Defining and Calculating Continuing Loss for Flood Estimation

Simon Lang
Senior Water Resources Engineer, Hydrology and Risk Consulting, Melbourne, Australia
E-mail: simon.lang@harconsulting.com.au

Peter Hill
Principal Hydrologist, Hydrology and Risk Consulting, Melbourne, Australia
E-mail: peter.hill@harconsulting.com.au

Matt Scorah
Hydrologist, Hydrology and Risk Consulting, Melbourne, Australia
E-mail: matt.scorah@harconsulting.com.au

David Stephens
Senior Hydrologist, Hydrology and Risk Consulting, Melbourne, Australia
E-mail: david.stephens@harconsulting.com.au

Abstract

The most commonly-used loss model in Australia for design flood estimation in rural catchments is initial loss – continuing loss (IL-CL). The initial loss represents rainfall losses to interception, infiltration and depression storages prior to the commencement of surface runoff. The continuing loss represents the average loss rate during the remainder of the storm.

Despite the simple conceptual nature of the IL-CL model, there are pitfalls in estimating continuing loss directly from recorded streamflow and rainfall. The continuing loss should not simply be estimated from a water balance of runoff volume less initial loss divided by the duration of the event. Furthermore, although not immediately apparent, the definition of continuing loss means its magnitude is dependent upon the modelling time step. This is because as the time step reduces, there is increased likelihood that there will be some time steps when the rainfall depth is less than the continuing loss. Therefore, to model the equivalent rainfall excess, the continuing loss will typically need to be increased as the time step is shortened.

Based upon events recorded in 18 catchments from around Australia, this paper describes a relationship for relating an hourly continuing loss to shorter time steps. The basis of IL-CL model is also discussed.

Keywords: rural hydrology, rainfall excess, rainfall loss, continuing loss, design flood estimation

1. INTRODUCTION

Loss is defined as the precipitation that does not appear as direct runoff, and is attributed to interception by vegetation, infiltration into the soil, depression storage and transmission loss through stream beds and banks (Figure 1).

The two types of empirical loss models most often used in Australian flood studies are initial loss – continuing loss (IL-CL) and initial loss – proportional loss (IL-PL) (Figure 2). The initial loss occurs at the beginning of the storm, prior to the commencement of surface runoff. It is comprised of interception losses, depression storage and infiltration before the soil surface is saturated.

The continuing loss represents the average loss rate during the remainder of the storm. Constant loss rates are most applicable to large storms, where a significant proportion of rainfall becomes runoff. The proportional loss model assumes a fixed percentage of the rainfall is lost at each time step after the initial loss is satisfied. This means that the loss magnitude varies throughout the storm in accordance with the temporal pattern of rainfall.

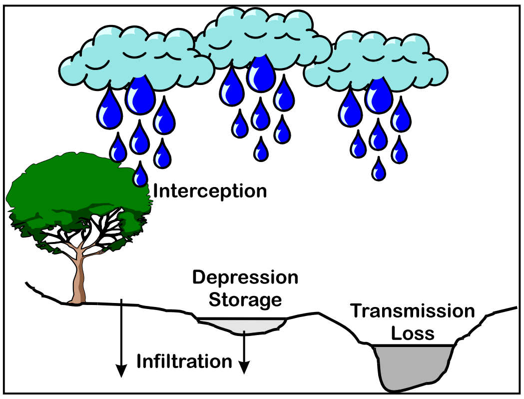

Figure 1 Physical processes which contribute to rainfall losses

Dyer *et al* (1994) compared the performance of the IL-CL and IL-PL models for 24 rural catchments and found the proportional loss model generally resulted in better rainfall-runoff model calibrations. This finding was supported by Hill *et al* (1996) based on rainfall-runoff model calibrations for 11 Victorian catchments.

However, more recent analyses by Hill *et al* (2014) were inconclusive as to which loss model works best. Even for catchments where one of the loss models performed better for a majority of events, there were still some events for which the other approach was superior. Similarly there was no obvious relationship between the relative performance of the loss models and hydro-climatic or catchment characteristics.

