AN AUSTRALIAN FIRST – FLOOD HAZARD MAPPING ON A MASSIVE SCALE

Introduction

There are currently large areas of Australia where there is little or no information on current flood behaviour and this is particularly true in Queensland. Typically these areas are where there is little or no data, where there had not been any significant flood history. This all changed during the summer floods of 2010/2011 which affected more than 75% of the state. The Queensland Floods Commission of Inquiry was set up to enquire into a range of matters arising from the 2010/2011 floods including the preparation and planning for floods by Governments, agencies and the community. The Queensland Floods Commission of Inquiry Final Report (QFCI, 2012) identified several key recommendations particularly considering the need for a risk based understanding of floodplains; specifically about the need to live with floods rather than trying to control them.

Until recently, models were unable to model much more than 10 million cells and even then the run time was very very long. A broad scale model could take weeks to run at the desired grid scale. BMT WBM is leading the way with recent innovations in flood modelling techniques which when combined with advances in consumer grade computer technology, can help engineers, emergency planners and land use planners to fill existing knowledge gaps regarding flood behaviour, especially in rural and remote locations. In addition, advances in ground surface data collection and in flood modelling proficiency represent the dawn of a new era in floodplain management in Australia where flood risks can be assessed and managed at a holistic whole of river basin level.

This paper will describe the catchment scale hydraulic model that was created for the entire Condamine-Balonne catchment which maximised the benefits of existing data. This was the first time that such a large scale flood model has been developed with a run time of days rather than weeks or more. The paper will explore the benefits of catchment scale modelling such as improving emergency management and informing regional land use planning. It will describe its potential use to Regional Planning Committees and the Western Downs Floodplain Management Study.

Description of the catchment

The Condamine-Balonne catchment covers an area of some 128,300km^2 which represents nearly 10% of the area of Queensland or nearly equal to the entire area of England. The area includes the local government areas (LGA) of Western Downs Regional Council, Toowoomba Regional Council, Southern Downs Regional Council, Balonne Shire Council and Maranoa Regional Council. The Condamine River rises from the Great Dividing Range close to Warwick and joins the Balonne River downstream of the township of Condamine. The Maranoa River flows in a southerly direction from the Carnarvon Range and meets the Balonne River at the Beardmore Dam, upstream of St George. The topography varies throughout the area with distinct tablelands, slopes and plains with nearly two-thirds of the area being relatively flat.

To date many of the townships within each of the LGAs in the Condamine-Balonne basin have been modelled individually, assessing the local impacts of flooding. Many of the townships forming part of the Queensland Reconstruction Authority's (QRA)

Flood Hazard Mapping Program, others being undertaken by the individual LGAs in response in particular to the flooding that has occurred in the last few years. These have been focussed on centres of population. However, rural areas are an on going challenge for traditional flood modelling, given their vast floodplain areas, cross catchment interactions and long flood event durations. To date, no flood modelling had been undertaken which links the catchment together, exploring the wider impacts in more remote areas.

