Flood Forecasting - What Can You Do With Your Data?

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Abstract

Driven by the large scale flooding over the past several years and growing community expectations, the need to predict likely flood extents and outcomes at the outset of meteorological events has become essential. It is now a key focus for government authorities and businesses that are responsible for emergency response, asset security and business interruption.

The recent growth in overland flood modelling coupled with the results of more traditional floodplain modelling provides a ready data source to rapidly convert discrete flood levels predicted from rainfall data, into gridded flood surfaces.

The flood surfaces can then be integrated with other common datasets such as LiDAR elevation models, cadastre, property and asset GIS data to determine who and what will be affected by the coming flood, by how much and when.

Such detailed intelligence can be used by emergency managers to plan and prioritise response effort, and a simplified version can be pushed out to a wider audience through SMS alerts and web maps of affected areas.

Rainfall data has also become more available with agencies able to access an increasingly large amount of real time rainfall and stream level data. Combined with the BoM's ADFD and PME forecast rain grids, any agency or business charged with flood response can use fallen or forecast rain, or a combination to predict expected levels at defined stream locations. This discrete level data can then be leveraged with the flood model results to generate an interpolated flood surface across the landscape that will represent the likely future flooding.

Introduction

Significant flooding in Australia over the past decade has significantly raised the profile of flooding across the country. This increase in community awareness, combined with rapid evolution of technology, has necessarily translated into greater expectations of what information should be provided by Government authorities during flood events, ahead of the onset of flooding.

Although flood forecasting has been commonplace in Australia for some time, and generally undertaken by the Bureau of Meteorology (*the Bureau*), this has been limited to catchments with sufficient natural warning time (*ie larger catchments with a higher natural lag*).

However, many communities are affected by flooding from rivers and creeks for which flood forecasts are not issued by the Bureau, and would benefit from advanced warning of impending flooding, including those catchments considered "flashy".

The base dataset requirements to develop both simple and more sophisticated real-time flood forecasting systems are generally readily available to Councils and Government authorities, and even some private enterprises.

By making use of this available information, an effective flood forecasting system that takes predictions of flood level at specific locations in the catchment and creates a likely flood surface, can be readily developed.

This not only delivers an indication of what the flood is likely to "look like", but allows the likely affectation, or impact, to be determined, which is critical in managing flood emergencies.

Data Requirements

The dataset requirements to build an effective flood forecasting system are actually quite modest.

The increasing ease and detail in which computer flood models can be setup and run has led to a large volume of flood model outputs being held with Councils and Government Agencies.

Combined with massive amounts of spatial data such as aerial imagery, terrain surfaces, property, road, and facility datasets, a rich collection of information is readily available for use in flood forecasting.

A flood forecasting system can be quickly developed with the following minimum datasets:

- Flood surfaces (*generally from flood model outputs*) for a range of flood magnitudes
- Digital Elevation Model (*DEM – often from LiDAR*)

