Hydrometeorological Advisory Service

HYDROLOGY REPORT SERIES

HRS Report No. 1

TEMPORAL DISTRIBUTIONS WITHIN RAINFALL BURSTS

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Melbourne
September 1991

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1. INTRODUCTION

This report describes the derivation of temporal distributions of rainfall. Temporal distributions of rainfall were required as a major component of the design rainfall information supplied to the Institution of Engineers, Australia for the third edition of "Australian Rainfall and Runoff – A Guide to Flood Estimation" which was published in 1987 (ARR87) (I.E. Aust, 1987). The project was carried out in co–operation with the School of Civil Engineering of the University of New South Wales. Professor D H Pilgrim of the University of New South Wales, who was Editor–in–Chief, Volume 1, of the 1987 edition of ARR, co–ordinated the work.

These temporal distributions are of a type specifically required as an input for various procedures used in engineering hydrology for the design of structures such as stormwater drains, culverts, bridges, retarding basins and small dams. The durations have been selected to cover the range used by design engineers and include the duration which is critical in producing the peak discharge, or maximum runoff, from a specified catchment area to a particular point or outlet in most cases. The average annual construction cost of these structures is estimated by Pilgrim (1986) at approximately $600 million.

One of the first quantitative design methods used by hydrologists to convert rainfall over a catchment into runoff was the Rational Method. This method assumed that the rainfall was uniform in time, as well as in space. It was superseded by the Unitgraph Method in which allowance is made for the rainfall to take different times in traversing a catchment, depending on the place within the catchment on which the rain falls. Because of this feature there was a need for rainfall inputs at successive equal time increments within a given duration. These were obtained by distributing the rainfall amount in the total duration according to the temporal distribution derived for that duration. More recently, Runoff–Routing Models have been used and these require the rainfall to be distributed in both space and time.

The main requirement of design temporal distributions is that, when used in a hydrologic design procedure with average catchment antecedent wetness conditions, they convert a 1 in Y–year design rainfall into a 1 in Y–year flood. Temporal distributions were required for two ranges of average recurrence interval (ARI) of storm burst: up to 30 years and 31 to 100 years, and a range of durations from 10 minutes to 72 hours. The time steps within these durations vary from 5 minutes to 4 hours.

The temporal distributions of rainfall bursts which are the subject of this report describe the variation in time of bursts of moderate to heavy rain. They do not describe the variations in time of the rainfall in complete storms in a meteorological sense, but only within specified storm bursts of various durations. These durations may be part of a storm, may exceed the duration of a storm, or may include more than one storm. This is consistent with the methodology used in deriving the Intensity Frequency Duration (IFD) rainfall information with which these temporal distributions are to be used.

2. DATABASE

The instrument used by the Bureau of Meteorology to record rainfall continuously is the Dines "pluviograph". A paper chart about 300mm long is attached to a drum which is rotated once in 24 hours by a clockwork mechanism. A pen, operated by a float in a chamber which collects the rain, draws a trace on the chart.

The basic rainfall data used in this analysis is taken from the archive of digitised pluviograph (pluviometer) data held by the Bureau of Meteorology. It is described by Kennedy (1979) and Nydam (1981). The resolution of the data is about 5 minutes. Computer programs used for data extraction and analysis block the data using a time interval which is a multiple of 5 minutes.

Pluviograph data are available for about 500 stations in Australia, although only about 300 are digitised routinely. Record lengths vary from about 10 years to about 100 years for some of the capital cities.

3. SELECTION OF ZONES AND PLUVIOGRAPH STATIONS

Before selecting the pluviograph stations for analysis, Australia was divided into eight zones, as shown in Figure 1. The zones were selected according to the types of meteorological situations which cause significant (eg having an ARI of at least one year) long duration (greater than about one hour) rainfall events. For durations less than about one hour, significant rainfall is usually caused by convective storms, which would not be expected to vary greatly in structure across the country. The boundaries of the zones were placed along the natural boundaries of river basins wherever possible, for ease of use of the temporal distributions in deriving runoff from catchments.

In selecting a network of pluviograph stations to represent each zone, several factors were considered :

a) Record Length

Ideally only data from stations with long records (eg greater than 30 years) should be used as there is a requirement for temporal distributions for two ranges of ARI (up to 30 years, and 31 to 100 years). In all zones, some stations with less than 30 years of record were used because of an insufficient number of stations with long records . Generally these stations had record lengths down to about 15 years, although in one case a station with 7 years of record was used.

b) Representativeness of a Zone

Where possible the pluviograph stations in a zone were selected to give a spatial coverage which is representative of the entire zone. In some cases stations with less than 30 years of record were used to improve the coverage of the zone.

c) Spatial Independence of Stations

It is desirable that a particular rainfall event be represented by only one pluviograph station. It is difficult to devise a simple objective method of ensuring spatial independence. The criterion used was that the stations selected in each zone had to be at least 50 km apart unless this criterion resulted in too few stations in a particular zone.

The stations used in each zone and the number of years of record are given in Appendix A.

4. CONSTRUCTION OF STORM BURST PARTIAL SERIES

For each station the n highest rainfall totals were obtained for each of 20 different durations of storm burst, where n is the number of years of record for a particular pluviograph station. For computational convenience the maximum number of storm bursts used to derive a temporal distribution was 301. Each of the 20 durations was divided into a number of equal time periods, or intervals, ranging from 5 minutes to 4 hours. These are the partial series of storm events for each station.

The above durations and the time intervals were specified by the user organisations. They reflect the range of response times of actual catchments and the resolution of the catchment models used to calculate runoff. The details of the durations and periods used are given in Table 1.

Table 2a is an example of a partial series for a station with 10 years of record.

The storm bursts were selected according to the following criteria:

(i) The rainfall total was sufficiently large for the event to be one of the n highest values for that duration from n years of record.

(ii) Successive falls of a given duration did not overlap in time (ie the events had to be independent in time).

(iii) For a duration with m periods, a storm burst was rejected if there were at least m/3 successive and equal non–zero values. Such values are the result of interpolation from the chart of successive values during part of a storm burst when the pluviograph cannot produce a legible trace during very heavy rain.

(iv) For a storm burst to be included, the rain did not have to persist for the entire length of the specified duration in order that the burst was a subset of the IFD data. The convention adopted was that the storm burst duration begins when the rain begins. This criterion was adopted in consultation with the University of NSW team.

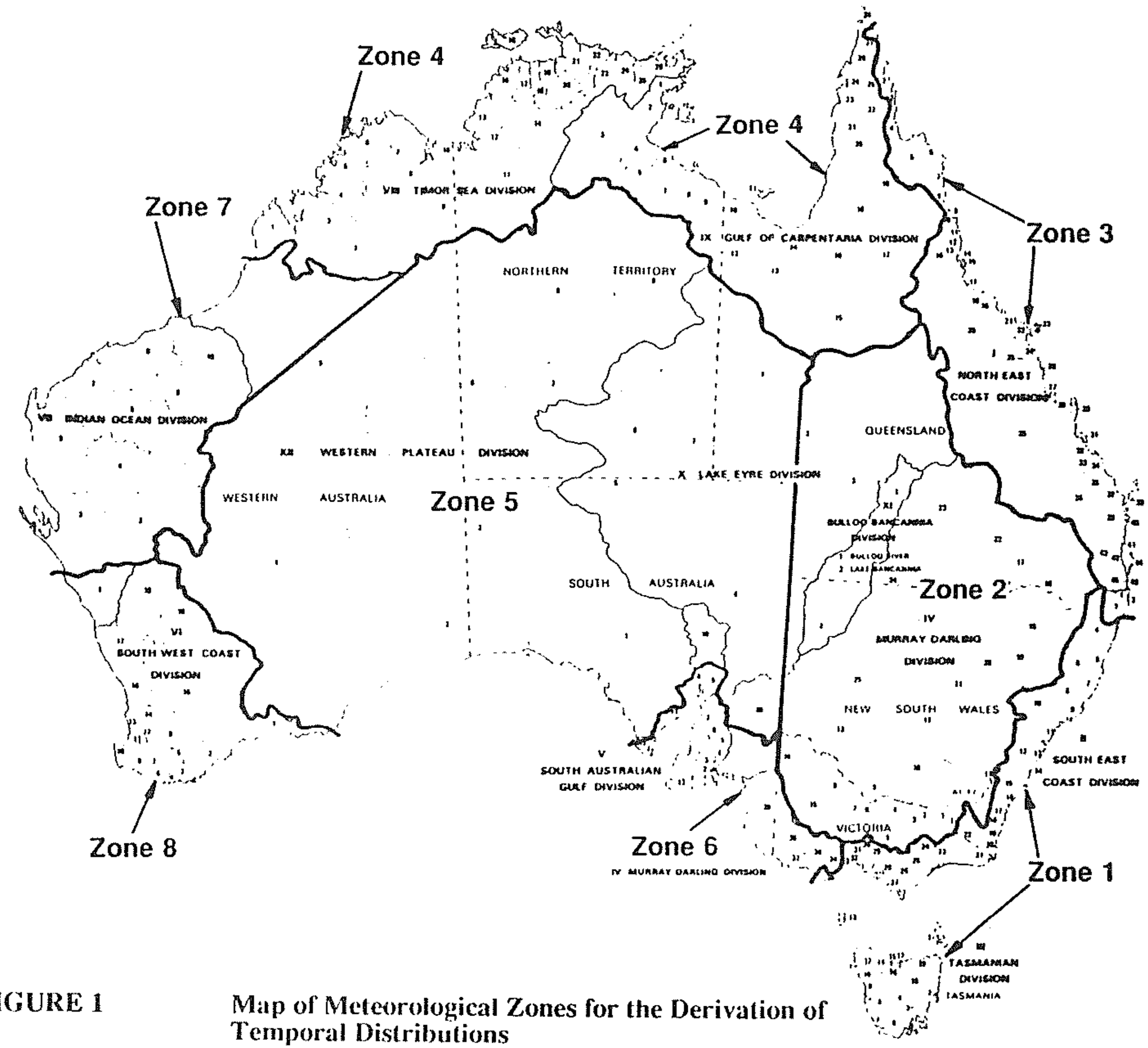

FIGURE 1 Map of Meteorological Zones for the Derivation of Temporal Distributions

TABLE 1

DURATIONS AND PERIODS USED IN DERIVING TEMPORAL DISTRIBUTIONS OF RAINFALL

PATTERN NUMBER	TOTAL DURATION	SUBDIVISION OF DURATION NUMBER OF SUBDIVISIONS	LENGTH OF SUBDIVISIONS
1	10 MINUTES	2	5 MINUTES
2	15	3	5
3	20	4	5
4	25	5	5
5	30	6	5
6	45	9	5
7	1 HOUR	12	5
8	1.5 HOURS	18	5
9	2	24	5
10	3	12	15
11	4.5	18	15
12	6	12	30
13	9	18	30
14	12	24	30
15	18	18	1 HOUR
16	24	24	1
17	30	15	2 HOURS
18	36	18	2
19	48	24	2
20	72	18	4

TABLE 2a

EXAMPLE OF STORM BURST PARTIAL SERIES OF 20 MINUTES DURATION FOR A STATION WITH 10 YEARS OF RECORD

Storm Date	Total Rain (mm)	Storm No.	Rain in Each Period (mm) Period 1	Period 2	Period 3	Period 4
20.11.1982	44.6	1	8.0	14.3	12.2	10.1
20.03.1984	43.1	2	7.6	11.6	11.2	12.7
29.09.1980	42.2	3	12.2	11.7	7.9	10.4
26.10.1980	39.9	4	10.7	16.5	8.9	3.8
09.03.1986	38.9	5	4.6	12.7	11.4	10.2
25.10.1978	38.2	6	10.2	6.9	10.4	10.7
20.11.1985	35.6	7	8.9	11.0	9.4	6.3
19.01.1981	35.3	8	9.1	12.2	10.2	3.8
25.09.1983	34.8	9	11.2	5.1	9.4	9.1
15.06.1979	33.7	10	10.7	10.2	8.9	3.9

5. MEAN TEMPORAL DISTRIBUTIONS

In order to derive the average temporal distribution of rainfall for each duration in each zone, the partial series of the storm burst samples from all the stations in each zone were combined to form a zone partial series.

i.e. Number of bursts in a combined series for a zone $= \sum_{i=1}^{m} n_i$

where m is the number of stations in the zone
and n_i is the number of years of record for station i.

In contrast, the procedure used to derive the zonal temporal distributions for the 1977 edition of "Australian Rainfall and Runoff" (Hall, 1977) was to derive the separate station distributions first and then to derive the zonal distribution subjectively from these station distributions.

The method used to derive mean temporal distributions of rainfall bursts in this report is the "Average Variability Method" (AVM) which was devised by Pilgrim, Cordery and French (1969). In essence, the average variability method first determines the most likely order of the k periods of the storm burst, expressed as rank 1,2...k, in descending order of magnitude. Then it determines the average amount of rainfall (expressed as a percentage of the total for the duration of k periods), associated with each rank number.

The method for analysing the zone storm burst partial series using the average variability method is illustrated in Table 2b and is summarised as follows :

(i) The rainfall amounts in each period of each storm burst (Table 2a) are expressed as a percentage of the total rainfall in the burst (Section A of Table 2b), and these percentages are then ranked.

(ii) The periods are assigned ranks according to these percentages. (Section B).

(iii) The rank numbers of period 1 are summed for all the storm bursts and the average rank is calculated. (Section C).

(iv) This is repeated for periods 2 to k.

(v) The period with the lowest average rank is designated as rank 1. (Section D).

(vi) The period with the next lowest average rank is designated rank 2, and so on, for ranks 3 to k.

(vii) The percentages for all the rank 1 periods (Section A) are summed and the average is taken. (Section E).

(viii) The average percentage calculated for all the rank 1 periods is assigned to the designated rank 1 period. (Section F).

(ix) Steps (vii) and (viii) are repeated for ranks 2 to k, giving the design temporal distribution.

TABLE 2b

SAMPLE APPLICATION OF AVM TO ZONE
STORM BURST PARTIAL SERIES OF 20 MINUTES DURATION

B

Rank of Each Period's Rainfall

Storm Date	Period 1	Period 2	Period 3	Period 4
20.11.1982	4	1	2	3
20.03.1984	4	2	3	1
29.09.1980	1	2	4	3
26.10.1980	2	1	3	4
09.03.1986	4	1	2	3
25.10.1978	3	4	2	1
20.11.1985	3	1	2	4
19.01.1981	3	1	2	4
25.09.1983	1	4	2	3
15.06.1979	1	2	3	4

A

Percent of Storm Burst for Ranked Periods

Rank 1	Rank 2	Rank 3	Rank 4
32	27	23	18
29	27	26	18
29	27	25	19
41	27	22	10
33	29	26	12
28	27	27	18
31	26	25	18
35	29	26	10
32	27	26	15
32	30	26	12

C

Average Rank	2.6	1.9	2.5	3.0

E Average Percent per Rank

32.2	27.6	25.2	15.0

D

Designated Rank	3	1	2	4

F

Period	1	2	3	4
Final Pattern (%)	25.2	32.2	27.6	15.0

It should be noted that the application of the average variability method to the partial series data gives temporal distributions which are applicable to **mean, or once in 2–year**, storm depths, Pilgrim et al. (1969).

Mean temporal distributions were derived for each of the required 20 durations for each zone by applying the procedures described above to the combined zone partial series for each duration. The results are given in Appendix B.

By comparison the method used by Hall (1977) to derive the temporal distributions of rainfall bursts for the second edition of ARR had an additional step. The complete partial series was used to find the rank 1 or peak position. Then the AVM was applied to only those storms which had their peaks in that position or an adjacent position.

6. TEMPORAL DISTRIBUTIONS FOR DIFFERENT RANGES OF AVERAGE RECURRENCE INTERVAL

An examination of the zone sample data sets indicated that the lower ranked storm bursts (the heavier, or longer ARI, falls) in the partial series, tend to be generally more uniform in time than the higher ranked storm bursts (lower rainfall totals with shorter ARIs). Storms which have higher rainfall totals are usually storms in which heavy rain persisted for most of the time. Storms which give lower totals for a given duration could result from either general but less heavy rainstorms or from thunderstorms which do not last for the total duration. Such a storm burst would have a temporal distribution which is very peaked at or near the beginning of the duration. An indication of the variability of the rainfall in two–hourly periods within a duration of 48 hours is given in Tables 3 and 4 for Zones 3 and 7.

For ARR87 two sets of patterns were derived to reflect the variation with ARI of the individual stormburst patterns, as described above. In contrast in ARR77 only the mean (or 2–year) design distributions were derived and these were used in conjunction with the full range (1 to 100 years) of IFD data.

A technique for quantifying the differences between the temporal distributions for rare storms and those for more frequent storms was devised. The highest 15 per cent of the storm bursts in each station partial series was taken to represent very severe storms and 100 per cent of the sample (mean distribution) moderately severe storms. The highest 15 per cent of the station partial series were then combined into zone samples representing the highest 15 per cent of the storm bursts. This method of selecting the storm bursts from the station series rather than the zone series avoids biasing the sample towards stations which have heavier rainfall due, for instance, to latitude or elevation.

Temporal distributions were derived using the AVM for the highest 15 per cent of the storm burst partial series for each standard duration of 60 minutes or more for each zone. It was found that the percentages for the rank 1 period and other low ranked periods decreased compared to those in the mean distributions, while those for the high ranked periods increased, ie the distributions were more uniform across period compared to the mean distributions. This occurred in all but 14 cases out of the 112 patterns for the highest 15 per cent of the samples. This is consistent with the finding of Pilgrim et al. (1969).

The consistency of the percentage decreases in the rank 1, 2 and 3 values and the increases in the values of the higher rank numbers was investigated. Table 5 is an example of the ratios of the percentages of each rank number in the sample obtained by taking the highest 15 per cent of the samples for Zone 3 divided by the percentages obtained for the corresponding rank numbers for the mean distribution. This was done for all durations which have 12, 18 and 24 periods (ie for durations greater than or equal to 60 minutes). The procedure used for durations with less than 12 periods is discussed in Section 7.

Often the rank 1, 2 percentages etc. for a distribution, derived from the highest 15 per cent of the samples, occurred in different periods to those in the corresponding mean distribution. It is considered that this is not statistically significant and is due to the much smaller numbers of storms in the highest 15 per cent of the samples rather than to a real difference.

An average of the ratios (for the ranks 1, 2...k) was calculated for each rank over all durations with the same number of periods. These average ratios were plotted against rank number and those for Zone 4 are shown in Figure 2. One smooth curve was fitted to all the points for a zone except for Zone 5, where it was found necessary to have a separate curve for durations which have 12 periods. These curves are given in Figures 3 and 4. The values of the ratios obtained from these curves are given in Table 6.

These ratios were applied to the percentages of the mean temporal distributions and the percentages in the higher ranked periods (lower percentages) were adjusted so that the total of the percentages for each duration was 100 per cent. The order of the ranks in the mean distributions was maintained. The effect of applying these ratios is shown in the example in Figure 5.

For completeness in this report, investigations were also carried out for more extreme events for which the top 5 per cent of samples were required. This was done because an original requirement was to obtain patterns for three ranges of ARI between 1 and 100 years. However, it was found during the course of the study that the small samples for the upper 5 per cent and the effect of filtering the patterns (Section 8) resulted in these patterns not being required. The results from this work are included in Appendix C as assistance for any future work, possibly on patterns for ARIs >100 years.

