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An Evaluation of the Antecedent Rainfall Prior to Significant Rainfall Events in Sydney

J. Blaikie[1], J.E. Ball[2*]

[1]Formerly Student, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, Australia
[2]Water Research Laboratory, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, Australia
*Corresponding Author Email - j.ball@unsw.edu.au

ABSTRACT
A common approach for the assessment of flood risk associated with a proposed development in a flood-prone area is the utilisation of a catchment modelling system. Numerous alternative hydrologic and hydraulic process models have been proposed for inclusion in these systems of process models. In a similar vein, a number of alternative rainfall models for the description of the spatial and temporal variation of rainfall have been proposed. Previous studies such as those by Walsh *et al.* (1991) and Hill *et al.* (1996) have shown the importance of the loss model, or the model by which water is removed from rainfall to produce potential surface runoff. While previous studies have indicated the importance of loss models in the estimation of a design flood flow with a pre-defined annual exceedance probability, little information has been developed to assist modellers with the task of converting rainfall of a given annual exceedance probability into flow with the same exceedance probability through the application of catchment modelling systems. Furthermore, even less information has been presented on the magnitude of likely antecedent conditions and the variation of these conditions with the desired annual exceedance probability. Presented in this proposed paper will be an analysis of rainfall across Sydney with the aim of developing the most likely antecedent conditions prior to a rainfall event of a defined annual exceedance probability. It will be shown that these conditions vary across the Sydney region and that a single design value is unlikely to be appropriate.

KEYWORDS
Losses, Rainfall, Precipitation, Model, Sydney, API

INTRODUCTION
The application of catchment modelling systems is now a common approach for obtaining the information necessary for management of catchments. Fundamental to the application of a catchment modelling system are the processes of calibration and validation of the many control parameters used to ensure that the simulated catchment response adequately reproduces the actual catchment response. The calibration process, in general, consists of the systematic variation of control parameter values until a set of values is obtained that results in the adequate reproduction of the actual catchment response as obtained through recorded catchment response data. In other words, the desire in the calibration process is the determination of control parameter values for the mathematical models representing the various catchment processes that influence the generation of surface runoff.

In the design situation, however, the desired information from the catchment modelling system is not the catchment response to a storm burst with particular rainfall statistics but rather the prediction of flows with particular statistical characteristics. In other words, the catchment modelling system is used to achieve the desired transformation of rainfall frequency to flow frequency. As a result, the values of the control parameters for the catchment modelling system are selected in a manner to ensure that the desired frequency transformation is maintained; ie the 100 year ARI rainfall results in the 100 year ARI flow.

There are many storm characteristics and catchment processes that influence the transformation of rainfall into runoff. The storm characteristics include the spatial extent of the rainfall and the temporal pattern of the storm burst. For a design situation, these storm characteristics commonly are predetermined. For example, within Australia the temporal pattern of the design storm burst is developed using the Average Variability Method of Pilgrim and Cordery (1975).

One of the catchment characteristics that influences the transformation of rainfall into runoff is the loss model which, together with the associated control parameters, has been shown through previous studies (see, for example, Hill *et al.* (1996) and Walsh *et al.* (1991)) to have a significant impact on the desired transformation of rainfall to runoff. Both of these studies have focussed on the larger rural catchments rather than the smaller urban catchments. As a consequence, there is limited information regarding appropriate control parameter values for a catchment modelling system when applied in a design situation within an urban environment.

When a loss model is implemented in a catchment modelling system there is a need to consider the spatial and temporal characteristics of the control parameters used to define the model. The form of the model implemented and the manner in which the catchment modelling system will be used also influences the values of the control parameters used for the loss model. It is pertinent, therefore, to review alternative forms of loss model. Cordery (1987) suggested that loss models can be categorised as

- loss (and hence runoff) is a constant fraction of rainfall in each time period. This is an extension of the runoff coefficient concept;
- constant loss rate, where the rainfall excess is the residual left after a selected constant rate of infiltration capacity is satisfied;
- initial loss and continuing loss, which is similar to the first case except that no runoff is assumed to occur until a given initial loss capacity has been satisfied, regardless of the rainfall rate. The continuing loss is at a constant rate. A variation of this model that is sometimes recommended is to have an initial loss followed by a loss consisting of a constant fraction of the rainfall in the remaining time periods;
- an infiltration curve or equation, representing capacity rates of loss varying (decreasing) with time; and
- standard rainfall-runoff relation, such as the US Soil Conservation Service curve number relationships.

