Flood Emergency Decision Support System for Gold Coast City Council

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Abstract

Gold Coast City Council has extensive rivers and floodplains. A large number of people have settled in the floodplain with a particular preference for water-front living. Council over the last decade has developed hydrological models and one and two-dimensional flood models for the City's major catchments and floodplains. Also substantial effort has gone into flood mapping and the collection of GIS-based properties and infrastructure data.

To better monitor the progression of a major flood and its likely impact on people and properties, Council is building a sophisticated Flood Emergency Decision Support System (DSS). The aim of the DSS is to integrate the hydrologic, hydraulic and GIS "flood intelligence" assessed over the last 10 years and extract and present vital flood emergency decision making information during an actual event.

This paper outlines the DSS strategy and show how the DSS extracts and displays all the various components of information to various groups which are required to respond to a flood emergency. Examples are provided of how the DSS interprets the basic hydraulic and hydrologic inputs and GIS data to provide flood intelligence such as:

- Flood Affected Properties – overfloor flooding associated with a predicted flood level.
- Evacuation and Exit Routes – the predicted depth and relative timing along evacuation routes to and from evacuation zones and nearest evacuation centers.
- Affected Road/Bridge crossings – the predicted impact on road crossings and bridges.
- Affected Demographics – display critical information on impacted population profiles. eg population data with age distribution.
- Flood Damage – post flood spatial assessment of the distribution of likely damage.

Introduction

The area covered by Gold Coast City Council includes extensive rivers and floodplains. A large number of people have settled in the floodplain with a particular preference for water-front living within the low relief coastal plain. Consequently, tens of thousands of people and their properties are at threat from severe flooding.

Over the last decade, Council has developed hydrological models and one and two-dimensional flood models for the City's major catchments and floodplains. Also substantial effort has gone into flood mapping and the collection of GIS-based properties and infrastructure data.

To better monitor the progression of a major flood and its likely impact on people and properties, Council is building a sophisticated Flood Emergency Decision Support System (DSS). It is anticipated that the DSS will engender a clearer understanding of flood behaviour and its impacts within the non-engineering community, and most importantly provide Council's Counter Disaster Unit with the tools to plan for and respond to flood events.

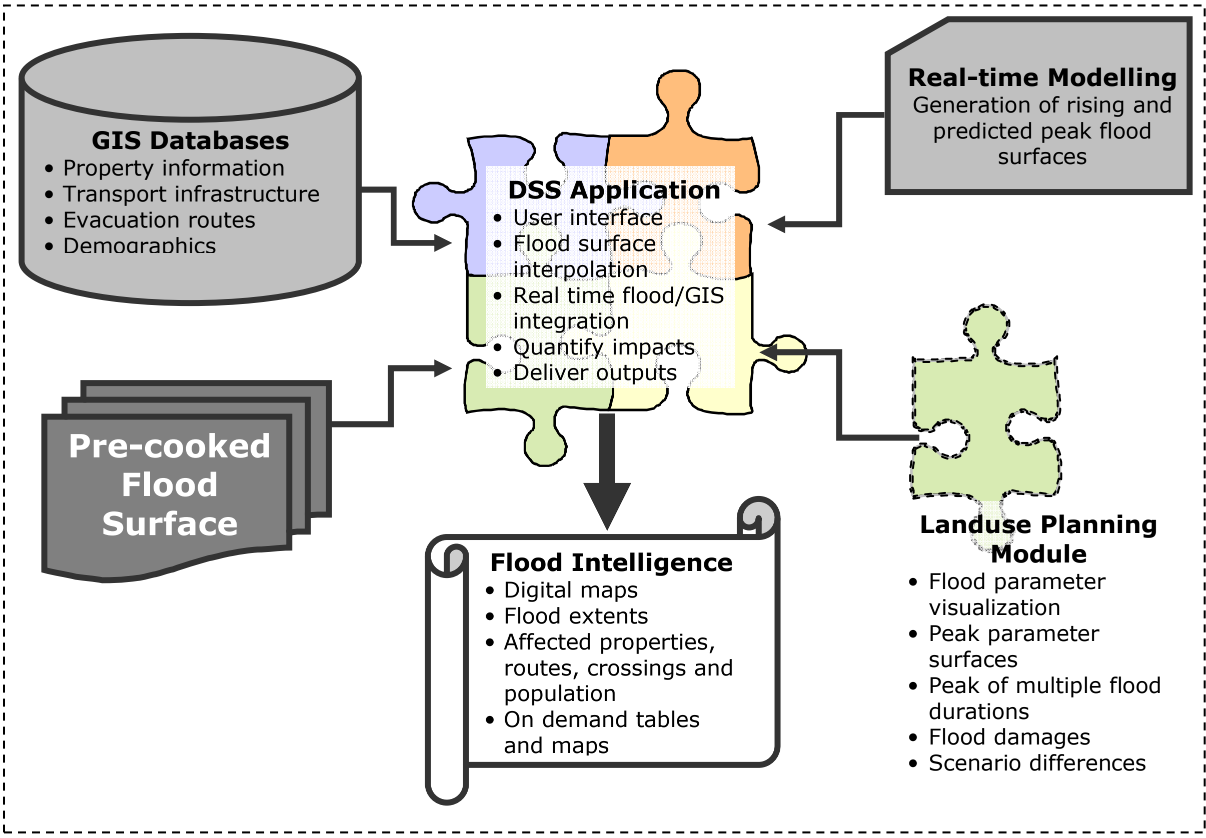
The aim of the DSS then, is:

- to integrate the hydrologic, hydraulic and GIS "flood intelligence" assessed over the last 10 years,
- to present design and historic flood results integrated with property, infrastructure and community data and thus assist in the preparation of emergency disaster plans,
- to generate a flood surface for an actual event by interpolating from a library of "pre-cooked" surfaces, or by running a flood model in real time using the predicted hydrograph for the event and converting the results,
- to extract and present vital flood emergency decision making information during an actual event, and
- to assist in incorporating flood impacts responsibly within landuse planning strategies.

Structure of the DSS

The following figure shows the DSS as the processing hub of all the information available to Council in an emergency viz:

- GIS database
- Pre-cooked Library of Flood Surfaces
- Real Time Flood Modelling, based on forecast flood hydrographs predicted by BOM
- Land Use Planning Module



In essence the DSS is a Windows application that connects the property, infrastructure and community GIS databases to the predicted flood surface and updates the various flood affected fields within those databases. This information can then be presented to support emergency response or planning decisions as thematic maps and tabular summaries.

A key element in the DSS is simplicity of use for emergency response personnel whilst maintaining flexibility in the variety of views and integration with any number of GIS layers.

In its current form, the DSS makes use of the following datasets:

- Baseline topographic data:
    - an ALS based digital terrain model
    - airphotos
- Baseline GIS data:
    - cadastre,
    - ALERT gauging stations,
    - waterways,
    - evacuation centres,
    - evacuation zones
- Flood data:
    - a library of design flood surfaces
    - an interpolated flood surface calculated by the DSS
    - a time series of flood surfaces calculated by the flood model for the real time hydrograph or for design hydrographs
- Integrated GIS data:
    - property floor levels

- bridges
- evacuation routes
- aged care, child care, schools

The DSS integrates all this information, including the automatic execution of flood models based on hydrographs predicted by BOM, to provide the Flood Intelligence needed to respond to a flood emergency. The static pre-cooked library of flood surfaces is being built in parallel to the real-time system so that it can be used in case the real-time system malfunctions.

The processing capability of the DSS includes the interpolation of a predicted flood surface from the library of design surfaces based on predicted peak flood levels at one or more gauges, **Figure 1**. The single gauge solution is relatively straight forward, i.e. applying the interpolation ratio between two design surfaces at the gauge to all nodes on the flood surface, however the multiple gauge interpolation requires "zones of influence" to be established for each gauge with a smooth transition being applied across zone boundaries.

In its real time mode, the DSS reads the predicted rainfall runoff hydrograph provided electronically by BoM and converts it to a suitable format for the MIKE-11 flood model. The flood model is then automatically run by the DSS and when finished, the DSS then converts the results onto the flood surface spatial framework. In this case all timesteps at a pre-selected interval are converted to generate a time series of the evolving flood surface.

Once the peak flood surface has been generated, either from the library or through real time modelling, the fields in the various integrated GIS layers can then be updated. This analysis typically includes the transfer of flood levels, the determination of flood depths relative to say a floor level or a road level, the determination of air space under bridges, and with the time series data, the anticipated time when key facilities such as evacuation routes, will become affected.

The results of the analysis are presented to the user in a series of pre-prepared views with thematically mapped data fields, eg showing the predicted depth of flooding over evacuation route low points, **Figure 1**, the depth of flooding over property floors, **Figure 2**, the depth and extent of flooding across the landscape, **Figure 3**, and thematic surfaces of velocity and V*d values to identify areas of high risk. Views can be zoomed and panned and printed out for hard copy reference.

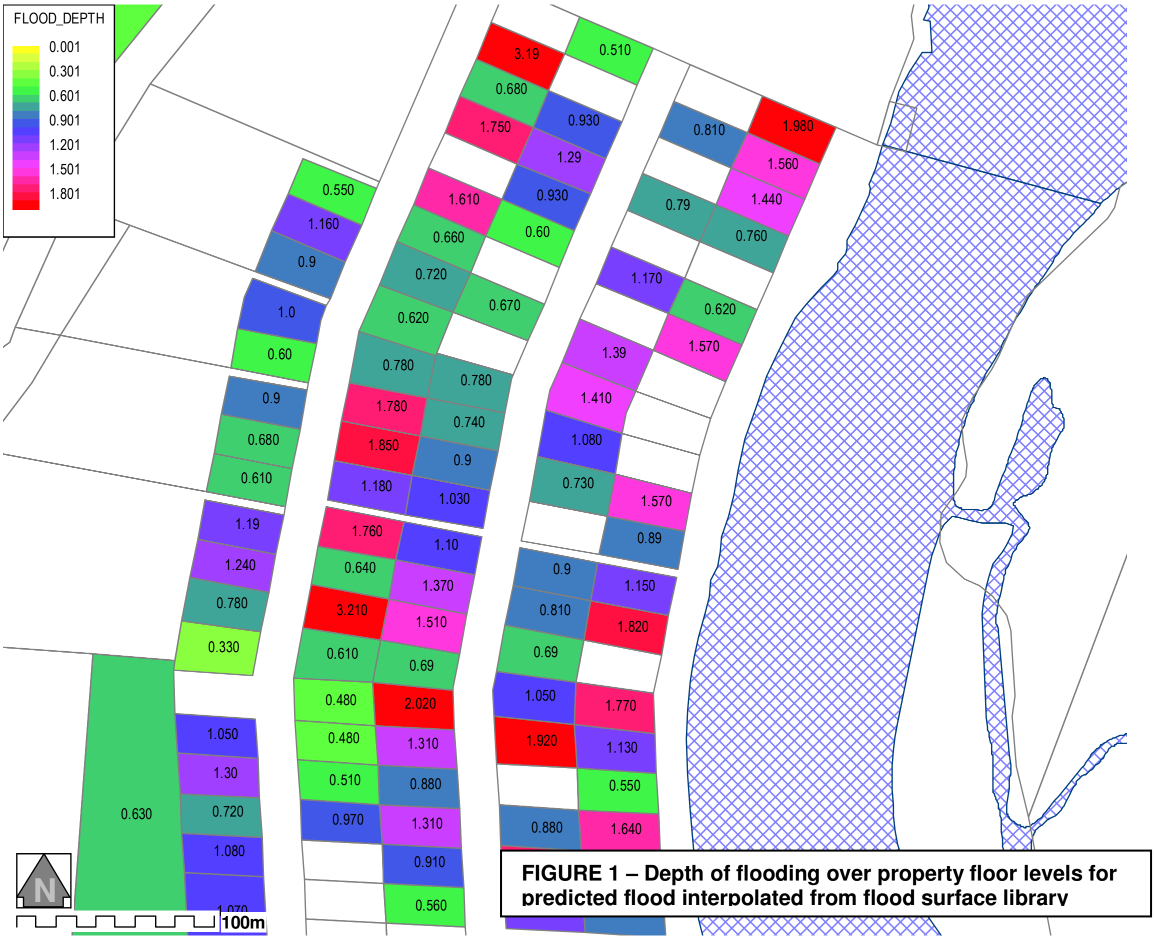


FIGURE 1 – Depth of flooding over property floor levels for predicted flood interpolated from flood surface library

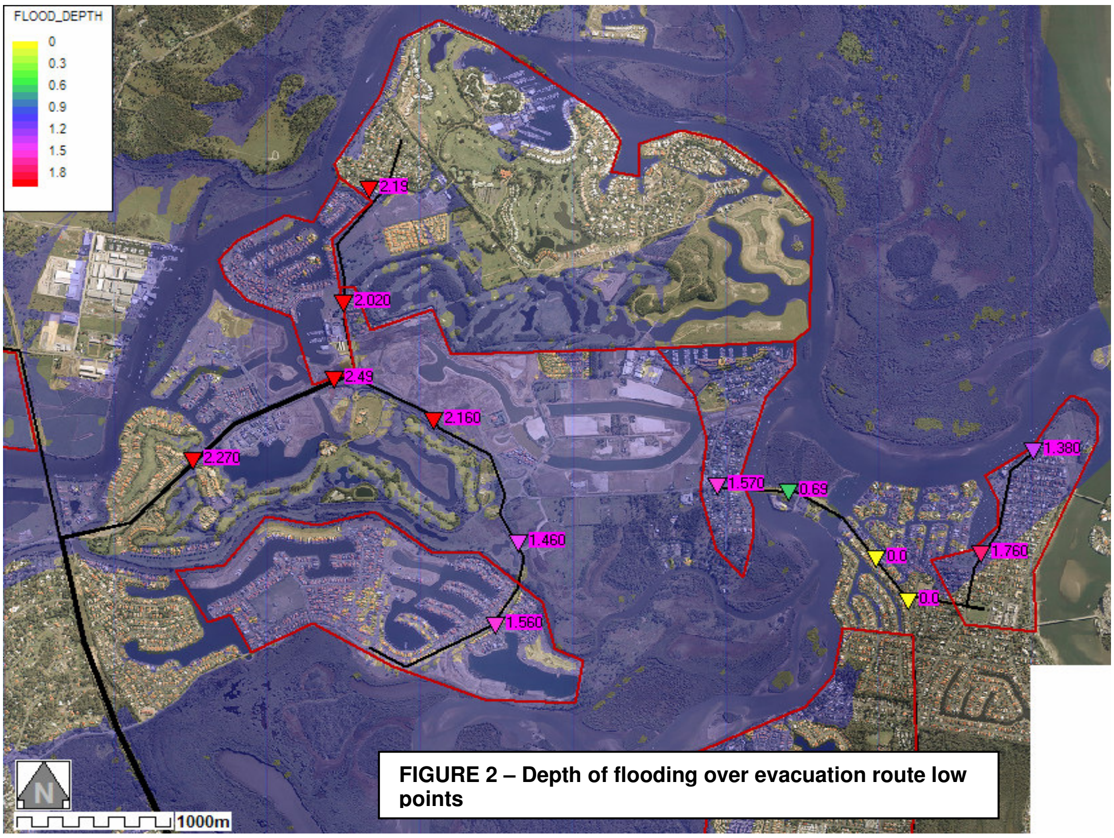


FIGURE 2 – Depth of flooding over evacuation route low points

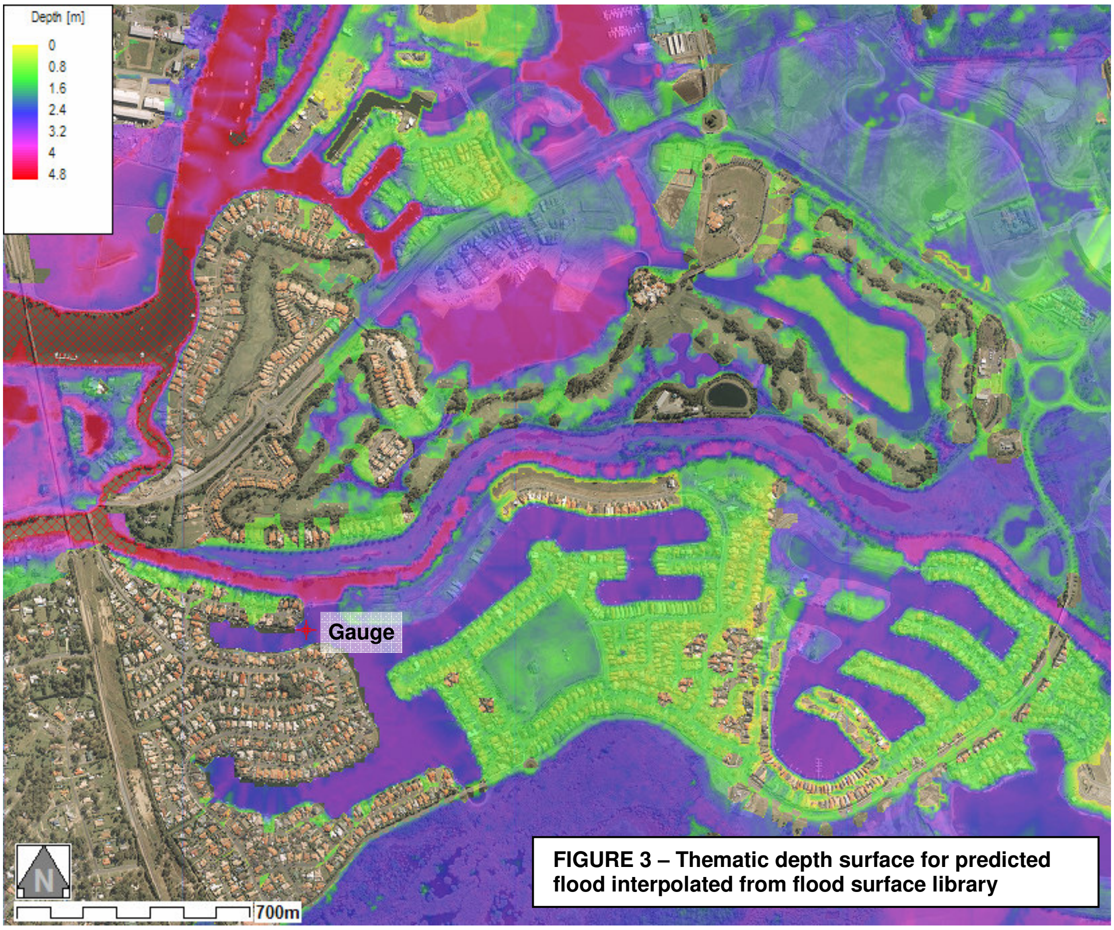


FIGURE 3 – Thematic depth surface for predicted flood interpolated from flood surface library

The DSS in Emergency Response Planning

The initial preparation of the DSS included a set of draft evacuation zones and routes. These were subsequently refined as part of a flood disaster planning process by Council's Counter Disaster Unit. The flood visualisation component of the DSS enabled CDU staff to become familiar with the potential behaviour of flooding including rates of rise, evolving flood extents, areas of high flood hazard and lead times prior to roads being cut. Although design floods rarely represent real events, they nonetheless provide a good indication of potential flood coverage, and they often replicate the rising stages of a major flood when the evacuation process is underway.

The preliminary evacuation zones were each scrutinised in detail with respect to :

- coherency for issuing warnings,
- lead time prior to evacuation routes being cut,
- identification of alternate evacuation routes,
- areas where evacuation route upgrades may be required,
- the need for on-site refuge,
- the traffic interplay with other zones along common evacuation routes,
- the flood conditions likely during any rescue operation,
- the distribution and size of facilities requiring managed evacuation, and
- the distribution of the elderly demographic where more assistance may be required.

This data immersion process instilled in the CDU staff, the magnitude of the impacts for a major or severe flooding event and the resources needed to execute such an evacuation. It is expected that further refinements would be applied as the built environment and associated demographic changes as well as after any flood event. However, one of the major benefits of a tool such as the DSS and its associated databases is the capturing of this knowledge for training and passing on to future generations of emergency personnel.

The DSS in Real Time Flooding

The two key elements of flood intelligence that are essential for an effective emergency response are knowing the eventual outcome or the area at risk, and having some idea of the rate at which flood waters are rising and likely to rise.

The BoM has a rigorous methodology for determining the peak of a flood, which of course improves with more rain having fallen in the upper catchment. Additionally, GCCC has arranged to obtain the runoff hydrographs generated by the BoM's rainfall analysis, and whilst the subsequent flood modelling and data processing by the DSS can take up to an hour, the outcomes will still provide many hours of advance notice of flood conditions. In the event of any modelling failure, the "pre-cooked" library of data, which takes only minutes to process can be relied upon. Library design floods with similar rates of rise can be used to predict the short term impacts and assist with prioritising resources.

In real time use, the DSS will assist in graphically identifying the community at risk and the magnitude of the impacts and thus identify the scope for any evacuation. Subsequently as the flood progresses, the DSS can be used to indicate the flood impacts in the near future (*say 1 to 2 hours*), enabling emergency response priorities and resources to be appropriately assigned.

Conclusion

The development of a flood emergency decision support system by Gold Coast City Council brings together a decade of hydrologic and hydraulic modelling into a platform where it can be integrated, as needed, with spatial databases on the community, properties, infrastructure and the environment. The tool has the ability to analyse and then graphically present the impacts of any flood on the community during the event so that an appropriate response can be mounted with as much advance notice as possible.

The DSS was initiated for the real time response capability, however it has proven to be very useful for gaining an appreciation of the magnitude of potential flooding and its impacts, has been invaluable for planning emergency response strategies, and will be a useful asset for training.

It will also provide useful baseline data and analysis capabilities in the area of landuse planning.

CLIMATE CHANGE – THE FUTURE IS UNCERTAIN

Duncan McLuckie[1], Doug Lord[2], Jane Gibbs[3].

Abstract

Floodplain risk management involves dealing with a wide range of current and future uncertainties. With climate change the scale of potential uncertainty increases.

Available historic flood data is generally limited by the amount of data available on rainfall, catchment condition and flood levels in previously developed areas. The data available for the most significant events is often considerably less than for events that may have occurred more recently. While modelling relies on this incomplete data, it requires decisions upon a range of assumptions that may impact on flooding.

Changing the time location of modelling, from historical situations to present time or into the future involves further assumptions on what will change and by how much? This has led to modelling based upon a range of assumptions affecting flows and flood levels and, therefore, predicted flood behaviour.

However, climate change has the potential to add significantly to this degree of uncertainty. This paper will discuss how the issue of climate change should be considered and canvass how decision making can be made more robust in light of increasing uncertainty.

The ramifications of these decisions may include:

- increased development costs and the potential to sterilise areas if decisions are too conservative; and
- increased frequency of inundation and damage if uncertainty is dismissed.

Key Words: *Uncertainty, Climate Change, Flooding, Risk Management*

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1. Introduction

The Inter-governmental Panel on Climate Change (IPCC) 2001 Assessment Report (Ref 3) concludes that sea level rise and climate change are inevitable, irrespective of the success of emission reduction strategies, and that these strategies now need to be complemented with adaptation strategies.

The New South Wales Government has accepted international scientific opinion that increased concentrations of greenhouse gases in the atmosphere are causing changes in our climate.

In short, climate change is occurring and needs to be considered in the preparation and implementation of floodplain risk management plans. Warmer global temperatures (Figure 1a) cause expansion of ocean waters and the melting of icecaps resulting in accelerating sea level rise as evidenced in Figure 1b. Global sea level rise is now estimated at 3 mm per year over the last ten years compared with 1 mm per yr over the preceding forty years. The rate of rise is expected to increase. In addition, general climate change predictions for south eastern Australia indicate an expectation of reducing annual rainfalls in many areas, but with the potential to result in increased storminess (ie less annual rainfall but more significant storm events) and associated higher rainfall intensities. The frequency of extreme events is also expected to increase.

Recent modelling by CSIRO of annual extreme events (Abbs et al Ref 5) highlights the potential for climate change to have significant implications for flooding due to an increase in occurrence of flood producing weather systems with associated increase in frequency of flood events for coastal areas of NSW. This work also predicts an increase in the confluence of extreme wind and rainfall events, with associated potential impacts on the level of wave activity (and ocean levels) during flood events with expected changes in ocean storm surge and run-up levels. This is in addition to changes in mean sea levels.

<table>
<tr><th>Figure 1a - Global Temperatures
1860 to 2000</th><th>Figure 1b - Global Average Sea Level
Rise - 1993 to Present</th></tr>
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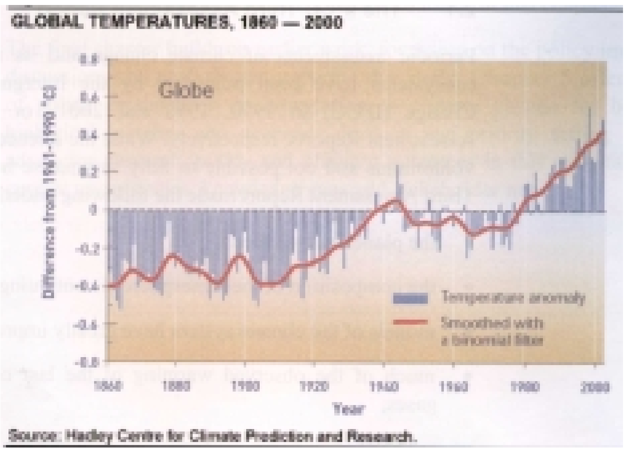

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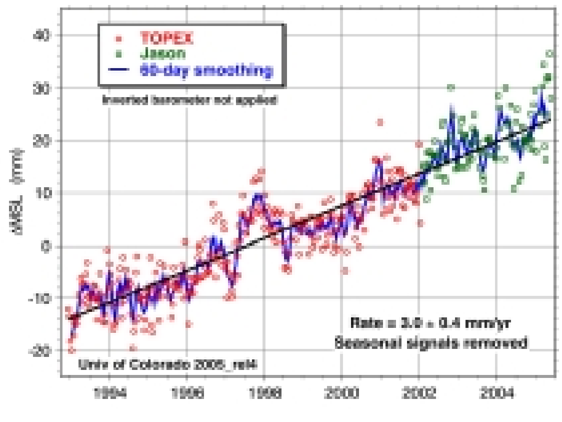

(source Leuliette et al (Ref 4))

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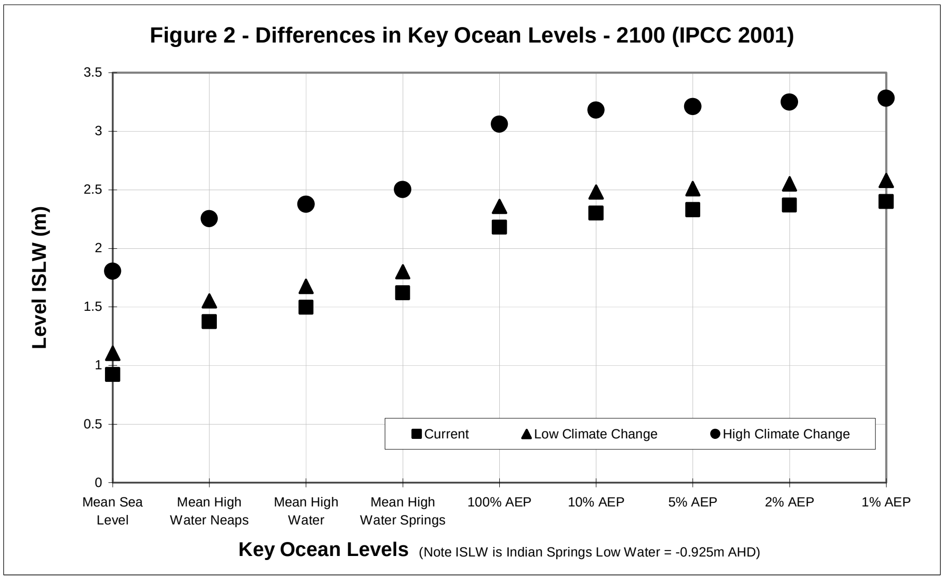
Figure 2 indicates the difference in key ocean levels for various climate change scenarios to 2100 (after Lord & Nalty, Ref 6). Significantly, this graph simply demonstrates that should the IPCC, (Ref 3) high climate change scenario occur by 2100 then current mean high water springs will be below mean sea level; and current 1% AEP ocean level will be equivalent to mean high water springs. This would mean that the current 1% AEP ocean level would be exceeded on most monthly tide cycles. Even with the low climate change scenario by 2100 the current 1% AEP ocean level will be below the 10% AEP ocean level.



