
13 DESIGN RAINFALL

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13.1 INTRODUCTION

Rainfall is, obviously, the driving force behind all stormwater studies and designs. An understanding of rainfall processes and the significance of the rainfall design data is a necessary pre-requisite for preparing satisfactory drainage and stormwater management projects.

13.1.1 Rainfall Patterns in Malaysia

An overview of the climate of Malaysia, with general rainfall characteristics is given in Chapter 1.

The frequency and intensity of rainfall in Malaysia is much higher than in most countries, especially those with temperate climates. Rainfall design methods, which have been developed in other countries, may not always be suitable for application in Malaysia. The design calculations for these methods have been adjusted in this Manual to suit Malaysian conditions.

13.1.2 Application

This Chapter supersedes Hydrologic Procedure HP1-1982 for urban stormwater drainage only. The Chapter does not deal with non-urban situations, such as dams or river engineering, for which the HP1 or other special hydrologic procedures should continue to apply.

The material in this Chapter draws upon that in HP1-1982, and its presentation has been revised to be more directly applicable to urban drainage problems. No additional analyses were performed. It is envisaged that both HP1 and this Chapter will be revised in the future, using additional data that is becoming available.

13.1.3 Climate Change

There is potential for global climate changes to occur due to the "Greenhouse Effect". A further discussion on climate change due to the Greenhouse Effect is given in Chapter 46, Lowland, Tidal and Small Island Drainage.

Some authors have suggested that climate change due to the Greenhouse Effect will cause an increase in storm rainfall intensity. At this stage the available evidence for any effects on rainfall intensity is not conclusive. This Manual does not recommend any increase in design rainfall intensities due to the Greenhouse Effect.

Nevertheless, designers of major urban stormwater drainage systems should consider the possibility of climate change due to greenhouse effect. Sensitivity testing can be performed in critical cases. Designs should be sufficiently robust and incorporate safety margins to allow for this possibility.

13.2 DESIGN RAINFALL INTENSITIES

13.2.1 Definitions

The specification of a rainfall event as a "*design storm*" is common engineering practice. The related concepts of frequency and average recurrence interval (ARI) were discussed in Chapter 11.

Although the design storm must reflect required levels of protection, the local climate, and catchment conditions, it need not be scientifically rigorous. It is more important to define the storm and the range of applicability so as to ensure safe, economical and standardised design.

Two types of design storm are recognised: synthetic and actual (historic) storms. Synthesis and generalisation of a large number of actual storms is used to derive the former. The latter are events which have occurred in the past, and which may have well documented impacts on the drainage system. However, it is the usual practice in urban stormwater drainage to use synthetic design storms and most of this Chapter concentrates on these storms.

Design storm duration is an important parameter that defines the rainfall depth or intensity for a given frequency, and therefore affects the resulting runoff peak and volume.

Current practice is to select the design storm duration as equal to or longer than the time of concentration for the catchment (or some minimum value when the time of concentration is short). Intense rainfalls of short durations usually occur within longer-duration storms rather than as isolated events. The theoretically correct practice is to compute discharge for several design storms with different durations, and then base the design on the "critical" storm which produces the maximum discharge. However the "critical" storm duration determined in this way may not be the most critical for storage design. Recommended practice for catchments containing storage is to compute the design flood hydrograph for several storms with different durations equal to or longer than the time of concentration for the catchment, and to use the one which produces the most severe effect on the pond size and discharge for design. This method is further discussed in Chapter 14.

13.2.2 Rainfall Intensity-Duration-Frequency (IDF) Relationships

The total storm rainfall depth at a point, for a given rainfall duration and ARI, is a function of the local climate. Rainfall depths can be further processed and converted into rainfall intensities (intensity = depth/duration), which are then presented in IDF curves. Such curves are particularly useful in stormwater drainage design because many computational procedures require rainfall input in the form of average rainfall intensity.

The three variables, frequency, intensity and duration, are all related to each other. The data are normally presented as curves displaying two of the variables, such as intensity and duration, for a range of frequencies. These data are then used as the input in most stormwater design processes.

13.2.3 Areal Reduction Factor

It is important to understand that IDF curves give the rainfall intensity *at a point*.

Storm spatial characteristics are important for larger catchments. In general, the larger the catchment and the shorter the rainfall duration, the less uniformly the rainfall is distributed over the catchment. For any specified ARI and duration, the average rainfall depth over an area is less than the point rainfall depth.

The ratio of the areal average rainfall with a specified duration and ARI to the point rainfall with the same duration and ARI is termed the areal reduction factor.

Areal reduction factors are applied to design point rainfall intensities only, to account for the fact that it is not likely that rainfall will occur at the same intensity over the entire area of a storm (the principle of design storms assumes that the design storm is centred over the catchment). The areal reduction is expressed as a factor less than 1.0. For large catchments, the design rainfall is calculated with Equation 13.1:

$$I_c = F_A \times I_p \tag{13.1}$$

where F_A is the areal reduction factor, I_c is the average rainfall over the catchment, and I_p is the point rainfall intensity.

Suggested values of areal reduction factor F_A for Peninsular Malaysia are given in HP No.1-1982. These values are reproduced in Table 13.1 below for catchment areas of up to 200 km². The values are plotted in Figure 13.1. Intermediate values can be interpolated from this Figure.

Table 13.1 Values of Areal Reduction Factors (F_A)

Catchment Area (km ²)	Storm Duration (hours)				
	0.5	1	3	6	24
0	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00
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

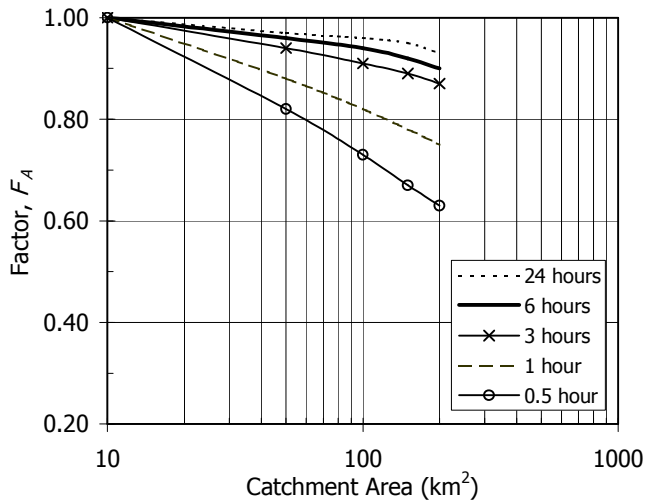


Figure 13.1 Graphical Areal Reduction Factors

No areal reduction factor is to be used for catchment areas of up to 10 km². The majority of urban drainage areas will fall into this category.

Areal reduction factors should not be applied to real rainfall data, such as recorded daily rainfalls. Instead an attempt should be made to obtain and use all available data from other rain gauges in the catchment.

Storm direction and movement can have marked effects, particularly in areas with predominating weather patterns, and are particularly relevant to the case of operation and/or control of a large system of stormwater drainage networks. However, for urban drainage it is customary to assume that design storms are stationary.

13.2.4 IDF Curves for Selected Cities and Towns

The publication “*Hydrological Data – Rainfall and Evaporation Records for Malaysia*” (1991) and “*Hydrological Procedure No. 26*” by the Department of Irrigation and Drainage (DID), have maximum rainfall intensity-duration-frequency curves for 26 and 16 urban areas in Peninsular Malaysia and East Malaysia (Sabah and Sarawak), respectively. These curves will cover the needs of the majority of users of this Manual.

Users need to be aware of the limitations of these IDF curves:

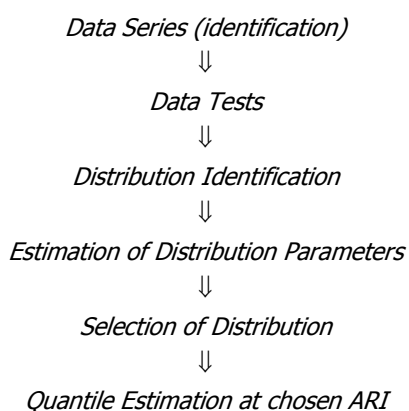
- The curves have not been revised since 1991. The patterns should be reviewed using the additional data that is now available.
- The period of data from which the curves was derived was very short, in some cases only 7 years. Few of the stations had more than 20 years of data. This means that there is a large potential error in extrapolating to long ARI such as 100 years.

