Keeping Communities Informed: Rapidly Mapping Flood Risk Without a Formal Flood Study

C Druery[1], D McConnell[2]

[1]WorleyParsons, Sydney, NSW

[2]WorleyParsons, Sydney, NSW

Abstract

The Brisbane flood of 2011 resulted in a significant change to the way various organisations plan for and respond to floods. Local government and insurers have responded to the issues raised by generating flood information at the community and property level.

Whilst traditional approaches to floodplain management involving detailed flood modelling and formal risk management studies provide a wealth of, usually, high quality data, the timeframe for completing such tasks (including direct rainfall or overland flow modelling) across an entire local government area, for example, is considerable.

A number of institutions including the local government sector and the insurance industry require access to flooding data, covering the entire extent of their “jurisdiction”, not just those areas covered by formal studies.

This paper shows how an approach that was developed to utilise readily available terrain datasets to rapidly create hydraulically “fit for purpose” flood surfaces can be used to provide an indication of likely flood risk on a jurisdiction-wide basis. The approach was designed to identify all areas at risk (both inundation and hazard), for a range of flood probabilities, with the amount of effort a fraction of that required for formal hydraulic modelling.

The approach has provided various agencies with additional datasets to augment and enhance their flood risk assessment and communication processes. The rapid flood risk assessment approach has been utilised by the industry for:

- Preliminary flood hazard assessment
- Community awareness on a Council-wide basis
- Identifying and prioritising areas requiring formal flood studies
- Quantifying flood risk for insurance purposes
- Augmenting or extending formal studies

Introduction

The January 2011 flooding in Brisbane and its surrounds significantly raised the profile of flooding across Australia. It left many communities and businesses questioning what their exposure to flooding is.

Government agencies charged with managing flood risk on behalf of the community, and various private organisations exposed to flooding (primarily insurers), moved to better quantify the risk, on a "jurisdiction-wide" basis.

Such information is available from traditional approaches involving formal flood studies (with detailed hydrologic and hydraulic modelling), and "overland flow modelling" (commonly referred to as "direct rainfall" modelling), however, there are significant gaps in the geographic coverage of this information nation-wide.

Using these traditional approaches to define the flood risk in these data gaps, whilst providing "best practice" risk profiles, is generally a time consuming process. Consequently, various organisations looked to approaches that could provide a "reasonable" indication of flood risk, across their area of interest.

This paper focusses on the expansion of the earlier work of *Druery et al (2010)*[1] and *McConnell et al (2011)*[2], in identifying likely flood risk for a range of Annual Recurrence Intervals (ARI's), at both localised and country-wide scales, using readily available datasets. In this work, a software tool called *GridFlow* was developed to determine likely flood depths for *overland* flow paths, using Digital Elevation Models (DEM) and Australian Rainfall and Runoff base datasets.

In this paper, we investigate the expansion of the *GridFlow* approach to incorporate the determination of indicative velocity and hazard (VxD) in addition to the standard flood depth, for *both* overland and riverine flooding, and investigate how the datasets can be used for planning and risk assessment tasks.

In this way, the aim of the approach was to provide integrated, consistent, and "fit for purpose" flood surface datasets covering entire catchments/LGA's, for a fraction of the time and effort of formal studies.

Appraisal of Previous Work

Druery et al (2010)[2] developed an automated approach to rapidly identify "at risk of overland flooding" zones across a floodplain by buffering flowpath centrelines. The symmetrical buffering at any point on a flowpath was proportional to the catchment area, with the specific amount determined through calibration to insurance industry claims from historical, significant 'overland flooding' events.

This approach provided a reasonable capture of those properties at which claims were made, however, tended to overestimate the number of properties, by capturing some properties at which claims were not made. The symmetrical buffering, or "distance to flowpath" approach, whilst readily automatable, was found to produce results that should be considered as "broad and conservative".

McConnell et al (2011)[1], expanded on the work of *Druery et al (2010)*[2] by incorporating a simplified hydrologic and hydraulic model to determine the water surface (and therefore flood depths). By more closely considering the hydraulics of flowpaths, this approach led to an “acceptable” match to water surface developed using detailed hydraulic modelling. This approach was found to be suitable as a base dataset for the identification and quantification of *overland* flood risk for the insurance industry.

Methodology

Overview

The GridFlow approach uses a DEM as the basis for determining flowpaths across an entire catchment(s). As the flowpaths are determined, a flow accumulation count for each cell along each flowpath is retained, providing the catchment area to that point. A combined hydrologic and hydraulic analysis, including calibration, can then be carried out for a full range of ARI’s (from frequent flooding to extreme), yielding flood depth, velocity and hazard surfaces.

The key components of the approach are:

1. Conditioning of the DEM

2. Flow Accumulation Analysis

3. Hydrology and Hydraulics, including calibration

Conditioning of The DEM

Readily available DEM’s, whether derived from LiDAR, contour mapping, photogrammetry or a range of other approaches rarely capture channel bathymetry. To appropriately simulate hydraulic behaviour, the conveyance capacity of rivers and creeks must be included in the analysis. To overcome this, indicative channel bathymetry was “burnt” into the DEM along significant flowpaths.

Provided the DEM is of sufficient resolution, overland flowpath “bathymetry” is usually adequately captured, and does not require conditioning of the DEM.

