Probability-distributed Initial Losses for Flood Estimation in Queensland

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Abstract: The rainfall based design flood estimation techniques are commonly adopted in hydrological design. Design loss is an important input to all rainfall runoff models. There is inadequate information on design losses in many parts of Australia and this is one of the greatest weaknesses in Australian flood hydrology. Present design losses in Queensland are not compatible with design rainfall information in Australian Rainfall and Runoff. This paper examines the variability of initial losses in ten eastern Queensland catchments. The observed initial losses from 882 rainfall events are found to be much higher than the currently recommended values by Australian Rainfall and Runoff for eastern Queensland. The initial losses in eastern Queensland are found to be much higher than those of Victoria. It has been found that a four-parameter Beta distribution can be used to approximate initial loss distribution for the selected catchments in eastern Queensland. The fitted Beta distribution can be used to generate initial loss data for flood estimation in these catchments using a Joint Probability Approach.

Keywords: Initial loss; Rainfall runoff modelling; Flood estimation; Joint Probability Approach

1. INTRODUCTION

Flood estimation is often required in hydrologic design and has important economic significance. For example, in Australia, the annual spending on infrastructure requiring flood estimation is of the order of $1 billion. Rainfall-based flood estimation techniques are most commonly adopted in practice; these require several inputs/parameters to convert design rainfalls to design floods. Of all the inputs/parameters, loss is an important one and defined as the amount of precipitation that does not appear as direct runoff. Loss includes the factors involved in reducing the runoff during a flood event. The concept of loss includes moisture intercepted by vegetation (interception loss), infiltration into the soil (infiltration), retention on the surface (depression storage), evaporation and loss through the streambed and banks. As these loss components are dependent on topography, soils, vegetation and climate, the losses exhibit a high degree of temporal and spatial variability during the rainfall event. Many loss models do not account for the interception, depression storage and transmission losses directly; all the loss is simply treated as infiltration into the soil.

In design flood estimation, the simplified lumped conceptual loss models are used because of their simplicity and ability to approximate catchment runoff behaviour. This is particularly true for design loss which is probabilistic in nature and for which complicated theoretical models may not be required. In Australia, the most commonly adopted conceptual loss model is the initial loss-continuing loss model [I. E. Aust., 2001; Hill et al., 1996a and b; Rahman et al., 2000]. For a specific part of the catchment, the initial loss occurs prior to the commencement of surface runoff, and can be considered to be composed of the interception loss, depression storage and infiltration that occur before the soil surface saturates. The continuing loss is the average rate of loss throughout the remainder of the storm.

The currently recommended design losses in Australian Rainfall and Runoff (ARR) [I. E. Aust., 2001] are not compatible with design rainfall information. Also design losses for observed storms show a wide variability and it is always difficult to select an appropriate value of loss from this wide range for a particular application. Despite the wide variability of initial loss values, in the widely used Design Event Approach, a single value of initial loss is generally adopted. Because of the non-linearity in the rainfall-runoff process, this is likely to introduce a high degree of uncertainty and possible bias in the resulting flood estimates.

A substantial improvement in design flood estimates can be achieved through a Joint Probability Approach, which considers probability-distributed model inputs/parameters (including initial loss) and their correlation structure to determine probability-distributed flood output [Rahman et al., 2001a and b].

This paper examines the variability of initial losses in selected eastern Queensland catchments and identifies a probability distribution to describe the observed initial losses. The fitted distribution can be used to generate initial loss data for flood estimation in the selected catchments using a Joint Probability Approach.

2. INITIAL LOSSES FOR FLOOD ESTIMATION IN AUSTRALIA

Initial loss is an important input to rainfall runoff models; however, the paucity of information on initial losses constitutes one of the greatest weaknesses in Australian flood design [Pilgrim and Robinson, 1988]. The design loss values, which are available for the initial loss and recommended in ARR, exhibit a wide range, which makes it difficult to select an appropriate value for a particular design application.

Many studies such as Hill and Mein [1996] and Waugh [1991] have found that the use of the design losses with the design rainfalls recommended in ARR results in overestimation of design peak flows, when compared with a frequency analysis of recorded peak flows. This indicates that, for many catchments, the design losses recommended in ARR are too low.

There are two inadequacies in the current loss values, most of which were derived from analysis of large flood events. The selection of high runoff events for loss derivation is biased towards wet antecedent conditions. That is loss tends to be too low. Storm losses do not account for the nature of design rainfalls, which have been derived from burst within longer storms. Since antecedent rainfall will pre-wet the catchment, losses derived for storms will tend to be too high for application to bursts. It is recognised in ARR that these two inadequacies have opposite effects, and it is assumed by users of the current design loss values that they compensate each other [I. E. Aust., 2001].