- The lower limit of the durations analysed was 15 minutes. DID should expedite the installation of digital pluviometers to capture data from short storm bursts, down to 5 minutes duration.
- The limits of rainfall ARI were between 2 years and 100 years.
- The curves were not in a convenient form for use in modern computer models.
- There was no guidance given for urban areas outside the 42 centres listed.

It is recommended that the curves should be updated by DID to incorporate additional data and extend the coverage as outlined above.

13.2.5 IDF Curves for Other Urban Areas

IDF curves are calculated from local pluviometer data. Recognising that the precipitation data used to derive the above were subject to some interpolation and smoothing, it is desirable to develop IDF curves directly from local rain-gauge records if these records are sufficiently long and reliable. The analyses involve the following steps:



The required analyses are highly specialised and would be outside the scope of interest of most users of this Manual.

Local authorities are advised to find out from the DID to the availability of IDF curves or coefficients for their respective areas, or to obtain local pluviometer data for those wishing to conduct their own analysis.

13.2.6 Polynomial Approximation of IDF Curves

Polynomial expressions in the form of Equation 13.2 have been fitted to the published IDF curves for the 35 main cities/towns in Malaysia.

$$\ln({}^R I_t) = a + b \ln(t) + c(\ln(t))^2 + d(\ln(t))^3 \quad (13.2)$$

where,

${}^R I_t$ = the average rainfall intensity (mm/hr) for ARI and duration t

R = average return interval (years)

t = duration (minutes)

a to d are fitting constants dependent on ARI.

Four coefficients are considered in Equation 13.2 to keep the calculation simple for a reasonable degree of accuracy. Higher degree of polynomial can be used to get more accurate values of rainfall intensity. The Equation can be used for deriving rainfall intensity values for a given duration and ARI, once the values of coefficients a to d are known. The equation is in a more suitable form for most spreadsheet of computer calculation procedures.

The curves in "Hydrological Data" (1991) are valid for durations between 15 minutes and 72 hours. Extrapolation of the curve beyond these limits introduces possible errors, and is not recommended. Also, Equation 13.2 should not be used outside these limits. Alternative procedures for deriving IDF values for short durations are given in Section 13.2.7.

The possible uncertainty range of the IDF figures derived in accordance with this Manual is likely to be up to $\pm 20\%$. Among the sources of error noted are: problems of extrapolation to long ARIs, use of local rather than generalised analysis, and problems with the accuracy of short-duration intensity records. The error is likely to be highest for the durations shorter than 30 minutes and longer than 15 hours, and for ARI longer than 50 years. For particularly critical applications it may be appropriate to conduct sensitivity tests for the effects of design rainfall errors.

Table 13.2 gives values of the fitted coefficients in Equation 13.2 for Kuala Lumpur, for rainfall ARIs between 2 years and 100 years and durations within 30 to 1000 minutes (see Figure 13.2 for the graphs). Appendix 13.A gives derived values of the coefficients in Equation 13.2 for the 26 and 10 urban centres in Peninsular and East Malaysia, respectively. Due to irregular shape of the curves, coefficients for 6 other urban centres in East Malaysia are not suitable to be used in Equation 13.2. IDF values for these 6 stations should be taken from their respective curves available in HP-26 (1983).

Table 13.2 Coefficients of the Fitted IDF Equation for Kuala Lumpur

ARI (years)	a	b	c	d
2	5.3255	0.1806	-0.1322	0.0047
5	5.1086	0.5037	-0.2155	0.0112
10	4.9696	0.6796	-0.2584	0.0147
20	4.9781	0.7533	-0.2796	0.0166
50	4.8047	0.9399	-0.3218	0.0197
100	5.0064	0.8709	-0.307	0.0186

(data period 1953 – 1983); Validity: $30 \leq t \leq 1000$ minutes

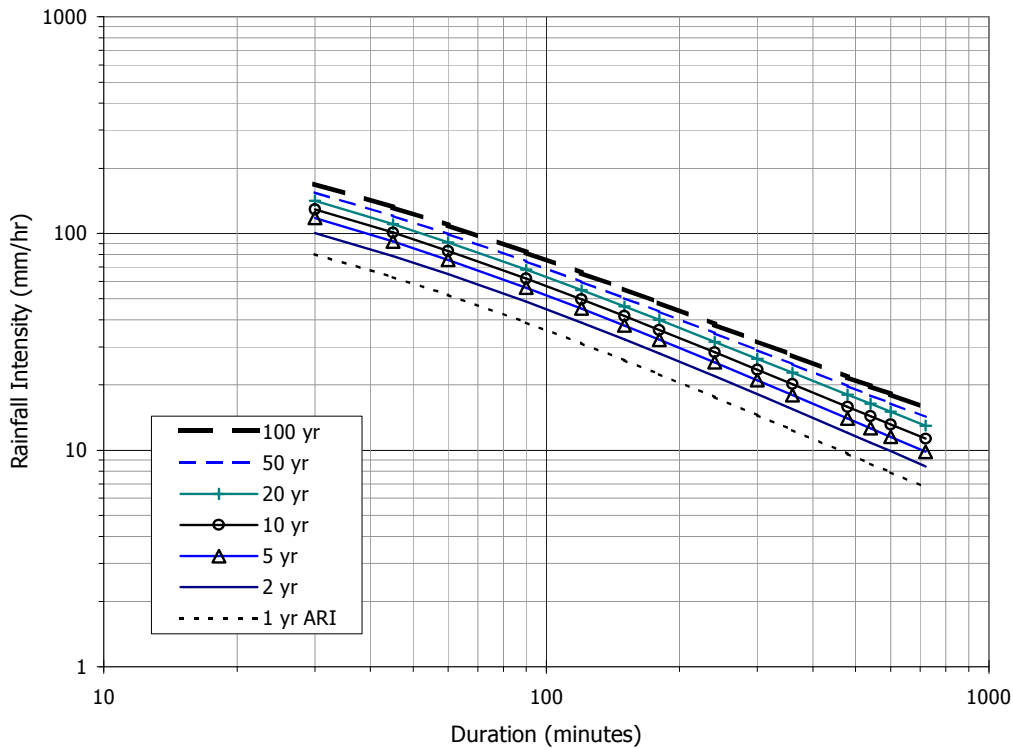


Figure 13.2 IDF Curves for Kuala Lumpur

13.2.7 IDF Values for Short Duration Storms

It is recommended that Equation 13.2 be used to derive design rainfall intensities for durations down to a lower limit of 30 minutes. This value corresponds to the original range of durations used in deriving the curves.

Estimation of rainfall intensities for durations between 5 and 30 minutes involves extrapolation beyond the range of the data used in deriving the curve fitting coefficients. The recommended method of extending the data is based on HP No.1-1982, which gives a rainfall depth-duration plotting graph for durations between 15 minutes and 3 hours. This graphical procedure was converted into an equation and extended as described below. An additional adjustment for storm intensity was included based on the method used in "PNG Flood Estimation Manual" (SMEC, 1990), for tropical climates similar to Malaysia. This adjustment uses the 2 year, 24-hour rainfall depth ${}^2P_{24h}$ as a parameter.

The design rainfall depth P_d for a short duration d (minutes) is given by,

$$P_d = P_{30} - F_D(P_{60} - P_{30}) \tag{13.3}$$

where P_{30} , P_{60} are the 30-minute and 60-minute duration rainfall depths respectively, obtained from the published design curves. F_D is the adjustment factor for storm duration

Equation 13.3 should be used for durations less than 30 minutes. For durations between 15 and 30 minutes, the results should be checked against the published IDF curves. The relationship is valid for any ARI within the range of 2 to 100 years.

The value of F_D is obtained from Table 13.3 as a function of ${}^2P_{24h}$, the 2-year ARI 24-hour rainfall depth. Values of ${}^2P_{24h}$ for Peninsular Malaysia are given in Figure 13.3. Intermediate values should be interpolated.