Flow Accumulation Analysis

A flow accumulation analysis yields all flowpaths across a DEM. Conceptually, a “drop” of water is placed on each cell of the DEM, and flows along the steepest flowpath to the edge of the DEM. As the drop passes through each cell, the flow accumulation account is incremented. The flow accumulation at any given cell, therefore, represents the number of “drops” from upstream cells that flow through that cell (ie it’s catchment area).

By setting a minimum flow accumulation area threshold (or minimum catchment area), the relative size of flowpaths suited to the analysis can be defined. This is illustrated in Figure 1 and Figure 2, below.

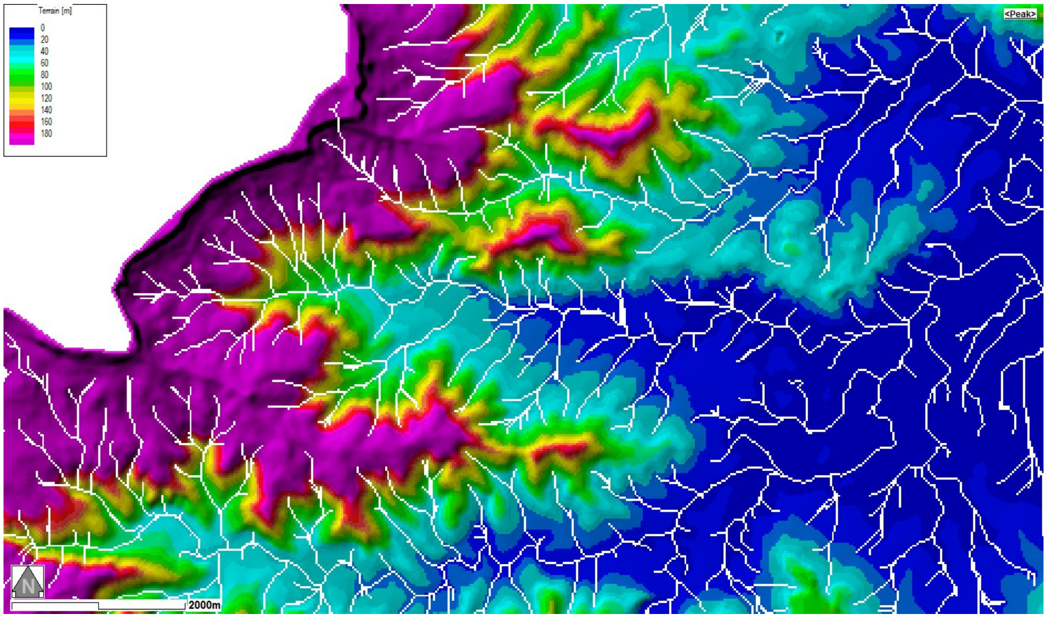

Figure 1 – Flow paths identified with a minimum count of 50.

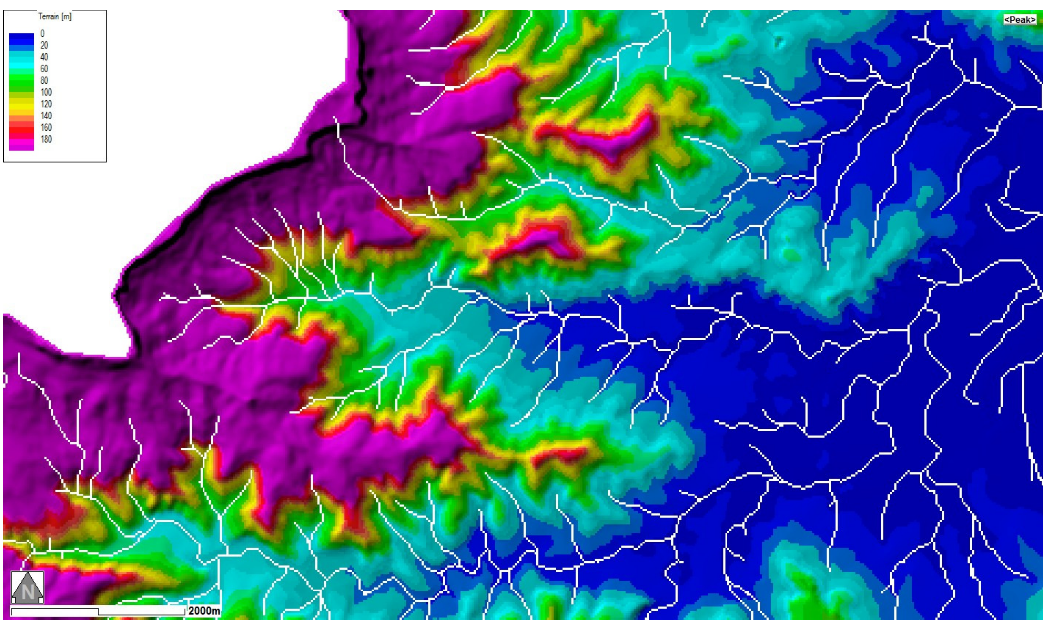

Figure 2 – Flow paths identified with a minimum count of 200.

An automated pit removal process ensures that the DEM is 'flow enforced'.