The advice in the current update of ARR will be that the IL-CL model is most suitable for design flood modelling for rural catchments, because it can be used to estimate flood peaks and volumes for all annual exceedance probabilities (AEPs). In contrast, it is often difficult to derived unbiased estimates of flood quantiles using the IL-PL model over the same range of AEPs. The IL-PL model underestimates peak flows for extreme floods if the proportional loss is not varied appropriately with AEP; and to date there is little evidence about how proportional loss varies with AEP. The remainder of this paper focus on the IL-CL model, and in particular the continuing loss.

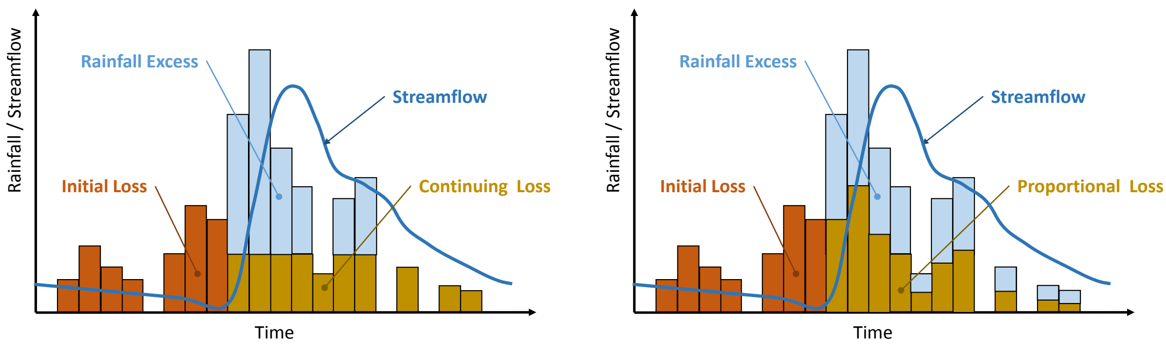

Figure 2 The initial loss – continuing loss model (left) and the initial loss – proportional loss model (right)

2. CONSIDERATIONS FOR ESTIMATING CONTINUING LOSS

Despite the simple conceptual nature of continuing loss, there are pitfalls in estimating it directly from recorded rainfall and streamflow.

In practice the point at which initial loss is satisfied and continuing loss commences is not always readily apparent from the recorded data. A number of previous studies on small catchments have estimated loss values directly from the recorded rainfall and streamflow and simply based this point on a threshold value of surface runoff. Hill *et al* (1996) considered the sensitivity of the loss values to a range of different thresholds and adopted 0.01 mm/h for small catchments in south-eastern Australia. This value has subsequently been applied in a number of other studies such as Rahman et al (2002) and Tularam and Ilahee (2007). However, Hill *et al* (2013) demonstrated that it was difficult to identify a single threshold of runoff that reproduced the same partitioning of initial loss and continuing loss as obtained when using a flood routing model. This becomes increasingly important for larger catchments.

It is therefore preferable to estimate the initial loss and continuing loss with a rainfall-runoff routing model which accounts for the catchment lag and hence provides a more accurate estimate of the loss values. Hill *et al* (2014) considered whether the loss values were sensitive to whether the channel and overland routing were split or lumped. This analysis concluded that the loss values were not particularly sensitive to the adopted routing model; the key point was that the lag was modelled.

The estimation of continuing loss from the analysis of recorded rainfall and streamflow should account for the temporal nature of the rainfall. It is likely that there are time steps for which the rainfall is less than the continuing loss threshold, and therefore the continuing loss should not simply be based upon a volume balance (i.e. the surface runoff less initial loss divided by the duration of the event). This simplified approach has been adopted in a number of recent studies (e.g. Ilahee and Rahman, 2003; Ishak and Rahman, 2006; Ilahee and Imteaz, 2009; El-Kafagee and Rahman, 2011). The continuing losses estimated in these studies are therefore likely to be conservatively low. This is because of the time steps in which rainfall is less than the continuing loss, and therefore the continuing loss is not fully met.

Although not immediately apparent, the definition of continuing loss also means its magnitude is dependent upon the modelling time step. This is because as the time step reduces, there is increased likelihood that there will be some time steps when the rainfall depth is less than the continuing loss. Therefore, to model the equivalent rainfall excess the continuing loss will typically need to be increased as the time step is shortened (Figure 3).