From a study of five Western Australia catchments, Waugh [1991] by examining the effect of the first inadequacy concluded that the selection of runoff events for the estimation of design loss underestimates the design loss. This underestimated design loss can result in over estimation of the design flood magnitude by up to 20%. This was because many sizeable summer storms yielded little or no runoff due to dry antecedent conditions, and were not represented in the analysis. Srikanthan and Kennedy [1991] examined the effect of the second inadequacy. They examined the degree to which the rainfall burst used to generate design temporal patterns was embedded within longer duration storms, and found that, for a given annual exceedance probability (AEP), antecedent rainfall prior to storm bursts decreased with increasing storm duration. This is because, as the duration of the bursts increases, more bursts represent complete storms. Some investigators [Walsh et al., 1991; Hill and Mein, 1996] have noted that, when applying the design losses recommended in ARR to the design rainfalls, the resulting critical duration is excessively long.

Hill et al. [1996a] mentioned that current design losses are inconsistent with design temporal pattern; because these design losses were taken from complete storms. But on the other hand, temporal patterns were taken from the bursts, many of which were embedded within longer duration storms. The design losses recommended in ARR lead to consistent overestimation of design peak flows compared to recorded peak flows. For AEP of 1 in 10, the average over-prediction was as high as 47 percent [Hill et al., 1997].

Hill et al. [1996a and b] derived design losses for Victoria which overcome the basic incompatibility between design rainfalls and losses used for design flood estimation. They found that baseflow index explains a greater variability in the calculated losses. By the application of the new design losses and new areal reduction factors, the 1 in 10 AEP design flood was predicted to within 25 percent of that estimated using flood frequency analysis.

More recently, Rahman et al. [2000] used initial loss-continuing loss model with the Joint Probability Approach for Victorian catchments. They considered initial loss as a probability distributed variable but continuing loss was represented by a single value.

The current Design Event Approach for flood estimation considers the probabilistic nature of rainfall depth but ignores the probabilistic behaviour of other inputs/parameters such as rainfall duration, losses, and temporal patters. The arbitrary treatment of the various flood producing variables, as done in the current Design Event Approach, is likely to lead to inconsistencies and significant bias in flood estimates for a given AEP. Rahman et al. (2001a and b) have developed a design flood estimation technique based on the Joint Probability Approach that can be applied easily under practical situations.

3. DATA SELECTION

A total of 10 catchments have been selected ranging from 93 km^2 to 480 km^2 (average: 227 km^2) from eastern Queensland, as shown in Figure 1. The selected catchments are mainly unregulated and rural and have reasonably long rainfall and streamflow records. A total of 882 rainfall events that have the potential to produce significant runoff are selected following the criteria described by Hoang et al. [1999]. This results in selection of about 4 rainfall events on average per year.

Figure 1. Locations of the study catchments in Queensland.

4. APPROACH

A pluviograph station was selected from each catchment. Partial series 'complete storm events' that have the potential to produce significant runoff, were selected from the hourly pluviograph data. A 'complete storm' is a period of significant rain preceded and followed by at least six dry hours [Hoang et al., 1999]. For each complete storm, a storm-core is identified, defined as the most intense rainfall burst within a complete storm [Rahman et al., 2001a and b].

The initial loss for a catchment is estimated following the approach of Hill et al. [1996a] from the concurrent hourly pluviograph and streamflow data. The initial loss for a complete storm (IL_s) is estimated to be the rainfall that occurs prior to the commencement of surface runoff. The storm-core initial loss (IL_c) is the portion of IL_s that occurs within the storm-core. In computing these loss values, a surface runoff threshold value equals to 0.01 mm/h has been used, similar to Hill et al. [1996a]; it is considered that surface runoff commences when the surface runoff threshold has been exceeded.

5. RESULTS

The computed IL_s and IL_c values of the selected catchments are shown in Table 1. Considering all the 882 rainfall events, the mean IL_s and IL_c values are respectively 46 mm and 40 mm, that is mean IL_c value is 15% smaller than mean IL_s value. The median values of IL_s and IL_c are respectively 40 mm and 35 mm. The standard deviations are relatively high (34 and 31 mm, respectively) showing a high degree of variability in computed loss values. Also the loss values show a high positive skewness with an average value of over 2. Some of the observed loss values are very high, e.g. an IL_s value of 329 mm for Andromache River catchment at Jochheims (Catchment ID: 124003). The corresponding rainfall event occurred on 27/08/98 and there was no appreciable rainfall in the catchment for a number of months prior to the event. The rainfall event and concurrent streamflow data for this loss value are plotted in Figure 2.