Hydrology and Hydraulics

The flow accumulation (catchment area) can be used to determine flows for a range of ARI's using Australian Rainfall and Runoff and the Rational Method, including aerial reduction. Whilst intended to be used on smaller catchments (including overland flowpaths), this approach can be used as a basis for determining flows which can then be 'calibrated' against gauge recordings. Where available, stream gauging records can be used to statistically determine recurrence intervals for a range of flows. These flows can then be compared to the rational method flows, and adjustments made as necessary by including a *flow enhancement factor* in the approach. These flows represent the statistical maximum flow at each cell, rather than reflecting a "real flow".

Once the flow at each location on a flowpath can be determined, a simplified hydraulic approach using Manning's equation and a backwater profile can be used to calculate flood levels and velocities along the flowpath. Automatically generated cross sections along each flowpath, spaced according to the catchment area to ensure consistent hydraulic behaviour, can be read from the DEM and the hydraulic solution applied. Where required, additional cross sections can be manually inserted to ensure representation of key hydraulic controls in the waterway.

As with the hydrology, the hydraulic approach can also be calibrated against more detailed flood study and direct rainfall modelled levels, or even historical flood levels.

Outputs

For the full range of ARI's, the outputs of the process are water level, velocity and hazard (VxD) gridded surfaces. Whilst Manning's approach typically provides an average velocity for an entire cross section, a further application of the approach can be used to distribute velocities across the cross section, thereby yielding a finer interpretation of velocities. Example outputs are shown in Figure 3 to Figure 5.

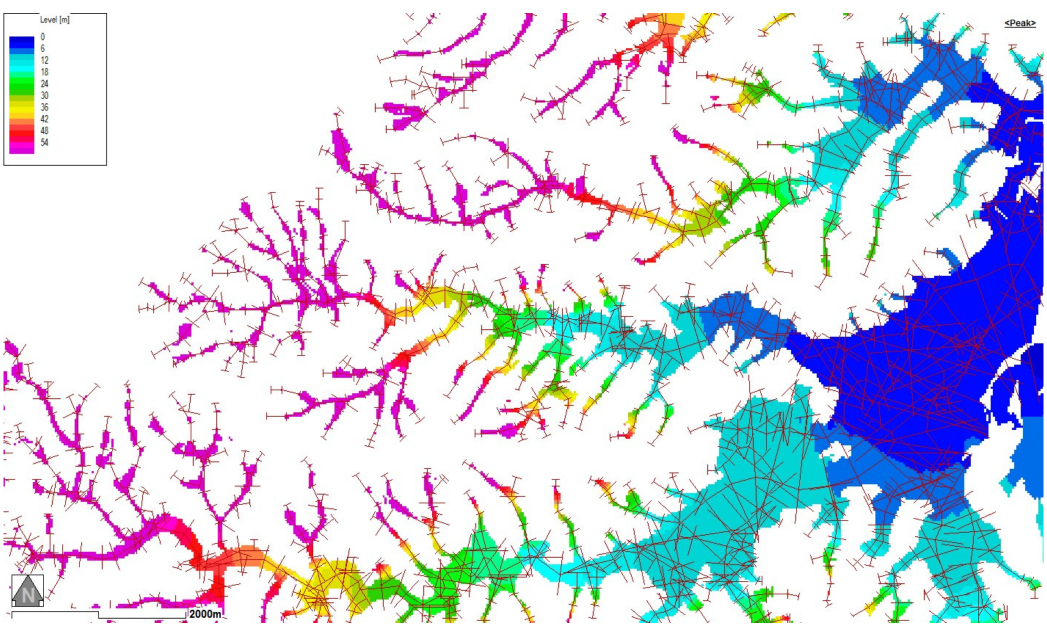

Figure 3 – Water Level Surface and Hydraulic Solution cross sections.

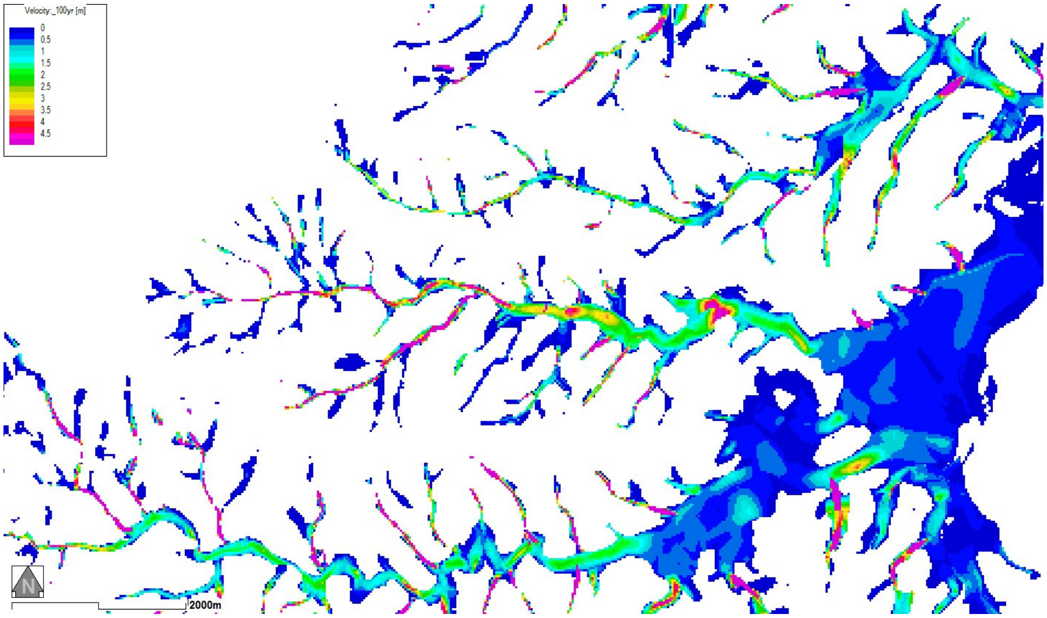

Figure 4 – Distributed velocity surface.