These alternative loss models are illustrated in Figure 1. Each of these alternative loss models can be applied in a design situation using a number of different approaches. Among these approaches are

- The classical design storm burst approach whereby the catchment modelling system is used to transform the design storm burst into a flood flow with the same probability as the rainfall intensity, ie an AEP or ARI neutral transformation;

- The Monte-Carlo approach (Weinmann *et al.*, 2002) whereby the catchment modelling system is used to estimate flood flows for a variety of catchment conditions and storm bursts to develop the annual series of flood flows; and
- The continuous simulation approach (see, for example, Muncaster *et al.*, 1997) whereby a continuous sequence of rainfall is transformed through a catchment modelling system to produce a continuous sequence of flow estimates which can be analysed using flood frequency techniques to develop the flood flow with the desired frequency.

The values of the control parameters will vary with the approach used. For example, Cordery (1987) suggests that median values should be adopted when the first of the above three approaches is used. However, previous studies have not defined appropriate median values for urban catchments.

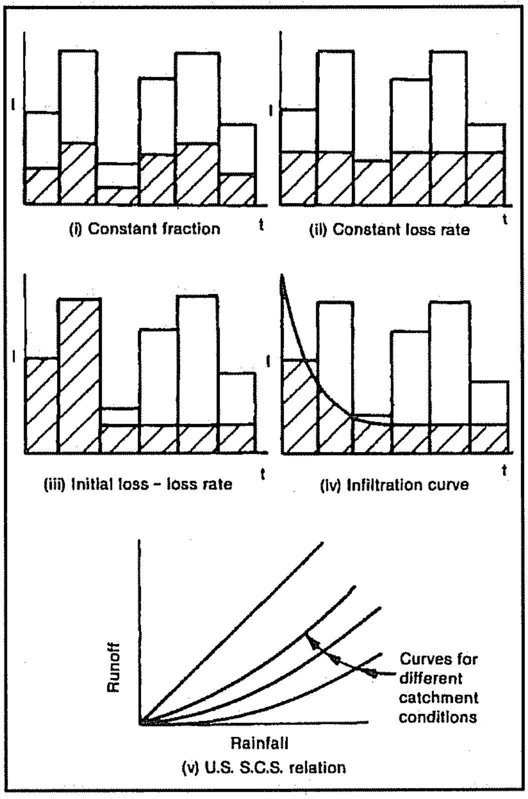

Figure 1. Alternative Loss Models Proposed by Cordery 1987

On the other hand, implementation of the second and third approaches requires a knowledge of how the control parameters vary so that, for the second approach, an appropriate sampling methodology can be employed while, for the third approach, models describing the variation in the control parameter values are required.

It is apparent, therefore, that a greater knowledge of the variation in control parameter values is needed. The aim of the study reported herein therefore was to provide information regarding the antecedent rainfall prior to the intense burst of rainfall in the Sydney region.

DATA

Spatial extent of Data

Data for analysis of the antecedent conditions prior to the onset of significant storm bursts in the Sydney region were obtained from pluviometers operated by the Bureau of Meteorology and by Sydney Water. Outlined in Table 1 are details of these pluviometers while their locations are shown in Figure 2.