The computed initial losses in the study catchments are much higher than that recommended by ARR [Table 3.6, Book Two, p. 48, I. E. Aust., 2001] for Eastern Queensland. The median initial losses from the selected 882 rainfall events has a range of 26-56 mm (average value: 40 mm) as compared with ARR recommended value of 15-35 mm. This indicates that ARR recommended median initial loss is 60-70% smaller than that obtained here. The use of smaller initial losses, according to ARR recommendation, is likely to result in significant overestimation of design floods, similar to the findings of Hill et al. [1996a and b] for Victorian catchments.

Table 1. Loss statistics for ten Queensland catchments (N = number of events, SD = standard deviation).

Station	N	Complete storm loss (IL_s)					Storm-core loss (IL_c)				
		Range	Mean	Median	SD	Skew	Range	Mean	Median	SD	Skew
116010	38	0.26-86	37.97	36.78	20.96	0.20	17-86	37.16	35.87	12.44	1.89
117002	48	1-207	58.83	51.17	45.52	1.49	2-207	60.11	50.33	42.37	2.10
117003	51	0.11-197	49.76	41.44	43.25	1.58	15-184	56.75	44.52	40.27	2.08
120014	34	2-71	30.39	26.49	20.02	0.54	2-71	28.78	26.78	17.81	0.57
124003	26	14-329	79.36	55.72	65.28	2.42	8-204	62.89	47.30	46.43	1.61
136112	124	0.47-120	40.61	38.92	18.84	0.81	3-104	38.71	34.90	16.77	1.01
138110	218	0.16-286	53.85	44.97	39.01	1.99	3-251	50.95	39.23	34.72	2.30
143110	137	0.77-174	39.57	34.21	22.81	2.15	1-119	36.48	30.69	19.43	1.52
926003	100	0.07-142	41.45	38.87	27.48	1.10	1-134	42.99	39.66	23.89	1.02
922101	106	0.26-160	41.21	42.72	29.16	1.13	3-160	43.61	45.68	25.97	1.32
Average	88	0.07-329	46.05	39.92	33.88	2.39	0-251	40.01	35.58	30.68	2.00

In comparison to Victorian catchments (Rahman et al., 2000), losses in Queensland exhibit a much greater variability (as shown in Table 2); the median, mean, standard deviation (SD), coefficient of variation (CV) and skewness values are respectively 74%, 84%, 161%, 42% and 155% greater than that of Victoria. This shows that losses in Queensland, in general, are much higher and having greater variability than that of Victoria. Given the degree of variability and wide range of IL_s and IL_c values for Queensland catchments, it appears to be unreasonable to adopt a single representative value (either mean or median) of losses for flood estimation, as done with the Design Event Approach.

Table 2. Comparison of initial loss values from Queensland and Victorian catchments.

Initial loss for complete storm (IL_s) in mm	Qld	Vic	Variation (% higher for Qld)
Lower limit	0	0	-
Upper limit	329	143	130
Median	40	23	74
Mean	46	25	84
SD	34	13	161
CV	0.74	0.52	42
Skew	2.40	0.94	155

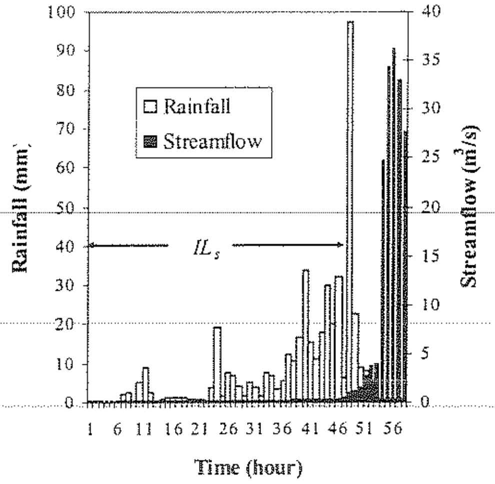

Figure 2. Illustration of the largest loss event.

The individual histogram of IL_s and IL_c values of all the 10 catchments are examined (examples are shown in Figures 3 and 4), and it is hypothesised that a four-parameter Beta distribution can be used to describe the loss distributions, similar to Victorian catchments [Rahman et al., 2000]. A four-parameter Beta distribution is fitted to individual site's IL_s data using observed values of lower limit (LL), upper limit (UL), mean and standard deviation of IL_s data. It may be noted here that fitting of a theoretical distribution to IL_s data is considered only because IL_c value can be estimated from simple relationship between IL_s

and IL_c, similar to Victorian catchments [Rahman et al., 2000]. For each catchment, a total of 10,000 values of IL_s are generated from the fitted four-parameter Beta distribution.

