FLOOD RISK SELF-ASSESSMENT -
DEVELOPMENT OF SIMPLE RAINFALL-BASED TRIGGERS FOR RESIDENTS IN FLASH FLOOD CATCHMENTS

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ABSTRACT

Flood warning and response agencies often struggle to deal with flash floods because of their fast and unpredictable nature. This can leave floodplain occupants fending for themselves to determine what, if any, action should be taken to manage their personal safety.

The authors recently became aware of a specific situation where a potential flash flood risk exists on a large creek floodplain. In the aftermath of a recent major flood at this location, residents asked whether further information could be made available to them that correlates rainfall and flood magnitude. This detail would be used in order to assist them with making personal decisions about evacuation.

This paper explores the technical aspects of developing simple rainfall-based triggers for flood evacuation and some of the opportunities and challenges that arise in application of those triggers to flood emergency response.

1 FLOOD WARNING IN FLASH FLOOD CATCHMENTS

Flash flooding occurs where the time lag between an occurrence of heavy rainfall and the resultant flood is short. The Bureau of Meteorology (BOM) provides one definition of this time lag as “flooding occurring within about 6 hours of rain”. This duration is an arbitrary selection, but has become important in practice since the BOM take the policy position that they do not provide detailed flood warnings for flash flood catchments, instead leaving this task to local authorities.

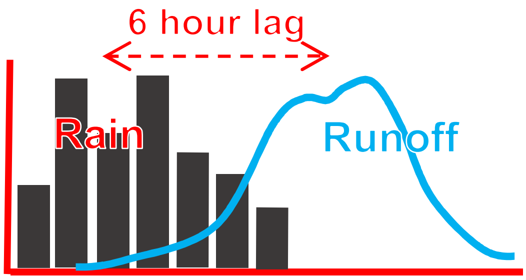


Figure 1: Time lag between rain and peak runoff in a flash flood scenario

This less than 6 hour lag condition occurs in small catchments, but can also occur where the catchment area could be considered quite large, in the order of 500 square kilometres. Flash flood risk situations are therefore potentially quite common. The task of warning people about a flash flood situation often presents a significant challenge.

Firstly, there are no accurate methods for forecasting the precise location and magnitude of heavy, short duration rainfall. This means there is normally only a short time window for providing warning to residents, part of which is taken up by first recognizing the problem and then the task of effecting a warning in advance of the flood peak.

Secondly, during an event within a region, there are often multiple storm cells present simultaneously at a number of locations , placing significant pressure and time demands on Council flood staff.

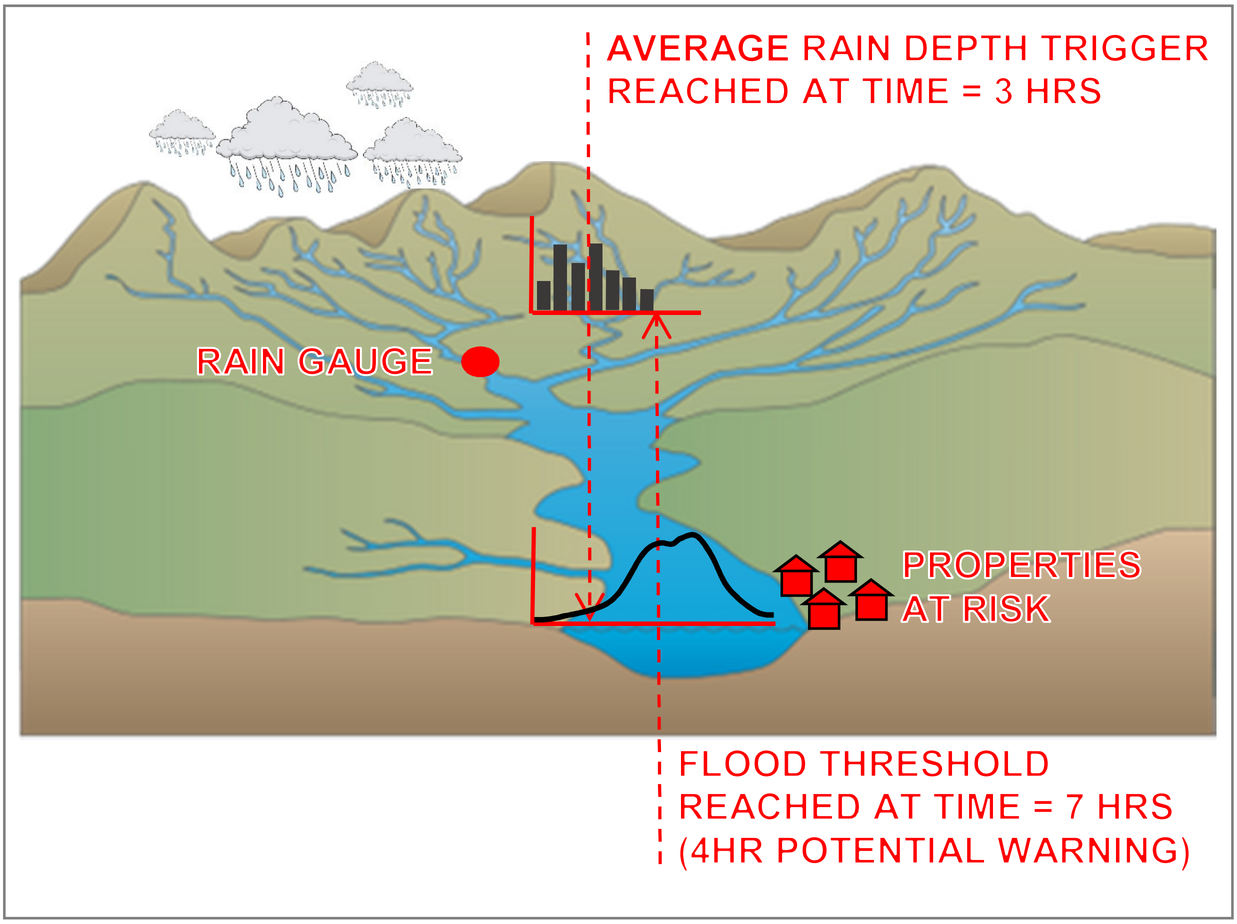
Not-withstanding these two challenges, flash flood warnings are important to provide floodplain occupants with more opportunity to implement a flood plan, and therefore should be pursued where possible.