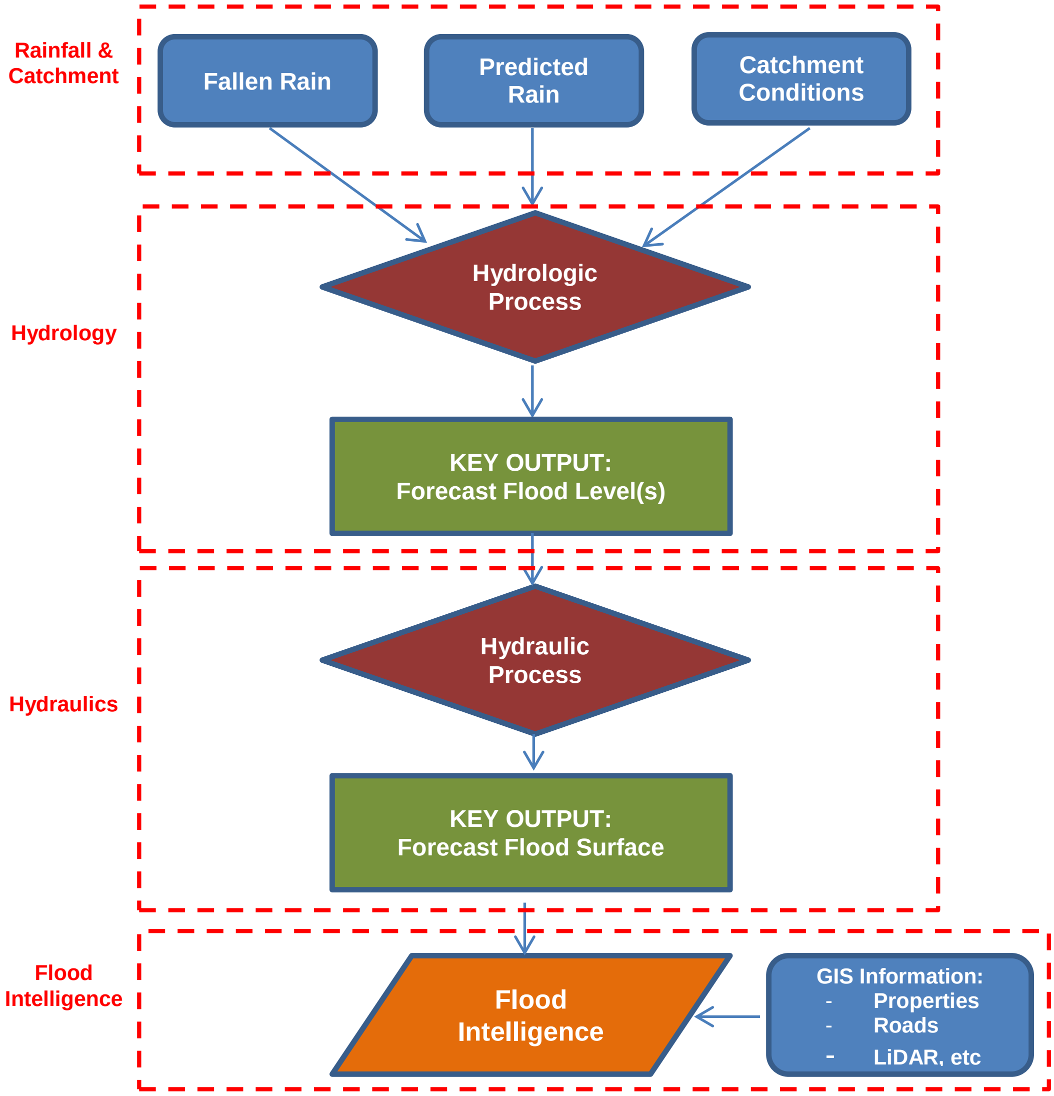
- Forecast flood levels in the catchment (*eg likely catchment and/or storm surge levels provided by the Bureau*)

The sophistication and capability of a system can be increased if the any/all of the following datasets are also available:

- Actual and forecast rainfall
- Hydrology model outputs
- A hydrologic model suitable for real-time hydrologic modelling
- GIS datasets of properties, roads, critical infrastructure etc

Conceptual Operation Of a Flood Forecasting System

The following **Error! Reference source not found.**, illustrates the general data flow of a real-time flood forecasting system.



The key components of any flood forecasting system are:

1. *Rainfall and catchment information*: how much rain is likely to fall and what are the likely catchment losses?
2. *Hydrologic process*: convert rainfall into likely runoff giving levels (via flow) at discrete locations in the catchment.
3. *Hydraulic process*: convert forecast flood levels into a flood surface (*a continuous water surface across the floodplain*).
4. *Flood outcomes*: the likely affectation of the forecast flooding in a context that is targeted to the various stakeholders managing/planning for a flood emergency.

Rainfall and Catchment Information

Rainfall (*actual and forecast*) along with catchment conditions are the key variable inputs for a flood forecasting system. Whilst some systems rely on utilising expected flood levels at locations in the catchment (*eg the Bureau providing peak level forecasts for various gauges*), at some point rainfall and catchment conditions have been analysed.

Catchment Conditions

There can be significant variation in the amount of runoff in any given catchment depending on antecedent conditions. In a wet catchment, most, if not all rainfall will find its way into the waterway system, whilst in very dry catchments, an entire storm can be “consumed” by the catchment with very little runoff.

Technical forecasters are likely to apply, at a minimum, pre-determined initial and continuing loss values for the state of the catchment, but may also use continuous hydrological modelling to gauge catchment conditions by comparing rainfall runoff with streamflows.

Operational forecasters might, however, be better served with catchment condition categories such as “wet”, “dry” or “average”, rather than referring to continuing and initial loss values. Where a catchment has significant variation losses, more pre-determined categories will be required to provide sufficient discretisation of appropriate losses.

Rainfall – Actual

A telemetered network of pluviometers, at sufficient spatial density, provides an automated means of collecting, interrogating and utilising fallen rainfall. Spatial interpolation between gauges can be used to extend coverage to the entire catchment and facilitate rainfall runoff modelling during an event.

Figure 1 shows a surface of actual rain in the last 24 hours derived from a rain gauge network. The surface represents a linear interpolation between rain gauges, and allows a rainfall hyetograph to be extracted at any location.