Note that Equation 13.3 is in terms of rainfall depth, not intensity. If intensity is required, such as for roof drainage, the depth P_d (mm) is converted to an intensity I (mm/hr) by dividing by the duration d in hours:

$$I = \frac{P_d}{d} \tag{13.4}$$

Table 13.3 Values of F_D for Equation 13.3

Duration (minutes)	${}^2P_{24h}$ (mm)				
	West Coast				East Coast
	≤ 100	120	150	≥ 180	All
5	2.08	1.85	1.62	1.40	1.39
10	1.28	1.13	0.99	0.86	1.03
15	0.80	0.72	0.62	0.54	0.74
20	0.47	0.42	0.36	0.32	0.48
30	0.00	0.00	0.00	0.00	0.00

Some computer models such as XP-RatHGL (see Chapter 17), require a continuous set of rainfall intensity data for a range of durations. If it is necessary to prepare data for such models, the recommended method is to use Equation 13.3 to derive intensities for short durations and use the resulting values in an IDF table or fitted polynomial curve.

13.2.8 IDF Values for Frequent Storms

Water quality studies, in particular, require data on IDF values for relatively small, frequent storms. These storms are of interest because on an annual basis, up to 90% of the total pollutant load is carried in storms of up to 3 month ARI. Chapter 4 recommends that the *water quality design storm* be that with a 3 month ARI. The typical IDF curves given in Appendix 13.A have a lower limit of 2 years ARI and therefore cannot be used directly.

The following preliminary equations are recommended for calculating the 1, 3, 6-month and 1 year ARI rainfall intensities in the design storm, for all durations:

$$^{0.083}I_D = 0.4 \times {}^2I_D \quad (13.5a)$$

$$^{0.25}I_D = 0.5 \times {}^2I_D \quad (13.5b)$$

$$^{0.5}I_D = 0.6 \times {}^2I_D \quad (13.5c)$$

$$^1I_D = 0.8 \times {}^2I_D \quad (13.5d)$$

where, $^{0.083}I_D$, $^{0.25}I_D$, $^{0.5}I_D$ and 1I_D are the required 1, 3, 6-month and 1-year ARI rainfall intensities for any duration D , and 2I_D is the 2-year ARI rainfall intensity for the same duration D , obtained from IDF curves.

Users should be aware of the limitations of these Equations 13.5a to 13.5d. They were derived by fitting a distribution to the 1-hour duration rainfalls, and extrapolating the distribution to frequent ARIs. This method is subject to considerable uncertainty. These preliminary equations were derived using Ipoh rainfall data. Further research is required to confirm the relationships, particularly in other parts of Malaysia where different climatic influences apply.

13.2.9 IDF Values for Rare Storms

Further research is required in order to allow design rainfall information to be given for storms with ARI greater than 100 years.

This Manual does not cover the design of major structures such as dams or bridges, for which a special hydrologic analysis is required.

13.3 DESIGN RAINFALL TEMPORAL PATTERNS

13.3.1 Purpose

The temporal distribution of rainfall within the design storm is an important factor that affects the runoff volume, and the magnitude and timing of the peak discharge. Design rainfall temporal patterns are used to represent the typical variation of rainfall intensities during a typical storm burst. Standardisation of temporal patterns allows standard design procedures to be adopted in flow calculation.

It is important to emphasise that these temporal patterns are intended for use in *design* storms. They should not be confused with the real rainfall variability in historical storms.

Realistic estimates of temporal distributions are best obtained by analysis of local rainfall data from recording gauge networks. Such an analysis may have to be done for several widely varying storm durations to cover various types of storms and to produce distributions for various design problems. Different distributions may apply to different climatic regions of the country.

Temporal patterns should be chosen so that the resulting runoff hydrographs are consistent with observed hydrographs. Therefore the form of the temporal pattern and the method of runoff computation are closely inter-linked. The statistical basis of this approach is discussed in "*Australian Rainfall and Runoff*" (AR&R, 1987).

A range of methods to distribute rainfall have been suggested in the literature:

1. Average temporal patterns developed from local point-rainfall data measured in short time intervals (15 minutes or less).
2. Simple idealised rainfall distribution fitted to local storm data by the method of moments.
3. Temporal patterns from local IDF relationships.

The second method is not recommended, as the idealised patterns are not representative of real storm patterns. Triangular patterns, for example, give unrealistically high peak intensities.

The third approach for distributing rainfall within a design storm makes use of the local IDF relationship for the design ARI. This approach is based on the assumption that the maximum rainfall for any duration less than or equal to the total storm duration should have the same ARI. For example, a 10 year ARI three-hour design storm of this type would contain the 10 year ARI rainfall depths for all durations from the shortest time interval considered (perhaps 5 minutes) up to three hours. These rainfalls are generally skewed.

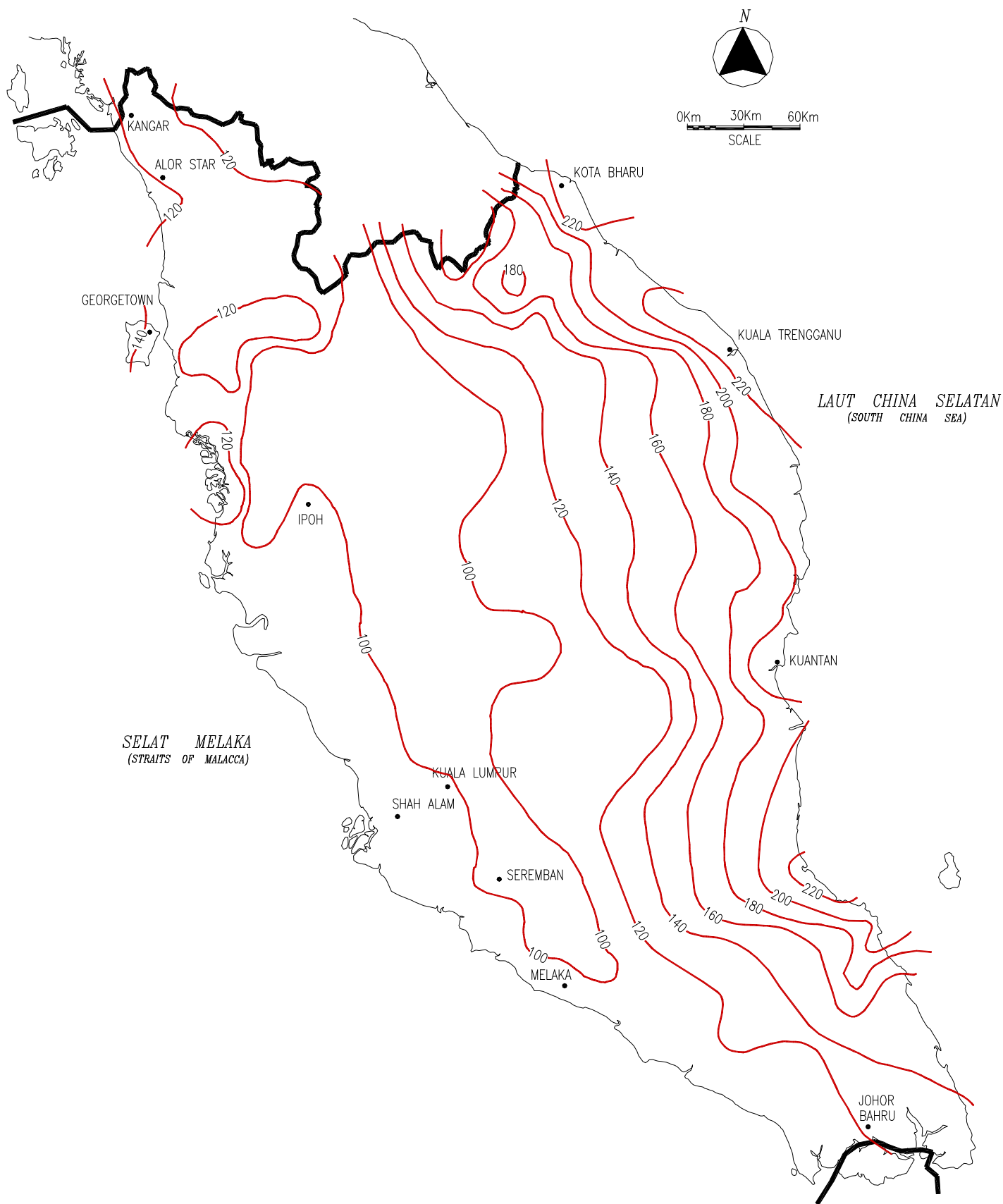


Figure 13.3 Values of ${}^2P_{24h}$ for use with Table 13.3
(source: HP 1, 1982)

Although there are some theoretical objections to the third approach, on the grounds that it combines peaks from different historical storms, it is nevertheless conservative and very convenient for design. It is therefore recommended.