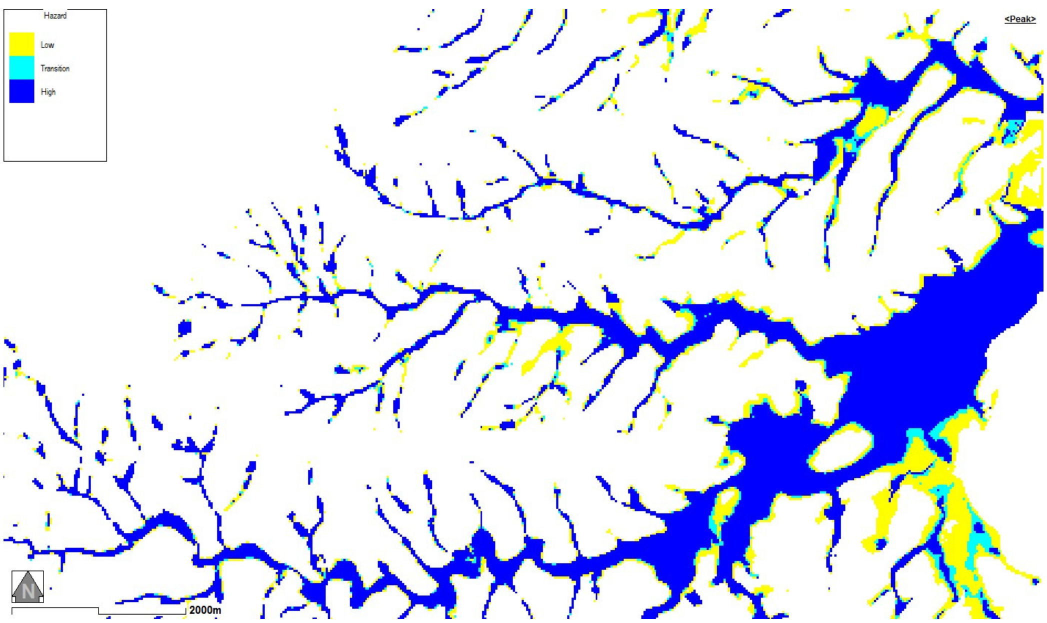

Figure 5 – Hydraulic Hazard (using NSW Floodplain Development Manual Categories – refer Figure 6).

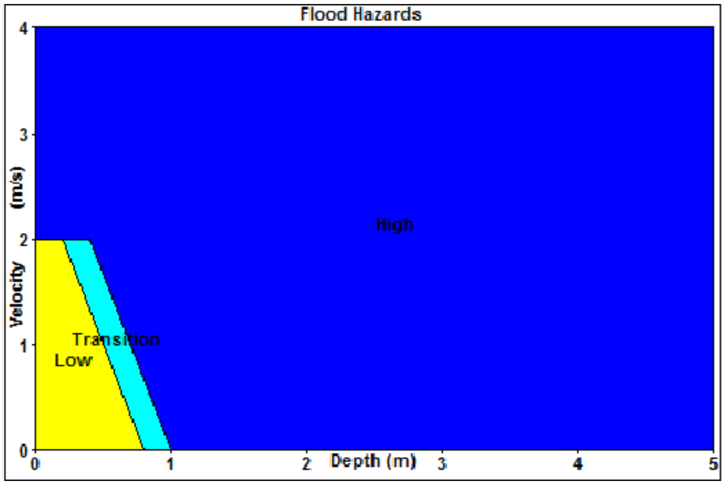

Figure 6 –NSW Floodplain Development Manual Preliminary Flood Hazard Categories.

Accuracy of Approach

As a means of determining the indicative accuracy, and therefore the *usability* of the approach, comparisons were made against detailed models developed as part of formal flood and overland flow studies for a number of catchments, as well as against recent flooding in Queensland (namely the 2011 Brisbane flood and the 2013 Bundaberg flood).

Comparison to Formal Flood Study Models

A number of comparisons were made between formal flood modelling (1D, 2D and direct rainfall) and the GridFlow approach. Figure 7 to Figure 9 provide a longitudinal water surface profile for nominal “1 in 100 year ARI” design floods for some example waterways. In all cases, comparisons are made against GridFlow surfaces derived from LiDAR datasets.