Wet Day Definition

An important component in the analysis is the definition of the minimum precipitation for a day to be classified as wet. Shown in Figure 3 is the relative frequency, based on the data recorded at the Observatory Hill pluviometer, of the length of the antecedent period for different precipitation depths used for delineation between days that would be considered to be a wet and those that would be considered to be a dry day. As shown in this figure, the length of the antecedent dry period is influenced by the adopted precipitation depth. The maximum value considered was 10mm which was the value adopted in a previous study by Minty and Meighen (1999) while the minimum value considered was 0.1mm. Since the mean daily potential evapotranspiration for the Sydney region varies between 1.5 and 5.8mm, it was considered that rainfall

Table 1 Pluviometer Details

NAME	SOURCE	LAT.	LONG.	RECORDS START	RECORDS END
Castle Hill Sewage Treatment Plant	Sydney Water	-33.712	150.985	31/12/1972	4/09/03
Hornsby Bowling Club	Sydney Water	-33.670	151.100	29/6/1982	1/09/03
Liverpool Pumping Station	Sydney Water	-33.923	150.926	1/1/1960	1/09/03
Lucas Heights ANSTO	Bureau of Meteorology	-34.052	150.980	1/1/1960	7/07/03
North Head Sewage Treatment Plant	Sydney Water	-33.808	151.303	29/8/1981	31/08/03
Observatory Hill	Bureau of Meteorology	-33.861	151.205	1/1/1960	7/07/03
Prospect Dam	Bureau of Meteorology	-33.819	151.913	1/1/1960	7/07/03
Richmond (UWS - Hawkesbury)	Bureau of Meteorology	-33.819	150.748	1/1/1960	31/05/03
Riverview Observatory	Bureau of Meteorology	-33.826	151.156	1/1/1960	7/07/03
Seven Hills (Collins St)	Bureau of Meteorology	-33.771	150.932	1/1/1960	31/05/03
Sydney Airport Meteorological Office	Bureau of Meteorology	-33.941	151.173	1/1/1960	7/07/03
Warragamba Meteorological Station	Sydney Water	-33.800	150.600	1/1/1960	3/09/03
Warriewood Sewage Treatment Plant	Sydney Water	-33.680	151.300	1/7/1976	1/09/03
West Epping Bowling Club	Sydney Water	-33.800	151.067	1/1/1980	31/08/03
West Ryde Pumping Station	Sydney Water	-33.808	151.085	1/1/1960	31/08/03