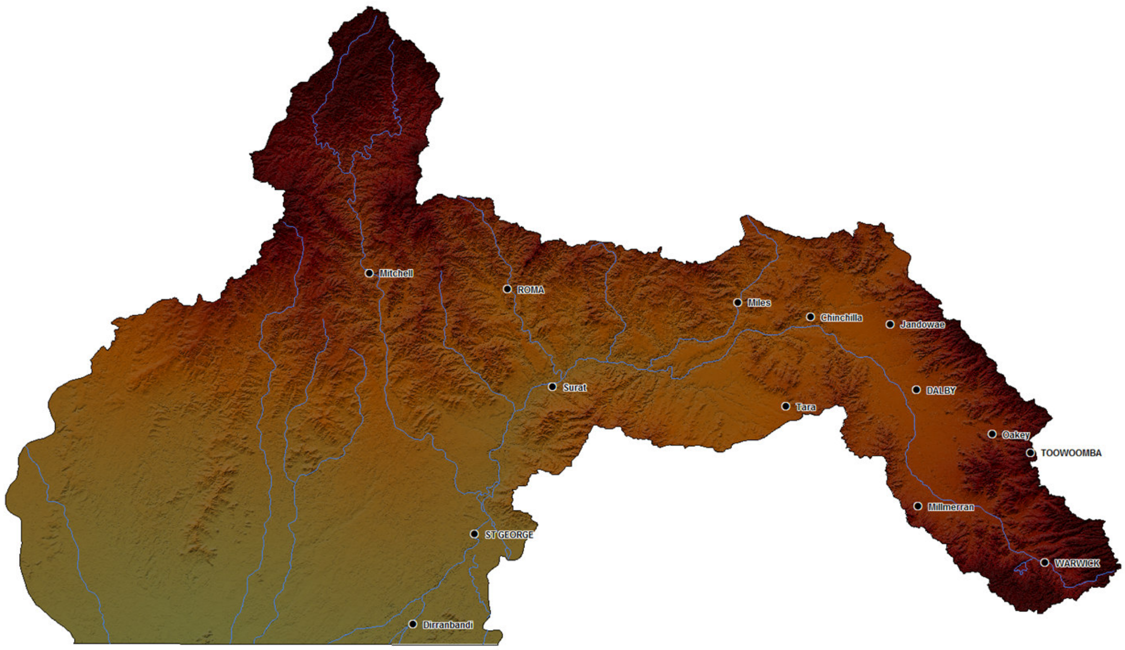

Figure 1 Condamine Balonne Catchment

Need for understanding

The benefits and utility of a catchment based approach to understanding flood behaviour can be linked to recommendations in a number of chapters of the Queensland Floods Commission of Inquiry Final Report (QFCI, 2012) primarily Chapter 2 Floodplain Management. The principle linkages are

- A catchment approach provides a common basis for identifying areas exposed to flooding and a common basis for prioritising and undertaking flood studies for urban areas (Rec 2.4 2.8 & 2.10)
- It provides a regional perspective for Councils to develop and maintain up to date flood information and understanding of floods (Rec 2.7)
- The catchment perspective and especially the animated presentation is an effective tool for informing elected representatives, planning and emergency response agencies and staff on communities and infrastructure exposed to flooding. This will assist with land use and emergency response planning. (Rec 2.9), priorities for floodplain management plans(Rec 2.12), identifying hazards at a regional scale (Rec 2.14) and identify areas that would require additional assessment for development applications. (Rec 2.14 and 2.15)

The QRA commissioned BMT WBM to undertake first catchment scale flood hazard mapping in Australia to pilot whether a tool could be created within reasonable timescales and within reasonable costs to aid state agencies and local government increase the flood resilience of the state. The model was designed to be able to maximise the use of existing data with an overall purpose of providing greater understanding of flood behaviour throughout the entire catchment during major flood events, and in many locations, providing flood mapping where none previously existed or had been loosely estimated.

About the model

The development of a new computational engine for TUFLOW by BMT WBM has enabled significant reductions in the overall model run times to be achieved and hence has facilitated catchment scale flood modelling. The TUFLOW GPU software solves the full 2D shallow water equations (SWE) including inertia and the sub-grid scale turbulence (eddy viscosity) terms. Other rapid 2D solvers often omit inertia and/or eddy viscosity and can consequently be inaccurate in complex flow areas. Importantly, the module utilises the immense parallel computing ability of modern GPUs. The speed of TUFLOW GPU arises from the ability to use the 1,000 plus threads or cores resident on standard and inexpensive gaming GPUs. This allows large models to run 10 to 100 times faster than the standard TUFLOW solver, which in itself is one of the fastest 2D software available for real-world applications. The power of modern GPUs means that very large models with fine grids can now be run in a sensible timeframe, yielding excellent in-bank resolution of rivers and waterways. Various explicit formulations are available including 1st, 2nd and 4th order in time, with optional adaptive time-stepping.

The flood model for the Condamine-Balonne catchment was developed using a grid resolution of 70m which generates 26 million individual model cells. At the time of development in 2012, this represented the upper limit of the GPU technology available. However the capacity of GPU is continually increasing and currently is able to cope with more than 75 million cells. The 70m cell size did not identify smaller drainage paths, however was considered acceptable for the purposes of flood mapping across the major river systems and areas which did not have any information.

Existing data

Ground data

The costs of LiDAR data collection are reducing due to rapid technological advancements in the size of equipment and in carrier vehicles as gyroplanes, ultralight aircraft and unmanned aerial drones can now be fitted with LiDAR. For very large areas, such as the Condamine-Balonne basin, complete LiDAR coverage is limited and probably somewhat impractical in terms of cost. As an alternative, satellite data such as NASA's Shuttle Radar Topography Mission (STRM) data are being used with increasing success despite limitations and compromises in accuracy.

Due to the sparse LiDAR coverage of the Condamine-Balonne basin, largely focussed on larger towns, the Condamine-Balonne flood model was developed using the STRM data using direct interpolation of the 30m STRM digital elevation model (DEM). As this model development was a pilot, the accuracy of local detail of obstructions to flow such as road/rail embankments, levees etc was limited to the representation of these features in the DEM.

Design inflows

The direct rainfall approach was used for the estimation of flows within the catchment given the area which was being considered. The approach successfully identified all the major flow paths throughout the catchment from headwaters to outlet and removed the need for a traditional rainfall-runoff model.