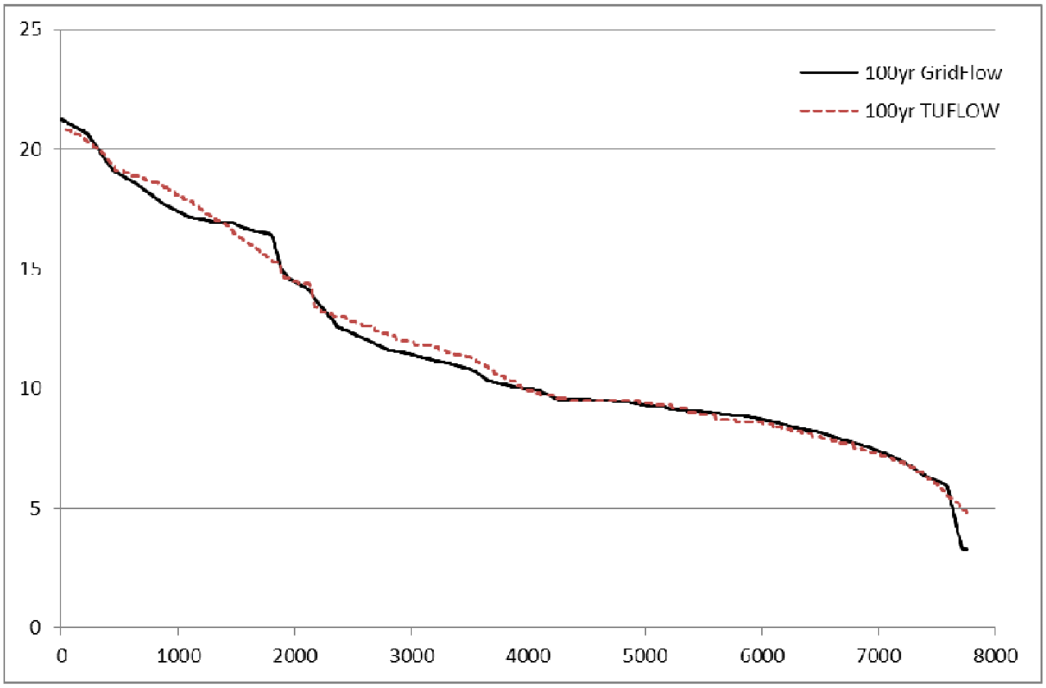

Figure 7 – Comparison of GridFlow against 2D TUFLOW model.

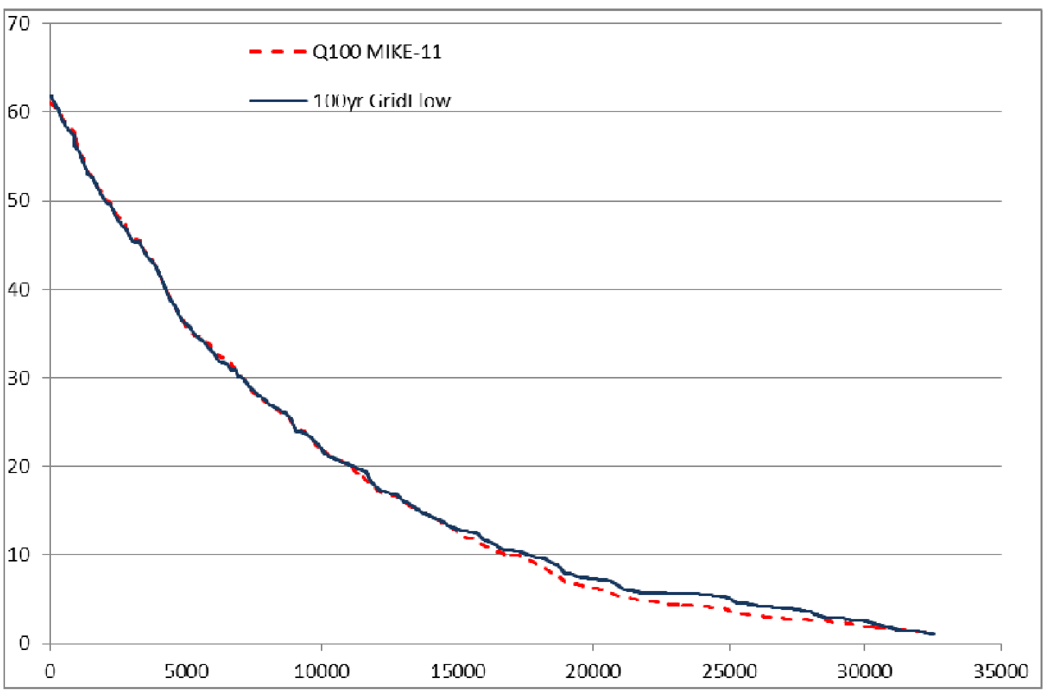

Figure 8 – Comparison of GridFlow against 1D MIKE11 model.

