COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

A MODEL FOR DISAGGREGATING DAILY TO HOURLY RAINFALLS FOR DESIGN FLOOD ESTIMATION

TECHNICAL REPORT
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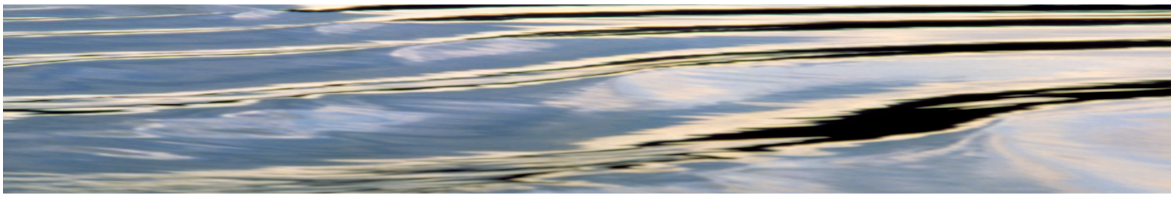
Walter Boughton



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Preface

The CRC Project FL1 'Holistic approach to rainfall-based design flood estimation', as its name suggests, investigated new ways to estimate design floods. The currently recommended procedure in Australia uses average values for the important input variables (eg rainfall intensity and temporal pattern, initial and continuous losses), rather than treating them as continuous variables which can interact one with another.

Project FL1 considered two approaches to incorporate parameter variability and interaction. The first evaluated the joint probability of key flood producing components to evaluate the probability distribution of the resultant design flood. The second used continuous rainfall-runoff modelling to produce long-synthetic sequences of runoff statistics. The latter included the development of a stochastic model to generate daily rainfalls.

This report addresses the task of producing 'appropriate' patterns of hourly rainfalls for the generated daily values, a process termed 'disaggregation'. For this, Walter Boughton has developed a procedure that has been applied to 28 Victorian pluviometer stations, and obtained good results for that region. Some additional testing of the methodology with a wider data set is underway, but we seek involvement and feedback from others to broaden experience of its application.

I commend it to you, and thank Dr Boughton for his continuing contributions to the profession through the CRC.

Russell Mein
Director
Leader, Flood Program (1992-1999)

Abstract

Data from almost 800 station years of pluviometer records at 28 stations across Victoria were analysed to develop a daily to hourly rainfall disaggregation model. The data were selected in 9 am to 9 am daily blocks of 24 hourly values to match the periods of daily rainfall records. Only data with the highest quality code were used to exclude accumulated, interpolated or estimated data, and only daily totals ≥ 15 mm were used to develop the disaggregation model.

The amount of rain in the hour of maximum rainfall in each day was expressed as a ratio R of the hourly rain to the daily total, i.e. the fraction of the daily total in the hour of maximum rain. A value of R = 1.0 means all rain fell in a single hour. A value of R = 0.04167 (1/24th of the daily total) means completely uniform rain through the day. The distribution of R is a major characteristic of hourly rainfalls and a major parameter in the disaggregation model.

Values of R were grouped into 20 ranges between 0.04167 and 1.0. The distribution of R was determined for each of the 28 pluviometer stations. These were so similar that an average distribution of R using all data was derived and used as the basis of the disaggregation model.

For each range of R, the average values of the other 23 fractions of the daily total were determined (using all data), and these were clustered to maintain the averages of the maximum 2-hour total in each range, and the maximum 3-hour, 6-hour and 12-hour totals in each range. The times of day when the hour of maximum rain occurred appeared to be equally spread throughout the day, so 24 temporal patterns were developed to arrange the clustered sequences of hourly fractions into daily temporal patterns. This gave a total of 20 ranges of R (which vary the rainfall from completely uniform to all in one hour) times 24 patterns of occurrence of the time of maximum rainfall, equals 480 different temporal patterns of the disaggregated hourly rainfalls.

In practice, a random number is used to select a range from the 20 ranges of R. This fixes the other 23 fractions of the daily total and their clustering pattern. A second random number selects the time of day of the maximum rainfall, and this fully determines the temporal pattern of the 24 hourly fractions of the daily total being disaggregated.

The disaggregation model was coupled with a daily rainfall generation model to generate thousands of years of daily rainfalls, from which values ≥ 15.0 mm/day were disaggregated. Annual maxima distributions of 1, 2, 3, 6, 12 and 24 hours were extracted and compared with IFD rainfall statistics from the pluviometer records and from ARR87. The model was tested with 5 pluviometer stations covering most of the region of data from Mildura in the north west to East Sale in south east Victoria, and including the Melbourne Regional Office. The results showed that a single disaggregation model using only daily rainfall input can adequately reproduce the IFD statistics of the region.

Abbreviations used in the report

ARR87 1987 edition of "Australian Rainfall and Runoff"

IFD Intensity-frequency-duration

ARI Average recurrence interval – years

1 Introduction

1.1 Background

Daily rainfall records are an abundant data base throughout most of Australia, but to date have been of little use in design flood estimation which needs sub-daily data. While it is not possible to determine the hourly rainfalls which made up an actual daily reading of a rain gauge, hourly temporal patterns can be stochastically generated by a disaggregation model which retain the daily total and the statistical characteristics of hourly rainfalls at the gauge site.

In an earlier report (Boughton, 2000), the writer presented two models for disaggregating 9 am to 9 am daily rainfalls to hourly values for design flood estimation. The Continuous Simulation System for Design Flood Estimation, which was developed as part of the FL1 flood hydrology research program at the CRC for Catchment Hydrology, uses a daily rainfall generation model to generate very long sequences of daily rainfalls and a disaggregation model to disaggregate the larger daily rainfalls to hourly values. The system, which has been developed to the stage of practical application (Boughton, 1999, Boughton et al, 1999), uses a disaggregation model based on the short duration rainfall statistics in Australian Rainfall and Runoff (Pilgrim, 1987), because the area covered by those data allows the model to be used anywhere in Australia.

The second disaggregation model was based on analysis of pluviometer records and consequently is superior in reproducing hourly rainfall statistics. The development and testing of this model were limited because only 2 pluviometer records were analysed to demonstrate the validity of the model. There was an obvious need for further testing. This report describes a much larger study using a substantial database of pluviometer records.

The FL1 flood hydrology research program included a Joint Probability study (Rahman et al, 1998, Hoang et al, 1999). As part of this program, pluviometer data from 28 stations in Victoria were prepared as hourly values. These data were made available for further testing of the disaggregation model. I am grateful to Tam Hoang for her work in preparing the data, and to Erwin Weinmann for his effort in making the data available for use.

1.2 Outline of the report

This report describes the further development and testing of the daily to hourly rainfall disaggregation model based on analysis of pluviometer records. The data are described in Section 2. A description of the disaggregation model is given in Section 3, and the results of testing of the model are documented in Section 4. The Conclusion in Section 5 contains some comments on the aspects of the study where further work would be beneficial.

1.3 Scope of the report

There are some aspects of the model that could produce problems if the model were used for inappropriate applications. The model disaggregates daily rainfalls as independent values without consideration of day to day continuity of multi-day storms. This might cause problems if the model were applied to large catchments where multi-day storms were the dominant flood producing rainfall. There is a need for further study of multi-day disaggregation. In addition, the model is based on rainfalls with daily totals ≥ 15 mm, which are the larger daily rainfalls of importance in flood studies, hence the model is not suitable for disaggregating small (< 15 mm) daily rainfalls.

All of the data used in the development of the disaggregation model are from Victoria. At the time of this writing, there is no information available to indicate in what other areas the model can be reliably used.

Finally, it is repeated that the model does not attempt to reproduce the actual hourly rainfalls that formed an actual daily total of rain except in the calibrating and testing procedures in this report. The disaggregation model is intended to be used in design flood estimation procedures, particularly in combination with a daily rainfall generation model. The major results in Section 4 "Tests of the model" show a direct comparison with the rainfall IFD statistics in ARR87.

2 Data used in the study

2.1 Description of the data

The 28 pluviometer stations from which records were used in the study are listed in Table 1. The locations of the stations are shown in Figure 1. The records varied in length from 14 years to 125 years, the latter at Melbourne Regional Office.

The data were initially prepared as hourly data and checked for homogeneity by Tam Hoang (see Hoang et al, 1999). For the present study, the data were selected as 9 am to 9 am daily blocks of 24 hourly values in order that the disaggregation model would be directly applicable for use in disaggregating daily read rainfalls.

Table 1 Pluviometer records used in the Study

Station identification		Latitude			Longitude			Period of record
No.	Name	d	m	s	d	m	s	
76031	Mildura Airport AMO	34	14	24	142	05	06	Apr 1953 – Oct 1993
79052	Rocklands Reservoir	37	13	53	141	57	34	Jan 1955 – Oct 1993
79082	Horsham SR&WSC	36	42	14	142	12	02	Jan 1958 – Dec 1991
79086	Avon No 3	36	51	57	143	07	09	Jan 1973 – Dec 1991
80067	Charlton Soil Conservation	36	16	11	143	20	46	Jan 1951 – Dec 1993
81003	Bendigo Prison	36	45	12	144	16	57	Jan 1968 – Dec 1991
81038	Natte Yallock	36	56	30	143	27	46	Jan 1974 – Dec 1991
84005	Buchan Post Office	37	30	00	148	10	18	Oct 1962 – Dec 1980
84015	Ensay Composite	37	21	45	147	50	15	Jan 1981 – Dec 1993
85000	Aberfeldy	37	42	00	146	22	00	Oct 1969 – Aug 1984
85026	Erica State Forest	37	58	30	146	23	24	Jan 1959 – Dec 1975
85034	Glenmaggie Weir SR&WSC	37	54	36	146	48	12	Dec 1957 – Nov 1993
85072	East Sale AMO	38	06	30	147	07	49	May 1953 – Dec 1991
85103	Yallourn	38	11	09	146	19	54	Jan 1956 – Jan 1972
85106	Olsens Bridge	38	29	10	146	19	26	Jan 1957 – Jan 1979
85170	Traralgon LVW&SB	38	13	16	146	31	24	Jan 1961 – Dec 1975
85176	Tanjil Bren Post Office	37	49	42	146	10	48	Jun 1957 – Dec 1979
85236	Callignee North	38	19	36	146	34	12	Jan 1961 – Dec 1975
85237	Noojee English HMSD	37	53	00	146	00	00	Jan 1959 – Jan 1981
85240	Ellinbank	38	14	28	145	55	38	Aug 1961 – Sep 1995
85256	Barkley River	37	30	45	146	32	52	Apr 1974 – Nov 1993
86038	Essendon Airport AMO	37	44	00	144	54	00	Feb 1951 – Nov 1986
86071	Melbourne Regional Office	37	48	33	144	57	57	Apr 1873 – Jul 1997
86142	Mount St Leonard	37	34	18	145	30	06	Jan 1954 – Dec 1982
86219	Coranderrk	37	41	24	145	34	36	Dec 1955 – Jan 1978
86224	Dandenong Composite	38	00	32	145	11	48	Jan 1965 – Dec 1991
86234	Croydon South	37	47	10	145	17	06	Apr 1965 – Oct 1991
86314	Koo Wee Rup SR&WSC	38	12	02	145	29	31	Jan 1957 – Dec 1991

