A Windows-based Program to Derive Design Rainfall Temporal Patterns For Design Flood Estimation

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EXTENDED ABSTRACT

Design flood estimation is often required in engineering practice such as design of hydrologic structures, flood plain management, river ecological studies and flood insurance studies. The national guideline for design flood estimation in Australia known as Australian Rainfall and Runoff (ARR) recommends the Design Event Approach as the preferred method of rainfall-based design flood estimation technique (I. E. Aust., 1987, 1997). This method requires formulation of a design rainfall event and use of a runoff routing model to convert the design rainfall event into the corresponding design streamflow event. A design rainfall event is specified by a rainfall duration, average rainfall intensity of a particular average recurrence interval (ARI) and rainfall temporal pattern. A rainfall temporal pattern gives the proportion of total rainfall in different periods within a given rainfall duration. This paper focuses on the design rainfall temporal patterns.

The main assumption of the Design Event Approach of flood estimation is that a rainfall intensity of a particular ARI can be converted to a streamflow hydrograph peak of the same ARI by using 'critical duration' and 'representative values' of other input variables to the runoff routing model such as initial loss. The ARR adopted the 'Method of Average Variability' to derive design rainfall temporal patterns for Australia for using with the Design Event Approach (I. E. Aust., 1987). This paper presents a windows-based program called 'Windows_TP' that can be used to derive design rainfall temporal patterns using the 'Method of Average Variability' as per the ARR 87 procedure.

The program Windows_TP requires formatted pluviograph data of 5 minutes interval from a set of pluviograph stations selected from the region of interest. These data can be obtained from the Australian Bureau of Meteorology. The selected pluviograph stations should have a minimum distance between them to satisfy the criterion of spatial independence. The output from the program requires smoothing and rationalization similar to the ARR 87 procedure to come up with the final set of design rainfall temporal patterns. The program gives design rainfall temporal patterns in 20 standard durations and in two ARIs (ARI ≤ 30 years and ARI > 30 years) similar to the ARR 87 procedure.

The paper demonstrates the application of the program Windows_TP in the Gold Coast Region in Queensland Australia. A total of 22 pluviograph stations over a radius of 90 km from Gold Coast were selected for this purpose. The final set of the design rainfall temporal patterns were validated in the Gold Coast region and were found to provide more reliable design flood estimates than the ARR 87 recommended design rainfall temporal patterns.

The main advantages of this program are that it is easy to use and it can process a large volume of pluviograph data to derive design rainfall temporal patterns. The use of this program allows the user to derive design rainfall temporal patterns based on the local pluviograph stations which are more relevant to a particular region. This is particularly useful for the regions where ARR 87 adopted very limited number of local pluviograph stations in the derivation of design rainfall temporal patterns. For example, for Zone 3 in the ARR 87 (the Eastern Queensland covering about 3000 km of coast line), only 10 pluviograph stations were used with only one station from the Gold Coast area.

It is expected that design rainfall temporal patterns obtained from the local pluviograph stations will increase the reliability of design flood estimates and as such the program Windows_TP is expected to have a wider application in hydrologic research and practice in Australia. The program can be purchased by contacting the first author of the paper on a.rahman@uws.edu.au.

1. INTRODUCTION

Flood estimation is often required in engineering practice such as the design of hydrologic structures, flood plain management, river ecological studies, and flood insurance studies. For flood estimation, rainfall runoff modeling is one of the most widely used techniques, which involves conversion of rainfall events into streamflow events using some rainfall runoff model. In Australia, the national guideline of design flood estimation known as the Australian Rainfall and Runoff (ARR) recommends the Design Event Approach as the preferred method of rainfall runoff modeling which involves formulation of a 'design rainfall event' and use of a runoff routing model to convert the rainfall event into streamflow event (I. E. Aust., 1997).

A design rainfall event is characterized by a duration, average rainfall intensity of a particular average recurrence interval (ARI) and rainfall temporal pattern. A rainfall temporal pattern gives the proportion of total rainfall in different periods within a given rainfall duration. The main assumption of the Design Event Approach of flood estimation is that a rainfall intensity of a particular ARI can be converted to a streamflow hydrograph peak of the same ARI by using 'critical duration' and representative values of other input variables to the runoff routing model such as initial loss.