TABLE 3

DISTRIBUTION OF RAINFALL IN STORM BURSTS FOR A DURATION OF 48 HOURS AT EMERALD (ZONE 3)

Rainfall (mm) Recorded During the Storm Burst in Successive 2-hour Periods

Period / Date of Storm Burst	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
26.02.1975	3	4	1	1	0	0	9	2	0	9	0	94	13	3	31	16	1	7	1	0	0	3	2	2
09.01.1969	6	1	0	0	3	112	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
28.01.1974	8	1	0	0	2	0	0	0	0	1	12	1	0	0	6	6	53	25	3	2	2	0	1	34
20.03.1974	1	0	1	1	0	6	5	3	10	8	2	1	11	23	37	26	3	0	0	0	0	0	0	0
21.03.1975	5	20	7	8	1	0	0	0	0	0	0	1	0	15	9	0	0	0	0	5	6	2	28	8
29.03.1974	5	0	0	0	26	60	9	5	0	4	1	0	0	1	0	0	1	1	0	0	0	0	0	0
25.03.1981	20	50	1	0	1	1	0	0	0	3	1	1	21	13	1	0	0	0	0	0	0	0	0	0
18.02.1972	10	0	0	0	0	0	0	0	1	0	2	8	12	6	3	3	8	12	6	0	6	27	11	5
22.02.1971	1	6	3	4	0	2	6	14	18	10	1	10	8	5	5	4	3	0	0	0	0	0	0	0
25.01.1966	8	24	6	3	1	3	1	2	1	6	1	1	0	6	14	6	1	0	0	2	1	2	2	3
08.03.1970	16	53	1	0	0	0	0	0	0	6	2	2	0	0	1	0	0	0	0	3	4	1	1	1
27.04.1965	1	4	12	9	3	2	0	3	7	4	5	10	8	10	12	1	0	0	0	0	0	0	0	0
12.02.1968	28	4	16	4	3	0	2	2	2	1	2	3	4	3	2	2	7	2	2	7	0	0	0	1
31.01.1967	76	12	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.03.1963	5	32	43	2	0	0	0	0	0	0	0	8	0	0	0	0	6	2	0	0	0	0	0	0
21.05.1981	1	2	1	0	1	1	2	1	1	1	3	5	1	2	4	1	7	1	5	8	34	8	1	3
12.03.1977	4	4	8	2	9	2	0	0	0	0	0	0	0	0	0	0	0	1	15	14	11	3	12	4
31.03.1973	3	62	5	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	1	1	2
29.03.1962	10	1	0	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	0	2	9	54	4	0
03.01.1981	7	1	1	0	0	0	12	0	0	0	49	3	0	0	0	0	0	0	0	0	0	6	3	0
05.03.1978	2	1	4	1	0	1	1	15	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

TABLE 4

DISTRIBUTION OF RAINFALL IN STORM BURSTS FOR A DURATION OF 48 HOURS AT ROY HILL (ZONE 7)

Period / Date of Storm Burst	Rainfall (mm) Recorded During the Storm Burst in Successive 2-hour Periods																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
17.02.1964	10	0	0	0	0	0	0	0	0	27	20	3	0	0	0	0	0	0	0	0	0	0	48	11
09.03.1976	2	1	0	2	10	6	2	2	0	0	0	0	0	0	4	20	9	19	12	9	2	0	0	0
06.01.1976	40	1	37	2	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09.02.1981	38	4	13	16	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0
29.04.1964	36	2	23	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.01.1976	33	3	0	0	11	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.05.1964	26	2	4	2	2	1	3	3	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.01.1974	24	5	0	1	0	1	0	0	0	0	0	12	0	1	0	0	0	0	0	0	0	0	0	4
19.01.1981	21	4	0	0	0	0	0	3	0	0	0	0	0	0	6	0	0	0	0	1	7	0	0	0
15.01.1977	19	3	2	3	3	0	0	0	0	0	0	0	0	0	0	0	3	0	3	2	0	0	0	0
28.05.1963	19	1	2	2	6	0	2	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.03.1965	17	5	0	3	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.03.1965	16	7	2	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.03.1963	15	0	0	0	0	0	0	0	0	0	0	0	1	11	0	0	0	0	0	0	0	0	4	0
23.01.1966	15	1	0	4	3	1	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0
18.01.1980	15	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
13.05.1974	13	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.03.1964	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07.08.1974	12	1	2	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 5

RATIO OF PERCENTAGES DERIVED FROM 15 PER CENT OF SAMPLE TO FULL SAMPLE PERCENTAGES (ZONE 3)

Pattern	Ratio for Rank Number: 1	2	3	4	5	6	7	8	9	10	11	12
12x5 mins	0.927	0.990	0.944	0.971	1.006	1.000	1.016	1.088	1.083	1.159	1.137	1.115
12x15	0.906	0.943	1.004	1.015	1.021	1.081	1.096	1.107	1.154	1.107	1.000	1.250
12x30	0.878	1.012	0.976	1.043	1.074	1.184	1.080	1.103	1.103	1.125	1.145	1.175
Means	0.904	0.982	0.991	1.004	1.023	1.052	1.065	1.092	1.113	1.130	1.127	1.180
18x5	0.929	0.964	1.021	0.985	0.957	0.988	1.009	1.034	1.061	1.046	1.071	1.083
18x15	0.864	0.910	0.934	0.959	1.013	1.074	1.104	1.105	1.139	1.127	1.124	1.164
18x30	0.725	0.899	0.945	1.022	1.062	1.084	1.106	1.176	1.200	1.255	1.285	1.309
18x60	0.756	0.897	0.907	1.013	1.047	1.107	1.137	1.180	1.240	1.233	1.258	1.300
18x120	0.809	0.996	1.132	1.066	1.061	1.098	1.045	1.015	1.006	1.003	0.988	0.968
18x240	0.861	0.916	1.019	1.042	1.059	1.147	1.179	1.226	1.286	1.294	1.377	1.380
Means	0.824	0.930	0.989	1.011	1.030	1.068	1.091	1.114	1.162	1.158	1.170	1.200
24x5	0.948	0.959	1.019	0.982	0.946	0.960	0.991	1.017	1.014	1.011	1.029	1.053
24x30	0.721	0.871	0.924	0.989	1.022	1.023	1.051	1.088	1.136	1.178	1.207	1.244
24x60	0.758	0.850	0.891	0.994	1.063	1.084	1.137	1.125	1.163	1.200	1.246	1.248
24x120	0.833	0.939	1.037	1.035	1.025	1.014	1.040	1.043	1.079	1.079	1.163	1.205
24x240	0.851	1.893	1.952	0.975	0.993	1.056	1.120	1.136	1.200	1.267	1.332	1.306
Means	0.822	0.902	0.965	0.996	1.010	1.031	1.068	1.082	1.118	1.147	1.195	1.211

Pattern	Ratio for Rank Number: 13	14	15	16	17	18	19	20	21	22	23	24
18x5	1.085	1.109	1.075	1.137	1.146	1.055						
18x15	1.177	1.184	1.263	1.229	1.282	1.175						
18x30	1.320	1.382	1.360	1.500	1.670	1.514						
18x60	1.367	1.433	1.483	1.550	1.714	1.725						
18x120	0.972	0.953	0.967	0.850	0.957	1.700						
18x240	1.380	1.457	1.426	1.667	1.500	1.400						
Means	1.217	1.253	1.261	1.322	1.348	1.428						
24x5	1.063	1.079	1.068	1.065	1.100	1.131	1.150	1.092	1.109	1.050	0.988	0.960
24x30	1.243	1.285	1.278	1.294	1.357	1.425	1.355	1.467	1.450	1.429	1.640	1.900
24x60	1.250	1.353	1.353	1.362	1.409	1.522	1.538	1.486	1.680	1.375	1.600	1.450
24x120	1.218	1.250	1.258	1.240	1.363	1.271	1.460	1.450	1.267	1.350	0.950	1.206
24x240	1.415	1.540	1.538	1.583	1.483	1.475	1.567	1.650	1.250	1.000	1.200	1.371
Means	1.238	1.301	1.299	1.309	1.342	1.365	1.414	1.429	1.351	1.461	1.276	1.377

TABLE 6

RATIOS FOR DERIVING DISTRIBUTIONS FOR THE HIGHEST 15 PER CENT OF THE SAMPLES FROM THE MEAN DISTRIBUTIONS

RANK	ZONES								
	1	2	3	4	5	5*	6	7	8
1	0.93	0.92	0.89	0.80	0.79	0.93	0.99	0.80	0.81
2	0.95	0.95	0.93	0.89	0.88	0.96	0.99	0.88	0.85
3	0.96	0.98	0.97	0.97	0.96	1.00	0.99	0.96	0.89
4	0.98	1.01	1.00	1.05	1.06	1.04	0.99	1.03	0.94
5	1.00	1.04	1.02	1.12	1.14	1.08	0.99	1.11	1.00
6	1.01	1.06	1.05	1.18	1.23	1.13	0.99	1.18	1.05
7	1.02	1.08	1.07	1.25	1.32	1.17	0.99	1.25	1.11
8	1.04	1.10	1.10	1.32	1.41	1.22	0.99	1.33	1.17
9	1.05	1.12	1.12	1.38	1.50	1.28	0.99	1.41	1.23
10	1.07	1.15	1.15	1.45	1.59	1.34	0.99	1.50	1.30
11	1.08	1.17	1.17	1.52	1.69	1.40	0.99	1.58	1.37
12	1.10	1.19	1.20	1.59	1.79	1.47	1.00	1.68	1.45
13	1.11	1.21	1.23	1.68	1.90		1.02	1.77	1.53
14	1.13	1.24	1.26	1.76	2.00		1.04	1.87	1.61
15	1.15	1.26	1.29	1.84	2.10		1.06	1.96	1.70
16	1.16	1.28	1.31	1.93	2.20		1.12	2.07	1.80
17	1.17	1.31	1.34	2.03	2.30		1.14	2.17	1.90
18	1.19	1.33	1.37	2.13	2.40		1.18	2.27	2.00
19	1.20	1.35	1.39	2.23	2.50		1.22	2.37	2.11
20	1.22	1.37	1.42	2.33	2.60		1.27	2.47	2.21
21	1.23	1.40	1.45	2.43	2.70		1.31	2.57	2.32
22	1.25	1.42	1.47	2.53	2.80		1.36	2.67	2.42
23	1.26	1.44	1.50	2.63	2.90		1.41	2.77	2.53
24	1.28	1.46	1.53	2.73	3.00		1.46	2.87	2.63

NOTE : * ZONE 5 ONLY HAS SEPARATE RATIOS FOR DURATIONS OF 12 DIVISIONS. FOR OTHER ZONES 12, 18 AND 24 DIVISIONS HAVE COINCIDENT RATIOS.

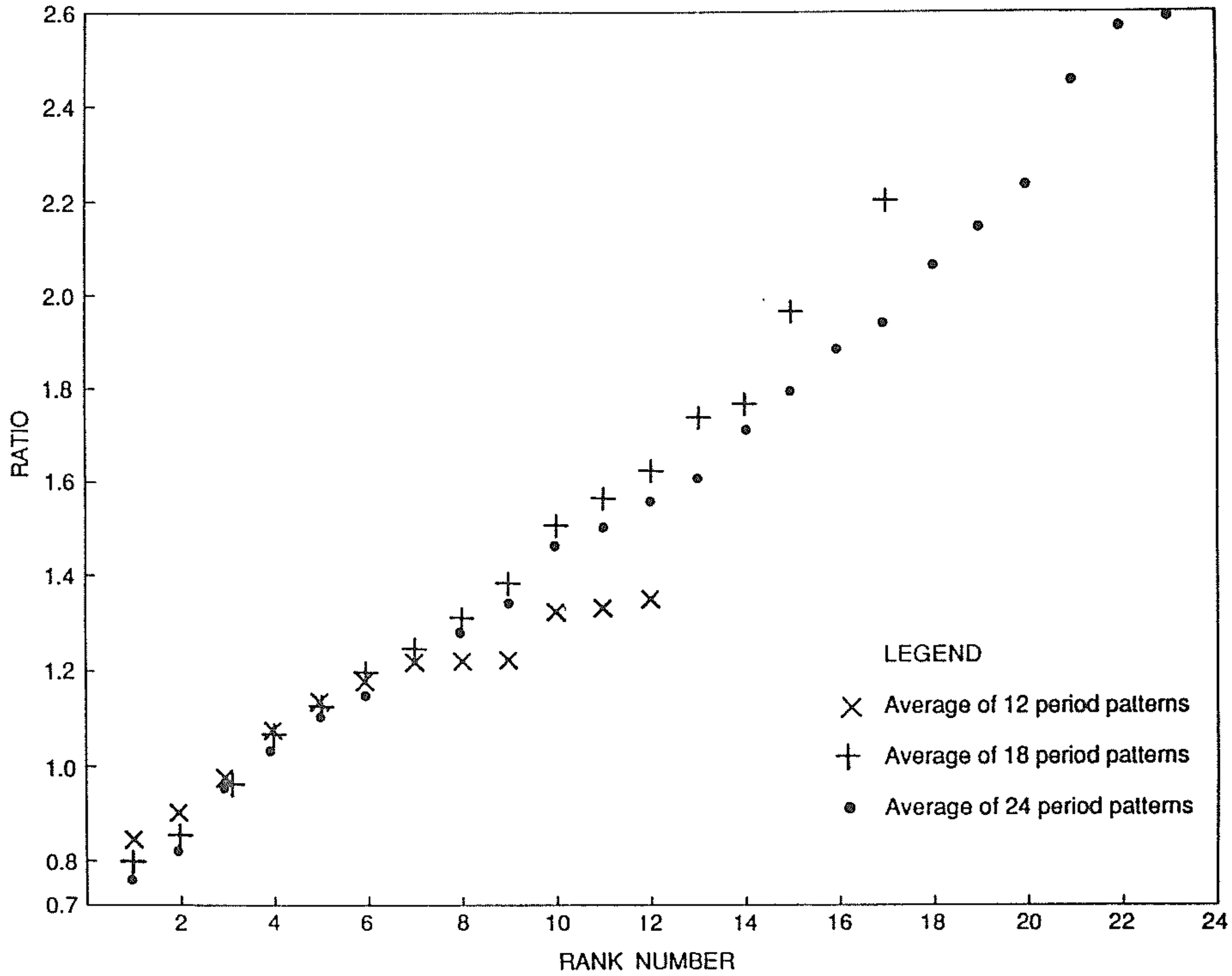

FIGURE 2 **Ratios of the Percentages of Each Rank Derived from the Highest 15 per cent of Sample to Percentages from Full Sample (Zone 4)**

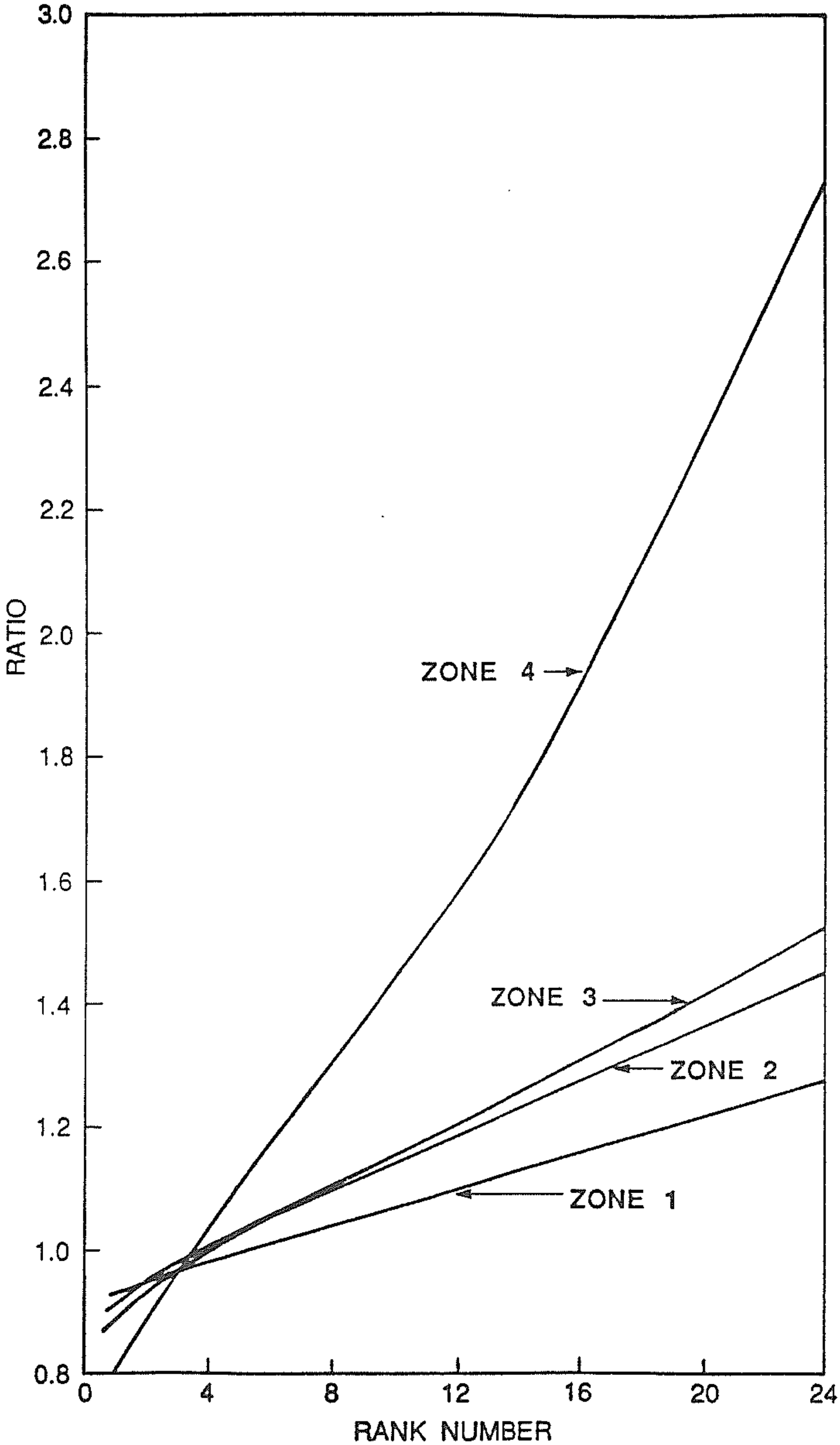

FIGURE 3 **Curves Drawn to the Ratios of Percentages of Each Rank Derived from 15 per cent of the Sample to the Full Sample Percentages for Zones 1 to 4**

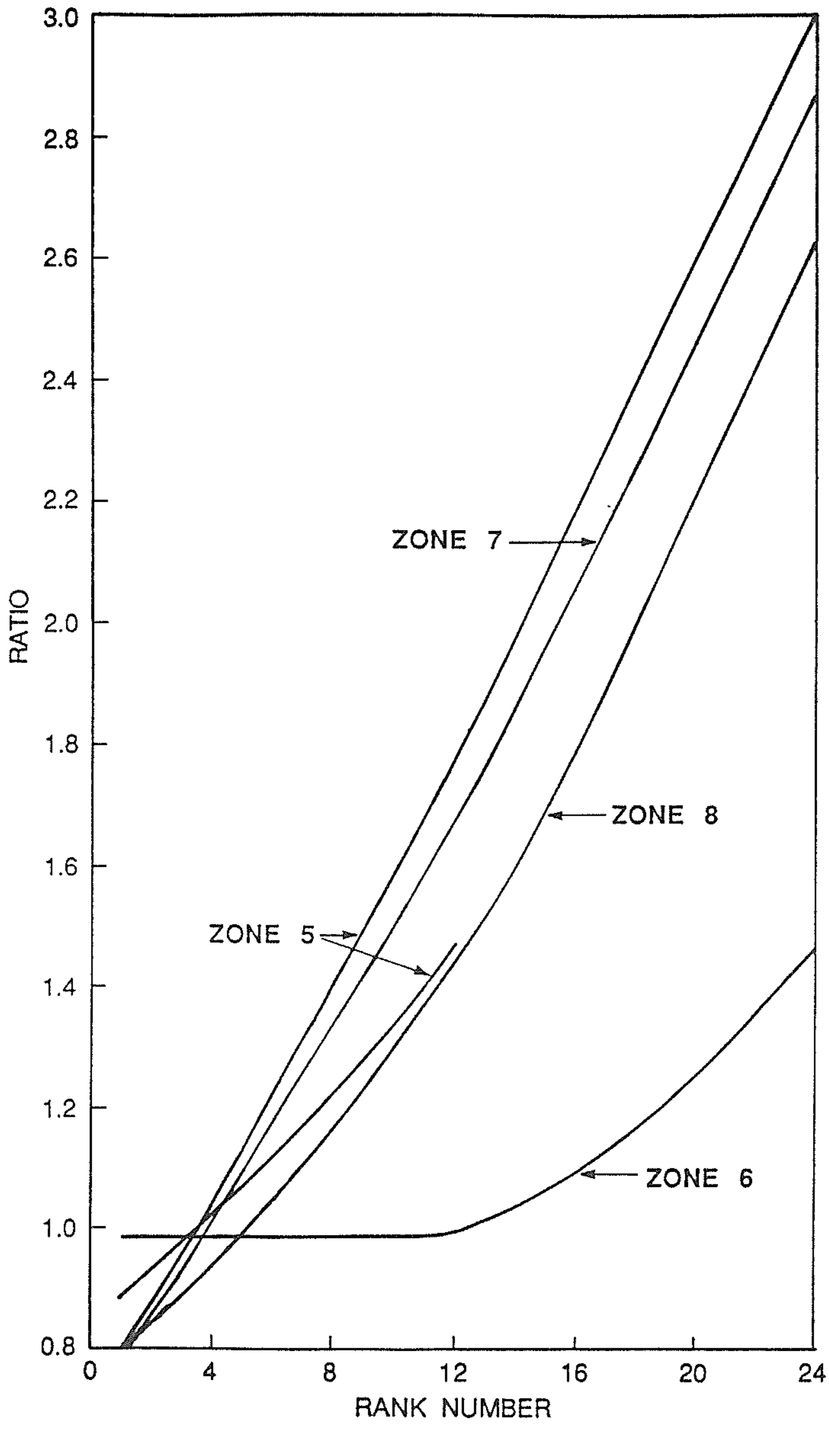

FIGURE 4 **Curves Drawn to the Ratios of Percentages of Each Rank Derived from 15 per cent of the Sample to the Full Sample Percentages for Zones 5 to 8**

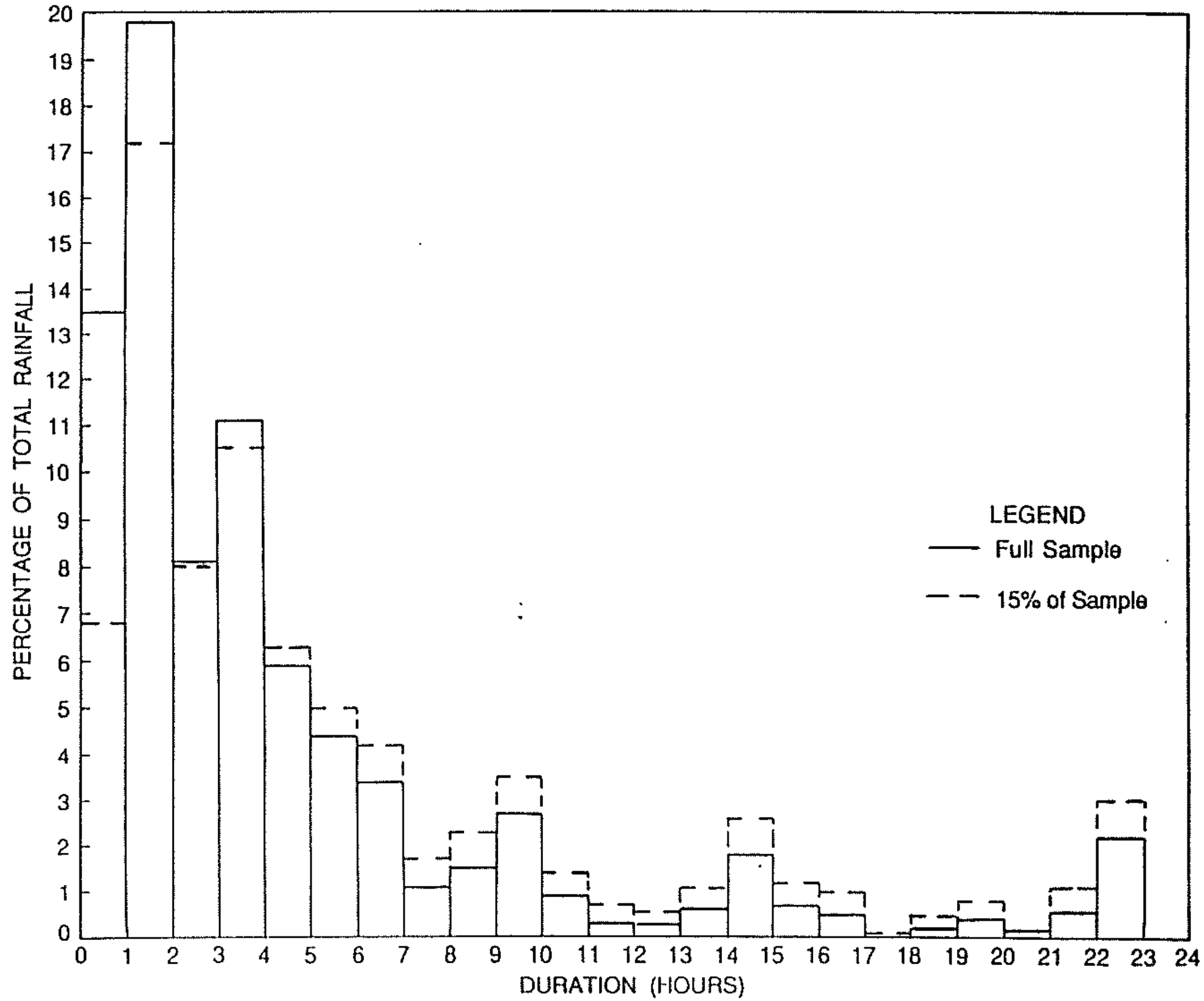

FIGURE 5 **Effect of Applying the Ratios to a Temporal Distribution**

7. TEMPORAL DISTRIBUTIONS FOR DURATIONS UP TO 60 MINUTES

French (1980), using the temporal distributions for the 6 zones given by Hall (1977), showed that only one set is needed for all zones, ie for the whole of Australia, for each duration up to 1 hour. A comparison of the 10– to 60–minute mean temporal distributions derived for each zone for the 1987 edition of ARR also supports this conclusion. This similarity across zones results because these short duration events are bursts of convective rainfall which have the same general characteristics wherever they occur.