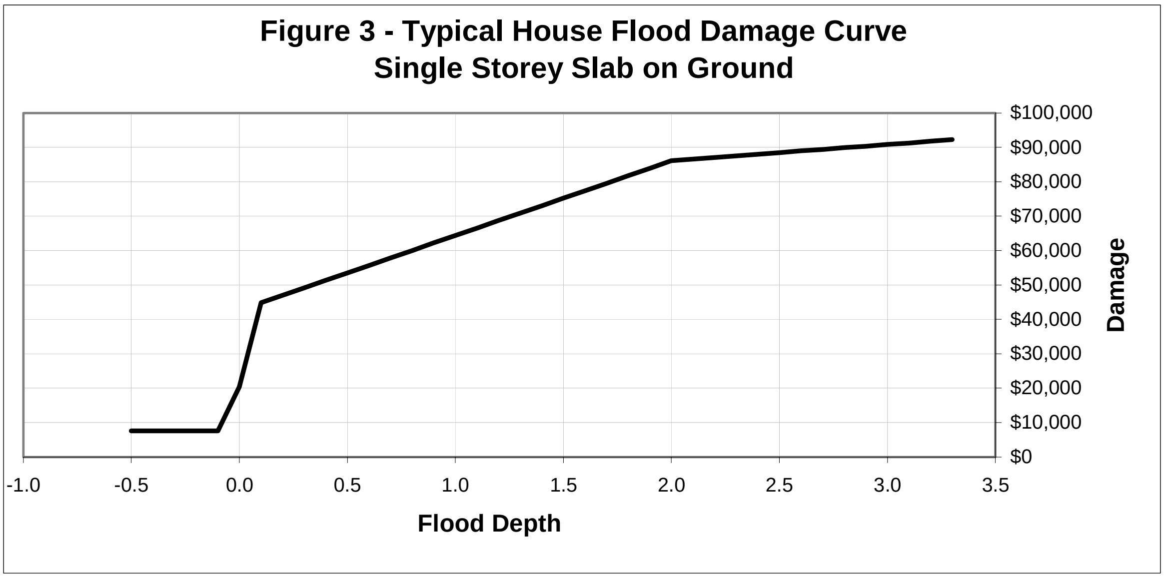
The potential changes in annual extreme rainfall intensities on the eastern seaboard due to increased concentrations of greenhouse gases in the atmosphere is the basis of ongoing work by CSIRO (Ref 5). Preliminary results from this work generally show a trend for maintaining existing rainfall intensities to 2030 with increased rainfall intensities across the NSW coast by 2070 across the full range of ARIs assessed. However, interpreting the graphs of changing ARIs in this preliminary work indicates that the differences between figures for the current and 2030 and 2070 climate scenarios increases as the ARI of the event increases. Therefore, the impacts of climate change on rarer events, of more interest in flood risk management, appears to be greater than in more frequent events and could be well in excess of 10% by 2030 and 20% by 2070. Therefore increasing rainfall intensities in higher ARI events is a real possibility for NSW even with a reduction in average annual precipitation.

2. Impacts on Flood Behaviour and the Associated Ramifications

Likely impacts of our changing climate on flood behaviour include:

- higher mean sea levels resulting in an increased area of tidal influence;
- storm surge and wave run-up may be higher;
- an increased number of flood producing rain events is likely;
- an increased potential for the confluence of rain and wind events with associated ocean effects;
- increased rainfall for the same AEP flood events. This may mean the same flood levels are reached more regularly, ie, the design levels for levees and the flood level against which protection of new development is designed may be reached more regularly. This will result in increased frequency of exposure of people to perilous situations and an increased frequency of damage. For example, with a 20% increase in rainfall intensity, the current estimated 1% AEP (1 in 100 yr ARI) flood level may be reached once every 20 years, ie, the same flood level will be reached 5 times as often; and
- floods of the same AEP will be higher and, therefore, result in increased flood damage and exposure of people to more danger for that design condition.

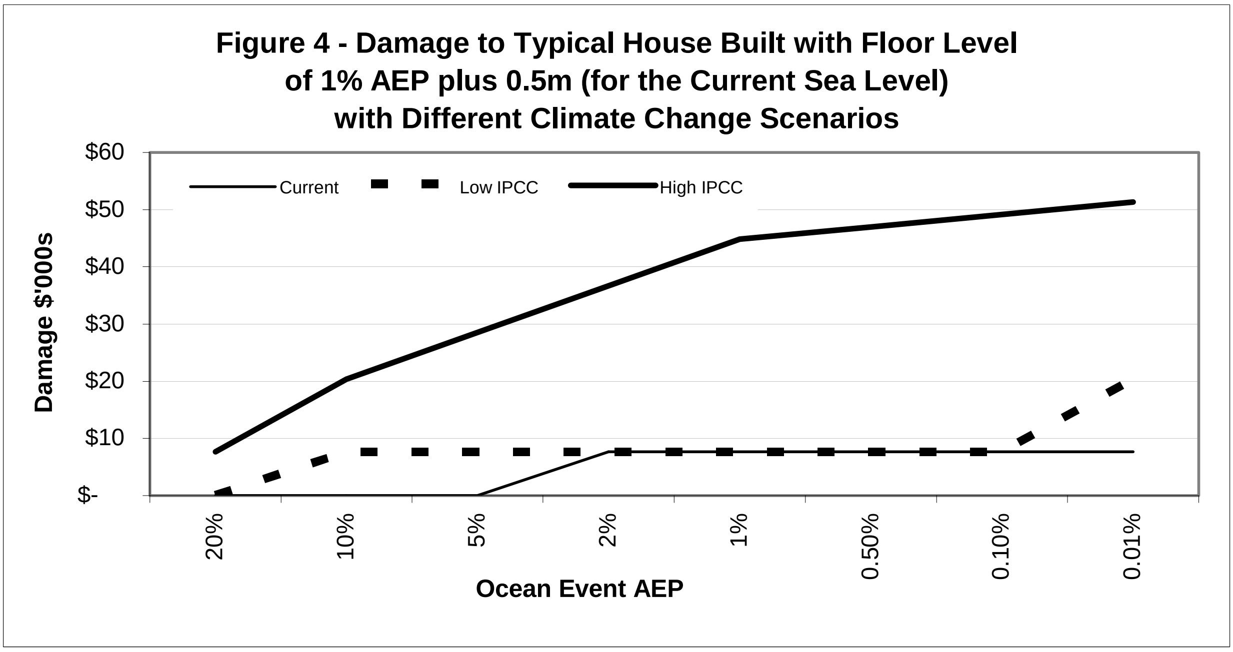
Assessing the scale of potential impacts of these changes on flood exposure is essential to inform decision making on management options for both existing and future development. Both flood damages and danger to people need to be considered. Figure 3 shows a curve of damages versus above floor inundation depth for a typical house (derived through Ref 7). This has been used to consider the potential impacts of climate change on flood damages.



2.1 Areas Where Flooding is Driven Solely by Ocean Levels

In areas where flooding is driven by ocean levels the impacts of climate change can be directly related to both the increase in frequency of flood events and the increase in scale of damages for particular events.

Figure 4 provides an example of the difference in damages for a typical house with a floor level built at the current 1% AEP flood level plus 0.5m freeboard (a typical minimum floor level requirement for new development in New South Wales) for different AEP events and incorporating sea level rise for different climate change scenarios. Note that this figure and subsequent calculations ignore any increase in rainfall intensities and associated ramifications and are therefore likely to be non-conservative. All figures are in present day dollars.



This figure highlights that flood damages increase markedly as both the frequency of damages and the damages for the same event frequency increase with ocean level rise. This results in changes to modelled annual average damage (AAD) from flooding from the current situation of $270 to $1,150 and $4,480 for low and high scenario IPCC projections at 2100 respectively.

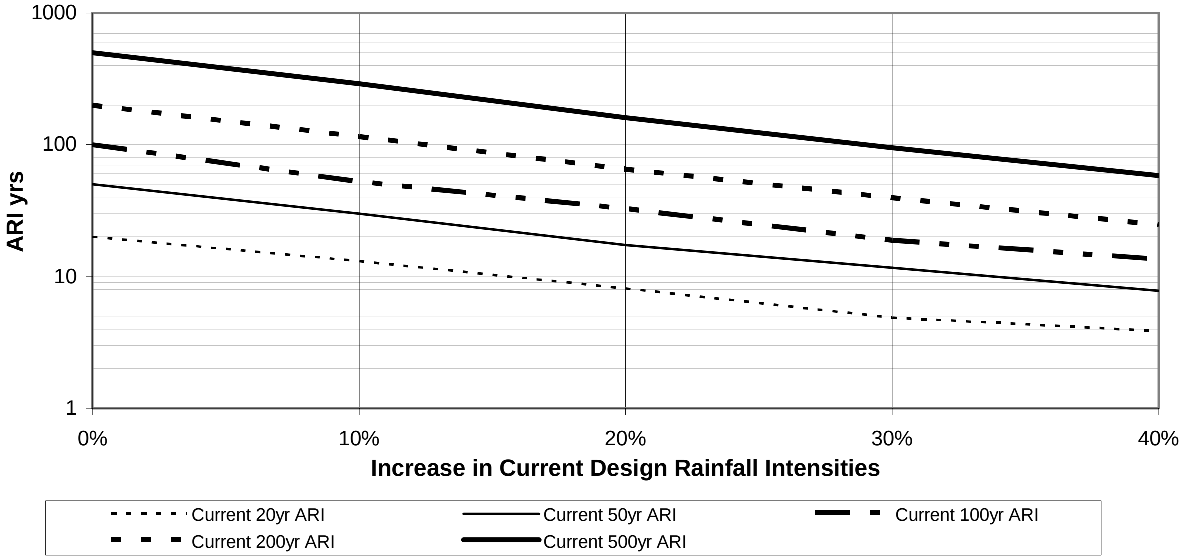
Therefore, on the basis of sea level rise alone (ignoring growth in the extent of flooding, the number of affected houses and changes in rainfall intensity), the AAD from flooding in coastal areas for a house built with protection from the current 1% AEP ocean level could more than quadruple for the low IPCC scenario and increase more than 16 fold for the high IPCC scenario over today's estimated damages.

2.2 Areas Where Flooding is Driven by Rainfall/Runoff rather than Ocean Levels

Away from areas where flooding is driven by ocean levels, climate change will relate more to the impact of rainfall intensity increases and the associated impacts upon flood levels and may alter future inundation extents and risk exposure.

Indicative impacts of increasing rainfall intensities by between 10 to 40% are provided in Figure 5. These impacts are assessed considering that all other catchment factors (including antecedent moisture conditions) are constant between current and future scenarios. This figure shows that current design events would happen more frequently as rainfall intensities increase. For instance, the current 100 year event could occur every 50 years as a result of an increase in rainfall intensity of just over 10%. The same event could occur every 20 years with a 30% increase in rainfall intensity. This may result in more regular damaging flood events with resultant increase in the frequency the community is exposed to the associated hazards and damages. Economic and social impacts could be potentially devastating.

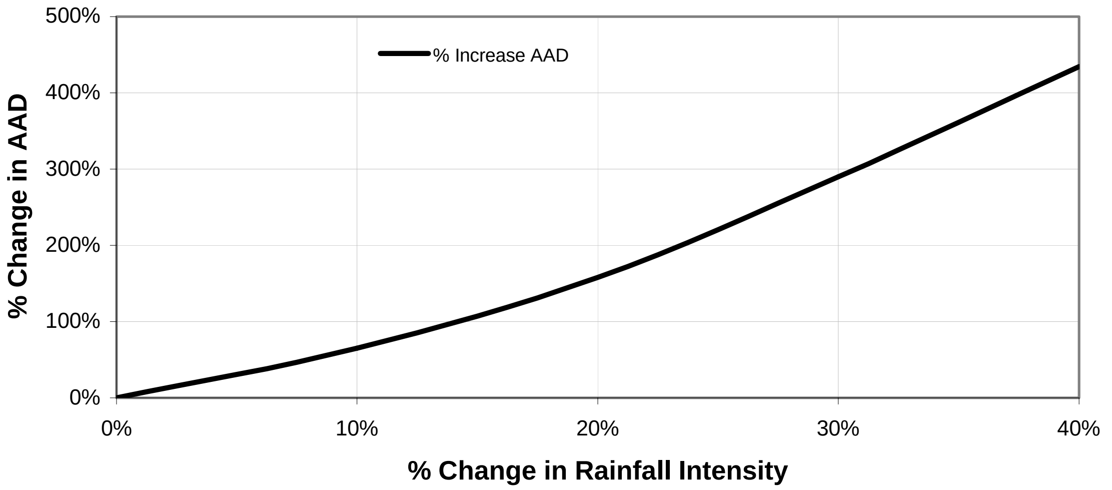
Figure 5 - Indicative Change in Current Design Event ARI as Rainfall Intensities Increase



The effects of increased rainfall on runoff and associated flood levels and damage are very dependent upon the conveyance/configuration of the individual floodplain, and exposure of development to hazard. Considering these changes on a floodplain, significant increases in flood related AADs would be expected as rainfall intensities increase (see Figure 6).

It is understood (*pers. comm. Brian Taylor*) that the Bureau of Meteorology is to undertake work on the impact of climate change on probable maximum precipitation in conjunction with the Queensland Government.

Figure 6 - % Increase in AAD over Current Damages due to Increased Frequency of Key Rainfall Events for a Specific Location



2.3 All Areas

Given the scale of these impacts, their persistence and associated ramifications, it is difficult to justify ignoring them in making informed floodplain risk management decisions. Future decisions should be both robust and adaptable in order to address likely future impacts.

3. NSW Government Floodplain Risk Management Policy

The NSW Government's preferred strategy for managing flood hazards as outlined in the Government's Flood Prone Land Policy and the Floodplain Development Manual (2005) (Ref 8) is through the preparation and implementation of floodplain risk management plans with a strategic focus, prepared through the floodplain risk management process (Ref 9).

The policy assigns responsibility for implementing the strategy to Local Government, with the State Government providing technical and financial assistance through the Department of Natural Resources.

The preparation of management plans requires detailed consideration of flood behaviour and the extent of hazard over varying timeframes and ranges of events to enable effective management of the risk to both people and infrastructure (public and private). There are over 100 management plans completed and adopted in NSW. Some plans are in draft form and with background studies and investigations leading to informed management plans now being undertaken in many areas across NSW.

A key issue for these management plans is, therefore, the potential influences of any change in the catchment (level or density of development or stream condition) and change in climate on flood behaviour and the associated impacts upon people and property within the floodplain. These issues need to be considered in the preparation of management plans as without consideration of change and the development of associated management strategies, floodplains cannot be managed strategically in accordance with the Floodplain Development Manual.

4. Consideration of the Impacts of Climate Change on Decision Making

The Manual indicates the need for climate change to be considered in both the flood study and the management study to determine both the potential impacts on flood behaviour and to enable robust and informed decisions on appropriate adaptive strategies for managing flood risk into the future.

This concept (as shown in Figure 7) fits well within the concept put forward by the Allen Consulting Group (Ref 2) based upon earlier work.

Figure 7 – Managing Climate Change Impacts (Adapted from Allen Consulting Group (2005) Ref 2)

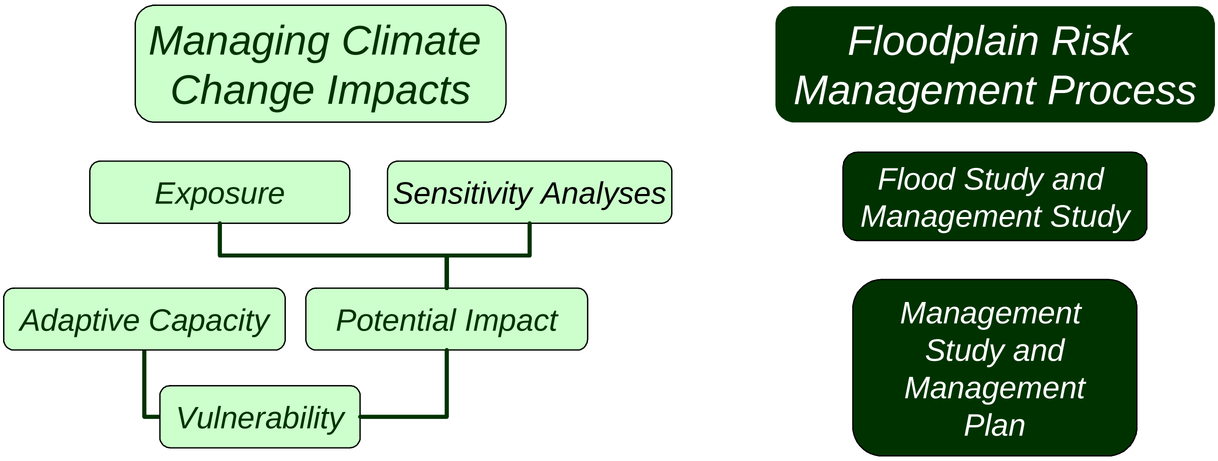


Figure 7 highlights the need to:

- understand the exposure of the community to flood hazard. This is the purpose of the flood study;
- understand the sensitivity of flood behaviour at the specific location to climate change to identify the significance of impacts. The sensitivity analyses undertaken should consider the science available at the time and the precautionary principle. As such, at this stage it is recommended that analyses be undertaken to assess the sensitivities of flood behaviour to the following scenarios:
  - sea level rises considering the range of rise anticipated by the IPCC by 2100. Consideration of rises of 0.18, 0.53 and 0.88m is recommended;
  - rainfall intensities. Consideration of changes in rainfall intensity of between 10% and 40% are recommended to provide an understanding of the sensitivity of the floodplain to these changes; and
  - envelopes of combined sea level rise and rainfall intensity changes identified above to understand the combined impacts, where applicable.
- understand the potential impacts of climate change on flood behaviour and associated ramifications for people, property and infrastructure as part of the management study to inform decision making of the associated ramifications;
- examine options to manage the impacts of climate change. This may involve additional assessment of options as part of management studies, and re-examination of existing management strategies in review of management plans. This may require consideration

of the potential need for new or revised strategies to manage increases in risk in an adaptive way as clarity improves on the scale of likely change; and

- consider different strategies for dealing with impacts in developed areas compared to planned land releases. This would be undertaken as part of management studies and management plan review.

The remainder of this paper will consider the adaptive capacity of current strategies and put forward some concepts of how adaptive capacity could be further built into future floodplain risk management decision making for both existing and future development.

5. Adaptive Capacity of Existing Flood Risk Management Decisions

The Floodplain Development Manual requires consideration of the full range of flood risk as part of the floodplain risk management process. This provides a good basis for informed decision making as it enables the identification of changes in behaviour of floods of different magnitude.

The management process, if followed strategically, leads to management decisions for both existing and future development, as discussed below. The process is sufficiently robust and flexible to allow for consideration of the impacts of climate change.

5.1 Future Development

Future development, by its nature, should be easier to manage when accommodating the potential impacts of climate change. A number of important steps to consider in managing flood risk to future development are outlined below.

F1. Identify areas where development should be avoided or at least severely limited. These include:

- areas where development may have a significant impact upon flood behaviour in other areas, generally defined by floodways and major flood storage areas;
- areas where development may have a significant impact upon emergency response in other areas;
- areas where the location itself will have significant emergency response difficulties that need to be managed if safe occupation is to occur;
- areas that need to be set aside to offset the impacts of urbanisation on flood behaviour, for example, land for detention basins; and
- areas where the continuing hazard from flooding, even allowing for the implementation of development conditions, is excessive.

F2. Identify suitable development opportunities. These could include land outside the areas identified above. That is, areas where the impacts of development on adjoining properties and impacts of flooding on the development and its occupants can be effectively managed.

F3. Identify types of development that may be appropriate in particular areas earmarked for development. For example, some forms of industrial, commercial or agricultural development may be suitable in an area where residential development is not appropriate due to likely flooding impacts and available management options.

F4. Determine appropriate conditions to reduce hazard exposure and impacts to acceptable levels in areas earmarked for future development.

F5. Where necessary, identify works (particularly detention basins) to offset the impacts of development for a current design event (1% AEP).

Points F1 to F3 aim to limit inappropriate development in the most hazardous areas of the floodplain. This will generally allow for robust management of flood risk as it considers both the 1% AEP event for damage issues and the probable maximum flood (PMF) for emergency response issues. However, in areas where new floodways form during events slightly larger than the design event, additional care needs to be taken in development decisions. It also needs to be acknowledged that the frequency of emergency response operations would increase with increased flood frequency.

Point F4 relates to the decision to apply conditions to provide a certain level of protection (1% AEP) to reduce flood frequency and therefore manage flood damages. In practice this means the derivation of flood planning levels (FPLs) in accordance with the Manual. FPLs include a freeboard which, in effect, acts as a factor of safety which should never be relied on to manage risk in events larger than the flood used to derive the FPL. The Manual indicates that freeboard should allow for the following:

- uncertainties in the estimates of flood levels. These can arise from a relatively short database of past floods and past storm surges in coastal waters, together with uncertainties and simplifications in the models used to predict flood discharges and flood levels. This does not include uncertainty for climate change.
- differences in water levels across the floodplain because of 'local factors'. These factors are not able to be determined in floodplain modelling, which assumes a static water level;
- increases in water level as a result of wave action are also not determined in floodplain modelling. Wave action can be of two types. Wind-induced waves across fetches of open water and waves induced by boats and vehicles moving through flooded areas. For example, wave action may be significant in the wide floodplains of the western rivers as a wind fetch 2 kilometres long could readily generate waves up to 0.5m high;
- an allowance for changes in rainfall patterns and ocean water levels as a result of climate change. A typical freeboard of 0.5m would generally include little allowance for the impacts of climate change; and
- the cumulative effect of subsequent infill development of existing zoned land.

Therefore, FPLs may have an allowance for climate change. If however, no allowance or inadequate allowance is made in freeboard for climate change the level of protection provided by the FPL will diminish with time as frequency of exposure to flood hazard and flood damages increases with climate change.

Whilst FPLs can be revised as improved information on the degree of change is available (ie) they can be adapted, this does not assist in managing the flood risk for development that will occur between now and when better information is available. Give the scale of potential change in exposure, it should not be considered appropriate to wait for definitive information on the impacts to occur before reacting. This could hardly be considered a strategic response to climate change. This view is consistent with the precautionary principle, where a lack of certainty about the likely extent of climate change impacts is not a reason to fail to address the issue at all.

Point F5, relating to mitigation works such as detention basins, is governed by a particular design event. These works are less effective, and may be ineffective, for larger scale flood events. If the original design event becomes more frequent under climate change, their capacity and capabilities will be exceeded more frequently.

5.2 Existing Development

There are numerous options for managing flood risk to existing development. However, it should be acknowledged that managing the flood risk from climate change for existing development presents significantly more challenges than instigating appropriate management for future development. Some key considerations in relation to options for managing flood risk to existing development are discussed below:

E1. Levees are designed to exclude flooding for a particular design event. Freeboard is built into the levee design level to account for uncertainty. Freeboards for levees need to include the factors outlined in Section 5.1. Earthen levees also need to consider of the following issues:

- post construction settlement that can occur. This effectively reduces the long term crest level of the levee;
- surface erosion due to vehicle, animal or pedestrian crossing can reduce the level of the levee crest;
- there is significant potential for surface shrinkage cracking and associated additional risk of failure where good grass cover and an appropriate moisture content cannot be maintained in earthen levees;
- the performance of earthen levees when they overtop is characterised by relatively quick vertical erosion resulting in an embankment breach. This can allow more water in quickly which can result in relatively fast rising flooding and difficult evacuation; and
- levees can be designed to include an allowance for climate change.

E2. Voluntary purchase removes development and occupants from particularly hazardous parts of the floodplain which cannot be effectively protected by other means. This solution can be adaptive as areas of voluntary purchase can increase as necessary. However, extension of voluntary purchase could have enormous cost and social implications.

E3. Voluntary house raising (VHR) involves the raising of house floor levels to a level derived from a particular design level (generally the 1% AEP flood level) plus a freeboard. This solution is only adaptive where VHR decisions and raised floor levels consider the impacts of climate change. This has associated cost implications. A further consideration is that VHR can result in evacuation problems, as people tend to not want to evacuate until their floors are overtopped. Therefore, more regular and deeper over ground flooding (that may result from climate change) may lead to increased exposure of residents to flood hazard in evacuating raised premises.

E4. Flow capacity increase options are generally not adaptive as they provide a set additional capacity for a particular design solution.

E5. Flood warning and emergency management generally target the larger scale flood events (ie) extreme or probable maximum floods and therefore cover the full range of potential flooding. These strategies, by their nature need to be robust to cater for widely varying flood behaviour. A key issue in emergency response planning is the timing of events (available warning time, time for cutting evacuation routes etc). Additional requirements for management studies (Ref 11) have been developed by DNR in consultation with the State Emergency Service to improve knowledge in this area to provide for more robust emergency response planning.

5.3 Overall

Management decisions and strategies that relate to the full range of flood risk, ie consider the upper limit of flood behaviour and its impacts, generally relate to emergency response or management. Emergency management planning by its nature has to account for natural variation between events and, therefore, strategies tend to be flexible and robust. Emergency management planning can therefore be considered adaptive with climate change if managed with knowledge of the altered range of risks and associated community flood awareness and readiness.

However, decisions that relate to a specific AEP event, where the recurrence interval of this event may change due to climate change, do not necessarily have adaptive capacity unless this is specifically built in.