This distribution can be derived from the local IDF curves and the analysis of skewness of actual storms. The design temporal patterns presented in this Chapter have been derived on this basis.

13.3.2 Present Malaysian Practice

The 1982 update of Hydrological Procedure No. 1 gave recommendations on temporal patterns to be adopted for design storms in Peninsular Malaysia. Patterns were prepared for six standard durations: 0.5, 3, 6, 12, 24 and 72 hours.

Nine rainfall stations located in different parts of Peninsular Malaysia were used in this analysis. The data covered nine years from July 1970 to June 1979.

The procedure used was to extract the rainfall pattern of the annual maximum stormbursts at each station. This is Method 1 of the previous sub-section. By comparing the results, a set of representative patterns were derived. It was found that different patterns applied to the West Coast and East Coast, except for the 0.5 hour duration, and therefore different regional patterns were recommended.

The recommended patterns were presented in HP No. 1 in graphical form (Figures D.8 to D.13 of HP No.1). These graphs are difficult to read and are subject to mis-interpretation. Therefore, the data has been converted to tables in this Manual, as shown in Appendix 13.B.

13.3.3 Review of Standard Temporal Patterns

This procedure used in HP No.1-1982 is less comprehensive than that used in, for example, AR&R (1987), because there was a much smaller amount of data available.

- 18 years have elapsed since Hydrological Procedure No. 1 was updated. The patterns should be reviewed using the additional data that is now available.
- The range of Standard Durations used in the Procedure is insufficient for the full range of design conditions. Design calculations need to be made for periods as short as 5 minutes, in the case of Roof Drainage (see Chapter 23). The gap between each Standard Duration in HP No.1-1982 is too wide.
- Temporal patterns should be internally consistent (AR&R, 1987). There are inconsistencies between the HP No.1-1982 patterns.
- Durations longer than 6 hours are not covered in this Manual as they are unlikely to be required in urban

stormwater drainage design. If a rainfall duration longer than 6 hours is required, the user should consult HP No.1-1982.

- No temporal pattern data is available in HP No. 26 for Sabah and Sarawak (1983). For preliminary studies, the patterns for the East Coast of Malaysia, in Appendix 13.B, could be adopted for Sabah and Sarawak. Because the climatic conditions are more comparable to the East Coast than the West Coast. A further study to derive temporal patterns suitable for use in Sabah and Sarawak should be undertaken by specialist hydrologists.
- There are too few data points found in each Standard Duration temporal pattern. This causes a systematic bias which will under-estimate the peak rainfall as shown in Figure 13.4. AR&R-1987 estimates that this error will underestimate the true peak by as much as 10%.

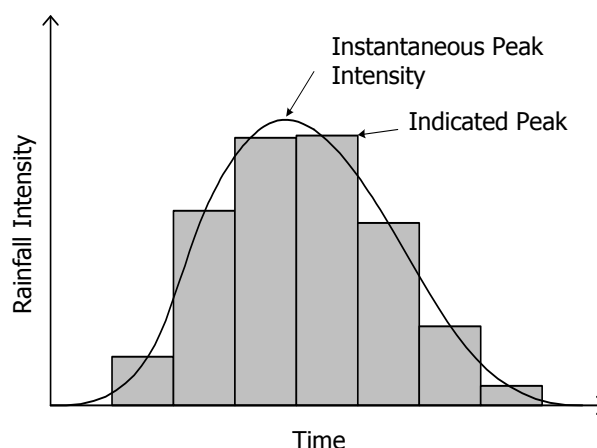


Figure 13.4 Example of the Under-estimation of a Hydrograph by Discretisation

13.3.4 Temporal Patterns for Standard Durations

The recommended patterns in this Manual are based on those from AR&R for durations of one hour or less and from HP No. 1 (1982) for longer durations.

The recommended patterns follow Method 3 mentioned in Section 13.3.1. Checks were made to ensure that the patterns comply with the requirements in Section 13.3.3. Where necessary, the ordinates of the patterns were adjusted to meet these requirements. Most of the adjustments made were relatively minor.

The standard durations recommended in this Manual for urban stormwater studies are listed in Table 13.4. The interim temporal patterns to be used for these standard durations are given in Appendix 13.B.

As these patterns are based on only limited data, and are subject to some uncertainty, it is recommended that a research study be undertaken using the latest rainfall data to derive updates for the temporal patterns.

Table 13.4 Standard Durations for Urban Stormwater Drainage

Standard Duration (minutes)	Number of Time Intervals	Time Interval (minutes)
10	2	5
15	3	5
30	6	5
60	12	5
120	8	15
180	6	30
360	6	60

Note that minutes are used in this Table, for consistency with the units in Equation 13.2.

13.3.5 Temporal Patterns for Other Durations

For other durations, the temporal pattern for the nearest standard duration should be adopted. It is *NOT* correct to average the temporal patterns for different durations.

13.4 RAINFALL TIME SERIES

13.4.1 Introduction

Calculations for stormwater quality may involve the time series of runoff, which in turn is related to the volume of rainfall.

Daily rainfall gauges are widespread throughout Malaysia, in comparison to the smaller number of pluviometers. Daily rainfall records are also of longer duration than pluviometer data. Both of these attributes make daily data valuable for statistical studies. Daily rainfall data is normally readily available at or close to any location of interest for urban stormwater studies.

13.4.2 Sources of Rainfall Data

In Malaysia, rainfall data is collected by several departments and authorities including the Meteorological Service and DID. Other agencies such as water and sewerage agencies, may collect data for their own purposes.

The quality of the designs and analyses depends to a large degree, on the quality of the rainfall data used. Therefore every effort should be made to search for and obtain data from the data collection agencies.

13.4.3 Data Quality and Acceptance

The daily rainfall record should be examined for quality, and in particular to identify any instances of missing records.

Occasional missing daily records may be acceptable, depending on the purpose for which the data is used. In general, for water quality studies the amount of missing record should not exceed 3% i.e. 10 days per year. For flood studies, particular care is required because it is often found that the missing record is the actual record of most interest, i.e. a large storm or flood event.

Some older daily rainfall records are still in English (Imperial) units.

13.4.4 Long-Duration Rainfalls

Some of the design guidelines given in this Manual require calculation of long-duration rainfall totals, such as the 75 percentile 5-day total. Daily records should be used for this purpose.

Example 13.C.2 in Appendix 13.C is a worked example of the calculation of 5-day rainfall totals for Ipoh, Perak. The 75 percentile 5-day rainfall is used in the design procedure for sediment basins, in Chapter 39.

13.4.5 Adjustment of Daily Rainfalls

Daily rainfall data is read with fixed observation times each day. Daily records do not necessarily reflect the rainfall figures for a 24 hour storm duration because the storm period is unlikely to commence at exactly the time of the daily reading.

If conversion is necessary from daily rainfall totals to 24-hour totals, it should be done using Equation 13.6:

$$I_{24h} = C \times I_D \quad (13.6)$$

where, I_{24h} is the 24-hour storm rainfall for a given ARI, I_D is the daily rainfall, and C is a conversion factor with values of 1.16 (East Coast) and 1.12 (West Coast).

This equation is unchanged from the 1982 edition of HP No.1. The conversion factor C is obtained from analyses of rainfall records. The values of C recommended above are consistent with those in SMEC (1990) and Miller et al (1973).

13.4.6 Continuous Simulation

Continuous simulation models are important for water quality studies. Most of these models are designed for use with daily rainfall data.

Continuous simulation models require a minimum simulation period of several months to achieve stability. Usually it is convenient to run the models for a 12-month simulation. This ensures that seasonal variations, if any, are taken into account.

The data requirement for such a simulation is a full year, or more, of continuous daily rainfall records. Even data with a small number of missing records can be accepted (see Section 13.4.3). The data should be prepared in the form of a list or spreadsheet column of daily rainfall totals, in millimetres. If, possible, data should be obtained in digital form to minimise data entry and the possibility of transcription errors.