Two flood events were tested using the model; an extreme event and the 1% Annual Exceedance Probability (AEP) design event.

Standard methods for calculating rainfall depth and temporal pattern were adopted. Given the whole of catchment approach, it was recognised that storms of different duration would produce greater extents of flooding in different parts of the catchment. Shorter more intense storms producing greater flood extent in locations further upstream with narrower and more steeply sloping elevations. Conversely, longer duration storms produce greater flood extents in the wide, relatively flat areas of the catchment downstream.

Model results

Given the whole of catchment approach, the term extreme flood event was adopted reflecting the fact that given the total area of the Condamine-Balonne catchment, the flood mapping produced may not strictly constitute a Probable Maximum Flood in all areas, in particular when considering the upper and lower part of the catchment. To compensate against this, the approach included the simulation of a range of storm durations designed to encompass the critical duration for the upper and lower parts of the catchment and these were then combined for mapping purposes, the composite flooding termed an extreme flood event.

The extreme flood mapping compares well with the QRA Interim Floodplain Assessment Overlay with good correlation (BMT WBM, 2012). There are areas where the extent of the extreme flood event is larger than the indicative flood overlay. Most notably, the extreme flood mapping provides mapping on many watercourses not included within the indicative overlay and provides mapping on the headwaters of watercourse which is not provided by the indicative flood overlay.

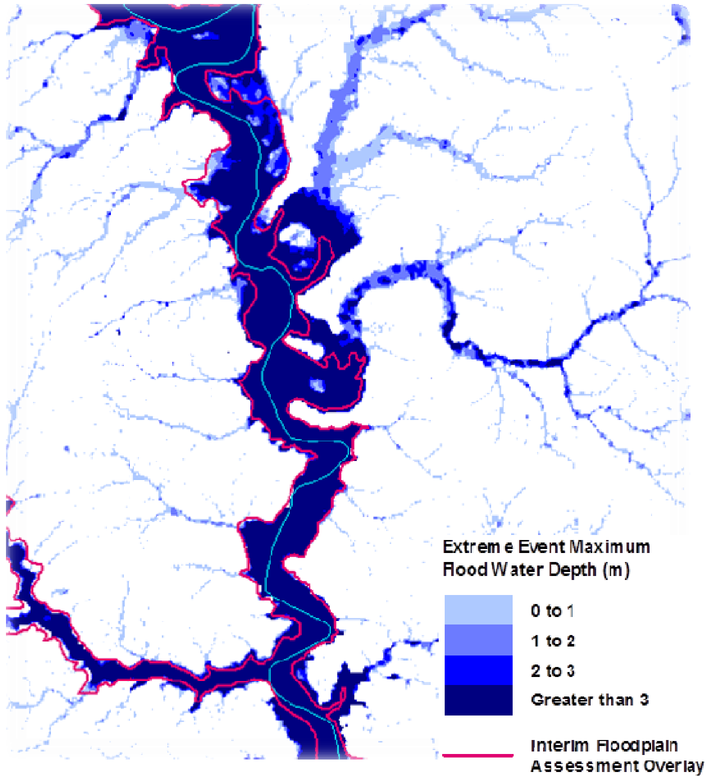

Figure 2 Extreme Flood Outline

The 1% AEP flood model was generated using the same approach as for the extreme flood event, using 1% AEP rainfall depths and AR & R zone 2 temporal patterns for different duration storms.

Maximum flood depth and velocity results were extracted from each of the flood models to deliver the flood hazard categorisation. The flood hazard criteria were generated using existing best practice guidance. For the purposes of this pilot study, three hazard categories were mapped; extreme, high and low. Animations were also produced to assist the end users to understand the flood behaviour through the entire catchment. Animations showing flood water depth for the extreme and 1% AEP flood events were produced which provide an excellent visualisation of the flood events.

Limitations of modelling

It should be noted that these are limitations to the applicability and accuracy of the hydraulic model when undertaken at a catchment scale. The results are suitable for testing the approach and even increasing understanding of flood risks but should not be solely relied upon for design of flood mitigation options such as levees or setting planning levels. The adopted catchment scale model has been developed using a grid resolution of 70m which generates nearly 10 million individual model cells. The 70m cell size does not identify smaller drainage paths, however this is acceptable for the purposed of flood mapping across the Condamine-Balonne catchment, particular in areas currently without any flood mapping information.

While there is a good correlation between the extent of a modelled extreme event and the QRA's Queensland Floodplain Assessment Overlay, using a model approach at a catchment scale may provide additional useful information (if desired) including a better understanding of likely extend of floods at various levels, a coarse understanding of flood hazard in terms of depth and velocity, and the timing and duration of flood events. This is of particular interests to evacuation planning and the identification of areas for more detailed investigation.