There are several potential approaches that can be taken in order to forecast an imminent flash flood. The available approaches vary in their level of complexity and accuracy. This paper does not attempt to describe and evaluate all these approaches. Instead it focusses on the use of rainfall-based forecasts, which have, in the authors' opinion, most potential to be widely deployed, including by members of the community in some circumstances.

2 RAINFALL-BASED FORECASTS

A rainfall-based flood forecast uses average catchment rainfall totals to estimate the expected flood conditions for an area of interest. For example, it may have been calculated that, for flooding to occur in a particular area, a minimum average 'rainfall trigger' of 100mm depth is required over (say) 3 hours within the upstream catchment. A forecast of flooding can therefore be provided by closely monitoring average catchment rainfall and making an assessment of whether this rainfall trigger has been reached and/or exceeded.

Figure 2: Rainfall-based flash flood forecast example



Since it can take a period of time before measured rainfall translates into a flood wave, there is a short intervening period of time where a forecast can be made and a warning issued. In the example provided in Figure 2, the average rain depth, measured at the rain gauge, exceeded the depth threshold at a time 3 hours after commencement of the storm. The flood threshold was reached at the properties at risk 4 hours later. This 4 hour time period is the maximum potential window for provision of a flood warning in this example.

The rainfall-based forecast approach is convenient since it does not rely on complex calculation and therefore can be deployed quickly, repeated as required, and also potentially automated or deployed by non-specialists who have limited training.

In order to use this approach, a robust rainfall monitoring system must be in place. In practice this means at least one BOM standard rainfall gauge is required, or for larger catchments a number of these gauges dispersed across the catchment. The more evenly spread the rainfall measurements across a catchment, the more reliable rainfall-based forecasts can become.

A limitation of this approach is its lack of hydrologic competence, since a simple measurement of average rainfall depth does not account for complexities such as varying storm patterns, antecedent conditions, routing and detailed hydraulic behaviour at the floodplain of interest.

The authors recently undertook a calculation of a rainfall trigger for flood forecasting purposes at a point of interest in a floodplain. For the calculation, a method was applied that partially manages the above-mentioned limitations. Since such calculations may be of broader interest to the industry the method followed is documented in **Section 3** of this paper for reference and discussion. A case study example is also provided in **Section 4**.

3 RAINFALL TRIGGER CALCULATIONS

The suggested method for calculation of a rainfall trigger involves the following three sequential tasks. Each task is described in more detail in the sub-sections that follow.

1. Calculate the critical flood level threshold and associated critical flowrate for your area of interest
2. Establish a hydrologic model of the catchment and deploy the model using a series of storm scenarios with varying depth, duration and pattern
3. Assess the storm scenarios where the critical flowrate is reached and select an appropriate rainfall depth trigger corresponding to the onset of flash flood

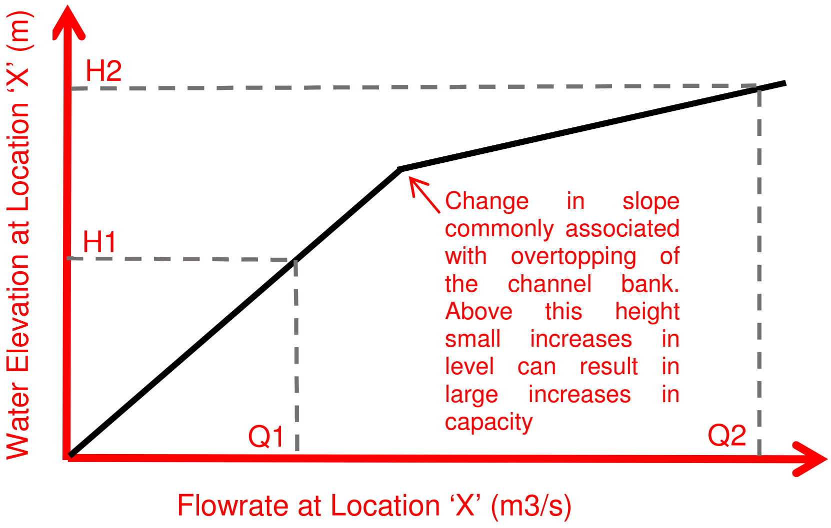
3.1 Calculate the critical flood level threshold and critical flowrate

In order to develop a rainfall trigger, it is first necessary to identify a specific location in the floodplain where the flood level prior to the onset of flash flooding can be determined - for example, a flood level corresponding to the top of a channel bank where further increase in water level would cause the first escape of floodwaters from the channel.

The location should also have a regular and predictable flow behaviour - for example, a reasonably uniform and straight section of channel with limited two-dimensional flow behaviour or backwater effects. Alternatively, nearby road crossings or other hydraulic structures may provide this opportunity.

