Derivation of Improved Initial and Continuing Losses in Design Flood Estimation for NSW Australia

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Abstract: Flood is one of the worst natural disasters that cause significant economic damage and loss of lives. Flood estimation is often required in the design and safety assessment of water infrastructure like bridges, culverts and flood control levees. Rainfall runoff model is often used in design flood estimation, which needs various inputs such as rainfall and catchment characteristics including rainfall duration, rainfall intensity, rainfall temporal patterns and losses. Loss is defined as the amount of precipitation in a rainfall event that does not appear as direct surface runoff at the stream gauge. The objective of this paper is to derive improved initial and continuing loss values using data from selected catchments in New South Wales (NSW). In this paper, a total of 253 rainfall runoff events are selected from five NSW catchments. From the analyses, the median initial loss has been found to be 17 *mm* which is closer to the lower limit of the Australian Rainfall and Runoff (ARR) 1987 recommended value of 10-35 *mm*. The median continuing loss value has been found to be 0.94 *mm/h* which is 62% lower than the ARR recommended value of 2.5 *mm/h*. The resulting design floods from the observed loss values are likely to be higher than those obtained from the ARR 1987 recommended loss values.

Keywords: *Joint Probability Approach, Monte Carlo simulation technique, Design Floods, Australian Rainfall and Runoff*

1. Introduction

Flood causes notable economic damage and loss of human lives. It causes millions of dollars of damage every year. In 2010-11 year alone, the flood damage bill in Australia exceeded $5 billion. Estimation of design floods is an important task in hydrology, which is needed to design water infrastructure such as bridges, culverts and flood embankment, and for various other planning and regulatory purposes such as flood risk assessment, flood insurance studies and flood plain mapping (Rahman et al, 2015).

Design flood estimation methods can be classified into two major categories: streamflow based methods and rainfall based methods. Rainfall based methods are widely adopted in practice as rainfall data is more readily available than flood data and physical catchment characteristics can easily be incorporated with these types of models. Rainfall based flood estimation methods require a number of input and parameters to transform a design rainfall event into a design flood event. Design loss is one of these input variables. Loss is defined as the amount of rainfall that does not appear as direct surface runoff in the river. Loss includes the precipitation intercepted by vegetation (interception loss), infiltration into the soil, retention on the surface (depression storage), evaporation and loss through the streambed. The amount of loss is dependent on a number of factors such as catchment topography, soil, vegetation, and the antecedent soil moisture.

In design flood estimation, simplified lumped conceptual loss models are commonly used for their simplicity and ability to approximate catchment runoff behavior. The lumped conceptual loss model named as the Initial Loss-Continuing Loss Model is commonly used in Australia (I. E. Aust., 1987). The Initial Loss (IL) is known to be the amount of rainfall that occurs before the start of surface runoff, while the

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Continuing Loss (CL) is assumed to be the average loss rate throughout the remainder of the rainfall event. The above definition may not completely represent the spatial and temporal distribution of the actual loss in a catchment; however, it is widely used in flood estimation in Australia as this can give quite acceptable design flood estimation. The Australian Rainfall and Runoff (ARR) (I. E. Australia, 1987) has recommended design IL and CL values for different regions of Australia (I. E. Aust., 2001).

Many studies such as Waugh (1991), Walsh et al. (1991), Hill and Mein (1996), Rahman et al. (2002a) and Ilahee et al. (2001) have indicated the limitations of the currently recommended design loss values in ARR. More recently, use of probabilistic losses are being common in design flood estimation as reported in Charalambus et al. (2013), Loveride et al. (2013), Loveridge and Rahman (2014), Caballero and Rahman (2014a) and Caballero and Rahman (2014b). These studies recommended probability distributions to specify IL and CL data for use in the Monte Carlo Simulation technique for design flood estimation. Furthermore, regional flood methods can utilise regional loss values to bench mark flood estimates by different methods (e.g. Haddad et al., 2010; Rahman et al., 2011).

The objective of this paper is to derive IL and CL values for selected catchments in NSW, Australia. This includes mean and median loss values as well as stochastic losses so that these can be used with both the Design Event Approach and Joint Probability Approach/Monte Carlo Simulation technique (Rahman et al., 2002b) to design flood estimation. It is expected that these data will be useful in hydrologic design in Australia. The methodology can be applied to other countries to derive improved design loss values in catchment hydrologic simulations.