13.4.7 Role of Small, Frequent Storms

Like most decisions on design standards, the selection of a suitable design standard for water quality control works involves performance and economic considerations. It requires a trade-off between the benefits of providing a higher level of protection, performance and the size and cost of works needed to provide that protection.

The land area and cost of a treatment facility such as a pond is approximately in proportion with its volume. Increasing the design standard from (say) 3 month to 6 month ARI will result in significant size/cost increase for only a minimal increase in pollutant removal and this can be expressed in terms of the *law of diminishing returns* that defines the point at which increasing the design standard is no longer cost-effective. It is generally found that for water quality control, most benefit is derived from the treatment of small frequent storms and that it is not cost-effective to design facilities for large, rarer events.

The preliminary calculations presented later (Chapter 15) using rainfall data for Ipoh give a guideline to determine a suitable choice of design storm for sizing the water quality treatment measures. The results of the calculations are plotted in Figure 13.5. From Figure 13.5 it can be seen that, for Ipoh (Perak):

*On a long-term average basis,
93% of total rainfall occurs in storms
equal to or smaller than 3 month ARI*

This conclusion is significant in terms of setting design standards for water quality control works, as discussed in Chapter 4. The result is likely to be similar in other parts of the West Coast of the Peninsula. Results in other parts of the country may be different due to different rainfall characteristics. Therefore, a similar calculation should be performed at other locations.

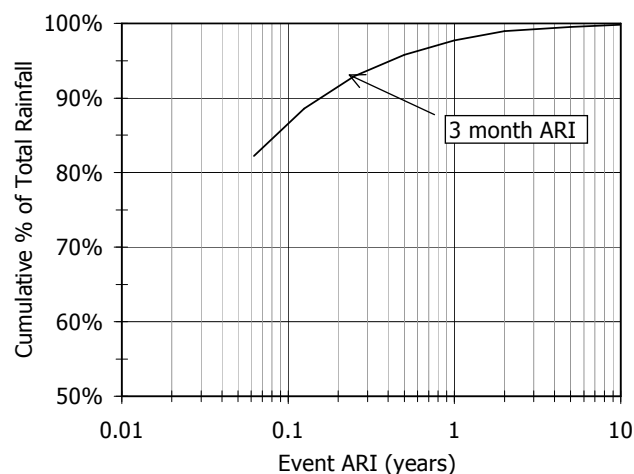


Figure 13.5 Amount of Total Rainfall which Occurs in Storms Less than a Given ARI (Ipoh Data)

13.5 HISTORICAL STORMS

A discussion of rainfall data would not be complete without mention of historical storms. Historical storm data is used in calibration of models, as well as for the checking of past flood occurrences.

In an urban drainage situation, it is relatively rare to have good historical rainfall data available close to the study area or catchment. Nevertheless, every effort should be made to obtain such data. Data sources are discussed in Section 13.4.2.

Goyen and O'Loughlin (1999) have shown the importance of locating rainfall gauges close to or preferably within the study area if accurate calibration is to be achieved. If detailed studies are being undertaken and good calibration data is required, the density of rain gauges should be at least 1 per square kilometre.

APPENDIX 13.A FITTED COEFFICIENTS FOR IDF CURVES FOR 35 URBAN CENTRESTable 13.A1 Coefficients for the IDF Equations for the Different Major Cities and Towns in Malaysia ($30 \leq t \leq 1000$ min)

State	Location	Data Period	ARI (year)	Coefficients of the IDF Polynomial Equations			
				a	b	c	d
Perlis	Kangar	1960-1983	2	4.6800	0.4719	-0.1915	0.0093
			5	5.7949	-0.1944	-0.0413	-0.0008
			10	6.5896	-0.6048	0.0445	-0.0064
			20	6.8710	-0.6670	0.0478	-0.0059
			50	7.1137	-0.7419	0.0621	-0.0067
			100	6.5715	-0.2462	-0.0518	0.0016
Kedah	Alor Setar	1951-1983	2	5.6790	-0.0276	-0.0993	0.0033
			5	4.9709	0.5460	-0.2176	0.0113
			10	5.6422	0.1575	-0.1329	0.0056
			20	5.8203	0.1093	-0.1248	0.0053
			50	5.7420	0.2273	-0.1481	0.0068
			100	6.3202	-0.0778	-0.0849	0.0026
Pulau Pinang	Penang	1951-1990	2	4.5140	0.6729	-0.2311	0.0118
			5	3.9599	1.1284	-0.3240	0.0180
			10	3.7277	1.4393	-0.4023	0.0241
			20	3.3255	1.7689	-0.4703	0.0286
			50	2.8429	2.1456	-0.5469	0.0335
			100	2.7512	2.2417	-0.5610	0.0341
Perak	Ipoh	1951-1990	2	5.2244	0.3853	-0.1970	0.0100
			5	5.0007	0.6149	-0.2406	0.0127
			10	5.0707	0.6515	-0.2522	0.0138
			20	5.1150	0.6895	-0.2631	0.0147
			50	4.9627	0.8489	-0.2966	0.0169
			100	5.1068	0.8168	-0.2905	0.0165
Perak	Bagan Serai	1960-1983	2	4.1689	0.8160	-0.2726	0.0149
			5	4.7867	0.4919	-0.1993	0.0099
			10	5.2760	0.2436	-0.1436	0.0059
			20	5.6661	0.0329	-0.0944	0.0024
			50	5.3431	0.3538	-0.1686	0.0078
			100	5.3299	0.4357	-0.1857	0.0089
Perak	Teluk Intan	1960-1983	2	5.6134	-0.1209	-0.0651	0.00004
			5	6.1025	-0.2240	-0.0484	-0.0008
			10	6.3160	-0.2756	-0.0390	-0.0012
			20	6.3504	-0.2498	-0.0377	-0.0016
			50	6.7638	-0.4595	0.0094	-0.0050
			100	6.7375	-0.3572	-0.0070	-0.0043
Perak	Kuala Kangsar	1960-1983	2	4.2114	0.9483	-0.3154	0.0179
			5	4.7986	0.5803	-0.2202	0.0107
			10	5.3916	0.2993	-0.1640	0.0071
			20	5.7854	0.1175	-0.1244	0.0044
			50	6.5736	-0.2903	-0.0482	0.00002
			100	6.0681	0.1478	-0.1435	0.0065
Perak	Setiawan	1951-1990	2	5.0790	0.3724	-0.1796	0.0081
			5	5.2320	0.3330	-0.1635	0.0068
			10	5.5868	0.0964	-0.1014	0.0021
			20	5.5294	0.2189	-0.1349	0.0051
			50	5.2993	0.4270	-0.1780	0.0082
			100	5.5575	0.3005	-0.1465	0.0058
Selangor	Kuala Kubu Bahru	1970-1990	2	4.2095	0.5056	-0.1551	0.0044
			5	5.1943	-0.0350	-0.0392	-0.0034
			10	5.5074	-0.1637	-0.0116	-0.0053
			20	5.6772	-0.1562	-0.0229	-0.0040
			50	6.0934	-0.3710	0.0239	-0.0073
			100	6.3094	-0.4087	0.0229	-0.0068

(Continued)

Table 13.A1 Coefficients for the IDF Equations for the Different Major Cities and Towns in Malaysia ($30 \leq t \leq 1000$ min)