Once the preferred location is identified, a 'rating curve' is developed for the location. A rating curve describes the relationship between flowrate and water elevation for a given point on a channel or floodplain.

Figure 3: Rating curve concept



The development of a rating curve can be a complex process, involving hydraulic calculations along the relevant reach, along with field measurements of flow velocity at a number of locations and depths across the channel during a range of flow conditions.

For flood warning purposes a simpler approach can be accepted where an estimate of channel capacity is instead derived from hydraulic calculations only. This should be based on a well calibrated hydraulic model which accounts for local patterns of floodplain topography and roughness.

The rating curve and/or hydraulic calculations, once completed, are then used to establish the flowrate corresponding to the critical flood level at the onset of flash flood.

3.2 Hydrologic Modelling

As a next step, a hydrologic model of the catchment upstream of the point of interest is prepared using a runoff-routing model, preferably a model tested and calibrated against observed flood behaviour.

There are various free and commercial software packages available for this purpose, and it is beyond the scope of this paper to discuss catchment modelling in general. However, several variables in this hydrologic modelling task need special consideration for this particular forecast application.

3.2.1 Antecedent rainfall conditions and infiltration losses

When undertaking hydrologic calculations for a particular storm, the antecedent rainfall condition (i.e. rainfall occurring prior to the storm) will influence the amount of infiltration that is assumed in the hydrologic model. If the general weather conditions have been wet prior to the storm, the amount of infiltration expected will be significantly less than if weather conditions had been dry. This effect is amplified in areas with clay soils (i.e. less antecedent rainfall is required to saturate a clay soil than a sandy soil).

Unless there is strong evidence of exceptionally sandy soils and deep aquifers, it is suggested that no infiltration loss be applied when establishing a hydrologic model for calculating rainfall triggers (e.g. initial loss of 0mm and a continuing loss of 0mm per hour).

This assumption will result in a rainfall trigger that is only appropriate for wet catchment conditions. This also means that under dry catchment conditions the level of flooding could be significantly less than normally associated with the rainfall trigger.

It is important to recognize this limitation and compensate for it by always confirming the level of saturation of the catchment prior to applying the rainfall trigger. In effect the measurement of rainfall should only commence once the catchment is saturated. This state is relatively easy to identify through experience and by assessment of real-time water level gauge data. Alternatively, for residents, visual inspection of the channel to assess whether runoff has begun to accumulate and flow in the base of the channel could be an option.

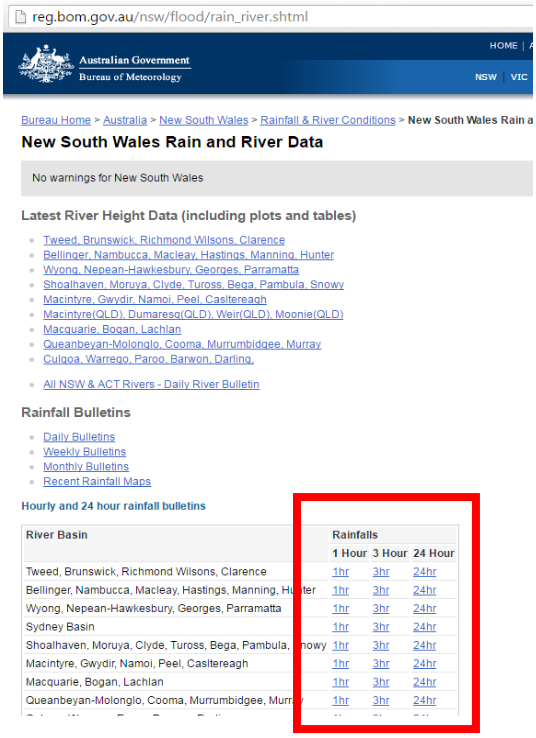
3.2.2 Storm Duration

The hydrologic response of a catchment will differ depending on the duration of a storm. Generally larger catchments will require longer storms with more volume to trigger a flood.

In a traditional design application, say for sizing of a road crossing, hydrologic calculations are normally undertaken for a range of storm durations to determine the peak flood discharge and peak flood level for a specific flood probability (e.g. 1% Annual Exceedance Probability).

When developing a rainfall trigger, the problem is quite different. There is no interest in peak discharge or peak level, nor the probability of these occurring. Instead, the rainfall trigger seeks to establish the rainfall depth that will cause a flood level threshold to be exceeded. To be clear, this may not be the peak level, and the probability of its occurrence is not particularly useful to the end user. This rainfall depth may also occur during a storm of almost any duration less than 24 hours.

Figure 4: BOM Rainfall Website Extract



reg.bom.gov.au/nsw/flood/rain_river.shtml

Bureau Home > Australia > New South Wales > Rainfall & River Conditions > New South Wales Rain a

New South Wales Rain and River Data

No warnings for New South Wales

Latest River Height Data (including plots and tables)

- Tweed, Brunswick, Richmond Wilsons, Clarence
- Bellinger, Nambucca, Macleay, Hastings, Manning, Hunter
- Wyong, Nepean-Hawkesbury, Georges, Parramatta
- Shoalhaven, Moruya, Clyde, Tuross, Bega, Pambula, Snowy
- Macintyre, Gwydir, Namoi, Peel, Casltereagh
- Macintyre(QLD), Dumaresq(QLD), Weir(QLD), Moonie(QLD)
- Macquarie, Bogan, Lachlan
- Queanbeyan-Molonglo, Cooma, Murrumbidgee, Murray
- Culgoa, Warrego, Paroo, Barwon, Darling,