6. Improving Adaptive Capacity of Flood Risk Management Decisions

Improving the adaptive capacity of flood risk management decision making needs to concentrate on decisions that relate to specific AEP events rather than the full range of events. These decisions generally relate to protection of existing and future development for a particular frequency of flood event. There are a number of ways in which additional adaptive capacity can be built into these decisions.

- Considering the potential for new floodways to form under various climate change scenarios. These new floodways may not exist in the design floods currently used for management decisions. Completing this task may identify areas which need to be set aside for this function or developed with the knowledge that they may perform this function in the future, and are therefore compatible with this function. This may have an impact on appropriate future land uses in limited circumstances.
- Considering the potential for significant changes in flood hazard in particular areas. Where areas are particularly sensitive to climate change, consideration could be given to directing future development types to those areas more compatible with the changing hazard. The result would be the steering of more vulnerable developments to less exposed areas.
- Considering the potential for changes in flood behaviour or hazard to impact upon the type of management option appropriate for a particular location. Considering the implications of climate change on flood behaviour when considering management options should ensure that the types of management options selected are robust enough to manage associated changes.
- Allowing an additional freeboard in FPLs (specifically for climate change) when setting fill levels and floor level controls for new development or for the construction of works, such as levees. Examination of the potential climate change implications (sensitivity analysis) for a specific location would enable assessment of an additional freeboard to allow for climate change impacts.
- Building flexibility into decision making to enable future works to allow for climate change. For new development this could involve setting aside land as part of new release areas to incorporate potential flood protection for future climate change. For a works project this may mean building flexibility into the design to enable upgrading in future. This could involve setting additional land aside for the raising of an earthen levee now or designing a concrete levee so that it can readily be raised in the future.

Decisions on the management options to consider will depend upon the practicality and feasibility (including financial) now and in the future at the particular location. However, it is important to remember the potential costs, both economic and social, of not considering climate change, as outlined in Section 2 of this paper.

7. Impacts on Management Plan Development, Review and Implementation

The floodplain risk management process culminates in the development and implementation of a floodplain risk management plan for a particular area. These plans provide the basis for managing flood risk to the existing and future community and the associated decision making.

This paper indicates the significant nature of potential impacts of climate change on flood damages and the resultant potential for exposure of the community to increased flood hazard. It highlights the need to consider climate change to ensure that management decisions are robust and appropriate in the long term. It is therefore essential that climate change be considered in the preparation and implementation of management plans and in associated decision making as outlined below.

7.1 Review of Completed Studies, Plans, Works and Existing Development Controls

Management plans outline the direction taken in managing flood risk in a particular area. Section 2.7 of the Floodplain Development Manual highlights the triggers for the review of management plans. These triggers include time (review regularly around every 5 years), after significant flood events, where significant changes occur that influence the decisions in plans, where impediments to implementation warrant review to examine ways to overcome these impediments, and where changes to future land use outside trends considered in the management plan are proposed.

Climate change ramifications for existing studies and plans should be examined as part of any review of management plans. Therefore the ramifications of climate change should be considered in all existing plans across NSW as they are reviewed. This would generally be expected to occur within the next 5 years.

The inclusion of climate change involves revisiting existing decisions for managing flood hazard to both existing and future development. It is likely to require remodelling of flood behaviour and management options where relevant sensitivity analyses have not been completed. This involves:

- an assessment of the performance of existing and proposed management works. This should include an examination of the potential performance of works under the range of climate change scenarios. Where the ramifications are significant this may involve:
  - examining the potential to improve or upgrade existing works;
  - examining the appropriateness of current management strategies; and
  - changing the design of proposed works.

  This would involve both flood and damages modelling and an assessment of the potential costs implications for management options;
- an assessment of the current development limit and controls from a strategic perspective. The review should extend to examine the ability of these controls to manage the implications of climate change. Options to alter controls to allow for any significant impacts of climate change which become apparent in the medium to long term should be examined; and
- updating the management plan to outline the potential impacts of climate change and how these have been considered in decision making.

7.2 Current and Proposed Management Plans and Background Studies

Current and proposed flood investigations need to consider climate change by:

- incorporating appropriate sensitivity analyses (as discussed in Section 4) into modelling of flood behaviour, damages and management options. Modelling would generally include some sensitivity analyses, however additional runs and associated interpretation may be required;
- considering the specific ramifications of changes in flood behaviour on existing and future development (people, property and infrastructure); and
- examining options to manage these ramifications, including associated benefits and costs.

This assessment will provide advice to decision makers on the management options available and the ramifications of both adopting and not adopting these options. The management plan needs to outline the potential impacts of climate change and how these have been considered in decision making.

7.3 Proposed Works Projects

Where work projects are proposed or under investigation and sensitivity to climate change has not been assessed during the preparation of the management plan, it is recommended that climate change be considered as part of preliminary design. The results of these investigations and the reasons for associated decisions should be fully documented for inclusion in the management plan, when next reviewed.

Dependent on the ramifications of climate change for the specific location and project, it may be necessary to consider:

- ensuring that the type of management options selected are robust enough to manage the ramifications of climate change; and
- accepting the level of protection provided and proceeding on the basis that protection will reduce in the future; or
- modifying the design to build in an allowance for climate change now, where the modification can cost effectively be built into the proposed project; or
- incorporating the ability to readily modify the work in the future to manage climate change implications. For example land could be set aside so that earthen levees could practically be raised in future, and concrete levees could be designed to be raised in the future.

7.4 Strategic Planning

Where strategic planning is being undertaken and sensitivity to climate change has not been assessed during the preparation of the management plan, it is recommended that climate change is considered to ensure that decisions on future land use consider the ramifications of climate change. The results of these investigations and the reasons for associated decisions should be fully documented for inclusion in the management plan, when next reviewed.

Depending upon the ramifications of climate change for the specific location it may be necessary to consider:

- that the impacts of climate change on flood behaviour or hazard may impact upon the decision to develop a particular area and the type of development appropriate for a particular location. Considering the implications of climate change on flood behaviour should ensure that development limits and controls are robust enough to consider potential climate change ramifications; and

- accepting the level of protection provided and proceed on the basis that protection will reduce in the future; or
- providing a level of protection based upon an agreed climate change scenario (this may provide a higher standard of protection at present) where the opportunity costs are relatively low; or
- incorporating the ability to readily provide protection to the development to manage future climate change implications. For example, land could be set aside as part of subdivisions so that earthen levees could be built in the future. Careful consideration needs to be given to the associated emergency response and cost implications.

8. Conclusions

Consideration of climate change based upon the best available information is a fundamental part of informed flood risk management decision making now and into the future. It therefore needs to be incorporated into:

- new management plans as they are developed;
- existing management plans as they are reviewed;
- strategic floodplain risk management decisions in relation to development; and
- decisions on mitigation works as they are made or designs as they are produced.

Improvements in the adaptive capacity of floodplain risk management decisions for climate change (section 6) are necessary in line with the policy direction of the Australian Greenhouse Office and NSW Government. This adaptive capacity should reflect the very real risk that climate change presents. The floodplain risk management process is sufficiently robust and flexible to allow consideration provides an appropriate process for considering climate change by enabling:

- assessment of the potential climate change implications for the specific locations and associated ramifications for exposure to hazard and flood damages. This can be achieved through sensitivity analyses as outlined in Section 4;
- assessment of the ramifications of these changes on decisions on management measures and siting of development. In some cases a management measure or development type that may be appropriate with current hazards and exposure may not be effective or appropriate with changed conditions. This may lead to the need to revise management options; and
- examination of the ability of management measures and development decisions to enable (now or in the future) additional protection to be provided for climate change implications in the future. This may involve asking questions such as: Should freeboards be increased? Can allowance be made to put protection works in place in future? Can allowance be made to upgrade proposed or existing works in future?

Our knowledge of the extent of climate change and the associated ramifications is improving. However, we cannot afford to wait for finite work on climate change to be finished nor significant climate change to occur before we decide to manage the impacts.

Importantly, we cannot ignore climate change and the potential significant impacts which may occur at particular locations with the associated large increases in potential flood damages and risk to life. Appropriate mitigation measures and sound planning, adopted now at minimal cost, will provide enormous benefits for future generations.

As such the Department of Natural Resources is preparing a Technical Guideline to address the consideration of climate change through the floodplain risk management process.

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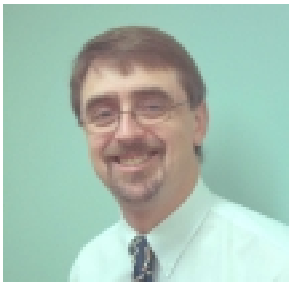
Presenters Biography



Duncan is a Flood Specialist in the Flood Unit of the NSW Department of Natural Resources. He holds a degree in Civil Engineering, Masters in Engineering (Water/Environmental) and Postgraduate Management Diploma. Duncan has extensive experience in hydrology, hydraulics and water resources, having worked in the area since the 1980's.

He has a particular interest in floodplain risk management and has completed a wide range of studies into flood risk in both mainstream and major urban drainage areas as a consultant and with Coffs Harbour City Council as Flooding and Drainage Engineer, where he also developed Council's floodplain management policy. Duncan is one of the main authors of the NSW Government's *Floodplain Development Manual* and is currently working on a range of flood policy issues at both a State and National level.

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IMPACTS ON ANNUAL AVERAGE DAMAGE –

CLIMATE CHANGE AND CONSISTENCY

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Presenter's Profile

Rhys is a first class honours graduate from the University of New South Wales. He has worked with Cardno Lawson Treloar for three years. Last year he completed a Masters of Commerce in Environmental Economics (UNSW).

Rhys' skills extend across hydrology, hydraulics and water quality as well as environmental economics. He has been involved in a number of projects, including recently the Brisbane Water Estuary Processes Study (Water Quality Modelling with MUSIC), Shell Cove Boat Harbour Flood Impact Analysis (hydrological and 1D/ 2D modelling), Stony Creek Flood Study (RAFTS hydrological modelling and 1D/2D hydraulic modelling), Mona Vale – Bayview Floodplain Risk Management Study & Plan (economic damage assessment) and the Fairy Towradgi & Hewitts Creek Estuary Management Study & Plan (hydraulic modelling and environmental economic analysis). Rhys also has undertaken studies on the impacts of rainwater tanks on flood conditions and last year presented a paper at last year's conference on this topic.

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Habib is a Senior Engineer in the Water Resources section of Cardno Lawson Treloar and has over ten years experience in the field of water resources. Habib graduated with honours in Civil Engineering from University of Engineering and Technology Lahore, Pakistan in 1989 and completed a Master of Science in Civil/Environmental Engineering from Iowa State University, USA in 1993. During his ten years in water resources engineering, Habib has developed expertise in hydraulic investigation, hydrologic assessment, flood estimation and floodplain management, which have involved urban, riverine and estuarine environments. Urban modelling projects have included a wide variety of flood studies, which have required detailed investigation and design of culverts, bridges and other hydraulic structures for flood management. His expertise also includes groundwater modelling and total catchment management studies.

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IMPACTS ON ANNUAL AVERAGE DAMAGE –

CLIMATE CHANGE AND CONSISTENCY

Rhys Thomson, Habib Rehman and Greg Jones

Abstract

The economic impact of flooding in a catchment is determined through the estimation of flood damages. The economic indicator used for this purpose is Annual Average Damage (AAD), which has many underlying assumptions. Since AAD plays an important role in funding allocation for a particular catchment, it is important that the set of assumptions underlying the Annual Average Damage are applied consistently across various catchments.

This paper discusses the concept of AAD, its derivation, the underlying assumptions and the impact of those assumptions on AAD estimation. This is demonstrated in a case study undertaken for the Stony Creek Catchment near Toronto in NSW. The paper reviews the need for consistent approaches in the calculation of AAD, including a discussion on the adoption of uniform 'damage curves' used in AAD estimation. Lastly, the long term impacts on AAD estimation are discussed, including the effects of climate change.

Key Words: Annual Average Damage, AAD, Damage Curves, Climate Change, Stony Creek

Introduction

The economic impact of flooding in a catchment is estimated through Annual Average Damage (AAD), which plays an important role in evaluating floodplain management options in the overall floodplain management process.

Inaccurate estimations of the AAD can lead to floodplain management options having vastly different cost benefit ratios. This can lead to an inappropriate selection or rejection of floodplain management options based purely on the method of AAD calculation.

AAD plays a significant role in the prioritisation of catchments by State and the Councils for funding allocation. However, differences in methodologies in estimating AAD makes it a misleading factor for this purpose.

Annual Average Damage

AAD is calculated using a probability approach. Flood damages are determined for each design event, and a probability approach is adopted in order to determine the flood damage that a catchment would incur on average in a year.

There are a number of factors that affect accuracy and consistency of the AAD calculations. Ignoring assumptions within the flood modelling itself, these factors include the choice of design storms, methodology used for AAD estimation and the flood damage curves.

AAD also has the potential to be significantly affected by time. Further development in the catchment, changes in societal wealth and climate change can all lead to changes to the AAD.

The Stony Creek Catchment

Stony Creek Catchment is part of the larger Lake Macquarie Catchment and is located approximately 120km north of Sydney near Toronto. The total catchment area is approximately 46km^2. It is affected by flooding from both Lake Macquarie and the local catchment. The catchment land-use consists of a mixture of residential, industrial and commercial properties, the majority being in the lower catchment.

A recent flood study (Cardno Lawson Treloar, 2005) analysed design events of 200 year, 100 year, 50 year, 20 year, 10 year and 5 year ARI together with the PMF event. A flood damages assessment was also undertaken as part of this study. The results of this study will be used for discussion in this paper.

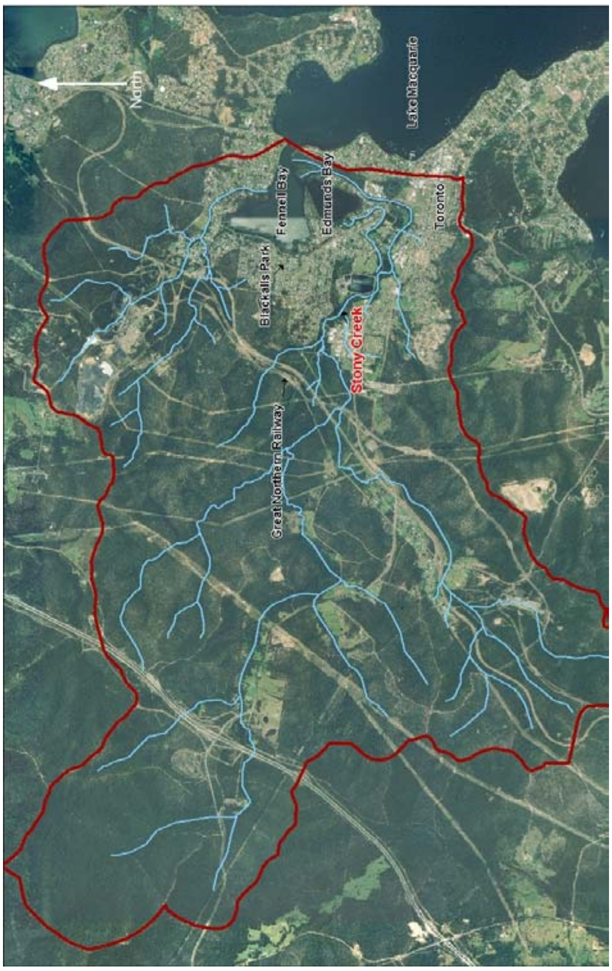

Figure 1. Stony Creek Catchment.

AAD Calculations

AAD is calculated on a probability approach, using flood damages calculated for each design event.

Flood damages (for a design event) are calculated by using 'damage curves'. These damage curves attempt to define the damage experienced on a property for varying depths of flooding. The total damage for a design event is determined by adding all the individual property damages for that event.

AAD attempts to quantify the flood damage that a floodplain would receive on average during a single year. It does this using a probability approach.

A probability curve is drawn, based on the flood damages calculated for each design event (see Figure 2). AAD is then calculated by determining the area under this curve.

Further information on the calculation of AAD is provided in Appendix M of the Floodplain Development Manual (DIPNR, 2005).

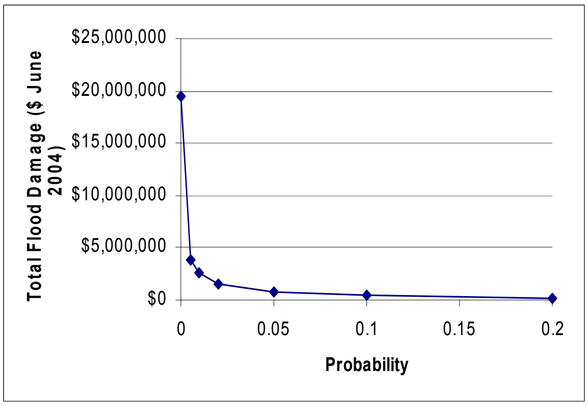

Figure 2. AAD Curve for Stony Creek.

Design Storm Choice

The design storms to be used for floodplain assessment are generally defined by Council at the Flood Study stage of the Floodplain Management process.

There are no strict guidelines in the Floodplain Development Manual on the design storms to be used, however, the choice of design storms can impact on the calculation of the AAD.

The choice of different set of storms would result in different AAD as the area under the AAD curve would be different for different sets of storms. In general, the less design storms that are chosen, the more likely the AAD value will overestimate the "true" value.

In order to see the significance of this deviation of AAD from the "true" value, data from the Stony Creek Flood Study was analysed. Testing was undertaken by comparing different scenarios to the base flood study results. Each scenario uses less design storm events to calculate the AAD. The results of this analysis are shown in Table 1.

Table 1. Impact of Design Storm Choice on AAD.

Scenario	AAD (June 2004 $)	Percent Difference to Base
Base Scenario (5yr, 10yr, 20yr, 50yr, 100yr, 200yr & PMF)	$248,821	-
5 year excluded	$355,751	43
10 year excluded	$261,186	5
50 year excluded	$260,772	5
200 year excluded	$285,396	15
5 year and 10 year excluded	$520,498	109
50 year and 20 year excluded	$298,656	20
50 year, 20 year and 10 year excluded	$396,679	59

Table 1 shows that the choice of design storm has the potential to significantly impact on the AAD value. The more design storms that are chosen, the more accurate the AAD value is likely to be. Particularly important are the design events at the extremes (the very frequent and the very infrequent design events).

Frequent Storms and AAD

There is very little guidance in the Floodplain Development Manual (DIPNR, 2005) as to how the high probability end of the AAD curve should be established (Figure 2). Two possible options are:

1. Assume that there are no damages for events with a greater frequency than those analysed. For the Stony Creek example, it would be assumed that no damages occur in events with a frequency greater than the 5 year ARI design storm.

2. Assume that the damage linearly increases from a probability of 1 through to the most frequently analysed storm. For Stony Creek, this would be to assume that the AAD curve linearly increases from zero damage for a 100% probability up to the 5 year ARI design storm damage.

The two options have been shown graphically in Figure 3.

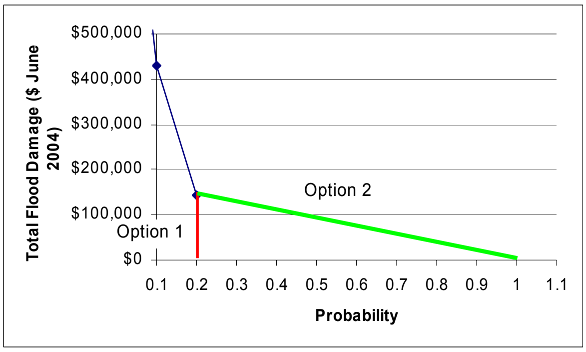

Figure 3. Options for Tail End of AAD Curve.

Both options have their limitations. The first option will result in less benefit when comparing flood mitigation options, particularly where those options impact on frequent design events. However, this method would probably only be suitable for studies where very frequent design events have been modelled.

The second option represents the more conservative approach and was used in the Stony Creek Flood Study. It assumes that damages occur up to the 1 in 1 year ARI design event.

Option 2 also assumes that no damage occurs in the floodplain for flood events with a greater frequency than the 1 in 1 year ARI design event. In some catchments (particularly urbanised catchments), flood damage may occur in events such as the 1 in 6 month event, which may have the potential to impact on the AAD value. This aspect should be considered in the selection of design storms for a particular catchment.

Flood damages calculated from the two options for the Stony Creek Catchment are provided in Table 2

Table 2. AAD Comparison of the Two Options

	AAD (June 2004 $)
Option 1	$191,348
Option 2	$248,821

Summary

It can be seen from the above worked example that the design storm choice can impact on the AAD for a given catchment. This is particularly important for the more frequent design events, with consideration of more frequent events resulting in a more “accurate” estimation of AAD.

Ignoring the more frequent design events can potentially result in a significant variation in the estimation of damages to a floodplain. This is particularly the case for option 2 described above.

Conservative estimates of AAD can exaggerate the economic viability of floodplain management options, while an underestimation of the AAD can have the reverse effect.

The results of this analysis indicate that design storms should be chosen such that they define both extremes of the curve. Ideally, an analysis should be conducted that incrementally models more frequent design storms until the damage is sufficiently close to zero. However, this may prove to the resource intensive.

Consistent Methodologies

AAD Calculation

As discussed above, the choice of design storm and methodology used in the calculation of the area under the AAD curve can lead to significant differences in the estimation of the AAD.

Standards are needed to ensure that similar methodologies are employed between floodplain management studies. These should ensure that the same design storms are used for studies.

The recommended standards are:

- Design storms used for flood studies should include a full range of design storms. The same design storms with lower frequency (e.g. 1 in 10 year to PMF) should be chosen for all flood studies. For more frequent design storms, flood studies should include the full range of design storms that result in damages in the catchment.

- If a full range of design flood estimation is not feasible for the more frequent storms, then a standard approach should be adopted for the calculation of the area under the high probability end of the AAD curve. It is recommended that the straight line, option 2 approach be adopted as standard without additional information. However, rather than using the 1 in 1 year design event, the design storm with no damages could be estimated after consideration of relevant catchment features, such as street drainage.

Damage Curves

The damage curves along with overfloor flooding data are used to calculate the damages and the consequent AAD. There are several damage curves in use, primarily for the three main categories of residential, commercial and industrial properties.

At the start of 2004, the then Department of Infrastructure, Planning and Natural Resources (DIPNR) (now the Department of Natural Resources (DNR)) published draft guidelines on the calculation of residential flood damages. These guidelines utilised the work undertaken by DNR and the Natural Hazards Research Centre at Macquarie University.

The guidelines are accompanied by a spreadsheet program that creates the damage curves based on input data from the user. These inputs allow the user to tailor the curves to the catchment analysed, and are broken into three main factors:

- Building Factors – such as duration of immersion, regional cost adjustments and average building size.

- Contents Factors – such as average contents value, flood awareness and effective warning time.

- Additional Factors – this includes post flood costs such as clean up and alternative accommodation/ loss of rent expenses.

The DNR draft residential damage curves provide damage data for slab on ground, high set and two storey houses.

These guidelines provided the first step in state wide application of uniform damage curves. However, this has not yet been extended to industrial or commercial properties.

These guidelines were utilised in the determination of residential flood damages for the Stony Creek Catchment. However, with no other guidelines available, best available information from FLDamage (Water Studies, 1992) and an industrial survey undertaken as a part of the Allans Creek Floodplain Management Study in 1998 (Cardno Lawson

Treloar, 2004) was used for the commercial and industrial properties.

Time Impacts on AAD

AAD figures are relevant for a relatively short time frame. As we move into the future, the AAD values of today will become less representative of the annual damage experienced by flooding in the future due to a number of factors, including:

- Development in the floodplain leading to an increase in the number of properties.
- A general increase in wealth
- Climate Change

Floodplain Risk Management Studies undertake cost benefit analyses by assuming that the AAD value remains constant through time. Depending upon the significance of these factors, the cost benefit analysis undertaken may not provide a true economic analysis.

Development within the Floodplain

Development within the floodplain leads to both an increase in the number of properties exposed to flooding, and can result in higher value properties placed at risk. An increase in the number of properties can be both a result of green field development or an increase in the density of the existing developed area.

If the floodplain is managed effectively, then this development impact on the AAD should be minimised, and may even result in a reduction to the AAD value.

Increase in Wealth

Historically, over time, the wealth of society has generally increased (Farmer & Hemmersbaugh, 1993). This may not continue to be the case, particularly with the on-set of climate change and other environmental degradation which may lead to increase costs on future generations. Regardless, the wealth of society is expected to change. This will impact on the AAD values calculated for a catchment.

An increase in wealth will result in an increase in the value of contents held within properties. This can affect both the relevance of the AAD value, as well as the damage curves used for new studies. Currently, the DNR draft residential guidelines attempt to counter this effect by using the increase in Average Weekly Earnings, rather than CPI, to factor the damage curves to current day dollars. A similar approach could be applied to the AAD value itself, in order to bring previously calculated AAD values to present day (this would reduce the need to recalculate all the input damage curves).

In cost benefit calculations, however, the AAD would change annually in a net present value calculation. As a result, an estimate of the future increases in average weekly earnings would be required.

Table 3 shows the increases in average weekly earnings over a 10 year period. This estimate of change in Average Weekly Earnings would overcome some of the economic fluctuations while still being fairly representative of future economic conditions.

While Average Weekly Earnings have increased by 5% pa on average over the last 10 years, inflation has increased on average by 2.39% pa over the same period (Table 4). As a result, the net increase in “real” weekly earnings is 2.61%.

This estimate would increase the value of the AAD by 2.61% annually (assuming that the increase in wealth is directly proportional to the expenditure on properties). For example, while the current AAD for Stony Creek is $248,821 (estimated for June 2004), an estimate of this value by 2009 would be $283,031 (in June 2004 dollar equivalent).

Table 3. Average Weekly Earnings for Full Time Adults (ABS, 2005).

Period	Average Weekly Earnings
May 1986	671.6
May 2005	1007.6
Increase	50.02%
Average p.a. increase	5%

Table 4. Consumer Price Index (ABS, 2006).

Period	Average Weekly Earnings
June 1986	119.8
June 2005	148.4
Increase	23.87%
Average p.a. increase	2.39%

Climate Change

Climate change is likely to both increase the intensity of severe storms, as well as increase the ocean levels McMichael et al (2002). The rise in ocean levels may have serious consequences for many coastal catchments.

The severity of the impact of climate change will not be a constant, but will continue to increase over the next century or centuries, unless production of greenhouse gases is reduced (Owen & Hanley, 2004).

As a result, the intensity and frequency of flooding is likely to increase over the next century with a consequent increase in AAD.

An analysis was undertaken by McMichael et al (2002) which analysed the increase in flood risk as a result of climate change. Flood risk was measured by the increase in likelihood of experiencing greater than the 1 in 10 year monthly rainfall during the year, over the baseline period of 1961 to 1970. Figure 4 shows estimates of the increase in flood risk expected in 2050, based on mid-range emissions estimates (McMichael et al, 2002). A risk from 0 to 1 indicates a reduction in the likelihood of experiencing a monthly 1 in 10 year event.

