FORECASTING FLASH FLOODS – WHAT CAN YOU DO?

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ABSTRACT

In recent times, flood forecasting systems have been successfully developed to allow floodplain and flood emergency managers to determine the affectation of impending flooding for larger river catchments. In such systems, both fallen and forecast rainfall can be used to determine likely river behaviour at some time in the future.

However, in “flashy” or “urban” catchments, successful forecasting and emergency management must be carried out prior to the commencement of significant rainfall. In such situations, the management of the uncertainty of likely rainfall volumes and intensities becomes critical, as does the ability to rapidly assess the implications of changing forecasts.

This paper explores some innovative approaches being used in Australia to inform decision makers managing “flashy” catchments. These approaches focus on leveraging readily available hydrologic, hydraulic and infrastructure spatial datasets, along with forecast rainfall amounts to rapidly provide real-time intelligence on what will be affected by the impending flood, such as:

- What could the flood look like?
- Who will be affected?
- What roads will be cut?
- What infrastructure will be affected?
- What is the sensitivity of the above to changing forecasts?

KEYWORDS

Forecasting, real-time, flash flood, interpolation, affectation, flood intelligence

PRESENTER PROFILE

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1 INTRODUCTION

A wide range of systems and approaches have been developed to assist in the real-time management of floods. Some systems are fairly basic, reporting likely flood levels at locations in the catchment, whilst others provide more sophisticated information in terms of the affectation of the impending flooding, covering both who and what will be affected.

However, most, if not all, of these systems focus on larger river catchments with longer warning times, where it is feasible to implement response strategies after rainfall has commenced, but prior to inundation.

Traditionally, catchments with a more rapid onset of flooding, or "flashy" catchments, have largely been serviced by warning systems which are reactive. Such systems consist of warning sirens that are triggered by catchment rainfall thresholds or changes in upstream levels.

In most cases, these systems do not add to effective warning time as rain must have fallen to trigger operation of the system. Consequently, response efforts have been largely left to "clean up" operations after flooding, due to the relatively short amount of time to react once rainfall has commenced.

With the increasing *availability* of forecast rainfall amounts, and a wealth of spatial datasets at hand (hydraulic modelling, terrain, properties, infrastructure and facilities), there is scope to increase the effective warning time by understanding not only what may happen to flood levels, but also what the implications of the expected flooding may be, before the storm has commenced, significant rain has fallen.

2 BACKGROUND

The more common form of longer duration flood forecasting systems utilises expected flood levels at key locations, usually gauges, in a catchment. Expected levels are commonly determined through real-time hydrologic modelling of a combination of actual and forecast rainfall.

This approach has the capability to capture both spatial and temporal variation in rainfall, but usually requires some form of technical background to operate the system during a flood event, and does not provide an indication of the likely *affectation* of the forecast flooding in its own right.

Recent floods in Australia have highlighted the need for a flood forecasting system to be simple enough to use by those without a technical background. In many cases, sophisticated and complex systems have been rendered "useless" as key operators were unable to operate the system during floods.

3 HYDROLOGIC INTERPOLATION

The hydrologic interpolation approach is conceptually very simple.

A number of variables affect how rainfall and subsequent runoff is routed through a catchment to determine potential flooding impacts, including:

- *Rainfall Volume:* Rainfall intensity and amount

- *Rainfall Distribution:* Spatial and temporal distribution of rainfall
- *Catchment Lag/Storage Characteristics:* Catchment shape, steepness, roughness
- *Rainfall Losses:* Initial and continuing losses

"Flashy" catchments, by their very nature, are relatively small. Consequently, it may be reasonable to assume that during a flood event, the rainfall across the catchment can be characterized as *uniform.* This uniformity may be *absolute* (the same rainfall across the entire catchment)*,* or *relative* in that rainfall events have a consistent spatial pattern across the catchment between event magnitudes.

This assumption allows the rainfall distribution variable to become a constant. The catchment lag characteristics can be determined for any given catchment through calibration, thereby also becoming a constant.