- All NSW & ACT Rivers - Daily River Bulletin

Rainfall Bulletins

- Daily Bulletins
- Weekly Bulletins
- Monthly Bulletins
- Recent Rainfall Maps

Hourly and 24 hour rainfall bulletins

River Basin	Rainfalls		
	1 Hour	3 Hour	24 Hour
Tweed, Brunswick, Richmond Wilsons, Clarence	1hr	3hr	24hr
Bellinger, Nambucca, Macleay, Hastings, Manning, Hu ter	1hr	3hr	24hr
Wyong, Nepean-Hawkesbury, Georges, Parramatta	1hr	3hr	24hr
Sydney Basin	1hr	3hr	24hr
Shoalhaven, Moruya, Clyde, Tuross, Bega, Pambula, nowy	1hr	3hr	24hr
Macintyre, Gwydir, Namoi, Peel, Casltereagh	1hr	3hr	24hr
Macquarie, Bogan, Lachlan	1hr	3hr	24hr
Queanbeyan-Molonglo, Cooma, Murrumbidgee, Murr y	1hr	3hr	24hr

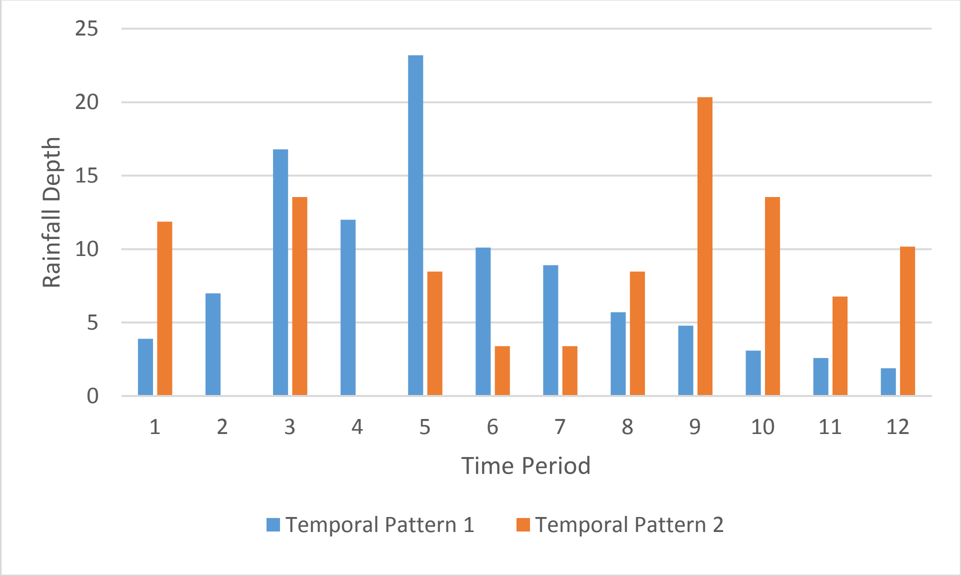
With this in mind, it is suggested that a suite of at least three storm durations be applied to the catchment, being a 1 hour, 3 hour and 6 hour storm.

These three specific durations have been chosen since they are typical durations of relevance to flash flood forecast scenarios. The depths for the 1 hour and 3 hour are also pre-calculated on the BOM website which may make it simpler for the public end-user to monitor rainfall depths for these two durations and any simple multiples (e.g. 6, 9, and 12). Longer durations may be considered for catchments at the larger end of the size spectrum.

3.2.3 Temporal Pattern

The hydrologic response of a catchment will also differ depending on the way in which the rain is distributed over time. This can be referred to as the ‘temporal pattern’.

Figure 4: Temporal Storm Pattern Examples



For design applications, the traditional hydrologic approach involves the use of a single pre-determined temporal pattern, assessed as having an average probability of occurrence. This pattern is published in the technical guideline Australian Rainfall and Runoff (IEAust, 1987).

For a rainfall trigger calculation it is suggested that a library of different temporal patterns also be assessed to ensure that the rainfall trigger ultimately derived is precautionary and conservative. The case study in Section 4 shows that a more natural storm variability could produce very different runoff patterns to the temporal pattern recommended by AR&R, which may even under-estimate flood discharge in some cases.

At present there is no guidance on temporal pattern ensembles to be used, however it is understood that this may change with the planned update to AR&R. For the case study in this paper, a selection of storm temporal patterns was developed by the authors. Alternatively, consider deriving patterns from actual storms, as recorded in the general area.

3.2.4 Model simulation

For each combination of storm duration and temporal pattern, a series of storms with an increasing total rain depth are then simulated.

The table below provides a hypothetical example listing a total of 84 model runs arising from a combination of 3 durations, 4 temporal patterns and 7 rainfall depths. Note that a real life example is likely to result in a larger number of depths chosen and therefore a larger number of model runs and corresponding results.