The time step adopted in design flood modelling should be the same as that used in the estimation of losses. However, if a different time step is adopted then the continuing loss values will need to be adjusted. Guidance in the current revision of Australian Rainfall and Runoff (ARR) on regional continuing losses in rural catchments will be based on hourly based rainfall-runoff modelling from sites around Australia. Therefore, practitioners using this guidance will need to make adjustments if their simulations are on different time steps.

3. ESTIMATING CONTINUING LOSSES FOR DIFFERENT TIME STEPS

To investigate the relationship between continuing loss and time step, 18 catchments from five states (Table 1) were selected where:

- There were concurrent periods of streamflow and pluviograph records
- There were enough rainfall stations to adequately capture the volume and spatial pattern of rainfall
- The catchments were small enough to reduce the influence of streamflow routing assumptions on the estimated losses

Hill *et al* (2014) provides detail on the method used to model continuing losses in each catchment for a number of events. A summary is given below.

3.1. Selecting events

For the 18 catchments in Table 1, between three and 13 events were selected for analysis. The selections were based on the annual exceedance probability (AEP) of recorded rainfall rather than runoff, because selecting the largest floods would have introduced a bias towards low losses. Estimating the rainfall AEPs required consideration of duration. For this study, the focus was continuing losses for time steps of one hour and shorter, and therefore the AEPs were calculated for 3 hour bursts.

Having identified the rarest 3 hour bursts of recorded rainfall, it was necessary to define the start and end of the complete storm for which the loss values were to be modelled. This was done by inspecting the time series of pluviograph data and streamflow.

3.2. Modelling continuing loss on hourly time step

The initial loss and continuing loss on an hourly time step was estimated for each complete storm by fitting a rainfall runoff model (RORB) to the observed surface runoff. The surface runoff was estimated by subtracting baseflow from the recorded streamflow.
RORB is a general runoff and streamflow routing program that is used to calculate hydrographs from rainfall and other catchment and channel inputs. The model subtracts losses from rainfall to determine rainfall excess, and routes this through catchment storages represented by stream length, to produce hydrographs at points of interest. The model accounts for both the temporal and spatial distributions of rainfall and losses.

When varying initial loss and continuing loss such that the RORB model results matched the observed surface runoff, several simplifications were made:

- The spatial distribution of rainfall for each event was derived from inverse-distance weighting of nearby daily rainfall stations, rather than manually estimated isohyets
- The RORB model routing parameter k_c was kept fixed for every event on a given catchment
- The contribution of baseflow to recorded streamflow was simulated using a recursive digital filter, rather than being manually estimated

3.3. Modelling continuing loss on shorter time steps

Determining the continuing loss required on shorter time steps to match the rainfall excess simulated in the hourly RORB models involved:

- Extracting the 5 minute time step pluviograph data between the start and end time of each complete storm, and checking no records were missing or accumulated
- Summing the pluviograph data to 15 minute, 30 minute and 45 minute time steps
- Calculating the continuing loss required at 5 minute, 15 minute, 30 minute and 45 minute time steps to match the rainfall excess estimated by the RORB models

