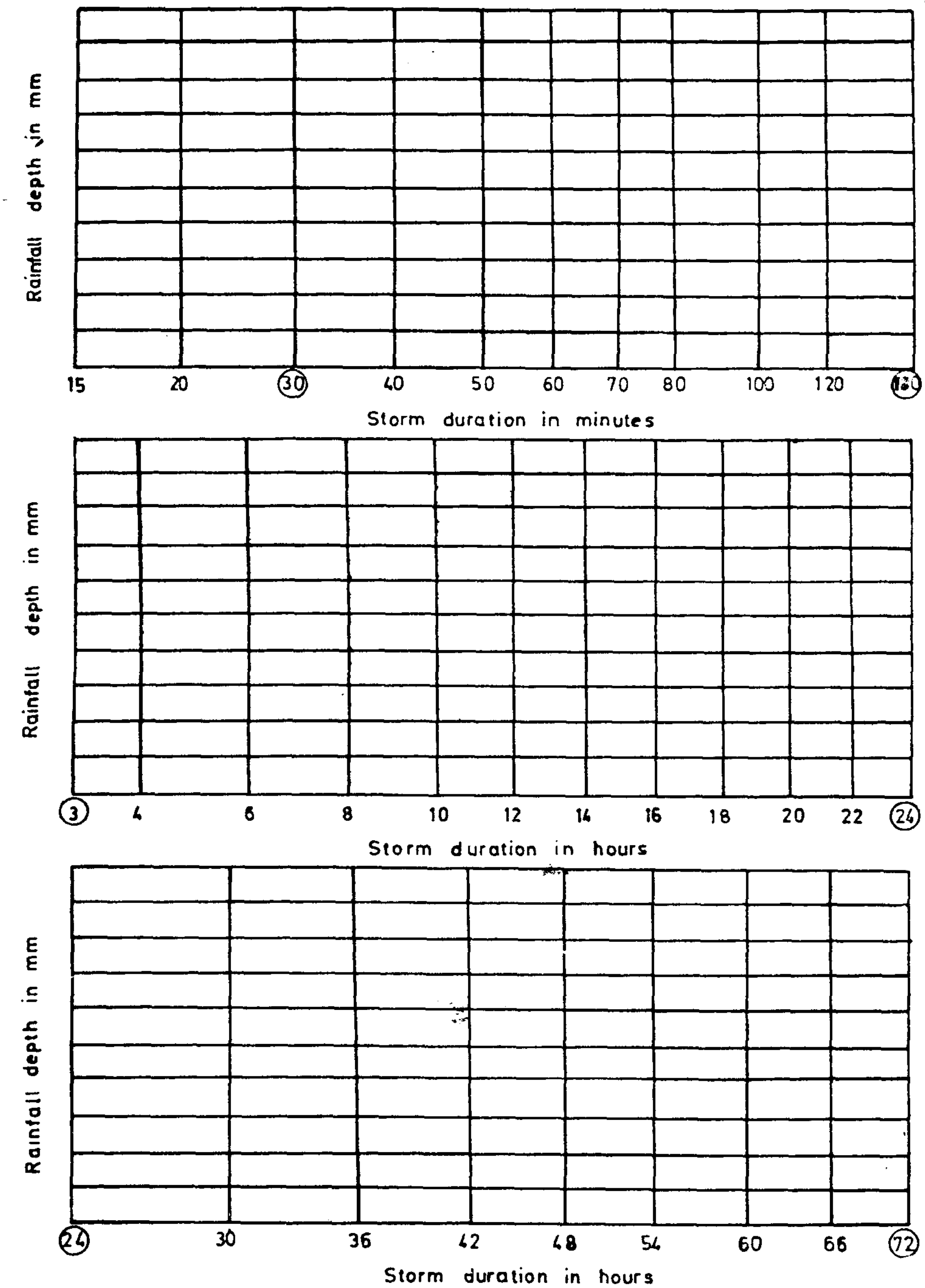


FIG. D.13



APPENDIX E

SAMPLE OF RAINFALL DEPTH-DURATION PLOTTING DIAGRAM



Legend
③ one of the cardinal storm duration

APPENDIX F

SAMPLE OF RAINFALL DEPTH – RETURN PERIOD PLOTTING DIAGRAM