This paper focuses on design rainfall temporal patterns. In 1987, the ARR derived design rainfall temporal patterns in which Australia was divided into eight different zones. For example, Zone 3 covered eastern coast of Queensland state extending over 3000 km of North-east coast line. In the derivation of ARR 87 temporal patterns for Zone 3, only 10 pluviograph stations were used from this vast region with only one station from the Gold Coast area. It seems to be more logical to derive design rainfall temporal patterns in a particular region based on more local pluviograph stations to reflect the local rainfall characteristics in the design rainfall temporal patterns. This paper presents a windows-based program that can be used to derive design rainfall temporal patterns for any region based on a set of selected pluviograph stations from the region.

2. DESIGN RAINFALL TEMPORAL PATTERNS IN AUSTRALIAN RAINFALL AND RUNOFF

In the ARR 87, design rainfall temporal patterns were given for 20 standard durations (10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes, 45 minutes, 1 hour, 1.5 hours, 2 hours, 3 hours, 4.5 hours, 6 hours, 9 hours, 12 hours, 18 hours, 24 hours, 30 hours, 36 hours, 48 hours and 72 hours) and for two ARIs (≤ 30 years and > 30 years). The ARR 87 considered only two ARIs because these design rainfall temporal patterns were intended for use with the Design Event Approach of flood estimation which has limited capability of incorporating the full stochastic nature of various flood-producing variables. Each of the standard durations was divided into a number of equal periods as shown in Table 1.

Table 1. ARR temporal patterns for 30 minutes duration for Zone 3 (6 periods of 5 minutes).

ARI	% of total rainfall					
Period	1	2	3	4	5	6
≤30 years	16	25	33	9	11	6
ARI>30 years	16	24	30	10	12	8

3. METHOD OF AVERAGE VARIABILITY

The Method of Average Variability is explained in Table 2 following Pilgrim et al. (1969) which gives the first 10 ranked storms of duration 20 minutes. Each storm is divided into four 5 minutes periods.

For example, in Table 2, Burst 1 has 32mm, 48mm, 48mm and 48mm rainfalls in Periods 1, 2, 3 and 4 respectively. The rank of each period is given in the next four Columns 8 to 11 and the percentage of rain in each period is given in the next four Columns 12 to 15. Where same amounts of rain falls in more than one period, an average ranks are assigned, as shown for Storms 1, 2, and 7. The average value for each column is obtained and the columns or periods are given assigned ranks on the basis of these average values. This is used to determine the most likely chronological order of the average heaviest period, second heaviest period, and so on, as noted in the "assigned rank" row.

In Columns 12 to 15, the percentages of rain in the various periods are listed in order of magnitude. For a given duration the average variation from a uniform burst is found by averaging the percentages of rainfall in the most intense period of each of the ranked bursts, then in the second most intense period of each burst, and so on. This is done by averaging the percentages of rainfall appearing in Columns 12 to 15 in Table 2, the average rainfall in the heaviest period being 31% of the total burst, the second heaviest 27% of the total burst, and so on. These average percentages of rainfall are a reasonable estimate of the percentages that would occur in the periods of the burst of rainfall of average variability.

Table 2. Method of Average Variability (Pilgrim et al., 1969)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date	Rain in mm	Rank	Rain in Each Period Period				Rank of Each Period's Rainfall Period				% of Rain in Period of Each Rank Rank			
			1	2	3	4	1	2	3	4	1	2	3	4
20.11.32	176	1	32	48	48	48	4	2	2	2	27	27	27	18
20.03.14	168	2	30	44	44	50	4	2.5	2.5	1	30	26	26	18
29.09.43	166	3	48	46	31	41	1	2	4	3	29	28	25	19
26.10.22	157	4	42	65	35	15	2	1	3	4	41	27	22	10
09.03.13	153	5	18	50	45	40	4	1	2	3	33	29	26	12
25.10.19	150	6	40	27	41	42	3	4	2	1	28	27	27	18
20.11.61	140	7	35	35	35	35	2.5	2.5	2.5	2.5	25	25	25	25
19.01.26	139	8	36	48	40	15	3	1	2	4	35	29	26	11
25.09.51	137	9	44	20	37	36	1	4	2	3	32	27	26	15
15.06.49	133	10	42	40	35	16	1	2	3	4	32	30	26	11
			Average				2.55	2.20	2.50	2.75	31	27	26	16
			Standard Deviation				1.25	1.11	0.66	1.13	4.6	1.5	1.4	4.8
			Assigned Rank				3	1	2	4				
			Period				1	2	3	4				
			Final Pattern (% of Total Rainfall)				26	31	27	16				