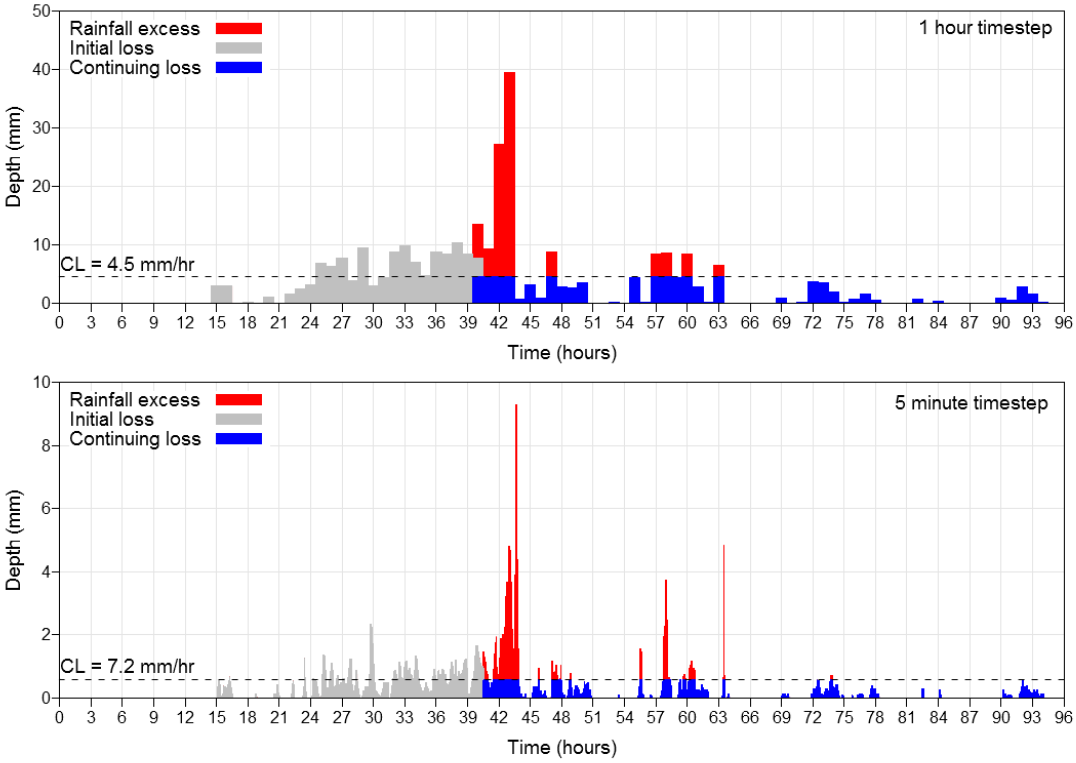

Figure 3 An example of how continuing loss (CL) needs to vary with modelling time step to simulate equivalent rainfall excess – Currambene Creek at Falls Creek, NSW, February 1977

Table 1 Case study catchments

Catchment				**Pluviograph**		
Gauge	**Name**	**State**	**Area (km²)**	**Number**	**Distance to catchment centroid (km)**	**Years***
216004	Currambene Creek @ Falls Creek	NSW	95	P68076	5.2	28
213200	O'Hares Creek @ Wedderburn	NSW	73	568065	4.9	30
211013	Ourimbah Creek @ U/S Weir	NSW	83	P61351	3.8	29
411003	Butmaroo Creek @ Butmaroo	NSW	65	570338	4.6	31
235219	Aire River @ Wyelangta	VIC	90	P90083	4.4	36
228217	Toomuc Creek @ Pakenham	VIC	42	586201	2.6	33
AW501500	Hindmarsh River @ Hindmarsh Vy Res Offtake	SA	56	P23824	1.9	38
A5040523	Sixth Creek @ Castambul	SA	44	P23801	4.6	32
120216A	Broken River @ Old Racecourse	QLD	78	P33172	1.2	38
142001A	Caboolture River @ Upper Caboolture	QLD	94	142001	5.2	21
126003A	Carmila Creek @ Carmila	QLD	82	126003	4.5	22
141009	North Maroochy River @ Eumundi	QLD	41	P40059	4.7	28
141001B	South Maroochy River @ Kiamba	QLD	33	P40282	5.9	23
422321	Spring Creek @ Killarney	QLD	32	P41056	3.9	38
701006	Buller River @ Buller	WA	34	508025	4.0	26
608002	Carey Brook @ Staircase Rd	WA	30	509296	3.1	36
602199	Goodga River @ Black Cat	WA	49	509011	3.7	38
614003	Marrinup Brook @ Brookdale Siding	WA	46	509213	2.3	20

* overlapping between pluviograph and streamflow gauge record

3.4. Results

Figure 4 shows for each event analysed how the continuing loss calculated for the shorter time steps compared with the hourly based continuing loss. This demonstrates that shortening the modelling time step generally increases the continuing loss, and introduces more variation in the relationship between the hourly based and shorter time step losses.