Where to now?

The use of catchment scale flood models can have multiple benefits for both state agencies and local governments across Australia to assist with a better overall understanding of flood behaviour. Using the TUFLOW GPU, acceptable modelling results can be generated to develop broad scale understanding in those areas where little information on flood behaviour is available and where funding constraints mean that a detailed flood study is unlikely to be undertaken in the near future.

It can be used to identify flood prone areas which may require further investigation into flood behaviour through more detailed flood studies. It can also subject to calibration, be used to provide boundaries for more detailed flood modelling. This can assist state agencies and local government to target investment in those areas at most risk considering the wider impacts across a larger area.

By constructing a model of an entire catchment, it can be possible to identify previously unknown flood behaviour. For example, the mapping for the Condamine-Balonne catchment has identified additional areas of flood storage within the catchment which until now were previously unknown. It can also identify high level breakouts and local connectivity. For example, the extreme flood extent has highlighted an area to the south west of Jandowae where anecdotal evidence has suggested interaction between minor catchments.

Regional land use planning

Broad scale catchment modelling can be applied to assist with regional land use planning. The extreme flood extent and 1% AEP mapping for the Condamine-Balonne basin will be useful for assisting in determining future strategic land use planning, highlighting where potential flooding could impact settlement patterns, infrastructure development and mining and agricultural activities.

Regional Planning Committees (RPC) are established to ensure the views of community and industry stakeholders are represented when planning at a regional level. Consisting of representatives from local governments, members of parliament, community and industry stakeholders and state agencies, RPCs develop statutory regional plans which are necessary in providing a holistic approach to planning, infrastructure and service delivery which is consistent with state policy. Statutory regional plans aim to foster diverse and strong economic growth; plan and prioritise infrastructure; manage impacts on the environment; and where necessary, plan for urban growth and resolve land use conflicts such as those arising between agricultural and mining activities.

Similar to regional planning, floodplain management is not restricted to a single jurisdiction or location. There is a strong nexus between the RPC level of collaboration and floodplain management, given the existing role of regional planning instruments in driving regional settlement and development outcomes. RPC can play a significant role in overseeing and coordinating floodplain management at a sub-basin level, particularly the regional planning process.

The Condamine-Balonne basin area is within seven local government jurisdictions, six of which are within the Darling Downs RPC area. The mapping of the Condamine-Balonne basin can inform future land use planning decision at a regional level and seek to deliver consistent floodplain management provisions in jurisdictions across the region.

Real Time Flood Warning

The Bureau of Meteorology (BoM) have unrivalled experience with forecasting floods across Australia, with the Condamine-Balonne River system being no exception to this. The numerous floods having occurred in the Condamine-Balonne River system since forecasting began have been critical for the BoM to refine their forecasting techniques and continually improve forecast accuracy. To date, most of the flood forecasting undertaken by the BoM has used unit hydrograph methods and lumped hydrologic modelling using the URBS software. Use of hydrodynamic modelling for flood forecasting in Australia is still in its infancy. National roll out of the Delft-FEWS forecasting platform by the BoM will open an opportunity for integration of models.

Generally modelling for flood forecasting and warning is limited to 1D models. The increased simulation times and potential stability issues associated with 2D models have limited its widespread use. The computational speed of the TUFLOW GPU solver addresses these concerns, now presenting a tool that can be used for this purpose. However, it is important to consider whether use of such models will actually add value to the flood forecast. In the Condamine-Balonne River system, current forecasts provided by the BoM are likely to be as good as you can achieve by using a hydrodynamic model. Notwithstanding this, modelling can provide more than an expected peak level and the associated time of occurrence. For example, duration of inundation can be predicted from models and is an essential piece of information required by response agencies and the wider community.

Emergency Management and Intelligence

The flood extents and animations produced on a catchment scale can enable emergency managers with no experience of an extreme flood event (or other flood events) to visualise the flood behaviour across an entire catchment. It has been demonstrated to identify areas for further investigation such as:

- Low road flood immunity
- Points of interest within the extreme flood extent and the 1% AEP extent
- Alternative evacuation routes

An initial desktop study can highlight those areas for more detailed consideration. For instance, the Carnarvon Highway south of Roma is significantly affected by the extreme flood event, as is the Mitchell – St George Road and many other major highways.