State	Location	Data Period	ARI (year)	Coefficients of the IDF Polynomial Equations			
				a	b	c	d
Federal Territory	Kuala Lumpur	1953-1983	2	5.3255	0.1806	-0.1322	0.0047
			5	5.1086	0.5037	-0.2155	0.0112
			10	4.9696	0.6796	-0.2584	0.0147
			20	4.9781	0.7533	-0.2796	0.0166
			50	4.8047	0.9399	-0.3218	0.0197
			100	5.0064	0.8709	-0.3070	0.0186
Malacca	Malacca	1951-1990	2	3.7091	1.1622	-0.3289	0.0176
			5	4.3987	0.7725	-0.2381	0.0112
			10	4.9930	0.4661	-0.1740	0.0069
			20	5.0856	0.5048	-0.1875	0.0082
			50	4.8506	0.7398	-0.2388	0.0117
			100	5.3796	0.4628	-0.1826	0.0081
Negeri Sembilan	Seremban	1970-1990	2	5.2565	0.0719	-0.1306	0.0065
			5	5.4663	0.0586	-0.1269	0.0062
			10	6.1240	-0.2191	-0.0820	0.0039
			20	6.3733	-0.2451	-0.0888	0.0051
			50	6.9932	-0.5087	-0.0479	0.0031
			100	7.0782	-0.4277	-0.0731	0.0051
Negeri Sembilan	Kuala Pilah	1970-1990	2	3.9982	0.9722	-0.3215	0.0185
			5	3.7967	1.2904	-0.4012	0.0247
			10	4.5287	0.8474	-0.3008	0.0175
			20	4.9287	0.6897	-0.2753	0.0163
			50	4.7768	0.8716	-0.3158	0.0191
			100	4.6588	1.0163	-0.3471	0.0213
Johor	Kluang	1976-1990	2	4.5860	0.7083	-0.2761	0.0170
			5	5.0571	0.4815	-0.2220	0.0133
			10	5.2665	0.4284	-0.2131	0.0129
			20	5.4813	0.3471	-0.1945	0.0116
			50	5.8808	0.1412	-0.1498	0.0086
			100	6.3369	-0.0789	-0.1066	0.0059
Johor	Mersing	1951-1990	2	5.1028	0.2883	-0.1627	0.0095
			5	5.7048	-0.0635	-0.0771	0.0036
			10	5.8489	-0.0890	-0.0705	0.0032
			20	4.8420	0.7395	-0.2579	0.0165
			50	6.2257	-0.1499	-0.0631	0.0032
			100	6.7796	-0.4104	-0.0160	0.0005
Johor	Batu Pahat	1960-1983	2	4.5023	0.6159	-0.2289	0.0119
			5	4.9886	0.3883	-0.1769	0.0085
			10	5.2470	0.2916	-0.1575	0.0074
			20	5.7407	0.0204	-0.0979	0.0032
			50	6.2276	-0.2278	-0.0474	0.00002
			100	6.5443	-0.3840	-0.0135	-0.0022
Johor	Johor Bahru	1960-1983	2	3.8645	1.1150	-0.3272	0.0182
			5	4.3251	1.0147	-0.3308	0.0205
			10	4.4896	0.9971	-0.3279	0.0205
			20	4.7656	0.8922	-0.3060	0.0192
			50	4.5463	1.1612	-0.3758	0.0249
			100	5.0532	0.8998	-0.3222	0.0215
Johor	Segamat	1970-1983	2	3.0293	1.4428	-0.3924	0.0232
			5	4.2804	0.9393	-0.3161	0.0200
			10	6.2961	-0.1466	-0.1145	0.0080
			20	7.3616	-0.6982	-0.0131	0.0021
			50	7.4417	-0.6247	-0.0364	0.0041
			100	8.1159	-0.9379	0.0176	0.0013

(Continued)

Table 13.A1 Coefficients for the IDF Equations for the Different Major Cities and Towns in Malaysia ($30 \leq t \leq 1000$ min)

State	Location	Data Period	ARI (year)	Coefficients of the IDF Polynomial Equations			
				a	b	c	d
Pahang	Raub	1966-1983	2	4.3716	0.3725	-0.1274	0.0026
			5	4.5461	0.4017	-0.1348	0.0036
			10	5.4226	-0.1521	-0.0063	-0.0056
			20	5.2525	0.0125	-0.0371	-0.0035
			50	4.8654	0.3420	-0.1058	0.0012
			100	5.1818	0.2173	-0.0834	0.0001
Pahang	Cameron Highland	1951-1990	2	4.9396	0.2645	-0.1638	0.0082
			5	4.6471	0.4968	-0.2002	0.0099
			10	4.3258	0.7684	-0.2549	0.0134
			20	4.8178	0.5093	-0.2022	0.0100
			50	5.3234	0.2213	-0.1402	0.0059
			100	5.0166	0.4675	-0.1887	0.0089
Pahang	Kuantan	1951-1990	2	5.1899	0.2562	-0.1612	0.0096
			5	4.7566	0.6589	-0.2529	0.0167
			10	4.3754	0.9634	-0.3068	0.0198
			20	4.8517	0.7649	-0.2697	0.0176
			50	5.0350	0.7267	-0.2589	0.0167
			100	5.2158	0.6752	-0.2450	0.0155
Pahang	Temerloh	1970-1983	2	4.6023	0.4622	-0.1729	0.0066
			5	5.3044	0.0115	-0.0590	-0.0019
			10	4.5881	0.5465	-0.1646	0.0049
			20	4.4378	0.7118	-0.1960	0.0068
			50	4.4823	0.8403	-0.2288	0.0095
			100	4.5261	0.7210	-0.1988	0.0071
Terengganu	Kuala Dungun	1971-1983	2	5.2577	0.0572	-0.1091	0.0057
			5	5.5077	-0.0310	-0.0899	0.0050
			10	5.4881	0.0698	-0.1169	0.0074
			20	5.6842	-0.0393	-0.0862	0.0051
			50	5.5773	0.1111	-0.1231	0.0081
			100	6.1013	-0.1960	-0.0557	0.0035
Terengganu	Kuala Terengganu	1951-1983	2	4.6684	0.3966	-0.1700	0.0096
			5	4.4916	0.6583	-0.2292	0.0143
			10	5.2985	0.2024	-0.1380	0.0089
			20	5.8299	-0.0935	-0.0739	0.0046
			50	6.1694	-0.2513	-0.0382	0.0021
			100	6.1524	-0.1630	-0.0575	0.0035
Kelantan	Kota Bharu	1951-1990	2	5.4683	0.0499	-0.1171	0.0070
			5	5.7507	-0.0132	-0.1117	0.0078
			10	5.2497	0.4280	-0.2033	0.0139
			20	5.4724	0.3591	-0.1810	0.0119
			50	5.3578	0.5094	-0.2056	0.0131
			100	5.0646	0.7917	-0.2583	0.0161
Kelantan	Gua Musang	1971-1990	2	4.6132	0.6009	-0.2250	0.0114
			5	3.8834	1.2174	-0.3624	0.0213
			10	4.6080	0.8347	-0.2848	0.0161
			20	4.7584	0.7946	-0.2749	0.0154
			50	4.6406	0.9382	-0.3059	0.0176
			100	4.6734	0.9782	-0.3152	0.0183

(Continued)

Table 13.A1 Coefficients for the IDF Equations for the Different Major Cities and Towns in Malaysia ($30 \leq t \leq 1000$ min)

State	Location	Data Period	ARI (year)	Coefficients of the IDF Polynomial Equations			
				a	b	c	d
Sabah	Kota Kinabalu	1957-1980	2	5.1968	0.0414	-0.0712	-0.0002
			5	5.6093	-0.1034	-0.0359	-0.0027
			10	5.9468	-0.2595	-0.0012	-0.0050
			20	5.2150	0.3033	-0.1164	0.0026
			50	5.1922	0.3652	-0.1224	0.0027
Sabah	Sandakan	1957-1980	2	3.7427	1.2253	-0.3396	0.0191
			5	4.9246	0.5151	-0.1886	0.0095
			10	5.2728	0.3693	-0.1624	0.0083
			20	4.9397	0.6675	-0.2292	0.0133
			50	5.0022	0.6587	-0.2195	0.0123
Sabah	Tawau	1966-1978	2	4.1091	0.6758	-0.2122	0.0093
			5	3.1066	1.7041	-0.4717	0.0298
			10	4.1419	1.1244	-0.3517	0.0220
			20	4.4639	1.0439	-0.3427	0.0220
Sabah	Kuamut	1969-1980	2	4.1878	0.9320	-0.3115	0.0183
			5	3.7522	1.3976	-0.4086	0.0249
			10	4.1594	1.2539	-0.3837	0.0236
			20	3.8422	1.5659	-0.4505	0.0282
			50	5.6274	0.3053	-0.1644	0.0079
			100	6.3202	-0.0778	-0.0849	0.0026
Sarawak	Simanggang	1963-1980	2	4.3333	0.7773	-0.2644	0.0144
			5	4.9834	0.4624	-0.1985	0.0100
			10	5.6753	0.0623	-0.1097	0.0038
			20	5.9006	-0.0189	-0.0922	0.0027
Sarawak	Sibu	1962-1980	2	3.0879	1.6430	-0.4472	0.0262
			5	3.4519	1.4161	-0.3754	0.0200
			10	3.6423	1.3388	-0.3509	0.0177
			20	3.3170	1.5906	-0.3955	0.0202
Sarawak	Bintulu	1953-1980	2	5.2707	0.1314	-0.0976	0.0025
			5	5.5722	0.0563	-0.0919	0.0031
			10	6.1060	-0.2520	-0.0253	-0.0012
			20	6.0081	-0.1173	-0.0574	0.0014
			50	6.2652	-0.2584	-0.0244	-0.0008
Sarawak	Kapit	1964-1974	2	3.2235	1.2714	-0.3268	0.0164
			5	4.5416	0.2745	-0.0700	-0.0032
			10	4.5184	0.2886	-0.0600	-0.0045
			20	5.0785	-0.0820	0.0296	-0.0110
Sarawak	Kuching	1951-1980	2	5.1719	0.1558	-0.1093	0.0043
			5	4.8825	0.3871	-0.1455	0.0068
			10	5.1635	0.2268	-0.1039	0.0039
			20	5.2479	0.2107	-0.0968	0.0035
			50	5.2780	0.2240	-0.0932	0.0031
Sarawak	Miri	1953-1980	2	4.9302	0.2564	-0.1240	0.0038
			5	5.8216	-0.2152	-0.0276	-0.0021
			10	6.1841	-0.3856	0.0114	-0.0048
			20	6.1591	-0.3188	0.0021	-0.0044
			50	6.3582	-0.3823	0.0170	-0.0054