This reduces the expected hydrologic behaviour to a function of likely rainfall volume, and rainfall losses. As variations in rainfall losses are largely a function of antecedent catchment conditions, characterising these into meaningful groups such as "average", "wet", and "dry" reduces the variation to a "limited variable".

Consequently, the resulting behaviour of the catchment becomes a function of incident rainfall volumes, for a given antecedent catchment condition, and the expected duration of the event.

During an event, one could employ real-time hydrologic modelling to determine the likely outcome for a given rainfall intensity and duration. Although simplified by reducing the number of variables, this still requires some degree of technical knowledge and, given the uncertainty in forecasting rainfall, is potentially too sophisticated.

An alternative is to batch run an hydrologic model across the domain of rainfall intensity/duration combinations (ie pre-cook "every" rainfall scenario). In this fashion, the likely flood behaviour of the catchment is "known" before an event.

By creating a matrix of likely flow for varying rainfall intensities and durations, one could simply "lookup" expected flow for a given forecast rainfall intensity and duration. This is referred to as a "hydrologic lookup table".

Despite hydrologic models being fast to run, it is unfeasible, and unnecessary, to run all combinations of rainfall duration and intensity. Rather, a discrete set of combinations can be identified and usually correspond to families of standard ARI's on an IFD curve. Interpolation can be used to infer values between these discrete sets.

An example hydrologic lookup table, with suitable discretisation, for a catchment in South East Queensland is provided in Table 1. The table also includes the indicative Annual Recurrence Interval of the rainfall intensity/duration combinations, for reference.

ARI	**5yr**		**10yr**		**20yr**		**50yr**		**100yr**		**500yr**		**2000yr**		**PMF**	
Duration (hrs)	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***	**Q** *m^3/s*	**Avg I** ***mm/h***
0.5	142	84	171	96	211	112	266	135	312	152	429	197	546	239	1227	480
1	206	58	249	66	308	78	390	94	456	107	631	139	797	170	1902	360
1.5	230	43	278	50	346	58	437	71	514	80	709	105	901	128	2154	273
2	244	35	295	40	367	48	465	57	547	65	757	85	969	105	2518	240
3	264	26	320	30	400	35	506	43	595	49	825	64	1054	79	2698	180
4.5	266	19	325	22	407	26	516	32	608	36	849	48	1091	59	2949	140
6	272	15	333	18	418	21	526	26	621	29	870	39	1120	48	2894	110
9	228	11	282	13	356	16	448	19	530	22	746	29	960	36	2633	87
12	236	9	291	11	367	13	451	16	534	18	750	24	970	29	2749	72
24	215	6	268	7	342	8	410	10	489	11	698	15	906	19	2955	52

Table 1 – Example "Hydrologic Lookup Table" for a given location (gauge) in a catchment.

The hydrologic lookup table then becomes simple to use during an event, through direct, two-way interpolation of a flow from the forecast rainfall intensity and duration. For example, 100mm of rain is expected in the next 2.5hrs. By interpolating between the 2hr and 3hr duration lines, the average forecast intensity of 40mm/hr sits between a flow of 307.5 m^3/s and 383.5 m^3/s (or a 10yr and 20yr ARI event). Interpolating through rainfall intensity results in a forecast flow of 366.0m^3/s at the relevant location (gauge). A rating curve can then be used to identify the flood level for the forecast flow.

By codifying this interpolation, the emergency manager can rapidly (within seconds) and robustly determine likely flood levels for the provided rainfall, using the lookup table for the appropriate antecedent catchment conditions. But what do these forecast levels at gauges in the catchment mean in terms of who and what is affected?

4 HYDRAULIC INTERPOLATION

Hydraulic interpolation techniques have been employed in flood forecasting systems for many years as a means of converting forecast levels at discrete locations in a catchment (gauges) into a continuous flood surface of likely flooding (Druery et al., 2003). The algorithm relies on a library of hydraulically correct flood surfaces derived from hydraulic modelling across a range of flood magnitudes (small through to large).

Based on a forecast level at a location, the two surfaces that span this forecast level are selected from the library and used to interpolate a surface representing the forecast level. As this interpolation is applied across the entire modelled area, a continuous water surface across the floodplain is created.