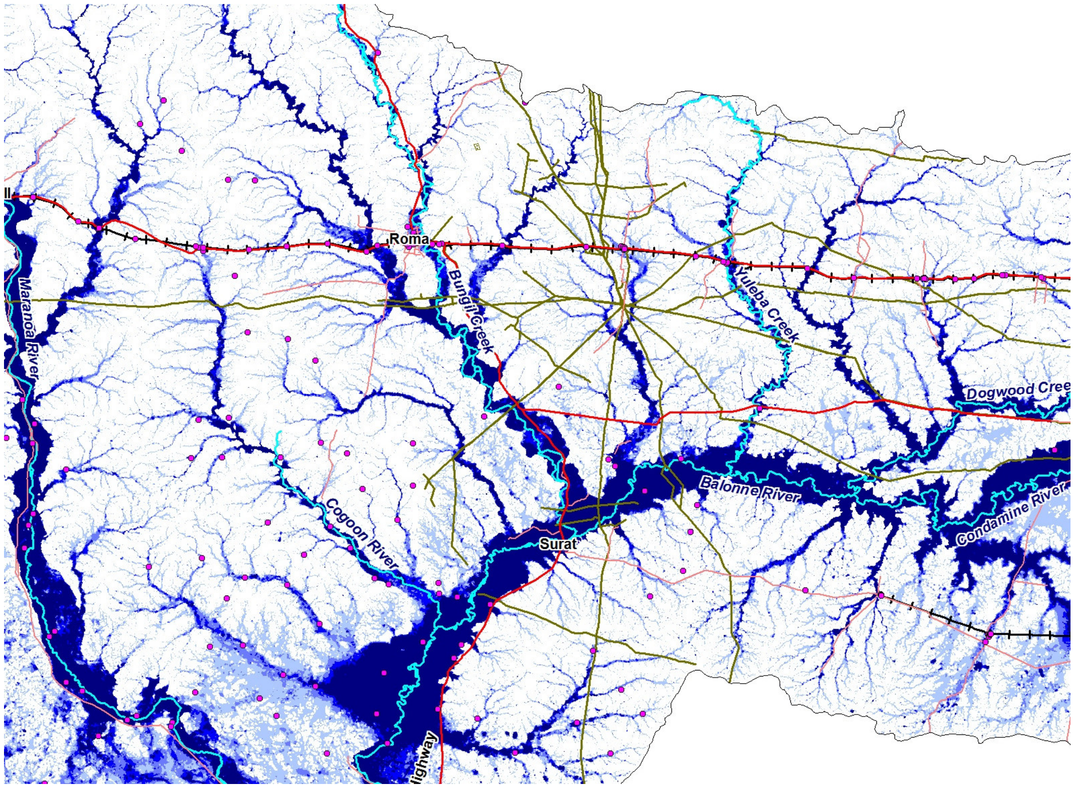

Figure 3 Extreme Flood Outline Roma

The mapping undertaken for the Condamine-Balonne catchment has also identified many locations throughout where points of interest such as schools, railway stations and other vulnerable infrastructure are within the extreme and 1% AEP flood extent. This information will be invaluable for emergency managers to consider wider impacts of flooding in areas previously unaffected. It also has the ability to highlight those localities where additional evacuation infrastructure should be provided.

The true value in the GPU model is in the interpretation of flood impacts (Turnley and Reynolds 2013). In NSW, the SES have developed Flood Intelligence Cards for most river gauges, where actual or predicted flood levels are translated into a sequence of events which occur in the catchment. For example, a gauge level of x metres, is likely to cause inundation of a key evacuation route. In Queensland, the BoM have similar tables, known as 'Flood Effects' tables. These tables are generally not accessible by the general public, therefore the predicted flood levels provided by the BoM can have little meaning to community members who are unable to relate the levels to previous floods, or to other consequences of such levels. Real-time use of the GPU model during a flood event, can provide response agencies and personnel with significant additional information regarding anticipated flood extents and associated consequences. For example, a Council could have a GPU model running in real-time, using observed rainfall and water levels, and predicted flood levels and timings from the BoM, to assess how long a particular evacuation route may remain open. Council and other emergency response agencies can then adjust their flood response actions to suit. Another example could be assessment of which houses or public infrastructure are likely to be inundated.

The catchment based mapping will also be a very useful tool for Councils when undertaking floodplain risk management studies, giving an overview of the flood behaviour across an entire LGA.

Local Applications of GPU Modelling

Western Downs Regional Council (WDRC) covers an area of around 38,000km^2 and has a population of 30,000 located approximately 200km west of Brisbane. Dalby is the principal town in the district with a population of 12,000. Other main towns include Chinchilla, Condamine, Miles, Warra, Jandowae, Tara and Wandoan. The floods of December 2010 and January 2011 were significant in magnitude and caused much damage and disruption throughout Council's area. More recently in 2013 the area has again been affected by flooding causing disruption.