2. Data selection

The study focuses New South Wales (NSW) in Australia. Five catchments from NSW are selected in this study as shown in Figure 1 and listed in Table 1. These catchments are rural and do not have any major regulations. There have been no major land use changes in these catchments since hydrologic records began at these stations. The areas of these catchments range from 62 km^2 to 220 km^2. To estimate IL and CL values, two types of data are required: pluviograph and streamflow data. The selected data for this study are summarised in Table 1. The concurrent record lengths of the selected pluviograph and streamflow data range from 11 to 35 years. The pluviograph data is obtained from the Australian Bureau of Meteorology and the streamflow data from the Department of Water NSW.

Figure 1 Locations of study catchments in NSW, Australia

Table 1 Selected study catchments and pluviograph stations from NSW, Australia

Catchment ID	River name	Pluviograph station	Distance between stream gauge and pluviometer (km)	Catchment area (km^2)	Record length (years)
218007	Wadbilliga	69075	7.48	122	14
215004	Corang	69049	5	166	35
203002	Coopers Ck	58072	5	62	23
418027	Horton	54138	7	220	30
210017	Moonan Brook	61335	6.3	103	11

3. Materials and Methods

3.1 Selection of storm and runoff events

To select storm events, a 'complete storm' event is used, which is defined as a period of significant rain preceded and followed by at least six dry hours following the approach of Rahman et al. (2002b). In this method all the storm events exceeding a threshold design rainfall intensity of $0.40\times{}^{2}I_D$ are taken as the candidate storm events (where ${}^{2}I_D$ is the 2 years average recurrence interval (ARI) and *D*-hour duration rainfall intensity obtained from ARR Volume 2). This threshold allows selection of 3 to 5 candidate rainfall events per year on average from a pluviograph station. These candidate storm events are then examined further to ensure that the corresponding runoff events are consistent, i.e. these are not affected by subsequent rainfall events and the total event runoff is smaller than the total event rainfall. In computing losses, a surface runoff threshold value of 0.01*mm/h* is adopted following the approach of Hill and Mein (1996).

3.2 Initial loss and continuing loss estimation

The value of IL is estimated to be the total rainfall that occurs prior to the commencement of surface runoff; whereas CL is the loss that occurs from the beginning of the surface runoff to the end of rainfall event (illustrated in Figure 2). The IL and CL can be expressed using the following water balance equation:

$$R = IL + CL * t_1 + QF \qquad (1)$$

Where R (*mm*) is the total event rainfall over the catchment, IL is in *mm*, CL is in *mm/h*, t_1 (hours) is the time from the start of surface runoff to the end of rainfall event and QF (*mm*) is the quick flow generated from the rainfall event.

Quick flow (QF) is calculated by subtracting the baseflow (BF) from total stream flow (SF_T). Therefore equation (1) can be expressed as:

$$R = IL + CL * t_1 + (SF_T - BF) \qquad (2)$$

To estimate CL, equation (1) can be expressed as:

$$CL = (R - IL - QF)/t_1 \qquad (3)$$

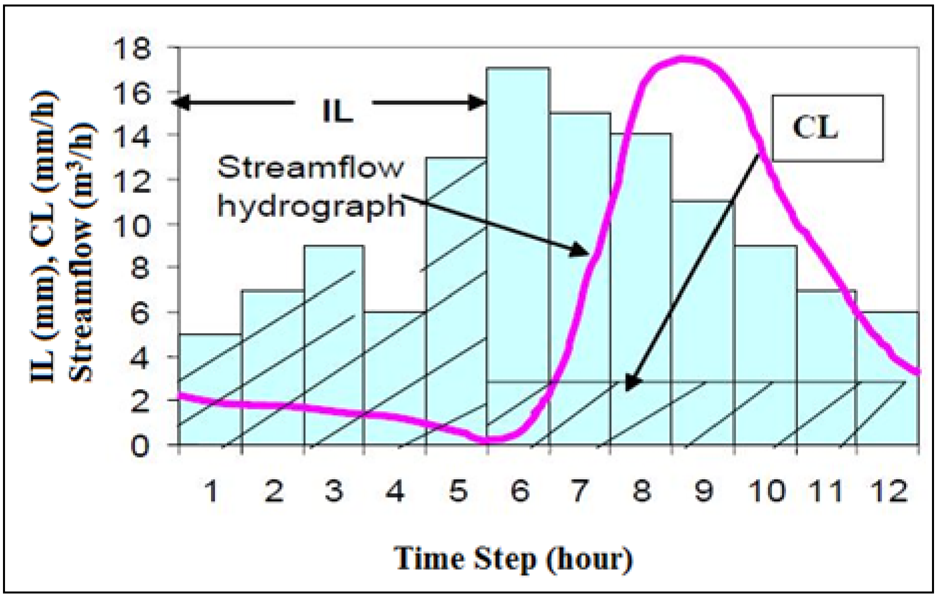

Figure 2 Initial loss (IL) and continuing loss (CL) model for a complete storm event

3.3 Baseflow separation method

For baseflow separation, the method proposed by Boughton (1988) is adopted, which assumes that the rate of increase in the baseflow depends on a fraction of the surface runoff α. Therefore, the baseflow at any time step i (BF_i) can be expressed as the baseflow in the previous time step (BF_{i-1}) plus α times the difference of total streamflow at step i (SF_i) and baseflow BF_{i-1}. At the beginning of surface runoff, the baseflow is assumed to be equal to the streamflow i.e. $BF_i = SF_i$. This can be expressed as:

$$BF_i = BF_{i-1} + \alpha(SF_i - BF_{i-1}) \tag{4}$$

To apply equation (4), the value of α needs to be estimated from the observed streamflow events in such a way that the adopted value of α provides a reasonable baseflow separation for the majority of the selected events for the catchment. It is evident that as the value of α increases a larger proportion of the total flow is separated (Figure 3). A design value of α is selected for a catchment by trial and error to achieve an acceptable baseflow separation for the catchment.

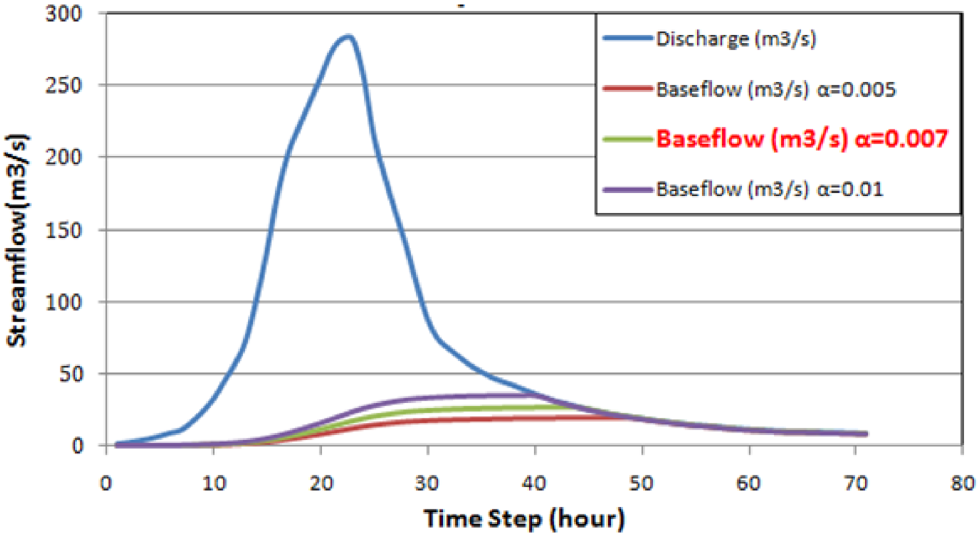

Figure 3 Baseflow separation method adopted in this study

3.4 Fitting a theoretical distribution to observed loss data

In the Joint Probability Approach/Monte Carlo simulation technique of design flood estimation (Rahman et al., 2002b), probability distributed losses are adopted. For example, Rahman et al. (2002a) adopted a four-parameter Beta distribution for IL. In this study, one-parameter Exponential and two-parameter Gamma distributions are tested to assess whether they can be used to describe the IL and CL distributions for the study catchments in NSW. To test the statistical hypothesis that the observed IL or CL values follow either an Exponential or Gamma distribution, two different tests are applied: Kolmogorov-Smirnov (K-S) test and Anderson-Darling (A-D) test at 1% and 5% level of significance. The K-S test is based on the maximum difference (D_{max}) between the observed cumulative distribution function $F_n(x)$ and expected cumulative distribution function $F_o(x)$. The A–D test gives a heavier weighting to the tails of a distribution where unexpectedly high or low values, called outliers might be present (Kottegoda and Rosso, 1997).