While the study undertaken by McMichael et al (2002) was subject to a number of assumptions, the results provide a rough indication that the majority of Australia would experience an increase in the risk of receiving a 1 in 10 year monthly rainfall event of at least between 1 to 2 (i.e. a 1 in 10 year monthly event would become between a 1 in 10 year and a 1 in 5 year monthly event).

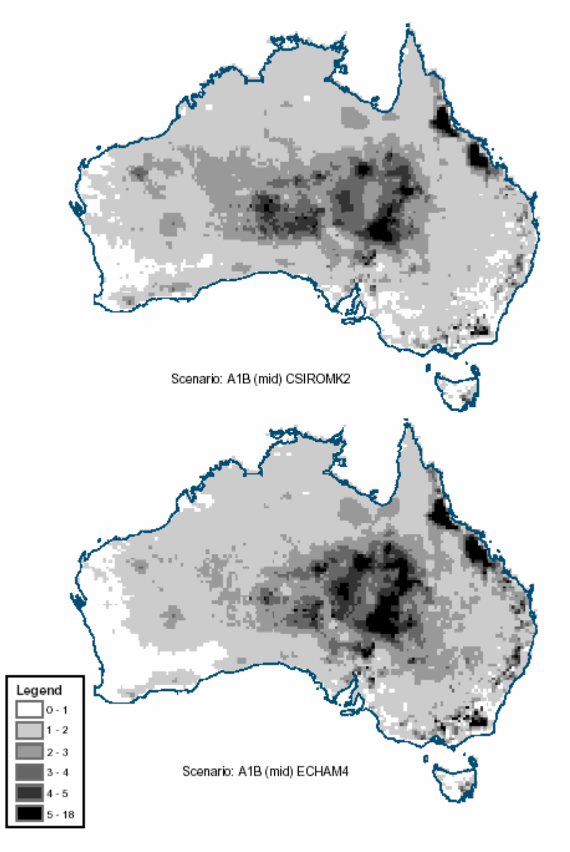

Figure 4. Estimates of Flood Risk in 2050, for mid-range emissions predictions, relative to a baseline period of 1961 to 1970 for two different climate models (*source:* McMichael et al., 2002).

If we assume that the monthly rainfall event is representative of the shorter duration events that we typically observe for flooding, then this analysis indicates that there are likely to be changes to the AAD as a result of Climate Change. These changes will generally result in an increase in AAD, particularly for coastal catchments which are also affected by potentially rising ocean levels. However, there will also be some catchments which may potential observe a reduction in AAD as a result of Climate Change.

Conclusions and Recommendations

The calculation of AAD is exposed to a number of estimation errors. These include the choice of design storms as well as methodology adopted for the calculating the AAD. Furthermore, the employment of different damage curves between studies can lead to it being difficult to make meaningful comparisons between catchments within an LGA or across the State.

Employing uniform methodologies in the calculation of AAD values can reduce some of these estimation errors, and lead to comparable AAD values. This paper recommends that:

- A consistent set of design storms should be used in the calculation of AAD. These should prescribe a full range of design storms. In order to reduce the errors at the tail end of the AAD curve, it is recommended that a flood studies should include the full range of design storms that result in damages in the catchment.

- If the full range of design flood estimation is not feasible for the more frequent events, then a standard approach should be adopted for the calculation of the area under the tail end of the AAD curve. It is recommended that the straight line, option 2 approach be adopted as standard without additional information. However, rather than using the 1 in 1 year ARI design event, the design storm with no damages could be estimated after consideration of relevant catchment features, such as street drainage.

- Standard damage curves be adopted for Industrial and Commercial damages, to expand the existing draft DNR residential damage curves.

In addition, time impacts on the value of the AAD should be considered. While Climate Change effects are somewhat more difficult to predict, increases in societal wealth with time can be estimated from Average Weekly Earnings. These can be included in cost benefit analyses of floodplain management options undertaken as a part of Floodplain Risk Management Studies.

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SPREADING THE WORD – COMMUNITY AWARENESS AND ALERTING FOR SHEPPARTON AND MOOROOPNA

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Presenter's Profile

Geoff Crapper has 33 years experience in the water industry specialising in the hydrology and flood warning field. He helped establish Melbourne Water's Flood Warning System in 1975 and been responsible for the development of new real-time modelling, flood warning and community awareness initiatives. Geoff managed Melbourne's Flood Warning Service from 1989 to 2003 and was a member of the Victorian Flood Warning Consultative Committee for ten years. Geoff joined Water Technology in June 2004 and until recently was based in Shepparton managing the Shepparton-Mooroopna Flood Warning and Emergency Management Project.

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SPREADING THE WORD – COMMUNITY AWARENESS AND ALERTING FOR SHEPPARTON AND MOOROOPNA

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Abstract

The Greater Shepparton City Council in conjunction with Goulburn Broken Catchment Management Authority, have recently completed the Shepparton-Mooroopna Flood Warning and Emergency Management Project. The project was principally focused on flood prevention and response for the Shepparton Mooroopna community and consisted of several key components aimed at delivering reduced flood damages and trauma for residents, businesses and property owners during future flood events. Potentially thousands of properties are impacted by the combined affects of the Goulburn River, Broken River and Seven Creeks during major floods. Previous investigations had developed a suite of flood inundation maps providing details of flood depths, levels, velocities and the location of affected properties for a range of flood magnitudes. This type of information provides a valuable resource for emergency management response agencies. The challenge was to utilise such information from a community viewpoint with the aim being to improve awareness, knowledge and preparedness to cope with major floods. To meet this challenge a number of initiatives were developed and refined as part of the project. The key questions asked by the community were: How do I find out about coming floods? Will I be affected and, if so, by how much? What can I do to safeguard my family and property? In response to these questions, the project investigated, amongst other things, the use of the Xpedite voiceREACH automated telephone messaging system, property-specific flood advice and simplified flood response booklets to encourage the affected community members to prepare their own Personal Flood Action Plan. To provide an ongoing level of flood awareness the project considered a range of community flood awareness initiatives.

Key Words: Flood warning, community alerting, emergency flood response, Personal Flood Action Plan

Introduction

This paper outlines the key community-focused outcomes of the Shepparton-Mooroopna Flood Warning and Emergency Management (S-MFWEM) project. These outcomes were aimed at educating and preparing the community to respond in an informed and timely manner to help minimise flood damage and prevent flood related trauma.

A project team led by Water Technology on behalf of the Greater Shepparton City Council (GSCC) and Goulburn Broken Catchment Management Authority (GBCMA) undertook the S-MFWEM project. Figure 1 shows the area covered by the project.

The project was jointly funded by the Federal and Victorian State Governments under the Regional Flood Mitigation Program.

This paper describes the community-focused outcomes of the project. Further details of the project can be provided by the authors.

Background

Shepparton-Mooroopna is located at the confluence of the Goulburn and Broken Rivers and Seven Creeks. The total catchment area to Shepparton is 16,125 km^2.

Major flooding in the project area has occurred in 1916, 1939, 1956, 1974, 1975 and 1993. These major historical floods have highlighted that the relative contribution from the Goulburn and Broken Rivers and Seven Creeks can vary significantly. In addition, the relative contribution from the three catchments can markedly influence flood behaviour within the project area.

The Shepparton Mooroopna Floodplain Management (SMFM) Study (SKM 2002) was undertaken for the GSCC and GBCMA in 2001-2002. This study undertook extensive topographic and field survey, hydrologic and hydraulic analyses, and flood damage assessment to define flood behaviour and risk within the study area. The analyses found some 6,500 properties were impacted by the combined affects of the Goulburn River, Broken River and Seven Creeks during a 100-year flood.

From this knowledge came the understanding of flood risk, which underpinned the development of a floodplain management plan. Community consultation during the SMFM study concluded that none of the proposed structural mitigation measures were desirable due to the predicted adverse flooding impacts to adjacent areas.

The SMFM study (SKM 2002) made the following recommendations:

- Adoption and implementation of revised land use planning maps.
- Improvements to flood warning tools/systems and arrangements.
- Refinement of flood response plans.
- Refinement of flood monitoring arrangements.
- Strengthening flood preparedness and community flood awareness.
- Development of improved information management systems.

The first recommendation was completed by GSCC and GBCMA. The remaining recommendations form the basis of the S-MFWEM project. In particular, the key community-focused elements of the S-MFWEM project included the following:

- Community involvement in decision making process.
- Community alerting procedures.
- Property-specific flood information.
- Community flood response advice and awareness.

As discussed, this paper is limited to the above project elements. Other key project elements included: Data collection network augmentation, review of the roles of authorities, flood warning and response arrangements, flood monitoring and information management systems.

A suite of flood inundation maps providing details of the flood depths, levels, velocities and the location of affected properties for a range of flood magnitudes were developed. This type of flood information is paramount as it enables flood height predictions, issued by the Bureau of Meteorology, to be meaningfully translated throughout major centres.

Authority and community consultation approach

A key requirement of the project was to establish and maintain strong and effective two way communication with stakeholders. For this project the major stakeholders can be divided into two groups.

Relevant authorities such as VICSES, Victoria Police, Bureau of Meteorology (Bureau), Goulburn-Murray Water, Goulburn Valley Water, Department of Sustainability and Environment, Goulburn Broken Catchment Management Authority and the Greater Shepparton City Council form one grouping of stakeholders. A Technical Steering committee (TSC) was convened with the above authorities represented. Regular TSC meetings during the course of the project allowed a range of views and considerations to be considered.

The Shepparton-Mooroopna community formed the other grouping of stakeholders. The project team, through previous experience, understood the importance of including the community in the decision making process throughout the project. After all, community safety and property are the key assets requiring protection during a flood event. As part of the SMFM study (SKM 2002), a community reference group (CRG) was formed. The CRG consisted of interested residents who volunteered their time and knowledge. At the project's inception, members of the SMFM study CRG were invited to continue their involvement and join the CRG for this project. Eighty community members in total responded positively to the invitation. Over the course of the project, five CRG meetings were held with about 20-25 CRG members generally in attendance. At these CRG meetings, various project outcomes/proposals were presented and feedback obtained.

In addition to the CRG meetings, a number of meetings were held between the project team and individuals/small groups of residents. These meetings helped facilitate improved understanding and awareness of flooding in the community with CRG members also promoting additional interest among friends and neighbours further widening the range of views expressed at meetings.

Several articles in the *Shepparton News* provided information on the project and encouraged community feedback, particularly a front page article following the significant rise in river levels during February 2005. The Council website also featured some general information on the project for the community.

Key outcomes required by the community

Through the consultation approach, community concerns and requirements were gauged. The key questions were:

- How do I find out about coming floods? (Community Telephone Alerting System)
- Will I be affected and, if so by how much? (Property-specific flood charts and FloodBank)
- What can I do to safeguard my family and property? (Community flood warning information brochures to assist affected landowners prepare their Personal Flood Action Plans).

The project team gained a strong sense from the community that flood warnings must enhance community safety and improve protection for community property. Further, the community wanted a streamlined response to flooding with all authorities understanding and performing their roles.

The following sections of this paper outline the project outcomes and initiatives developed to address the community's key questions.

How do I find about coming floods?

As discussed previously Shepparton-Mooroopna is located at the confluence of three major rivers. The flooding behaviour observed during floods is dictated by the relative magnitudes and timing of floods in the three contributing catchments. This offers a challenge in providing reliable flood estimates immediately upstream of Shepparton-Mooroopna.

In response, the Bureau developed an URBS Runoff Routing model for the upstream catchments, which provides best estimates of peak flows for the Goulburn and Broken Rivers, and Seven Creeks. The URBS model's performance has been enhanced by the additional real-time rainfall and streamflow available through the improved data collection network. The newly upgraded system was tested in September 2005 during a minor flood event.

Based on the URBS modelling results, the BoM can provide forecast flood levels and flood categories to the relevant authorities and the community through the BoM website: www.bom.gov.au/weather/hydro/flood/vic.

However, as pointed out by the CRG, not all of the community are web/internet literate. To provide effective and timely flood warnings to as many residents as possible additional options were developed including:

- Radio: ABC local radio.
- Community telephone alerting.

ABC Radio has entered into an agreement with the State Government to provide updated warnings for a number of emergency situations. Under this agreement, normal programming can be interrupted at any time to broadcast appropriate warning messages.

This project implemented an automated telephone alerting system called voiceREACH marketed by Premiere Global Services-Xpedite. This system allows a voice message to be simultaneously sent to thousands of landlines and mobile phones. The Shepparton-Mooroopna community telephone alerting system has the potential to send simultaneous flood messages to properties at risk of flooding during major floods. This is the largest scale application of the Xpedite voiceREACH communication system for community flood alerting purposes anywhere in Australia.

The flexibility of the voiceREACH system enables warnings and advice to be targeted for any locality or flood risk in the region. As the flood warning lead times for Shepparton-Mooroopna are up to 24 hours, a series of updated warnings can be provided to keep residents informed.

Trialling of the voiceREACH system with the CRG met with a favourable response and prompted useful feedback on the nature and structure of the warnings.

Will I be affected and, if so by how much?

Flood warnings provided by the Bureau relate to specific river level gauges and are often only able to describe generalised flood effects. The full value of the warning to residents can be realised if the resident can relate their property and access/egress routes to forecast flood levels on the local gauge most relevant to them.

The SMFM study (SKM 2002) undertook extensive topographic and property floor level survey, and hydraulic modelling to provide guidance on the flood behaviour and properties affected during a range of flood magnitudes. This previous analysis led to the development of flood affected property listings and flood inundation maps for various key locations and gauge heights. The previous analysis considered two scenarios for the relative contribution of the three catchments.

The outcomes from the SMFM study (SKM 2002) provided valuable information for emergency response.

The flood data together with floor height and property listing data was manipulated to provide succinct information designed for the resident. The CRG played an important part in developing the property-specific flood charts to suit the resident's needs.

Figure 2 shows a sample property-specific flood chart. These flood charts provide each property with the key river gauge levels for when their property may be affected and when their dwelling may be flooded above floor level. The flood charts will progressively be distributed to each property in Shepparton-Mooroopna likely to be affected by floods up to the 100-year flood.

As discussed, the SMFM study (SKM 2002) developed flood inundation maps based on two catchment inflow scenarios. The project team through further investigation and community feedback considered a third scenario should be assessed. This third scenario was based on the relative catchment contributions in the October 1993 flood. A third set of inundation maps and property listings were developed for this third scenario as part of this project.

Forecast levels on the Shepparton gauge can occur from various combinations of inflows from the three contributing catchments. The flood behaviour and in turn properties affected along the Goulburn and Broken Rivers, and Seven Creeks upstream of their respective confluences is dependant on these inflow combinations. The critical flood forecast levels for properties south and east of Shepparton are therefore the upstream gauges on the Broken River at Orrvale, Seven Creeks at Kialla West, or the new gauge on the Goulburn River at Arcadia Downs rather than the Goulburn River gauge at Shepparton.

However, the old saying that "no two floods are the same" must be kept in the mind. While the project team considers the three catchment inflows scenarios to provide a reasonable representation of the possible range of the relative catchment inflows it is unlikely that future flood events will exactly mirror one of these three scenarios. As such the project team has adopted a conservative approach to assignment of critical gauge levels. The critical level given for a property is the lowest gauge level under the three scenarios considered.

Examples of possible flood chart formats were provided to the CRG for their input and a range of responses received. Finally, each CRG member was provided with a sample flood chart containing flood details for their own properties. This provided further valuable feedback and additional revisions made to the charts to improve clarity and interpretation.

The CRG comments highlighted the possible variation in flood behaviour due to catchment inflows and other contributing factors. Some

CRG members reported their flood chart did not reflect their observation from past floods. These comments represent a significant community education challenge. The project team responded by considering a number of avenues to communicate the difference between design floods and historical floods. Again "no two floods are the same".

These comments were mirrored by community feedback from residents of Lismore in northern NSW following the flood there in late June 2005. At a public meeting to discuss the flood residents expressed concerns about differences in flood levels at their properties compared to previous flood levels on the town's central flood gauge. There was also apparent confusion within the North Lismore community, in particular, caused by the Council's individual property flood level information not relating the dwelling floor level and ground level to the main Lismore flood gauge (Lismore City Council, August 2005).

What can I do to safeguard my family and property?

With the telephone alerting system and property-specific flood chart, residents now know a flood is coming and the likely effects on their property. But what should they do?

Feedback from the CRG highlighted the residents' needs for clear and concise advice on practical measures to reduce danger to their personal safety and property.

Previous flood warning and community awareness projects in Victoria have generally produced a set of community flood response guidelines. These guidelines have been provided to the community as a colour booklet of 20 pages or so in length with the content of these guidelines also available on some relevant local authority websites.

Discussions with the TSC suggested these 20 page flood response booklets were often unable to be located by residents after a relatively short time following distribution. This raised concerns about their likely availability when needed by residents during a flood situation. The colour booklets are also costly to reprint and limit the ability to continue flood awareness promotion and update information after the initial project is completed.

In response, the project team and TSC developed a two page A3 size double-sided community flood warning information brochure able to be printed in black and white or colour by any standard colour printer. It was considered best to provide a brief succinct flood brochure with enough information to encourage residents to prepare their own Personal Flood Action Plan along the same lines as the Country Fire Authority's promotion of Bushfire Survival Plans.

The brochure provides community information and practical advice on the following:

- Historical flooding in Shepparton-Mooroopna.
- How the flood warning system works.
- How to develop their Personal Flood Action Plan
- How to interpret their property-specific flood chart.

The community flood warning information brochure will be distributed with the property-specific flood chart. The relatively simple print format of the flood warning information brochure will enable regular re-prints to continue promotion of community flood awareness programs in a timely and cost-effective manner, refer to Figure 3.

The GSCC website contains more detailed information to further assist the community prepare their Personal Flood Action Plan. This information details how the flood warning system works, provides additional flood response advice and access to the FloodBank web-based suite of flood maps and links to real time rainfall and river height data on the BoM website. The project team based the design of the flood section of the website on elements from the Wangaratta, Benalla and Lismore Council websites.

Community awareness initiatives

Significant flooding in Shepparton-Mooroopna is not a frequent occurrence. As such maintaining and, where possible, improving the level of community flood awareness is an ongoing and challenging task.

The project team investigated a number of possible initiatives including:

- Historical/design flood markers along riverside pedestrian/bicycle paths.
- Educational information for schools
- Regular reminders in Council newsletters, local newspapers and the electronic media.

Shepparton-Mooroopna has a variety of fibreglass cows located within the public open space areas as part of the Council's Moooving Art promotion. One of these "bovine flood markers" featured very prominently at the 2005 Victorian Flood Management Conference in Shepparton. The success of this novel initiative has prompted the project team to consider featuring one or more of these cows to help promote community flood awareness.

Conclusion

Generally, during the last ten years extensive flood mapping resulting from detailed technical studies has meant that the information provided by BoM in terms of providing height predictions, can now be meaningfully translated laterally to provide flood extents, levels, velocities and depths.

Many practitioners are now in a good position to provide flood data in such a manner to encourage affected residents to prepare their Personal Flood Action Plan.

The Shepparton-Mooroopna Flood Warning and Emergency Management Project reflects the continuing strong commitment of the relevant authorities, particularly the Greater Shepparton City Council, in reducing flood related trauma within Shepparton Mooroopna. The project has delivered a number of community focused outcomes including:

- Property-specific flood charts
- Community telephone alerting system
- Community flood warning information brochure

Individual property-specific flood charts containing flood gauge levels to indicate when floor and ground levels are likely to commence flooding will enable residents to assess the level of flood risk for their own property. The project team is unaware of any other flood charts with such information being available anywhere else in Australia on such a scale.

The Shepparton-Mooroopna community telephone alerting system is also understood to be the largest such application of this technology for flood warning purposes in Australia.

The project team sees the involvement of the local community in the decision making throughout the project as invaluable. This involvement has enhanced the community useability of the project outcomes.

Acknowledgments

The authors wish to thank Greg McKenzie (Greater Shepparton City Council) for his contributions to this paper and the valuable contribution made to the project by the members of the TSC and CRG, in particular personnel from the Bureau of Meteorology Victorian Regional Office. The project team also acknowledges work undertaken for this project by Thiess Environmental Services and assistance from Theo Pykoulas, Maribyrnong Council Manager Emergency Management.

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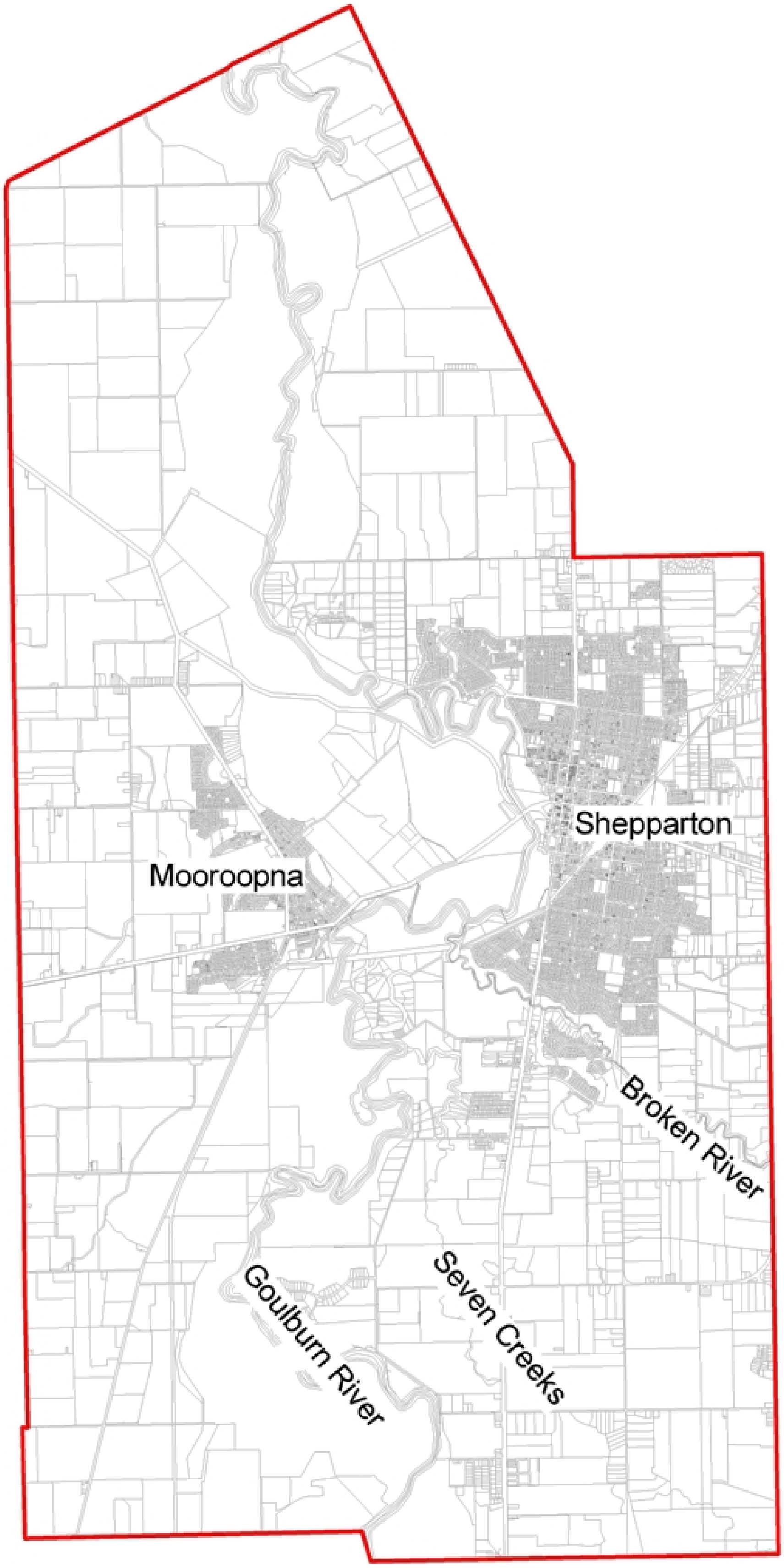
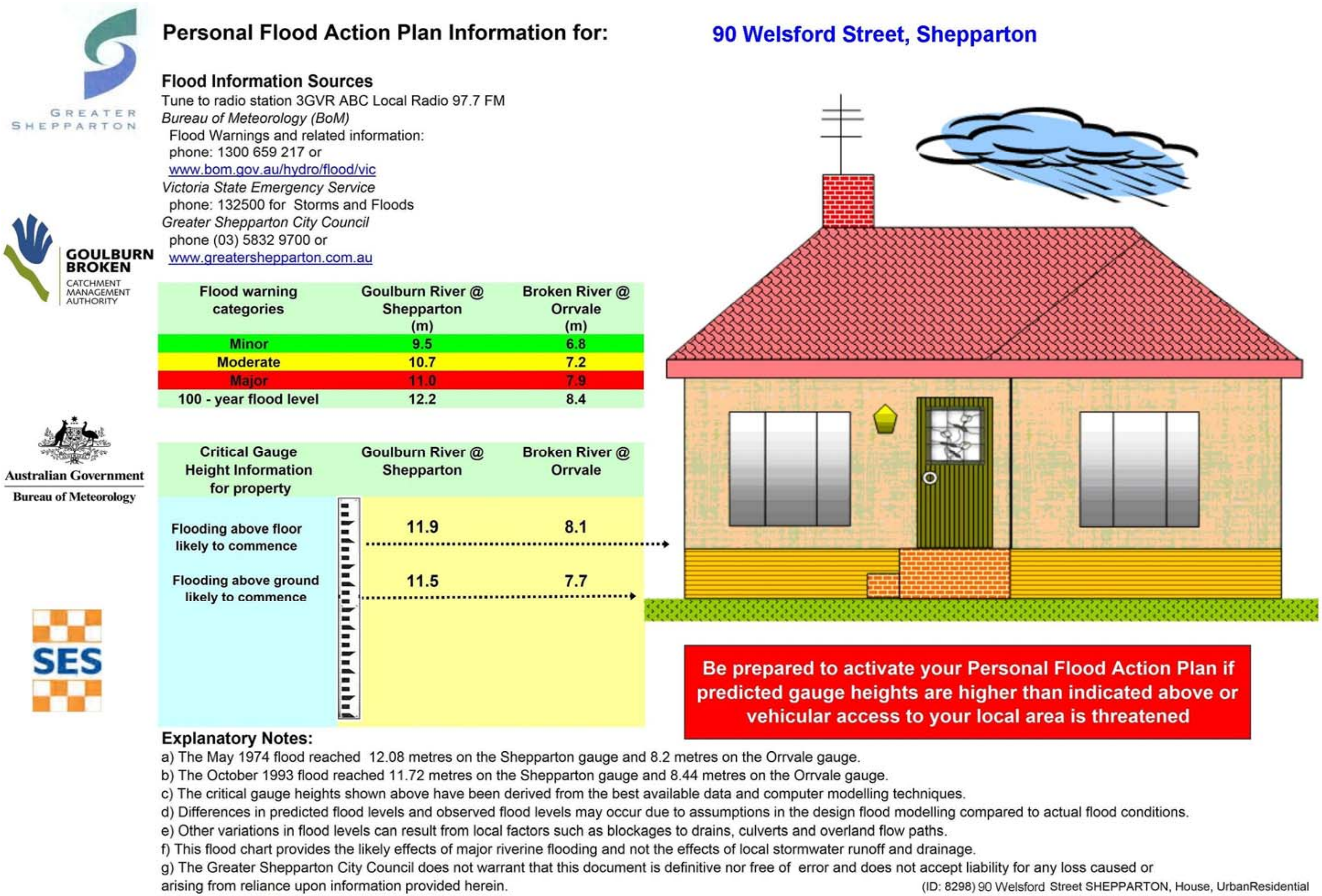


Figure 1 Project area



Personal Flood Action Plan Information for: 90 Welsford Street, Shepparton

Flood Information Sources

Tune to radio station 3GVR ABC Local Radio 97.7 FM
Bureau of Meteorology (BoM)
Flood Warnings and related information:
phone: 1300 659 217 or
www.bom.gov.au/hydro/flood/vic
Victoria State Emergency Service
phone: 132500 for Storms and Floods
Greater Shepparton City Council
phone (03) 5832 9700 or
www.greatershepparton.com.au

Flood warning categories	Goulburn River @ Shepparton (m)	Broken River @ Orrvale (m)
Minor	9.5	6.8
Moderate	10.7	7.2
Major	11.0	7.9
100 - year flood level	12.2	8.4

Critical Gauge Height Information for property	Goulburn River @ Shepparton	Broken River @ Orrvale
Flooding above floor likely to commence	11.9	8.1
Flooding above ground likely to commence	11.5	7.7

Be prepared to activate your Personal Flood Action Plan if predicted gauge heights are higher than indicated above or vehicular access to your local area is threatened

Explanatory Notes:

a) The May 1974 flood reached 12.08 metres on the Shepparton gauge and 8.2 metres on the Orrvale gauge.
b) The October 1993 flood reached 11.72 metres on the Shepparton gauge and 8.44 metres on the Orrvale gauge.
c) The critical gauge heights shown above have been derived from the best available data and computer modelling techniques.
d) Differences in predicted flood levels and observed flood levels may occur due to assumptions in the design flood modelling compared to actual flood conditions.
e) Other variations in flood levels can result from local factors such as blockages to drains, culverts and overland flow paths.
f) This flood chart provides the likely effects of major riverine flooding and not the effects of local stormwater runoff and drainage.
g) The Greater Shepparton City Council does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

(ID: 8298) 90 Welsford Street SHEPPARTON, House, UrbanResidential

Figure 2 Sample property-specific flood chart

Australian Government Bureau of Meteorology | SES | GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY | GREATER SHEPPARTON

IMPORTANT FLOOD INFORMATION FOR THE HOUSEHOLDER

SHEPPARTON-MOOROOPNA COMMUNITY FLOOD WARNING INFORMATION
Edition 1, November 2005

Source: *Shepparton News*, October 1993

Do you remember the May 1974 and October 1993 floods?