The mean temporal distributions for each duration from 10 to 60 minutes from all the zones were examined to find common characteristics in the magnitudes and positions of the various ranks. The main details noted are that the magnitude of the rank 1 period, or main peak, decreases consistently as duration increases and that its position often progresses from period number 1 in the 10–minute duration to period 4 or 5 in the 60–minute duration. From these characteristics a single distribution was constructed for each duration. In this set of distributions the main peak shifts progressively from period 1 in the 10–minute duration distribution to period 5 in the 60–minute duration distribution. A secondary peak is located in period 5 of the constructed 30–minute distribution and shifts to period 3 of the 60–minute distribution as this approximates the trend in the original mean distributions.

The shortest duration for which the ratios of the ranks of the temporal distributions for the highest 15 per cent patterns (see Section 6) were derived was 60 minutes (ie for distributions with a minimum of 12 periods). These ratios were then applied to the constructed mean distributions for durations less than 60 minutes, to give distributions appropriate to the ARI ranges required. For example, consider a distribution of 15 minutes which has three 5–minute periods. The ratio for the rank 1 period of the 12 period (60–minute) distribution was applied to the rank 1 period of the 15–minute distribution. The ratio for the rank 2 period of the 60–minute distribution was applied to the rank 2 period of the 15– minute distribution. The rank 3 percentage of the 15–minute distribution was adjusted to ensure that the total of the percentages for this distribution was 100.

For each rank, the result of applying the relevant 60–minute distribution ratios to the percentage depth was plotted against duration for all durations less than 1 hour. A smooth curve was fitted to these values and the modified percentage depths were taken from these curves. Figure 6 shows an example of this procedure for the rank 1 or peak value.

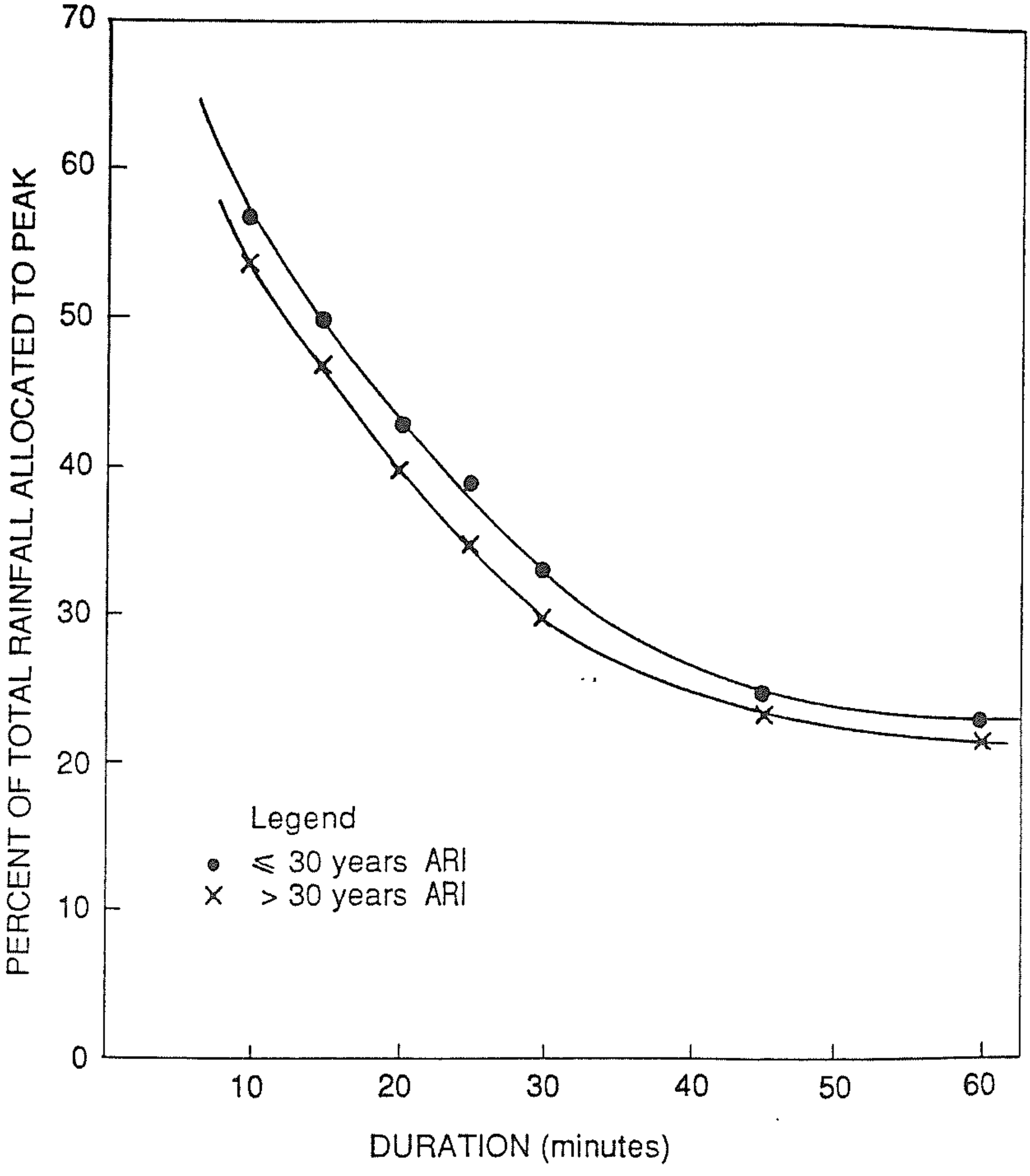

FIGURE 6 **Plot of the Rank 1 Percentages in Temporal Distributions for Durations up to 60 Minutes**

8. TESTING OF TEMPORAL DISTRIBUTIONS

8.1 Consistency Checks

The derived temporal patterns were tested on various catchments by the University of NSW and other authorities. (Rowbottom et al. 1986, Pilgrim et al. 1987).

The testing consisted of examining the effects of the different distributions on flood peaks and hydrograph shapes for a range of catchments. This type of investigation is more meaningful than simple visual or statistical comparison of distributions as the sole purpose of the distributions is for the calculation of design floods. In testing on catchments against recorded floods other factors such as the type of model used, initial losses and continuing losses also affect the result and it is difficult to isolate the effects and/or problems associated with any individual factor.

Floods were calculated using the individual storm bursts in the zone samples. Rowbottom et al.(1986) state that the averages of the peaks of these floods were usually within 5 per cent of the values of the flood peaks calculated using the mean temporal distributions. This indicates that the distributions are valid for their purpose in estimating design floods.

8.2 Problems Identified

A number of problems were identified in the distributions. The nature of the problems and the methods used to overcome the problems are described below.

a) In the Positioning of the Peaks

(i) Multiple peaks occur in many of the temporal distributions. This is realistic since the individual storm bursts in the zone samples are mostly multipeaked.

(ii) Fluctuations in the plots of peak discharge versus duration made it difficult to determine the peak discharge and the critical duration. This is attributed to the positions of the main and secondary peaks for different duration temporal distributions in the same zone being very different. This was identified in all zones.

When the peak discharge from a catchment is obtained for a range of durations it is necessary in practice that the peak discharge increase consistently as duration increases, reach a maximum, and then decrease consistently. An example is given by Pilgrim et al. (1987). The duration at which the maximum peak discharge is reached is the critical duration for the catchment. Large fluctuations in the magnitude of the peak discharge with duration can make it impossible to find a maximum in the peak discharge versus duration curve. The peak discharge is mainly determined by the rank 1 percentages, the percentages immediately adjacent to the rank 1 percentage and the positions of the main and secondary peaks of the temporal distribution. This problem can be reduced by changing the position in which the peak is located in a distribution.

(iii) As noted by Pilgrim et al. (1987), where the main peak occurs in the first or second period the computed peak discharge is very sensitive to the initial loss assumed. While this in itself does not imply a deficiency in the temporal distributions it does lead to practical problems in terms of the sensitivity to the choice of initial loss when the distributions are applied.

b) **In the ARI of Depths of Sub–durations within Distributions**

When a temporal distribution is applied to a particular rainfall IFD value, the rainfall total calculated for the peak or some other sub–duration in the distribution may have an ARI which exceeds the ARI originally used for the total duration. This was observed in all durations and all zones, with the exception of a few cases in Zone 8. This was identified as a significant problem for the hydrologist in application, but it may be meteorologically and statistically valid. It may result from :

(i) The choice of input data.

Inherent in the storm burst distributions associated with the partial series from a given duration (a subset of the IFD database) are distributions associated with sub–duration bursts that have much lower rank (higher ARI) at the sub–durations than at the given duration. This means that unless the data input to the AVM is screened in some form (eg by restricting sample to storm bursts with rainfall over a significant proportion of the total duration) sub–duration depths of higher ARI than that used in the total duration must be expected.

(ii) The choice of method used to determine the "mean" distributions from the chosen input sample.

The AVM may have a tendency to produce peaks which are too coherent (broad) compared with the individual bursts in the sample but this may be a result of the input data including storm bursts that do not last a significant proportion of the total duration.

(iii) The smallness of sample sizes.

In order to achieve adequate sample size it is neccessary to use samples which are representative of a lower ARI than preferred, and then to adjust the distributions to be representative of a higher ARI through filtering.

8.3 Consistency Improvement

The inconsistencies identified during testing of the temporal distributions on catchments indicated that some modifications to the distributions were required. Minor manual modifications and a mathematical filter (designed for minimal effect on the pattern shapes) were applied to the distributions. These are discussed below.

a) **Manual Modifications to Temporal Distributions**

As a result of the consistency checks undertaken by the School of Civil Engineering of the University of New South Wales, and, on their recomendation, minor manual adjustments were made to many distributions. The adjustments to the distributions were based on the discharges calculated using the distributions on various catchments. These modifications mainly involved swapping the positions of adjacent rank numbers. Sometimes an extra peak was created. These modifications are discussed in ARR87 by Pilgrim et al. (1987).

Standard deviations and significance levels for the degree of association between rank and period were calculated for each of the rank positions when the mean distributions were derived. These values ranged from 1 per cent to greater than 30 per cent. Often the mean ranks for the periods ranked 1 and 2, or 2 and 3, etc. were almost the same (see an example in Section C of Table 2b) and the difference between them was much less than the standard deviation about these mean values. In those cases it was considered that the peaks could be interchanged without significantly affecting the validity of the distributions. As stated by Pilgrim et al. (1987), it has not been possible to adjust the

distributions to give completely smooth curves (which may not be desirable) of peak discharge versus duration for all catchments. Some minor fluctuations are inevitable due to variations in the distributions from one duration to the next.

b) Filtering of Temporal Distributions

As has been discussed in Section 7(b), the application of these temporal patterns and IFD to flood models results in some "inconsistencies". These are due to the statistical nature of the temporal patterns which are basically raw and unsmoothed. To avoid some of the problems in application, it was required by the University of NSW team that a form of filtering be undertaken. This was to remove or reduce the amount by which sub–duration rainfall depths exceeded the ARI of the depth of the whole temporal pattern distribution.

In order to carry out this filtering, IFD values, which are available in grid point form for all of Australia, were retrieved from the "Computerised Design IFD Rainfall System"–CDIRS (Canterford et al., 1985,1986). These data were used to compare the ARIs of the depths, obtained for various sub–durations by applying a distribution to a particular duration, with the ARI of the depth used for the total duration, ie to determine whether the rank 1 rainfall values, then the rank 1 plus an adjacent value, etc. were significantly different from the CDIRS value for the same duration and ARI.

A mathematical filter was applied to the distributions from all zones to reduce the differences referred to above to 10% in most cases (up to 20% for a very small number of patterns). The ratios derived from the highest 15 per cent of the samples were then applied to the filtered mean distribution to produce the filtered 15 per cent pattern. This was done after the minor manual modifications described in Section 8.3a.

The philosophy of the filtering process was to achieve a reasonable degree of consistency between the ARI of the sub–duration and the total duration, while maintaining the basic integrity or shape of the patterns.

Plots of filtered versus unfiltered distributions were done for all distributions and in the majority of cases only minor adjustments were made by the filter. If the differences in ARI had been totally filtered out, more significant changes would have resulted.

Several filtering methods were tried (ie reducing to 0 %, and 20% differences). These were tested on catchments by several water authorities at the time. They found that too much filtering reduced the flood peaks of their models, whilst too little filtering created problems in determining a critical duration. Therefore the value of 10% was adopted in most cases.

The procedure used to filter the mean distributions is summarised below :

(i) The CDIRS rainfall intensity value for an ARI of 20 years was obtained at each grid point in a 1 degree latitude/longitude grid covering Australia, for each of the 20 durations for which the mean temporal distributions were derived.

(ii) For a given duration and zone the amount of rainfall in the peak or rank 1 position of a temporal distribution was calculated at a particular grid point. The 20–year ARI CDIRS rainfall intensity value was obtained at that grid point for a duration equal to the sub–division or period of that temporal distribution. If the rainfall value for the rank 1 period was more than 10 per cent greater than the 20–year value it was reduced to a value 10 per cent greater than the latter. The excess rainfall was distributed amongst the rest of the temporal distribution (ranks 2 to k) in proportion to the magnitudes of those ranks.

(iii) This process was repeated for the rank 1 period plus the higher of the two adjacent periods. Then the values for the rank 1 period and both adjacent periods were summed and tested, etc. until all the periods had been included.

(iv) This procedure was repeated at each grid point in each zone and this condition had to be satisfied at 95% of the grid points. An example of the effect of the filtering procedure on a temporal distribution is illustrated in Figure 7.

The effect of the filtering procedure is to raise the ARI associated with the distributions.

The resulting temporal distributions were considered to be those appropriate to ARIs of <30 years (full sample) and >30 years (top 15% sample). The use of the filtering procedure is also discussed by Pilgrim et al. (1987).

9. UNRESOLVED PROBLEMS AND FUTURE RESEARCH

The main aspects to the development of design temporal distributions for use with IFD data are :–

. determining the requirements and expectations of the users,

. the choice of method used to construct a "mean" distribution from a suitable input sample,

. the choice of restrictions on, or screening of, a sample used as input to the method so that it is representative of typical or average patterns associated with depths of a certain range of ARIs (within limitations of sample size),

. the choice of suitable geographical and climatological zones,

. the testing of patterns on a range of catchments.

In determining the direction of any future research all these aspects must be considered, not any one in isolation.

Developing a design temporal pattern to meet the user requirement of converting a 1 in Y–year design rainfall to a 1 in Y–year design flood (when used with average antecedent conditions) is not straightforward. A more practical way of expressing this is that, in application, the temporal distribution should preserve the ARI/probability of the IFD depth. Many other factors influence the ARI/probability of the design flood. The validity of the patterns can only be properly evaluated by testing against recorded flood data on a range of catchments. In this type of testing other factors such as catchment characteristics, type of model used, initial losses and continuing losses, and on larger catchments, areal reduction factors and spatial distribution, also affect results and it is difficult to isolate the effects and/or problems associated with any individual factor. This resulted, in the past, in conflicting feedback from users. More effective and systematic evaluation methods need to be considered.

As an alternative means of testing design temporal distributions, the median peak discharge should be derived by simulation for a range of test catchments in each of the 8 zones and compared with the peak discharge generated by using the design temporal distributions on those same catchments. That is, all the relevent subset of storm bursts patterns should be used with the catchment model and the median flood compared with the relevent design flood. This provides a means of evaluating and validating design patterns by isolating the effects of temporal patterns from the other factors stated above and also the quality of catchment flood frequency analysis against which the design flood is compared.

This was undertaken by Rowbottom et al. (1986) for a subset of the storm burst samples for Zones 1 and 7. Their work showed that the average of the peaks in the floods were

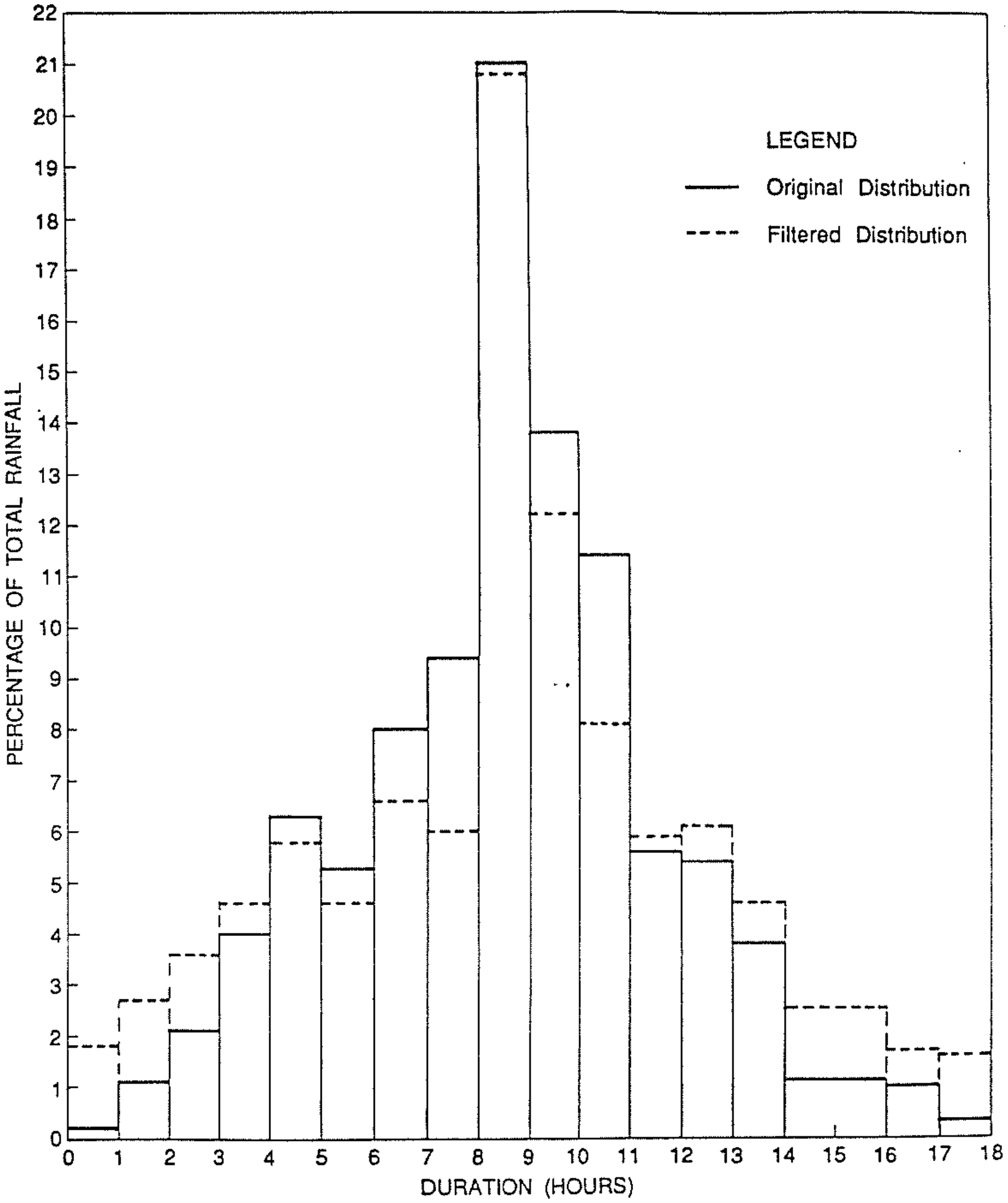

FIGURE 7 **The Effect of the Filtering Procedure on a Temporal Distribution**

within 5 per cent of the values of the flood peaks calculated using the design distributions. This tends to indicate that the design temporal distribution are reliably reproducing the "average" peak flood generated by the storm burst input data for Zones 1 and 7.

Two problem areas have been identified by users (see Section 8). They are :–

a) **Positioning of Peaks**

A feature of the Average Variability Method, and presumably of any other method of deriving temporal distributions, is the variability in the number and positions of peaks for distributions of different durations. This is mainly due to the large natural variability in observed rainfall. The minor rearrangement of parts of some distributions is considered reasonable in cases where the position of a peak has low significance and where more consistent peak discharges can be obtained in modelling actual catchments. Further investigations are needed into the cause of the variability and the scope of possible rearrangments.

A second possible cause of the inconsistencies in peak positions is that some of the zones may be too large. For longer durations, this could result in a mixture of storm types in the samples. Zones which have a large north–south extent, such as Zones 1, 2 and 3, could be subdivided into smaller zones and new sets of distributions derived. This has been examined during a pilot project on new temporal distributions carried out by the Bureau of Meteorology. It was found that further work on other aspects of the method is required before the benefit of having smaller zones can be assessed.

Another factor which needs to be considered is the magnitude of the time steps. Those selected for ARR87 are short in comparison with the duration of the storm bursts and would be expected to give statistical sampling errors. ARR77 had longer time steps and the problem was not as severe.

As pointed out by Rowbottom et al. (1986) it would be preferable if, in applying the Average Variability Method, the distributions were based on medians rather than means. While this may not make a large difference it should be considered if the temporal distributions are rederived in the future.

b) **ARI of Depths of Sub–durations within a Distribution**

A more fundamental problem, whether real or perceived, is that the peak values and the peak values combined with some values either side of the peak, can result in rainfalls which have larger ARIs than that used for the total duration.