Figure 5 includes box plots of the scaling factor that was required for the hourly based continuing loss to match rainfall excess on shorter time steps in four hydro-meteorological regions identified by the Bureau of Meteorology: the GSAM inland and coastal regions, and the GTSMR coastal and south-west Western Australia regions (http://www.bom.gov.au/water/designRainfalls/pmp/). GSAM refers to southeast Australia, where tropical storms are not prevalent; while the GTSMR regions are where tropical storms contribute the greatest rainfalls depths.

Figure 5 shows the scaling factors in the two coastal regions were similar. The scaling factors in the GSAM inland region were slightly higher in comparison. The GTSMR south-west Western Australia region had the highest scaling factors, and most variation.

4. IMPLICATIONS FOR DESIGN FLOOD MODELLING

The implications of the results in Figures 4 and 5 for design flood modelling were considered by generalising the findings. Figure 6 shows for each catchment in Table 1 the average scaling factor versus the average storm depth for the events analysed. Lines of best fit have been added to the 5 minute, 15 minute, 30 minute and 45 minute time step results.

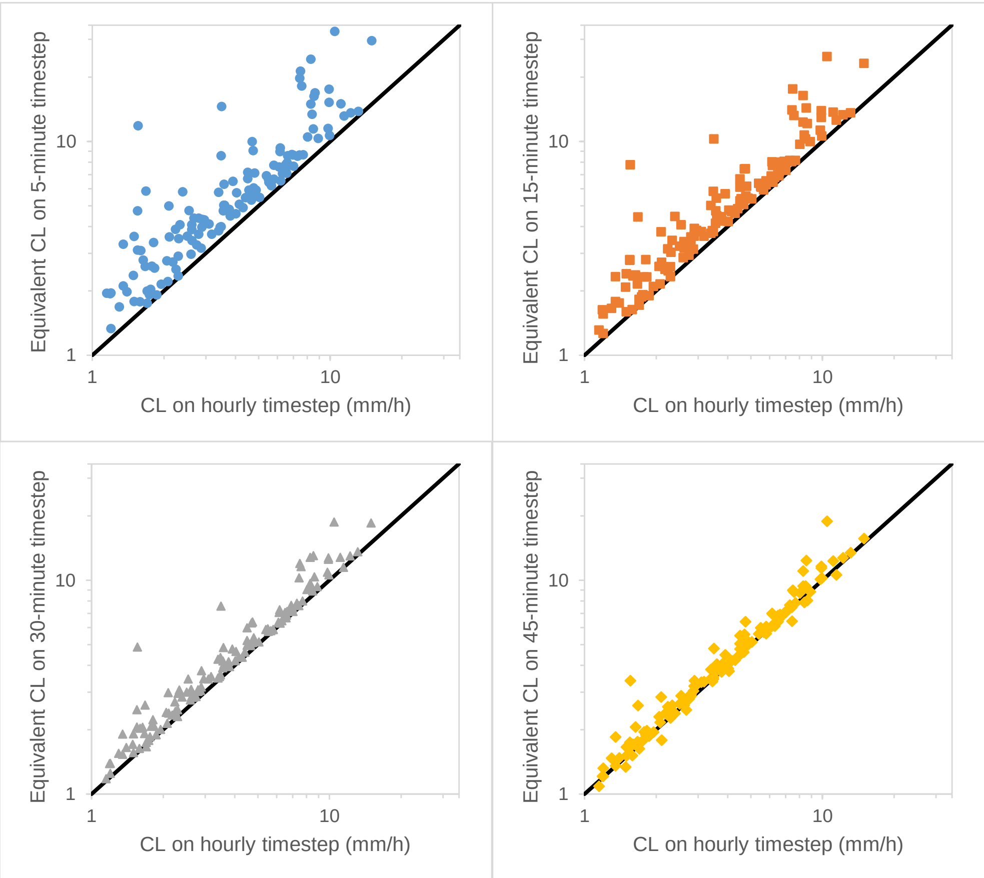

Figure 4 Continuing loss required on shorter time steps to match the rainfall excess estimated from hourly rainfall-runoff modelling. The 1:1 line is shown in solid black.