As a water surface represents water levels across the entire floodplain (on a grid or TIN framework), the water surface elevation is known at all locations. Surfaces provide a framework from which additional information can be readily created by integrating with other surfaces (eg water level minus terrain provides a depth surface). This is in contrast to traditional approaches using flood extent mapping.

For example, Figure 2 shows the likely flood extent for a forecast rainfall of 150mm in the next 4 hours. Whilst it shows the properties that are likely to be affected, it does not provide any indication of the degree to which they are affected. Figure 4 shows a depth surface (water surface minus terrain) for the same area, showing depths ranging from 0.0m to in excess of 5.0m, providing valuable information to the emergency manager.

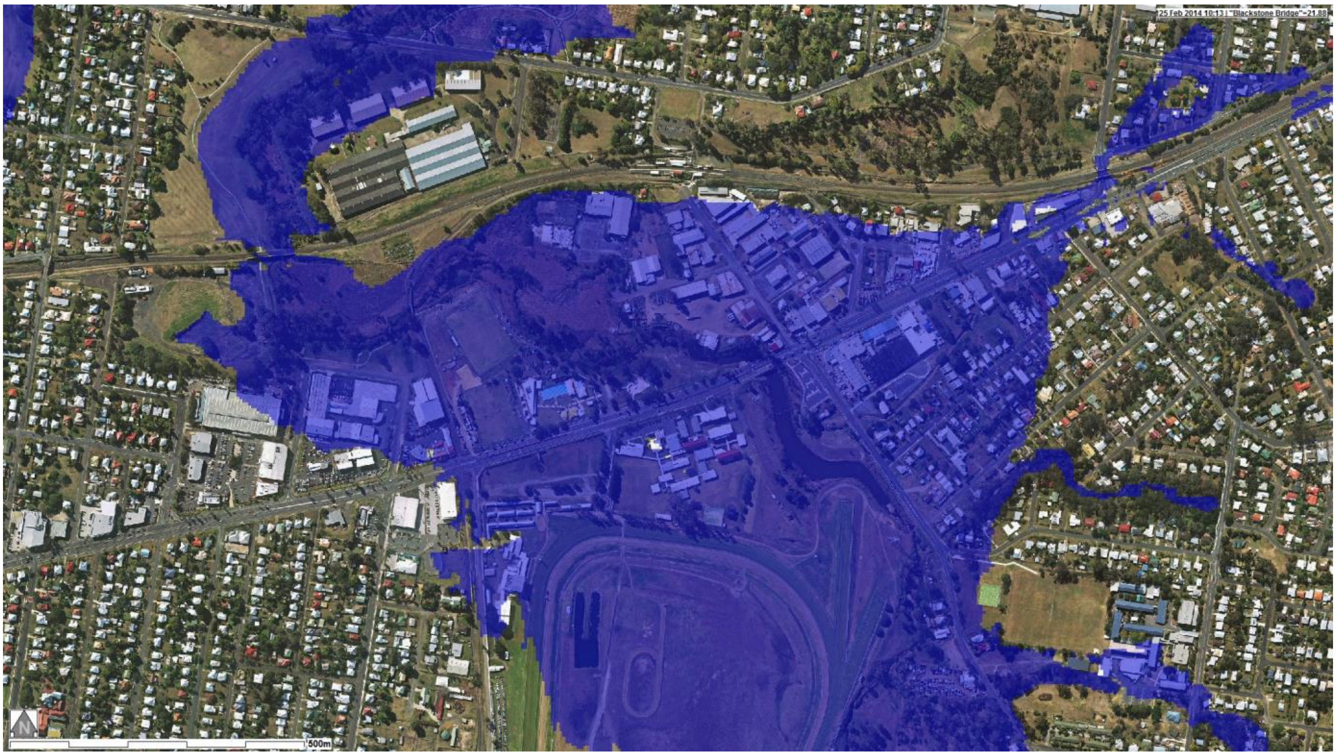

Figure 1 – Forecast flood extent map.