APPENDIX 13.B DESIGN TEMPORAL PATTERNS

Table 13.B1 Temporal Patterns – West Coast of Peninsular Malaysia

Duration (min)	No. of Time Periods	Fraction of Rainfall in Each Time Period											
10	2	0.570	0.430	-	-	-	-	-	-	-	-	-	-
15	3	0.320	0.500	0.180	-	-	-	-	-	-	-	-	-
30	6	0.160	0.250	0.330	0.090	0.110	0.060	-	-	-	-	-	-
60	12	0.039	0.070	0.168	0.120	0.232	0.101	0.089	0.057	0.048	0.031	0.028	0.017
120	8	0.030	0.119	0.310	0.208	0.090	0.119	0.094	0.030	-	-	-	-
180	6	0.060	0.220	0.340	0.220	0.120	0.040	-	-	-	-	-	-
360	6	0.320	0.410	0.110	0.080	0.050	0.030	-	-	-	-	-	-

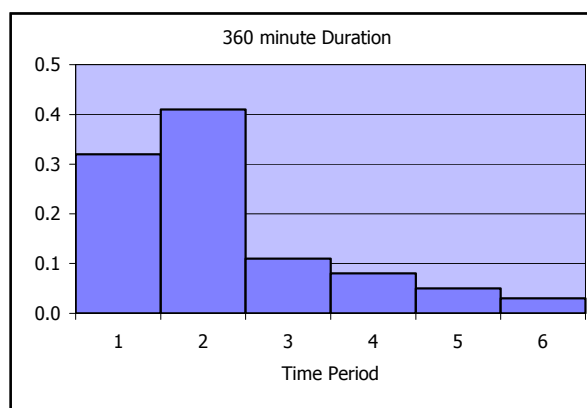
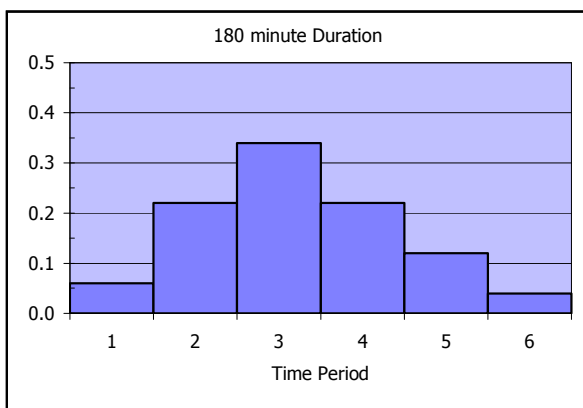
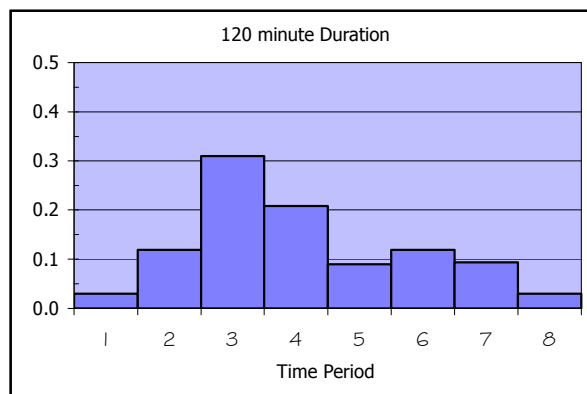
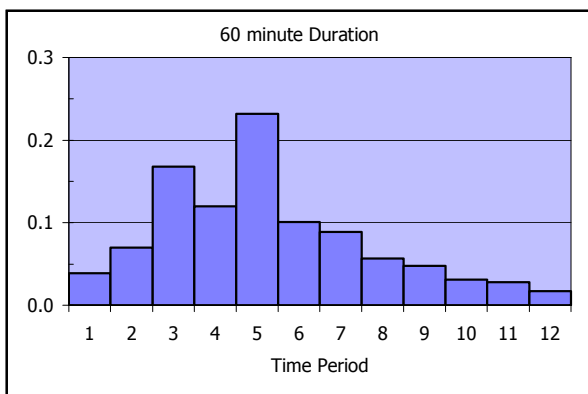
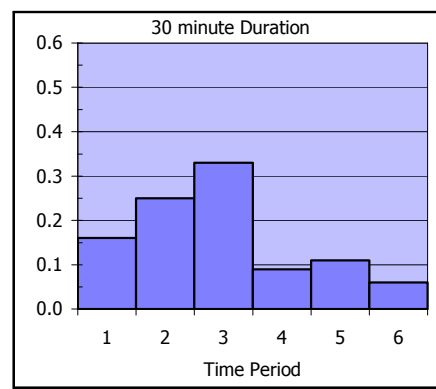
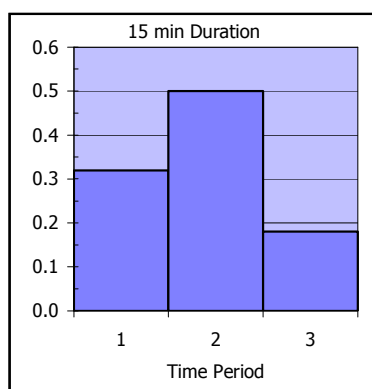
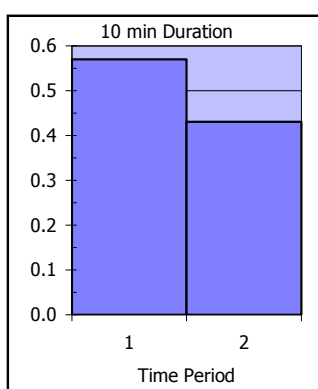
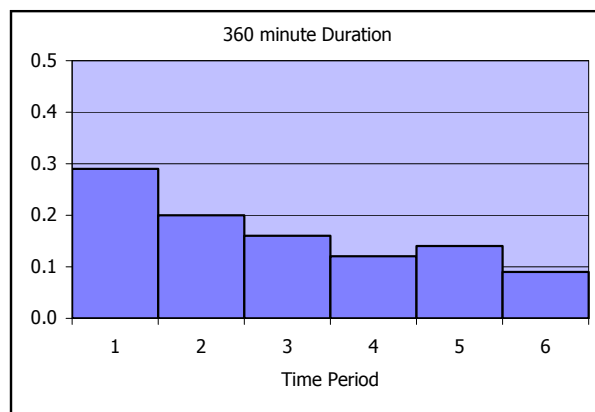
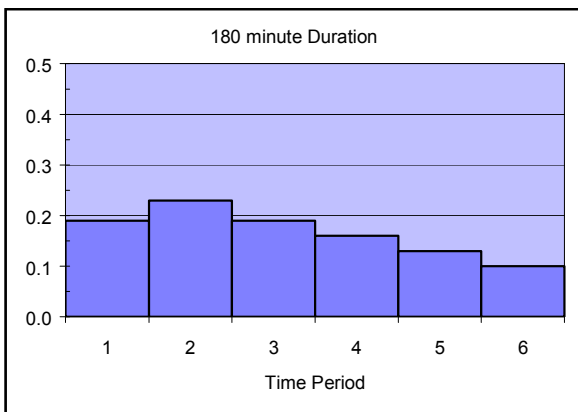
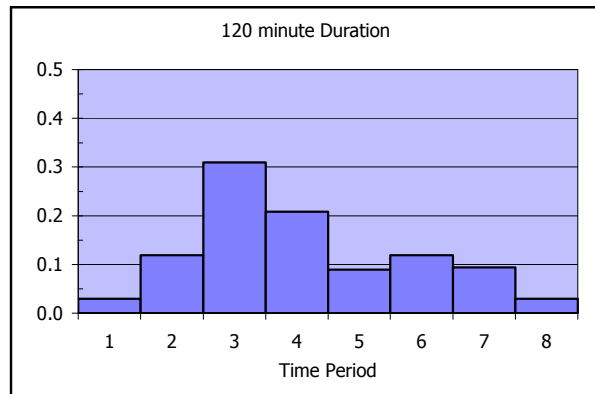
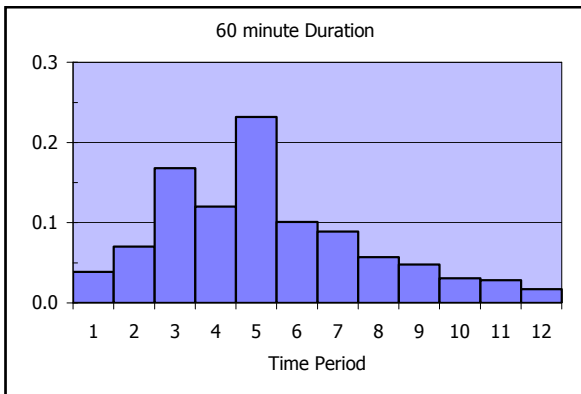
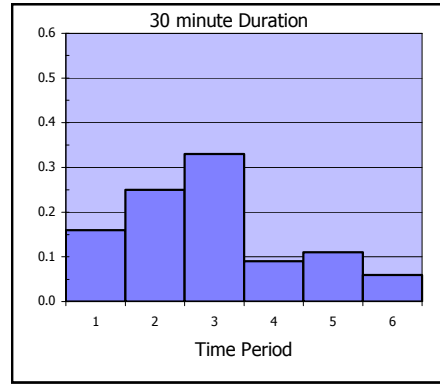
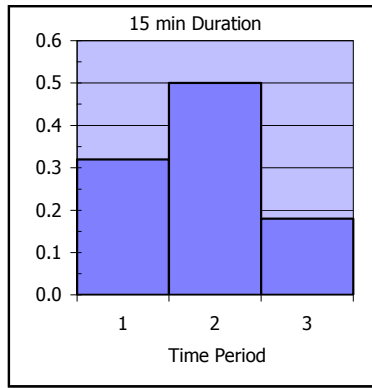
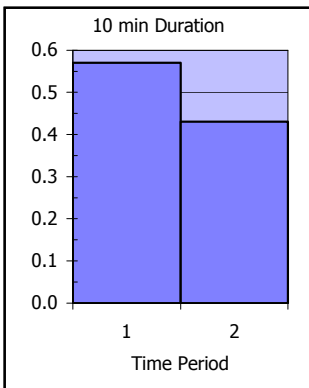