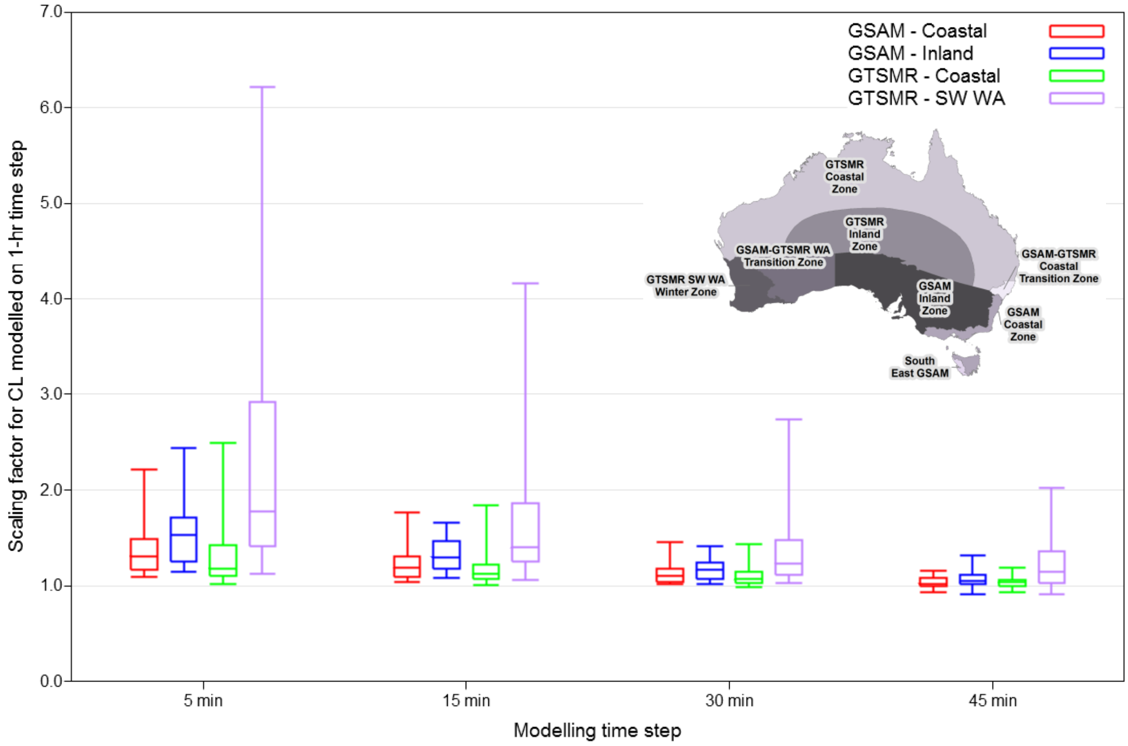

Figure 5 Box plots (median, inter quartile range, 5th and 95th percentiles) of the scaling factor applied to hourly continuing losses to match rainfall excess at shorter time steps.