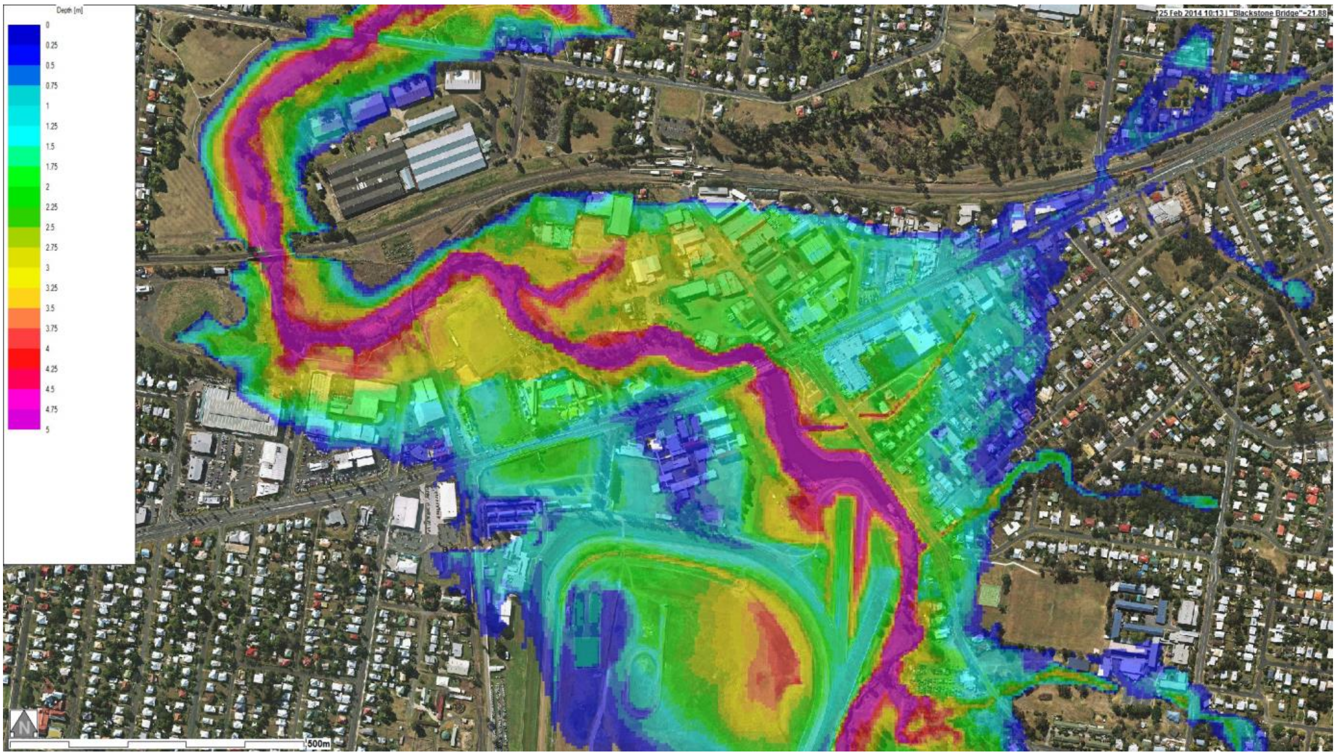

Figure 2 – Forecast surface integrated with terrain to provide expected flood depths.

Additional, more targeted, information can be created by integrating surfaces with available GIS datasets.

5 FLOOD INTELLIGENCE

A wealth of flood intelligence can be created by integrating a forecast flood surface with various readily available spatial datasets through GIS interfaces such as waterRIDE™ (Druery et al., 2007).

Examples of such flood intelligence include:

- Flood extent and depth
- Affected properties
- Affected facilities and critical infrastructure
- Evacuation route status

At the base level, the forecast surface will provide a likely flood level for each object within a GIS layer (eg the level at a property). Further integration with field data associated with the GIS object can yield more detailed, and more useful, intelligence (eg subtracting a property's floor level from the flood level provides the depth over floor). In our example, the properties likely to affected by over floor flooding are shown on Figure 3.