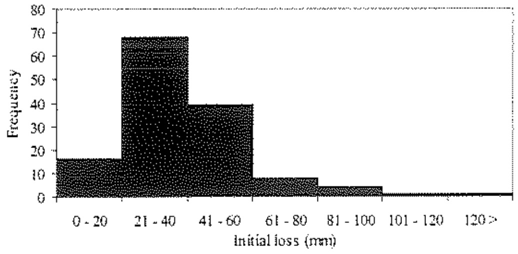

Figure 3. Histogram showing distribution of IL_s for catchment 143110.

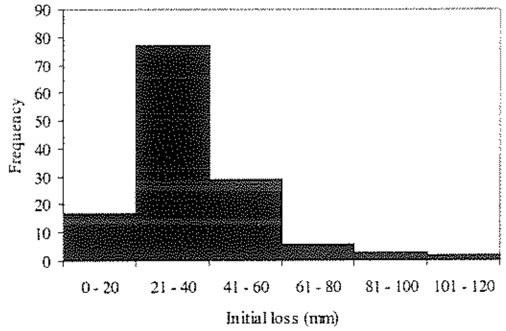

Figure 4. Histogram showing distribution of IL_c for catchment 143110.

The statistics of the observed and generated IL_s data are compared in Table 3, which shows that the generated data preserves the statistics of the observed loss value very well with respect to mean value (variation is in the range 0.68-2.42% with an average of 1.87%) and standard deviation (variation in the range 0-0.68% with an average of 0.36%). The lower limits of both the generated and observed data are very close to 0. In the case of the upper limit, the generated data, in general shows a smaller value; for 5 catchments (out of 10), the generated data underestimates the upper limit by < 2%, for three other catchments, this is 4%, 7% and 11%, respectively; for the remaining two catchments, the underestimation is 20% and 24%. Thus, the average deviation is 7% for the upper limit considering all the ten catchments. In the case of skewness, the generated data show a smaller skewness (10 to 65% smaller with an average value of 41%) as compared with observed data. The effects of the smaller value of skewness in the generated IL_s data on design flood estimates (using the Joint Probability Approach) is under investigation.

6. CONCLUSION

This paper examined the variability of initial losses in 10 eastern Queensland catchments. This uses 882 rainfall events that have the potential to produce significant runoff to compute initial losses.

Table 3. Comparison of at-site observed and generated IL_s data for the 10 catchments.

ID		LL	UL	Mean	SD	Skew
116010	Observed	0.26	86.00	37.97	20.96	0.20
	Generated	*0.01*	*85.29*	*37.05*	*20.96*	*0.22*
117002	Observed	1.00	207.00	58.83	45.52	1.49
	Generated	*1.01*	*204.90*	*57.42*	*45.37*	*0.81*
117003	Observed	0.11	197.00	49.76	43.25	1.58
	Generated	*0.00*	*195.23*	*48.79*	*43.26*	*0.94*
120014	Observed	2.00	71.00	30.39	20.02	0.54
	Generated	*2.00*	*70.99*	*29.78*	*19.98*	*0.35*
124003	Observed	14.00	329.00	79.36	65.28	2.42
	Generated	*14.00*	*325.50*	*78.82*	*65.38*	*1.18*
136112	Observed	0.47	120.00	40.61	18.84	0.81
	Generated	*0.88*	*107.63*	*39.84*	*18.63*	*0.42*
138110	Observed	0.16	286.00	53.85	39.01	1.99
	Generated	*0.05*	*228.75*	*52.85*	*39.25*	*1.01*
143110	Observed	0.77	174.00	39.57	22.81	2.15
	Generated	*0.31*	*132.02*	*38.90*	*22.84*	*0.75*
922101	Observed	0.26	160.00	41.23	29.16	1.13
	Generated	*0.03*	*149.81*	*40.43*	*28.96*	*0.81*
926003	Observed	0.07	142.00	41.45	27.48	1.10
	Generated	*0.05*	*137.49*	*40.69*	*27.55*	*0.68*

The following conclusions can be drawn from the study:

- The observed initial losses are much greater than the currently recommended values in the ARR for eastern Queensland. The observed median initial loss is found to be 60-70% greater than the ARR recommended value. This finding is being confirmed with a larger data set.

- The initial losses in eastern Queensland show a greater variability than that of Victoria. The median, mean, standard deviation (SD), coefficient of variation (CV) and skewness of initial losses in Queensland are 74%, 84%, 161%, 42% and 155% greater than those of Victoria.

- The initial losses in eastern Queensland can be approximated by a four-parameter Beta distribution. The generated initial losses from the fitted Beta distribution preserve the lower limit, mean and standard deviation of the observed losses very well. The upper limit of the generated data shows a moderate variation by about 7%. The skewness of the generated losses is much smaller (by about 41%) as compared with the observed values. The effects of smaller skewness in the generated loss data on flood estimates (using the Joint Probability Approach) are under investigation.

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