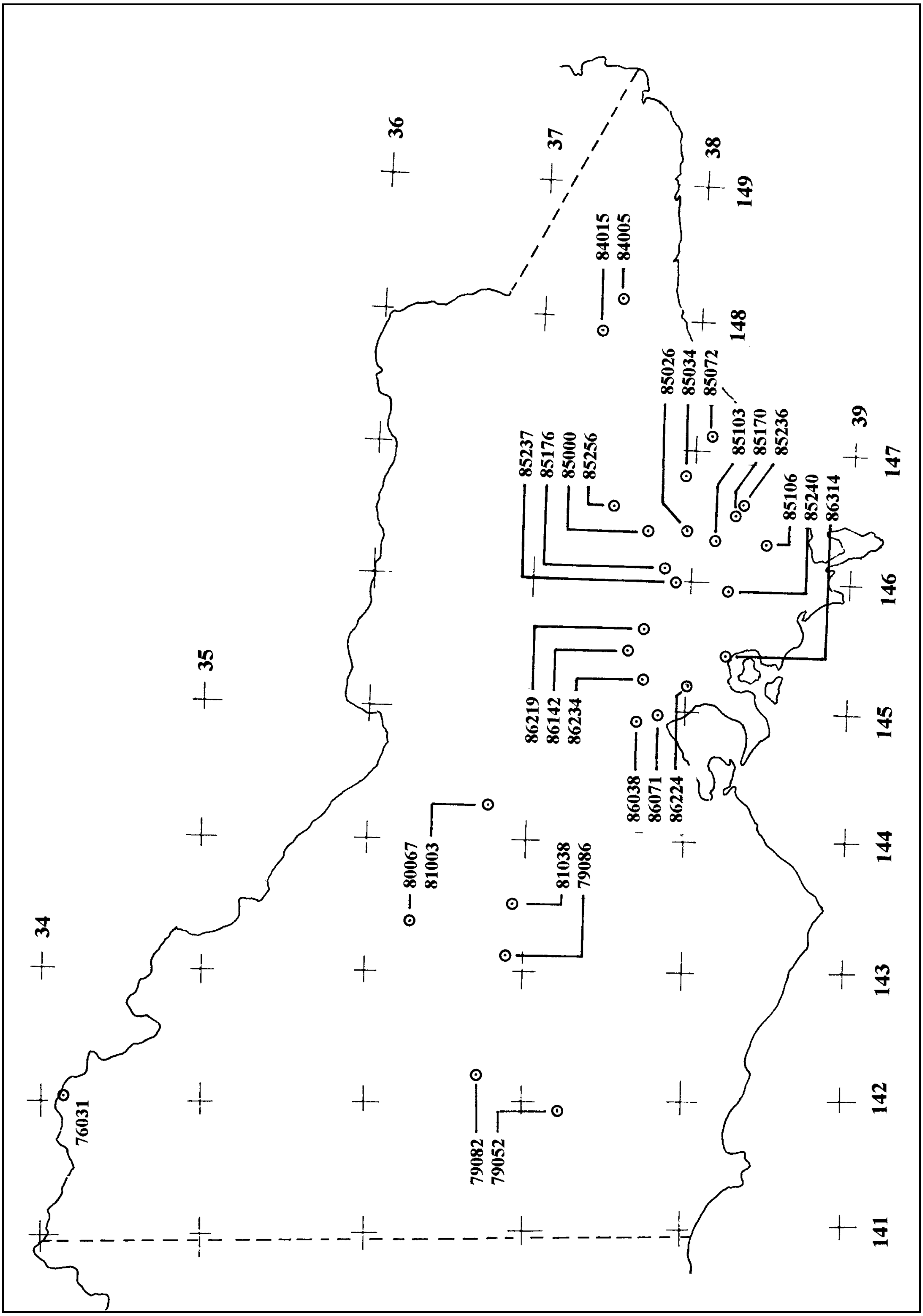

Figure 1 Locations of pluviometer stations

2.2 Selection of data

There are substantial differences in the hourly temporal patterns between small and large daily rainfalls. In particular, it is common that all rainfall can occur in a single hour when the daily total is small, whereas this is not a common pattern with large daily totals. The purpose of the present study is to disaggregate the larger daily rainfalls that are important in flood studies, hence it was essential to avoid the bias that would be introduced from the much more abundant small daily rainfalls. For this reason, only daily rainfalls ≥ 15 mm were used to develop the disaggregation model. The first processing of the data was to select only those days with ≥ 15 mm rainfall. The choice of 15 mm as the threshold value was influenced by the daily rainfall generation model in which rainfalls ≥ 15 mm form the upper class for generation purposes – see Boughton (1999).

The second selection criterion was to avoid estimated data or days where the hourly values had been estimated from a daily total. The second step was to select only those days with quality code "1" thus eliminating any estimated data or accumulated data or interpolated data. If any hour in a day had a quality code that was not "1" the day was discarded.

The number of days available for analysis varied among the 28 pluviometer records from the highest of 921 days at Melbourne Regional Office to the lowest of 98 days at Natte Yallock. It is noted that the model treats each day as an independent event for disaggregation, so the selection of days for analysis did not depend on whole months or whole years meeting the criteria.

3 Description of the disaggregation model

3.1 Structure of the model

The model consists of 4 parts:

(i) the primary part of the model is the distribution of the fraction R of the daily total that occurs in the hour of maximum rainfall

(ii) for each value of R, there is an average set of values for the other 23 fractions of the daily total

(iii) given the 24 hourly fractions from 1. and 2., the values are clustered to maintain the average values of the highest 2-hour, 3-hour, 6-hour and 12-hour fractions.

(iv) the clusters are then arranged into random patterns, which reproduce the variations in 9 am to 9 am daily temporal patterns while retaining all of the statistics of hourly rainfalls used in parts 1. to 3. above.

In application, a random number is used to select a value of the fraction R of the daily total that occurs in the hour of maximum rain. R is the ratio of the highest hourly rainfall to the daily total. The selection of R is made from the distribution of R, which is derived from the pluviometer records. This value of R automatically determines the other 23 fractions based on the average sets of values derived from the pluviometer records, and the clusterings required to maintain the average multi-hour fractions. The 24 fractions are multiplied by the daily total to give the hourly rainfalls, which are then arranged into a daily temporal pattern.

3.2 Distribution of R

The fraction R of the daily rainfall that occurs in the hour of maximum rain has a distribution of values that is a major characteristic of sub-daily rainfall statistics. A value of R = 1.0 means that all rainfall fell in a single hour and is the boundary of non-uniformity of rainfall during a day. Completely uniform rainfall during a day would have 0.04167 of the daily total in every hour. This is the lower bound of R.

Figure 2.a shows a typical distribution of R, using 9 am to 9 am rainfall blocks with totals ≥15mm from the pluviometer records at the Melbourne Regional Office of the Bureau of Meteorology (station 86071). The distribution is based on 921 days of data in the period 1873 to 1997. The values of R were collated into 20 ranges – 0.0417 to 0.075, 0.075 to 0.125, 0.125 to 0.175, etc. to 0.975 to 1.000 (see Appendix A for further details). The distribution shows the proportion of all values in each of the ranges. There is a characteristic peak about R = 0.200 and the tails stretching to the upper and lower limits. The average of all values is R = 0.321 at this station.

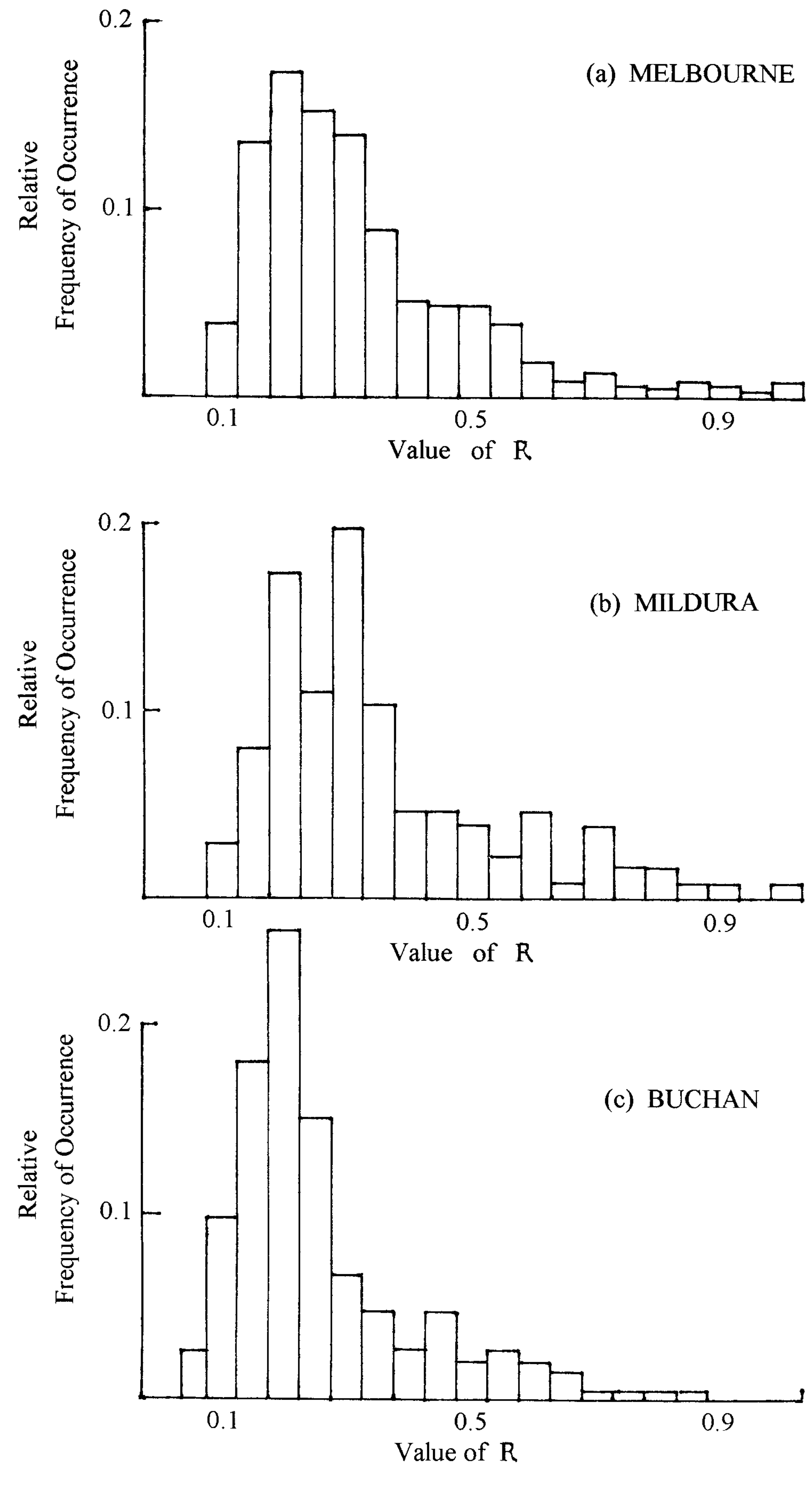

Figure 2 Distributions of R at three pluviometer stations

Figures 2.b and 2.c show the corresponding distributions of R for two other stations – Mildura Airport (76031) in the north west of Victoria, and Buchan Post Office (84005) in the southeast. These latter stations represent the geographic limits of stations in the database with Melbourne Regional Office about the middle. Mildura has a shorter record than Melbourne and shows more irregularity in the distribution, but all 3 distributions are very similar in overall shape. Mildura has a slight tendency towards higher values (average R = 0.353) while Buchan has a slight tendency towards lower values and more uniform rain (average R = 0.259). It is emphasised that the distributions show fractions of the daily totals in the hour of maximum rain and are not values of rainfall.