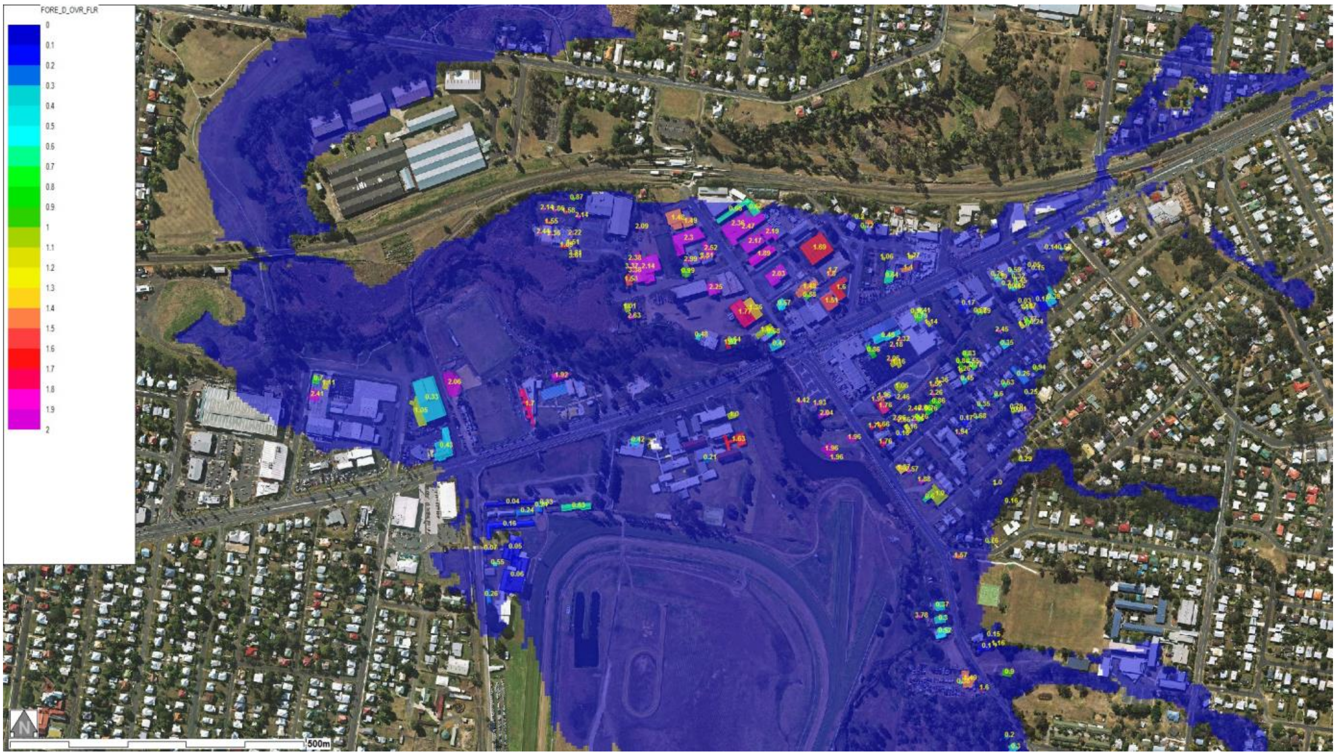

Figure 3 – Affectation of forecast rainfall: properties affected by over floor flooding.

The value of any derived flood intelligence is in addressing the specific needs of emergency managers during an event, rather than having the emergency manager infer their needs from base datasets.

Whilst such flood intelligence is widely used for longer duration flooding, the same intelligence is equally valuable to those managing flash floods, although consideration must be made of the time available in which to utilise such information, and to its accuracy.

6 MANAGING UNCERTAINTY

With all flood forecasting, there is a large degree of uncertainty inherent in the process stemming from areas such as:

- Forecasting future rainfall volume
- Extrapolation of fallen rain from point based recordings at gauges
- Defining antecedent conditions
- Underlying model calibration parameters

Flash flood forecasting somewhat compounds these uncertainties and its rapid nature necessitates the requirement for understanding what the implication of any uncertainty is.