4. Results and discussion

A total of 253 rainfall and runoff events are selected from the 5 study catchments. It is found that a α value of 0.01 provides a reasonable baseflow separation for the majority of the selected events. The computed CL values are found not to be too sensitive to the selection of a α value.

Tables 2 and 3 provide the summary statistics of the derived IL and CL values. Considering all the 253 events, the median IL value is found to be 16.89 *mm* (range: 0.13 *mm* to 111.53 *mm*). The average IL value is 21.84 *mm* with a standard deviation of 18.88 *mm* and a coefficient of variation of 0.86. These results highlight that the observed IL values exhibit a high variability across storms and catchments. The median CL value is found to be 0.94 *mm/h* (range: 0.003 *mm/h* to 6.42 *mm/h*). The average CL value is 1.20 *mm/h* with a standard deviation of 1.20 *mm/h* and a coefficient of variation of 0.87. These results highlight that the observed CL values show a wide variability across storm events and catchments similar to IL. Given the variability of the observed IL and CL values, it appears to be a difficult task to select a representative value of IL and CL in the application of the Design Event Approach of design flood estimation as recommended by ARR 1987 (I. E. Aust., 1987). Thus, it is more logical to specify stochastic losses, as discussed below, which can be applied with the Monte Carlo simulation technique to design flood estimation.

The observed median IL value is towards the lower limit of the ARR1987 recommended value of 10-35 *mm* for eastern NSW. The observed median CL value is 62% lower than the ARR1987 recommended value of 2.5 *mm/h*.

In specifying the stochastic losses, the empirical distributions of the IL and CL values are examined in Figures 4 and 5. These figures show that the majority of the observed IL and CL values are smaller than 50 *mm* and 1.5 *mm/h*, respectively. Based on the K-S and A-D tests, it is found that the Gamma distribution can be used to specify the observed IL and CL distributions at the 1% level of significance. That is, the stochastic IL distribution is specified by a Gamma distribution with mean = 22 *mm* and standard deviation = 19 *mm*. The stochastic CL distribution is specified by a Gamma distribution with mean = 1.20 *mm/h* and standard deviation = 1.04 *mm/h*. These stochastic losses can be applied with the Monte Carlo simulation technique to design flood estimation for eastern NSW.

Table 2 Summary of results (Initial Loss) (LL = lower limit and UL = upper limit)

Catchments	No. of Events	Initial Loss				
		LL (mm)	UL (mm)	Mean (mm)	Median (mm)	SD (mm)
Coopers Ck	97	0.3	55.85	15.65	12.78	12.69
Corang	41	0.13	76.11	22.2	16.5	18.49
Horton	76	0.46	111.53	29.85	24.37	22.99
Moonan Brook	10	0.27	10.04	5.23	5.64	2.91
Wadbilliga	29	0.6	60.65	26.8	27.64	17.82
ALL EVENTS	253	0.13	111.53	21.84	16.89	18.88

Table 3 Summary of results (Continuing Loss) (LL = lower limit and UL = upper limit)

Catchments	No. of Events	Continuing Loss				
		LL (mm/h)	UL (mm/h)	Mean (mm/h)	Median (mm/h)	SD (mm/h)
Coopers Ck	97	0.06	4.2	1.47	1.27	0.96
Corang	41	0.03	3.11	0.76	0.53	0.72
Horton	76	0.003	4.46	0.88	0.58	0.94
Moonan Brook	10	0.23	1.99	0.95	0.90	0.57
Wadbilliga	29	0.25	6.42	1.84	1.56	1.43
ALL EVENTS	253	0.003	6.42	1.20	0.94	1.04