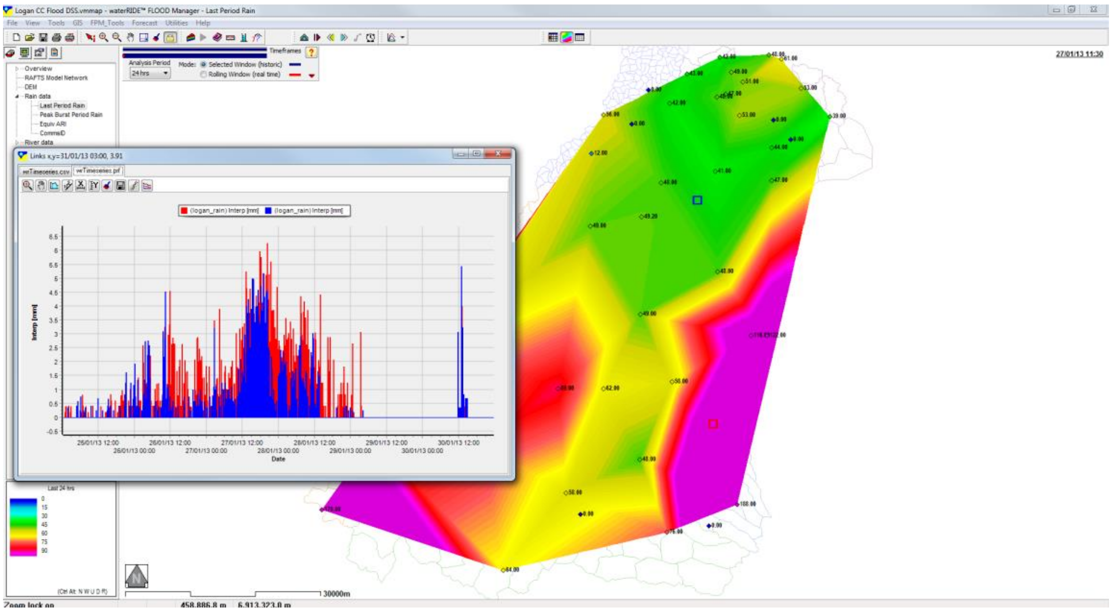


Figure 1 – Example rainfall gauge distribution, the resulting interpolated "rainfall surface", and rainfall hyetographs extracted at two locations.

During an event, allowance must be made for gauges that may fail or be unavailable. Recent experience in Queensland shows that as much as 10% of the rain gauge network could "fail" during an event.

Rainfall - Forecast

Forecasting rainfall is undoubtedly the most difficult component of a real-time flood forecasting system. In catchments with sufficient natural lag, forecast rain can be used as a "heads up" of potential flooding, with better estimates generated as rain starts to fall.

In flashy catchments, forecast rain is the only valid means of incorporating rainfall as there is insufficient natural catchment lag to utilise fallen rain and deliver timely forecast information.

Simple rainfall forecasts typically take the form of total rainfall across region or catchment over a specified period (*eg up to 200mm over 24 hours*). Rain radar provides a means of identifying potential rain, but must be calibrated, or "ground truthed" against actual rain gauges.

Recently developed products from the Bureau include the national-coverage ADFD (*Australian Digital Forecast Database*) and PME (*Poor Man's Ensemble*) 3-hourly rainfall surfaces. The ADFD product provides a 2-day, 3 hourly rainfall quantity forecast at 10%, 25% and 50% exceedance probabilities, on a 6km grid. The PME product extends the same 3 hourly coverage to 7 days, but at a coarser grid size of 40km. Figure 2 provides example information available in this forecast surface.

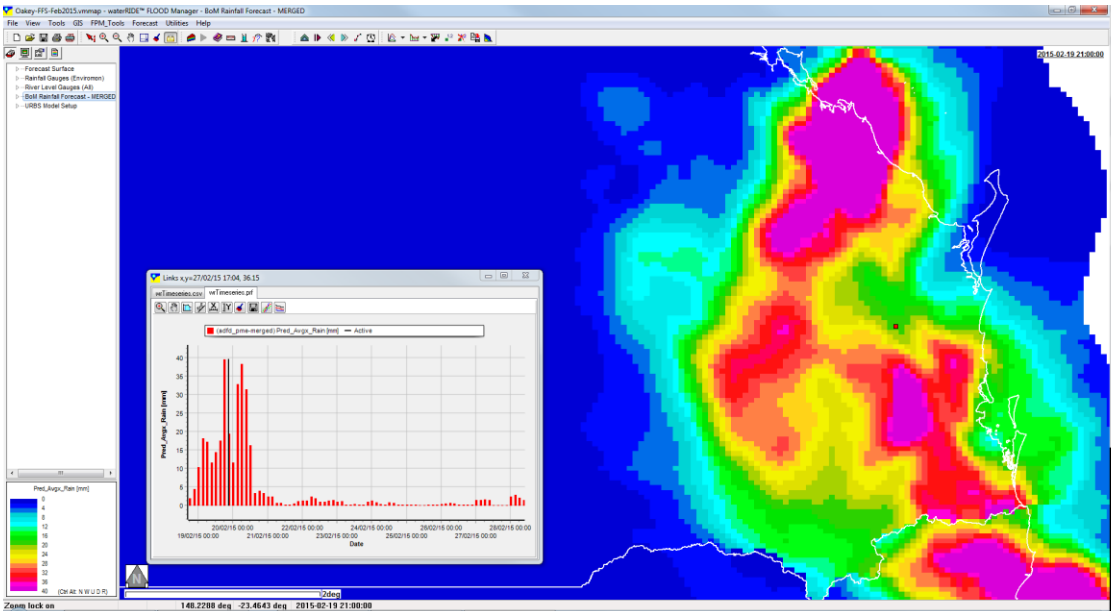


Figure 2 – The Bureau's 6km grid, 2-day, 3-hourly forecast rainfall surface.