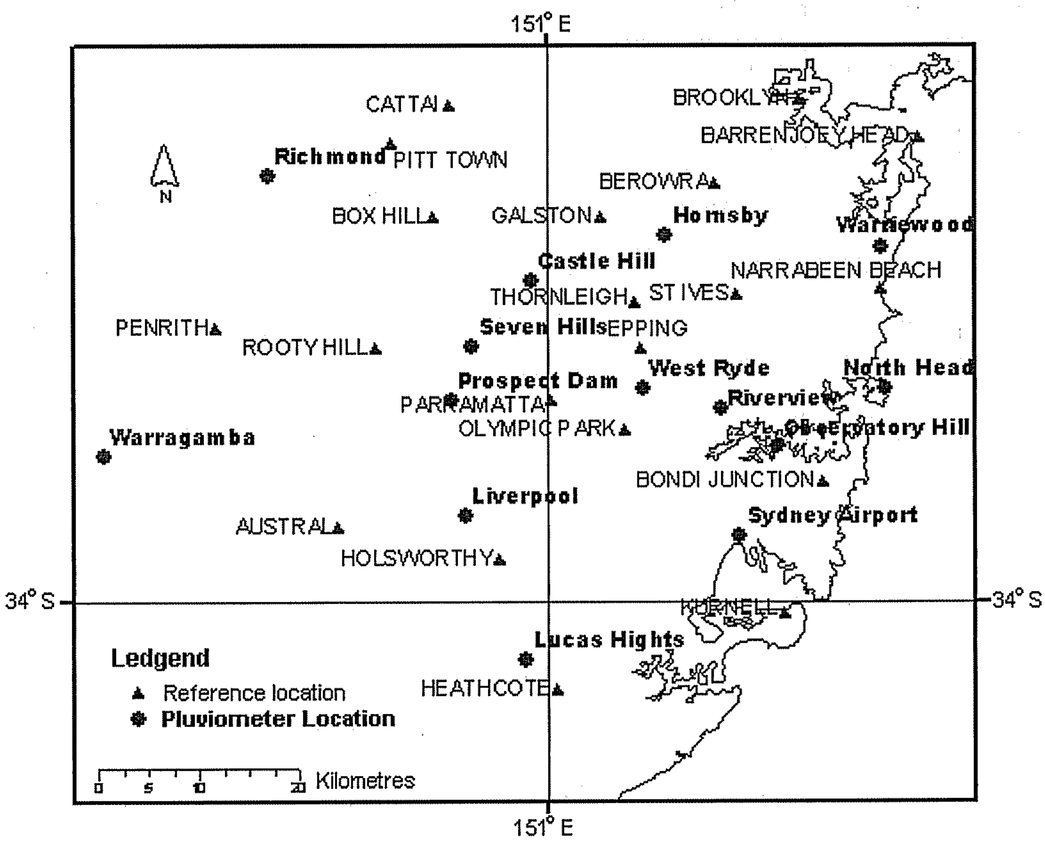

Figure 2. Locations of Pluviometers

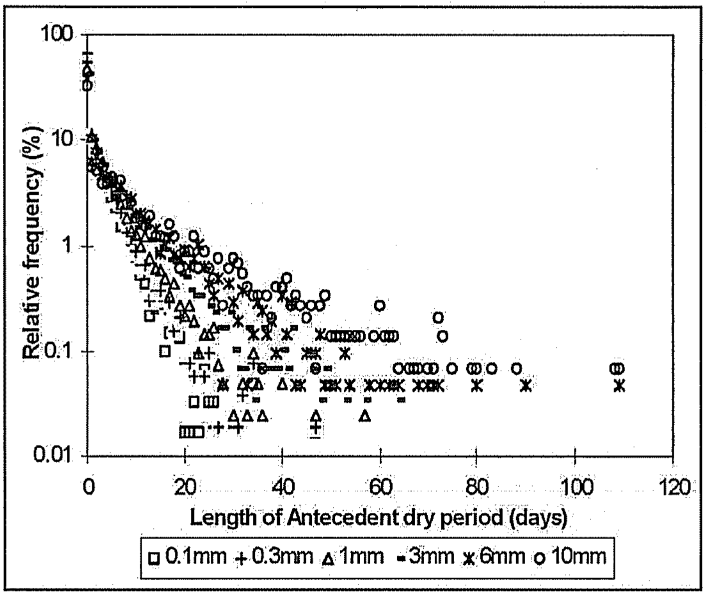

Figure 3. Relative Frequency of Antecedent Dry Periods with Different Minimum Precipitation values

less than 6mm will have negligible impact on the soil moisture (particularly in January) and hence on the infiltration capacity of the soil. As shown in Figure 3, the relative frequencies of the length of the antecedent dry period are similar when 6mm and 10mm were used as the delineation point. Therefore, a value of 10mm was adopted.

General Data Obtained

For each pluviometer, the data were analysed to obtain the following information

- Antecedent Dry Period;
- Rainfall in the day prior to the wet day; and
- Rainfall in the 5 days prior to the wet day.

Using this information, the length of the antecedent dry period and the depth of antecedent rainfall were determined as a function of the precipitation depth on a wet day. In addition, regression relationships were developed at each pluviometer to enable prediction of the likely antecedent rainfall for a given precipitation depth in a storm burst. Data from these relationships were used to develop spatial estimates of the antecedent rainfall for given rainfall depths in 24 hour storm bursts.

Results from Castle Hill Pluviometer

Typical results obtained are shown in Table 2 where results from analysis of the pluviometer at Castle Hill are presented. As indicated by consideration of the difference between the mean and median results, the data are highly skewed and a normal distribution is not an appropriate representation of the data. For this reason, the predicted antecedent rainfall for different ARI storm bursts will be presented in terms of the median depth rather than the mean depth.