A simple way to express the uncertainty is to allow for a variation in rainfall amount (eg +/- 20%). The *impact* of that uncertainty can then be quantified by looking at the change in affection between the upper and lower bounds of the "uncertainty limits" through the hydrologic and hydraulic interpolation techniques.

For example, Figure 4, below, shows three surfaces created using hydrologic and hydraulic interpolation techniques. The blue surface represents the flood extent associated with expected rainfall of 150mm over the next 4 hours. The yellow surface represents the extent of 20% *less* rainfall (ie 120mm over 4 hours), and the red surface the extent for 20% *more* rainfall (ie 180mm over 4 hours).

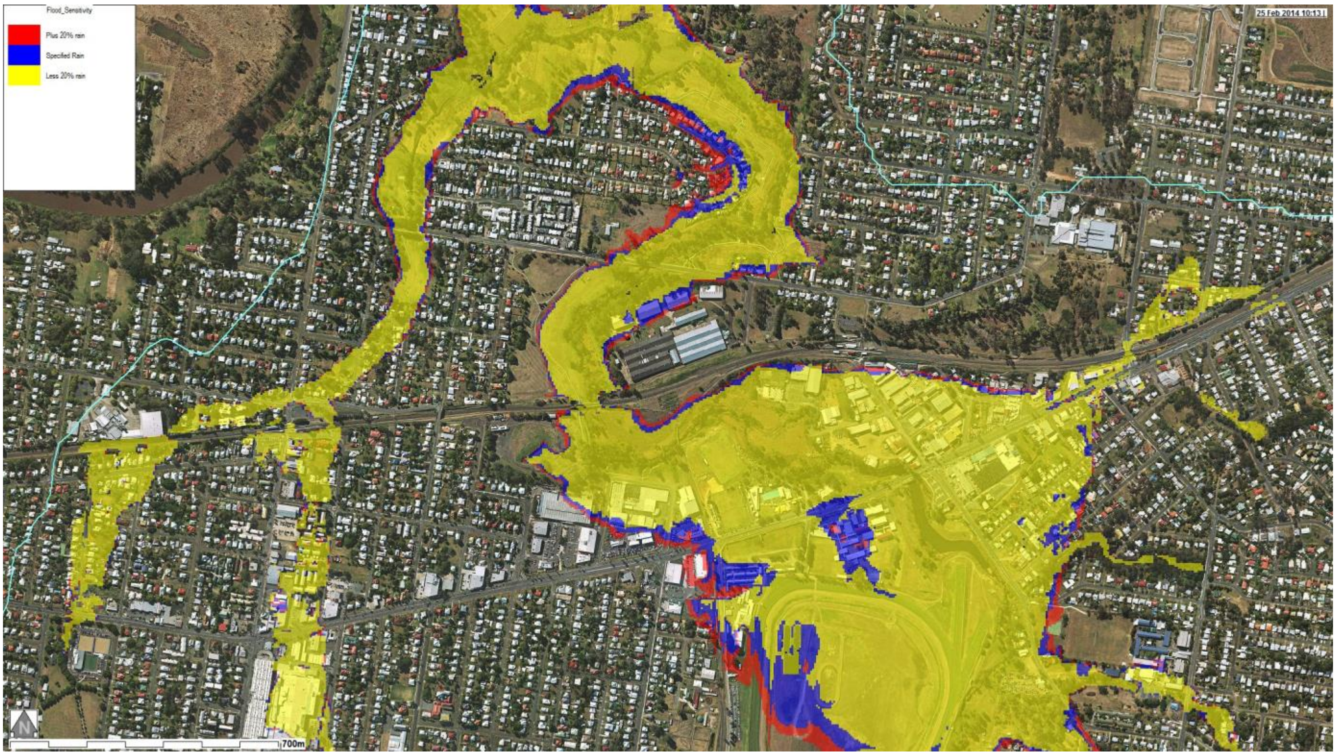

Figure 4 – Managing forecast uncertainty: Blue = flood surface for expected rainfall, yellow = flood surface with 20% less rainfall, red = flood surface with 20% more rainfall

It is clear from Figure 4 that, from an emergency management perspective (population to evacuate), there is little difference between the upper and lower “certainty bounds” (the red and yellow surfaces). Seeming somewhat contradictory, despite the uncertainty in expressed in the forecast, the relative certainty in outcome for the forecast flood (in terms of flood extent) is actually quite high.