The ADFD and PME datasets provide a useful forecast rainfall surface which includes expected temporal and spatial variations, and is well suited for incorporation in real-time hydrologic models.

Hydrologic Process

The hydrologic process is the means of routing actual and/or predicted rainfall through the catchment, into likely flows and levels at specific locations (*usually gauges*) in the catchment.

There are a number of approaches that can be employed to do this routing, and are generally related to catchment size and available datasets.

Medium-Large Catchments: Real-Time Hydrologic Modelling

Real-time hydrologic modelling involves loading a hydrologic model (*eg RAFTS, URBS, WBNM etc*) with the actual and/or forecast rainfall, selecting appropriate losses, and running the model to provide likely flows at locations in the catchment.

Forecast flows can be converted into levels using ratings curves. Rating curves extracted from the time series of the base flood modelling runs are frequently used as they can be extended beyond the largest flood experienced and inherently incorporate the effects of *hydraulic* storage in the catchment.

Hydrologic models are typically quick to run, and forecast levels can be readily compared against levels at actual gauges for real-time verification and calibration, if desired, as shown in Figure 3.

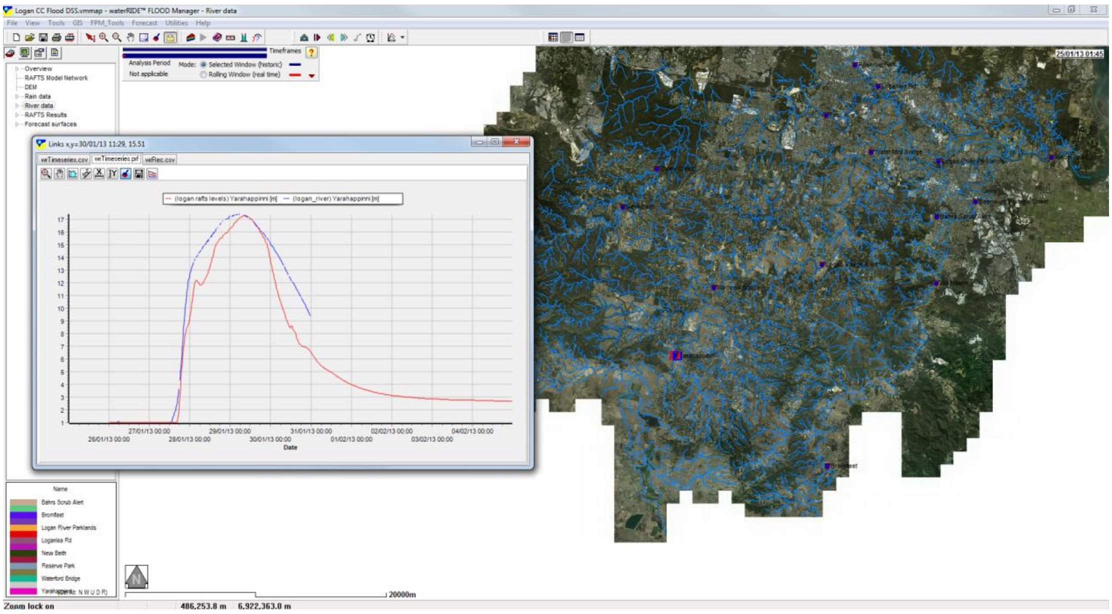


Figure 3 – Real-time verification of forecast flood levels against actual gauge data.

Real-time hydrologic modelling captures both the spatial and temporal variation in actual and forecast rainfall, making it ideal for use on larger catchments, despite necessarily adding some complexity to the system.

Flash Flood Catchments: Hydrologic Interpolation

In small, fast response catchments, there is usually limited warning time and an effective flood warning system must be proactive (*ahead of actual rainfall*) rather than reactive (*responding to rain once it has fallen*).

Druery et al (*2014*) proposed a *hydrologic interpolation* methodology particularly suited to flashy catchments called. It relies on the principal of “pre-cooking” sets of hydrologic model runs across the possible domain of rainfall duration and intensity combinations for the catchment, for a range of catchment conditions.