Table 1: Storm scenario concept

Rain Depth (mm)	Temporal Pattern 'A'			Temporal Pattern 'B'			Temporal Pattern 'C'			Temporal Pattern 'D'		
	1 hr	**3 hr**	**6 hr**	**1 hr**	**3 hr**	**6 hr**	**1 hr**	**3 hr**	**6 hr**	**1 hr**	**3 hr**	**6 hr**
50	*Run 1*	*Run 8*	*Run 15*	*Run 22*	*Run 29*	*Run 36*	*Run 43*	*Run 50*	*Run 57*	*Run 64*	*Run 71*	*Run 78*
55	*Run 2*	*Run 9*	*Run 16*	*Run 23*	*Run 30*	*Run 37*	*Run 44*	*Run 51*	*Run 58*	*Run 65*	*Run 72*	*Run 79*
60	*Run 3*	*Run 10*	*Run 17*	*Run 24*	*Run 31*	*Run 38*	*Run 45*	*Run 52*	*Run 59*	*Run 66*	*Run 73*	*Run 80*
65	*Run 4*	*Run 11*	*Run 18*	*Run 25*	*Run 32*	*Run 39*	*Run 46*	*Run 53*	*Run 60*	*Run 67*	*Run 74*	*Run 81*
70	*Run 5*	*Run 12*	*Run 19*	*Run 26*	*Run 33*	*Run 40*	*Run 47*	*Run 54*	*Run 61*	*Run 68*	*Run 75*	*Run 82*
75	*Run 6*	*Run 13*	*Run 20*	*Run 27*	*Run 34*	*Run 41*	*Run 48*	*Run 55*	*Run 62*	*Run 69*	*Run 76*	*Run 83*
80	*Run 7*	*Run 14*	*Run 21*	*Run 28*	*Run 35*	*Run 42*	*Run 49*	*Run 56*	*Run 63*	*Run 70*	*Run 77*	*Run 84*

It is suggested that rainfall depths be selected in increments of 5 or 10mm, with the range of rain depths selected such that calculated peak flows straddle the critical flowrate identified in the first task. This requires some initial iteration as it is not obvious from the outset what depth of rain is required to achieve a given target flowrate.

3.3 Assess results and select a rainfall trigger

Once complete, the estimated flowrate at the location of interest is extracted from each hydrologic model run and tabulated. This tabulation is used to assess those storm scenarios where the estimated flowrate exceeds the critical flowrate at the onset of flash flood.

Table 2: Storm scenarios exceeding the critical flowrate (highlighted red)

Rain Depth (mm)	Temporal Pattern 'A'			Temporal Pattern 'B'			Temporal Pattern 'C'			Temporal Pattern 'D'		
	1 hr	**3 hr**	**6 hr**	**1 hr**	**3 hr**	**6 hr**	**1 hr**	**3 hr**	**6 hr**	**1 hr**	**3 hr**	**6 hr**
50	*Run 1*	*Run 8*	*Run 15*	*Run 22*	*Run 29*	*Run 36*	*Run 43*	*Run 50*	*Run 57*	*Run 64*	*Run 71*	*Run 78*
55	*Run 2*	*Run 9*	*Run 16*	*Run 23*	*Run 30*	*Run 37*	*Run 44*	*Run 51*	*Run 58*	*Run 65*	*Run 72*	*Run 79*
60	*Run 3*	*Run 10*	*Run 17*	🟥 *Run 24*	*Run 31*	*Run 38*	*Run 45*	*Run 52*	*Run 59*	*Run 66*	*Run 73*	*Run 80*
65	🟥 *Run 4*	*Run 11*	*Run 18*	🟥 *Run 25*	🟥 *Run 32*	*Run 39*	*Run 46*	*Run 53*	*Run 60*	🟥 *Run 67*	*Run 74*	*Run 81*
70	🟥 *Run 5*	🟥 *Run 12*	🟥 *Run 19*	🟥 *Run 26*	🟥 *Run 33*	🟥 *Run 40*	*Run 47*	*Run 54*	*Run 61*	🟥 *Run 68*	🟥 *Run 75*	*Run 82*
75	🟥 *Run 6*	🟥 *Run 13*	🟥 *Run 20*	🟥 *Run 27*	🟥 *Run 34*	🟥 *Run 41*	🟥 *Run 48*	*Run 55*	*Run 62*	🟥 *Run 69*	🟥 *Run 76*	🟥 *Run 83*
80	🟥 *Run 7*	🟥 *Run 14*	🟥 *Run 21*	🟥 *Run 28*	🟥 *Run 35*	🟥 *Run 42*	🟥 *Run 49*	🟥 *Run 56*	🟥 *Run 63*	🟥 *Run 70*	🟥 *Run 77*	🟥 *Run 84*

At this point, judgement must be applied to select a trigger value from those rain depth scenarios where the critical flowrate is exceeded. It is possible to choose:

i. a single rainfall depth trigger likely to result in exceedance of the critical flowrate representative of all durations. This option is simple to apply but may lead to less accurate prediction.

ii. a suite of three representative rainfall depths, one for each rainfall duration, likely to result in exceedance of the critical flowrate. This option is more complex to apply as more rainfall depth calculations are needed, however is more likely to give an accurate prediction.

Regardless of which option is selected, the depth trigger(s) should be selected conservatively. This means that the depth value selected is one of the lowest values identified as exceeding the critical flowrate. However outliers should be disregarded to avoid the trigger being exceeded too regularly.

For the example in Table 2 above a single rainfall depth trigger of 65mm or 70mm may be appropriate with the single exceedance at 60mm ('Run 24') disregarded.

3.4 Refinement using Observations

The above methodology is intended for situations where there is a limited historic record of rainfall and associated flooding. If good historic data exists, the historic record can be 'mined' to correlate rainfall and associated flooding as an alternative to the modelling approach described. Alternatively it can be used to inform and progressively refine the results of the modelling approach over time.

4 LILLIPUT CREEK CASE STUDY

The following case study is based on a real-life example where the above methodology was used to calculate a rainfall depth trigger. The calculations and results are based on this real-life example however the actual name of the creek and the location are not disclosed for privacy purposes.

Lilliput Creek is a 1500 hectare creek catchment located on Australia's sub-tropical east coast. Lilliput Creek is served by a rainfall gauge and a water level gauge. Moderate flooding was found to cause isolation and inundation of a significant number of properties alongside Lilliput Creek. The flooding experienced is considered to be 'flash flood' and no detailed warnings are provided by the BOM or Council.