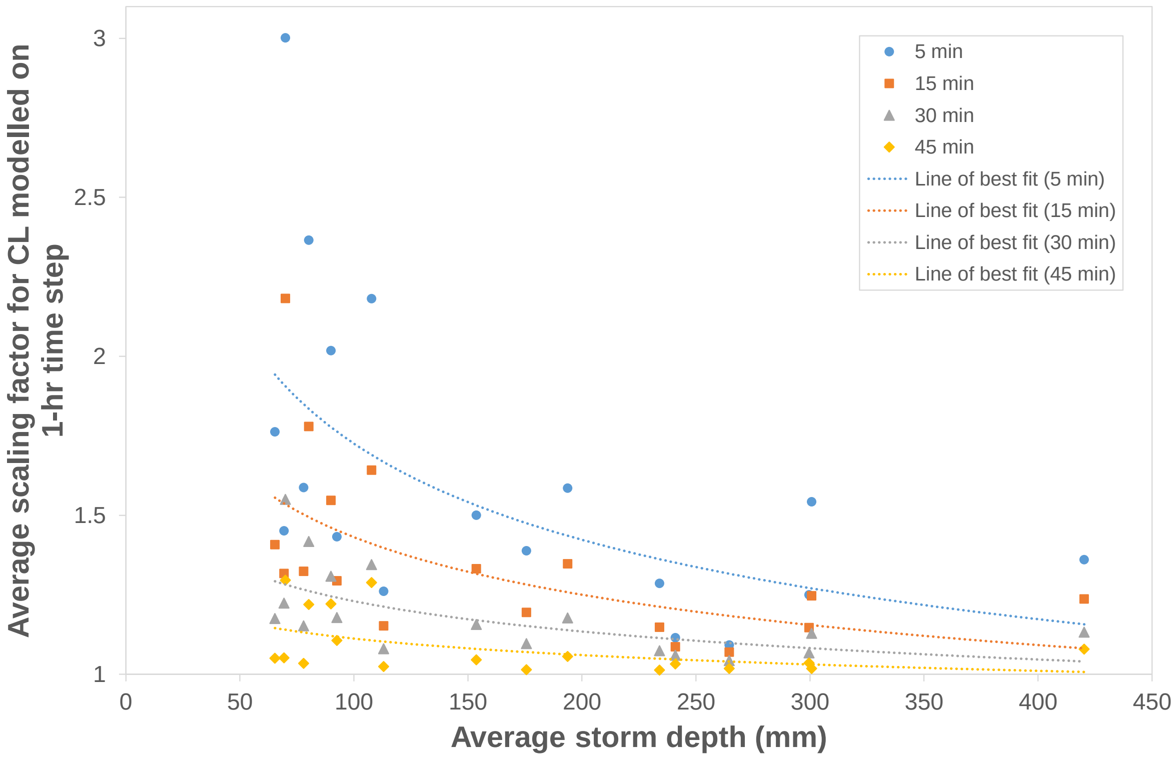

Figure 6 Continuing loss required on shorter time steps to match the rainfall excess estimated from hourly rainfall-runoff modelling.

Rainfall depth was used as the predictor of scaling factor for two main reasons. First, as depths increase, continuing loss is expected to become invariant with modelling time step, because rainfall will be greater than the loss regardless of time step. Secondly, the average storm depth in each region shown in Figure 5 varied, and therefore the variation of losses by region is potentially a proxy for variation by rainfall depth.

In the absence of site-specific data, Figure 6 can be used in conjunction with ARR guidance on continuing losses in rural catchments, to estimate the equivalent continuing loss if the modelling time step is less than one hour. The scatter arounds the lines of best fit needs to be kept in mind.

Losses are one input of the many required for design flood modelling. The other inputs include the rainfall depth, duration, temporal pattern and spatial pattern, the runoff routing parameters, the baseflow, etc. Best practice is to model the interaction of these flood producing factors in a joint probability framework, such as described by Nathan *et al* (2002, 2003). The correlation between initial losses and continuing losses is not well understood, but continues to be an area of active research. Current practice is for initial losses to be sampled from a distribution, while the continuing loss is held constant. Hill *et al* (2015) provides an update of appropriate initial loss distributions for use in design flood modelling.

5. CONCLUSIONS

The most commonly-used loss model in Australia for design flood estimation in rural catchments is initial loss – continuing loss. Despite the simple conceptual nature of the model, there are a number of important considerations when estimating loss values directly from rainfall and streamflow data

- *Partitioning initial loss and continuing loss* – in practice the point at which initial loss is satisfied and continuing loss commences is not always readily apparent. A number of previous studies on small catchments have estimated loss values directly from the recorded rainfall and streamflow and simply based this point on a threshold value of surface runoff. However, it is preferable to estimate the initial loss and continuing loss with a rainfall-runoff routing model which accounts for the catchment lag and hence provides a more accurate estimation of these loss values.
- *Accounting for the temporal nature of rainfall* – The estimation of continuing loss from the analysis of recorded rainfall and streamflow data should account for the temporal nature of the rainfall. It is likely that there are time steps for which the rainfall is less than the continuing loss threshold; therefore the continuing loss should not simply be based on a volume balance.
- *Sensitivity to the modelling time step* – The definition of continuing loss means that its magnitude is dependent upon the modelling time step. Therefore, practitioners using the ARR guidance (which is based upon a 1 hour time step) will need to make adjustments if simulating design floods using different time steps. In the absence of site-specific data, Figure 6 can be used to estimate the equivalent continuing loss for time steps less than one hour.

6. ACKNOWLEDGEMENTS

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