Table 13.B2 Temporal Patterns – East Coast of Peninsular Malaysia #

Duration (min)	No. of Time Periods	Fraction of Rainfall in Each Time Period												
10	2	0.570	0.430	-	-	-	-	-	-	-	-	-	-	
15	3	0.320	0.500	0.180	-	-	-	-	-	-	-	-	-	
30	6	0.160	0.250	0.330	0.090	0.110	0.060	-	-	-	-	-	-	
60	12	0.039	0.070	0.168	0.120	0.232	0.101	0.089	0.057	0.048	0.031	0.028	0.017	
120	8	0.030	0.119	0.310	0.208	0.090	0.119	0.094	0.030	-	-	-	-	
180	6	0.190	0.230	0.190	0.160	0.130	0.100	-	-	-	-	-	-	
360	6	0.290	0.200	0.160	0.120	0.140	0.090	-	-	-	-	-	-	



(# these patterns can also be used in Sabah and Sarawak, until local studies are carried out)

APPENDIX 13.C WORKED EXAMPLE

13.C.1 Calculation of 5 minute Duration Rainfalls

Problem: Calculate the 5 minute duration, 20 year ARI rainfall for use in a roof design in Kuala Lumpur.

Solution: Five minutes duration is shorter than the period of validity of Equation 13.2. Therefore, refer to the procedure for other durations in Section 13.2.7.

From Equation 13.2, for 20 year ARI and $t = 30$ minutes we obtain ${}^{20}I_{30} = 142.4$ mm/hr and the corresponding rainfall depth is ${}^{20}P_{30} = 71.2$ mm.

Similarly, ${}^{20}I_{60} = 91.0$ mm/hr and the corresponding rainfall depth is ${}^{20}P_{60} = 91.3$ mm.

From Figure 5 in HP1-1982, P_{24h} for Kuala Lumpur is read as approximately 100 mm. The corresponding F_D factor from Table 13.3 is 2.08.

Substituting these values in Equation 13.3,

$$\begin{aligned} {}^{20}P_5 &= 71.2 - 2.08 \times (91.3 - 71.2) \\ &= 29.4 \text{ mm} \end{aligned}$$

Convert this depth to a rainfall intensity using Equation 13.4:

$${}^{20}I_5 = 29.4 / (1/12)$$

$${}^{20}I_5 = 352.7 \text{ mm/hr}$$

13.C.2 Use of Daily Rainfall Data

Problem: Use daily rainfall records to calculate the 5-day rainfall totals for Ipoh, Perak. Compute the 25 percentile, 50 percentile and 75 percentile 5-day rainfall totals. The 75 percentile 5-day total is required for design of a wet sediment basin, in accordance with Chapter 39.

Solution: The results are presented in Table 13.C1. Some of the intermediate lines of data have been omitted. Calculations are carried out using statistical functions in a spreadsheet such as EXCEL.

Table 13.C1 Example of Calculation of Daily and 5-day Rainfall Totals Rainfall Station 451111, Politeknik Ungku Omar at Ipoh, Perak

Date	1994		1996	
	Daily	5 Day Total	Daily	5 Day Total
1/1	?		0.0	
2/1	?		0.0	
3/1	?		0.0	
4/1	?		0.0	
5/1	?	0.0	0.0	0.0
6/1	?	0.0	9.5	9.5
7/1	?	0.0	0.0	9.5
8/1	?	0.0	0.5	10.0
9/1	?	0.0	0.0	10.0
10/1	0.0	0.0	4.5	14.5
11/1	0.0	0.0	6.0	11.0
12/1	0.0	0.0	0.0	11.0
13/1	0.0	0.0	0.0	10.5
14/1	0.0	0.0	0.0	10.5
(Intermediate Data from 15/1 to 19/12 are not Shown)				
20/12	0.0	0.0	0.0	12.0
21/12	0.5	0.5	9.5	21.5
22/12	0.0	0.5	0.0	21.5
23/12	0.0	0.5	10.5	30.5
24/12	0.0	0.5	0.0	20.0
25/12	7.5	8.0	0.0	20.0
26/12	7.0	14.5	0.5	11.0
27/12	0.0	14.5	2.5	13.5
28/12	0.0	14.5	0.0	3.0
29/12	0.0	14.5	0.0	3.0
30/12	0.0	7.0	43.5	46.5
31/12	0.0	0.0	1.5	47.5
Total	1783.0		2051.0	
Missing days	9		15	
25 percentile		4.5		0.5
50 percentile		14.5		18.5
75 percentile		36.0		37.5
Maximum		166.5		187.0

? – Indicates Missing Data