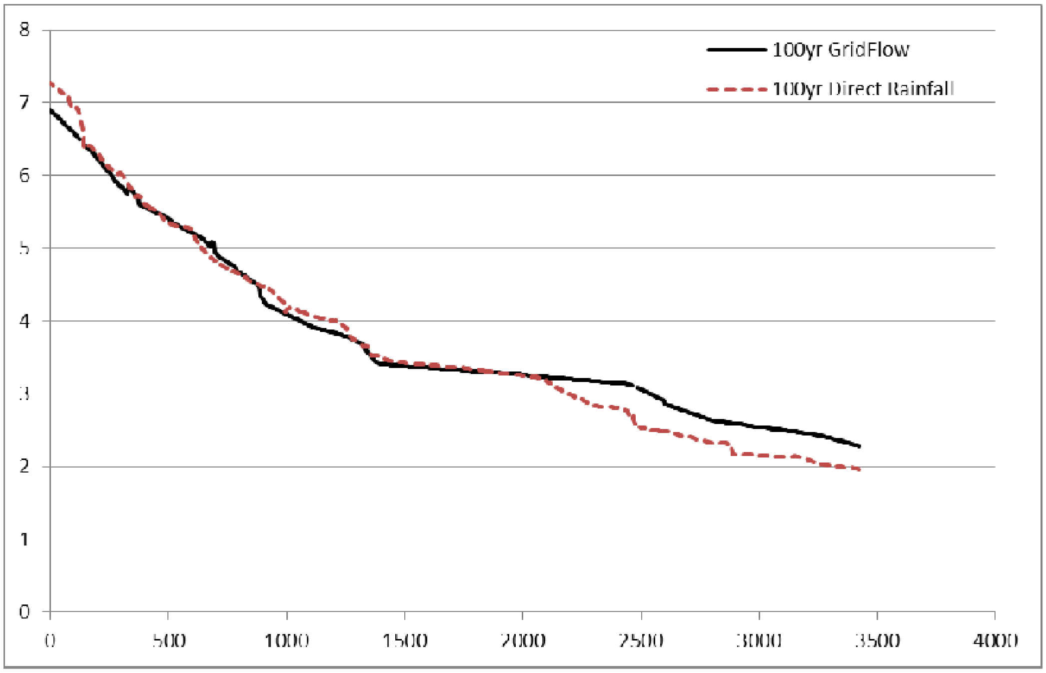

Figure 9 – Comparison of GridFlow against 2D "Direct Rainfall" TUFLOW model.

For comparison across an entire catchment, the following table provides average errors for a large river and 11 tributaries. A range of 1D and 2D model types were used in the formal, detailed hydraulic modelling for this catchment.

Stream	Modelled Length (km)	Average Error (m)
Mainstream	75	0.32
Tributary 1	34	0.13
Tributary 2	6.5	0.18
Tributary 3	3.5	0.16
Tributary 4	7.5	0.01
Tributary 5	27	0.12
Tributary 6	8.5	0.09
Tributary 7	21	0.86
Tributary 8	11	0.86
Tributary 9	17	0.35
Tributary 10	6.5	0.18
Tributary 11	1.8	0.03
	Average	**0.27**

Table 1 – Average Errors Across a Catchment.

Table 1 shows that the approach provides a fairly close match to the formal model results across most catchments. It is interesting to note that during the comparison process, it became evident that the "detailed" models were not necessarily correct, as some were based on older terrain than the LiDAR used in the GridFlow approach. In some instances, the flood levels from the detailed modelling were below ground when compared to the LiDAR dataset. Consequently, the reported “error” may, in fact, not be a reliable measure of the error in the approach. However, the GridFlow approach was found to consistently provide a reasonable match to water surfaces across more than 20 areas for which detailed comparisons were made.

Comparison to Recent Large Floods in Queensland

The GridFlow approach creates hydraulic surfaces that are “steady state maximums”, representing a flood surface that “cannot exist” in nature, but rather is the “worst case” flooding for each ARI at all locations. Notwithstanding this, interesting comparisons can be made to evaluate the approach against some recent, large floods in Queensland.

Figure 10 provides a comparison between the January 2013 Burnett River flooding at Bundaberg (black line) as surveyed by the Queensland Government, and the corresponding GridFlow surface (in blue).