Appendix A contains the distributions of R at each of the 28 stations in the data set. The average distribution of R, based on pooling data from all 28 stations is shown in Table 2. Each of the individual distributions of R shows the variability of daily rainfalls from uniform to very non-uniform. This variability is relatively constant over all of the data sets.

In application, a random number is used to select a value of R from the distribution shown in Table 2. This fixes the fraction of the daily total (which is being disaggregated) that occurs in the hour of maximum rainfall. The following section describes how the other 23 hourly values are determined.

3.3 Ranked series of 24 hourly fractions of the daily total

If the fraction R of the daily total in the hour of maximum rain is 1.0, then all other 23 fractions must be zero. If the rainfall is completely uniform, then all 24 fractions will be 1/24 of the daily total.

If the fraction R is just a little less than 1.0, then it is highly likely that the rest of the daily rainfall will occur in one or two of the other hours while the other 22 or 23 hours will have zero rainfalls. If the fraction R is just a little larger than 0.04167, then the other 23 values will be slightly less than but close to 0.04167. The significance of these comments is that the fraction R in the hour of maximum rainfall has a strong influence on the values in the other 23 hours.

After the average distribution of R was established (Table 2 and Appendix A), the data from the 28 stations were processed to find the other 23 fractions of the daily total for each value of R. All 24 hourly fractions were ranked in order of magnitude (with R as the largest), and the ranked series were averaged in each of the 20 ranges of R shown in Table 2. Appendix B shows the averaged ranked series of hourly fractions for each range of R using data from all 28 stations. Figure 3 shows 3 of the averaged ranked series of fractions of the daily totals.

Table 2 Average Distribution of R based on 28 stations

Range of R	Percent in Range	Range of R	Percent in Range
0.042-0.075	1.6%	0.525-0.575	2.0%
0.075-0.125	6.3%	0.575-0.625	1.5%
0.125-0.175	17.5%	0.625-0.675	0.9%
0.175-0.225	19.9%	0.675-0.725	1.0%
0.225-0.275	15.4%	0.725-0.775	0.7%
0.275-0.325	11.8%	0.775-0.825	0.5%
0.325-0.375	7.7%	0.825-0.875	0.5%
0.375-0.425	5.3%	0.875-0.925	0.4%
0.425-0.475	4.0%	0.925-0.975	0.2%
0.475-0.525	2.5%	0.975-1.000	0.4%

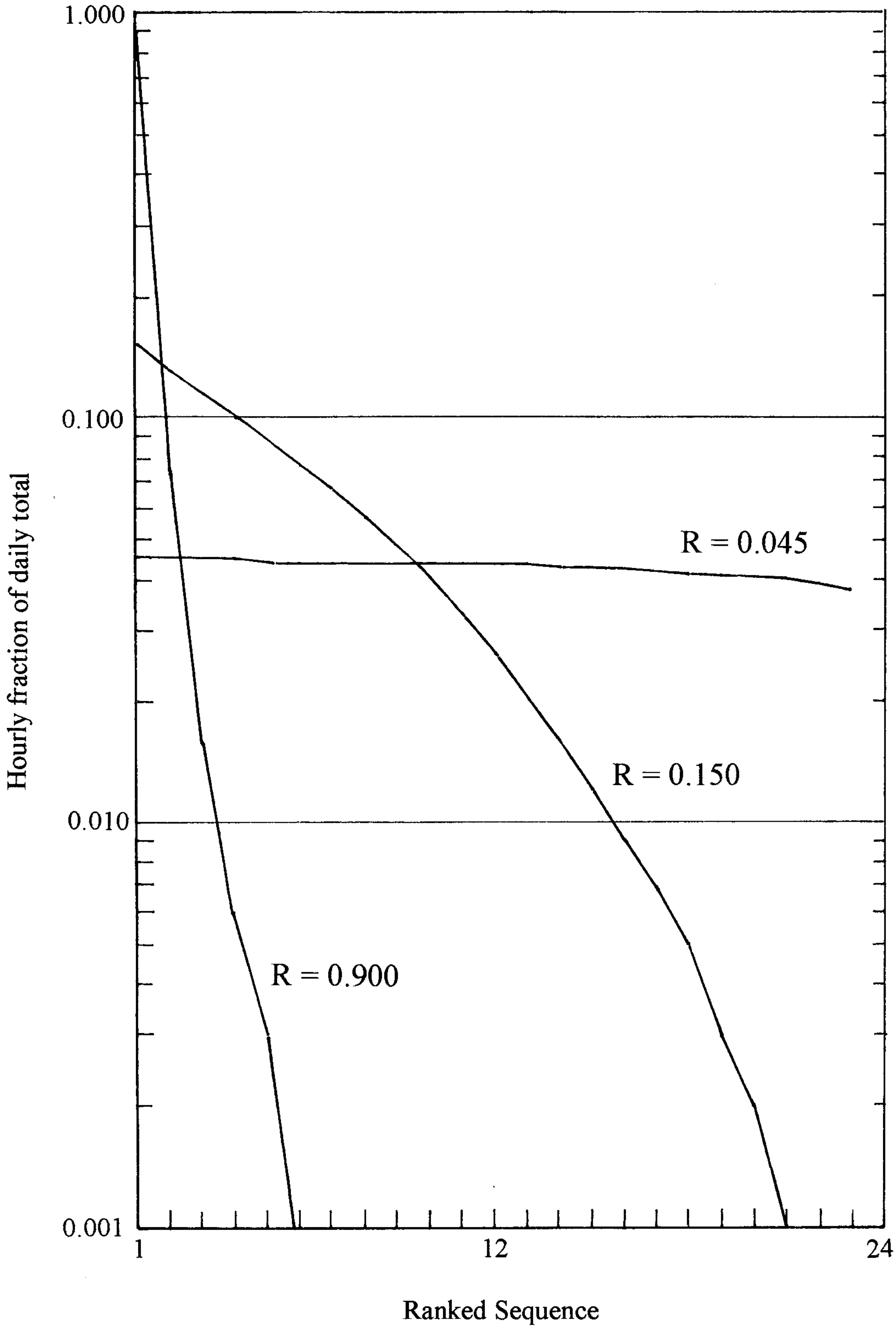

Figure 3 Average ranked series of fractions of the daily total

The averaged series in Appendix B form the second step in the development of the disaggregation model. The third part of the disaggregation model, which is to arrange the values into a daily temporal pattern, is described in the following sections, and is documented in Appendix C.

3.4 Clustering of larger hourly rainfalls

To provide the needed information on clustering, the data from all 28 stations were again processed to find the highest 2-hour fraction of the daily total, the highest 3-hour fraction, the highest 6-hour fraction, and the highest 12-hour fraction. All of these fractions were averaged for the range of R in which the data occurred. This provided an average 2-hour fraction for each range of R, an average 3-hour fraction, an average 6-hour and an average 12-hour fraction for each range of R.

A computer program was used to find the appropriate values from the ranked series in Appendix B. For the first range of R (0.04167 to 0.075), the program checked the sum of the first value in the ranked series with each of the other 23 to find which of the 23 gave the best match with the average 2-hour fraction for that range. After fixing that value as the value to accompany the first value for the highest 2-hour fraction, the program checked for the next value to accompany these two to form the highest 3-hour fraction. This was followed by finding the next 3 values to form the highest 6-hour fraction, and then finding the next 6 values to form the highest 12-hour fraction.

Using the numerals "1" for the highest fraction (i.e. R), "2" for the fraction that accompanies "1" to form the 2-hour fraction, "3" for the fraction that accompanies "1" and "2" to form the 3-hour fraction, etc., the clustered values are shown in Appendix C for each of the 20 ranges of R. These data in Appendix C form the main part of the disaggregation model. A random number is used to select a range of R. Appendix C then provides the other 23 fractions clustered in the correct sequence to maintain the highest 2-hour fraction, the highest 3-hour, 6-hour and 12-hour fractions.

The clustered fractions in Appendix C are ranked in sequences "1", "2", etc. which put the highest fraction first, then next fraction which forms the highest 2-hour when paired with the highest fraction, then the next fraction which forms the highest 3-hour, etc. The following section describes how these clustered sequences are randomly arranged to reproduce the natural variations in 9 am to 9am daily temporal patterns.

3.5 Daily temporal patterns of hourly rainfalls

There is no dominant or common temporal pattern of rainfall within the 9 am to 9 am blocks that can be used as a single pattern in the manner suggested in ARR87. The temporal patterns show a very wide range from nearly uniform to highly variable rainfall, as shown by the frequency distributions of R. There is also no pattern in the times when high or low rain occurs.

The times of day when the highest rainfall occurred were determined for each of the 28 stations. Table 3 shows the results for the Melbourne Regional Office (station 86071). The values shown are percentages of the total that occurred in each of the 24 hours of the day.

The values in Table 3 suggest that a random selection for the time of peak rainfall together with the clusterings shown in Section 3.4 can provide an appropriate variability of the temporal patterns of hourly rainfalls within the limits of the daily total and the statistics of hourly rainfalls set out in 3.1 to 3.4 above. The approach used with the disaggregation model is to reproduce the variability of temporal patterns rather than try to average or select a single pattern for use.

Table 3 - Hour of Day of Highest Hourly Rainfall Melbourne Regional Office

Hour	% in hour	Hour	% in hour	Hour	% in hour	Hour	% in hour
1	3.7	7	5.3	13	4.9	19	4.0
2	2.9	8	4.7	14	2.6	20	3.9
3	4.6	9	5.0	15	4.2	21	3.7
4	4.2	10	4.9	16	4.3	22	3.5
5	5.3	11	5.5	17	5.2	23	2.1
6	4.7	12	4.2	18	3.4	24	3.1

Table 4 shows 24 arrangements of the clustered sequences from Appendix C which can be used to allow for the peak hourly rainfall to occur in any hour of the day. When combined with the distribution of R, which allows for variation between uniform and non-uniform rainfall, these arrangements provide 24 x 20 = 480 different temporal patterns with variation between uniform and very non-uniform rainfall. Figure 4 shows a sample of the 480 different temporal patterns that the disaggregation model produces.