Shown in Figures 4 to 5 are graphical representations of the results obtained from analysis of the data recorded at the Castle Hill pluviometer together with relevant regression relationships through the data points. The first of these figures relates to the dry period prior to a wet day with the specified rainfall while the second of these figures is related to the depth of antecedent rainfall prior to a wet day with the specified rainfall.

Table 2 Results from Castle Hill Pluviometer

Min Rainfall	Days with Rain > Min Value	Median			Mean		
		Previous Day Rain	Total Rain Previous 5 Days	Dry period Duration	Previous Day Rain	Total Rain Previous 5 Days	Dry period Duration
0.1	2618	1.4	8.5	0	6.3	22.3	1.6
1	1781	2.5	10.0	0	8.1	24.4	2.9
3	1187	4.0	12.0	0	10.6	28.5	4.8
6	781	5.6	16.0	1	13.4	32.8	7.9
10	516	7.6	20.2	2	16.6	36.8	12.4
20	247	14.3	30.0	0	23.5	46.8	10.8
30	134	17.8	35.5	0	29.6	56.1	9.0
40	79	19.5	42.2	0	37.3	68.0	8.5
50	49	20.4	43.6	0	42.6	75.2	6.9
60	31	34.6	55.9	0	50.8	84.5	2.9
70	24	26.2	57.3	0	47.7	83.1	3.8
80	14	60.4	79.0	0	67.7	118.8	1.8
1y 24h ARI	9	78.4	98.1	0	83.6	112.9	2.4
2y 24h ARI	5	78.4	98.1	0	81.0	93.4	-
5y 24h ARI	2	83.1	85.5	0	83.1	85.5	-

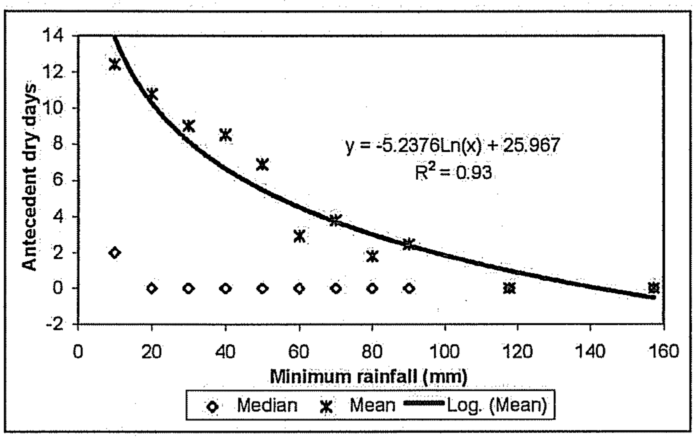

Figure 4. Antecedent Dry Period at Castle Hill

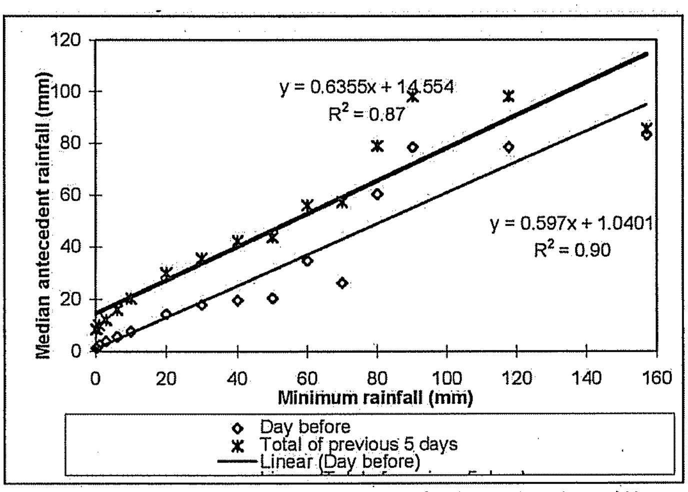

Figure 5. Antecedent Dry Period at Castle Hill

Variation in Antecedent Dry Period Duration

From consideration of the available data, a wet day in the Sydney region is very likely to be preceded by a wet day. Therefore, a second analysis of the antecedent dry period was undertaken with only the wet days preceded by a dry day considered. As shown in Table 3, the mean and median dry period increased when only the wet days preceded by a dry day were considered.