A rainfall trigger calculation was undertaken with the intent of providing guidance to residents so they could self-assess their flood risk and evacuate to high ground if necessary. The following is a summary of the calculations undertaken.

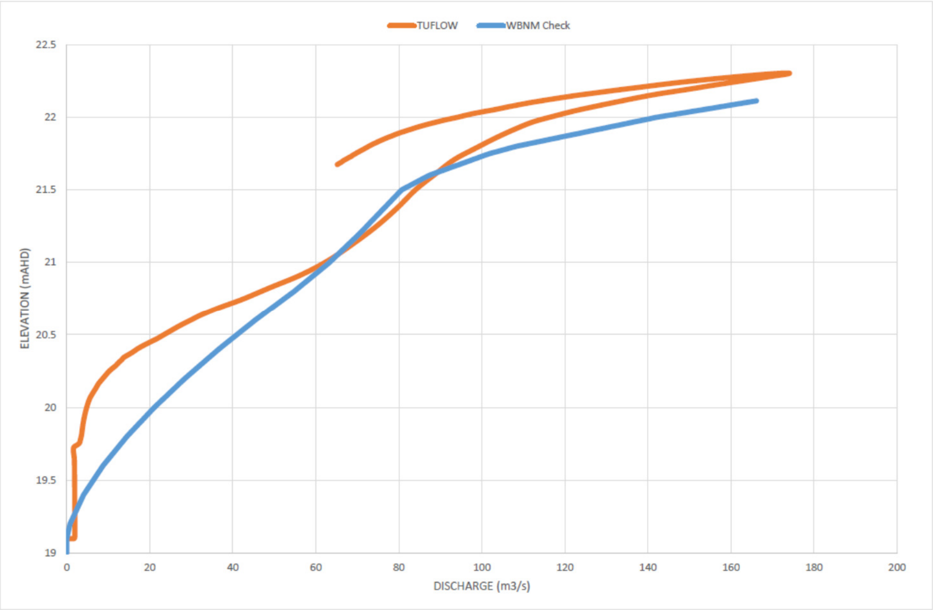
4.1 Task 1 - Lilliput Creek critical flood level threshold and critical flowrate

Water level conditions immediately upstream of the Lilliput Creek Road culverts have been identified as a suitable proxy for general flood conditions in this floodplain. Specifically, when water levels reach the road level (RL 21.8 mAHD), flood conditions begin to deteriorate, including break out of flow from the main channel and through properties. This level also corresponds to a gauge level of 2.2m above the gauge zero and a 'moderate' BOM flood classification at the gauge. A decision to evacuate must be made before this critical threshold is reached.

A rating curve was developed to correlate water level with flowrate upstream of the road crossing. The rating curve was established using output from a calibrated 2D flood model, prepared using the hydraulic modelling software package TUFLOW. The figure below shows the TUFLOW derived rating curve (orange line) along with an independent sensibility check using the hydrologic model software WBNM (blue line). For a 'moderate' flood classification level of 21.8m AHD the estimated discharge using the TUFLOW derived rating curve is 105 m^3/s.

Note the curve derived from the falling limb of the hydrograph (top part of orange line) was ignored as this is not relevant for flood warning.

Figure 5: Lilliput Creek Culvert Rating Curve



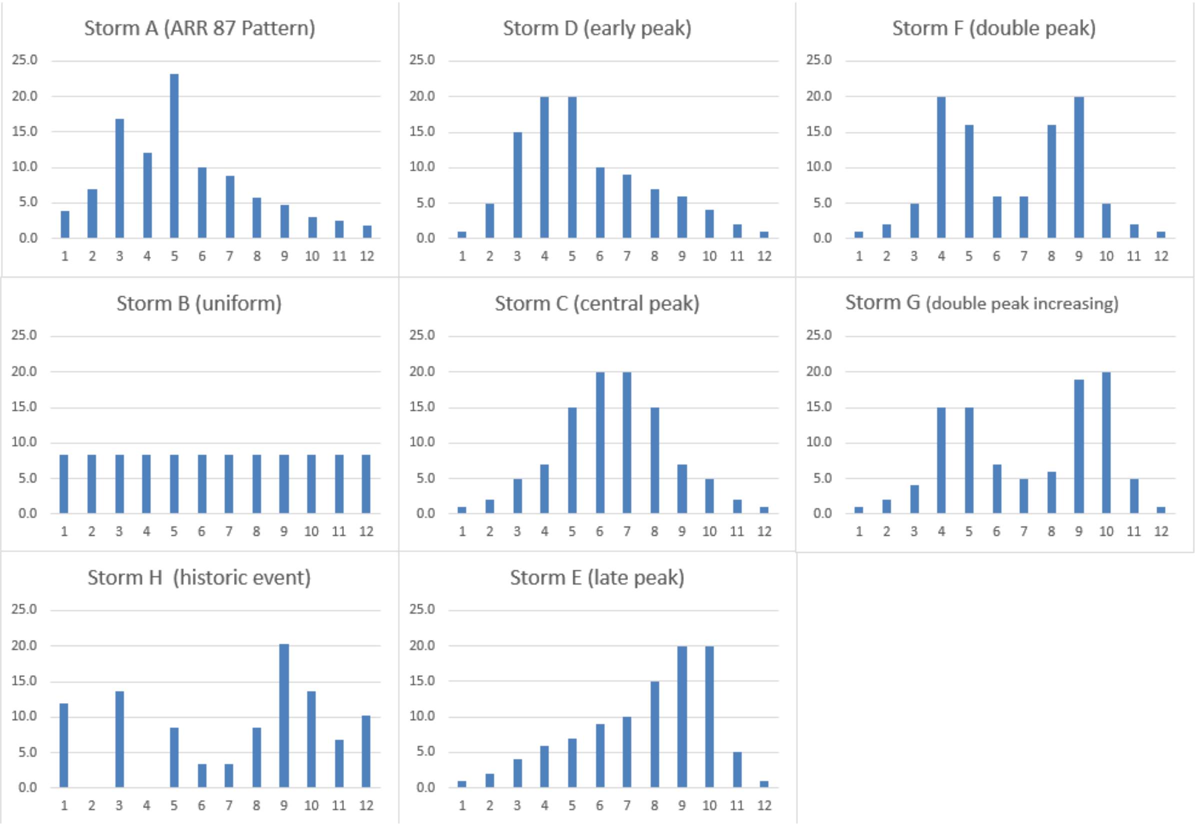
4.2 Task 2 - Lilliput Creek Hydrologic Modelling