The problem may be exaggerated by the model used to create the "mean" distribution by producing distributions that are too coherent, ie the peaks are too broad, compared to those of the storms in the sample. Some distributions may not contain as many peaks as the storm bursts typically do. This would occur if the calculated mean ranks for the periods around the main peaks are too low. A method could be devised for forcing the distributions to have a certain number of peaks and to maintain certain distances between the peaks. This would give less coherent, or more variable, distributions. This would be desirable if, on the average, the storms in the samples are more variable than the derived distributions.

Given that to a certain degree the problem is inherent in the data input into the method, screening of input data may be necessary to ensure only distributions with rainfall over a substantial part of the total duration are used. Although it was a user requirement that the data used in deriving the design temporal distributions was as consistent as possible with that used in deriving the IFD, this may be mutually exclusive with the user expectation that the ARI of depths of sub–durations not exceed the ARI of the depth for the total duration.

10. CONCLUSION

Design temporal distributions, or "patterns", of rainfall bursts were derived for each of 20 durations, ranging from 10 minutes to 72 hours, for 8 zones covering Australia. These temporal distributions are based on a partial series of rainfall bursts within storms and were derived using the average variability method of Pilgrim, Cordery and French (1969). In addition, by taking the highest 15 per cent of the storm burst samples, temporal distributions were derived for a longer average recurrence interval than for the mean temporal distributions. The resulting distributions were filtered to reduce differences in the ARI of embedded segments (or sub–durations) to 10% (in some cases 20%). This extends the ARI of the patterns to make them suitable to represent ARIs of up to 30 years and greater than 30 years. These distributions were published in the 1987 edition of "Australian Rainfall and Runoff".

11. ACKNOWLEDGEMENTS

This project was undertaken at the request of the Institution of Engineers, Australia and was coordinated by Professor D H Pilgrim of the School of Civil Engineering of the University of New South Wales. The project provided a major input to the design rainfall section of the revised edition of "Australian Rainfall and Runoff – A Guide to Flood Estimation", which was published by the Institution of Engineers, Australia in 1987.

The assistance of Mr G J Smith of the Hydrology Branch of the Bureau of Meteorology is gratefully acknowledged. Extensive testing of the temporal distributions was carried out by many people, notably by Mr I A Rowbottom and Associate Professor I Cordery of the University of New South Wales, Dr A H Wong of Gutteridge, Haskins and Davey Pty Ltd, Associate Professor G G O'Loughlin of the University of Technology, Sydney and Dr S N Webb of Webb, Mc Keown and Associates Pty. Ltd. The results of the tests were collated by Professor D H Pilgrim.

Ms L J Minty of the Hydrology Branch of the Bureau of Meteorology provided valuable assistance by undertaking extensive reviewing and editing of this report during its preparation.

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APPENDIX A

PLUVIOGRAPH STATIONS USED IN DETERMINING TEMPORAL DISTRIBUTIONS

TABLE A.1

STATIONS USED IN ZONE 1 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Bellbrook	1933	1981	48
East Sale	1953	1981	28
Hobart	1911	1982	71
Launceston	1938	1982	44
Melbourne	1873	1984	100
Parwan	1954	1973	19
Scotsdale	1953	1969	16
Sydney	1913	1981	68
Walcha	1959	1974	15
Williamtown	1952	1981	29
Scone	1952	1980	28
Robertson	1962	1981	19
		TOTAL	496

TABLE A.2

STATIONS USED IN ZONE 2 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Prairie	1966	1979	13
Tambo	1963	1981	18
Longreach	1966	1983	17
Dalby	1953	1981	28
Charleville	1953	1983	30
Moree	1964	1982	18
Gunnedah	1946	1982	36
Inverell	1947	1982	35
Cowra	1941	1982	41
Wellington	1961	1982	21
Canberra	1937	1983	46
Wagga	1945	1982	37
Griffith	1931	1973	42
Cobram	1957	1980	23
Tatura	1960	1979	19
Lake Eildon	1957	1983	26
		TOTAL	450

TABLE A.3

STATIONS USED IN ZONE 3 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Cairns	1942	1983	41
Townsville	1953	1983	30
Charters Towers	1964	1981	17
Mackay	1959	1983	24
Emerald	1962	1982	20
Biloela	1937	1982	45
Rockhampton	1939	1983	44
Springbrook	1965	1983	18
Brisbane	1908	1984	76
Dorrigo	1954	1971	17
		TOTAL	332

<u>TABLE A.4</u>

STATIONS USED IN ZONE 4 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Kunnunarra	1953	1966	13
Gibb River	1963	1981	18
Halls Creek	1955	1982	27
Broome	1948	1983	35
Darwin Apt.	1953	1983	30
Gove	1966	1973	7
Daly Waters	1953	1974	21
Weipa	1964	1981	17
Normanton	1964	1981	17
Cloncurry	1953	1975	22
		TOTAL	207

TABLE A.5

STATIONS USED IN ZONE 5 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Meekathara	1953	1982	29
Mundiwindi	1963	1979	16
Forrest	1960	1983	23
Kalgoorlie	1939	1981	42
Giles	1956	1982	26
Tennant Creek	1969	1983	14
Rabbit Flat	1969	1983	14
Alice Springs	1951	1983	32
Woomera	1955	1984	29
Oodnadatta	1961	1984	23
Boulia	1964	1981	17
Quilpie	1963	1981	18
Mildura	1953	1982	29
		TOTAL	312

TABLE A.6

STATIONS USED IN ZONE 6 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Ceduna	1954	1982	28
Jamestown	1951	1983	32
Adelaide	1897	1979	82
Mt. Gambier	1942	1983	41
Stirling	1964	1981	17
Rocklands	1955	1983	28
Lake Bolac	1968	1981	13
Wyelangta	1952	1982	30
Hopetoun	1958	1980	22
Horsham	1958	1980	22
Charlton	1951	1983	32
Cleve	1962	1983	21
		TOTAL	368

TABLE A.7

STATIONS USED IN ZONE 7 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Port Hedland	1953	1983	30
Roy Hill	1963	1981	18
Pannawonica	1963	1977	14
Onslow	1961	1981	20
Carnarvon	1956	1982	26
		TOTAL	108

TABLE A.8

STATIONS USED IN ZONE 8 ANALYSIS

STATION NAME	DETAILS OF RECORD LENGTH		
	FIRST YEAR	LAST YEAR	No. OF YEARS
Geraldton	1953	1983	31
Wongan Hills	1952	1982	30
Perth	1946	1983	37
Dwellingup	1953	1983	30
Albany	1965	1982	17
		TOTAL	145

APPENDIX B

MEAN TEMPORAL DISTRIBUTIONS WITHIN RAINFALL BURSTS

TABLE B.1a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 1

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	61.4	32.6	18.5	10.8	8.3	3.8	2.8	2.5	1.9	5.4
2	38.6	48.4	41.5	26.5	34.2	10.6	6.4	15.4	4.8	17.9
3		19.0	29.2	38.1	24.7	14.4	7.8	8.6	3.4	24.7
4			10.8	18.0	16.5	27.7	18.8	11.3	7.7	9.5
5				6.6	11.3	20.8	25.2	20.5	10.0	12.6
6					5.0	8.4	13.0	7.2	6.4	7.6
7						6.6	9.6	6.0	17.9	4.5
8						5.2	5.2	5.1	13.3	6.3
9						2.5	4.2	4.4	5.5	3.8
10							3.4	3.4	2.7	3.2
11							2.1	3.8	3.0	2.6
12							1.5	2.9	3.7	1.9
13								2.2	4.2	
14								1.7	2.2	
15								1.9	2.0	
16								1.4	2.5	
17								1.0	1.7	
18								0.7	1.0	
19									1.4	
20									1.5	
21									1.2	
22									0.9	
23									0.7	
24									0.4	

TABLE B.1b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 1

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	1.6	2.5	1.6	1.0	1.0	0.7	1.2	0.7	2.0	10.0
2	5.2	7.7	6.2	3.8	2.8	0.8	2.8	1.2	3.2	13.1
3	10.7	25.3	4.2	3.3	1.6	1.0	4.4	2.0	2.3	7.6
4	8.5	17.0	3.7	1.2	4.2	1.8	6.5	3.0	3.8	26.0
5	19.3	12.5	3.3	0.8	5.5	3.7	3.5	6.4	2.8	1.7
6	14.3	9.6	7.2	1.6	6.4	1.4	16.4	5.2	7.5	4.8
7	4.6	6.4	2.6	2.0	10.7	2.4	7.9	7.8	11.1	3.7
8	4.1	5.5	8.4	4.1	7.4	2.6	9.9	9.5	5.3	0.6
9	7.0	3.9	5.4	2.5	19.7	2.9	24.4	22.6	14.4	6.0
10	6.0	4.6	10.6	2.2	8.7	8.0	12.5	15.8	20.5	3.0
11	3.6	3.2	13.6	3.0	13.9	9.6	5.3	12.0	8.9	2.3
12	3.3	1.8	19.3	7.6	4.8	17.0	2.2	4.4	4.5	1.3
13	2.5		4.8	9.5	3.7	12.1	1.7	3.6	6.3	18.0
14	2.2		2.9	16.6	2.4	4.1	0.8	2.5	1.3	0.9
15	2.9		2.2	4.6	3.2	5.3	0.5	0.9	0.7	0.4
16	1.9		1.9	1.8	2.0	4.7		0.5	1.6	0.3
17	1.3		1.2	5.8	1.3	6.9		1.6	0.5	0.2
18	1.0		0.9	11.8	0.7	6.0		0.3	0.6	0.1
19				6.6		1.6			1.1	
20				5.1		3.3			0.9	
21				1.4		2.1			0.3	
22				2.7		1.2			0.2	
23				0.6		0.5			0.1	
24				0.4		0.3			0.1	

ZONE 1

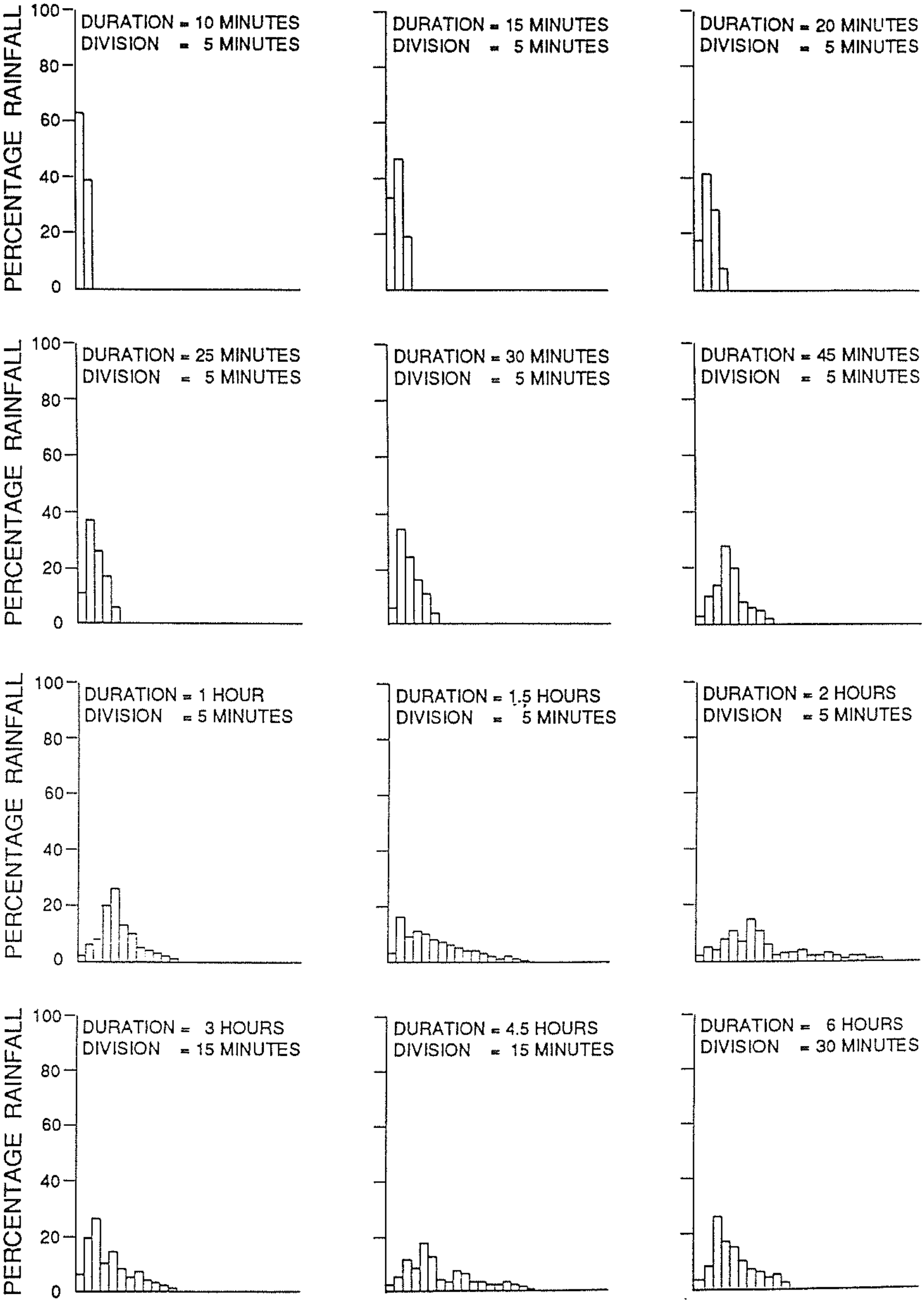

FIGURE B.1 **Mean Temporal Distributions for Zone 1**

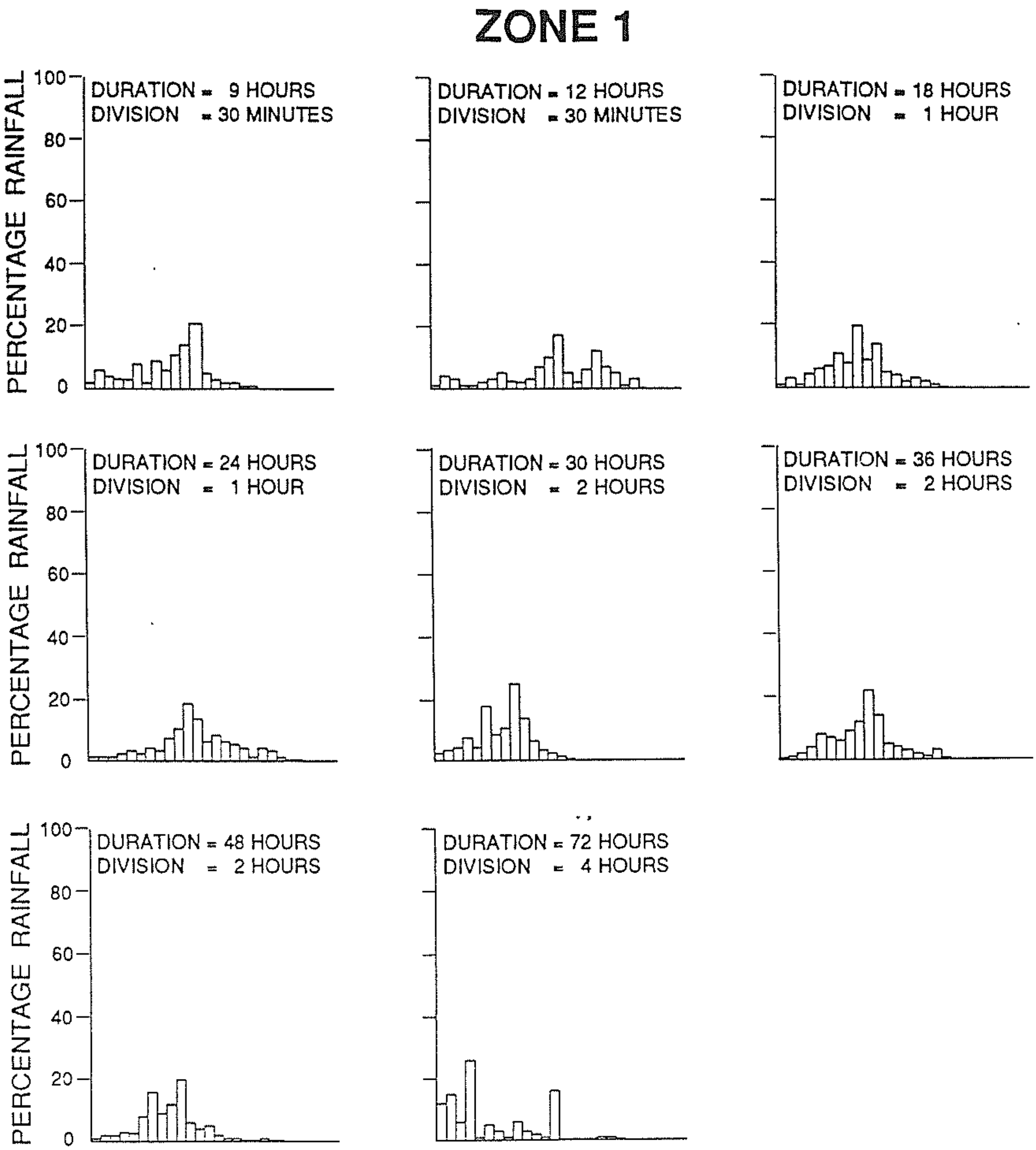

FIGURE B.2 **Mean Temporal Distributions for Zone 1**

TABLE B.2a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 2

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	39.1	32.2	19.1	12.5	9.2	3.8	3.5	3.6	1.7	9.1
2	60.9	47.0	40.5	25.4	32.1	14.8	6.6	15.4	8.8	30.8
3		20.8	28.3	35.9	23.2	26.8	17.7	22.1	13.6	20.0
4			12.1	18.0	12.6	19.9	13.3	9.6	7.2	13.4
5				8.2	16.9	11.3	23.6	11.7	18.2	6.8
6					6.0	8.9	10.6	6.0	10.7	5.1
7						6.7	8.5	7.6	5.9	4.2
8						5.2	5.3	5.0	5.0	3.3
9						2.6	4.4	4.3	4.3	2.6
10							2.7	3.0	2.8	2.1
11							2.1	2.6	3.7	1.5
12							1.5	2.2	3.2	1.1
13								1.9	2.5	
14								1.6	2.2	
15								1.3	1.9	
16								1.0	1.5	
17								0.8	1.4	
18								0.5	1.2	
19									1.1	
20									0.9	
21									0.8	
22									0.6	
23									0.5	
24									0.3	

TABLE B.2b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 2

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	4.5	6.8	11.2	7.9	16.6	11.3	19.7	19.3	18.3	36.4
2	24.3	31.6	26.7	23.8	27.4	25.1	32.3	31.6	29.7	20.8
3	17.2	19.1	16.8	15.1	5.6	15.6	13.1	12.8	12.7	13.8
4	12.2	12.7	8.3	10.4	6.9	8.6	5.3	9.1	9.1	9.2
5	9.0	9.0	3.8	5.3	8.9	5.6	3.9	4.0	6.9	6.1
6	6.8	4.3	2.8	4.5	3.9	4.7	9.3	6.8	5.4	4.2
7	5.4	5.5	3.3	6.3	11.9	6.8	7.0	5.2	4.1	3.0
8	3.8	3.6	2.4	2.6	4.7	3.9	2.9	3.0	3.3	2.0
9	3.2	2.8	1.6	2.3	2.6	1.4	2.1	2.3	2.5	0.7
10	2.7	2.2	5.5	2.0	1.4	2.8	1.6	1.7	2.0	1.5
11	2.0	1.5	6.6	3.9	1.7	2.3	1.1	1.3	1.6	0.5
12	2.3	0.9	4.6	3.0	0.8	1.6	0.8	1.0	1.2	0.3
13	1.7		2.0	3.4	3.2	2.0	0.5	0.7	0.5	1.1
14	1.5		1.4	1.7	2.1	3.3	0.3	0.3	0.7	0.2
15	1.2		0.9	1.1	1.1	0.9	0.1	0.5	0.9	0.1
16	1.0		1.1	1.5	0.6	1.1		0.2	0.4	0.1
17	0.7		0.6	1.3	0.4	0.5		0.1	0.2	0.0
18	0.5		0.4	1.0	0.2	0.3		0.1	0.1	0.0
19				0.8		0.8			0.3	
20				0.5		0.6			0.1	
21				0.7		0.4			0.1	
22				0.3		0.2			0.0	
23				0.4		0.1			0.0	
24				0.2		0.1			0.0	