Peak levels at a location in the catchment are extracted from each hydrologic model run and stored in a lookup table. Likely levels for a given forecast rainfall amount and duration (*eg 200mm over the next 4 hours*) can then be near-instantly interpolated from the lookup table.

This approach effectively *buys* warning time, as “what if” analysis can be carried out rapidly prior to the onset of rain, without the added complexity of real-time hydrologic modelling. However, its applicability is limited to small catchments, where a consistent rainfall pattern is appropriate.

Upstream Controls (Dams, Weirs etc)

In a catchment where there are upstream controls or structures such as dams and weirs, a lookup table of flow through the control vs water level at locations in the catchment can be used to directly determine likely flood levels.

The *outflow v downstream level* lookup table may be determined through hydrologic or hydraulic modelling, or a combination of the two.

Such an approach is reactive, as it relies on hydrologic analysis by the dam operator to estimate future outflows.

Combined Hydrology and Hydraulics

“Direct rainfall” or “rainfall on the grid” models are becoming increasing popular for urban catchments. In such models, rainfall is applied directly to the hydrodynamic model, essentially creating an integrated hydrology and hydraulics solution.

A lookup table of *rainfall vs level* can be extracted directly from the modelling, and forecasting can then bypass the need to convert rainfall into flows and then into levels.

This is discussed in more detail in the following section.

Hydraulic Process

The hydraulic process is the means of converting point based flood level forecasts (*often at gauges*) into a continuous flood surface, covering the modelled floodplain or overland flow area. The creation of a flood surface (*as opposed to a flood extent polygon*) enables ready integration with other datasets to derive flood intelligence, which is discussed in the following section.

Hydraulic Interpolation - Standard

This well established approach relies on a library of flood modelling (*usually design flood model outputs*) for a range of flood magnitudes, covering smaller floods through to larger floods, and overcomes the inherent approximation of adopting the “closest” available flood modelling results. This is especially so when the rainfall is spatially varied and tributaries have differing ARI magnitudes.

Forecast levels at locations in the catchment are used to interpolate a likely flood surface from the two surfaces in the library that span the forecast level. In this way, the hydraulic gradient of the waterway is used in the interpolation, with the result being a hydraulically correct flood surface covering the floodplain.

Where multiple flood level forecasts are available across the catchment, the surface can be warped to account for the spatial variation in flooding (*eg one tributary is experiencing a nominal 1 in 63 year flooding, whilst another a 1 in 91 year*).

The approach is pictorially presented in Figure 4.

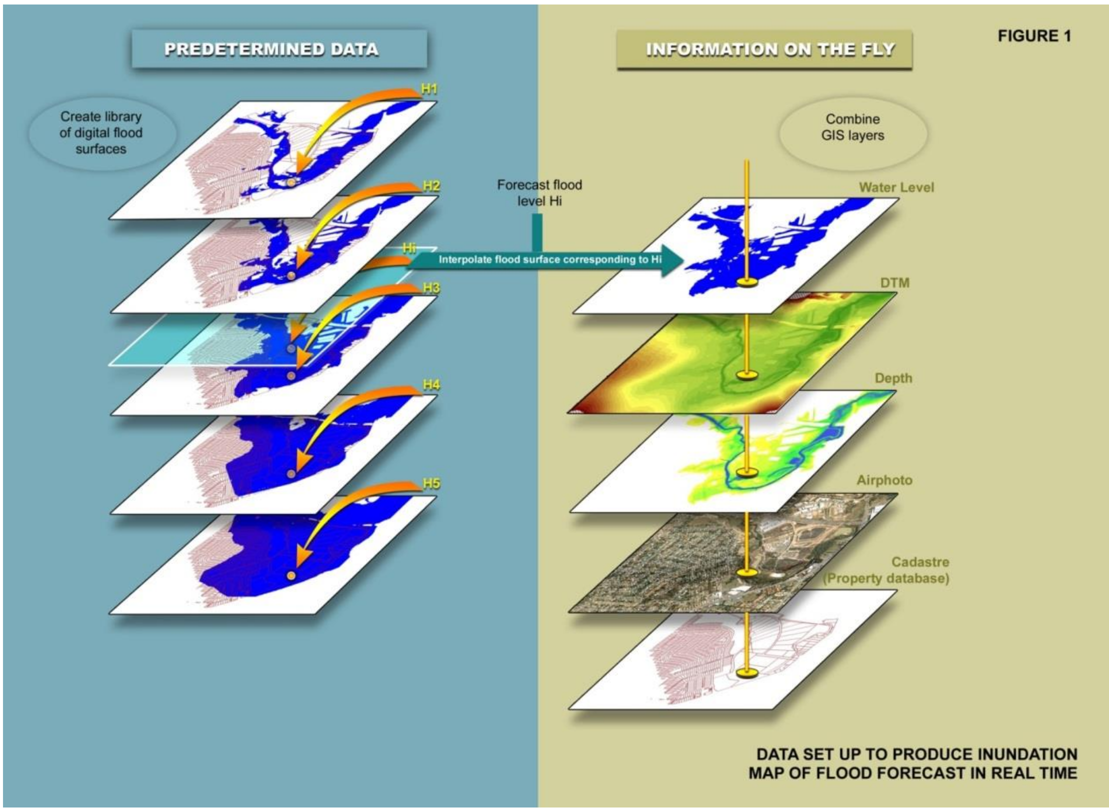


Figure 4 – Hydraulic Interpolation Theory - Single Gauge.