Table 4 – 24 Samples of Temporal Arrangements of the Hourly Rainfalls

Sample	Sequence																							
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	2	1	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
3	3	2	1	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
4	6	5	4	1	2	3	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	6	5	4	2	1	3	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6	6	5	4	3	2	1	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
7	9	8	7	6	5	4	1	2	3	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
8	9	8	7	6	5	4	2	1	3	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
9	9	8	7	6	5	4	3	2	1	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10	12	11	10	9	8	7	6	5	4	1	2	3	13	14	15	16	17	18	19	20	21	22	23	24
11	12	11	10	9	8	7	6	5	4	2	1	3	13	14	15	16	17	18	19	20	21	22	23	24
12	12	11	10	9	8	7	6	5	4	3	2	1	13	14	15	16	17	18	19	20	21	22	23	24
13	15	14	13	12	11	10	9	8	7	6	5	4	1	2	3	16	17	18	19	20	21	22	23	24
14	15	14	13	12	11	10	9	8	7	6	5	4	2	1	3	16	17	18	19	20	21	22	23	24
15	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	16	17	18	19	20	21	22	23	24
16	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	1	2	3	19	20	21	22	23	24
17	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	2	1	3	19	20	21	22	23	24
18	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	19	20	21	22	23	24
19	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	1	2	3	22	23	24
20	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	2	1	3	22	23	24
21	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	22	23	24
22	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	1	2	3
23	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	2	1	3
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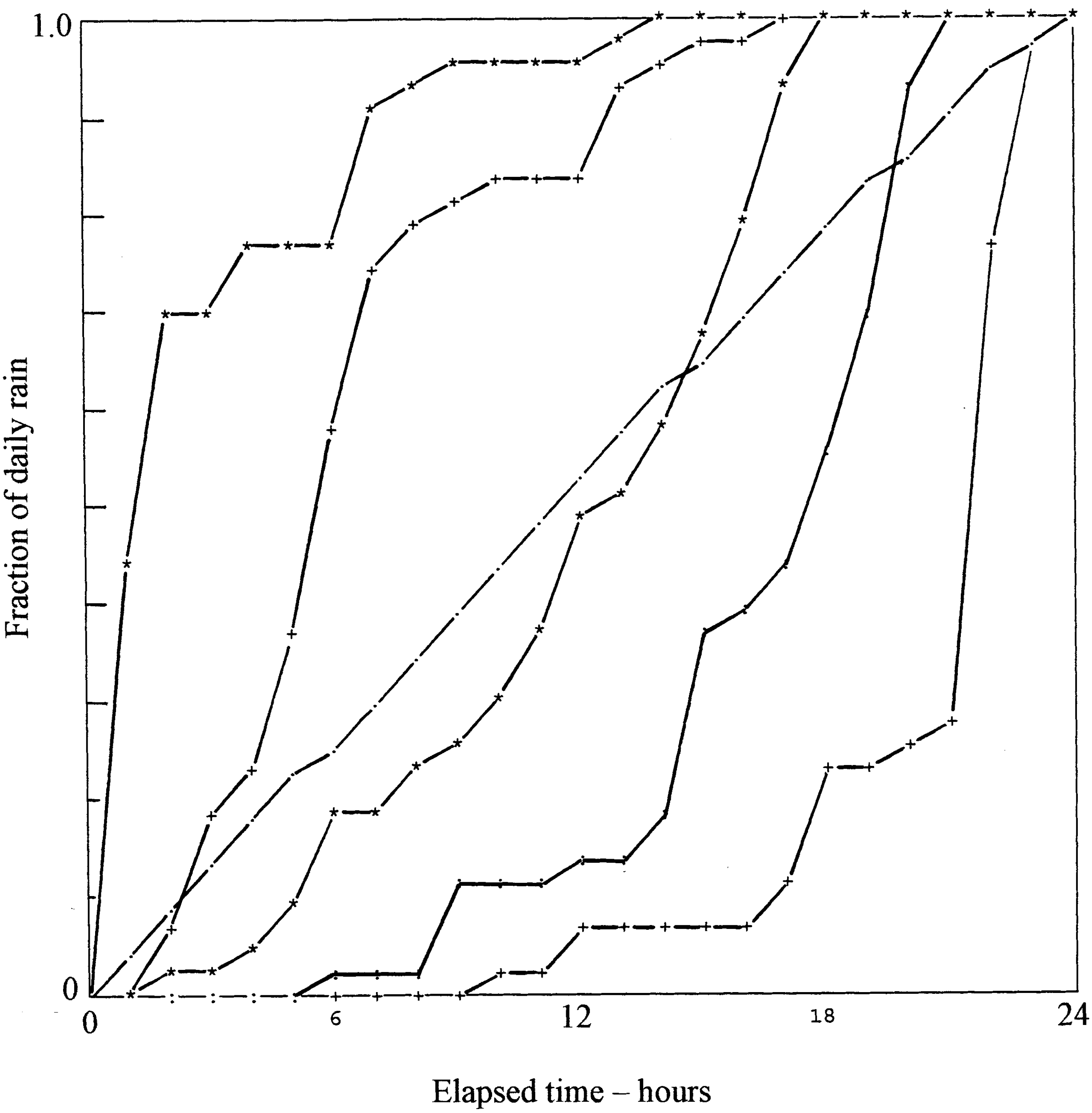


Figure 4 Examples of the 480 different temporal patterns which are randomly selected by the disaggregation model

3.6 Summary of the disaggregation model

In application, a random number is used to select a range of R from the 20 ranges – see Table 2. This selection fixes all 24 fractions of the daily total and the clusterings, which form the 2, 3, 6 and 12-hour sub-totals - see Appendix C. A second random number is then used to select from the 24 temporal arrangements in Table 4. The fractions are multiplied by the daily rainfall to give the disaggregated temporal pattern of hourly rainfalls.

It should be noted that the disaggregation procedure is fully automatic and does not involve manual lookup of tables. Tables 2 and 4 and Appendix C are incorporated into the computer program of the model, and the disaggregation of input rainfalls occurs without any action needed from the user.

4 Tests of the model

4.1 Test of 24 hour duration rainfalls

The disaggregation model is designed to be used with a daily rainfall generation model. When so used, a sequence of 2000 years of daily rainfalls is generated by the generation model and those rainfalls ≥ 15 mm are disaggregated to hourly values. It is necessary to test the generated daily rainfalls against the pluviometer records before the accuracy of the daily to hourly disaggregation can be established. Table 5 shows the results of this testing.

Five pluviometer records were selected to demonstrate the comparisons of 24-hour duration rainfalls. Melbourne Regional Office is the main test station because the amount of useable pluviometer record of 106 years is the longest record by far, more than double the length of the next longest record. Two stations with useable record > 30 years were selected in the drier western limit of the region covered by the data – Mildura Airport AMO and Horsham SR&WSC. A similar pair of stations towards the southeastern limit of the region were also selected – Glenmaggie Weir SR&WSC and East Sale AMO.

Each of the 5 pluviometer records was processed to avoid use of interpolated, estimated or accumulated data. Any day containing even a single hour of such data was ignored. From the remaining data, annual maxima 9 am to 9 am daily totals were extracted. A frequency distribution (log Pearson 3) was fitted to the annual maxima data and values for ARIs 2, 5, 10, 20, 50 and 100 years were estimated from the fitted distribution. These are shown in Table 5 identified by the label "Pluvio".

Using the generalised rainfall information in ARR87, design values of 24-hour duration rainfalls were calculated for the same values of ARI. These values are shown identified by the label "ARR87" in Table 5. It should be noted that the ARR87 values are unrestricted 24-hour duration values, not the restricted 9 am to 9 am values extracted from the pluviometer record. As an approximate guide, the unrestricted values are likely to be about 15% greater than the 9 am to 9 am values (Pierrehumbert, 1972, Weiss, 1964).

In order to calibrate the daily rainfall generation model, values of CRC-FORGE daily rainfalls (Weinmann et al, 1999) were obtained for each of the test stations. These cover the range of ARI from 50 to 2000 years, and are shown in Table 5 identified by the label "CRC-Forge". The CRC-FORGE rainfalls are unrestricted 24-hour values and are compatible with the ARR87 values, but are higher than the pluviometer values.

Using all of the above, the daily rainfall generation model was calibrated, partly using the 9 am to 9 am data from the pluviometer record to provide the statistics for the transition probability matrices (see Boughton, 1999). The calibration of the parameter A in the generation model is based on large ARI annual maxima daily rainfalls. In this instance, the parameter was calibrated such that the large ARI generated values were about 15% less than the unrestricted CRC-FORGE values so that the generated values corresponded to the restricted 9 am to 9 am values taken from the pluviometer records. Table 5 shows the results from the calibration of the daily rainfall generation model under the label "Gen-Dis".

The results for Melbourne and the two western stations, Mildura and Horsham, show that the generated daily rainfalls in the range of ARI 10 to 100 years are larger than the values from the pluviometer record. The two south eastern stations, Glenmaggie and East Sale, show an opposite result with the pluviometer records giving larger values than the daily rainfall generation model. In the case of Glenmaggie Weir, the restricted pluviometer rainfall for ARI 100 years (203 mm) is some 20% higher than the unrestricted ARR87 value (162 mm). This inconsistency seems to be a result of extrapolating from the 33 years of pluviometer data to ARI 100 years, and is more likely to be an artefact of extrapolating from a fitted frequency distribution rather than a true character of the pluviometer record. In each of the 5 stations, there is good agreement between the generation model and the pluviometer record for ARI 2 years, and the differences increase as the ARI increases. These results have a major effect of the testing of the sub-daily disaggregated rainfalls because any difference between generated and pluviometer 24 hour values is propagated into the disaggregated values.

Table 5 - Comparisons of 24 hour Duration Rainfalls
Note: Values shown for CRC-Forge and ARR87 are unrestricted 24 hr values.
Values for Pluvio and Gen-Dis are restricted 9 am to 9 am values.

86071 Melbourne Regional Office 106 years

ARI years	2	5	10	20	50	100	200	500	1000	2000
CRC-Forge	-	-	-	-	119	133	148	169	186	204
ARR87	58.8	73.9	84.5	98.9	119	136	-	-	-	-
Pluvio	43.0	58.3	69.4	80.2	94.8	106	-	-	-	-
Gen-Dis	45.5	62.0	74.0	85.0	101	115	129	149	165	178

76031 Mildura Airport AMO 38 years

ARI years	2	5	10	20	50	100	200	500	1000	2000
CRC-Forge	-	-	-	-	95.5	110	126	150	170	191
ARR87	41.4	57.1	66.9	79.4	96.2	110	-	-	-	-
Pluvio	30.8	41.8	49.8	57.9	69.2	78.3	-	-	-	-
Gen-Dis	33.7	49.5	61.1	73.1	87.2	101	120	160	164	188

79082 Horsham SR&WSC 32 years

ARI years	2	5	10	20	50	100	200	500	1000	2000
CRC-Forge	-	-	-	-	98.0	113	128	151	170	191
ARR87	45.3	59.0	68.6	81.4	99.4	114	-	-	-	-
Pluvio	27.9	37.2	43.1	48.7	55.6	60.7	-	-	-	-
Gen-Dis	29.7	39.4	46.8	57.2	73.9	94.9	1116	144	168	181

85034 Glenmaggie Weir SR&WSC 33 years

ARI years	2	5	10	20	50	100	200	500	1000	2000
CRC-Forge	-	-	-	-	138	155	172	196	214	233
ARR87	70.1	88.8	102	119	143	162	-	-	-	-
Pluvio	48.5	78.5	103	129	169	203	-	-	-	-
Gen-Dis	47.6	64.7	78.9	95.7	123	136	153	168	175	211