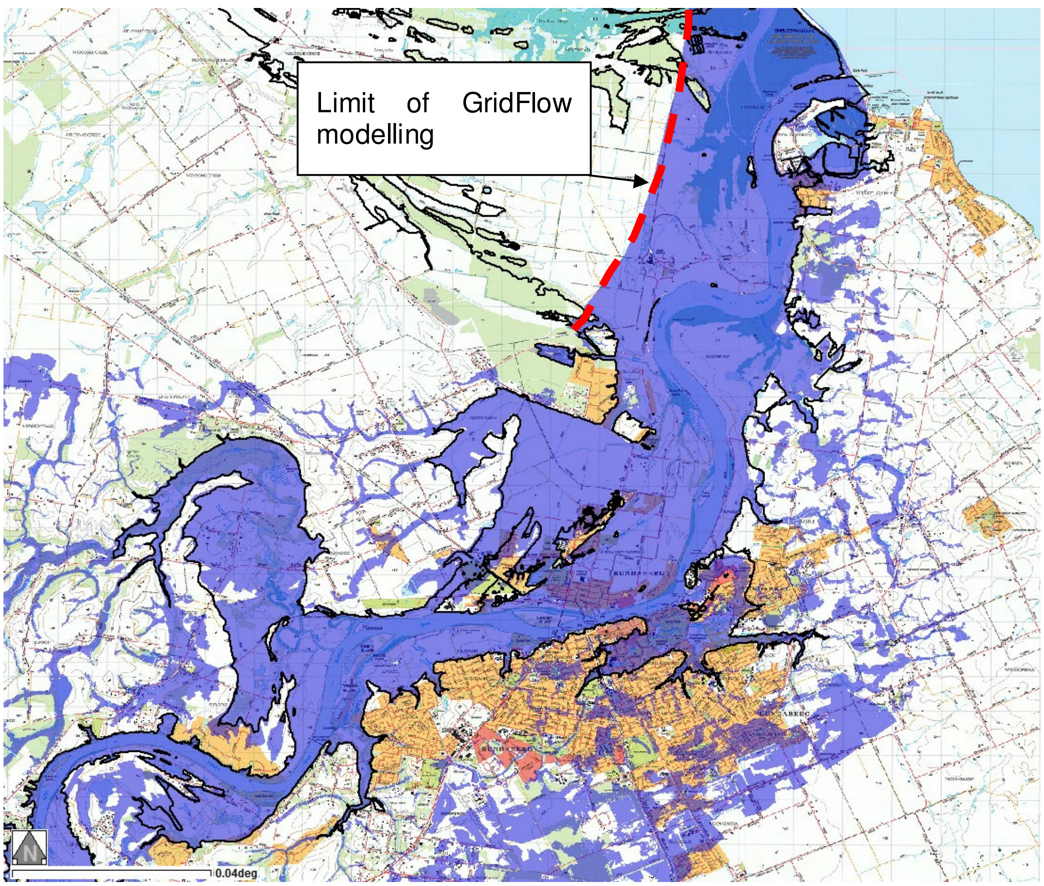

Figure 10 – Burnett River at Bundaberg, 2013 Flood - GridFlow surface (blue) compared to Queensland Government Surveyed Flood Extents (black line)

As shown in Figure 10, the GridFlow surface provides a very close match to the actual flood across the catchment. In addition, the GridFlow surface also shows flooding along tributaries to the Burnett River. As the 2013 flood was predominantly a Burnett River flood, the blue area extending beyond the black flood extent lines represents an equivalent probability flooding from local catchment flows, which are, clearly, higher than the Burnett River backwaters in many areas.

Figure 11 provides a comparison between the January 2011 Brisbane River flooding at Brisbane (black line) as surveyed by the Queensland Government, and the corresponding GridFlow surface (in blue).

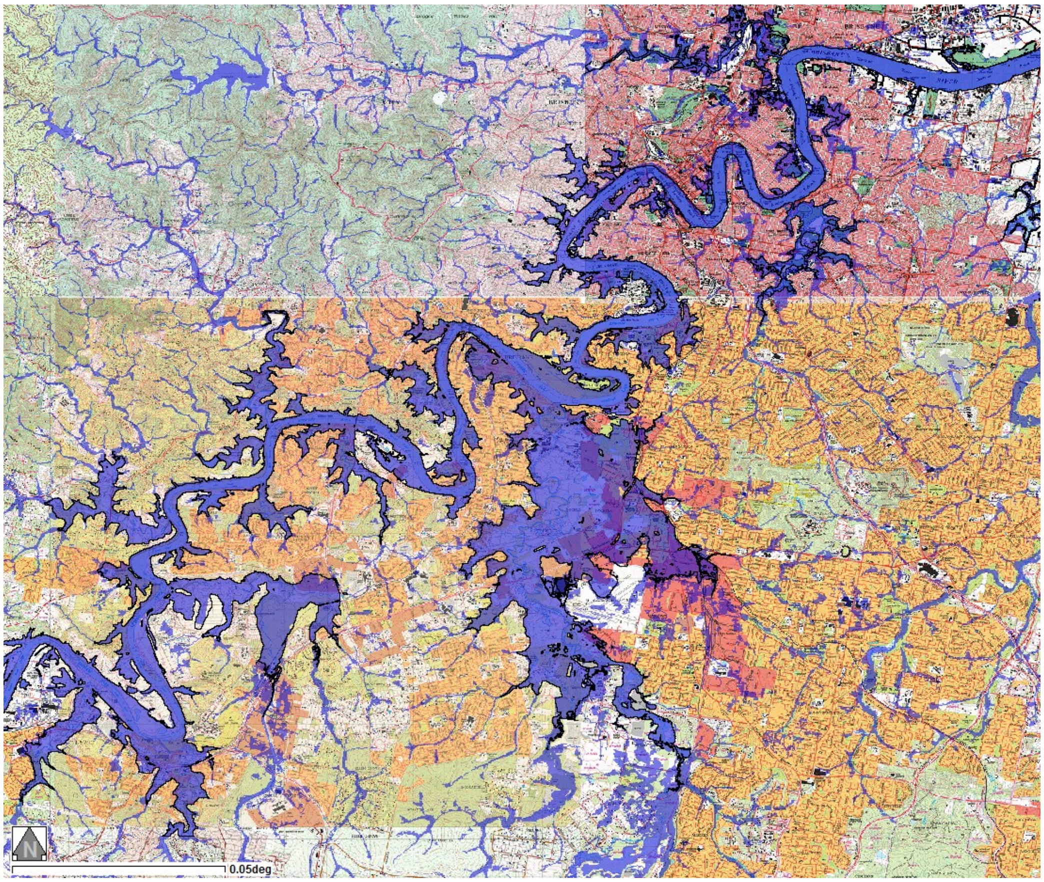

Figure 11 – Brisbane River at Brisbane City, 2011 Flood - GridFlow surface (blue) compared to Queensland Government Surveyed Flood Extents (black line)

Again, Figure 11 shows a close match between the GridFlow flood surface (blue) and the (surveyed) event flood extents. Similarly to the Bundaberg flooding, the GridFlow surface shows additional inundation on tributaries beyond that caused by the Brisbane River backwaters.