This approach provides a means of understanding, and potentially overcoming the large uncertainties associated with forecasting rainfall, in particular for flash flooding.

7 REQUIRED DATA

The hydrologic interpolation approach is designed to leverage readily available datasets. Consequently, base data requirements are relatively modest and include:

- Hydrologic modelling outputs (covering the rainfall frequency domain)
- Hydraulic modelling outputs (from small through to large floods)
- A Digital Elevation Model
- Rating curve (to convert flows into levels)
- A means of forecasting rainfall

Further value can be added to the approach if GIS information is available from which to generate flood intelligence such as property, infrastructure and evacuation route datasets.

8 VARIATIONS ON “HYDROLOGIC INTERPOLATION”

The approach presented in this paper is focussed on leveraging “classic” hydrologic and hydraulic modelling techniques where both components are run separately. Increasingly, “direct rainfall” approaches are used to model urban catchments.

In such models, the hydrology and hydraulics are combined in the one solution technique. As a result, there is no separation of rainfall and flow, but rather rainfall leading directly to a flood level(s).

In such cases, the hydrologic lookup table could be changed to an intensity/duration/level structure, as levels at key locations can be directly read from the relevant model surface. As forecasts are made, the flood level is interpolated directly from the lookup table and used as the basis for hydraulic interpolation

If extensive “direct rainfall” modelling is available, across the domain of rainfall intensity and duration combinations, then the hydrologic lookup table could be bypassed entirely and a direct surface interpolation made between the forecast intensity/duration and a “library” of direct rainfall model outputs.

9 LIMITATIONS OF THE APPROACH

There are a number of key limitations of the hydrologic interpolation approach that must be considered in determining its applicability to a catchment.

The first is that it must be reasonable to assume that the catchment experiences uniform rainfall, or at least a common spatial pattern in rainfall (ie proportionally higher intensity rainfall in the upper catchment than the lower catchment across the range of rainfall events). For catchments where there is significant spatial variation in rainfall, a real-time hydrologic model combined with hydraulic interpolation may provide more reliable outcomes.

The adequacy of the rating curves used to convert forecast rainfall into flood levels is important. To account for any dynamic storage of the system and hydraulic routing, it may be preferable to derive rating curves from the base hydraulic modelling used in the hydraulic interpolation library.

The discretisation of the hydrologic lookup table is important to ensure that there is adequate definition of key hydrologic behaviour changes in the catchment. For example, ensuring that there is adequate capture of when storages are initially activated and ultimately filled in the rainfall/intensity combinations. This may need to be considered in conjunction with rating curves and the hydraulic surfaces that form the hydraulic interpolation library.

Finally, the quality of the rainfall forecasts is paramount. Despite the fact that there are techniques for addressing and managing uncertainty, if the base rainfall forecasts are grossly inadequate, then the outcomes of any forecasting system, including one employing hydrologic interpolation, will be misleading.

10 CONCLUSIONS

The hydrologic interpolation technique provides a rapid, robust, and conceptually simple alternative to more complex real-time hydrologic modelling approaches for "flashy" catchments.

Most importantly, it can be run well *before* rainfall has commenced, potentially "buying" significant additional warning time to more reactive approaches that rely on fallen rainfall.

Despite its conceptual simplicity, the approach has clear merit in its ability to provide useful and timely intelligence to emergency managers to assist in the decision making process.

The approach to quantifying uncertainty provides flood emergency managers with "real world" outcomes, and its speed and simplicity readily lends the approach to "what if" analysis, both during an event and in planning phases.

As the approach uses readily available datasets, it can be implemented quickly and efficiently.

However, there are a number of shortcomings that must be investigated if considering using such an approach. The most important being the assumption of uniform rainfall across the catchment during a given event.

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