85072 East Sale AMO 38 years

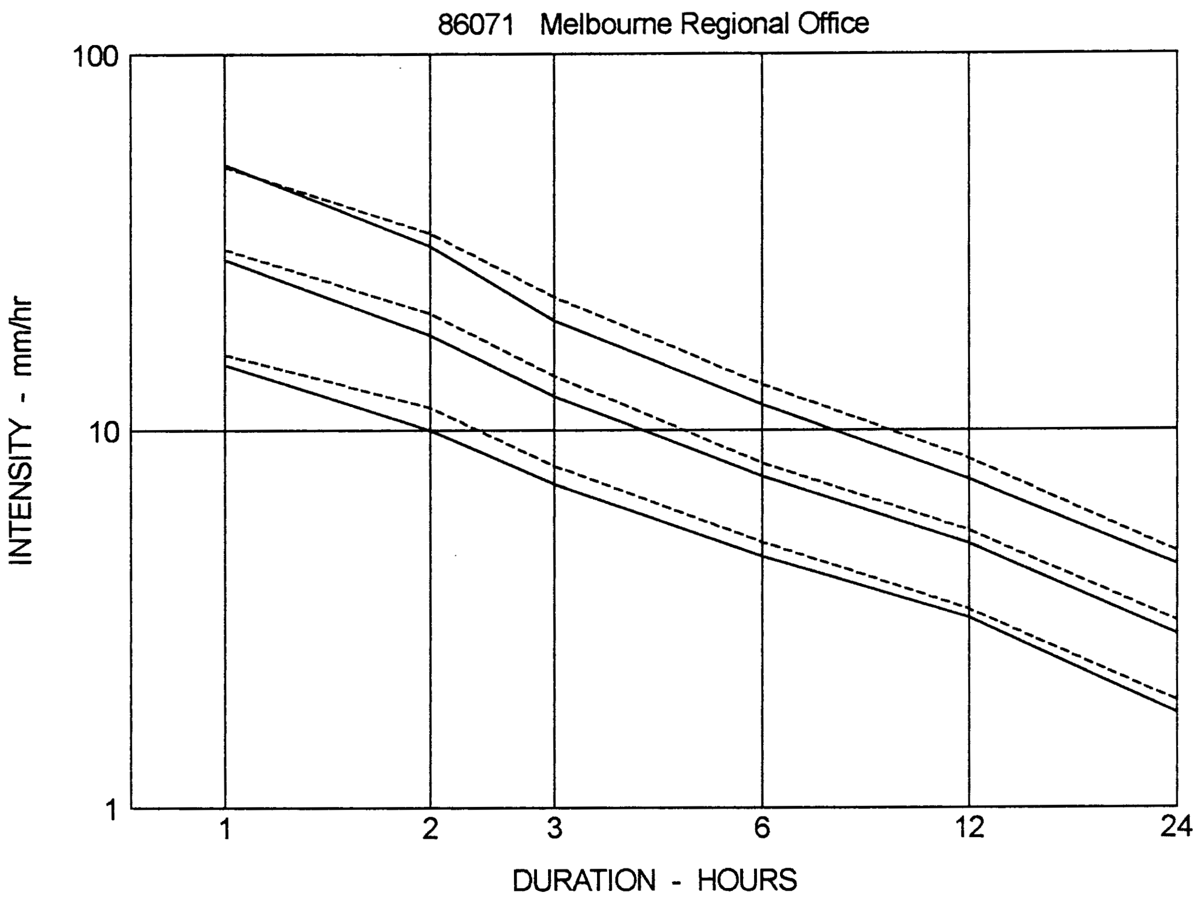
ARI years	2	5	10	20	50	100	200	500	1000	2000
CRC-Forge	-	-	-	-	132	148	165	189	208	228
ARR87	58.0	76.1	89.1	107	131	152	-	-	-	-
Pluvio	44.0	63.0	77.0	91.3	111	128	-	-	-	-
Gen-Dis	44.4	61.7	75.5	88.9	106	120	140	167	175	205

4.2 Test of IFD statistics

The pluviometer records were processed again to obtain sub-daily statistics. In the same manner as before, days with any interpolated, estimated or accumulated data were ignored, and annual maxima values were obtained for rainfalls of durations 1, 2, 3, 6, and 12 hours (in addition to the 24 hour values previously obtained). For each pluviometer record, LP3 frequency distributions were fitted in turn to the annual maxima values for each duration, and the fitted distributions were used to estimate values for ARIs 2, 10 and 100 years.

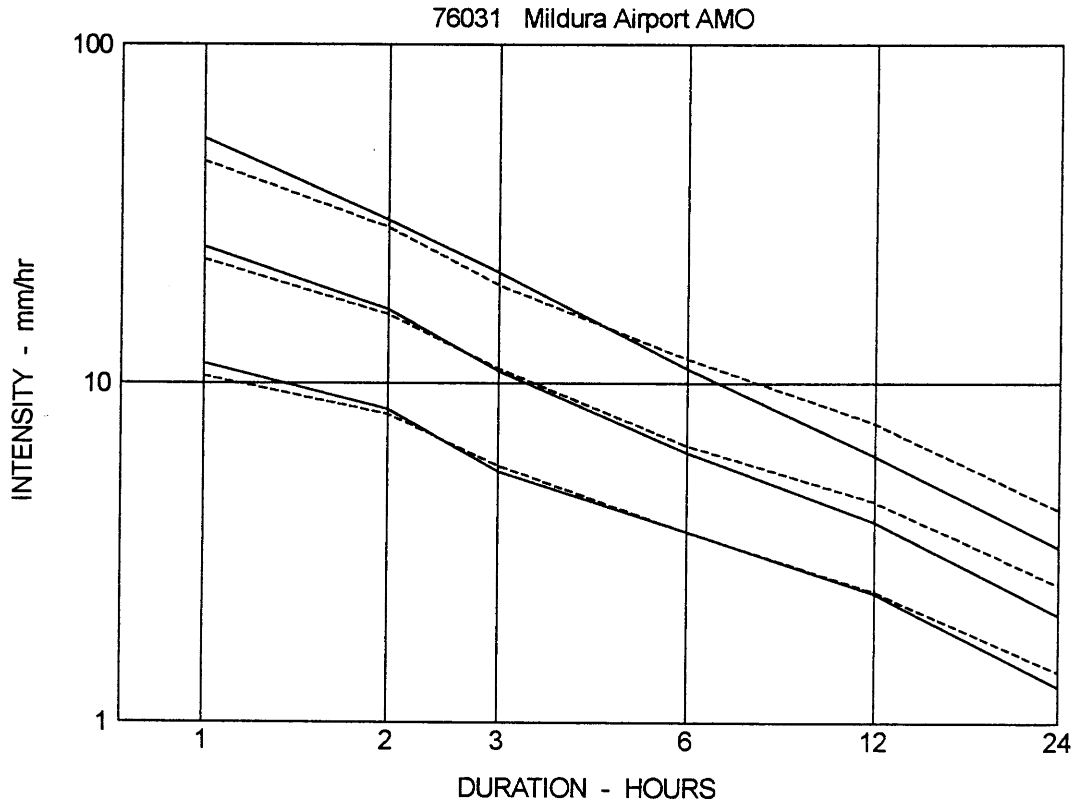
For each pluviometer station, the calibrated daily rainfall generation model was used to generate a single sequence of 2000 years. All daily rainfalls ≥ 15 mm were disaggregated to hourly values using the disaggregation model. Annual maxima data were selected for durations 1, 2, 3, 6, 12 and 24 hours, and values corresponding to ARIs 2, 10 and 100 years were extracted from the 2000 years of data.

The results are shown in Figures 5, 6 and 7.



Full line: Pluviometer data
Dashed line: Generation-Disaggregation Model
Top: ARI 100 years
Centre: ARI 10 years
Bottom: ARI 2 years

Figure 5 Comparison of IFD Statistics – Melbourne Regional Office



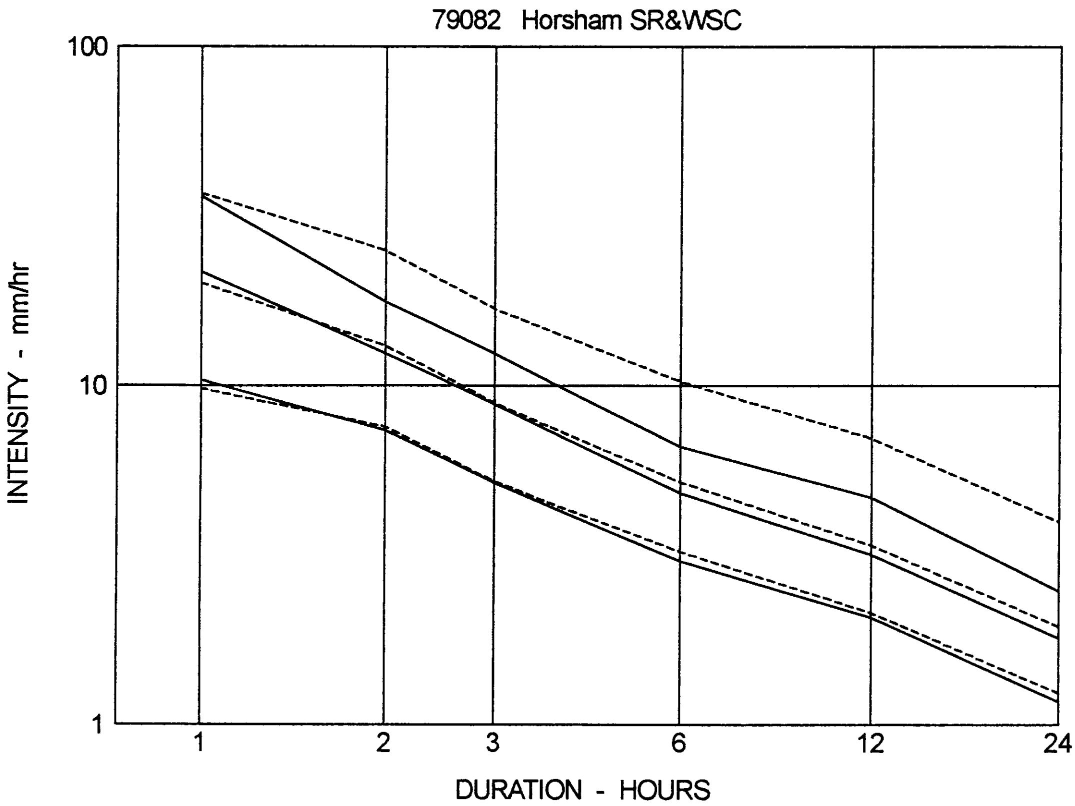
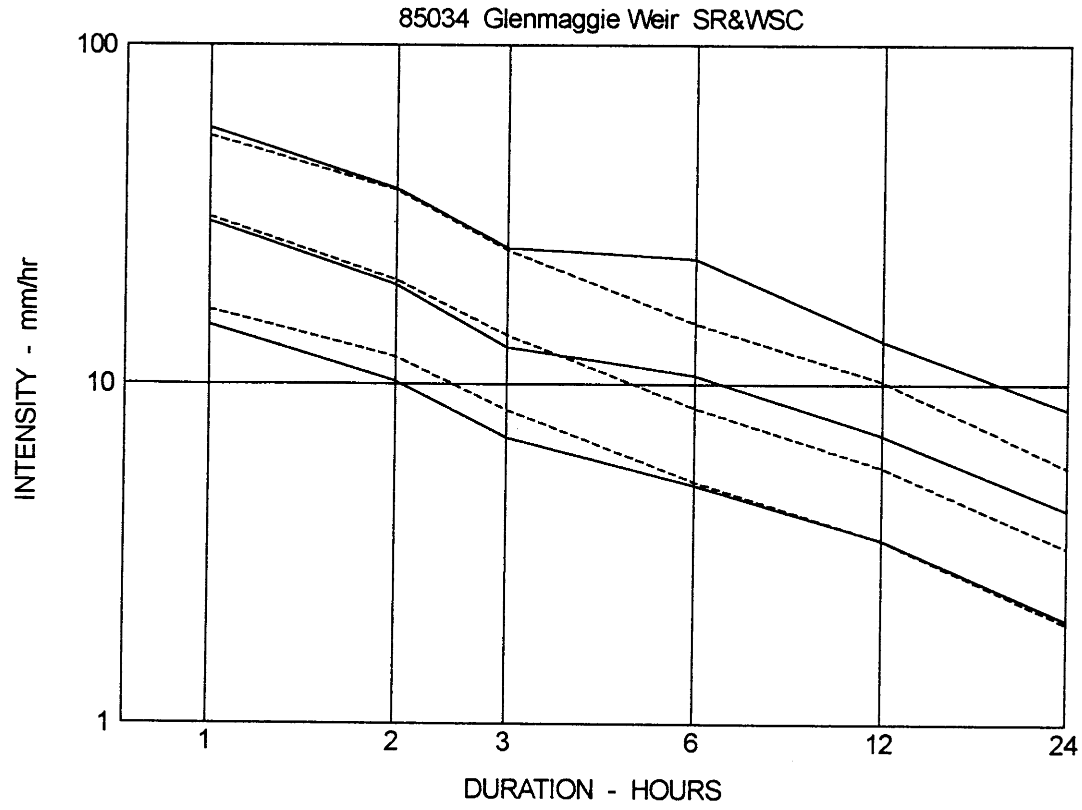