ZONE 2

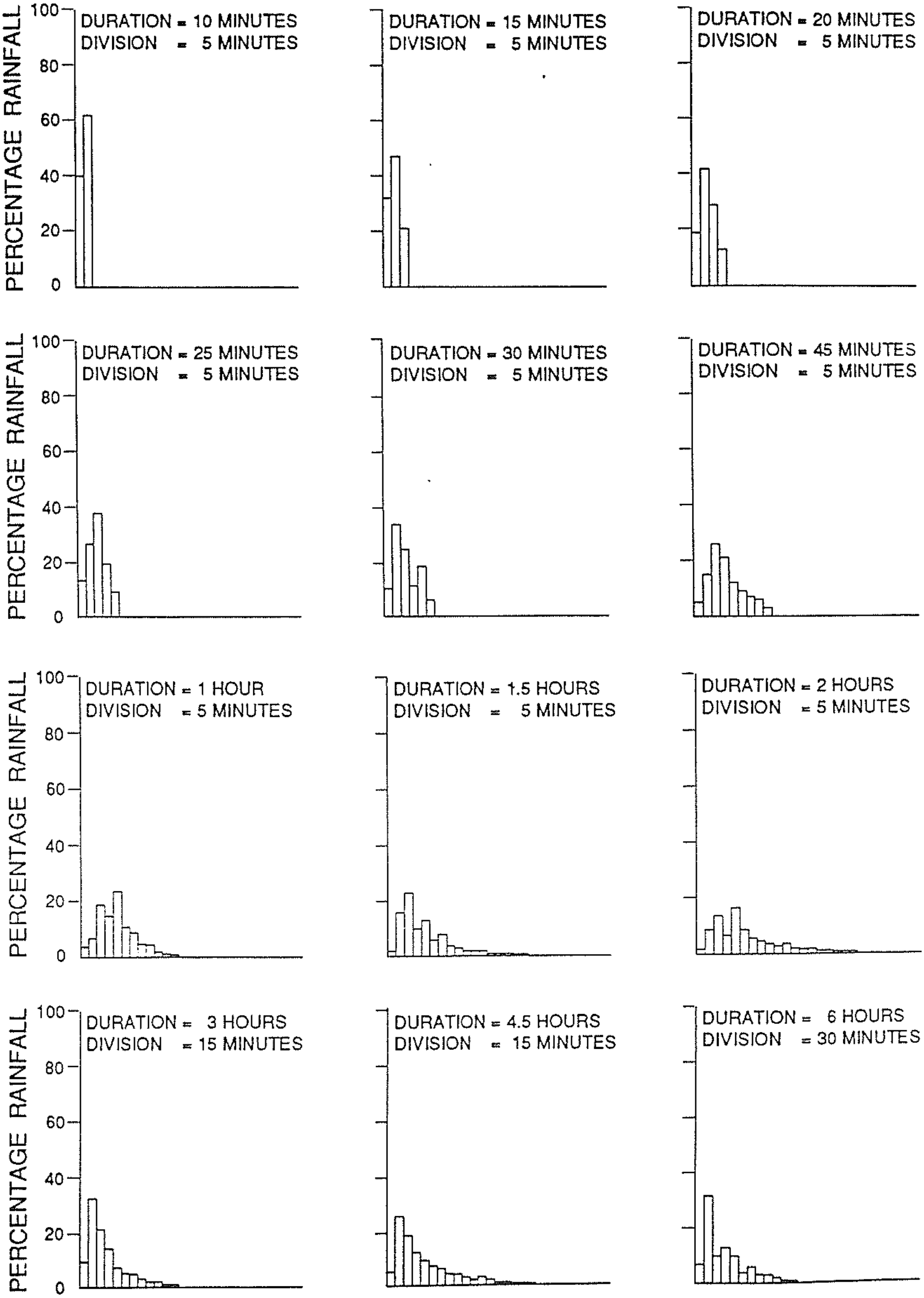

FIGURE B.3 **Mean Temporal Distributions for Zone 2**

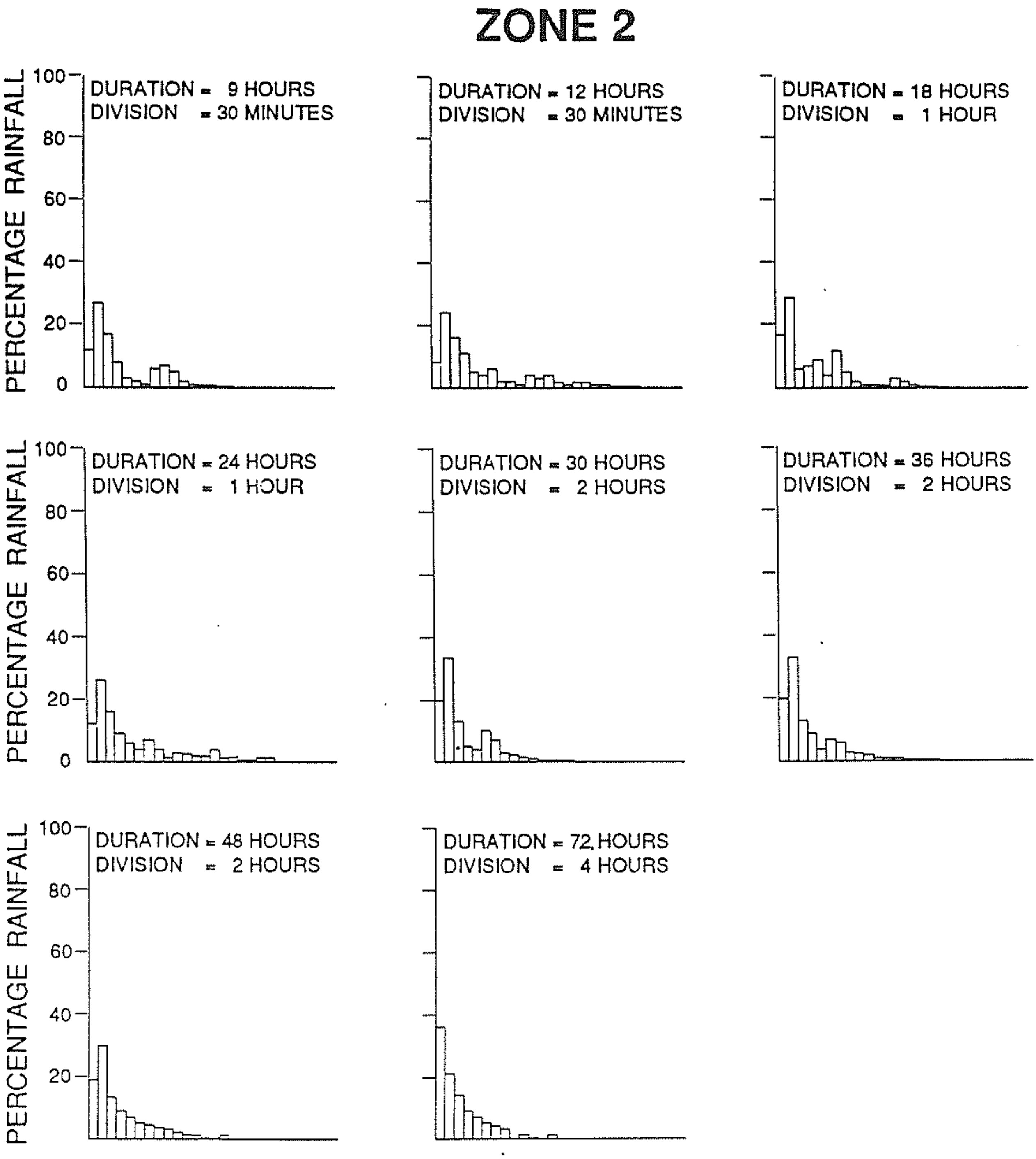

FIGURE B.4 **Mean Temporal Distributions for Zone 2**

TABLE B.3a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 3

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	60.1	21.1	13.1	13.6	9.9	4.8	2.7	3.4	1.6	2.9
2	39.9	46.1	28.0	34.5	22.5	14.2	5.1	7.7	3.4	18.0
3		32.8	39.2	18.1	31.0	24.7	10.6	9.3	6.9	13.4
4			19.7	24.9	13.2	18.3	21.2	5.7	5.3	24.3
5				8.9	16.9	9.5	15.8	12.8	9.6	10.3
6					6.5	11.6	12.8	6.6	6.0	8.0
7						7.5	8.8	16.6	14.5	6.3
8						6.1	7.3	10.7	11.5	4.2
9						3.3	6.1	5.0	8.3	5.2
10							4.2	4.4	4.7	3.5
11							3.4	3.9	4.2	2.3
12							2.0	2.0	3.8	1.6
13								3.0	3.0	
14								2.6	2.7	
15								2.3	2.4	
16								1.7	2.0	
17								1.3	2.2	
18								0.9	1.8	
19									1.4	
20									1.1	
21									1.3	
22									1.0	
23									0.8	
24									0.5	

TABLE B.3b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 3

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	1.6	3.4	8.6	3.6	3.0	14.9	1.5	16.5	24.4	28.9
2	11.9	26.1	15.8	14.3	15.9	22.7	28.3	5.8	15.4	4.3
3	14.8	18.5	23.0	20.4	3.5	10.8	3.7	7.1	5.7	1.3
4	18.9	6.1	3.6	5.4	2.2	6.5	4.7	1.8	0.3	0.5
5	9.7	13.0	3.1	7.9	4.1	4.6	0.8	3.3	0.8	1.0
6	7.6	9.7	4.1	10.1	8.8	2.3	3.1	2.7	0.4	2.2
7	6.1	7.5	5.8	1.6	1.5	0.5	1.1	1.1	0.2	12.3
8	2.9	4.1	2.0	1.4	1.0	1.5	1.9	0.6	0.5	18.2
9	2.5	5.0	4.9	2.0	5.8	2.6	2.4	0.9	1.2	5.6
10	3.8	2.8	2.7	4.1	7.0	0.7	9.2	2.2	4.0	2.7
11	4.3	2.2	6.9	2.8	1.8	1.1	7.3	0.5	6.8	0.7
12	5.1	1.6	11.1	6.4	1.2	0.8	17.2	1.4	2.0	1.7
13	3.3		2.3	4.7	4.9	3.0	12.3	4.7	2.4	7.3
14	2.2		1.5	2.5	24.2	4.0	6.0	26.2	1.7	9.3
15	1.9		1.2	2.3	11.4	3.5	0.5	12.0	8.5	3.4
16	1.4		1.0	1.2	2.6	1.7		9.0	11.2	0.3
17	1.2		1.7	1.1	0.7	0.9		3.9	4.8	0.2
18	0.8		0.7	3.2	0.4	5.5		0.3	1.4	0.1
19				1.8		8.2			3.4	
20				0.9		1.3			1.0	
21				0.7		2.0			0.7	
22				0.8		0.4			2.9	
23				0.5		0.3			0.2	
24				0.3		0.2			0.1	

ZONE 3

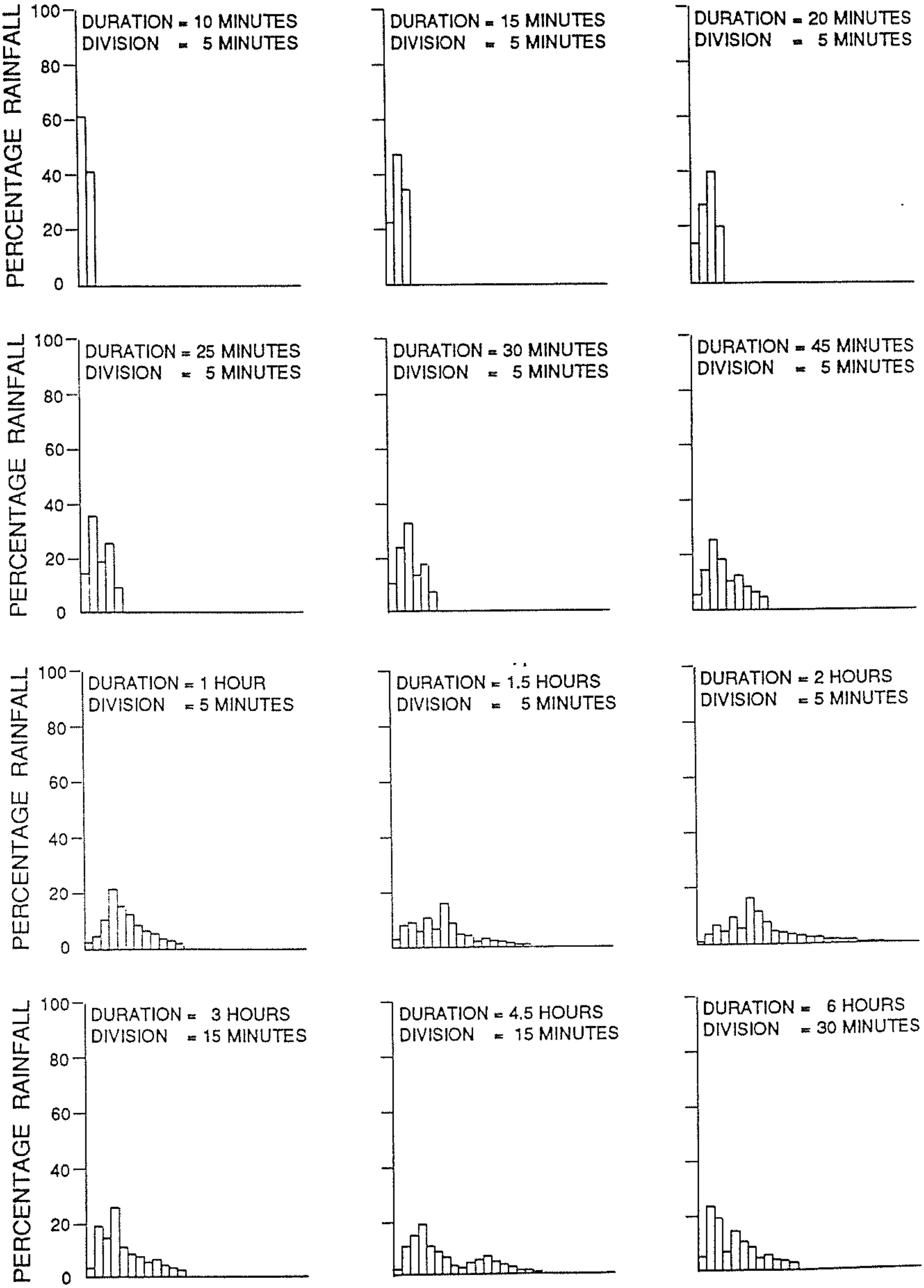

FIGURE B.5 **Mean Temporal Distributions for Zone 3**

ZONE 3

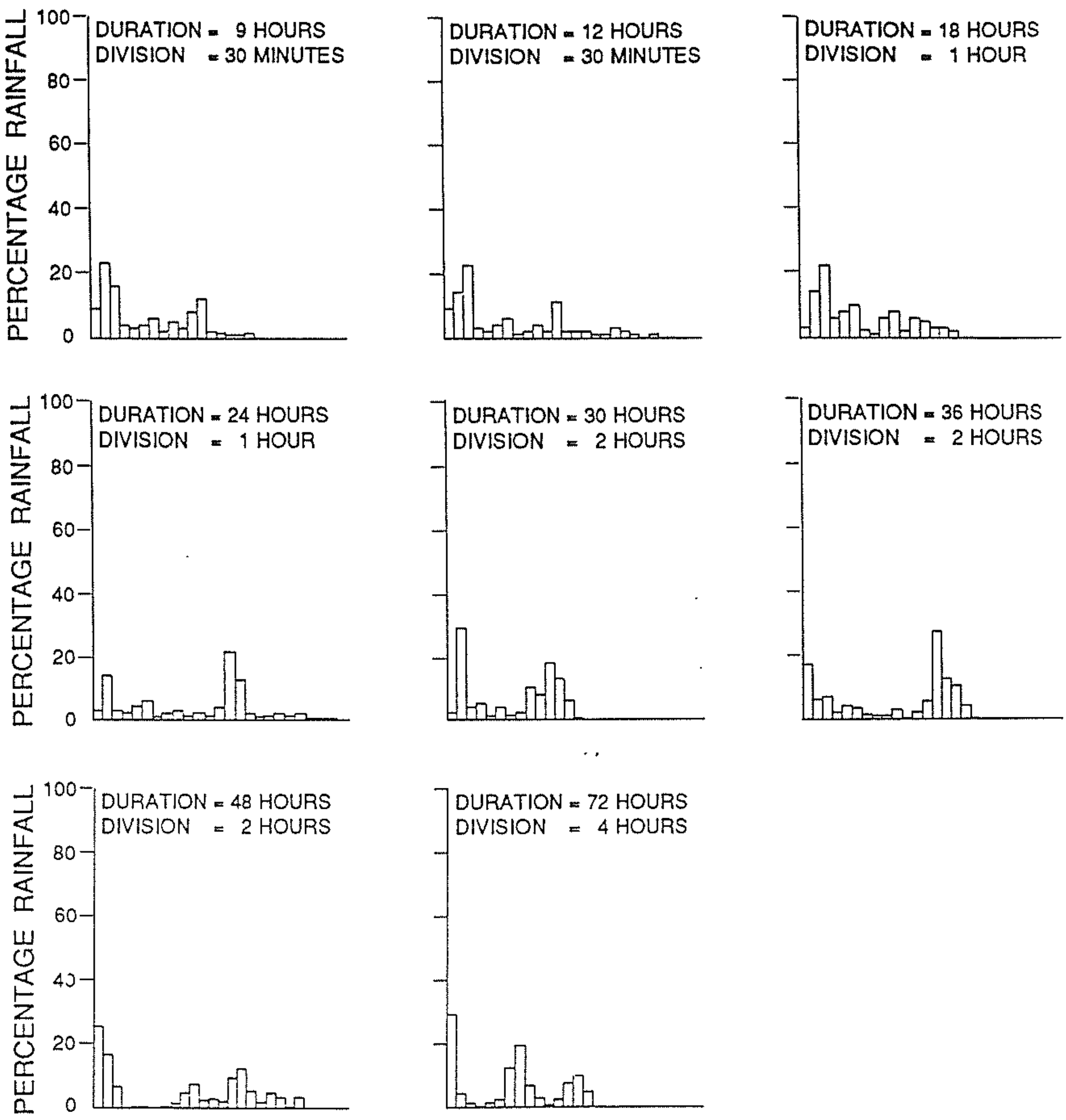

FIGURE B.6 **Mean Temporal Distributions for Zone 3**

TABLE B.4a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 4

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	59.4	33.1	19.9	13.6	10.2	4.7	3.3	2.0	1.6	4.2
2	40.6	45.9	38.4	33.4	30.6	24.7	7.3	9.8	4.7	20.3
3		21.0	28.6	18.4	16.8	11.4	10.9	17.0	15.7	27.9
4			13.1	25.1	13.1	18.4	13.2	13.4	12.3	14.4
5				9.5	22.5	14.1	15.9	11.4	9.0	10.4
6					6.8	9.5	21.2	7.9	10.4	7.3
7						7.7	8.9	5.9	7.4	5.6
8						6.2	6.1	6.7	5.5	3.2
9						3.3	5.0	4.9	6.3	2.4
10							4.2	4.3	4.2	1.9
11							2.4	3.7	3.6	1.4
12							1.6	3.2	3.2	1.0
13								2.4	2.5	
14								2.8	2.8	
15								1.6	2.1	
16								1.3	1.9	
17								1.0	1.4	
18								0.7	1.2	
19									1.1	
20									0.9	
21									0.6	
22									0.8	
23									0.5	
24									0.3	

TABLE B.4b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 4

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	3.6	9.1	12.5	19.0	33.9	31.4	20.0	35.8	33.4	37.1
2	24.2	32.3	30.0	28.5	20.1	19.1	37.8	19.3	19.0	19.9
3	17.2	21.7	20.0	11.9	8.2	11.9	12.7	12.4	12.2	0.3
4	10.0	13.5	8.7	8.4	12.3	8.2	3.1	4.4	0.9	0.0
5	13.1	6.5	4.7	4.7	5.9	6.0	1.0	1.5	0.1	0.0
6	7.2	4.8	6.3	3.8	4.6	4.7	0.3	0.1	0.0	2.4
7	5.7	3.7	3.8	3.0	3.5	2.2	0.2	0.1	0.0	8.6
8	4.5	2.8	3.0	6.2	2.0	0.9	0.5	0.3	0.2	6.2
9	3.0	2.2	2.5	2.5	1.3	0.4	0.7	0.2	0.1	0.4
10	2.5	1.6	2.0	2.1	1.6	0.3	1.3	0.7	0.7	0.1
11	2.0	1.1	1.7	1.8	0.9	0.3	1.7	1.2	3.5	0.9
12	1.7	0.7	1.1	1.1	0.2	0.2	2.3	0.9	0.6	3.4
13	1.4		1.4	1.5	2.7	0.1	5.9	3.4	4.4	12.3
14	1.1		0.8	1.3	0.7	0.1	8.3	6.1	6.2	4.6
15	1.0		0.6	0.9	0.5	0.2	4.2	8.6	8.5	0.2
16	0.8		0.4	0.8	1.1	0.8		2.5	1.8	0.6
17	0.6		0.3	0.6	0.4	0.5		2.0	0.4	1.8
18	0.4		0.2	0.5	0.1	0.6		0.5	0.3	1.2
19				0.4		1.3			0.1	
20				0.3		1.8			0.2	
21				0.3		1.5			1.1	
22				0.1		2.8			2.2	
23				0.2		3.6			2.7	
24				0.1		1.1			1.4	