It was found, also, that the median and mean duration of the antecedent dry period decreases with an increase in the minimum, or specified, depth of rainfall on a wet day.

Variation in 5 Day Antecedent Rainfall

The antecedent rainfall for the previous day and the total depth of rainfall over the previous five (5) days are shown in Figure 5. As discussed previously, regression equations were fitted through these two sets of data.

Table 3 Antecedent Dry Period at Castle Hill Pluviometer

Location	1mm Dry Period Definition				10mm Dry Period Definition			
	Median		Mean		Median		Mean	
	All Wet Days	First Wet Day	All Wet Days	First Wet Day	All Wet Days	First Wet Day	All Wet Days	First Wet Day
Castle Hill Sewage Treatment Plant	0	5	2.9	7.0	2	12	12.4	22.2
Hornsby Bowling Club	1	4	3.1	5.9	3.5	10	10.6	16.7
Liverpool Pumping Station	0	5	2.9	7.6	1	16	14.3	26.0
Lucas Heights ANSTO	1	4	3.3	6.2	4.5	11	12.2	17.9
North Head Sewage Treatment Plant	1	4	3.2	6.0	5	10	10.7	15.5
Observatory Hill	1	4	2.8	5.5	5.8	14.8	9.9	9.0
Prospect Dam	1	4	3.5	6.5	5	11	13.7	19.5
Richmond (UWS - Hawkesbury)	1	4	3.7	6.8	5	11	15.0	21.0
Riverview Observatory	1	4	1.4	5.8	4	9	1.4	16.1
Seven Hills (Collins St)	1	4	3.5	6.5	6	11	13.6	19.3
Sydney Airport Meteorological Office	1	4	3.0	5.7	4	10	10.9	15.6
Warragamba Meteorological Station	0	5	2.5	7.7	0	15	13.2	27.9
Warriewood Sewage Treatment Plant	0	4	2.3	6.2	1	12	6.1	18.8
West Ryde Pumping Station	1	4	3.6	6.6	5	11	13.4	18.6

An interesting result arising from consideration of Figure 5 is that the majority (up to 83%) of the precipitation occurring over the preceding five days occurs in the day immediately prior to the day being considered. This result needs further investigation to address the implication of the majority of the 5 day antecedent rainfall occurring during the day immediately prior to the day being considered on the likely initial infiltration capacity at the onset of the design storm burst.

Spatial Variation in Antecedent Rainfall Depth

Using the regression relationships obtained from analysis of the data at each of the fourteen pluviometers distributed across the Sydney region, the predicted 5 day antecedent rainfall depths were predicted for the 1, 2, 5, 10, 20, 50, and 100 year 24 hour rainfall bursts. These predictions are presented in Figures 6 to 9 for the 1, 5, 20 and 100 year ARIs; predictions for the other ARIs are presented by Blaikie (2003). As indicated in these figures, the predicted antecedent depth of rainfall is not constant across the Sydney region. High antecedent depths of rainfall are predicted along the coast with lower depths of antecedent rainfall inland. This is consistent with the gradient in average annual rainfall which is highest along the coast and decreases as the distance to the coast increases.

CONCLUSIONS

Rainfall records from 14 pluviometers distributed across the Sydney region were analysed to ascertain the antecedent rainfall prior to a 24 hour storm burst. From this analysis, it was determined that a significant portion (up to 85%) of the 5 day antecedent rainfall occurred on the day prior to a wet day and the antecedent depth of rainfall increased with the storm burst rainfall depth. Furthermore, the antecedent rainfall depth for a given ARI was not constant across the Sydney region.