Figure 6 Comparison of IFD Statistics – Western Stations
Full line – Pluviometer Data Dashed line – Generation-Disaggregation Model
Top – ARI 100 years Centre – ARI 10 years Bottom – ARI 2 years



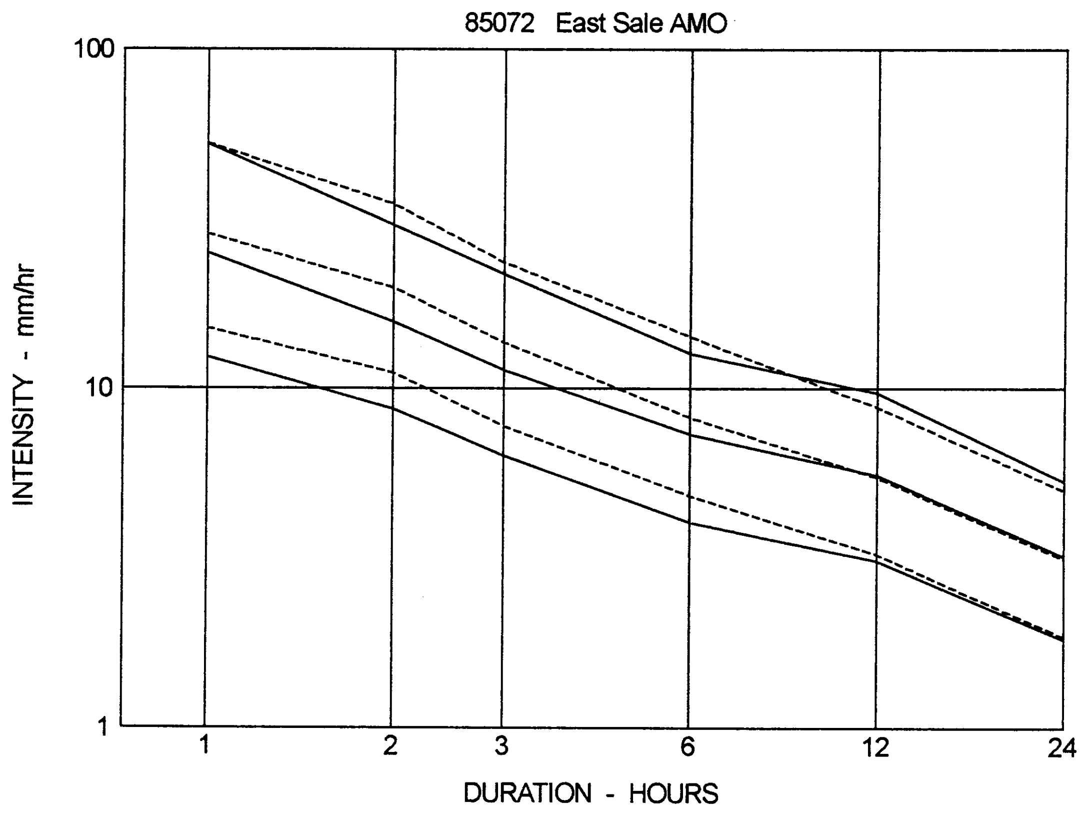


Figure 7 Comparison of IFD Statistics – South Eastern Stations
Full line – Pluviometer Data Dashed line – Generation-Disaggregation Model
Top – ARI 100 years Centre – ARI 10 years Bottom – ARI 2 years

The very good results in Figure 5 for the Melbourne Regional Office reflect the advantage of having over 100 years of data on which to base the test. The differences between the generated and pluviometer statistics are less than 16% at all points on the IFD plot. There are differences between generated and pluviometer values of 24-hour rainfalls of about 8%. If an adjustment is made to eliminate these differences, then the disaggregation model is reproducing the sub-daily IFD values within 7% over the whole range of durations and ARIs. It is significant that these best results were obtained where the long length of record gives most reliable estimates of pluviometer IFD statistics.

The results for the western stations in Figure 6 should be considered in 3 steps – for ARI 2 years, then ARI 10 years and finally ARI 100 years. For both Mildura and Horsham, the generated 24-hour value for ARI 2 years is very close to the value from the pluviometer record. In both cases, the sub-daily disaggregated values are almost identical between the two data sources for this ARI. There is similar but less close agreement between the 24-hour values at ARI 10 years and this is reflected in close but not quite as good agreement between the sub-daily values. The extrapolated 24-hour values for ARI 100 years have differences of 30% in the case of Mildura and 46% in the case of Horsham (see Table 5). These large differences in the 24-hour values have a major effect on the accuracy of reproducing the sub-daily statistics. Figure 6 shows that the ratios of generated sub-daily to daily values, indicated by the slope of the IFD lines, are similar to the ratios for ARIs 2 and 10 years, which reflects the same ratios in the ARR87 data. The major anomalies seem to be in the estimated ARI 100 years values from the 32 years of pluviometer record in the Horsham data, and not from the disaggregation model.

The results for the southeastern station in Figure 7 are more irregular than those for the western stations. The very high estimates of 24-hour rainfalls at ARI 100 years from the Glenmaggie pluviometer record have already been discussed in Section 4.1, and the irregularity of all 3 ARI lines for the pluviometer record would be impossible to match with any disaggregation model. There is good agreement between the generated and pluviometer values of 24 hours duration at ARI 2 years, and the maximum difference in the sub-daily values at this ARI is about 20% at 3 hours duration. The irregularity of the pluviometer data line is enough that the generated data line is a more convincing estimate of the IFD values.

The results for East Sale are the most difficult to interpret. The best agreement between generated and pluviometer statistics is at ARI 100 years with the worst results at ARI 2 years. At ARI 100 years, the agreement is good over all durations from 1 to 24 hours. The most difference occurs at 2 hours duration for all 3 ARIs, and the differences at this duration increase from least at ARI 100 years to most at ARI 2 years.

4.3 Comparison with ARR87 rainfall statistics

Some comparisons with ARR87 statistics were made in Table 5, which deals with 24-hour rainfalls. Table 6 extends the comparison to sub-daily duration down to one hour. The 24-hour intensities for ARR87 and the pluviometer record in Table 6 correspond to the 24-hour totals in Table 5. The generated intensities for 24 hours in Table 6 come from a different generation sequence, so there are small differences between the tables for the "GenDis" results.

The results for Melbourne Regional Office in Table 6 show the same good agreement as in Table 5 and Figure 5. For ARI 2 years, the results from the generation-disaggregation models follow the pattern of the ARR87 values and are 16% lower at 1 hour duration and 22% lower at 24 hours duration, about the expected differences between restricted and unrestricted data. The ARI 2-year results from the generation-disaggregation models are consistent with both the pluviometer data and the ARR87 data.

For ARI 100 years, the restricted 1-hour values from both the pluviometer record and the generation-disaggregation models are both higher than the unrestricted ARR87 values by about 5%. This anomaly is minor but serves as a reminder that none of the data in Tables 5 and 6 are perfect. The results for Melbourne in Table 6 show that the generation-disaggregation models reproduce the IFD statistics from both the pluviometer record and ARR87 to a high order of accuracy.

The results from the 34 years of pluviometer record at Essendon show the problems with estimating IFD information direct from the pluviometer data. Essendon is the closest of the other pluviometer stations to Melbourne, and the ARR87 values in Table 6 show that the IFD statistics of the two stations should be similar. While the results from the generation-disaggregation models are consistent with the ARR87 values, the results from the pluviometer data are very bad. For example, the 1-hour intensity at ARI 100 years from the pluviometer data (21.2 mm/hr) is only 43% of the corresponding ARR87 value (49.6 mm/hr). There would normally be an expectation that 34 years of data would give a reasonable estimate of the ARI 10 years value, but the 1-hour 10-years intensity from the pluviometer record (18.1 mm/hr) is only 61% of the corresponding ARR87 value (29.5 mm/hr). The comparison between the results for Melbourne and Essendon in Table 6 is evidence of the difficulty of evaluating the results from the generation-disaggregation models.

The results for Mildura in Table 6 give numerical confirmation of the good results for that station shown in Figure 6.

The results for East Sale in Figure 7 show a significant difference between the values from the pluviometer record and the generation-disaggregation models at ARI 2 years, with maximum difference at 1 hour duration and least at 24 hours. Table 6 shows that the 1-hour 2-year value from the generation-disaggregation models (15.1 mm/hr) is 16% less than the ARR87 unrestricted value, whereas the corresponding value from the pluviometer record (12.4 mm/hr) is 30% less. The ARR87 values give more support to the generation-disaggregation estimates than to those from the pluviometer record.

Table 6 - Intensity-Frequency-Duration Estimates in mm/hr
Note: ARR87 values are unrestricted for the durations shown.
Others are restricted to the relevant clock hours

86071 Melbourne Regional Office

Duration	ARI 2 years			ARI 10 years			ARI 100 years		
Hours	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87
1	14.9	15.9	18.9	28.4	30.4	28.6	50.8	50.1	48.1
2	9.94	11.5	12.2	17.9	20.4	18.2	30.9	33.4	30.0
3	7.22	8.06	9.37	12.3	13.9	13.8	19.6	22.6	22.6
6	4.63	5.05	5.97	7.55	8.18	8.63	11.7	13.2	13.9
12	3.19	3.36	3.81	5.01	5.43	5.42	7.42	8.38	8.60
24	1.79	1.92	2.45	2.89	3.13	3.52	4.41	4.77	5.65

86038 Essendon Airport AMO

Duration	ARI 2 years			ARI 10 years			ARI 100 years		
Hours	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87
1	12.7	14.8	19.5	18.1	27.2	29.5	21.2	47.3	49.6
2	9.14	10.8	12.6	13.3	18.4	18.7	16.3	30.4	30.6
3	6.56	7.57	9.74	9.92	12.6	14.2	13.5	20.3	23.0
6	4.14	4.73	6.23	7.02	7.56	8.85	12.1	11.8	14.0
12	2.87	3.16	4.00	5.17	5.00	5.54	9.16	7.58	8.53
24	1.69	1.82	2.50	3.28	2.85	3.57	6.12	4.30	5.67

76031 Mildura Airport AMO

Duration	ARI 2 years			ARI 10 years			ARI 100 years		
Hours	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87
1	11.6	10.5	17.9	25.4	23.2	29.1	52.8	45.0	48.0
2	8.41	8.09	10.8	16.5	16.0	17.6	30.4	28.9	29.1
3	5.50	5.69	8.07	10.7	11.0	13.1	21.3	19.5	21.5
6	3.64	3.63	4.83	6.24	6.55	7.83	11.0	11.8	12.8
12	2.40	2.43	2.90	3.89	4.47	4.69	6.11	7.62	7.70
24	1.28	1.41	1.72	2.08	2.55	2.79	3.28	4.23	4.56

85072 East Sale AMO

Duration	ARI 2 years			ARI 10 years			ARI 100 years		
Hours	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87	Pluvi	GenDis	ARR87
1	12.4	15.1	17.9	25.0	28.6	27.9	52.5	52.8	48.2
2	8.70	11.1	11.8	15.7	19.8	18.2	30.3	34.9	31.0
3	6.34	7.74	9.18	11.3	13.7	14.0	21.8	23.5	23.8
6	4.04	4.82	5.98	7.30	8.21	9.02	12.7	14.2	15.1
12	3.11	3.24	3.90	5.54	5.47	5.81	9.69	8.78	9.59
24	1.83	1.85	2.42	3.21	3.15	3.71	5.32	4.98	6.31

4.4 Summary of test results

The structure of the disaggregation model forces the results to match the statistics of sub-daily ratios to the 24-hour values. The spread of temporal patterns from uniform to very variable hourly rainfall is fixed by use of the distribution or R in Table 2. The average values of the other 23 hourly rainfalls for a given value of R are fixed by the use of the statistics in Appendix C.