The chronological sequence of the periods is then determined. It is considered that the most intense rainfall within the storm should be assigned to the period whose average rank is the lowest. Similarly, the second most intense rain is assigned to the period whose average rank is second lowest and so on. This is shown in Columns 8 to 11 in Table 2 where the lowest average rank occurs in Column 9, which represents the second period of the rainfall burst, the next lowest average rank is in the third period of the burst, and so on.

Thus the pattern of the 20 minutes rainfall burst of average variability derived from the 10 most intense 20 minutes duration bursts as shown would have 5 minutes periods containing respectively 26%, 31%, 27%, and 16% of the total rainfall, respectively.

4. DESCRIPTION OF THE PROGRAM WINDOWS_TP

The program WINDOWS_TP was developed using Microsoft Visual Basic 6.0 and Microsoft Access 2000. The main dialog box of this program is shown in Figure 1.

The program allows selection of data file path and thereafter selection of pluviograph stations to be included in the derivation of temporal patterns. This requires selection of the desired duration for which design rainfall temporal pattern is sought. The number of rainfall events to be included in the derivation of temporal pattern needs to be selected. The button "Process Data" is used to select required number of rainfall events from the selected pluviograph stations. Finally, there are two buttons to calculate design rainfall temporal patterns for ARIs ≤ 30 years and ARI > 30 years as per the Method of Average Variability described in Section 3. The program opens Microsoft Excel at this stage and creates an output file containing raw temporal patterns.

The program requires formatted pluviograph data at 5-minutes interval. In selecting the rainfall events the ARR 87 method is adopted, the criterion for independence of storm bursts is that there should be no overlapping in time of successive storm bursts. Also, the rainfall within each storm burst does not have to persist for the full length of the subject duration, in which case the storm burst is taken to commence at the start of the rainfall, with little or no rainfall over the latter periods of the storm duration.

To select the burst, a threshold value of rainfall intensity is considered, which is 90% of 1 year ARI rainfall intensity for a given duration. Any event having rainfall intensity over the threshold value is selected in the preliminary set of candidate events. Finally, based on the rank of rainfall intensity, *N* number of rainfall events are selected from a station where *N* is the record length of rainfall data in years for the station.

The raw temporal patterns need to be checked for the position of the peak. When the peak is located in the first or second periods, this needs to be shifted to later periods to avoid initial loss sensitivity problem in design flood estimation as per the ARR 87 procedure.

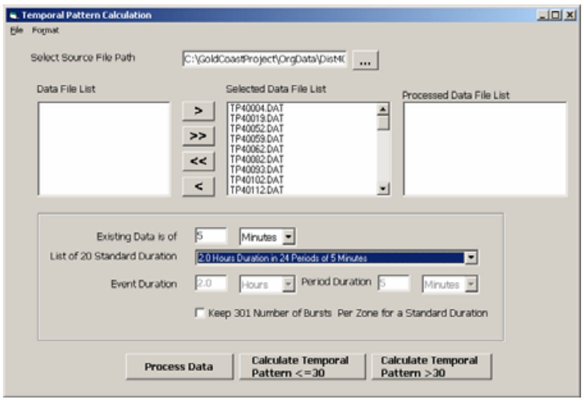

Figure 1. Main dialog box of the program Windows_TP to derive design rainfall temporal patterns

The internal consistency of the raw temporal patterns with respect to the sub-duration rainfalls needs to be tested at a number of selected locations in the study area. For this, a set of rainfall intensity-frequency-duration (IFD) data is compiled for each of the 20 standard durations at each of the selected locations using the ARR 87 procedure. The rainfall intensity of 20 years ARI value is then calculated at each of the selected locations for each of the 20 durations. These values are then used (as per the ARR 87 method) to test the sub-duration consistency of the temporal patterns, as follows.