The economic cost and personal trauma within the community caused by the 1974 and 1993 floods remind us of the need for a flood management system.

- A flood of the magnitude of May 1974 could be expected to flood 830 houses and effect about 4,000 residential and commercial properties
- Damage caused in 1974 would be in the order of $23 million by today's dollars
- Flood waters cut most major roads into and out of Shepparton and Mooroopna for more than two days
- Property damage suffered by individual residents (repair, replacement & time in cleaning up damage)
- Damage to industrial and commercial properties
- Cost to public authorities of repairing service utilities and road infrastructure.
- Environmental damage through erosion and siltation
- Indirect damage such as loss of business, trauma, stress and worry, both short and long term, suffered by residents.

Flooding in Shepparton-Mooroopna

- Can occur from localised heavy rain or from prolonged heavy rain in upstream catchments.
- Often catches people by surprise and unsure of what to do.
- Has potential to cause considerable loss and damage in the Greater Shepparton area.
- Will occur again.

Need for improved flood warning and emergency management systems

- The need for improved flood warning and emergency management systems was identified as one of the most cost-effective recommendations from the Shepparton-Mooroopna Floodplain Management Study.
- A subsequent review also identified the need for improving community awareness of flood warnings and flood preparedness.

Information

- This information brochure has been compiled with the help from locals who have experienced previous floods, as well as staff from Council, Victoria Police, VICSES, Bureau of Meteorology, Goulburn-Murray Water, Goulburn Valley Water, Department of Sustainability and Environment and Goulburn Broken Catchment Management Authority.
- Passing their experience and knowledge on to you will help minimise the amount of flood damage and cost to your property.

Please take the time to read this brochure. Consider the tips and advice given and utilise them to help develop a Personal Flood Action Plan for your property. If you do, you and your family will be better prepared for the next flood.

Remember, be prepared to protect your family and property from the damaging effects of a flood

Flood Category Guide for Key Locations

Bureau of Meteorology flood warnings are categorised as **Minor, Moderate** or **Major**. The forecast peak level relative to the pre-determined flood level at various key locations determines the warning category.

MINOR			
Goulburn River @ Shepparton 9.5m	**Goulburn River @ Arcadia Downs 9.0m**	**Broken River @ Orrvale 6.8m**	**Seven Creeks @ Kialla West 4.5m**

Minor flooding causes inconvenience. Low lying areas adjacent to watercourses are flooded, requiring removal of stock and equipment. Minor Roads may be closed and low-level bridges may be submerged (eg Mitchell Road, Watt Road, Raftery Road).

MODERATE			
Goulburn River @ Shepparton 10.7m	**Goulburn River @ Arcadia Downs 10.2m**	**Broken River @ Orrvale 7.2m**	**Seven Creeks @ Kialla West 5.0m**

In addition to the results of minor flooding, **moderate** flooding may require the evacuation of some houses. Main traffic routes may be closed (eg Kialla Lakes Drive, Archer Road).

MAJOR			
Goulburn River @ Shepparton 11.0m	**Goulburn River @ Arcadia Downs 10.5m**	**Broken River @ Orrvale 7.9m**	**Seven Creeks @ Kialla West 6.6m**

In addition to the effects of moderate flooding, **major** flooding causes flooding of extensive rural areas and urban areas. Properties are likely to be either flooded or isolated with houses threatened or major traffic routes closed (eg Goulburn Valley Highway, Midland Highway Causeway, etc). Numerous evacuations may be required.

Property-Specific Flood Charts

Property-specific flood charts have been produced for each potentially flood affected property on the current Shepparton-Mooroopna flood database up to and including the 100-year flood. Each flood chart indicates how a predicted flood on the Goulburn River, Broken River or Seven Creeks may impact on that property.

Flood warnings always include a predicted maximum river gauge reading and estimated time of arrival of the peak. For the Shepparton-Mooroopna area these warnings include a predicted peak level on the Broken River at Orrvale, Seven Creeks at Kialla West, Goulburn River at Shepparton as well as the new Goulburn River gauge at Arcadia Downs.

The flood charts provide important flood gauge information for each property including the following information to help you prepare your Personal Flood Action Plan –

- Flood gauge or gauges most relevant to each property, eg the Shepparton gauge for Mooroopna Township and all properties downstream throughout Shepparton, the Goulburn River at Arcadia Downs gauge for properties upstream of Mooroopna, Orrvale for properties adjacent to the Broken River and Kialla West for properties adjacent to Seven Creeks.
- The approximate gauge height when flooding of the property and floor level is likely to commence.
- Explanatory notes detailing the peak gauge heights for the May 1974 and October 1993 floods on the gauge or gauges most relevant for each property.
- Key sources of flood information, including the designated emergency local radio station and contact details for the Bureau of Meteorology, Council and Victoria State Emergency Service.
- Additional explanatory notes and qualifying advice about use of the flood chart.

Secure the flood chart in a safe place, such as your electricity meter box, for future reference in the event of a major flood in your area.

Figure 3 Community Flood Warning Information brochure, pages 1 and 4

TO FLEE OR NOT TO FLEE – AN EVALAUTION OF WARNING AND EVACUATION EFFECTIVENESS

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Abstract

Substantial flooding occurred in communities of the North Coast of New South Wales and South East Queensland on the 30th of June, 2005. The SES in response to flood warnings issued by the Bureau of Meteorology conducted warning and evacuation operations. The flood posed the first test to the new Lismore levee. Of concern to the SES was the community's understanding of the level of protection provided by the levee; whether or not warnings provided were effective; and how previous community education programs had influenced the community's response to flooding. The SES initiated a community survey to investigate these points and was strongly involved in debriefing following the flood. This paper summarises the results of debriefs and the community survey and provides recommendations on how local government and the SES can work closer together to overcome deficiencies.

Key Words: Flood Warning, Flood response, Evacuation

Introduction

On the 30th of June 2005, substantial flooding occurred in communities of the North Coast of New South Wales and South East Queensland, including Lismore City and Byron Shire communities.

Flooding occurred as a result of widespread rainfall occurring from the 26th to the 30th of June. The rainfall was triggered by an inflow of moist air from the Tasman sea into a slow moving upper low pressure system. In addition, a surface trough deepened off the east coast resulting in strengthening north-easterly winds and flooding rainfall in the far north-east of NSW. Numerous rainfall stations recorded their highest ever daily rainfall for June including: Tweed Heads, Mullumbimby, Woodburn, Alstonville, Byron Bay and Murwillumbah. (MHL & Department of Commerce, 2005). Record flooding was recorded at Billinudgel on Marshalls Creek.

The most serious consequences of flooding occurred in the communities of Lismore, Ocean Shores, New Brighton, South Golden Beach, Pottsville, Tweed Heads and Billinudgel, where several hundred homes and businesses were flooded and infrastructure was damaged. One person died in Byron Bay and two in South East Queensland.

In response to the flood situation the Australian Government Bureau of Meteorology (BoM) issued Flood Watches, Flood Warnings and Severe Weather Warnings for Flash Flooding. In response to the magnitude of flooding forecast the State

Emergency Service (SES) conducted evacuation operations, the largest of which were focused in Lismore, Ocean Shores, South Golden Beach, New Brighton, Billinudgel and Pottsville.

Warning and Evacuation Operations

In Lismore the SES warned approximately 5000 people to evacuate including North, South and Central Lismore residents, in response to a flood height prediction at the Lismore Rowing Club gauge of 10.4m AHD. Central Lismore, is located behind the newly constructed CBD levee, which at the actual flood peak of 10.3m AHD (not the initially predicted 10.4m AHD) came within 0.3 metres of overtopping at one of its three spillways.

After the initial prediction and evacuation decision based upon that prediction there was a downward revision to 10.0m AHD. As a result the evacuation of South and Central Lismore was cancelled, leaving only approximately 650 people to evacuate from North Lismore. However, only approximately 50 people were accommodated at the established evacuation centre.

The evacuation decision for Lismore was made at a time when the SES had to deal with considerable uncertainty relating to:

- A new levee not tested in any flood and for which the relationship between the various spillways and the key warning gauge, including the issue of flood gradient, were still being determined; and
- The peak flood level given that predictions were being made under conditions where further heavy rain was still possible.

In Byron Shire, approximately 150 people were evacuated from the communities of Billinudgel, New Brighton, Ocean Shores, South Golden Beach and Mullumbimby. Some additional residents were evacuated from the Tweed Shire communities of Pottsville and Tweed Heads.

Evacuation warnings were delivered in these communities via radio stations, doorknocking, mobile public address announcements and telephone calls to selected residents.

Effective warning time was far greater for Lismore than Byron Shire, since Byron Shire is comprised of communities situated in flash flood catchments. Typical warning time available for Lismore is 12 to 15 hours compared with less than six hours for Byron Shire communities.

The SES also operates an emergency assistance telephone number 132 500, which received 524 requests for flood and storm assistance in the North Coast area.

The State Emergency Service and a Philosophy of Continuous Improvement

The SES is the combat agency (lead agency) for flooding in NSW, with its role being comprehensive, incorporating floodplain risk management, community education, flood emergency planning and flood response. The SES seeks to continually improve the service it offers to the community by capturing the lessons of past events and conducting innovative research and development. The Service was therefore eager to evaluate its warning and evacuation performance as well as study community attitudes and behaviour in response to flood and evacuation warnings.

To achieve these goals the SES leads internal and external debriefs, community meetings and community surveys after flooding.

Following the North Coast floods all of these activities were undertaken. The most comprehensive of which were a community survey undertaken by Molino Stewart Pty Ltd on behalf of the SES and a community meeting facilitated by Lismore City Council. The results of these activities and key outcomes are discussed in this paper.

The Service in recent years has undertaken similar community surveys following flooding in Jingellic, 2003 and Grafton, 2001 (Pfister, 2002); and contributed to a survey following the Kempsey, 2001 flood (Gissing, 2002). The Service has also learnt from related inquiries regarding recent bushfires, rail accidents and overseas events.

In addition, the Service is also undertaking work to improve its plans, intelligence systems, operational information management and its understanding of the dynamics of large scale evacuations.

Evaluation Methodology

Community Survey

The community survey had two goals. Firstly, to evaluate the effectiveness or otherwise of communication methods used for warnings; and secondly, to assess peoples actions in response to warnings (including their awareness and preparedness for the flood risk).

The thirty six question survey dealt with: awareness and preparedness of respondents for the flood risk; sources of information for flood and evacuation warnings; responses to these warnings; understanding of the warnings and satisfaction with the warning service.

Surveys were conducted face to face by Molino Stewart Pty Ltd representatives in the three to four weeks following the flood. In total, 192 surveys were completed. Of these, 40% were businesses and 60% residences.

Due to the majority of evacuations taking place in Lismore City and Byron Shire communities, the community survey focused on these areas. Byron Shire communities involved in the survey included Billinudgel, Ocean Shores, South Golden Beach and New Brighton, whilst Lismore City communities were North, South and Central Lismore. The majority of surveys (78%) were completed by respondents in Lismore City.

Surveys were designed to assess the differences in warning response between the communities and identify factors which may have influenced responses.

Community Meeting

On the 27th of July 2005 a community meeting was held in Lismore and was facilitated by Lismore City Council. The meeting was attended by over one hundred residents, predominately from North Lismore. Speakers represented Lismore City Council, SES, BoM and Richmond River County Council. The minutes of this meeting are available on the Lismore City Council website (www.liscity.nsw.gov.au).

Results

Awareness of the Flood Risk

Most respondents were aware that there was some risk of flooding to their properties before the June, 2005 floods as shown in Figure 1. However, this awareness was much higher in Lismore than in Byron Shire. In Lismore, the SES and Council for several years have undertaken a flood education program, including community specific FloodSafe brochures, media supplements, shopfront displays and public meetings. In Byron Shire, an A4 laminated sheet showing evacuation routes and centres, with contact information and advice on the reverse side had been distributed not long before the June, 2005 flood. Lismore has some recent flood experience being last flooded in 2001. However, the last major flood to affect areas of Byron Shire was 1987; the exception being Billinudgel which last suffered major flooding in 2003.

Very few respondents (6%), however, thought flooding posed a threat to their personal safety at any point during the floods, even when their properties were being flooded. This is important because it emphasises both a lack of appreciation for the serious risks flooding does pose and suggests that appeals to prepare for floods based upon personal risk are less likely to be as effective as they might be for other natural hazards such as fire. This is despite statistics that show floods have claimed an estimated 1090 lives in NSW between 1788 and 1996 (Coates, 1999), a number which is far greater than deaths caused by bushfires. This is supported by other research which found that businesses at high risk of flooding perceived the risk of fire to be greater than flood (Molino and Gissing, 2005).

By contrast, most respondents (74%) did believe that flooding was a threat to their property or possessions when they first thought their property might flood. There were no major differences between Lismore and Byron Shire. There was a slight difference between businesses and residences with businesses being slightly more cautious.

Despite the extensive community education program conducted in Lismore, only 32% of Lismore respondents indicated that information provided over the past few years influenced their decisions during the June, 2005 flood.

It was evident at the community meeting that there was a high level of confusion about the interpretation of flood levels. In recent years residents have been provided with property specific diagrams representing the relationship between individual property spot heights (eg. floor and ground) and flood levels based on the Australian Height Datum (AHD). Residents were clearly unable to interpret these diagrams, thinking that AHD property levels referred to flood gauge heights. This resulted in an inability to interpret flood warnings.

Effectiveness of Warning and Notification Systems

The extent of warning coverage varied between location and type of warning product. Warning coverage was more effective in Lismore than Byron Shire. In Byron Shire 56% of respondents heard Severe Weather Warnings, in contrast to 71% of Lismore respondents. Only 30% of respondents in Byron Shire heard Flood Warnings, in contrast to 84% in Lismore. Only two percent of respondents in Byron Shire heard evacuation warnings, in contrast to 61% of Lismore residents.

Not all respondents that received warnings believed that they applied to them. Lismore respondents were much more likely to think warnings applied to them. Reasons given by respondents for why they thought warnings didn't apply to them included: didn't believe they could flood (36%); and didn't hear their specific locality mentioned (28%).

Respondents were questioned regarding their understanding of what key warning terms meant. These terms were 'Severe Weather Warning', 'Flood Watch' and 'Flood Warning'. Respondents were asked unprompted what these terms meant to them.

The large majority of respondents used words such as rain (43%), wind (34%) or storm (19%) to describe what they thought a 'Severe Weather Warning' meant, indicating a good understanding of the warning product.

Respondents understanding of Flood Watches were largely poor, with only 20% giving responses which corresponded to the correct meaning of a Flood Watch. Thirteen percent of respondents said they didn't know what 'Flood Watch' meant. Further discussion of Flood Watches is presented in Opper and Gissing (2005).

Flood warnings were largely understood to mean that flooding was imminent or highly likely (50%), or that there was a chance of flooding (20%).

Numerous methods are used by the SES to warn the public, including radio, television and doorknocking. In addition, people are regularly informed about warnings through informal sources such as neighbours, family and friends; and by environmental signals such as heavy rain or river rises.

Respondents were asked what sources first made them think that they may be flooded. Environmental signals of heavy rain (40%) and the observation of flood waters (19%) were the most common responses. Radio was the most effective source for disseminating official warnings (21%). Informal notification through friends, neighbours or relatives was stated by 10% of respondents.

In Byron Shire, 85% percent of respondents indicated environmental signals in contrast to 51% of Lismore respondents. This may be explained by the fact that Byron Shire is a flash flood environment where flooding can occur with little warning.

Sixty eight percent of respondents in Lismore and 44% in Byron Shire indicated they had attempted to validate flood warnings. The most common sources used to validate warning information were the radio (40%) and the SES (36%). In Lismore, 42% of respondents said they checked the internet, but only 18% of respondents in Byron Shire did likewise.

Respondents were asked what source first made respondents think they may have to evacuate. In Lismore, the majority of respondents indicated radio (30%) and doorknocking (32%) as the sources, while again the majority of Byron Shire respondents (47%) indicated environmental signals, perhaps due to the better coverage of evacuation warnings in Lismore. Informal notification was significant in both locations accounting for 12% of responses overall.

Action in Response to Warnings

Respondents generally took actions to reduce or prevent loss of or damage to property and possessions. Most lifted possessions to higher levels and many in Lismore moved their car to a location which was not flood prone before roads were closed.

The majority of total respondents did not evacuate with only 40% of Lismore (72% were businesses) and 19% of Byron Shire respondents evacuating. Businesses were more likely to evacuate than residences with 62% of businesses compared with 21% of residents evacuating. The low proportion of residents evacuating is consistent with previous research of the Lismore community which indicated that only 36% of residents would be likely to evacuate their homes during a flood if asked to do so (Scott & Vitartas, 2003).

Of those that did evacuate their reasons varied upon locality. The primary reasons given for evacuation included that it was 'better to be safe than sorry'; and that a firm belief was held that the building would flood. The average time taken by both residences and businesses to prepare to evacuate was four hours. The minimum preparation time was 10 minutes and the maximum 48 hours for an electrical business.

The majority of those that evacuated from residences relocated to a friend's, relative's or neighbour's residence. Only a small percentage relocated to an official evacuation centre. Many evacuated to friends or relatives because it was convenient, they felt comfortable there or they knew the sleeping arrangements. Ninety five percent of evacuees from businesses reported that they relocated to their home, the remaining 5% relocated to a friend's house.

Seventy seven percent of respondents evacuated using their own vehicle. The remainder walked, used a friend's or neighbour's vehicle, or were transported by emergency services supplied transport.

When respondents indicated they did not evacuate, they were asked why. In Lismore, answers were influenced by flooding not occurring in Central and South Lismore after it was predicted to do so. Thirty two percent did not evacuate because they did not think the building would flood, of which 74% were in South Lismore. Twenty five percent stayed to protect their property or possessions from flood water, of which 67% were in North Lismore. Eighteen percent said they knew how to manage and a similar percentage cited that there was not a great enough threat to personal safety. Twenty one percent said there was no need to evacuate in the end and 11% cited the need to protect property or possessions from looters.

Of those in Byron Shire that did not evacuate, 52% said it was because they did not believe their building would flood. Seventeen percent said they did not evacuate because the flood was not a great enough threat to their personal safety and 17% stayed to protect property or possessions from flood water. Ten percent said they simply did not know where to go.

An issue raised at the Lismore community meeting related to the extent of the SES's legal power to evacuate people from their homes and businesses. The SES does have the legislated power to call for an evacuation of any scale (SES Act 1989 - Section 22). It is not clear (no precedent) whether or not if a person chooses to ignore an evacuation warning, if a legal penalty applies. However, the SES can request a person to leave a property and may do all such things as are reasonably necessary to ensure compliance.

Satisfaction with Flood Warning Service

The majority of respondents were happy with the flood warning service they received from the SES, particularly in Lismore. In Byron Shire, a number were unhappy with the service. This was perhaps to be expected considering the lower levels of community flood experience in Byron Shire, the limited coverage of warnings and the shorter length of possible effective warning time. By contrast, respondents in Lismore were much more aware of the flood risk and received considerable warning of impending flooding before the event. In addition, flooding in Lismore was less severe than warnings had suggested, and respondents were generally happy that the SES was being cautious in its warnings.

Those who heard the warnings in both communities generally found them easy to understand. One thing that did cause confusion in Lismore was the recent change in gauge measurements to AHD.

Recommendations for Improvement

Respondents were asked to nominate ideas of how flood warning services could be improved. Suggestions included:

- more local information provided in warnings;
- more extensive use of doorknocking;
- provision of community education material regarding AHD, flood evacuation and the new Lismore flood levee;
- provision of guidelines to media outlets to ensure consistent reporting of the flood situation;
- more face to face information regarding the flood situation;
- restriction of access to flood affected areas to prevent sightseers;
- clarification about what flood levels mean, including advice about what streets may be affected; and
- provision of graded evacuation notification where the first warning would be ‘ prepare to evacuate’ and the second to ‘evacuate now’.

How Councils and the SES can work closer together to improve warning and evacuation performance

Councils and the SES already have strong relationships, but these can be strengthened to further ensure the effective emergency management of flooding.

Flood Studies and Floodplain Risk Management Studies are a valuable source of flood information to the SES when conducting planning for warning and evacuation operations. To ensure that the information requirements of the SES are met in relevant studies, SES and DNR are developing a Floodplain Risk Management Guideline titled, ‘Information for SES from the Floodplain Risk Management Process’. This guideline details the recommended information requirements of the SES.

In addition, useful information regarding flood consequences can be collected following floods. The Floodplain Development Manual (2005) encourages councils to assist SES following floods to collect information regarding flood consequences. This information can then be used in emergency planning, community education and future flood operations.

The SES needs to have an understanding of the operation and design of levees. It is essential that councils and floodplain management authorities involve the SES in the design, construction and audit of levees to ensure that an adequate understanding of levees from an emergency risk management perspective is developed and incorporated into flood emergency plans.

Some of the specific information requirements which the SES must be provided include:

- Description of a levee, detailing: location; construction type; and the communities protected.
- The following heights relative to the relevant flood warning gauge; and the

Annual Exceedance Probability of the respective heights:
    - Levee Design Height
    - Overtopping heights of levee low points
- Likely locations of levee overtopping and the sequence of overtopping and flooding.
- Size of the population; the number of residential and commercial properties; and critical infrastructure affected by levee over-topping or failure.
- The height relative to the relevant flood warning gauge that any backwater flooding commences impacting upon urban areas behind a levee and the pattern of inundation.
- Once over-topped the length of time taken to fill the basin area behind a levee and the pattern and behaviour of inundation.
- Location of any parts of each levee which need to be closed other than drains (eg. gates for roadways and railways) and the height relative to gauge that action must be completed by.
- Knowledge of any critical issues including structural integrity affecting a levee.

It is likely that in many cases outputs relating to overtopping and backwater flooding will vary between different floods. In these cases a description of each flood scenario, details of associated required outputs and an indication of confidence will be required.

Flood aware and prepared residents are able to effectively respond to flood warnings. Most communities in NSW lack recent flood experience and are unlikely to be prepared for flooding, as discovered by Molino and Gissing (2005). To enhance the awareness and preparedness of NSW communities the SES has developed a comprehensive education strategy branded FloodSafe. The strategy has now been delivered in many NSW flood prone communities and the demand on it continues to grow. The program has many components including brochures, newspaper supplements, media interviews, public meetings, displays and school visits. Brochures are tailored to local flood prone areas, and contain information on the local flood risk and how to prepare for and respond to floods when they occur.

More recently the SES has developed a Business FloodSafe toolkit, designed to increase the preparedness of businesses in flood prone areas, by encouraging them to produce a business flood plan. The program has recently won awards in the Australian Safer Community Awards and is available on the SES website www.ses.nsw.gov.au. The program was piloted in Wagga Wagga and Kempsey and is discussed in Gissing et al. (2005).

Floodplain Risk Management Studies regularly recommend the delivery of community education programs. The SES Public Communications Branch can provide councils with advice regarding how to deliver effective community education programs and resources in the production and delivery of them.

Conclusions

The evaluation results present clear evidence of the need to continue with efforts to enhance warning and evacuation performance. The results will also form the basis of recommendations for further improvement programs.

The SES will continue current programs to enhance warning effectiveness. These programs include: pre-writing of warning messages; research and development of GIS flood information tools to improve flood warning client identification; development of closer relationships with media outlets; the relaunching of the standard emergency warning signal; improvements in the availability of flood information on the internet; and community education programs focused upon improving the understanding of warning products and appropriate responses to warnings.

The results provide valuable information regarding the perceptions and behaviour of residents. Similar perceptions and behaviours can be expected to occur in future floods. The SES attempts to ensure that its warning and evacuation planning is consistent with the likely behaviour of residents.

Incorporation of these results into planning assumptions will ensure that this occurs.

The comparison between the two study areas, Lismore and Byron Shire, suggests some influence by factors such as effective warning time, property type and flood experience and awareness in determining community responses to warnings. Further research is required to confirm the influence of these factors.