ZONE 4

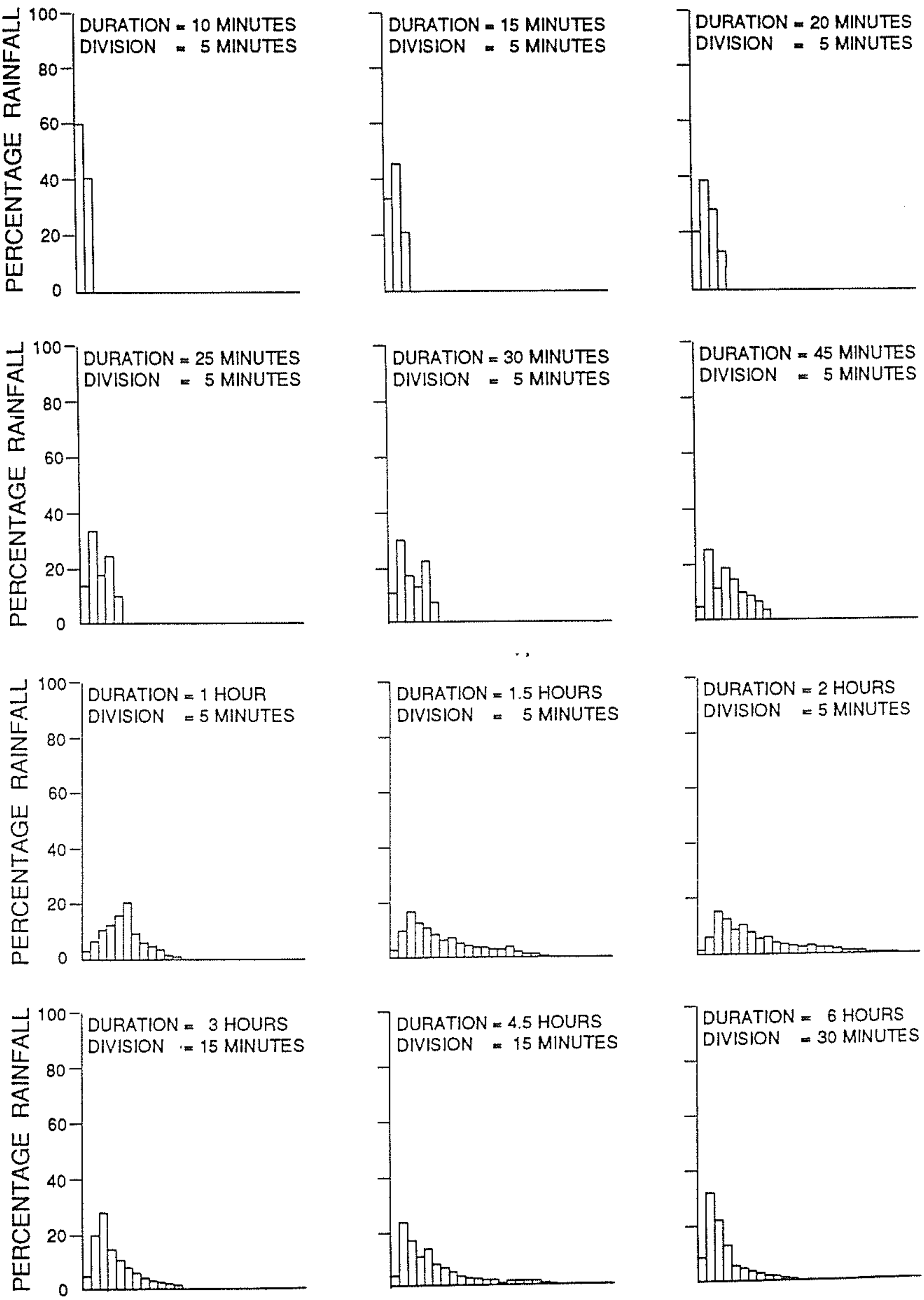

FIGURE B.7 **Mean Temporal Distributions for Zone 4**

ZONE 4

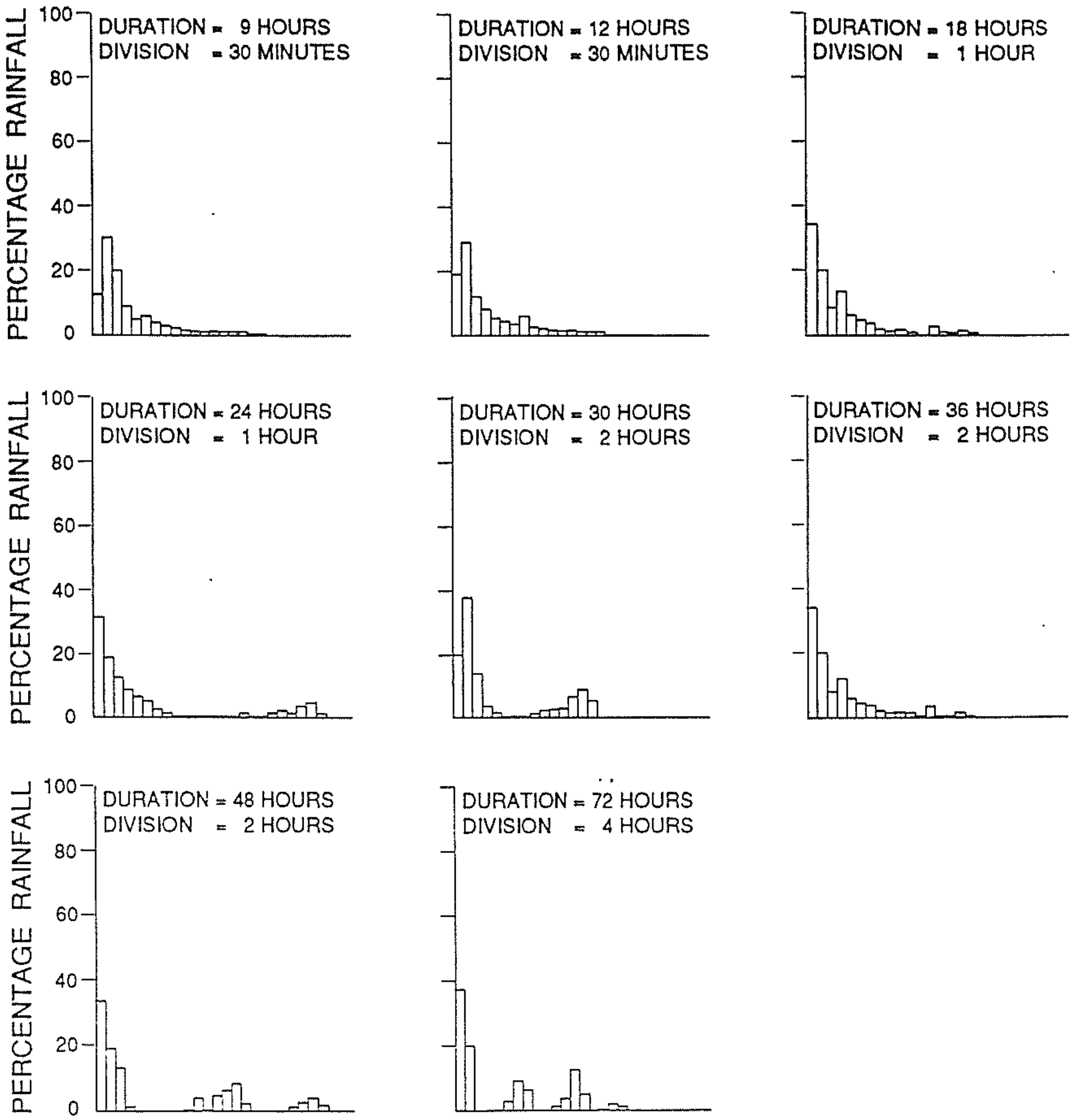

FIGURE B.8 Mean Temporal Distributions for Zone 4

TABLE B.5a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 5

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	42.1	20.9	19.6	12.6	8.7	5.3	3.4	6.7	2.3	6.8
2	57.9	45.0	29.7	34.5	24.7	14.9	8.4	24.2	7.1	30.0
3		34.1	38.4	26.8	31.6	25.9	18.0	18.0	17.0	20.1
4			12.3	18.1	17.0	20.5	22.5	11.8	13.6	13.3
5				8.0	12.4	11.3	14.4	8.7	11.0	9.2
6					5.6	8.6	11.4	5.4	8.9	5.4
7						6.7	6.4	4.5	5.8	4.3
8						4.0	5.2	3.8	5.0	3.4
9						2.8	4.2	3.2	4.3	2.7
10							2.7	2.3	3.7	2.1
11							2.1	2.7	3.3	1.6
12							1.3	1.7	2.9	1.1
13								1.2	2.5	
14								0.8	1.8	
15								1.0	2.0	
16								2.0	1.4	
17								1.4	1.3	
18								0.6	1.6	
19									1.1	
20									0.8	
21									1.0	
22									0.7	
23									0.5	
24									0.4	

TABLE B.5b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 5

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	3.8	12.8	19.2	18.2	34.7	33.5	39.3	38.0	36.0	43.8
2	23.8	33.3	32.4	30.7	18.6	18.6	20.8	20.6	19.9	22.0
3	16.8	20.1	11.6	11.3	11.6	6.1	12.6	12.9	12.9	12.4
4	12.4	8.9	8.1	5.8	8.3	11.9	8.2	8.2	8.3	8.0
5	9.4	6.7	5.9	7.9	6.2	8.3	5.7	5.7	5.9	4.9
6	5.6	5.1	4.7	4.6	4.7	4.7	4.0	4.1	4.3	3.2
7	4.6	3.9	3.7	3.8	2.8	3.5	2.9	3.0	3.2	2.0
8	7.0	3.0	3.0	3.1	3.6	2.7	2.1	2.2	2.5	0.9
9	3.2	1.8	2.5	2.6	2.3	2.2	1.5	1.2	1.8	1.4
10	2.3	2.4	1.1	2.2	1.5	1.4	1.1	1.6	1.4	0.6
11	2.0	1.2	0.9	1.5	1.8	1.7	0.7	0.8	0.8	0.3
12	2.7	0.8	1.6	1.8	1.1	1.2	0.5	0.6	1.0	0.2
13	1.7		1.4	0.8	0.9	0.9	0.2	0.4	0.6	0.1
14	1.4		2.1	1.3	0.7	0.8	0.3	0.3	0.4	0.1
15	1.2		0.7	0.6	0.5	0.2	0.1	0.1	0.3	0.1
16	0.9		0.4	0.9	0.4	0.1		0.2	0.1	0.0
17	0.7		0.5	0.4	0.2	0.6		0.1	0.1	0.0
18	0.5		0.2	0.5	0.1	0.5		0.0	0.2	0.0
19				1.1		0.4			0.2	
20				0.3		0.2			0.1	
21				0.2		0.1			0.0	
22				0.2		0.3			0.0	
23				0.1		0.1			0.0	
24				0.1		0.0			0.0	

ZONE 5

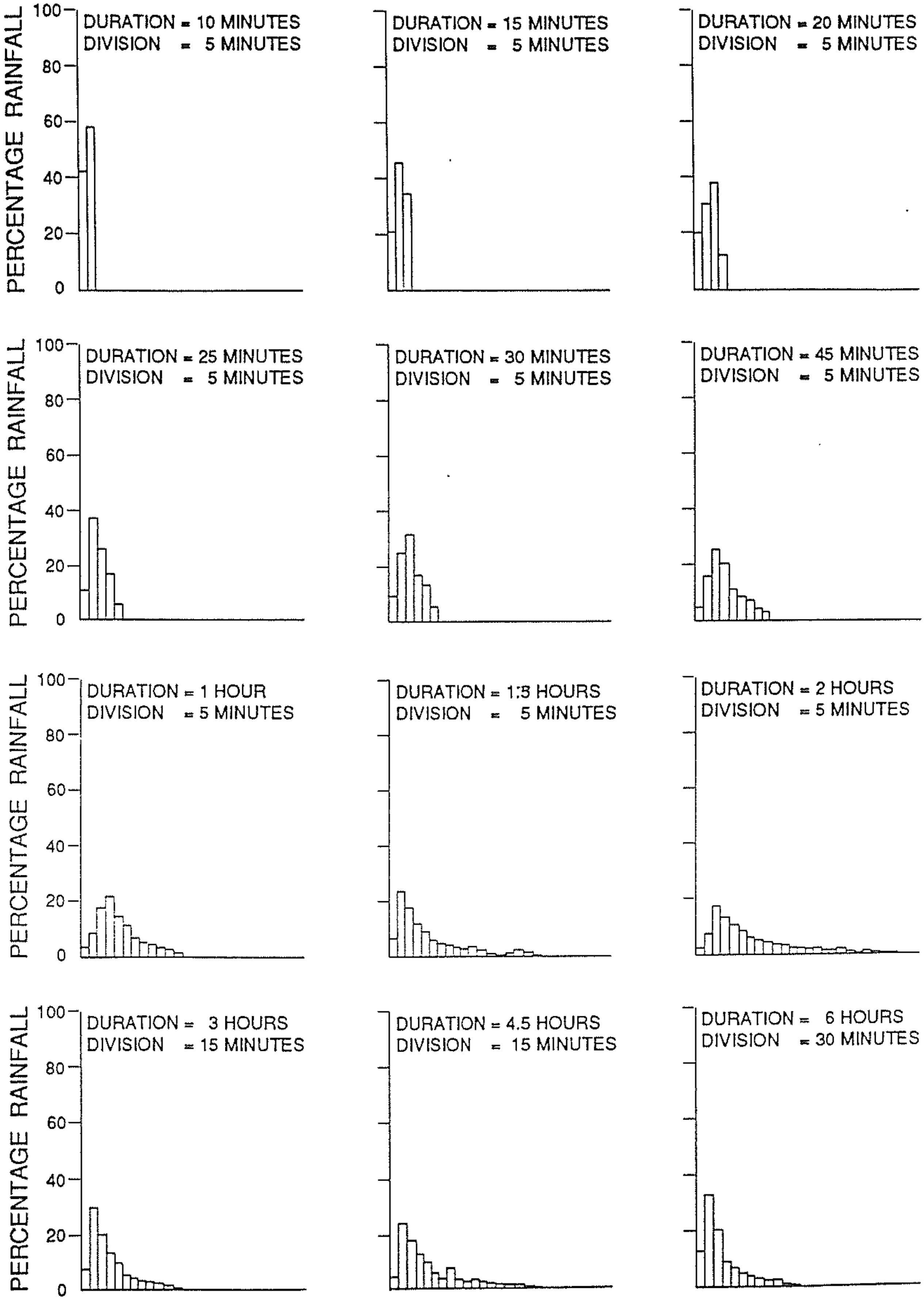

FIGURE B.9 Mean Temporal Distributions for Zone 5

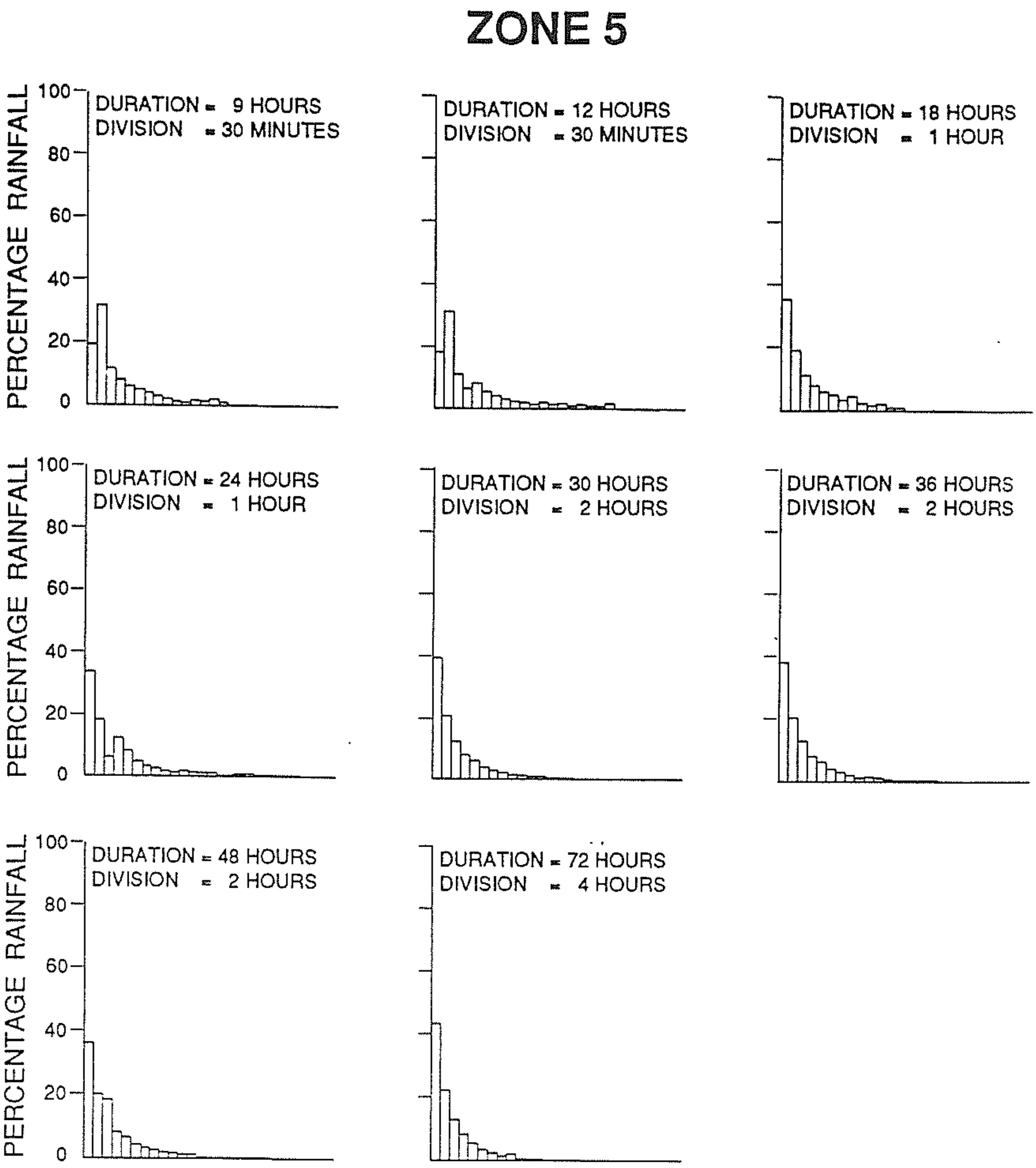

FIGURE B.10 Mean Temporal Distributions for Zone 5

TABLE B.6a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 6

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	39.0	32.6	18.7	12.3	8.9	4.5	2.9	3.2	1.7	6.1
2	61.0	47.8	41.3	37.0	32.9	9.1	13.4	3.5	16.3	27.2
3		19.6	28.3	25.5	23.7	25.6	17.3	5.2	12.4	18.2
4			11.7	17.5	16.7	18.7	23.6	7.2	5.8	12.6
5				7.7	12.3	14.8	10.9	19.5	3.5	9.5
6					5.5	11.7	8.2	8.8	8.4	7.5
7						7.5	6.6	11.1	6.9	5.0
8						5.4	5.4	14.4	9.9	4.2
9						2.7	4.4	6.0	5.1	3.4
10							3.7	2.8	2.8	2.8
11							2.2	4.0	3.2	2.1
12							1.4	4.6	4.0	1.4
13								2.4	4.5	
14								1.1	2.6	
15								1.4	1.9	
16								2.1	2.3	
17								1.8	1.3	
18								0.7	2.1	
19									1.5	
20									1.1	
21									0.9	
22									0.8	
23									0.6	
24									0.4	

TABLE B.6b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 6

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	1.8	4.2	7.0	8.3	7.4	15.2	13.4	12.9	16.9	34.0
2	21.6	7.8	25.7	23.4	25.9	24.1	30.7	29.4	27.5	19.0
3	14.9	27.2	5.7	4.0	12.2	9.0	18.7	18.1	12.3	12.8
4	5.2	17.4	11.3	10.5	16.2	11.6	7.4	9.6	9.2	9.1
5	7.1	12.5	16.1	14.9	4.1	5.9	9.8	7.2	7.1	6.6
6	8.7	9.8	8.9	6.7	3.3	7.2	5.5	4.3	5.6	3.7
7	11.0	6.4	4.8	5.5	9.5	4.9	4.1	5.5	2.8	4.9
8	3.9	5.2	4.0	4.7	4.9	4.1	2.3	3.3	4.5	2.8
9	4.5	3.5	2.4	3.5	6.0	3.4	3.1	2.5	3.5	1.5
10	6.0	2.7	1.6	2.6	2.7	2.8	1.7	2.0	2.3	2.1
11	3.4	2.0	3.4	2.2	2.1	1.9	1.2	1.5	1.8	0.6
12	2.2	1.3	1.1	1.4	1.7	1.6	0.9	1.1	0.9	1.1
13	2.9		2.0	1.9	1.0	2.3	0.6	0.6	1.5	0.8
14	2.5		2.9	3.0	1.3	1.3	0.4	0.9	1.2	0.2
15	1.5		0.8	1.6	1.0	0.7	0.2	0.3	0.5	0.3
16	1.2		1.3	1.2	0.5	1.1		0.5	0.7	0.0
17	0.9		0.6	1.0	0.4	0.9		0.2	0.6	0.4
18	0.7		0.4	0.9	0.2	0.6		0.1	0.3	0.1
19				0.6		0.4			0.3	
20				0.7		0.3			0.2	
21				0.5		0.3			0.1	
22				0.3		0.1			0.0	
23				0.4		0.1			0.1	
24				0.2		0.2			0.1	