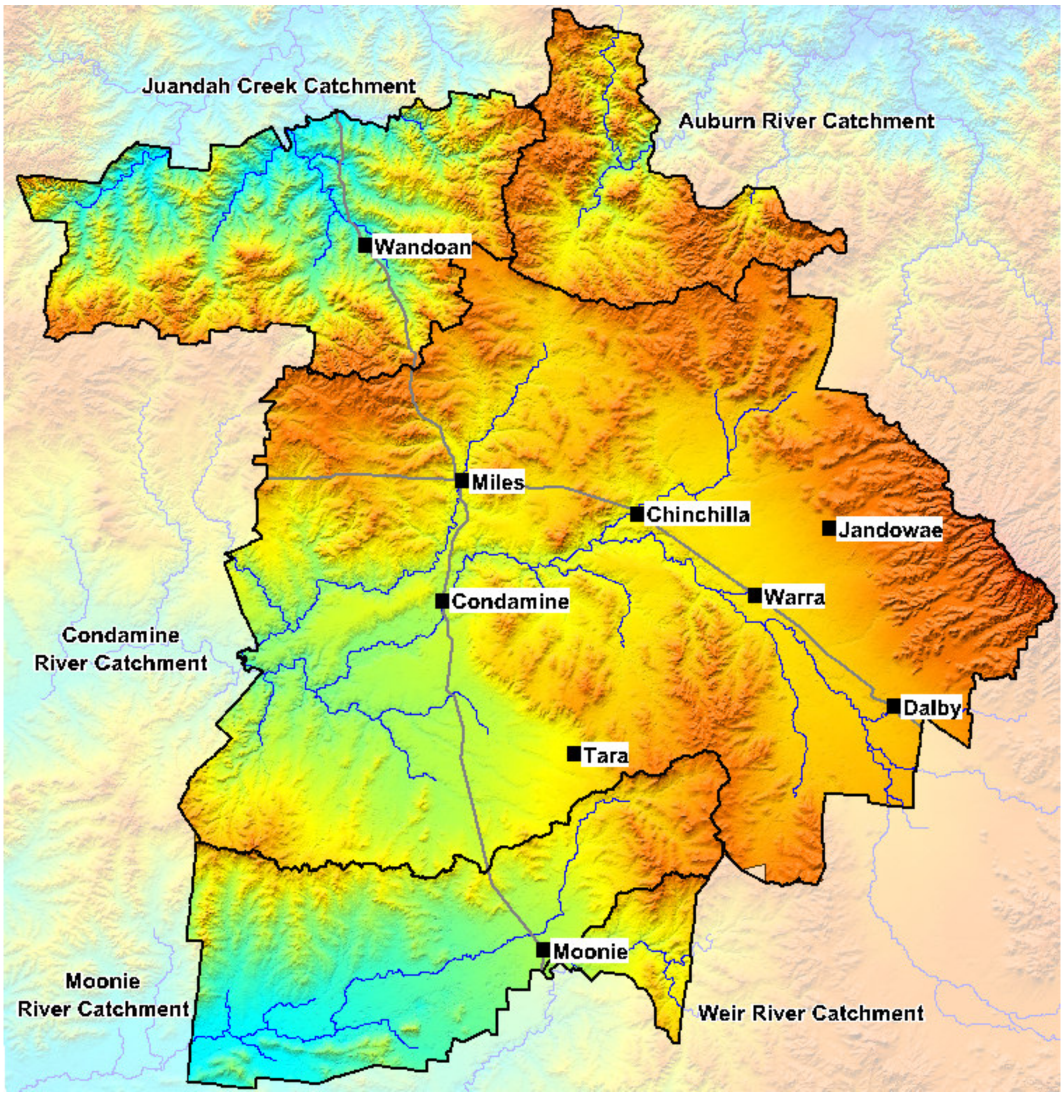

Figure 4 – Western Downs LGA

WDRC identified that there was a need to develop a comprehensive and forward thinking plan for managing current and future flood risk within the area as no such plan previously existed. It was recognised that the adopted approach must be flexible, adaptable and reviewed on a regular basis using the best available data and be fit for purpose, delivering an approach to floodplain risk management which delivers community and environmental resilience.

The Condamine-Balonne flood model presents the opportunity through refinement to develop tools to assist WDRC to manage flood risk across the entire local government area (LGA) such as

- Emergency planning – lead times of towns being cut off, evacuation planning exercises;
- Targeting future development;
- Community Awareness; and
- Real time flood forecasting.