At each selected locations, the derived temporal patterns are used to assign rainfall increments to each of the periods for each of the 20 standard durations. This is done on a spreadsheet. If inconsistencies are found i.e. when the sub-duration rainfalls derived from the temporal patterns exceed by 10% from the sub-duration rainfall obtained from the ARR design rainfalls, a filtering procedure is adopted to adjust the raw temporal patterns to reduce the difference to about 10%.

According to the ARR 87 procedure for derivation of temporal patterns for ARIs > 30 years, the developed program filters the data from the database and keep only the highest 15 percent of the bursts, based on the rainfall intensity for each of the 20 standard durations, for each of the selected pluviograph stations and then calculate the temporal patterns using the Method of Average Variability. The raw temporal patterns for ARI > 30 years need to be adjusted following the ARR 87 procedure to have ranking positions similar to that of the temporal patterns for the ARIs ≤ 30 years.

5. APPLICATION OF THE PROGRAM WINDOWS_TP

The program WINDOWS_TP was applied to the Gold Cast region in Queensland Australia. A total of 22 pluviograph stations over a radius of 90 km from the Gold Coast were selected. The selected stations were at least 7 km apart from one another and have at least 6 years of continuous data. The average length of pluviograph data of these stations was 31.7 years. The final set of design rainfall temporal patterns for the Gold Coast region is provided in Table 3 for selected durations, which is referred to as the UWS 2004 temporal patterns.

To compare the UWS 2004 temporal patterns and the ARR 87 temporal patterns, the highest percentage value and its location are compared in Table 4 for eight selected durations. It is interesting to note that the highest percentage values are not very dissimilar in the two methods, but the position of the highest value varies significantly. For example, for the 12 hours and higher durations, the positions of the highest values in the ARR 87 temporal patterns are at the initial parts of the storms but for the UWS 2004 temporal patterns, the highest values are located in the later parts of the storms. This is likely to produce smaller peak floods while using the ARR 87 temporal patterns as compared to the UWS 2004 temporal patterns.

A simple conceptual runoff routing model was used to validate the UWS 2004 rainfall temporal patterns. For this purpose, the Coomera River catchment at Army Camp (catchment area 88 km^2) was selected. The initial loss (IL) and continuing loss (CL) values in the runoff routing were selected from calibration of the model using a number of selected rainfall and streamflow events from the catchment.

Table 3. UWS 2004 design rainfall temporal patterns in the Gold Coast region for selected durations. Percentages of total rainfall in each period.

	Period																	
ARI (years)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
10 minutes duration in 2 periods of 5 minutes																		
≤ 30	62.7	37.3																
> 30	55.8	44.2																
15 minutes duration in 3 periods of 5 minutes																		
≤ 30	32.9	47.4	19.7															
> 30	36.6	42.2	23.2															
1 hour duration in 12 periods of 5 minutes																		
≤ 30	2.2	5.8	8.9	13.5	21.6	16.8	11.0	7.3	4.7	3.8	2.9	1.5						
>30	2.7	6.4	9.3	13.0	19.2	15.5	11.0	7.9	5.3	4.4	3.5	1.9						
4.5 hours duration in 18 periods of 15 minutes																		
≤ 30	1.5	4.2	9.1	15.3	11.5	21.5	7.3	6.0	5.0	3.7	3.2	2.7	2.4	2.0	1.7	1.2	1.0	0.7
>30	1.8	4.6	9.1	14.1	11.0	19.1	7.5	6.4	5.3	4.1	3.6	3.1	2.7	2.3	2.0	1.4	1.2	0.8
6 hours duration in 12 periods of 30 minutes																		
≤ 30	3.3	6.1	27.7	18.2	12.7	7.5	9.4	4.9	4.1	2.7	2.1	1.4						
>30	4.0	6.8	24.7	16.7	12.2	8.0	9.4	5.6	4.8	3.4	2.7	1.9						
18 hours duration in 18 periods of 1 hour																		
≤ 30	1.3	2.4	2.8	3.8	4.5	8.9	15.1	22.3	11.1	7.3	5.2	6.2	3.3	2.0	1.7	1.0	0.7	0.4
>30	1.5	2.8	3.2	4.2	4.9	8.9	13.9	19.8	10.7	7.5	5.6	6.6	3.7	2.3	2.0	1.2	0.8	0.5
36 hours duration in 18 periods of 2 hours																		
≤ 30	1.1	1.8	2.3	5.1	2.8	3.5	9.3	16.1	24.8	11.8	7.5	6.2	4.2	1.4	0.8	0.6	0.4	0.2
>30	1.4	2.2	2.7	5.6	3.2	3.9	9.3	14.8	22.1	11.3	7.7	6.6	4.7	1.7	1.0	0.7	0.5	0.3
72 hours duration in 18 periods of 4 hours																		
≤ 30	0.9	1.6	2.1	4.5	5.8	3.4	9.5	12.8	18.0	28.2	7.4	2.7	1.2	0.7	0.5	0.3	0.2	0.1
>30	1.3	2.0	2.6	5.0	6.1	3.9	9.5	12.3	16.6	25.1	7.6	3.2	1.6	1.0	0.8	0.5	0.4	0.3