As this approach relies on interpolation, the surfaces in the library should span the domain of flooding. A frequent addition to a library of "design flood models" is a surface covering the "no flooding" case. This surface can be from actual modelling, or is frequently statistically extrapolated from the library.

Hydraulic interpolation is very fast, with the interpolation process typically less than a few minutes.

Hydraulic Interpolation – Flash Flooding Catchments

Whilst the standard hydraulic interpolation approach can be equally applied to long duration and flashy catchments, a further alternative is available where "direct rainfall" hydraulic modelling outputs are available.

In this approach, the rainfall duration and intensity is assigned to each output flood surface from a direct rainfall model, thereby building a library of rainfall amount/duration vs resulting flood surface.

The forecast rainfall (*amount and duration*) is then used in a *two-way interpolation* between the four surfaces that span the forecast. The first pass is applied to the rainfall amount and the second pass between the derived duration amounts.

For the end user, this approach is simple to apply, going directly from forecast rain to likely flood surface, with no intermediate steps. However, as the rainfall patterns have already been simulated in the library surfaces, this approach is best limited to flashy catchments with consistent rainfall patterns.

Time Varying Design Flood Surfaces

In some catchments, "walking through" a hydrograph from a suitable design flood modelling can be used to create a surface of likely flooding. A timestep in either the rising or falling limb of the design flood hydrograph can be selected matching a forecast level in the catchment.

Whilst not as sophisticated as the hydraulic interpolation approach, this approach is near instant, and provides an indication of the flood travel time through the catchment. Care should be taken when determining peak flood extents using this approach as it is dealing with a snapshot of a dynamic evolving surface, rather than a peak (*or envelope*) surface.

Real-Time Hydraulic Modelling

Real-time hydraulic modelling involves the incorporation of the outputs of real-time hydrologic modelling (*classic hydraulic model*), or forecast rainfall (*direct rainfall model*) as inputs to the hydraulic model which is then executed in real-time.

This approach becomes viable when the run time of the hydraulic model can be significantly reduced from standard runs (*with run times often measured in multiple hours and days*), and is generally suitable for providing detail in small catchments or coarser output in larger catchments where model run times are acceptable.

It is also, clearly, imperative that the hydraulic model is very robust across all magnitudes of possible flooding.

Flood Intelligence

The most important part of any flood forecasting system is providing outputs in a format targeted to the needs of the end users of the information, providing details on the likely affectation of the forecast flooding (*ie "what will the flooding mean"*).

Flood intelligence is typically created through the integration of the forecast flood surface with external spatial datasets. The aim of the intelligence is to answer questions such as:

- What will the flood look like?
- Who will be wet?
- When will they be wet?
- What roads will be open?
- What critical infrastructure will be operational?

Most often, the consumers of the output from a flood forecasting system do not have a technical hydrologic or hydraulic background. Therefore, a system must be able to provide information in a usable format for these users.

Examples of derived flood intelligence might include:

a. ***Flood Extents:*** The simplest piece of information is a flood extent map or GIS layer, which, of course is limited to identifying the flooded area and the potential for properties and infrastructure to be affected.

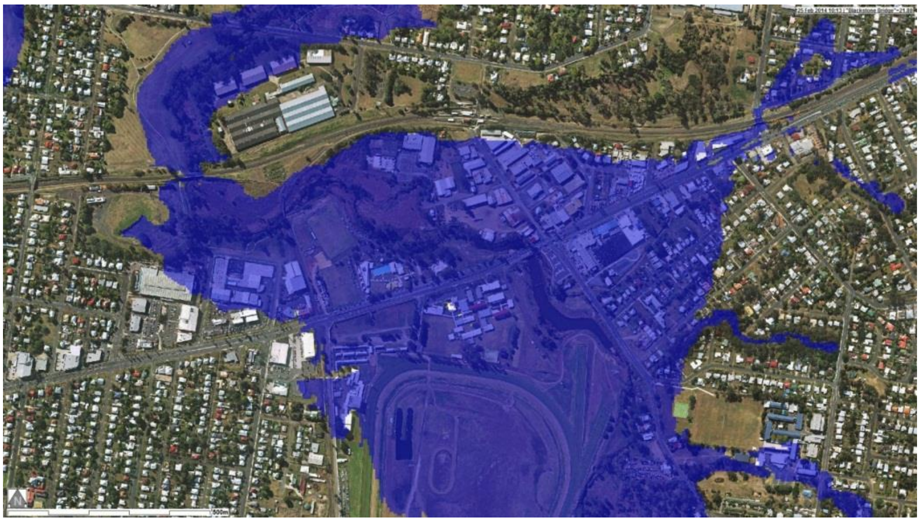


Figure 5 – Sample Flood Extent.