The main purpose of testing has been to see if the use of a single average disaggregation model for the entire region covered by the data set gives an acceptable reproduction of the IFD rainfall statistics for durations 1 to 24 hours and ARIs 2 to 100 years. The results shown in Tables 5 and 6 and in Figures 5, 6 and 7 show no evidence of systematic bias from East Sale in the south east to Mildura in the north west.

For the main test station of Melbourne Regional Office with over 100 years of data available for analysis, there is a high order of agreement between the IFD intensities produced by the generation-disaggregation models and those from ARR87 and from direct analysis of the pluviometer record. It is noteworthy that those results were produced from just the daily rainfall record and the disaggregation model. The long record of daily rainfalls served to give an accurate calibration of the daily rainfall generation model. The good agreement with 24-hour totals makes it easy to see the agreement at sub-daily durations down to 1 hour.

The need for a good calibration of the daily rainfall generation model in the first instance has restricted the testing to those pluviometer stations with more than 30 years of useable record. As a general observation, the errors in reproducing the 24-hour totals have been minor and secondary to the problems of getting reliable IFD statistics from the pluviometer records other than the Melbourne record. In practice, it can be expected that it is usually possible to obtain a daily rainfall record of much greater length than 30 years to calibrate the daily rainfall generation model, and so keep this source of errors in the final IFD statistics small and minor.

Because of the problems of getting reliable IFD statistics direct from the pluviometer records, the main test results are those between the unrestricted ARR87 values and the restricted values from the generation-disaggregation models in Table 6. The results in Figures 6 and 7 supplement the numeric values in Table 6. There are no significant inconsistencies between the generation-disaggregation results and the ARR87 values in Tables 5 and 6 which span the region from Mildura to East Sale. The main result is that there is no significant bias introduced by the use of an average disaggregation model across the whole range of the data, and there is no need to use disaggregation models adapted to individual regions within the range of the data.

In addition, the IFD statistics obtained from the generation-disaggregation system are clearly consistent with the ARR87 statistics when allowance is made for the difference between restricted 9 am to 9 am data and the unrestricted ARR87 data. Table 6 shows that the IFD statistics obtained from a reliable calibration of the daily rainfall generation model and then disaggregation to hourly values with the average disaggregation model are of an accuracy that is acceptable for design flood estimation purposes until a better daily to hourly disaggregation model becomes available. In particular, the use of the generation-disaggregation models with continuous simulation of losses by catchment water balance provides a valuable new tool for design flood estimation.

5 Conclusions

5.1 Results from the study

The model for disaggregating 9 am to 9 am daily rainfalls to hourly values, which has been developed in this study, is a significant improvement on the model described in an earlier report (Boughton, 2000). The earlier model based on ARR87 IFD information always has the same ratios of sub-daily intensities to 24-hour intensities, which does not reproduce the natural range of variation. That particular drawback is overcome in the present model.

The major component of the model is the ratio R of the rainfall in the hour of maximum rain to the daily total, i.e. the fraction of the daily total in the hour of maximum rainfall. This ratio ranges from 0.04167 (completely uniform rain during the day, 1/24 of the daily total in every hour) to 1.00, i.e. all of the daily rainfall in a single hour. The distribution of R was remarkably similar among the 28 pluviometer records that were analysed during this study. An average distribution of R based on these data was adequate to reproduce the IFD statistics in each of the stations tested.

The other 23 ratios or fractions of the daily totals are related to R. If R = 1.0, then each of the other 23 values must be zero. If R = 0.04167, i.e. uniform rain, then every other value is also 0.04167. For values of R between these upper and lower limits, the average distributions of the other 23 values were collated and are shown in Appendix B. The results of testing suggest that these distributions are also common and are not site specific.

An important component of the model is the clustering of values to give statistics for 2-hour durations, 3-hour, etc. The clusterings derived from the data set (documented in Appendix C) show some minor variations with the ARR87 statistics that most likely reflect the smoothings of the ARR87 values. In particular, the pluviometer data consistently show higher values for 2-hour totals than the interpolated 2-hour values obtained from the ARR87 statistics.

The final component of the model is the random selection of a temporal pattern. There are 20 ranges of the ratio R and these are combined with 24 patterns that allow the peak rate of hourly rainfall to occur at any of the 24 hours of the day. This combination gives 20 x 24 = 480 different temporal patterns, which matches the wide variation in temporal patterns seen in the actual data.

The reproduction of the ARR87 IFD information from daily rainfalls without site specific calibration of the disaggregation model is a severe test of the model. The results shown in Figures 5, 6 and 7 and in Table 6 are good, considering the inaccuracies inherent in the measurement of daily rainfalls. The ability to generate thousands of years of hourly rainfalls in a sequence that permits the water balance calculation of losses, with an accuracy as indicated in Figures 5, 6 and 7 and in Table 6, is a significant step forward in the utilisation of available hydrological data.

5.2 Future work

The major need for the immediate future is to test the model in other areas of Australia to determine if the disaggregation model has general applicability or needs further development. It is possible to test the model against ARR87 IFD statistics, as shown in Table 6, using only daily rainfall input.

A second need is to extend the disaggregation model to deal with multi-day storms instead of treating each day as independent. The primary purpose of disaggregating daily rainfalls to hourly values is for design flood estimation, and the present model is adequate for dealing with flood estimation on catchments up to several hundred square kilometres. A preliminary study of days of rainfall ≥ 15 mm and the daily rainfalls immediately before and after showed no identifiable serial correlations on which a multi-day model might be based. This matter remains for detailed testing in another study.

A third need is to disaggregate down to sub-hourly values - down to 6- or 15-minute periods. The main application for this additional work would be erosion studies in which erosivity is directly related to short duration rainfall intensities. This would be a relatively simple extension of the model, which would permit the generation of thousands of years of temporal patterns of erosion and sediment movement. The data set used in the present study were all hourly rainfalls with no sub-hourly data, so it was not possible to appraise what might be involved in this additional work.

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APPENDIX A – Distributions of R at 28 pluviometer stations

Each of the 28 pluviometer records were processed into 9 am to 9 am daily blocks, and the days with total rainfall ≥ 15.0 mm were selected for analysis. The ratio R of the amount of rain in the highest hourly fall to the daily total were collated into the following ranges:

No.	Range	No.	Range	No.	Range	No.	Range
1	0.0417-0.075	6	0.275-0.325	11	0.525-0.575	16	0.775-0.825
2	0.075-0.125	7	0.325-0.375	12	0.575-0.625	17	0.825-0.875
3	0.125-0.175	8	0.375-0.425	13	0.625-0.675	18	0.875-0.925
4	0.175-0.225	9	0.425-0.475	14	0.675-0.725	19	0.925-0.975
5	0.225-0.275	10	0.475-0.525	15	0.725-0.775	20	0.975-1.000

The distributions of R in those ranges are set out, for a number of stations, as follows:

Station number & identification

1 2 3 4 5 6 7 8 9 10

11 12 13 14 15 16 17 18 19 20

(1 is range 1, 2 is range 2, etc.)

Using 76031 Mildura Airport AMO as an example, there were no values in the first range, 0.031 of the total (3.1%) in the second range, 0.079 (7.9%) in the third range, etc.

```
76031  Mildura Airport AMO
  0.000  0.031  0.079  0.173  0.110  0.197  0.102  0.047  0.047
0.039
  0.024  0.047  0.008  0.039  0.016  0.016  0.008  0.008  0.000
0.008

79052  Rocklands Reservoir
  0.000  0.036  0.121  0.193  0.188  0.126  0.099  0.063  0.045
0.045
  0.018  0.018  0.009  0.013  0.009  0.000  0.004  0.000  0.004
0.009

79082  Horsham  SR & WSC
  0.000  0.024  0.144  0.192  0.144  0.144  0.040  0.064  0.072
0.048
  0.040  0.016  0.016  0.016  0.008  0.000  0.000  0.008  0.008
0.016

79086  Avon No 3
  0.008  0.046  0.100  0.154  0.162  0.138  0.108  0.062  0.085
0.015
```

0.015 0.008 0.015 0.023 0.015 0.023 0.000 0.008 0.008
0.008

80067 Charlton Soil Conservation
0.000 0.027 0.122 0.154 0.144 0.117 0.117 0.085 0.069
0.032
0.021 0.027 0.000 0.021 0.005 0.016 0.016 0.011 0.000
0.016
81003 Bendigo Prison
0.014 0.028 0.161 0.199 0.147 0.137 0.057 0.071 0.043
0.038
0.038 0.024 0.009 0.009 0.005 0.005 0.005 0.005 0.005
0.000

81038 Natte Yallock
0.041 0.020 0.133 0.214 0.102 0.214 0.082 0.061 0.051
0.031
0.010 0.020 0.000 0.000 0.000 0.000 0.010 0.000 0.000
0.010

84005 Buchan Post Office
0.026 0.097 0.179 0.262 0.149 0.067 0.046 0.026 0.046
0.021
0.026 0.021 0.015 0.005 0.005 0.005 0.005 0.000 0.000
0.000

84015 Ensay Composite
0.071 0.071 0.223 0.205 0.098 0.071 0.089 0.045 0.045
0.027
0.009 0.009 0.000 0.009 0.009 0.000 0.009 0.000 0.000
0.009

85000 Aberfeldy
0.033 0.093 0.166 0.185 0.166 0.093 0.046 0.060 0.040
0.026
0.033 0.007 0.026 0.007 0.007 0.007 0.007 0.000 0.000
0.000

85026 Erica State Forest
0.000 0.122 0.253 0.201 0.111 0.104 0.076 0.028 0.024
0.014
0.003 0.010 0.010 0.021 0.000 0.003 0.007 0.003 0.003
0.003

85034 Glenmaggie Weir SR&WSC
0.000 0.077 0.178 0.171 0.164 0.104 0.070 0.057 0.030
0.023
0.027 0.010 0.017 0.007 0.020 0.017 0.007 0.013 0.003
0.003

85072 East Sale AMO
  0.000 0.075 0.182 0.186 0.175 0.139 0.057 0.029 0.039
0.029
  0.025 0.018 0.011 0.007 0.007 0.000 0.007 0.004 0.004
0.007

85103 Yallourn
  0.000 0.064 0.203 0.198 0.168 0.094 0.089 0.074 0.035
0.015
  0.010 0.005 0.000 0.005 0.010 0.010 0.005 0.010 0.005
0.000

85106 Olsens Bridge
  0.015 0.121 0.215 0.234 0.171 0.100 0.050 0.042 0.025
0.019
  0.002 0.002 0.002 0.000 0.000 0.000 0.002 0.000 0.000
0.000