ZONE 6

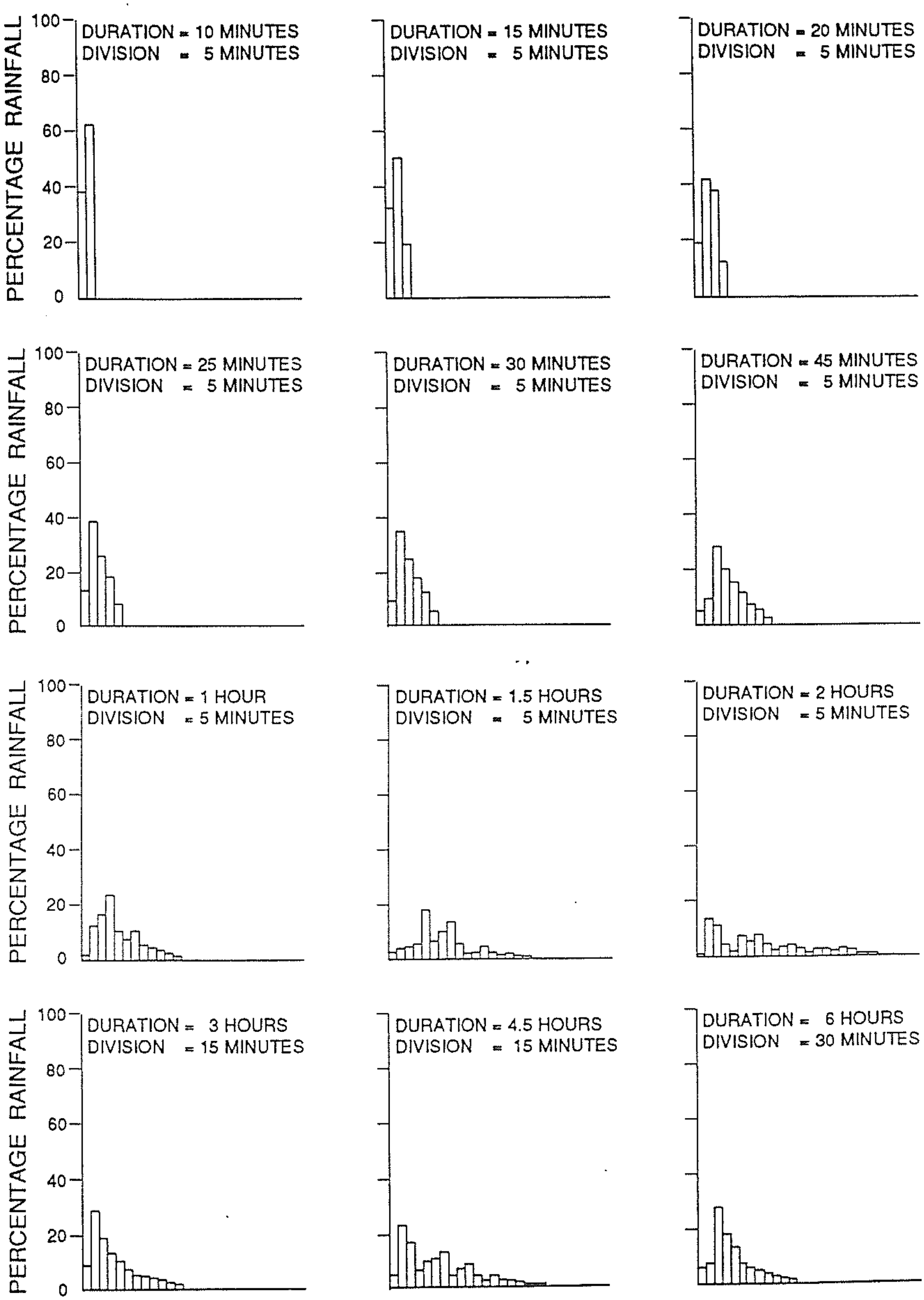

FIGURE B.11 Mean Temporal Distributions for Zone 6

ZONE 6

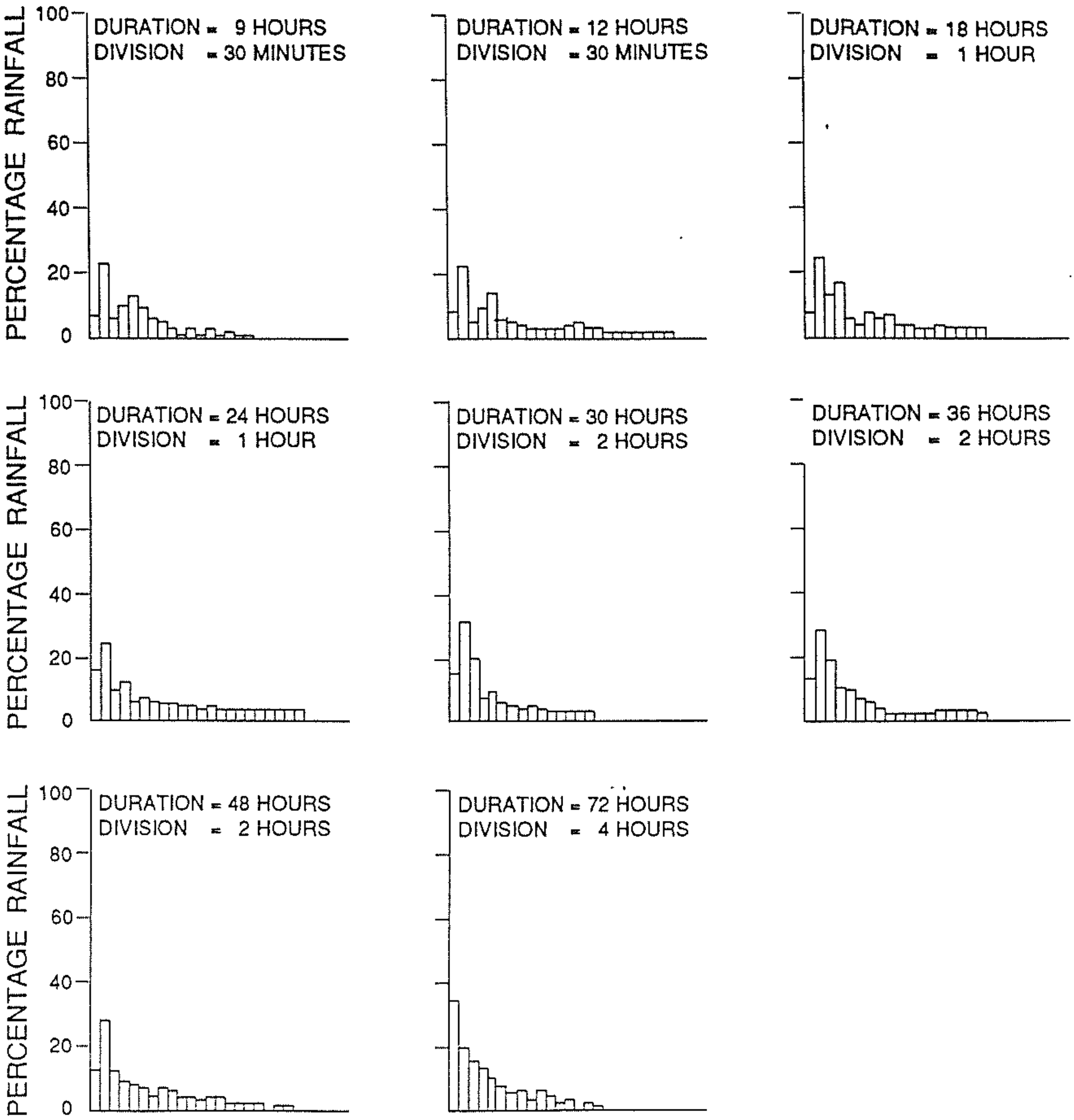

FIGURE B.12 **Mean Temporal Distributions for Zone 6**

<u>TABLE B.7a</u>

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 7

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	57.8	32.6	16.2	9.7	5.9	3.8	2.9	5.4	3.9	2.8
2	42.2	43.9	35.0	19.6	15.3	15.7	6.7	17.9	12.8	19.2
3		23.5	27.5	30.4	22.7	19.4	12.0	14.3	16.3	26.9
4			21.3	24.8	27.7	23.9	17.3	11.5	9.2	14.0
5				15.5	18.4	6.8	8.9	6.3	5.9	11.0
6					10.0	9.4	21.4	10.2	7.2	5.8
7						13.3	13.9	7.8	10.3	2.2
8						5.3	4.4	3.0	5.2	4.5
9						2.4	5.5	3.5	4.4	7.4
10							3.6	4.6	3.5	3.6
11							2.1	4.0	3.0	1.6
12							1.3	2.6	2.4	1.0
13								1.6	2.6	
14								1.0	2.1	
15								1.9	0.5	
16								1.4	0.9	
17								2.3	1.7	
18								0.7	1.4	
19									0.7	
20									1.2	
21									1.5	
22									1.9	
23									1.0	
24									0.4	

TABLE B.7b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 7

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	4.5	5.3	3.2	2.8	20.3	33.4	40.7	40.1	39.5	45.6
2	24.3	29.6	9.0	23.5	34.4	19.8	12.5	12.3	20.2	22.4
3	17.2	13.8	7.0	8.6	8.3	8.1	21.3	20.8	11.9	12.0
4	12.2	19.4	4.7	4.5	4.3	11.1	7.9	7.8	7.7	5.0
5	9.0	10.1	2.7	3.3	11.6	5.9	5.3	5.2	5.3	7.0
6	6.8	2.6	3.9	2.4	6.0	4.4	2.6	2.7	4.0	2.9
7	5.4	1.5	15.5	3.8	3.3	3.4	1.0	1.1	2.9	1.9
8	3.8	2.1	12.0	5.4	1.8	1.1	0.4	3.9	1.2	0.5
9	3.2	4.1	25.9	11.4	2.7	1.5	1.9	2.0	1.6	0.1
10	2.7	7.3	5.7	14.9	1.4	2.7	0.7	0.9	0.9	0.2
11	2.0	3.3	2.3	6.6	0.6	0.9	1.4	0.6	0.5	0.3
12	2.3	0.9	1.6	2.2	2.2	0.3	3.7	1.5	2.1	1.2
13	1.7		2.0	1.9	1.1	0.1	0.3	0.4	0.7	0.8
14	1.5		0.4	1.7	0.8	0.6	0.2	0.3	0.3	0.1
15	1.2		1.1	1.2	0.5	1.8	0.1	0.2	0.4	0.0
16	1.0		0.9	1.4	0.4	0.7		0.1	0.2	0.0
17	0.7		1.4	0.7	0.2	0.5		0.1	0.1	0.0
18	0.5		0.7	0.9	0.1	0.1		0.0	0.2	0.0
19				1.1		0.2			0.2	
20				0.4		0.4			0.0	
21				0.2		0.2			0.0	
22				0.6		0.6			0.0	
23				0.4		2.2			0.1	
24				0.1		0.0			0.0	

ZONE 7

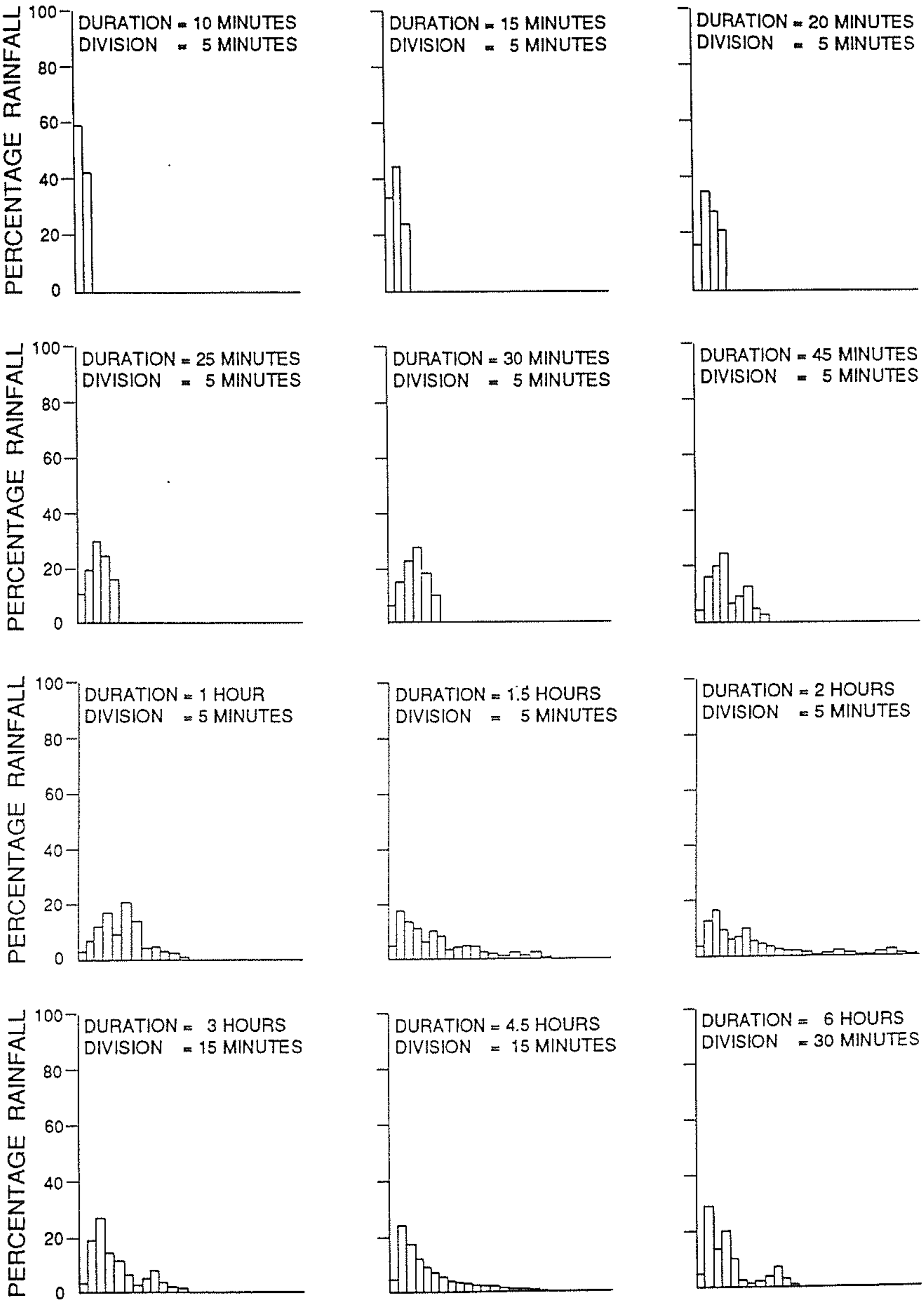

FIGURE B.13 Mean Temporal Distributions for Zone 7

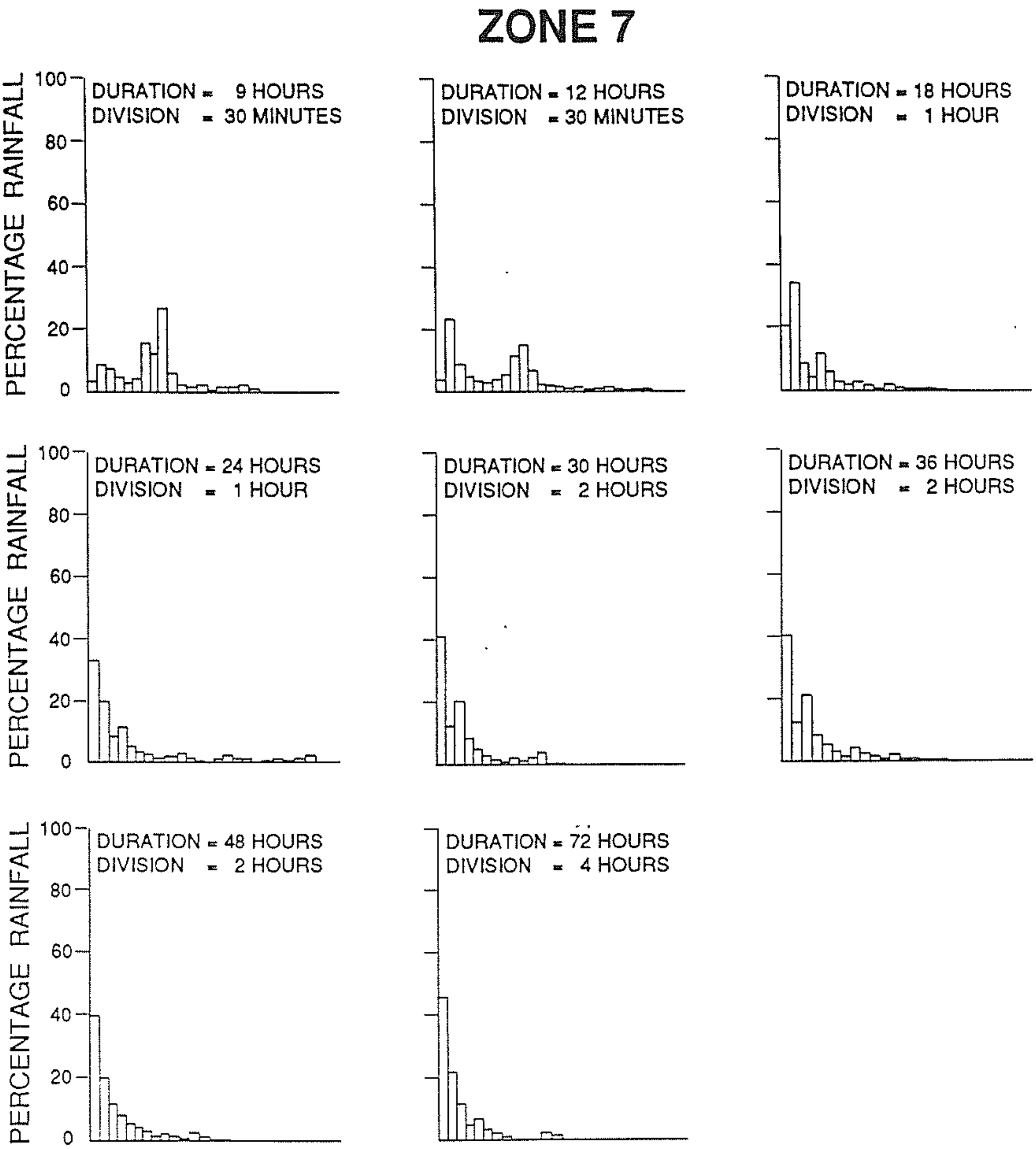

FIGURE B.14 **Mean Temporal Distributions for Zone 7**

TABLE B.8a

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 8

PERIOD	DURATION (minutes)									
	10	**15**	**20**	**25**	**30**	**45**	**60**	**90**	**120**	**180**
1	37.8	31.2	18.9	12.3	8.6	4.9	2.2	5.5	1.2	12.8
2	62.2	48.6	41.4	24.6	16.8	11.0	5.7	18.7	17.0	29.2
3		20.2	27.8	37.4	34.0	19.6	8.5	13.8	9.9	9.4
4			11.9	17.5	23.0	28.9	13.1	11.1	8.2	4.9
5				8.2	11.9	14.8	23.5	7.4	5.8	6.0
6					5.7	8.4	10.7	6.4	6.7	18.3
7						6.5	16.7	9.1	12.4	7.4
8						3.5	7.0	2.4	5.0	3.9
9						2.4	4.5	3.6	2.1	2.4
10							3.7	4.1	1.8	3.0
11							2.9	3.1	3.1	1.7
12							1.5	2.7	2.8	1.0
13								4.8	1.7	
14								1.5	1.3	
15								1.2	2.3	
16								2.0	2.6	
17								1.8	3.9	
18								0.8	3.5	
19									4.4	
20									1.5	
21									1.0	
22									0.8	
23									0.6	
24									0.4	

TABLE B.8b

MEAN TEMPORAL DISTRIBUTION WITHIN RAINFALL BURSTS FOR VARIOUS DURATIONS – ZONE 8

PERIOD	DURATION (hours)									
	4.5	**6.0**	**9.0**	**12.0**	**18.0**	**24.0**	**30.0**	**36.0**	**48.0**	**72.0**
1	7.5	10.1	16.7	15.6	12.0	27.0	13.3	16.9	29.1	33.7
2	22.6	18.3	11.8	27.5	28.4	15.7	31.1	12.6	16.4	17.9
3	14.6	5.8	29.6	10.8	16.6	11.3	18.3	29.2	11.7	12.4
4	9.4	30.3	6.9	6.7	4.7	8.6	9.6	9.4	8.6	8.8
5	11.6	13.3	8.8	8.4	9.3	4.6	7.4	7.3	6.9	5.1
6	3.7	7.5	5.6	5.5	3.1	6.9	4.1	5.6	5.4	6.6
7	2.8	3.6	4.5	3.7	7.4	3.8	5.6	3.6	4.3	2.4
8	5.2	4.6	3.6	4.4	5.9	5.6	3.1	4.4	2.9	4.0
9	6.1	2.6	3.0	3.2	1.9	2.7	0.6	1.0	0.5	1.0
10	3.2	1.8	1.5	1.1	2.4	3.2	0.9	0.3	0.6	1.4
11	2.4	1.3	1.2	1.3	3.8	2.2	1.8	1.3	1.6	1.8
12	0.6	0.8	0.9	0.9	1.4	1.8	0.4	1.8	0.8	0.0
13	0.9		2.3	2.6	0.8	1.5	1.3	2.9	0.3	0.3
14	1.5		0.5	2.2	1.1	1.2	2.4	2.2	3.6	0.1
15	1.9		0.7	1.8	0.5	1.0	0.1	0.5	1.0	0.2
16	4.4		1.9	1.5	0.4	0.8		0.1	1.9	3.1
17	1.2		0.3	0.7	0.2	0.6		0.7	0.4	0.7
18	0.4		0.2	0.4	0.1	0.2		0.2	1.3	0.5
19				0.1		0.5			0.2	
20				0.6		0.0			2.3	
21				0.5		0.1			0.1	
22				0.2		0.4			0.0	
23				0.2		0.1			0.1	
24				0.1		0.2			0.0	