Table 4. Comparison of ARR 87 and UWS 2004 design rainfall temporal patterns

Duration	Highest temporal pattern (%)		Position in the period	
	ARR 87	UWS 2004	ARR 87	UWS 2004
30 Minutes	33	31.2	3	3
1 Hour	23.2	21.6	5	5
3 Hours	24.1	26.0	4	4
6 Hours	25.6	27.7	3	3
12 Hours	20.3	18.5	3	12
24 Hours	22.0	19.9	2	13
48 Hours	22.4	23.1	1	9
72 Hours	28.9	28.2	1	10

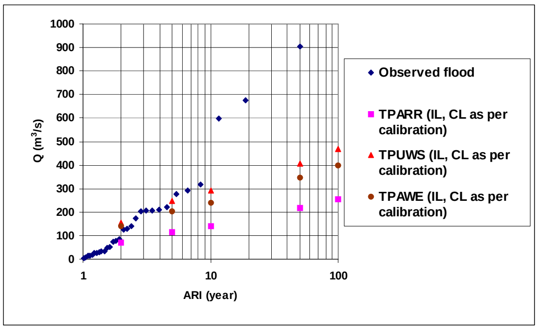

Figure 2. Impacts of the ARR 87 and UWS 2004 design rainfall temporal patterns on flood estimation

In Figure 2, three sets of temporal patterns are compared: the UWS 2004, ARR 87 and Australian Water Engineering (AWE) temporal patterns (AWE, 2000). The AWE temporal patterns were obtained in year 2000 based on 12 pluviograph stations in the Gold Coast region. Of all the three temporal patterns, the UWS 2004 temporal patterns are found to provide best match with the observed floods up to 10 years ARI. None of the temporal patterns provides a satisfactory fit for the higher ARI floods.

6. CONCLUSIONS

The paper presents a windows-based program called WINDOWS_TP to compute design rainfall temporal pattern which is an important input to the rainfall-based design flood estimation method. The program requires formatted pluviograph data of 5 minutes interval from a set of pluviograph stations selected from the region of interest. The program uses the recommended technique by the Australian Rainfall and Runoff (ARR) known as the 'Method of Average Variability' to derive design rainfall temporal patterns. The output from the program requires smoothing and rationalization similar to the ARR procedure to come up with the final set of design rainfall temporal patterns. The program gives design rainfall temporal patterns in 20 standard durations and in two average recurrence intervals, less than 30 years and greater than 30 years similar to the ARR procedure.

The main advantages of this program are that it is easy to use and it can process a large volume of pluviograph data to derive design rainfall temporal patterns. The use of this program allows the user to derive design temporal patterns based on the local pluviograph stations which may be more relevant to a particular region. It is expected that such design rainfall temporal patterns will increase the reliability of design flood estimates and as such the program is expected to have a wider application in hydrologic research and practice in Australia.

7. ACKNOWLEDGEMENTS

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