Emergency Planning

The Condamine-Balonne flood model presents the opportunity to assist WDRC to manage flood risk across adjacent LGAs. As the catchment extends across local government boundaries, so do the associated issues and emergency management partnerships required during major flood events. In February 2012, a major flood was predicted causing the evacuation of the St George township, to the Western Downs town of Dalby. Such a tool could have assisted during the emergency planning phase, reviewing lead times of towns being cut off, evacuation routes and then during the repatriation process.

The Condamine-Balonne flood model presents WDRC with a tool to assist in the development of knowledge of flood behaviour within the LGA. Council has recognised that while it has a good understanding at present, having been subject to fairly frequent flooding in the past few years, that significant historical local information and experience will be lost very easily. Recent statistics indicate the average age of a Council officer is greater than 50 and it is likely that existing flood knowledge, particularly in the more remote areas will decrease with time. It is a high risk that such important information is stored with such a small group of individuals. It has been very difficult for this information to be shared, in particular prior to events occurring, as this knowledge has only be gained via experience over many years. The Condamine-Balonne flood model has the potential to be used as an emergency management training tool, giving Council officers and other emergency responders the opportunity to explore various 'what if' scenarios relating to different design flood events across the catchment. This will help to understand the potential flood behaviour across multiple local catchments, identifying road immunity and evacuation issues.

The GPU flood modelling output has enabled previously unverified anecdotal evidence from the community to be assessed and understood in broader terms. The township of Jandowae is situated about 50km to the north of Dalby. Until recently the flooding which occurs to the south of the township which affects several roads, leading to isolation of properties was not understood in terms of impact. The GPU flood model has provided Council with additional information on the likely impacts and consequences of flooding in this remote area, enabling future planning to consider the impacts. This has been repeated throughout the LGA.

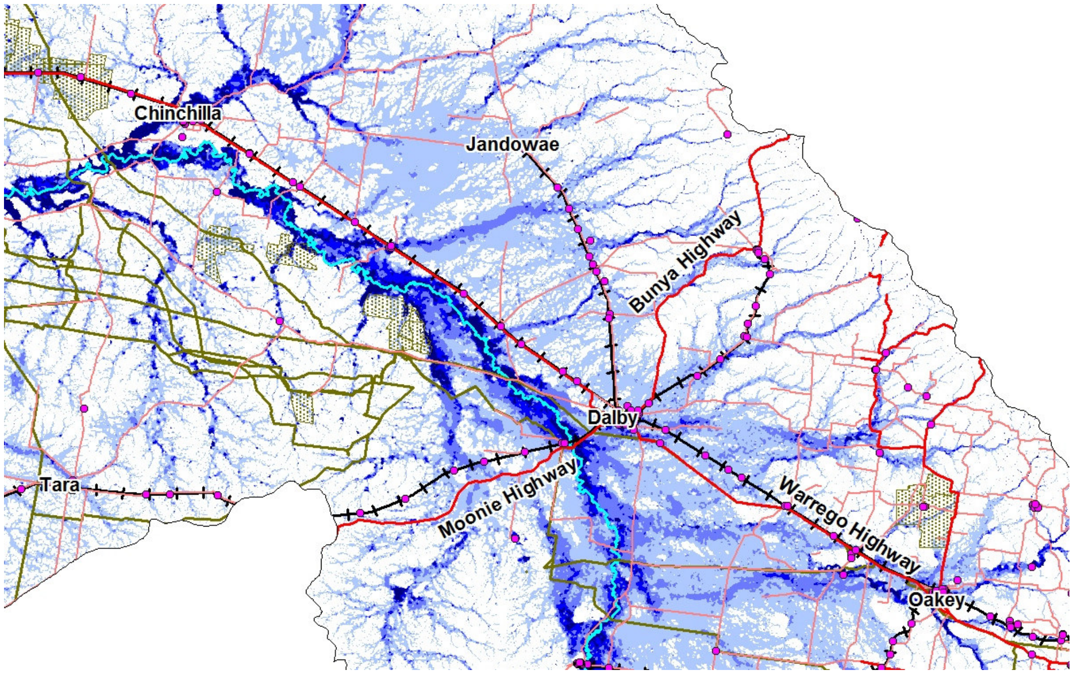

Figure 5 Flooding in Jandowae Locality

Targeting Future Development

The Western Downs region has experienced unprecedented growth over the past few years. The area is a hub of growth based on the continuing growth in manufacturing and agriculture. The LGA faces challenges of how to manage future development, particularly regarding the energy and resource sectors. The Western Downs Economic Development Plan (WDRC 2011) sets out the scenarios to influence the region's future prosperity. Key transport links across the LGA are susceptible to the impacts of flooding and the use of GPU flood modelling can assist in continuing the future development of the area through developing a thorough understanding of the wider impacts of flooding in as yet undeveloped areas enabling mitigation strategies to be developed alongside development. The GPU flood modelling fills existing knowledge gaps regarding flood behaviour, especially in rural and remote locations. This can help ensure that the region continues to develop in a sustainable fashion allowing confidence in future investment.