The next step undertaken was to determine the amount of rainfall that would result in a flowrate of approximately 105 m3/s at Lilliput Creek Road. A hydrology model was developed for the catchment. The model assumed 0mm initial and continuing losses, consistent with a fully saturated catchment.

A library of storm combinations were simulated using the model. The library comprised storm durations of 1 hour, 3 hour and 6 hour and a series of 8 different storm temporal patterns as shown in Figure 6.

For each combination of storm duration and pattern a range of total rain depth values was applied in 5mm increments.

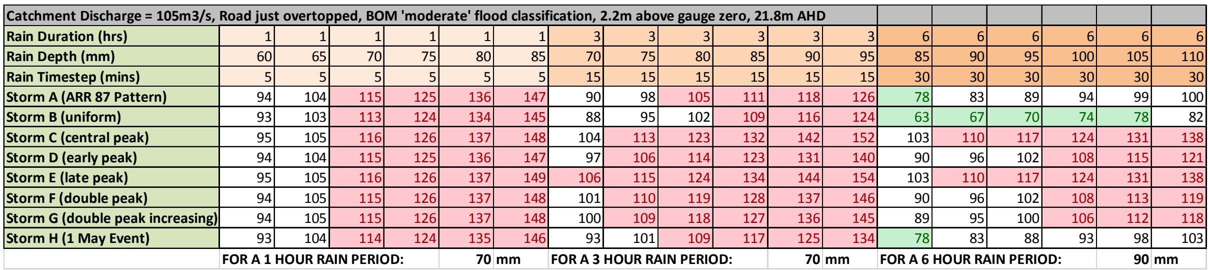
Figure 6: Lilliput Creek Case Study Temporal Patterns



4.3 Task 3 Lilliput Creek results and rainfall trigger recommendation

The table below shows the peak discharge at Lilliput Creek Road culvert from 144 combinations of storm duration, temporal pattern and depth simulated. Values shaded red exceed the 105m^3/s critical flow threshold.

Table 3:Lilliput Creek Storm Simulation Results



Catchment Discharge = 105m3/s, Road just overtopped, BOM 'moderate' flood classification, 2.2m above gauge zero, 21.8m AHD																		
Rain Duration (hrs)	1	1	1	1	1	1	3	3	3	3	3	3	6	6	6	6	6	6
Rain Depth (mm)	60	65	70	75	80	85	70	75	80	85	90	95	85	90	95	100	105	110
Rain Timestep (mins)	5	5	5	5	5	5	15	15	15	15	15	15	30	30	30	30	30	30
Storm A (ARR 87 Pattern)	94	104	115	125	136	147	90	98	105	111	118	126	78	83	89	94	99	100
Storm B (uniform)	93	103	113	124	134	145	88	95	102	109	116	124	63	67	70	74	78	82
Storm C (central peak)	95	105	116	126	137	148	104	113	123	132	142	152	103	110	117	124	131	138
Storm D (early peak)	94	104	115	125	136	147	97	106	114	123	131	140	90	96	102	108	115	121
Storm E (late peak)	95	105	116	126	137	149	106	115	124	134	144	154	103	110	117	124	131	138
Storm F (double peak)	94	105	115	126	137	148	101	110	119	128	137	146	90	96	102	108	113	119
Storm G (double peak increasing)	94	105	115	126	137	148	100	109	118	127	136	145	89	95	100	106	112	118
Storm H (1 May Event)	93	104	114	124	135	146	93	101	109	117	125	134	78	83	88	93	98	103
	FOR A 1 HOUR RAIN PERIOD:				**70**	**mm**	**FOR A 3 HOUR RAIN PERIOD:**				**70**	**mm**	**FOR A 6 HOUR RAIN PERIOD:**				**90**	**mm**