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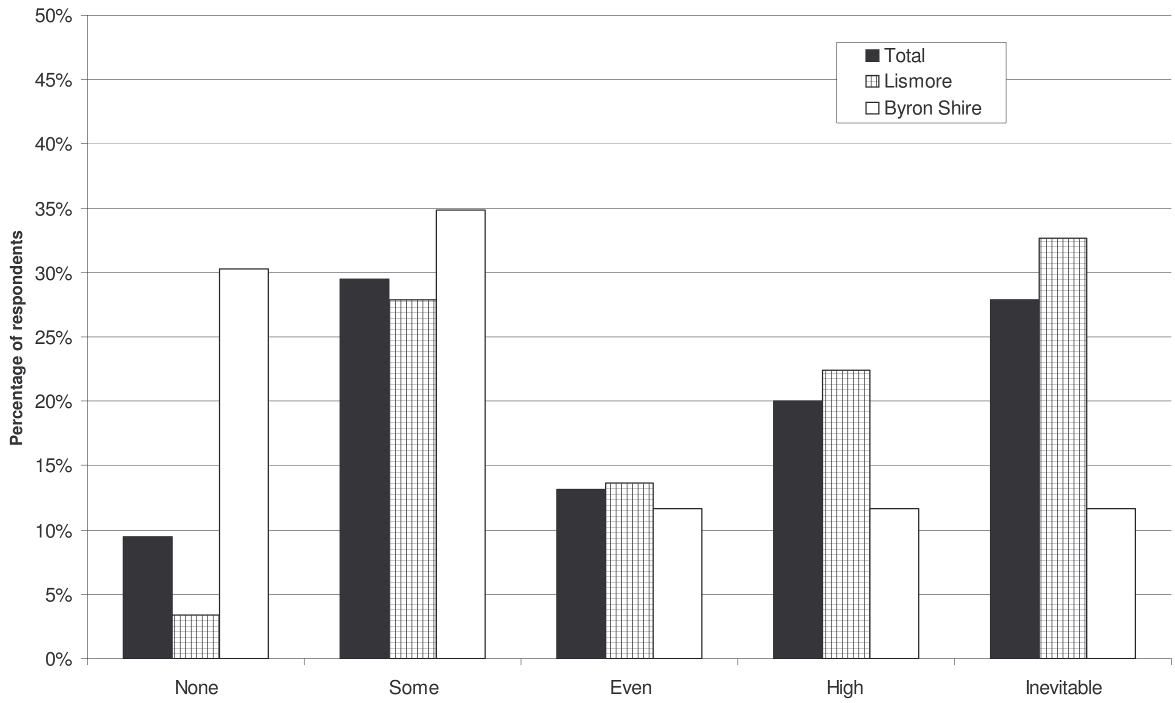
Appendix A

Figure 1: What respondents thought the chance of their property being flooding was prior to June 2005



2D or not 2D – Is That the Question! Rationalising Hydraulic Model Selection.

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Abstract: The ever increasing complexity of hydraulic models has made selection of the most suitable model for a particular flooding problem a difficult task. It is fundamentally important that the observed flood behaviour and required modelling outputs drive selection of the model, not vice-versa. Key characteristics of flood behaviour and typical modelling outputs are discussed and a pre-selection matrix matching some of the more basic model capabilities to modelling needs is presented as a starting point for model selection. It is noted that real world flooding problems will, in many cases, require deeper consideration than that provided by this pre-selection matrix.

Keywords: Flood, Behaviour, Hydraulics, 1D, 2D, Model, Capabilities, Selection

1. INTRODUCTION

1.1. Background to the Issues

During the 1960s and 1970s, the increasing availability, ease of use and power of the then mainframe and mini computers led to the development of a new generation of computer based models in the field of fluvial hydraulics. These new models were substantially more capable than their manual predecessors, and most importantly, able to calculate a flood profile in a stream in a fraction of the time taken by the earlier manual methods.

In the last two decades, computers (hardware and software) have undergone further almost explosive development. This development has in turn triggered the creation of an even more complex and capable generation of fluvial hydraulic models. In general this new generation of models is now graphically driven, provides full support for the import and export of spatial (GIS) data and can display/export the results of a simulation in a spatial context.

All of these newer models are capable of simulating flood behaviour throughout a flood event (not just at the peak) and many have greatly extended the range or complexity of structures that can be incorporated in a model. Some have been extended beyond simulation of basic fluvial hydraulics to incorporate geomorphological impacts (sediment transport, scour and deposition etc.) while others have been extended to incorporate environmental impacts (water quality, eutrophication, thermal plumes, oxygen demands etc.). All models however now require extensive spatial data if their full capabilities are to be utilised.

As a consequence of this growth, a rather bewildering array of complex hydraulic models is now available for a modeller to choose from. In addition, increasing expectations (driven somewhat by the impressive graphic output of these newer models) have compounded the difficulty in rationalising the selection of an appropriate model for a particular modelling task.

While future developments may lead to the development of models capable of accurately simulating every aspect of flood behaviour, all current models have limitations. It is essential that modellers and reviewers/users of current models be aware of these limitations and understand the implications of these limitations in respect to the flooding problem to be simulated.

The model selection process is overviewed in 'Australian Rainfall and Runoff' Book 7(1998) and described in considerable detail in the Dutch Dept of Works 'Good Modelling Practice Handbook' (1999). Charteris, Syme and Walden (2001) presented a comparison between 1D (Mike11) and 2D (Tuflow) models concluding that 2D models have advantages when modelling floods in an urban environment. In general however most current modelling literature focuses on specific models and does little to assist readers understand the relative merits of models or promote rational selection.

This paper has been prepared to remind those active in Floodplain Management that a model must be selected that can

- simulate observed flood bevaviour in a particular area at an appropriate level of accuracy and
- provide the output required to resolve the flooding problem identified.

One should be vary careful to avoid recasting the flooding problem to fit the model!

It is hoped that the material presented will;

- Assist flood modellers with limited experience choose an appropriate model at the outset, without having to switch models mid stream

- Assist reviewers and users of flood models to understand some of the strengths and/or weaknesses of a proposed model.

2. FLOOD BEHAVIOUR

2.1. Introduction

An hydraulic model is in itself simply a means to an end. The need for such a model arises solely from a need to simulate flood behaviour in a particular area, to provide information on flooding that can not be obtained by observation. As such, both an understanding of the behaviour of flooding in the study area and a clear view as to the required outputs required from modelling, are fundamental to the choice of an appropriate model.

The various types of flood behaviour that might be encountered are discussed further in this section and the various outputs that might be required from the simulation are discussed in the following section 3.

2.2. Flood Spatial Characteristics

When most flow occurs parallel to the stream centerline, this is described as linear or one dimensional (**1D**) flood behaviour. When a flood flows across a surface with many changes in direction and little correlation with the alignment of the stream from which it emanated, this is described as two dimensional (**2D**) flood behaviour. Where the direction and velocity of flood flow also varies significantly with depth, this is described as three dimensional (3D) flood behaviour. While 3D behaviour is of considerable significance in estuaries and lakes, most land based flooding can be adequately simulated by 1D or 2D flood models.

As a 1D model can not (directly) simulate 2D flood behaviour it is important to establish at the outset whether flood behaviour in the study area is 1D or 2D. If flood behaviour is strongly 2D a1D model will be unable to reliably simulate actual flood behaviour. While 2D models are rapidly closing the gap with 1D models in terms of speed and ease of use, it should be noted that if flood behaviour is strongly 1D, a 1D model will often provide a quicker, and in some cases more accurate solution than a 2D model.

Guidance on flood behaviour can be obtained from discussion with residents that have experienced flooding in the area, flood photography and from consideration of contour maps of the area. While a 2D model will ultimately confirm flood behaviour (1D or 2D), a 1D model provides no direct feedback as to the correctness of the assumed behaviour. When a 1D model is adopted, it is important to manually review the predicted flood surface levels with the underlying land surface to confirm that other flow paths are not possible.

2.3. Flood Temporal Characteristics

In a multi-branched stream network, it is likely that flooding at a site located below the confluence of several branches will exhibit more than one peak as the flow peak from each branch arrives at the site. When multi peaked flows are likely in the study area, the selected model must be able to reflect this temporally variable (**unsteady)** flood behaviour. Only when there is a clear, well defined (single point of time) flow peak across the study area, can other simpler (**steady** state) approaches to modelling be considered. This aspect of flood behaviour is therefore an important input to the selection process.

2.4. Flood Hydraulic Characteristics

Consideration of the presence of super-critical flow or transitions between sub and super-critical flow in a particular area, will often be difficult to pre-assess without the benefit of some earlier modelling. As some models handle transitions between super and sub-critical flows poorly, and in some cases not at all, it is important to try and confirm this characteristic of flood behaviour before adopting a particular model.

All models discussed in this paper handle sub-critical flows quite well. The important question is – are there locations in the study area where flows could become super-critical at some point in the simulation. In considering this question it should be recognised that super-critical flows may arise at low flow and disappear at higher flows (as may occur on a short steep reach that ultimately is drowned out as flow increases) .

Transitions to super-critical flow are likely to be triggered by;

- Steep surface slopes – particularly when smooth (low Manning's 'n')
- Rises (humps) in the bed form
- Plan contractions in the channel
- Steep localised flood surfaces (eg outfalling to a low tide)

Unhappily those models that have difficulty with super-critical flow and flow transitions will often become unstable and crash with little useful feedback, when flows do become super-critical. Some considerable time can be spent tracking down the reason for such crashes. Unless it is very clear that these transitions will not occur, one should assume that they can occur, when selecting an appropriate model.

3. MODELLING REQUIREMENTS

3.1. Hydraulic Requirements

Basic hydraulic outputs typically required from a simulation include;

- **Elevation** of the floodwater
- **Depth** of the floodwater
- **Velocity** of the floodwater

Other derived outputs typically required include;

- Hydraulic **Hazard** Classification
- Flood **Risk** Classification

3.2. Temporal Requirements

Some model outputs may be required for the full duration of the flood event (as in the variation in depth of flow across a road during an event). Other outputs may only be required at one point in time (as at the peak of the flood).

The required hydraulic outputs may be described as;

- **Static** or temporally steady if outputs are only required at one point in time or,
- **Dynamic** or temporally unsteady if outputs are required at different times or over a particular period of time.

3.3. Spatial Requirements

Some model outputs may only be required at a point (as at a particular site), others may be required along a line (as in a flood profile along a stream) and others may be required across an area (as in flood hazard across a study area). It should be noted that these user driven requirements are not necessarily related to the spatial behaviour of flooding in the study area.

The required spatial output attributes may be described as;

- **Point** Only or
- **Line** Only or
- **Spatial**

3.4. Resolution Requirements

It is a fundamental requirement that any model under consideration must be able to simulate flood behaviour at the resolution of the problem it is to investigate. For example, in a 1D situation, a rapidly varying flood surface will need closely spaced cross-sections to properly simulate flood behaviour. In a 2D situation the dimensions of the cell or element representing a creek or bridge waterway will need to be no more than about one quarter of the creek or opening width to properly simulate flood behaviour.

This requirement is normally resolved by considering whether the problem can be adequately described with elements that are;

- **Fixed** at one discrete size/orientation
  As in a single cell size grid - or need to be
- **Multiple** discrete sizes (and orientations)
  As in a nested or multi-domain grid - or need to be
- **Variable** in size (and orientation)
  As in a finite element mesh

3.5. Detailed Hydraulic Requirements

All models incorporate some simplifying assumptions in their solution methodology. This can lead to an inability to simulate some of the more 'detail' aspects of flood behaviour. If for example affluxing of flow against buildings or eddy patterns are actually relevant to your study, then the model must be able to simulate this relatively detailed flood behaviour.

3.6. Flexibility Requirements

The need for flexibility in a model is often difficult to pre-assess and will realistically need to be balanced against possible application cost increases. Consideration of flexibility is most likely to arise in staged studies where the initial Flood Study can be completed (well) with a particular model but the Risk Management Study requires different capabilities.

3.7. Portability Requirements

Portability issues are also likely to arise in staged studies or in modelling that a council wishes to take over after a study has been completed. The ever increasing use of GIS as the primary data store in new models is fortunately reducing the impact of this problem, but it remains an issue for consideration in selecting an appropriate model.

3.8. Other Requirements

The above requirements are those likely to be required in most flood studies. There is however an ever expanding demand for information on other flood related matters including;

- Geomorhological Impacts
- Ecological Impacts
- Flood Damages
- Emergency Management

These are likely to feature more prominently in future flood studies and consequently be added, at least as optional modules, into future flood models..

4. MODEL CAPABILITIES

4.1. Introduction

There presently exists a great many models that could be classified, at least in part, as hydraulic models. The focus of this paper is however in respect to those hydraulic models that have been specifically developed to simulate flood hydraulics .

In the following description of models, the term 'Quasi 2D'(Q2D) is introduced. This is a feature of some 1D models that reflects their ability to model branched networks, thereby simulating, in a simplified fashion, the flowpaths that develop in an area of 2D flow.

Models with local support and some use in recent Flood Studies in NSW include;

ID and Q2D Models:

- **ESTRY**
  A 1D/Q2D hydrodynamic model using an implicit finite difference solution to the 1D St Venant equations. Integrated with Mapinfo and SMS for GIS data storage and display purposes.
  www.tuflow.com

- **HEC-RAS**
  A 1D/Q2D hydrodynamic model based on partial solution of the 1D St Venant equations. with integrated graphics and interaces to several external graphics suites.
  www.hec.usace.army.mil

- **MIKE 11**
  A 1D/Q2D hydrodynamic model using an implicit finite difference solution to the full St Venant equations, with many options and integrated graphics.
  www.dhisoftware.com/Mike11

- **XPFLOOD**
  A 1D/Q2D SWMM based model integrated wth the 12D graphics package to provide hydrologic and hydraulic analysis tools relevant to flood plain management.
  www.xpsoftware.com

2D Models:

- **FLO2DH** (recently renamed FST2DH)
  A 2D FEM based hydrodynamic model using the Galerkin (method of residuals) formulation to solve the 2D St Venant equations. Integrated with the SMS graphic suite for construction and display purposes.
  www.ems-i.com (SMS & FST2DH)

- **MIKE 21**
  A 2D grid based hydrodynamic model using an implicit finite difference solution to the full St Venant equations, with many options and integrated graphics.
  www.dhisoftware.com/mike21

- **TUFLOW**
  A 2D grid based hydrodynamic model using an implict finite difference solution to the 2D St Venant equations. Integrated with Mapinfo and SMS for GIS data storage and display purposes. Integrated with 1D (Estry) networks.
  www.tuflow.com

Hydraulic models with less local application (but significant application in other parts of the world) include;

- RMA2
  www.ems-i.com (SMS & RMA2)

- TELEMAC-2D
  www.telemacsystem.com

- INFOWORKS
  www.wallingfordsoftware.com

- WATFLOOD
  www.civil.uwaterloo.ca/watflood/

- FLO2D
  www.flo-2d.com

- SOBEK
  www.sobek.nl

4.2. Model Capabilities

All of the above models are highly capable. It is not practical to begin to discuss their full capabilities in a paper such as this. Readers are referred to the various web sites for details of these capabilities.

A very simplified indication of key capabilities relevant to flood simulation needs has however been assembled by the author and is presented in the following section. It should be noted that the models are all developing rapidly. The capabilities listed will no doubt expand as time passes.

5. MODEL SELECTION

5.1. Matching Needs to Capabilities

As previously noted – the key to rationalising the model selection process lies in matching a model's capabilities with the observed flood behaviour and required outputs from modelling.

While a simple statement, the mix of experience required and complexity of available models, makes the matching process difficult to execute.

This process is further complicated by;

- The modeller's familiarity with particular models.
- The cost of purchasing and developing an appropriate skill level in the use of a new model.

Notwithstanding these complications, the model selection process should be as rational as circumstances permit. To assist in this process, a selection matrix follows in which the key capabilities of a range of models are identified in terms of their ability to simulate observed flood behaviour and provide the required outputs.

MODEL	FLOOD BEHAVIOUR TO BE SIMULATED											MODELLING OUTPUTS REQUIRED													
	SPATIAL				TEMPORAL		HYDRAULIC		STRUCTURES			TEMPORAL		SPATIAL			RESOLUTION			OTHER			GRAPHICS	
	1D	Q2D	2D	M2D	STDY	USTDY	SUB	SUP	C/B/W	1DC	1DD	STAT	DYN	POINT	LINE	DIST	FIXED	MULT	VBLE	SED	QUAL	ECOL	HIQUAL	FLEXIBILE
YOUR NEEDS																								
HEC-RAS	✓	✓	NA	NA	✓	✓?	✓	✓	✓	NA		✓	✓?	✓	✓	✓?	Section and node point spacings may be varied to suit reqd outputs			✓			✓?	✓?
MIKE 11	✓	✓	NA	NA	✓	✓	✓	✓	✓	NA	✓	✓	✓	✓	✓	✓?				✓AM	✓AM	✓AM	✓	✓
XPFLOOD	✓	✓	NA	NA	✓	✓	✓	✓	✓	NA	✓	✓	✓	✓	✓	✓?							✓	✓
MIKE21	✓	NA	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓AM		✓AM	✓AM	✓AM		
FST2DH	✓?	NA	✓	✓	✓	✓?	✓	✓	✓		✓	✓	✓?	✓	✓	✓	✓	✓	✓	✓			✓AS	✓AS
RMA2	✓?	NA	✓	✓	✓	✓?	✓		✓			✓	✓?	✓	✓	✓	✓	✓	✓				✓AS	✓AS
RIVER2D		NA	✓		✓	✓?	✓	✓				✓	✓?	✓	✓	✓	✓	✓	✓				✓?	✓?
SOBEK(URBAN)	✓	NA	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓AM					✓	✓
TUFLOW	✓	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓AM					✓AS	✓AS

✓	Indicates robust capability
✓?	Indicates problematic capability
✓AM	Indicates capability not available at core level but may be added by acquisition of additional modules
✓AS	Indicates capability not available at core level but may be added by acquisition of third party software

FLOOD MODEL PRE-SELECTION MATRIX

As model flexibility and portability, user familiarity and acquisition cost are user specific considerations, they have not been included in the above matrix. They are however extremely important considerations and should form part of the pre-selection assessment process.

6. CONCLUSIONS

The level of complexity and sophistication of the various hydraulic models available today makes for difficulties when trying to match the particular modelling needs of a site to an appropriate model.

Notwithstanding these difficulties, it is important to select a model on the basis of its ability to simulate the observed flood behaviour and to provide the required modelling outputs.

It is most important that users understand both the flood behaviour they seek to emulate and the capabilities/limitations of the various models on offer if a selection is to be made on a rational basis.

Without this understanding, there is a very real danger that a problem could be recast to fit the adopted model, with potentially serious consequences for the quality of the resulting simulation. While relevant and accurate output is important, users should not be overwhelmed by the glitz factor of some 2D models.

In the author's view, 2D or not 2D is only a small part of the question to put when approaching selection of an appropriate flood model. Modellers must focus on ensuring that the adopted model can properly simulate observed flood behaviour and provide the required answers at an appropriate level of accuracy.

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FLOODPLAIN MANAGEMENT IN THE MODERN ERA – EMBRACING TECHNOLOGY

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Presenter's Profile

Having considerably experience as a floodplain engineer, Lloyd has been involved in floodplain risk reduction studies throughout Australia, South East Asia and the United Kingdom. Lloyd was heavily involved in flood analysis for the now successful London 2012 Summer Olympics Bid.

He has an excellent knowledge of floodplain processes and has established a strong understanding of community consultation and the application of GIS. He has experience with a wide range of computer modelling packages including TUFLOW, MIKE21, SOBEK, MIKE11, XP-UDD, HecRas, RAFTS-XP, RORB and URBS.

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Abstract

Floodplain management today is moving in time with technology. New methodologies for managing the risk of an imminent disaster are constantly being developed and the environment in which we work changes as rapidly as a river breaking its banks. It is these changes in the tools available to floodplain managers that often challenge us as much, or even more than the inherent science of the flooding phenomenon.

Key Words: Computer Modelling, GIS Data Management, Latest Technologies, Data Collection

1. Introduction

Flooding is a phenomenon that affects the lives of thousands of Australians every year. It is with our incredible country that we accept and deal with floods such that our way of life is both protected and managed.

This paper provides an overview of the consolidated approach to floodplain management utilising the latest technologies and recent advancements in computer modelling and data management. It will discuss the relative merits of the digital age and illustrate examples of how these technologies are being applied to enhance the level of information readily available to today's floodplain manager and to the broader community.

2. The Underlying Information

Understanding the natural system that forms the floodplain and the inherent condition of the catchment is an imperative component of determining ways to manage the system. The more information we know about the system the easier it becomes to deal with the risks associated with it. To this end, data collection forms the basis for a lage proportion of our floodplain management activities.

It is no secret that the most fundamental component of any floodplain planning process is the underlying data on which outcomes are based. In the case of planning process where strong reliance is placed on results from computer modelling of the physical system, underlying data describing the natural state of the area of interest is not only important, but is the "be all and end all". It comes back to garbage in = garbage out, if garbage information is used to generate information, that information will in all likelihood be garbage as well.

A very wide range of data can be utilised to develop strategies for managing floodplains. Physical catchment information, recorded historic information and anecdotal information from communities are all widely used in the management and planning process.

3. Topographic Data Collection

Topographic data used to describe ground surface features can be considered as the foundations on which most floodplain modelling is built. With increased reliance on broad scale topographic data collection, it is well worth considering how this data is collected and the inherent issues related to the range of data collection methods.

3.1 Traditional Ground Survey

Collected using slow yet accurate methods, ground survey is a time consuming and labour intensive methodology. Due to the intensive nature of traditional survey methods, it is expensive for use in the collection of data over a large area. It does however offer very good accuracy and it is favourable to use in and around critical areas of floodplains such as hydraulic controls like bridges, levees, weirs and culverts. Its use is also limited in remote and difficult to access areas.

3.2 Remote Sensing Technology

The area of "board scale" topographic data collection using remote sensing, data collection by aerial means, is advancing very rapidly. Recent technologic advancements have seen an increase in the availability of cost effective, high resolution digital elevation models (DEM), primarily constructed using data collected by remote sensing techniques such as Photogrammetry or Aerial Laser Scanning (ALS).

Remote sensing technologies have the advantages of "broad scale" data collection, allowing:

- Data capture for large areas to become feasible;
- Data capture for large areas with less expense;
- Quicker collection of data over large areas;
- Supplementing more detailed data (combining data sets); and
- Providing a high density of data over the area of interest.

3.2.1 Photogrammetry

Data can be collected using photogrammetry over large areas relatively quickly using photos taken from above the area of interest. The accuracy of the final product is heavily reliant on the scale of the photography (i.e. high level vs low level), the skill of the photogrammetric operator(s) and the extent of photographic obstruction. It has often been a significant issue for this type of data collection that ground surfaces are not always easily seen from above due to dense vegetation cover, poor weather conditions or obstructions such as bridge decks or other structures.

Another limitation of the data collection methodology is that no below water information can be achieved. In cases where below water information is important, further survey and data manipulation is required to define topography under the waterline.

3.2.2 Airborne Laser Scanning (ALS)

Airborne laser scanning, or LIght Detection And Ranging (LIDAR), is a cost and time effective technique for the acquisition of topographic data. Airborne Laser Scanners emit rapid pulses of laser light in order to precisely measure distances from the sensor mounted on an aircraft to the ground surface. Airborne laser scanners are capable of measuring heights to accuracies of 5-10cm. However, relative vertical accuracies from commercially available ALS systems typically are in the order of +/-150mm. Errors are common in ALS survey in areas of dense vegetation where the laser light may not reach the ground, or where the light bounces on other surfaces other than the ground. These errors are typically filtered out in post processing. However, it is not always possible to automatically remove all anomalies and as such some degree of manual data manipulation is occasionally required.

One of the key areas of advancement in the field of data collection for use in floodplain management appears to be in the form of a Laser Survey capable of penetrating water bodies to accurately define river bathymetry. This technology is currently in use in America and is soon to be trailed here in Australia. At this stage the technology is in it's infancy and is likely to be prohibitively expensive. Concerns also exist over the ability of the laser to penetrate water which is highly turbid.

3.2.3 Bathymetric Data Collection

Bathymetry data is data relating to the depth of a body of water and is typically used to define the ground profile of the bottoms of creeks, rivers, lakes, estuaries and the ocean. These depths are almost always derived indirectly by measuring the time required for a signal to travel from a transmitter, to the bottom, and back to a receiver. This travel time is then converted to a depth based on a variety of estimations of the signal speed through the water column. Bathymetric data can be collected anywhere a boat has access. In the US wave runners are being tested to get into places boats can't such as narrow creeks or across bar ways.

In modelling terms, bathymetric data allows more accurate representation of waterway characteristics in both hydraulic and water quality models. This data can not be currently collected using the broad scale data collection techniques discussed above as these techniques will only typically define the water surface. Therefore, for more detailed representation of waterways, bathymetric data, where available, should be used ahead of other data sources. To do this, it is possible to merge the bathymetric data with other data (i.e. Photogrammetry or ALS to create accurate detail of creeks/rivers where broad scale methods such as ALS are less accurate, and provide floodplain definition (where accuracy of the broad scale techniques are typically better).

Bathymetric data is being collected across Australia. In Fact, most of northern NSW has had data collected for DIPNR.

3.2.4 Satellite Photography

Data collection using satellite photography is an emerging field. Currently, mostly broad scale, relatively inaccurate information is collected using this method; however data captured using this method may be the next frontier in broad scale data collection.

4. Floodplain and Catchment Analysis

Advancing data collection techniques are quickly enabling a much greater volume of data to be collected at ever improving accuracies. The availability of this data and the ever improving technologic advancements in the floodplain management field is facilitating rapid improvement in the types and detail of analysis being undertaken.

4.1 Catchment Delineation and Automated Stream Ordering

The availability of catchment wide topographic data, often collected using one of the aforementioned techniques, has seen several modelling techniques evolve. These include automated catchment delineation and stream prioritisation. Software packages have become available that use the catchment topography to determine parameters such as contributing areas to each point in the catchment and the slope at each point which is then used to simulate catchment response. Two available outputs from this process are delineated sub catchments that can be used for hydrologic modelling and detailed stream ordering often used for both water quantity and quality prioritisation.

4.2 Broad scale flood mapping

Broad scale flood mapping provides likely inundation extents of complete catchments. It is an example of the development of innovative ways to use available data, and has been made possible by the availability of topographic data for entire catchments. This process relies only on the existence of a good quality DEM to determine the areas within a catchment that are likely to be at risk of inundation at a broad scale. The process provides analysis in areas where detailed flood modelling is not available, but is not a substitute for detailed hydraulic modelling for fine scale uses.