Community Awareness

Through the floodplain management study, the impacts of flooding for the Western Downs Regional Council communities can be visually illustrated to increase awareness. Supported by the studies recommendations, future mitigation strategies can be adopted and funding sought. While an understanding of the risks (or remaining risks) can be communicated to the community on both a local scale and across the wider area. The use of animations of the flooding across the entire LGA will assist in this process.

This community consultation will give the community ownership and assist them in preparing their families, homes and businesses. As the events soon become a distant memory, this tool can act as a reminder, visually demonstrating the impacts.

Real Time Flood Forecasting

Chinchilla is located immediately to the east of Charley's Creek, a major tributary of the Condamine River which it joins a further 13km downstream. The town is situated at an elevation around 305mAHD and has a population of approximately 5,700 making it the second largest town in the Western Downs region. Towards the south of Chinchilla, Charley's Creek combines with Rocky Creek and between them they have an upstream catchment area of approximately 3,800km^2. There is one major road crossing of Charley's Creek which is for the Warrego Highway. To the south of Chinchilla on the Condamine River is Chinchilla Weir.

Significant floods have occurred in Chinchilla in 1942, 1983 and 2010. The highest on record was in 1942 when a level of 7.95m was reached at Charley's Creek Bridge. The double flood event of 2010/2011 resulted in peak levels of 7.25m and 7.45m respectively which have only be exceeded by the 1942 flood in recorded history. The flood in 1983 is now the fourth largest on record at 6.75m. The impact is most significant to Chinchilla's business houses, and the rural primary producers along the catchment. Homes are inundated and the community is significantly disrupted by local road closures. Significant disruption is caused when the Warrego Highway is closed with major resupply issues for towns and major logistic implications for the large volume of heavy transport traffic.

The flood warning time for the Charley's Creek catchment is approximately 12 hours. Whilst this does provide just about sufficient time for emergency responders to take appropriate action, no two floods are the same. Recent flooding, particularly the two events which occurred in 2010 demonstrated the different times to peak of both Rocky and Charley's Creek.

By feeding the rainfall predictions generated by the BoM into a refined version of the broad-scale GPU model for the local Charley's Creek catchment, and by computing detailed flood level results significantly faster than real time, this could allow for flood warnings and emergency management information to be generated on a unique per event basis. Although rainfall predictions would be a limiting factor, this technique could enable flood warning and response to be tailored to respond to the specific nature of the event affecting Chinchilla rather than to be 'approximated' using pre-defined 'design' flood events. This would generate far more meaningful information to be made available to emergency responders to estimate timeframes and identify trouble spots. By responding to the unique behaviour of an individual flood rather than a peak design flood could lead to more efficient and targeted use of limited resources.

WDRC has commenced a program to improve flood warning within the catchment with a planned program to replace the existing manual reader with additional automatic stations. There is the real opportunity to tie in the additional gauges with a local GPU flood model to provide better intelligence on the possible impact of flooding in combination with the floodplain management plan and potential structural measures.

Conclusion

Technology is rapidly advancing with new generation GPUs being released typically on a yearly basis. As GPUs develop over the coming years two potential outcomes will significantly enhance the understanding of flood behaviour across large catchments. These faster GPUs will allow even finer resolution model grids, approaching, or even surpassing those currently used in detailed urban models. More computation power will help justify the time and expense of building greater detail into the catchment wide models, such as would be expected and required in a more traditional flood model. Therefore these broad-scale models could be used for any number of purposes from setting designated flood levels and extents, building controls, development impact assessments through to assessing flood mitigation schemes.

The development of the Condamine Balonne model has demonstrated the opportunities that now exist for increasing resilience across the state by providing more detailed information on flood behaviour particularly in remote and rural areas. The ability to run a model of this scale in days rather than weeks represents a new era in flood modelling. One of the key outcomes is the ability for those in state government to understand the nature of the flood behaviour across large areas for both emergency management and future economic development, helping to target limited resources. At a local scale, there exists the real chance to further develop flood warning tools to complement those that already exist assist with the community's resilience and how to live with floods rather than trying to control them.

References

BMT WBM (2012), Flood Study Pilot – Condamine Basin

QFCI (2012). Queensland Floods Commission of Inquiry Final Report

Turnley and Reynolds (2013) Broad scale flood modelling utilising recent advances in technology, 8th Victorian Flood Conference

WDRC (2011) Western Downs Economic Development Plan 2011-2015