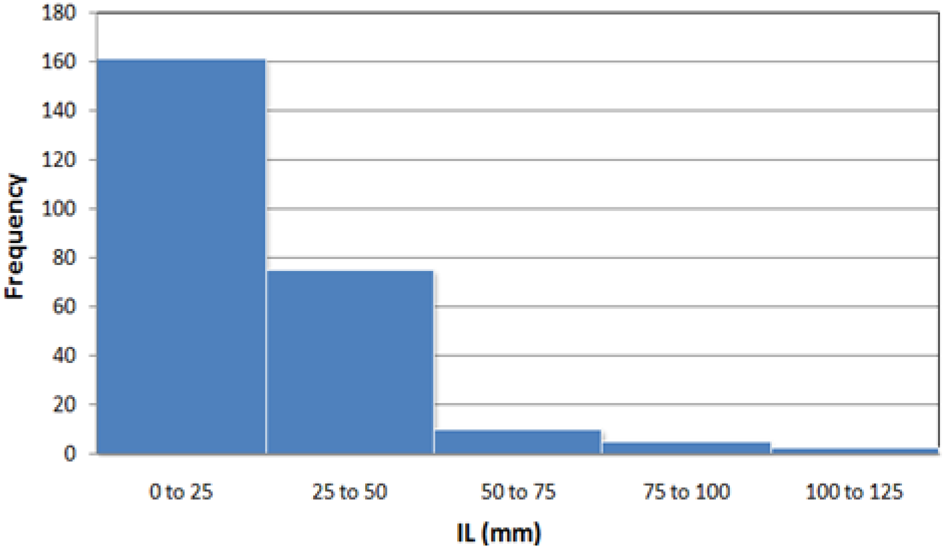

Figure 4 Distribution of observed IL values

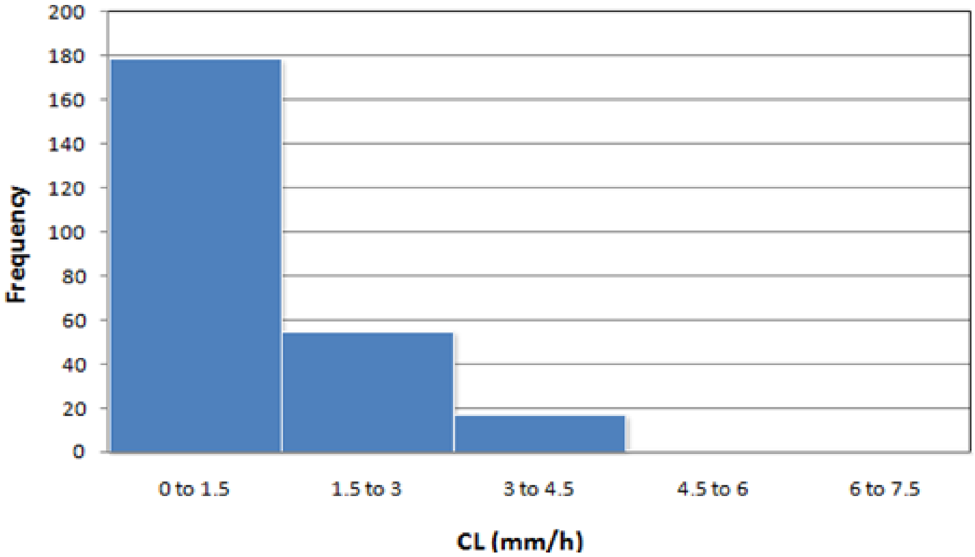

Figure 5 Distribution of observed CL values

5. Conclusion

This study has examined initial and continuing loss values for 253 rainfall and runoff events selected from five NSW catchments. The newly derived losses for NSW are lower than the ARR1987 recommended values. The median initial loss value is found to be 17 *mm* which is closer to the lower limit of the ARR1987 recommended value of 10-35 *mm*. The median continuing loss value is estimated to be 0.94 *mm/h* which is 62% lower than the ARR recommended value of 2.5 *mm/h*. The design flood estimates based on these new loss values are expected to be higher than those obtained from the ARR1987 recommended values. The observed initial loss and continuing loss values show a wide variability from storm to storm and catchment to catchment. It is thus more logical to adopt stochastic losses in design flood estimation rather than fixed values of losses. It has been found that two-parameter Gamma distribution can be used to describe the observed initial loss and continuing loss distributions. The stochastic losses described by the Gamma distribution can be used in design flood estimation by adopting Joint Probability Approach/Monte Carlo simulation technique. The Gamma distribution to be used for this purpose is specified by a mean value of 22 *mm* and standard deviation of 19 *mm* for initial loss, and a mean value of 1.20 *mm/h* and standard deviation of 1.04 *mm/h* for continuing loss. These new loss values will have practical applications in Australian hydrologic practice.

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