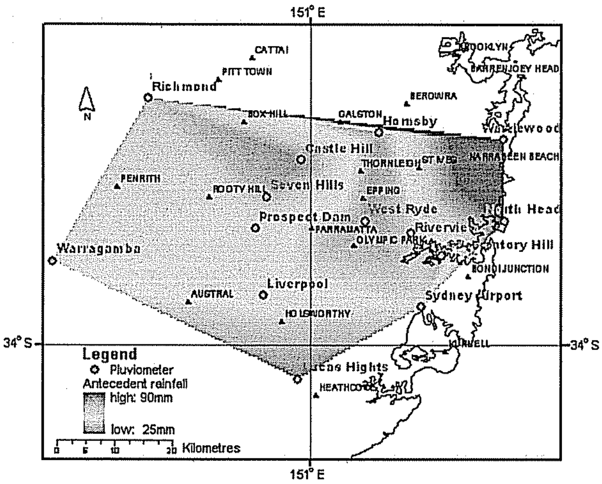

Figure 6. 1 Year ARI 5 Day Antecedent Rainfall

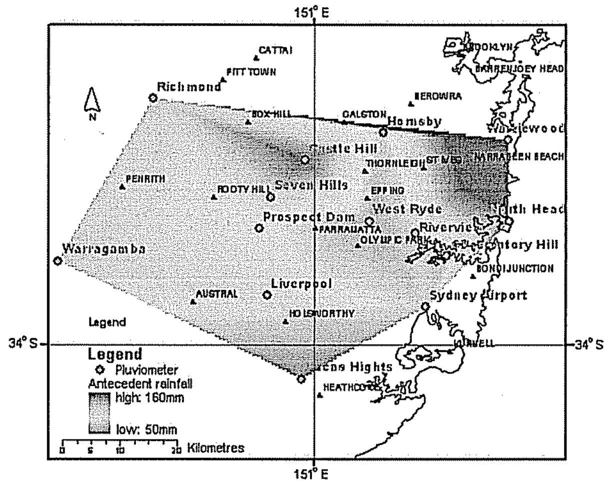

Figure 7. 5 Year ARI 5 Day Antecedent Rainfall

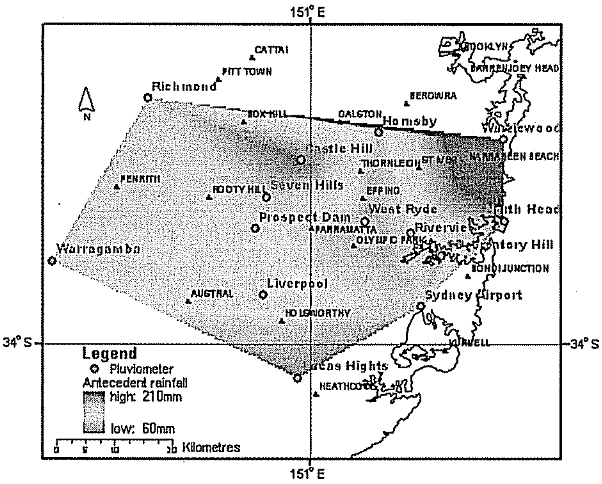

Figure 8. 20 Year ARI 5 Day Antecedent Rainfall

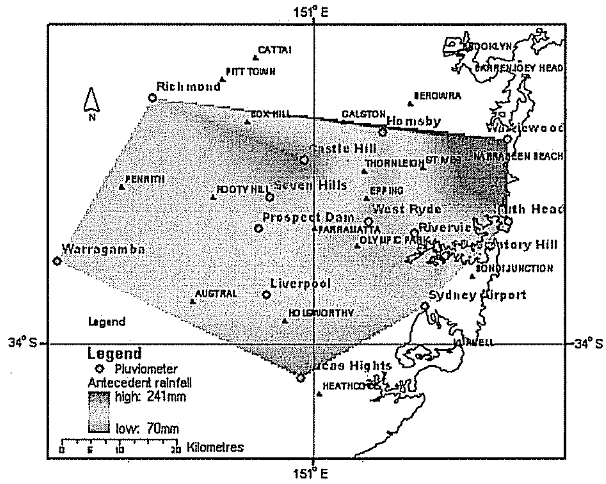

Figure 9. 100 Year ARI Predicted 5 Day Antecedent Rainfall

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