85170 Traralgon L.V.W. & S.B
  0.000 0.034 0.259 0.190 0.172 0.112 0.078 0.043 0.017
0.017
  0.017 0.026 0.000 0.009 0.017 0.000 0.000 0.000 0.000
0.009

85176 Tanjil Bren Post Office
  0.027 0.132 0.246 0.214 0.133 0.076 0.066 0.042 0.019
0.010
  0.012 0.010 0.003 0.004 0.004 0.000 0.000 0.000 0.000
0.000

85236 Callignee North
  0.000 0.110 0.184 0.243 0.132 0.088 0.074 0.059 0.029
0.000
  0.022 0.007 0.022 0.022 0.000 0.000 0.007 0.000 0.000
0.000

85237 Noojee English HMSD
  0.008 0.085 0.262 0.243 0.156 0.095 0.048 0.040 0.021
0.011
  0.008 0.005 0.011 0.003 0.003 0.000 0.000 0.003 0.000
0.000

85240 Ellinbank
  0.037 0.050 0.174 0.195 0.183 0.106 0.081 0.041 0.050
0.019
  0.017 0.019 0.006 0.012 0.002 0.002 0.002 0.000 0.002
0.002

85256 Barkley River
  0.058 0.080 0.200 0.209 0.156 0.084 0.053 0.040 0.027
0.018

0.022 0.009 0.013 0.004 0.009 0.009 0.009 0.000 0.000
0.000

86038 Essendon Airport AMO
0.020 0.032 0.151 0.179 0.179 0.131 0.071 0.083 0.048
0.036
0.020 0.012 0.016 0.004 0.004 0.008 0.004 0.000 0.000
0.004

86071 Melbourne Regional Office
0.000 0.039 0.137 0.173 0.153 0.141 0.089 0.051 0.049
0.048
0.039 0.020 0.009 0.012 0.007 0.008 0.009 0.007 0.003
0.009

86142 Mount St Leonard
0.017 0.068 0.193 0.233 0.151 0.120 0.078 0.052 0.027
0.013
0.017 0.012 0.010 0.000 0.002 0.005 0.002 0.000 0.000
0.002

86219 Coranderrk
0.002 0.072 0.207 0.191 0.172 0.132 0.072 0.046 0.033
0.017
0.015 0.014 0.004 0.004 0.004 0.002 0.006 0.004 0.002
0.002

86224 Dandenong Composite
0.023 0.036 0.127 0.163 0.158 0.131 0.145 0.068 0.045
0.018
0.027 0.009 0.009 0.009 0.009 0.014 0.000 0.005 0.005
0.000

86234 Croydon South
0.026 0.058 0.128 0.196 0.173 0.128 0.087 0.061 0.042
0.029
0.019 0.010 0.000 0.013 0.003 0.000 0.016 0.010 0.003
0.000

86314 Koo Wee Rup SR & WSC
0.015 0.026 0.184 0.213 0.193 0.105 0.091 0.050 0.026
0.029
0.023 0.015 0.015 0.003 0.006 0.003 0.003 0.000 0.000
0.000

AVERAGE DISTRIBUTION OF R
0.016 0.063 0.175 0.199 0.154 0.118 0.077 0.053 0.040
0.025
0.020 0.015 0.009 0.010 0.007 0.005 0.005 0.004 0.002
0.004

APPENDIX B – Average ranked series of hourly fractions

Using days with rainfall ≥ 15.0 mm from all 28 pluviometer stations, the 24 fractions of each daily total were ranked in order of magnitude, and then averaged in the ranges of R used in the discrete distribution of R shown in Appendix A.

The following shows the averaged ranked series of hourly fractions for each of the 20 ranges of R. Given a value of R (the fraction of the daily total in the hour of maximum rain), the following series give the fractions of the daily total in the other 23 hours ranked in order of magnitude.

The results are set out, for a number of stations, as follows:

R Range of data
Ranked values for 12 highest hours in order 1 to 12
Ranked values for other 12 hours in order 13 to 24

```
R Range  0.0417-0.075
0.045 0.045 0.045 0.045 0.044 0.044 0.044 0.044 0.044 0.044 0.044 0.044
0.044 0.043 0.043 0.043 0.042 0.041 0.041 0.040 0.040 0.039 0.038 0.013

R Range  0.075-0.125
0.108 0.097 0.090 0.082 0.076 0.070 0.065 0.060 0.055 0.049 0.044 0.039
0.033 0.028 0.024 0.020 0.016 0.013 0.010 0.008 0.006 0.004 0.003 0.001

R Range  0.125-0.175
0.152 0.129 0.112 0.099 0.086 0.076 0.066 0.056 0.048 0.040 0.033 0.026
0.020 0.016 0.012 0.009 0.007 0.005 0.003 0.002 0.001 0.001 0.000 0.000

R Range  0.175-0.225
0.200 0.161 0.132 0.110 0.089 0.072 0.057 0.045 0.035 0.027 0.020 0.015
0.011 0.008 0.006 0.004 0.003 0.002 0.001 0.001 0.000 0.000 0.000 0.000

R Range  0.225-0.275
0.249 0.184 0.141 0.110 0.085 0.063 0.047 0.034 0.025 0.018 0.013 0.010
0.007 0.005 0.003 0.002 0.002 0.001 0.001 0.000 0.000 0.000 0.000 0.000

R Range  0.275-0.325
0.299 0.207 0.149 0.106 0.074 0.051 0.035 0.025 0.017 0.012 0.009 0.006
0.004 0.003 0.002 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.325-0.375
0.350 0.221 0.142 0.093 0.063 0.043 0.029 0.019 0.013 0.009 0.006 0.004
0.003 0.002 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.375-0.425
0.399 0.236 0.138 0.083 0.049 0.031 0.021 0.014 0.010 0.006 0.004 0.003
0.002 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
R Range  0.425-0.475
0.448 0.246 0.133 0.068 0.039 0.023 0.015 0.010 0.006 0.004 0.002 0.002
0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
```

R Range 0.475-0.525
0.498 0.231 0.110 0.062 0.037 0.021 0.013 0.008 0.006 0.004 0.003 0.002
0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.525-0.575
0.550 0.232 0.094 0.053 0.029 0.015 0.009 0.006 0.004 0.003 0.002 0.001
0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.575-0.625
0.599 0.201 0.092 0.040 0.027 0.017 0.009 0.006 0.004 0.002 0.001 0.001
0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.625-0.675
0.655 0.187 0.069 0.039 0.021 0.012 0.007 0.004 0.002 0.002 0.001 0.001
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.675-0.725
0.700 0.167 0.066 0.035 0.016 0.008 0.004 0.002 0.001 0.001 0.001 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000

R Range 0.725-0.775
0.748 0.132 0.058 0.027 0.016 0.010 0.005 0.002 0.001 0.001 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.775-0.825
0.798 0.116 0.040 0.021 0.011 0.006 0.004 0.001 0.001 0.001 0.001 0.001
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.825-0.875
0.846 0.085 0.034 0.014 0.009 0.005 0.003 0.001 0.001 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.875-0.925
0.900 0.074 0.016 0.006 0.003 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.925-0.975
0.943 0.046 0.007 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range 0.975-1.000
0.996 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

APPENDIX C – Clustered sequences of hourly fractions for design use

Using days with rainfall ≥ 15.0 mm from all 28 pluviometer stations, the fractions of the daily totals in the maximum 2, 3, 6 and 12 hours were averaged in the ranges of R shown below. The averaged ranked sequences in Appendix B were then rearranged such the maximum 2, 3, 6 and 12 hour totals matched the values found from the pluviometer records.

The following clustered sequences have the maximum hourly fraction R at the left of the first line after the identification line, then the second hour which forms the maximum 2 hour total with R, then the third hour which forms the maximum 3 hour total with the first two values, etc.

```
R Range  0.0417-0.075
0.045 0.045 0.044 0.045 0.045 0.043 0.045 0.044 0.044 0.044 0.044 0.044
0.044 0.044 0.044 0.043 0.043 0.042 0.041 0.041 0.040 0.040 0.039 0.038

R Range  0.075-0.125
0.108 0.082 0.060 0.090 0.070 0.006 0.097 0.076 0.055 0.044 0.033 0.004
0.065 0.049 0.039 0.028 0.024 0.020 0.016 0.013 0.010 0.008 0.003 0.001

R Range  0.125-0.175
0.152 0.112 0.056 0.086 0.076 0.020 0.129 0.066 0.040 0.033 0.026 0.005
0.099 0.048 0.016 0.012 0.009 0.007 0.003 0.002 0.001 0.001 0.000 0.000

R Range  0.175-0.225
0.200 0.132 0.057 0.110 0.004 0.072 0.161 0.045 0.035 0.020 0.006 0.000
0.089 0.027 0.015 0.011 0.008 0.003 0.002 0.001 0.001 0.000 0.000 0.000

R Range  0.225-0.275
0.249 0.141 0.063 0.110 0.034 0.034 0.184 0.047 0.013 0.005 0.002 0.000
0.085 0.025 0.018 0.010 0.007 0.003 0.002 0.001 0.001 0.000 0.000 0.000

R Range  0.275-0.325
0.299 0.149 0.074 0.106 0.003 0.051 0.207 0.009 0.002 0.001 0.000 0.000
0.035 0.025 0.017 0.012 0.006 0.004 0.001 0.001 0.000 0.000 0.000 0.000

R Range  0.325-0.375
0.350 0.221 0.000 0.142 0.000 0.000 0.093 0.063 0.043 0.001 0.000 0.000
0.029 0.019 0.013 0.009 0.006 0.004 0.003 0.002 0.001 0.001 0.000 0.000

R Range  0.375-0.425
0.399 0.236 0.000 0.083 0.031 0.004 0.138 0.021 0.010 0.006 0.003 0.001
0.049 0.014 0.002 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.425-0.475
0.448 0.246 0.000 0.015 0.001 0.068 0.133 0.023 0.010 0.002 0.002 0.000
0.039 0.006 0.004 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.475-0.525
0.498 0.231 0.000 0.013 0.013 0.008 0.110 0.037 0.021 0.003 0.001 0.000
0.062 0.006 0.004 0.002 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000
```

```
R Range  0.525-0.575
0.550 0.232 0.000 0.015 0.004 0.029 0.094 0.009 0.006 0.003 0.002 0.001
0.053 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.575-0.625
0.599 0.201 0.000 0.009 0.040 0.000 0.092 0.017 0.006 0.004 0.001 0.000
0.027 0.002 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.625-0.675
0.655 0.187 0.000 0.001 0.012 0.004 0.069 0.039 0.002 0.002 0.001 0.000
0.021 0.007 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.675-0.725
0.700 0.167 0.000 0.000 0.000 0.000 0.066 0.035 0.004 0.002 0.001 0.000
0.016 0.008 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.725-0.775
0.748 0.132 0.000 0.010 0.001 0.000 0.058 0.016 0.002 0.001 0.000 0.000
0.027 0.005 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.775-0.825
0.798 0.116 0.000 0.001 0.001 0.011 0.040 0.021 0.004 0.000 0.000 0.000
0.006 0.001 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.825-0.875
0.846 0.034 0.014 0.009 0.009 0.009 0.085 0.000 0.000 0.000 0.000 0.000
0.005 0.003 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.875-0.925
0.900 0.074 0.000 0.000 0.000 0.000 0.016 0.003 0.000 0.000 0.000 0.000
0.006 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.925-0.975
0.943 0.046 0.000 0.000 0.000 0.000 0.007 0.000 0.000 0.000 0.000 0.000
0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

R Range  0.975-1.000
0.996 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
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