b. ***Flood Depth Surface***: A flood depth surface can be readily created by draping the forecast water surface onto a Digital Elevation Model (DEM). The depth surface ***not only*** provides information on the likely flood extent***, but also*** on the severity of flooding (*in terms of depth*) across the floodplain (Figure 6).

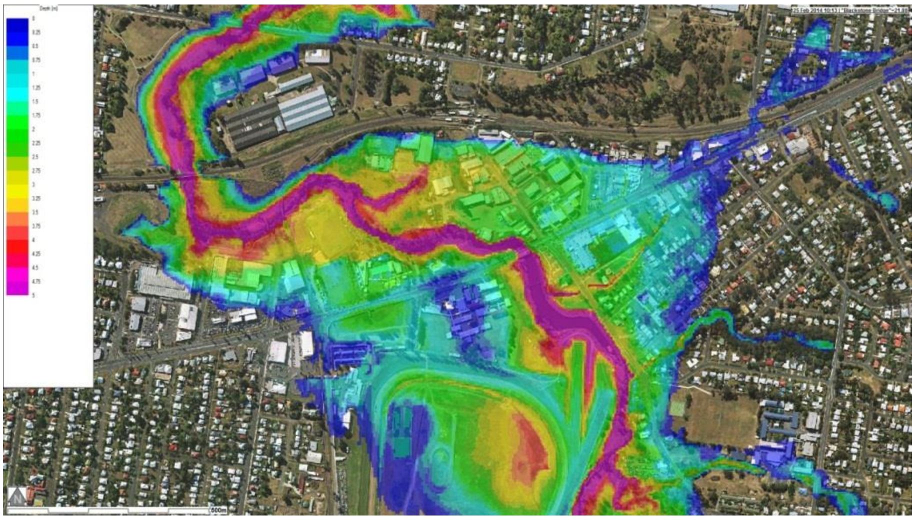


Figure 6 – Sample Flood Depth Surface.

c. ***Integration with GIS Datasets*** : Perhaps the richest source of flood intelligence can be created by integrating the forecast flood surface with GIS datasets. GIS datasets contain attribute fields which can be used to determine the impact of flooding on the object.

For example, a GIS dataset may contain the base levels on all transformers for electricity sub-stations in the region. By integrating the forecast flood surface with the levels in this field in the GIS dataset, an indication of whether power will be available to the region can be quickly ascertained.

Figure 7 shows an alternative example with a thematic map of the depth of flooding above floor for flood affected properties within the floodplain, for a given forecast flood.

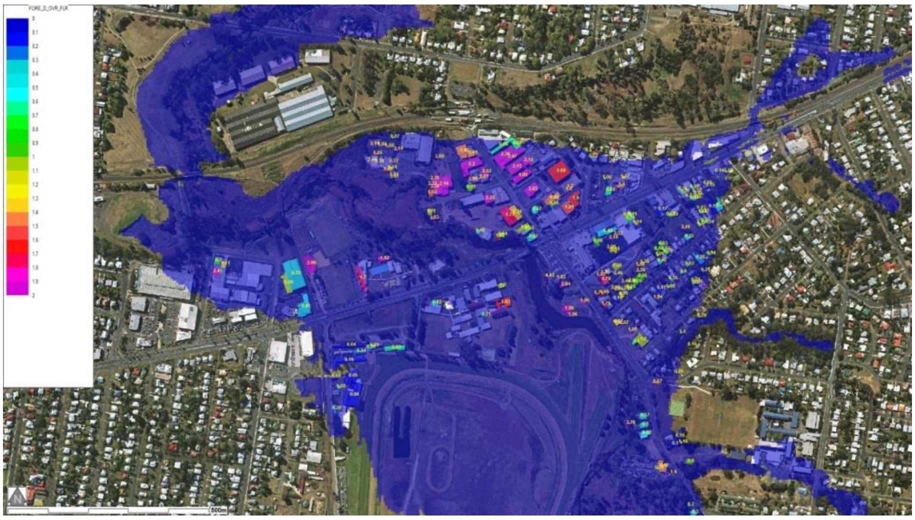


Figure 7 – Depth of Above Floor Flooding.

Other examples might include low points on evacuation routes to determine what routes are passable, facilities requiring managed evacuation, e.g. nursing homes, etc.