Factors Affecting Accuracy

The overall accuracy of the approach is influenced by (in decreasing order of influence):

1. DEM quality (source and resolution)

2. Suitable location of hydraulic cross sections

3. Calibration of hydrologic data

4. Manning's roughness variations

The DEM quality was found to have a noticeable impact on the quality of the hydraulic surfaces generated. *McConnell et al (2011)*[2] found that LiDAR derived DEM's provided the highest quality results, assuming the LiDAR data had been adequately processed to reflect the ground surface (ie removal of buildings, vegetation, transmission lines etc). DEM's based on shuttle radar required significant smoothing effort to develop a hydraulically enforced DEM. Traditional contour-based DEM's occasionally exhibited a "parallel sheet flow" phenomenon which resulted in multiple, parallel flowpaths down hillsides. This was caused by the smoothing algorithms usually used to create gridded DEM's from contour datasets and had the potential to underestimate water levels, but inundate more of the landscape. Where encountered, this phenomenon was generally confined to the upper reaches of catchments. There is also the need to adequately condition the DEM to ensure representative bathymetry is included in the waterway conveyance.

The cell size of the DEM also impacts the quality of the hydraulic surfaces. *McConnell et al (2011)*[2] found that a 5m LiDAR based DEM provided a good compromise between computational effort and output quality. It is important to ensure that the cell size adequately reflects the scale at which the outputs are to be used.

The quality of the DEM impacts the quality of *any* flood modelling, including formal and direct rainfall modelling. If the formal modelling was carried out using a lower quality DEM, then the apparent "error" in the GridFlow surfaces is difficult to quantify. In any case, the higher the quality DEM, the more reliable the hydraulic surface, whether it has come from formal modelling or the rapid GridFlow approach.

As the GridFlow approach is primarily automated, there is potential for key hydraulic controls on a waterway to be "missed". This can be overcome by manually inserting cross sections at key hydraulic locations (bridges, flow constrictions, weirs, dams etc) to ensure that their hydraulic impact is captured in the approach.

Often gauging data is only available across a relatively short period of record, which can become problematic when investigating less frequent floods, and can be an area of uncertainty in the approach. Often, it is also worthwhile considering calibration to the results of detailed hydrologic modelling.

The GridFlow approach assumes a constant Manning 'n' value across the catchment. *McConnell et al (2011)*[2] found that there was variance in water levels of , on average, of 0.1m when varying Manning's 'n' between 0.035 and 0.055, which are reasonable roughness parameters for habited areas. This variance is within the overall accuracy of the approach investigated in this paper, and is therefore considered to be a lower importance to overall accuracy levels. The incorporation of varying Manning's 'n' values across the catchment has not been investigated.

Applications of the GridFlow Approach

The expansion of the GridFlow approach to prepare both velocity and hazard surfaces, as well as water level and depth surfaces makes the approach more useful in identifying indicative flood risk for an area that does not have any modelling information available.

Local Governments have made use of the information to “fill gaps” or extend existing modelling datasets, especially when such datasets can be used for calibration of the approach. Others have found the approach suitable for prioritising areas for future, detailed studies.

Some government authorities have used the approach to prepare LGA-wide indicative flood risk maps for the general community. The aim of such mapping was to help inform the community of potential flood risks where formal studies do not exist, and to help raise the general awareness of the community to different types of flooding (riverine and overland). Since the approach can replicate actual floods, it provides a holistic means of extending the community’s knowledge of flood risk beyond an “event” based mentality.

In the early phases of “greenfield development” projects, where formal studies are unlikely to be available (and potentially too time consuming to carry out), the GridFlow approach provides an ideal means of identifying likely flooding issues, ensuring that flooding is considered throughout the project, rather than retrofitting “flood considerations”.

Clearly, the insurance industry can make much use this approach in identifying flood risk on a country-wide scale, across the full range of flooding probabilities.

The approach should be considered “fit for purpose”, and would not be suitable for all functions of a government authority such as the setting minimum floor levels for development.

Limitations of the Approach

The approach is heavily dependent on the quality of the DEM. The higher the quality of the DEM, the greater the reliability of the surface and the finer the scale the GridFlow surfaces are suitable to be used at.

As the approach is a steady state hydraulic analysis, its applicability for use on catchments with significant storage effects should be carefully considered. However, if using suitable calibration data, this limitation may be overcome to some extent.

Given the overall accuracy of the approach, it is not a suitable replacement for formal, detailed flood modelling, but rather can be used to complement such modelling.

Future Enhancements

One key area for enhancement is the hydrologic routing component of the approach. Incorporating a dynamic rainfall routing model into the approach may enhance the reliability of the determination of flows, capturing catchment storage and lag in a less empirical manner.

In the near term, changes to Australian Rainfall and Runoff hydrologic processes should be incorporated into the approach.

The variance in manning's 'n' values across a catchment was found to have a relatively small impact on surface quality given the overall accuracy of the approach, for an area of relatively consistent hydraulic roughness. However, for catchments with significant roughness variation, incorporating a variable Manning's 'n' derived in an automated fashion (or supplied as a GIS input) may enhance the overall quality of surfaces delivered.

Conclusion

The GridFlow approach was found to provide a good representation of flood risk for both overland flow paths and defined waterways.

Given the relatively automated implementation, it provides a "fit for purpose" rapid means of identifying flood risk across large areas.

It was found to provide particularly good matches to more detailed flood modelling when a suitable LiDAR DEM was used in conjunction with calibration.

References

[1] Druery C, McConnell D, Jones K, Fortune R (2010), *Overland Flood Risk Exposure – A Rapid Appraisal Method,* Proc. 2010 Floodplain Management Authorities Conference, Gosford, Australia.

[2] McConnell, D, Druery, C (2011), *A Rapid Approach to Modelling Overland Flood Risk,* Proc. 2011 IAHR Conference, Brisbane, Australia.