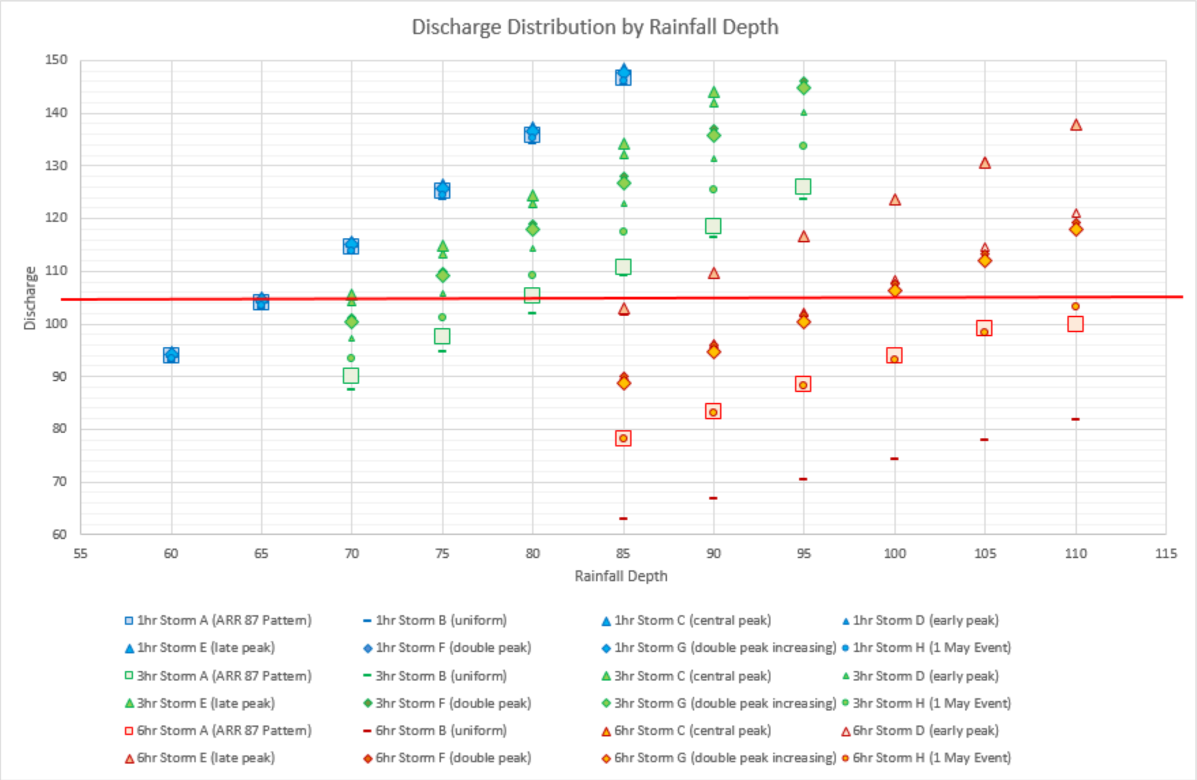
For a 1 hour period the rainfall depth that first causes exceedance of the critical flow threshold is 70mm (all 8 temporal patterns).

For a 3 hour period the rainfall depth that first causes exceedance of the flow threshold is 70mm (Storm E 'Late Peak' only). However this could be considered an outlier. A broader range of temporal patterns exceed the flow threshold once a 75mm rain depth occurs (5 out of 8 temporal patterns).

For a 6 hour period the rainfall depth that first causes exceedance of the threshold is 90mm (2 out of 8 patterns). However the majority of patterns do not exceed the flow threshold until 100mm depth of rain.

From these results we observe that temporal pattern becomes a more significant influence on peak discharge as rain duration increases. This means that for very small catchments it may be less critical to test a range of temporal patterns (refer Figure 7).

Figure 7: Lilliput Creek Discharge Distribution by Rainfall Depth



Based on these results the following rainfall depth triggers were recommended:

- 80mm for a single encompassing value applying to all storm durations OR
- 70, 75 and 100mm for the 1 hour, 3 hour and 6 hour storm respectively.

For simplicity, an average value of 80mm has been adopted for the purpose of an initial guide to residents. However it is noted that in reality there is likely to be a considerable range of storm depths that cause the flow threshold exceedance. Accordingly it was recommended that this initial guide be refined over time using observed data from the catchment.

5 IMPLEMENTATION CHALLENGES

While a rainfall-based flood forecast system may help people to implement their flood plan in a timelier manner, there are challenges to consider if seeking to encourage its use for flood risk self-assessment.

- The rainfall monitoring network must be robust, with well distributed gauging across the catchment. Consider more than one gauge for larger catchments.
- The rainfall gauge(s) needs a reliable public interface to assist with monitoring. Preferably an interface that serves data in the exact form needed. For many locations

there currently is a reliance on the BOM website. This is in itself a challenge to consider.

- Regardless of the quality of the hydraulic and hydrologic calculations, the rainfall trigger values derived will never be precise, and will always benefit from refinement using a period of observation of actual events.
- Trained flood staff from the local Council are best placed to apply a rainfall-based forecast. Self-assessment by residents should not be the first preference for areas with a significant flood risk.
- If residents are expected to apply the forecast method, they need clear information and training on how to best monitor rainfall and undertake the required calculations. They also need to be made aware of the limitations of the forecast method and the potential for false alarms.

5 SUMMARY

Flash flood catchments with warning durations of less than 6 hours can present significant challenges for residents and emergency staff alike.

Correlating the levels of flood experienced in such catchments to the depth of rainfall can be useful for flood emergency planning. Especially in those catchments where a rainfall gauge is present in the catchment and its data is made available online with regular updates.

This paper has identified a method of developing ‘rainfall triggers’ which can be of use in those catchments to assist ‘at risk’ residents to identify flood risk and implement their flood plan.

Following the identification of a flow rate at a critical location in the catchment which is likely to lead to flash flooding, hydrologic modelling software can be deployed to simulate a series of storm durations, temporal patterns and rainfall depths to identify the ‘rainfall triggers’ leading to this flow rate.

There are inherent limitations to this approach, such as the assumption that the catchment is already fully saturated from earlier rainfall when the rainfall count commences.

Nevertheless, ‘rainfall triggers’ may represent a useful tool in the arsenal of residents and emergency management staff alike in assessing flood risk. Should a recommendation to apply those triggers be made to residents, this must be provided as part of a flood risk management package, which must comprise adequate training and the provision of tools to easily access the relevant information.