In addition to peak forecast information, a time-based flood forecasts could be used to determine when elements will first be affected and for how long they might be inundated.

d. ***Managing Uncertainty*** : Flood forecasting inherently involves a significant amount of uncertainty. Generally, as the event progresses, the confidence in the likely outcomes increases, but the response time reduces. For systems with sufficient natural lag, this is useful. For flashier catchments, this certainty comes too late.

Causes of uncertainty can be quite varied, from the ability to accurately predict likely rainfall, to the vagaries of catchment rainfall runoff and errors in underlying modelling datasets.

A conceptually simple way to address the issue of uncertainty is to look at the implications of the potential uncertainty. That is, by quantifying the upper and lower limits of uncertainty, it is possible to determine if the uncertainty has a material impact on what the response to the likely flooding will be.

For example, Figure 8, below, shows three surfaces from a flood forecasting system employing 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*).

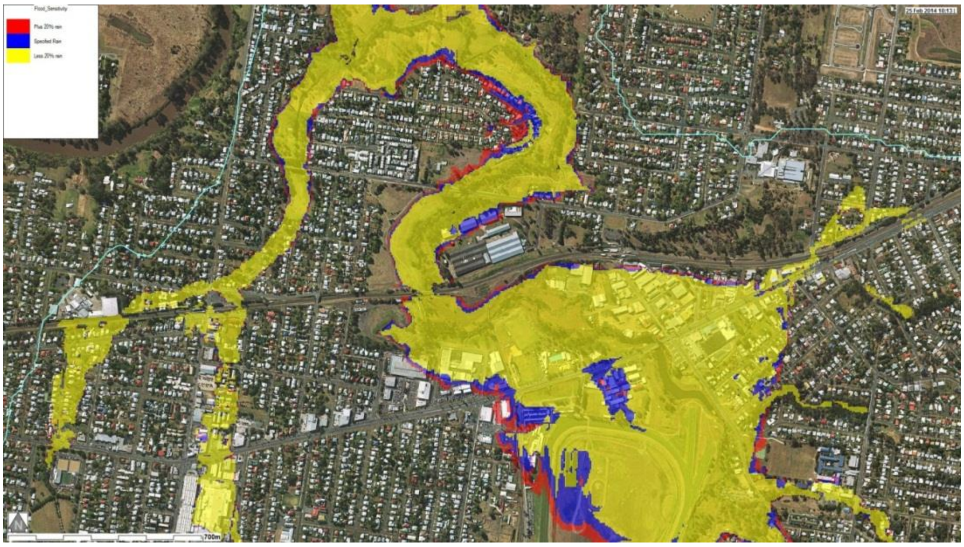


Figure 8 – Managing forecast uncertainty: Blue = flood surface for expected rainfall, yellow = flood surface with 20% less rainfall, red = flood surface with 20% more rainfall

Figure 8 clearly shows that, from an emergency management perspective, there is little difference between the upper and lower uncertainty bounds (*the red and yellow surfaces*). Although there may be significant uncertainty in the forecast, there is actually relative certainty in the outcome of the forecast flood in terms of what properties will be flooded and what response actions will be required.

This approach provides a means of understanding, and potentially overcoming the large uncertainties associated with forecasting rainfall, and is particularly useful in flash flood forecasting.

Information Distribution

Whilst the flood intelligence being generated by a flood forecasting system is serving the informational requirements of end users, the way in which these users wish to consume the information, and the sharing of information to a wider audience such as the general public, is an equally important part of the system.

The common, spatial nature of datasets created by a flood forecasting system lend themselves well to distribution through existing spatial server infrastructure. Combined with SMS and email alerts, automated triggers can be identified for varying phases of a flood emergency.

However, an essential step of the information distribution process is verification of the forecast surface. This allows the surface to be reviewed for consistency and sensibility prior to being “published” for wider distribution.

Conclusion

A simple flood forecasting system can be easily and quickly built using datasets available to most Councils and relevant Government Agencies. As little as design flood modelling outputs and a DEM can be used to develop and effective system.

This provides agencies with the means to deliver meaningful information during flood events to both emergency management personnel, as well as the general community.

There is significant variety in forecasting approaches that provides the necessary flexibility to make the best use of readily available information for any given catchment.

A suitable flood forecasting system provides an ideal way to leverage the significant investment made in creating the base datasets, for use both during, and in planning for, flood emergencies.

References

Druery B, McConnell D, Druery C, Kamenos L, “*Mapping Flood Hazards in Real Time”,* Natural Hazards Forum, Wollongong, 2003

Druery C, McConnell D and Adair L “*Real-Time Flood Risk Management – Putting Certainty Into the Uncertain*”, Proc 5th Victorian Flood Management Conference, October 2007

Druery, C, McConnell, D, (2014), *Forecasting Flash Floods – What Can You Do?,* Proc. 2014 New Zealand Stormwater Conference, Christchurch, New Zealand.