4.3 Hydraulic Modelling

There has been significant advancement in hydraulic modelling in recent years. With rapid advancements in computer speeds and the increased need of spatial information relating to flood hazard on floodplains, two dimensional (2D) hydraulic modelling is quickly becoming a commonly used tool. A number of key 2D hydraulic models are now commonly used within Australia. These models are constantly evolving and new techniques emerging. A number of key emerging features are discussed in the following sections.

4.3.1 Combined 2D and 1D models

2D models allow simulation of complex flow patterns across a floodplain and spatially detailed presentation of flood outputs. They can provide better representation of complex floodplain behavior than 1D models that may “force” flow patterns in the floodplain. They also provide the ability to undertake more accurate flood mapping. However, 2D models do not have the ability to model small drainage structures or critical “1D” components of a floodplain. Thus, the combination of 1D and 2D models has developed to harness the benefits of both modelling methods into one. This can include, but is not limited to:

- Insertion of Pipes and Culverts;
- Modelling of complex bridge and weir structures; and
- Inclusion of “sub grid scale” 1D channel elements;

JWP use three of the industry accepted 1D/2D packages that have this functionality, including TUFLOW (WBM), MIKEFLOOD (DHI), and SOBEK (DELFT).

4.3.2 Multiple 2D Domains

The ability of 2D models to have multiple domains has further improved the flexibility of 2D models to represent the flow on a floodplain. This development allows key areas of interest, such as within a township or heavily developed area, to be represented at a finer grid resolution and other areas where fine detail is not required to be represented at a coarser grid size. This allows a detailed model to be developed while optimising the number of grids cells required, and thus reducing the modelling time and providing more detail in key areas of large models than previously possible.

4.3.3 Direct Rainfall

Applying rainfall directly to the modelling area, without the use of a hydrologic model, is another of the emerging areas of 2D flood modelling. Typically useful in urban areas where the entire catchment is being modelled this technique may prove very useful in managing complex flooding situations in built up areas.

4.3.4 Computational Fluid Dynamics

The use of Computational Fluid Dynamics (CFD) in floodplain management is an emerging application. CFD is computer-based numerical modelling to provide 3D behaviour of fluid flow. It has been applied in various studies to model the effects of bridge piers (including scour and turbulence) in high flow situations and for the design of complex hydraulic structures such as dam spillways. This highly detailed and complex technology is continuing to develop and more varied and widely used applications for this technology are expected to emerge in the coming years.

4.4 Real Time Flood Warning

Right around the world, flood warning is being used as one of the key methods for the reduction of risk for communities affected by flood waters. Warning the community of an imminent flood has been proven as a very effective strategy in risk reduction and for this reason increasingly complex flood warning systems are being developed. With the introduction of catchment monitoring available online (internet) and the increase in speed at which hydrologic and hydraulic models can be run, real time flood warning is coming to the fore. Many flood warning systems are currently in use around the world where real time rainfall is quickly and effectively used to generate estimates of catchment response (runoff) that is then input into hydraulic models to estimate flood levels and extents of flood inundation. Currently, only broad scale modelling and flood mapping is generally adopted as timing of information is critical. As technology enhances, it is likely to become possible to undertake more detailed forecasting using more complex models and data.

A number of constraints exist in terms of the application of flood forecasting. One of most prohibitive is the fact that many systems still rely on an experienced operator to manipulate the system in an emergency situation. This can cause problems because flooding can occur at any time of the day or night and due to the nature of these events a significant amount of time can pass between uses of the system, leaving the operator out of practical experience.

The future of flood warning certainly points towards fully automated, online systems. Systems which log rainfall and other catchment conditions and use these readings to predict areas at risk. These systems will invariably become more involved and make use of more complex technologies to generate more detailed information.

5. The Outcomes

Ultimately, much of what is done in managing the risks of flooding relies principally on the outcomes from investigation into the physical system presenting the risk. And because people from a diverse background use this information, using the latest technologies and techniques to present data in the most easy to digest manner is an important role of today’s floodplain managers.

5.1 GIS Data Management and Consolidation

The use of Geographical Information Systems (GIS) has been fundamental to the improvement of modelling techniques, result presentation and the collation and storage of data. Hydrologic and hydraulic modelling using GIS allows models and model results, to be created in real space, overlayed on aerial photos, DEMs and cadastral boundaries. This information can then be quickly and easily integrated into a complete GIS database enabling more complete use of the data.

Many local government authorities are putting resources into the collation and GIS integration of data over their entire municipal area. For example various Councils have developed water quality and flood databases to manage data, creating one central repository of information both old and new. This process then removes the need for staff to search through piles of old reports and maps to find relevant information.

On a larger scale the Queensland Water Resource Data Strategic Directions Committee (QWRDSDC) has been set up to improve the collection and availability of water resource data in QLD. The committee aims to facilitate the ongoing implementation and development of a state-wide water information framework.

5.2 Information Presentation

With the ever increasing need for the management of flood risks to be undertaken in consultation with communities, presentation of information in an easy to understand yet technically sound manner is critical to success. The more wide spread use of modelling techniques and process which present results spatially is certainly aiding in making information more digestible to the broader community. The use of computer animation technologies and other computer graphics enables today's floodplain managers to deliver a clear and precise message.

6.0 Conclusion

Just like the floods that we manage, technology is a fluid entity. Advancements in the fields that we operate in will continue to challenge us, as well as help us to deliver on our aim of making our country less vulnerable to the ravages of floods.

Invariably new technologies will emerge in all the areas of floodplain management and flexibility to adapting to these will be critical as our populations grow and a greater degree of understanding of our natural systems is needed.

USE OF WEB-BASED FLOOD MAPPING DURING EMERGENCY RESPONSE OPERATIONS

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Abstract

A common output from a flood study is a suite of flood inundation maps for a range of flood magnitudes. These maps typically show flood characteristics and the flooding status on an individual property. As such, the maps provide a valuable resource in emergency flood response operations. However, the maps are often provided as a hard copy and/or in a specific GIS application format. This can limit their use when access to hard copy flood maps or use of a specific GIS application is required. A web-based GIS interface has been developed to enable online access and interpretation of flood inundation maps. The interface displays flood characteristics and property related flood status. Further the interface can provide guidance on required response actions for a given flood magnitude. The web-based format of the interface allows access fore a variety of stakeholders including relevant agencies and the community. The application of this interface to the Shepparton-Mooroopna area is discussed.

Key Words: Flood warning, flood mapping, emergency response, web-based GIS mapping

Introduction

This paper outlines the application of web-based flood mapping for emergency response as part of the Shepparton-Mooroopna Flood Warning and Emergency Management project (S-MFWEM). The web-based flood mapping aimed to improve emergency response planning before a flood event and operations during a flood event.

A project team led by Water Technology on behalf of the Greater Shepparton City Council (GSCC) and Goulburn Broken Catchment Management Authority (GBCMA) has undertaken the Shepparton-Mooroopna Flood Warning and Emergency Management Project. Figure 1 shows the project area.

The project was jointly funded by the Federal and Victorian State Government under the Regional Flood Mitigation Program.

This paper is limited to the application of a web-based flood GIS mapping interface to emergency response in the Shepparton and Mooroopna area. Further details of the S-MFWEM project are provided in the paper by Crapper et al 2005. Further information on the technical details of the web-based mapping platform is provided in Zerger, A. and MacLaren, G. (2003).

Background

Shepparton-Mooroopna is located at the confluence of the Goulburn and Broken Rivers, and Seven Creeks. The total catchment area to Shepparton is 16,125 km^2.

Major flooding in the project area has occurred in 1916, 1939, 1956, 1974, 1975 and 1993. These major historical floods have highlighted that the relative contributions from the Goulburn and Broken Rivers, and Seven Creeks can vary significantly. The relative catchment contributions can markedly influence flood behaviour within the project area.

The Shepparton Mooroopna Floodplain Management Study (SMFM) (SKM 2002) was undertaken for the GSCC and GBCMA in 2001-2002. The SMFM study undertook extensive topographic and field survey, hydrologic and hydraulic analyses, and flood damage assessment to define flood behaviour and risk within the study area. The analyses found some 6,500 properties were impacted by the combined affects of the Goulburn River, Broken River and Seven Creeks during a 100-year flood.

From this knowledge came the understanding of flood risk, which underpinned the development of a floodplain management plan. Community consultation during the SMFM study concluded that none of the proposed structural mitigation measures were desirable due to predicted adverse flooding impacts to adjacent areas.

The SMFM study made the following recommendations:

- Adoption and implementation of revised land use planning maps;
- Improvements to flood warning tools/systems and arrangements;
- Refinement of flood response plans;
- Refinement of flood monitoring arrangements;
- Strengthening flood preparedness and community flood awareness, and;
- Development of improved information management systems.

The first recommendation was completed by GSCC and GBCMA. The remaining recommendations form the basis of the S-MFWEM project.

This paper is limited to the final project element listed above, namely the development of improved information management systems.

As discussed previously, Shepparton and Mooroopna lie at the confluence of three major river systems: Goulburn River, Broken River and Seven Creeks. The flooding characteristics (flood depths, extents and velocities) and in turn, the required response actions are heavily influenced by the relative contributions and timings of flood flows from the three catchments.

To cater for a variety of catchment inflows, hydraulic modelling was undertaken for three scenarios:

- Goulburn River dominant flood events (SKM 2002);
- Goulburn/ Broken/ Seven Creeks Neutral flood events (SKM 2002), and;
- Broken River/ Seven Creeks dominant flood events in the S-MFWEM project.

A suite of hard copy flood inundation maps providing details of flood depths, levels, velocities and the location of affected properties were prepared for the three catchment inflow scenarios across a range of flood magnitudes.

This type of flood information is paramount as it enables flood height predictions, issued by the Bureau of Meteorology, to be meaningfully translated throughout major centres.

The development of an improved information management system focused on utilising the information shown on the hard copy flood maps within an interactive web-based based GIS interface.

Web-based flood mapping interface

The project utilised a web-based GIS interface to facilitate flood response operations. The GIS interface is based on the FloodBank interface. Floodbank is an Internet mapping system used to catalogue study areas and associated flood event databases generated from flood models. FloodBank was developed with the assistance of a grant from the Emergency Management Australia Projects Program (Zerger et al 2003). FloodBank was developed in conjunction with CRSIRO, University of Melbourne and ESSolutions.

During the course of the S-MFWEM project, significant enhancements and refinements were made to the originally developed FloodBank interface.

The interface enables users to visually interrogate the catalogue of study areas and associated simulations of flood events, to spatially visualise flood risk, and for distributing flood event data to users requiring more sophisticated analysis. FloodBank is an Internet application, comprising a user interface, data querying and reporting toolbox, data management catalogue (i.e. metadata database) and a data warehouse. The application has been developed using a range of technologies that includes Microsoft Active Server Pages (ASP) for the construction of the user interface and database querying engine, Microsoft Access databases for the data management. (Zerger, A. and MacLaren, G. (2003))

More technical details of FloodBank can be obtained from Zerger, A. and MacLaren, G. (2003) and Zerger et. al. (2003).

Functionality and Enhancements for Shepparton and Mooroopna

The web-based GIS interface utilises the hydraulic modelling outputs from the development of the hard copy flood inundation maps. Further extensive floor level data (SKM 2002) is employed to assess the impact of flooding on an individual property basis.

As part of the S-MFWEM project, considerable enhancements were made to the web-based GIS interface as initially developed by Zerger et. al. (2003). These enhancements focused on providing specific information on flood hazard and risk to properties, and infrastructure. In turn this specific information provides response agencies with guidance for effective and efficient response actions.

The following sections outline the web-based GIS interface's functionality and enhancements.

Selection of Catchment Inflow Scenarios

As discussed previously, modelled flooding characteristics are available for the three catchment inflow scenarios.

During future flood events, the Bureau of Meteorology will issue flood forecasts and warnings for the Shepparton-Mooroopna area. These forecasts and warnings will enable determination of the appropriate catchment inflow scenarios and relative magnitude of the flood event.

The interface user can then select the most appropriate modelled flood event to the Bureau's flood forecast from the interface shown in Figure 2.

Basic GIS functionality and Information

Once a modelled flood event is selected, the event viewer window is opened. The event viewer window allows the following basic GIS functionality:

- Selection of layers for viewing
- Zoom in and out tools
- Pan tool
- Query tool

The maps layers include:

- Flood properties (below and above floor level)
- Traffic hazard within the road reserve
- Water depth
- Aerial photos
- Cadastre

An animation of the flood propagation through Shepparton and Mooroopna can be viewed for a flood event. Alternatively a particular time step or the maximum envelope of flood extent can be selected for viewing. The maximum envelope is equivalent to the flood characteristics shown on the corresponding hard copy flood map. The animation allows for the temporal and spatial variation of flood behaviour to be considered in the assessment of response actions. Also the animation facilitates effective resourcing of flood monitoring activities.

The right hand panel provides summary information of the flood event being considered.

Figure 3 shows the event viewer window layout.

Flood information

The query tool can be used to determine the flood depth at any location for a given flood event. The flood depth is provided as flood depth categories rather than absolute depth. This use of flood categories significantly reduces the information requiring storage in the database. The use of the flood depth categories mirrors the flood depth information shown on the hard copy flood maps.

Figure 4 shows the flood information available through the query tool.

Property information

Similarly the query tool can be used to select a flooded property. For the selected property the following information is provided:

- Address
- Ground level (m AHD)
- Floor level (m AHD)
- Flood depth (m)
- Flood level elevation (m AHD)

Figure 5 shows the property information available through the query tool.

Traffic hazard

During a flood the traffic-ability of a street/ road affects the mode of transport employed for response actions and the potential hazard faced by the response personnel.

The flood hazard (depth * velocity) has been determined within the road reserves.

Figure 6 shows the information provided on traffic hazard.

Council infrastructure

During flood events, a number of penstocks prevent backwater flooding within the project area. The Greater Shepparton City Council has developed flood intelligence linking the operation of penstocks to the flood level for the Goulburn River at Shepparton. This flood intelligence on the operation of penstocks is being incorporated into the web-based GIS interface.

Inclusion of the web-based GIS interface in Emergency Response Planning and Operations

As part of the S-MFWEM project, revision and updating of the Greater Shepparton City Council Municipal Emergency Management Plan Flood Sub-Plan is currently underway. The Flood Sub-Plan defines the flood response actions for the relevant agencies.

To enable the effective use of this web-based GIS interface during a flood event, detailed instructions are being included in the Flood Sub-Plan. GSCC and VICSES personnel have been consulted in the development and application of the web-based GIS interface.

Conclusion

A common output from flood studies in Victoria is a suite of flood inundation maps. These flood inundation maps show the flood characteristics for a range of flood magnitudes. These flood maps show properties affected below and above floor level. The flood maps are a valuable resource in the flood response planning and operations. Typically the flood maps show the maximum flood extent. Hence the flood maps do not provide information on the spatial variation during the course of the flood event.

The web-based GIS interface developed by the S-MFWEM project utilises hydraulic modelling outputs to display the spatial variation of flood characteristics during the course of the flood event.

The web-based GIS interface provides a useful tool in flood response planning and operations. The web-based GIS interface shows the spatial and temporal variation of a flood across the entire study area. Key information for flood response operations, such as flood affected properties, flood hazard along roads and required response actions for Council infrastructure, is visually displayed

Acknowledgments

The authors wish to thank the members of the S-MFWEM project Technical Steering Committee for their contributing to the enhancements and refinements of the web-based GIS interface.

The authors acknowledge CSIRO, University of Melbourne and ESSolutions as the initial developers of FloodBank. Further the authors acknowledge the initial development of Floodbank was funded by EMA.

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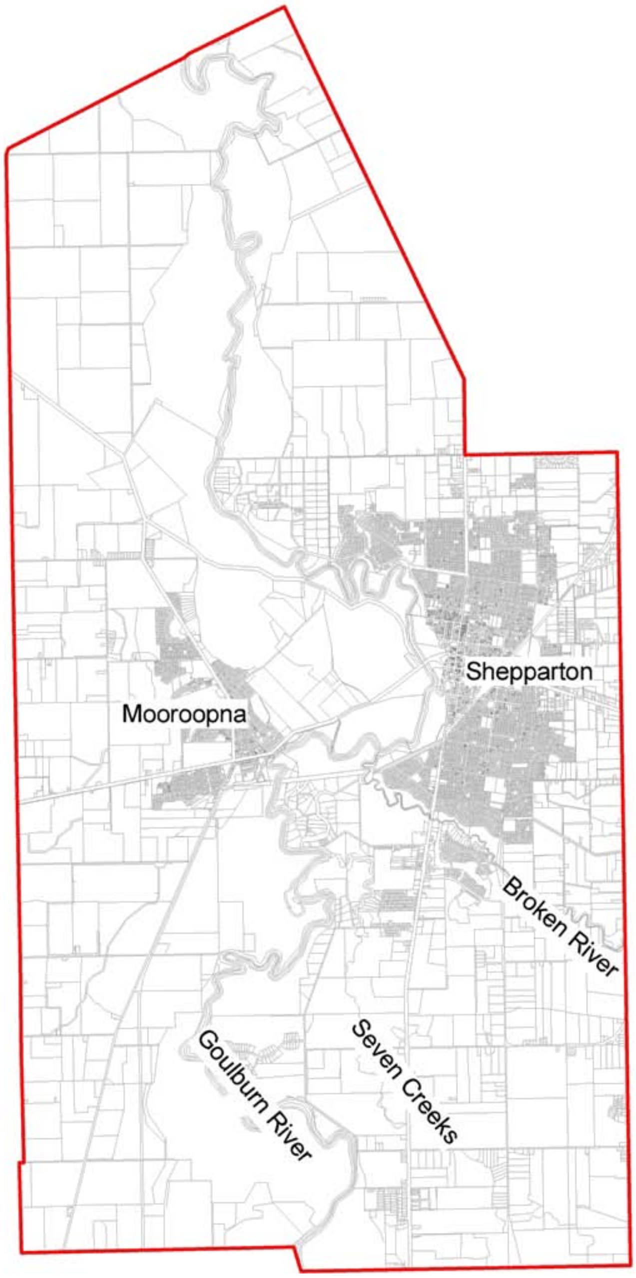