ZONE 8

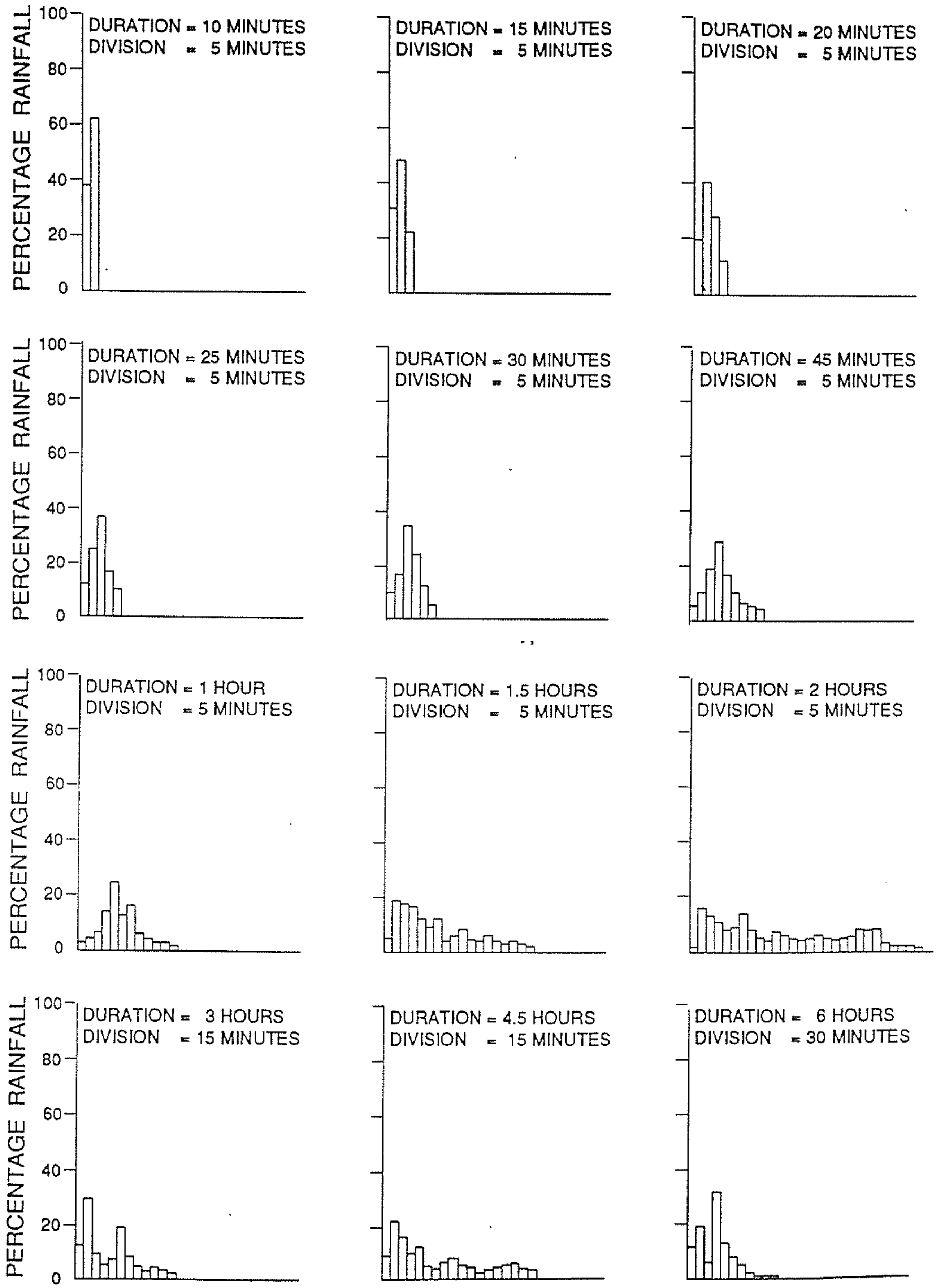

FIGURE B.15 **Mean Temporal Distributions for Zone 8**

ZONE 8

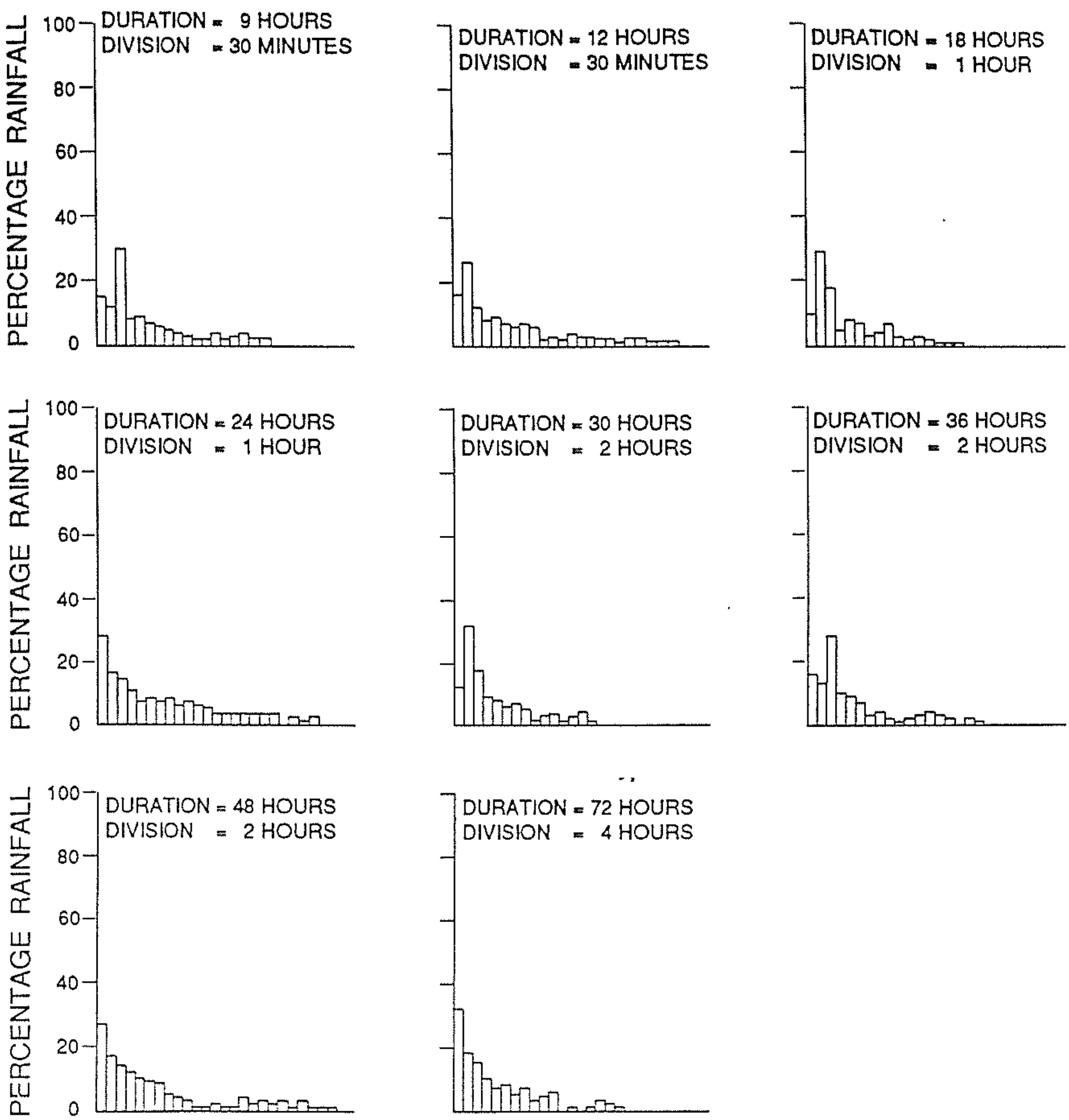

FIGURE B.16 Mean Temporal Distributions for Zone 8

APPENDIX C

TEMPORAL DISTRIBUTIONS FROM HIGHEST 5 PER CENT OF THE STORM SAMPLES

TEMPORAL DISTRIBUTIONS FROM HIGHEST 5 PER CENT OF THE STORM SAMPLES

As part of the Temporal Distribution project, investigations were originally carried out for the top 15 and 5 per cent of the samples, to obtain patterns for 3 ranges of ARI between 1 and 100 years. However, it was found during the course of the study that the small samples for the upper 5 per cent and the effects of filtering the patterns (Section 8) resulted in the patterns not being required for ARR87. The results from this work are included here as assistance for any future work.

An example of the ratios obtained from the highest 5 per cent of the sample is given in Table C.1 for Zone 1. This corresponds to Table 5 in Section 6. The average of the ratios for ranks 1,2...k was calculated for each rank number and those for Zone 1 are shown in Table C.2 and Figure C.1. Smooth curves were fitted to these points and are given in Figures C.2 and C.3

TABLE C.1

RATIO OF PERCENTAGES DERIVED FROM 5 PER CENT OF SAMPLE TO FULL SAMPLE PERCENTAGES (ZONE 1)

Pattern	Ratio for Rank Number: 1	2	3	4	5	6	7	8	9	10	11	12
12x5 mins	0.940	1.037	0.954	1.000	1.000	0.969	1.019	1.024	1.118	1.143	1.190	1.133
12x15	0.875	0.932	0.907	1.021	1.041	1.212	1.256	1.217	1.225	1.280	1.300	1.357
12x30	0.841	0.959	1.072	1.042	1.039	1.016	1.036	1.130	1.179	1.219	1.240	1.167
Means	0.885	0.976	0.978	1.021	1.027	1.066	1.104	1.124	1.174	1.214	1.243	1.219
18x5	0.835	0.906	1.985	1.060	1.092	1.000	1.063	1.135	1.233	1.261	1.353	1.385
18x15	1.067	1.014	1.056	0.953	0.943	0.900	0.923	0.935	0.951	1.000	1.000	1.000
18x30	0.886	0.934	1.019	1.000	0.972	0.984	1.019	1.042	1.071	1.081	1.091	1.069
18x60	0.729	0.871	0.972	1.023	1.027	1.000	1.073	1.063	1.095	1.162	1.219	1.250
18x120	0.796	0.823	0.942	1.000	1.038	1.063	1.077	1.136	1.222	1.233	1.240	1.300
18x240	0.917	0.955	0.714	1.012	1.042	1.017	1.039	1.045	1.105	1.118	1.138	1.080
Means	0.872	0.917	0.948	1.008	1.019	0.944	1.032	1.059	1.113	1.143	1.174	1.181
24x5	0.782	0.887	0.850	0.922	1.000	1.036	1.104	1.119	1.162	1.176	1.233	1.259
24x30	0.902	0.932	0.979	0.961	0.939	0.948	1.000	1.022	1.024	1.026	1.091	1.067
24x60	0.872	0.909	0.968	0.988	0.971	0.967	1.000	0.979	1.024	1.054	1.061	1.103
24x120	0.814	0.778	0.865	0.944	0.987	1.016	1.075	1.156	1.158	1.188	1.214	1.261
24x240	0.817	0.882	0.944	1.031	1.135	1.133	1.122	1.150	1.281	1.231	1.238	1.294
Means	0.837	0.878	0.921	0.969	1.006	1.020	1.060	1.085	1.130	1.135	1.167	1.197

Pattern	Ratio for Rank Number: 13	14	15	16	17	18	19	20	21	22	23	24
18x5 mins	1.444	1.667	1.750	1.667	1.500	1.000						
18x15	1.000	1.000	1.000	1.000	1.077	1.000						
18x30	1.077	1.136	1.158	1.77	1.250	1.222						
18x60	1.333	1.350	1.500	1.538	1.600	1.571						
18x120	1.438	1.667	1.889	2.000	2.200	2.000						
18x240	1.001	1.105	1.059	0.929	0.900	0.857						
Means	1.231	1.321	1.393	1.387	1.421	1.275						
24x5	1.200	1.273	1.250	1.58	1.176	1.200	1.143	1.230	1.300	1.222	1.143	1.500
24x30	1.037	1.040	1.136	1.100	1.111	1.125	1.214	1.250	1.300	1.500	1.667	1.500
24x60	1.115	1.125	1.190	1.222	1.188	1.143	1.167	1.300	1.375	1.286	1.400	1.333
24x120	1.300	1.438	1.538	1.727	1.778	2.000	2.000	1.800	2.333	2.500	4.000	2.000
24x240	1.308	1.300	1.375	1.333	1.500	1.333	1.000	1.000	1.000	1.000	1.000	1.000
Means	1.192	1.235	1.298	1.308	1.351	1.360	1.305	1.320	1.462	1.502	1.583	2.053

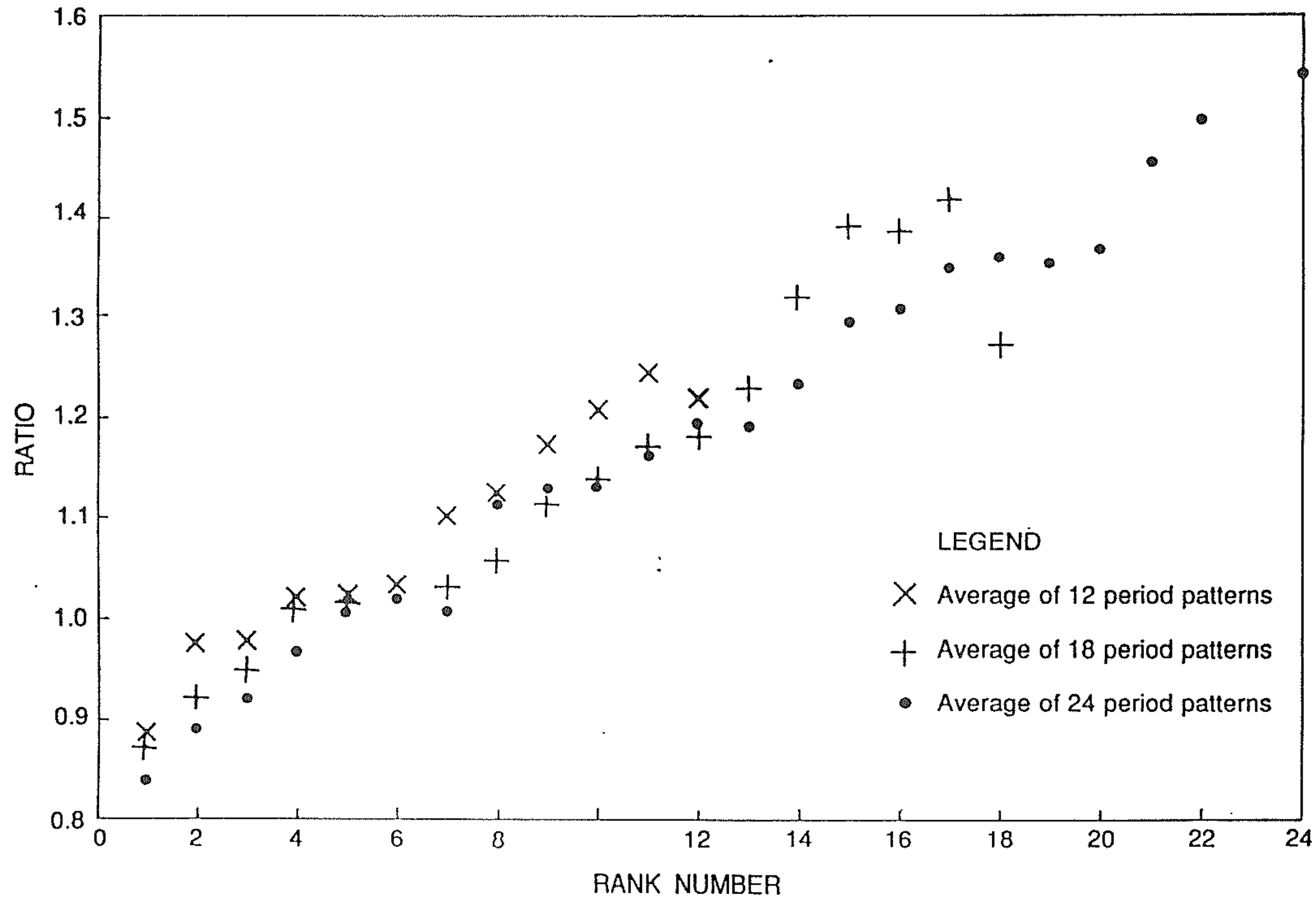

FIGURE C.1 Ratio of Percentages of Each Rank Derived from the Highest 5 per cent of Sample to Percentages from Full Sample (Zone 1)

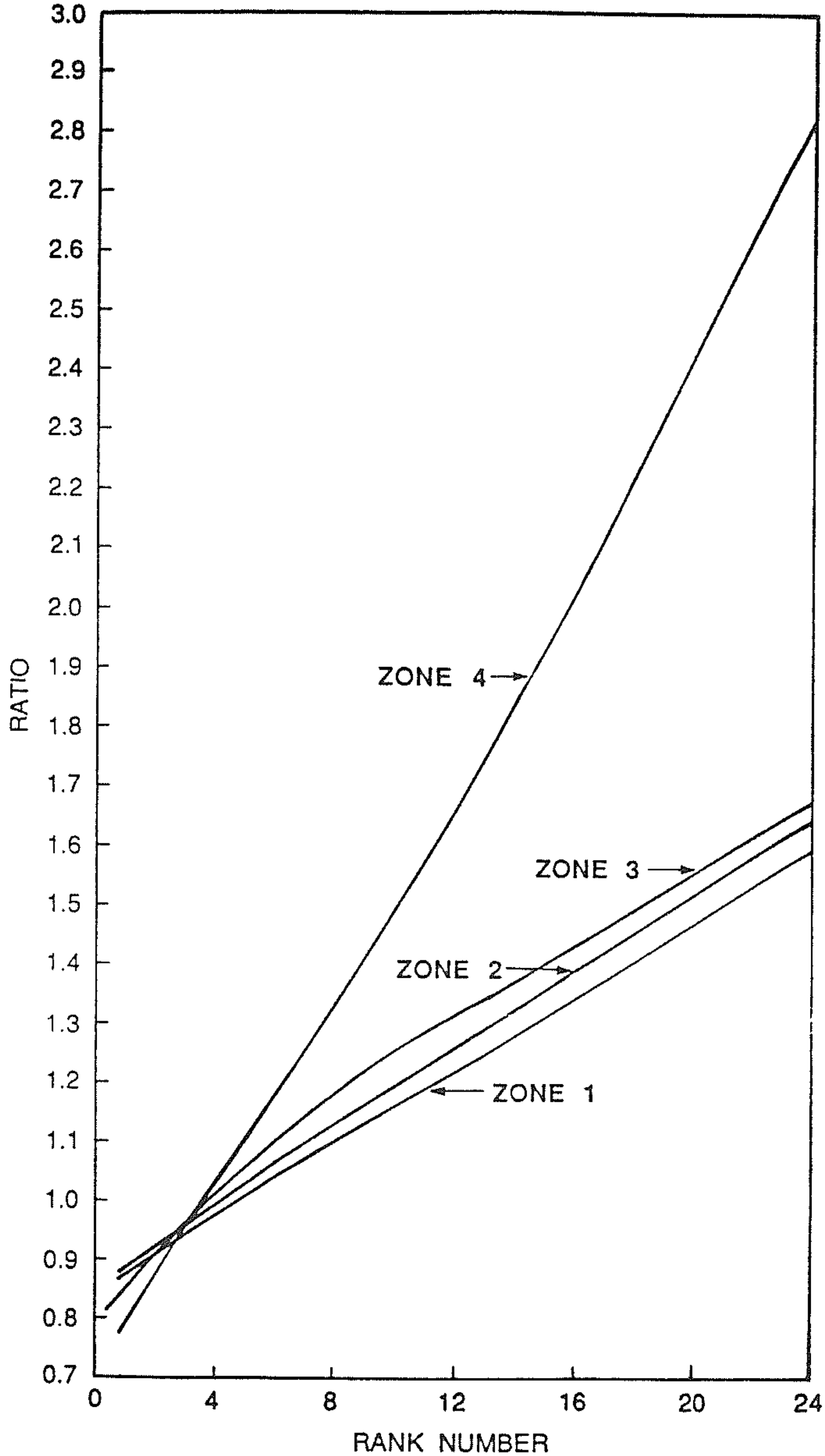

FIGURE C.2 Curves Drawn to the Ratios of the Percentages of Each Rank Derived from 5 per cent of the Sample to the Full Sample Percentages for Zones 1 to 4

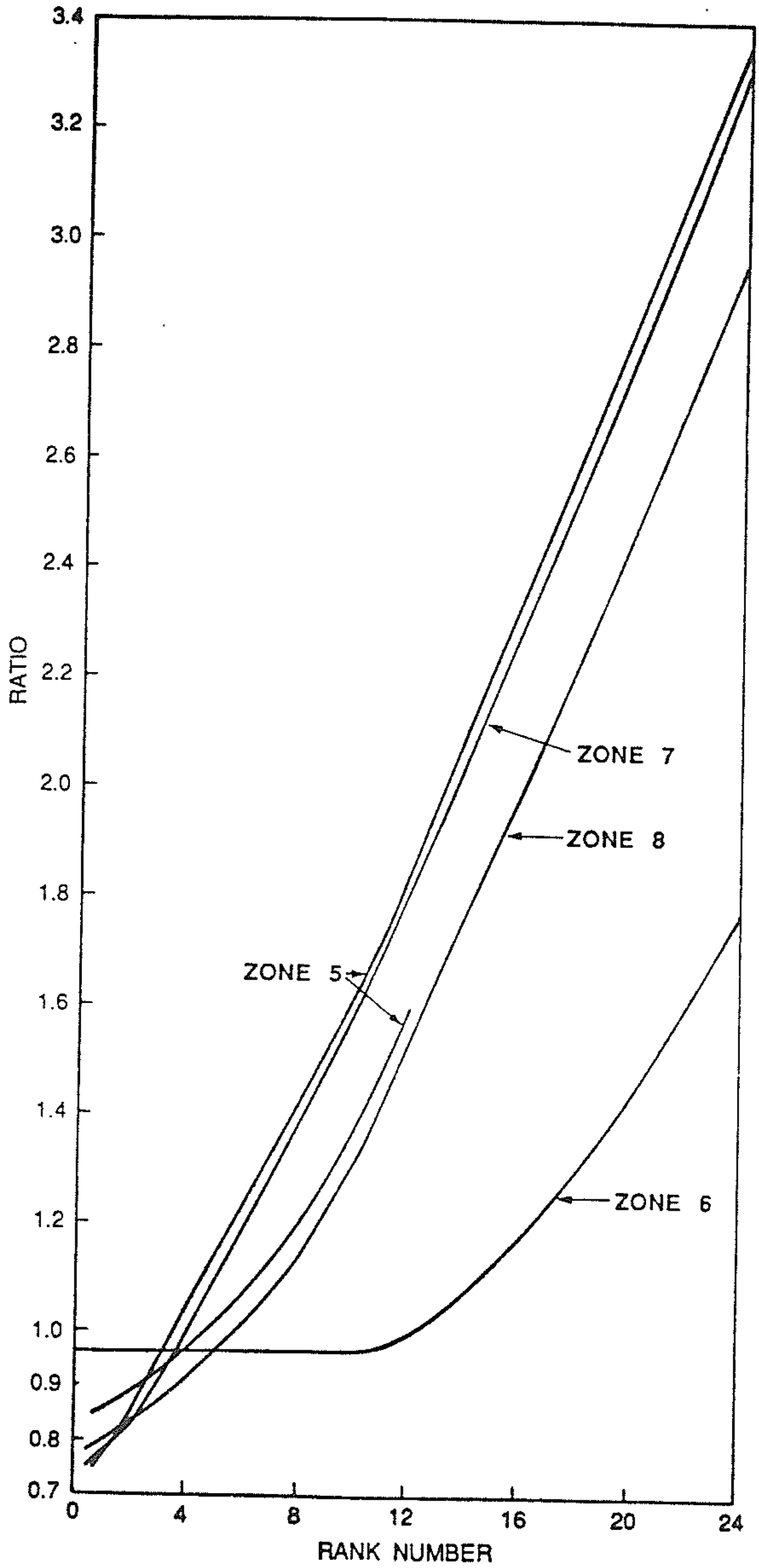

FIGURE C.3 Curves Drawn to the Ratios of the Percentages of Each Rank Derived from 5 per cent of the Sample to the Full Sample Percentages for Zones 5 to 8

<u>TABLE C.2</u>

RATIOS FOR DERIVING DISTRIBUTIONS FOR THE HIGHEST 5 PER CENT OF THE SAMPLES FROM THE MEAN DISTRIBUTIONS

RANK	ZONES 1	2	3	4	5	5*	6	7	8
1	0.88	0.89	0.86	0.79	0.77	0.86	0.97	0.78	0.80
2	0.92	0.93	0.91	0.88	0.85	0.89	0.97	0.85	0.83
3	0.95	0.97	0.97	0.96	0.95	0.93	0.97	0.93	0.88
4	0.99	1.00	1.02	1.04	1.05	0.97	0.97	1.02	0.93
5	1.02	1.03	1.06	1.12	1.15	1.02	0.97	1.11	0.98
6	1.05	1.07	1.11	1.19	1.25	1.08	0.97	1.20	1.04
7	1.08	1.10	1.14	1.26	1.34	1.14	0.97	1.30	1.11
8	1.10	1.13	1.18	1.33	1.43	1.21	0.97	1.40	1.19
9	1.13	1.16	1.21	1.41	1.53	1.29	0.97	1.50	1.27
10	1.17	1.20	1.24	1.49	1.63	1.36	0.97	1.60	1.35
11	1.20	1.23	1.27	1.57	1.74	1.48	0.98	1.70	1.45
12	1.23	1.26	1.31	1.67	1.85	1.60	1.00	1.81	1.55
13	1.27	1.30	1.34	1.75	1.97		1.03	1.92	1.65
14	1.29	1.33	1.37	1.85	2.10		1.07	2.03	1.76
15	1.32	1.36	1.40	1.94	2.22		1.12	2.16	1.87
16	1.35	1.39	1.43	2.03	2.35		1.18	2.28	1.99
17	1.38	1.43	1.47	2.13	2.48		1.23	2.41	2.11
18	1.41	1.46	1.50	2.23	2.60		1.29	2.54	2.23
19	1.44	1.49	1.53	2.33	2.73		1.36	2.67	2.35
20	1.47	1.52	1.56	2.43	2.86		1.44	2.80	2.47
21	1.51	1.55	1.59	2.53	2.99		1.52	2.93	2.60
22	1.54	1.58	1.62	2.63	3.12		1.60	3.06	2.73
23	1.57	1.61	1.65	2.73	3.25		1.69	3.19	2.86
24	1.60	1.65	1.67	2.83	3.38		1.78	3.32	2.99

NOTE : * ZONE 5 ONLY HAS SEPARATE RATIOS FOR DURATIONS OF 12 DIVISIONS. FOR OTHER ZONES 12, 18 AND 24 DIVISIONS HAVE COINCIDENT RATIOS.