Figure 1 Project area

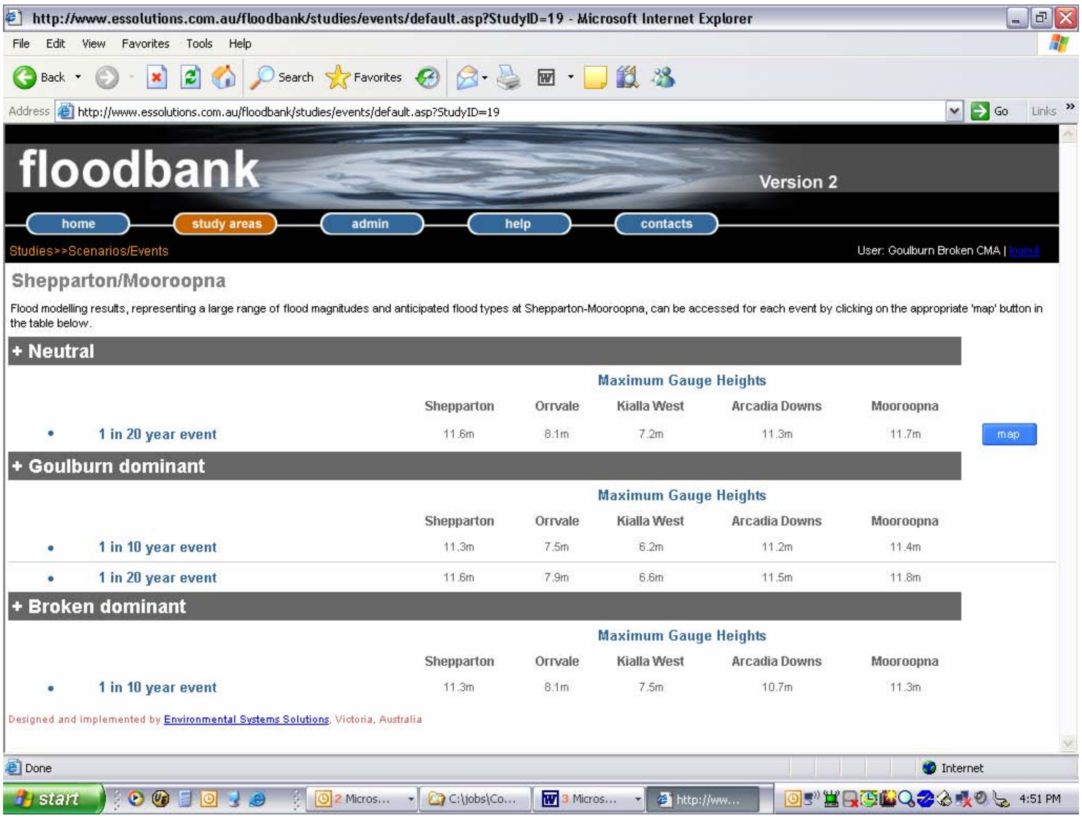

Figure 2 FloodBank Scenario Selection Window

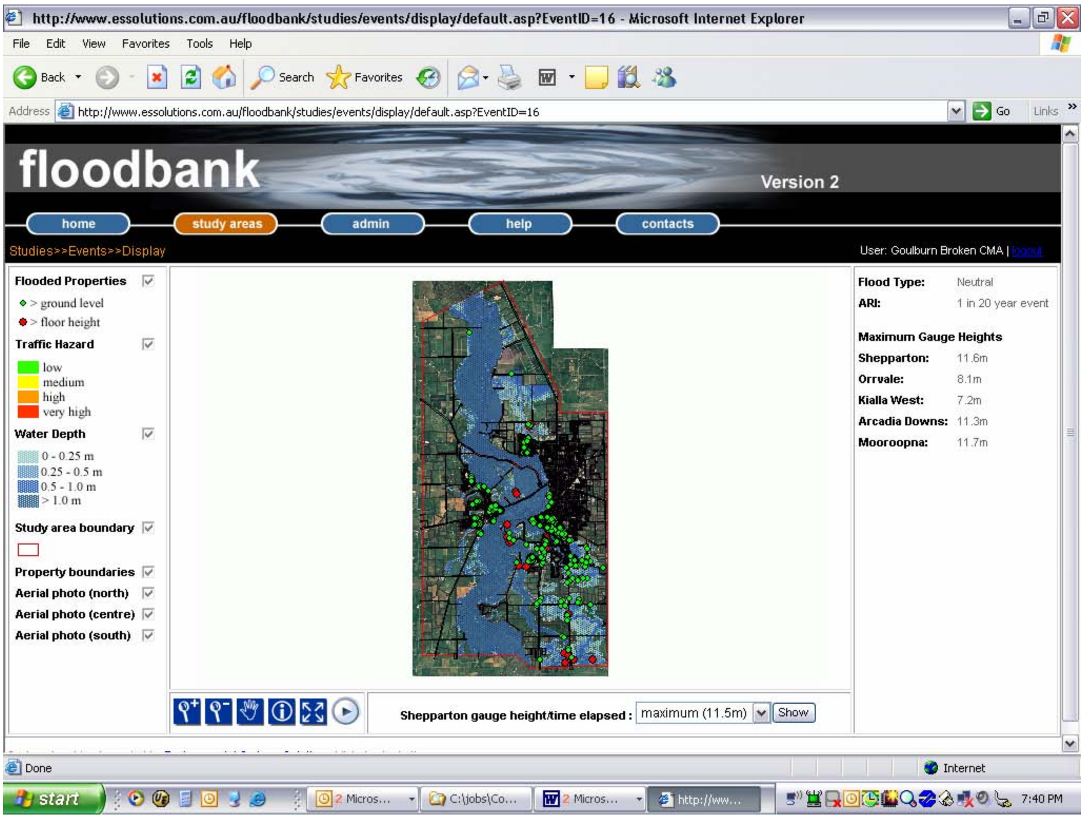

Figure 3 Event viewer window

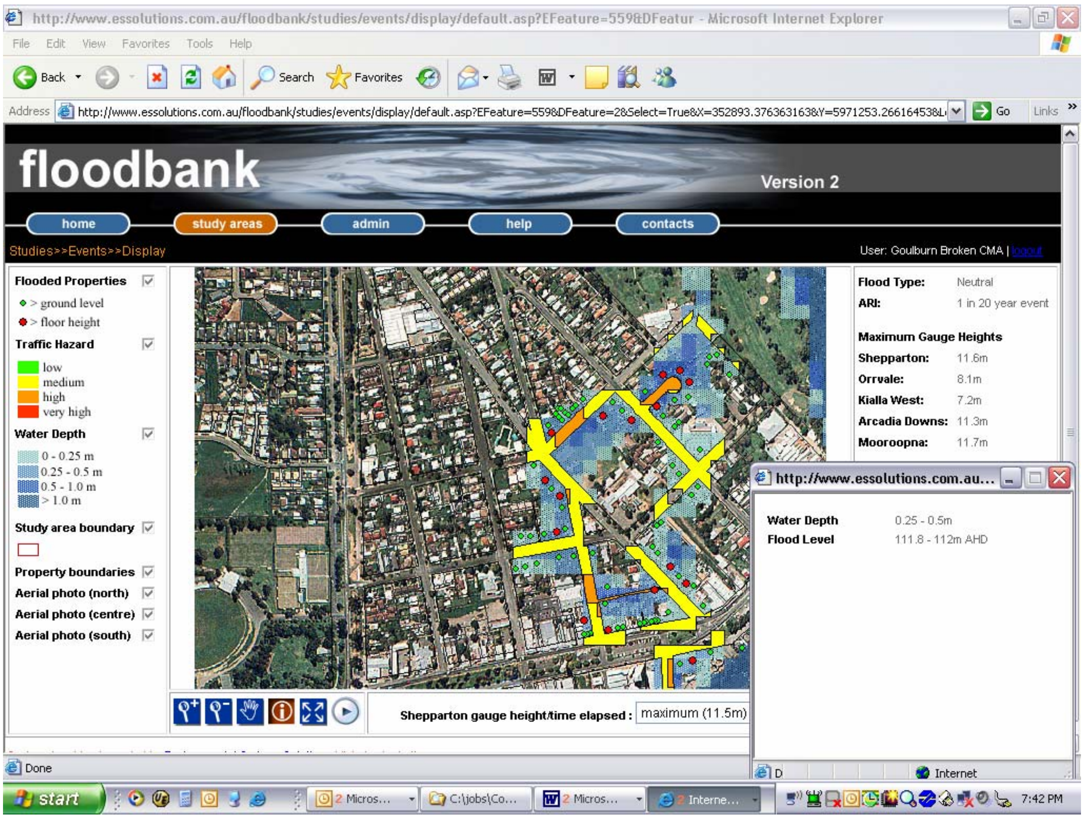

Figure 4 Flood information query

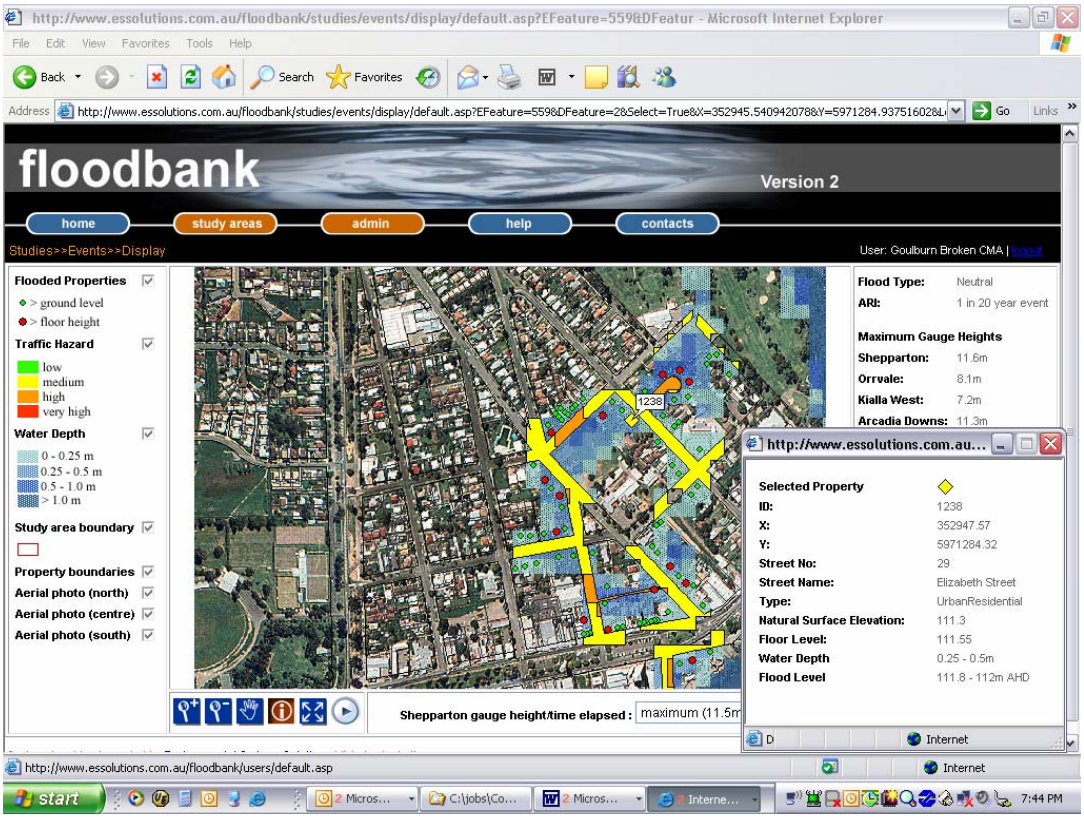

Figure 5 Property information query

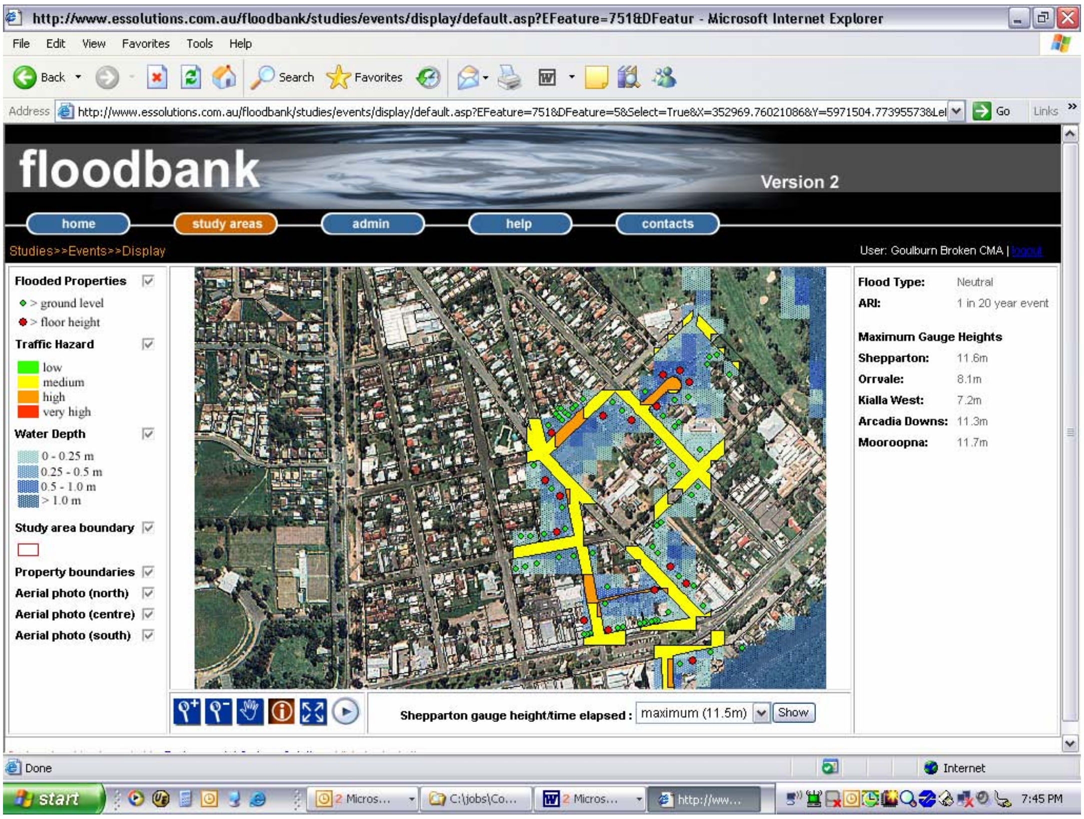

Figure 6 Traffic hazard

46th Floodplain Management Authorities Conference
Lismore, 28 February – 2 March 2006

Improving the Management of Urban Runoff using On-Site Detention

by

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ABSTRACT

A common On-Site Detention (OSD) policy was adopted by the Upper Parramatta River Catchment Trust (UPRCT) and four local councils in November 1991 and has been applied to all new developments – private and public - in the catchment since that time. The Trust has supported the OSD policy with policy and technical advice, OSD inspections, database, marketing and publishing a detailed OSD Handbook. The third edition of the Handbook was released in December 1999. The fourth edition, just released, is based on a completely revised OSD policy that controls site runoff in the full range of storm magnitudes.

The core objectives of the revised Handbook are:

- limiting of flow peaks throughout the catchment, in a 100 year ARI event, to the estimated peak flows under 1999 conditions, even if the further development of the catchment is equivalent to full medium/high density redevelopment throughout the catchment; and
- reducing post-development flow peaks, throughout the catchment, in the 1.5-year ARI event to as close to natural levels as practical.

Until now the OSD policy has prescribed Site Storage Requirement and Permissible Site Discharge values of 470 m^3/ha and 80 L/s/ha respectively. It has also been required that the stormwater outlet incorporates 'high early discharge' (HED) and that the detention storage is off-line.

The paper briefly outlines the studies carried out from 2001 – 2005 to refine the concept design of an OSD system that controls site runoff in both the 1.5 year ARI and 100 year ARI storms, and all storms in between. The result is a revised OSD policy that requires a two-orifice outlet, no HED, on-line storage and a slightly reduced Site Storage Requirement. As the studies progressed it was increasingly necessary to address various practical design issues, such as how to modify the OSD parameters when part of the lot's runoff bypasses the OSD system and/or when a rainwater tank is installed.

The revised OSD Handbook includes various design aids, such as an Excel spreadsheet to facilitate OSD design and checking, as well as guidance on a small post-OSD water quality treatment device. It is concluded that the new OSD Handbook will improve the sustainability of urban drainage practices in the upper Parramatta River catchment. Whilst still preventing increased flooding in major (100 year ARI) storms, the revised OSD policy will also better control flooding in frequent (1-2 year ARI) storms that cause most of the stream bank erosion, aquatic habitat disturbance and pollution in urban waterways. The new OSD will meet most of the objectives of the proposed Stormwater BASIX. Indeed, the upper Parramatta River catchment has been chosen as one of four case studies to trial Stormwater BASIX for possible broader application later on.

Keywords: Flooding, On-Site Detention, Rainwater tanks, Urban runoff

PAPER

THE CATCHMENT

The upper Parramatta River catchment covers an area of 110 square kilometres of the freshwater portion of the Parramatta River, the principal tributary of Sydney Harbour. The catchment includes parts of the LGAs of Baulkham Hills, Blacktown, Holroyd and Parramatta. It stretches from Carlingford in the east to Blacktown in the west, and from Castle Hill in the north to Merrylands in the south. The catchment is roughly circular, with Toongabbie Creek flowing through the centre linking a dozen smaller creeks draining the upper catchment.

The development of Parramatta occurred from the infancy of the colony because the river flats there provided arable land for farming to feed the growing population. The river remained an important transport route for many years and early buildings tended to remain close to creeks and rivers. Most of the upper catchment remained rural well into the mid twentieth century.

But when most of the catchment was urbanised in the 1960s and 1970 scant regard was paid to flooding issues even though floods had been recorded since the earliest days of European settlement. However, the late 1970s and 1980s were wetter than average and flooding of causeways and low lying properties became more frequent. Disagreements between the councils on the causes of flooding and limitations on spending money outside their own council area finally led to the four catchment councils supporting the establishment of the Upper Parramatta River Catchment Trust to address the issues on a catchment wide basis. The Trust was formed in April 1989 to "mitigate the impacts of flooding, drainage surcharge and deteriorating water quality"[1] in the catchment.

ON-SITE STORMWATER DETENTION

Urbanisation worsens flooding in two ways. The increased impervious areas reduce the opportunities for infiltration and local ponding, as well as the interception of rainfall by vegetation. This increases the volume of stormwater runoff. As well, the increased efficiency of modern urban drainage systems reduces the time taken for runoff to reach creeks and streams, causing the increased runoff to concentrate in the creek, resulting in increased peak flows. In the upper Parramatta River Catchment, this is further exacerbated because the catchment's near circular shape often causes most of the flows from the higher catchment to take approximately the same time to reach Toongabbie Creek.

The Trust and councils realised that effective floodplain management would need both works on the ground to address existing problems as well as planning and development controls to ensure that further development or redevelopment does not worsen flooding. The Parramatta Central Business District is situated right at the catchment outlet and the Seven Hills industrial area located on low lying land at the confluence of two major tributaries. So there is no real opportunity to increase the size of the main creeks to safely direct the increased flows downstream to the tidal reaches. Accordingly the prime aim of the catchment's flood management strategy has been to hold back the flood flows from the upper catchment as much as possible, so as to allow the remaining flows to get away first. Since 1984 thirteen regional basins have been constructed to cater for existing problems, whilst a uniform On-site Stormwater Detention (OSD) policy was adopted by the Trust and four councils in 1991 to ensure that subsequent development does not worsen the flood potential.

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[1] Quotation taken from Cabinet papers at the time of the establishment of the Trust.

OSD is a way of ensuring that new development[1] does not worsen flooding for all storms up to the 1 in 100 year event. Water is temporarily stored on site and gradually released at a controlled rate.

The catchment OSD policy was developed following months of modelling by the Trust's Investigation Engineer. The hydrologic model subdivided the catchment into some 50 sub-catchments and assumed various uniform increases in impervious area in each to allow for future development. The discharge per hectare was then varied for the full range of storms up to the 1 in 100 year event. It was found that discharges had to be limited to a rate of 80 litres per second per hectare (called the Permissible Site Discharge (PSD)) to prevent any increases in flood peak flows from redevelopment. It was found necessary to temporarily store up to 470 cubic metres of water per hectare (the Site Storage Requirement (SSR)) to maintain this PSD without overflow in any storm. These two parameters have remained the basis of the catchment OSD policy since 1991. Experience showed that an orifice was generally the most effective way to limit the site discharge. An off-line storage, utilising high early discharge, ensured that the maximum permitted flow was reached very early in the storm and reduced the volume of storage required. As the volume required in the catchment is considerably more than anywhere else in Sydney - volume of storage is the main factor in the cost of an OSD installation - efficiency of storage is very important.

The following diagrams show how such OSD systems operate:

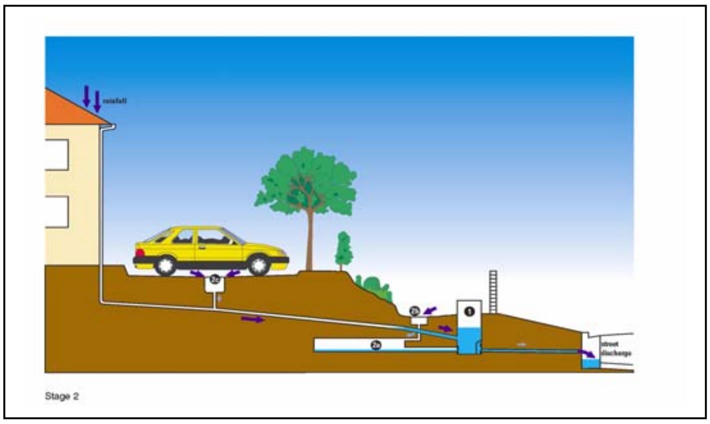

Fig 1. Rainfall commences, Discharge Control Pit starts to fill.

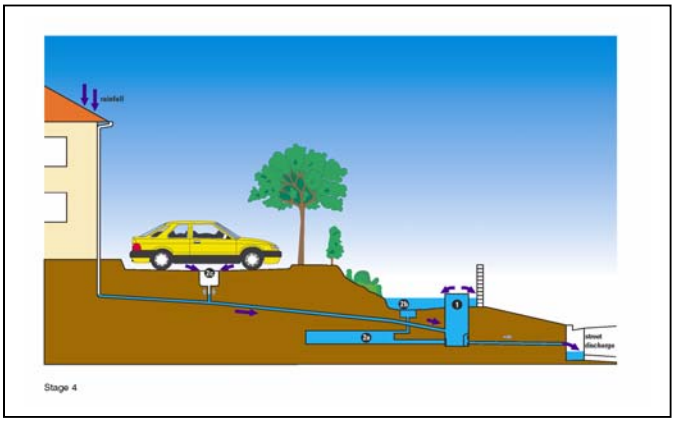

Fig 2. Primary storage fills, Discharge Control Pit overflows into secondary storage.

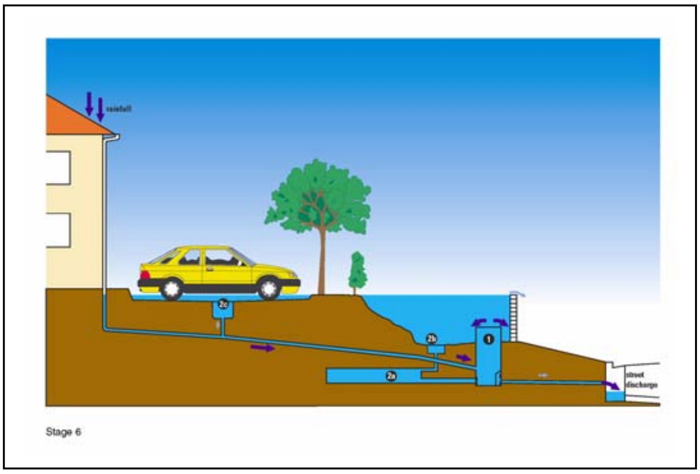

Fig 3. Secondary and tertiary storages fill, overflow commences

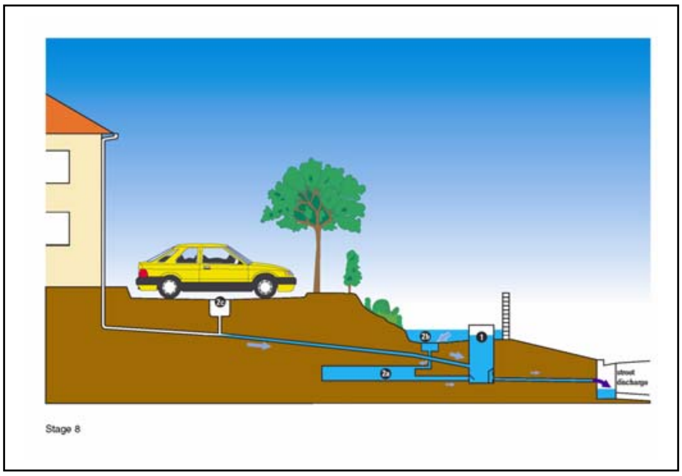

Fig 4. Rainfall stops and OSD storages empty progressively

1 Including redevelopment

The implementation of OSD in the catchment has developed over time as knowledge of both theoretical and practical applications has increased. The Trust's OSD Handbook has become the repository of much of this wisdom. It has grown from 66 pages in 1991 to 197 pages by the time of the second revision of the Third edition in June 2004.

OSD does not change the volume of stormwater that flows from the site, but it increases the duration of the flows and reduces the peak rate of flow. This, in turn, reduces the maximum depth of water in the drainage system. In a quick response catchment, like the upper Parramatta River catchment, the main determinant of damage from flooding is the depth of floodwaters. Floods tend to pass through the catchment within a matter of hours, so reducing the depth of flooding reduces the number of properties inundated and hence limits the damage. In addition, for such quick floods, the length of time that a house is inundated does not greatly increase the flood damage. Carpets, wall furnishings and electrical fittings are damaged as soon as the water touches them.

In the upper Parramatta River catchment the 13 large regional flood retarding basins reduce the peak flood levels and hence flood damages, whilst the OSD policy ensures that the effectiveness of these and other flood mitigation works is not compromised by further developments.

SITE STORMWATER MANAGEMENT

While the focus on reducing flood damages was understandable, given the genesis of the Trust, flooding is not the only impact of stormwater. For some years, the Trust has been concerned at how best to manage the whole urban water cycle. A number of factors contributed towards this changed attitude:

- the progressive reduction in the number of flood liable properties in the catchment and the extended period since a major flood has allowed a wider focus of Trust activities;
- the catchment Stormwater Management Plan identified the benefits of at-source control for water quality improvement;
- the Trust's leading role in the development and carriage of Water Sensitive Urban Design (WSUD) in Sydney has reinforced the importance of sustainability in development;
- an understanding that improved river health would be the best indicator of the effectiveness of the Trust;
- research showing that there is no significant opportunities in this catchment to allow infiltration to recharge ground water supplies and reduce flooding by reducing the runoff generated by storms;
- the drought in the metropolitan catchment area and subsequent water restrictions, which increased the number of calls from residents for permission to store rainwater permanently in OSD storages for garden watering;
- calls for offsetting the volume of rainwater tanks against the OSD requirement, which prompted research showing that some offset was possible, provided the water was used inside the dwelling, as well as for outside uses;
- a number of WSUD proposals for individual lots seeking OSD reductions because of the stormwater reuse;
- an understanding that bank-full flows (generally agreed to be 1 in 2 year to 1 in 5 year flows) had a much greater influence on creek bank erosion than major floods;
- an appreciation that 70 to 90% of annual rainfall is generated by very small storm events (less than 1 in 1 year storms);
- concerns raised by residents that OSD was not working because they never saw their OSD storage filling up, despite the thousands of dollars it had cost to build;
- catering only for flooding in major storms meant that OSD systems do not even begin to control flows until the rainfall intensity reaches at least 28 mm per hour;

- most council stormwater drainage systems had been designed to cater for 1 in 5 year storms and thousands of properties across the catchment could still be impacted by surcharging stormwater drainage systems in major storms;
- the pivotal role in stormwater and urban waterway management played by Melbourne Water and Brisbane City Council which is not matched by Sydney Water;
- the introduction of the Building Sustainability Index (BASIX) in NSW, which will ultimately lead to a BASIX for stormwater;
- the need for considerable local catchment data to permit a system such as stormwater BASIX to work effectively; and
- steadily increasing land prices and urban development strategies are reducing lot sizes and increasing the number of medium/ high density developments in the catchment.

However, while the benefits of having an OSD facility that catered for a wider range of storms was becoming clear, it was still imperative that:

- the vital flood mitigation purpose was not compromised, and that
- demonstrable, catchment-wide benefits must be achieved.

An opportunity arose, as a result of research undertaken by Dr Allan Goyen of Cardno Willing who had developed his next generation XP-RAFTS rainfall/runoff model as part of a PhD thesis in 2000. This computer model bridged the gap between the individual lot to neighbourhood-scale based hydraulic analysis tools used for drainage design and the larger scale catchment runoff models used to predict flood discharges. The new XP-RAFTS model can be used to calculate flows from pervious and impervious areas of a representative individual lot and then aggregate the results to predict peak flows at the neighbourhood scale, sub-catchment scale and finally for the full catchment. This can be done despite the fact that the Trust's hydrologic model has grown from the 70 nodes in 1991 to 780 nodes in 2001. Figures 5 and 6 show how the typical lot fits into the catchment model.

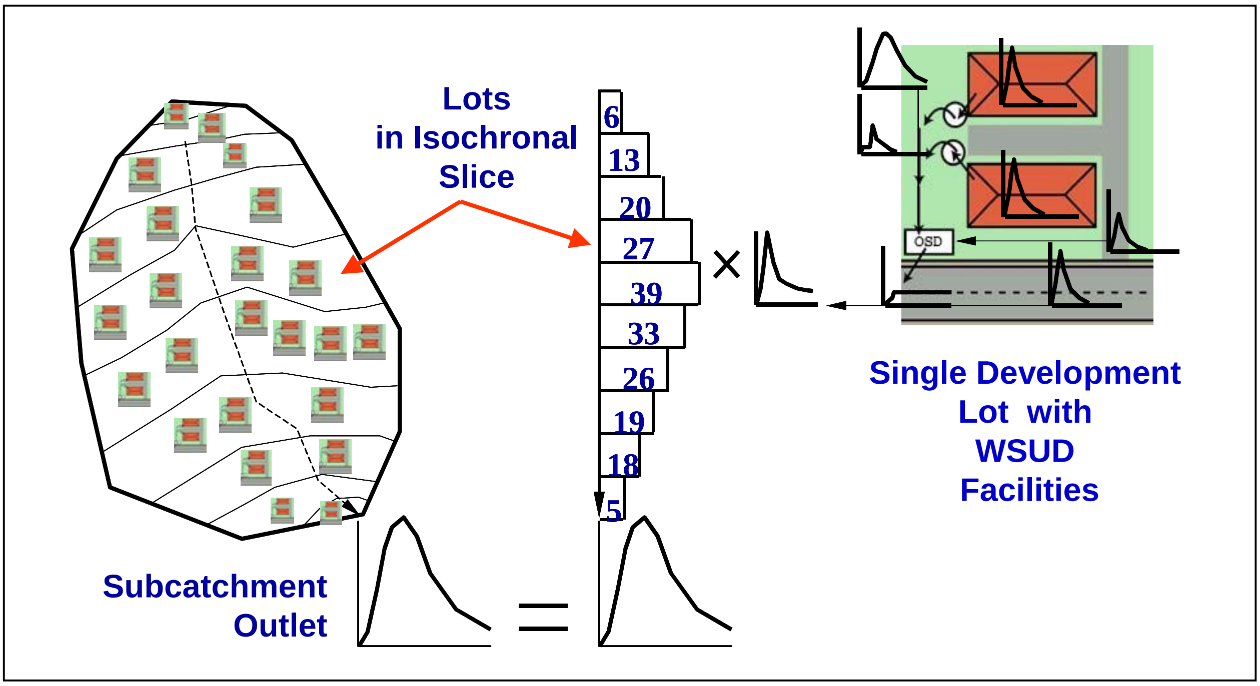

Fig. 5 Peak flows are computed at the allotment scale and then aggregated to the sub-catchment scale

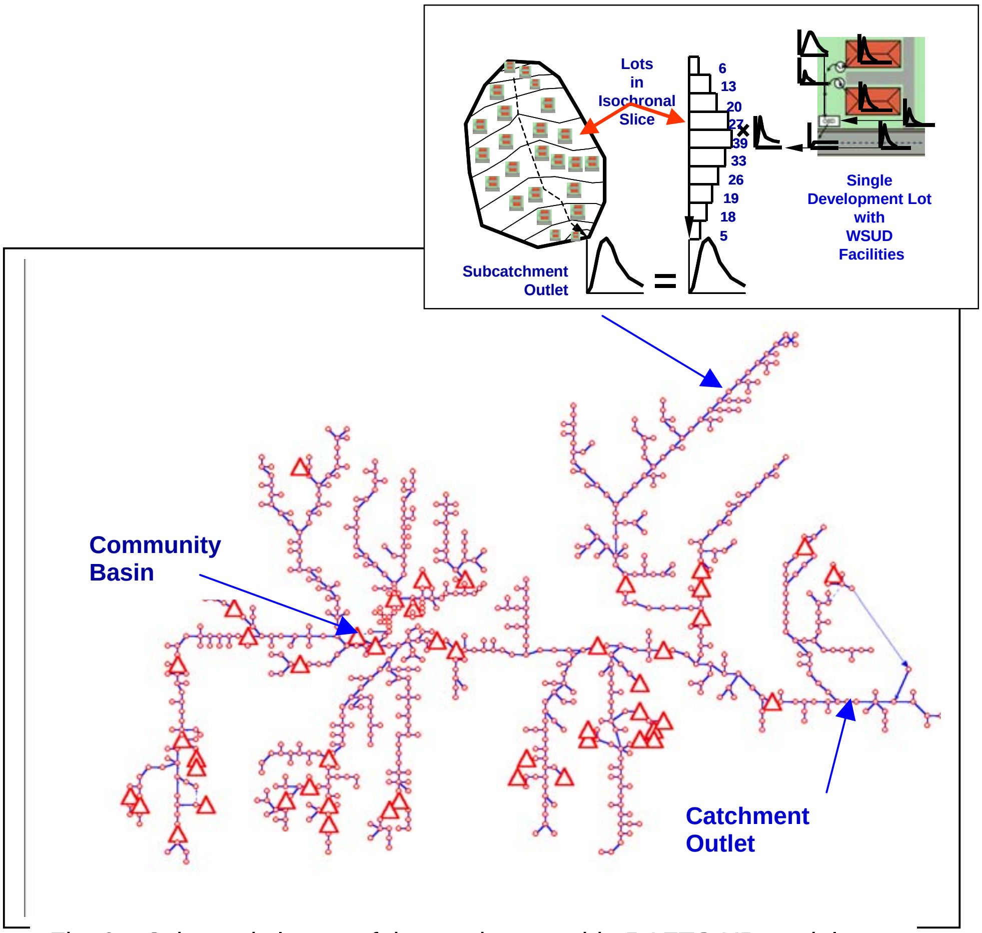

Fig. 6 Schematic layout of the catchment-wide RAFTS-XP model showing how the subcatchment flows fit in

Dr Goyen's work meant that it was now possible to model the impacts at the catchment scale, of detaining smaller, very frequent rainfall events at the lot scale. So, in 2001, the Trust commissioned Cardno Willing to:

- firstly, undertake a review of the OSD policy to determine whether the ten-year-old parameters were still appropriate; and
- secondly, determine what changes to the parameters would be required if OSD was to control the flows from much more frequent storms.

Node	Area (ha)
908.0C	44
8.030L	783
6.140L	1,465
1.220L	5,366
1.300L	7,085
1.320L	10,400

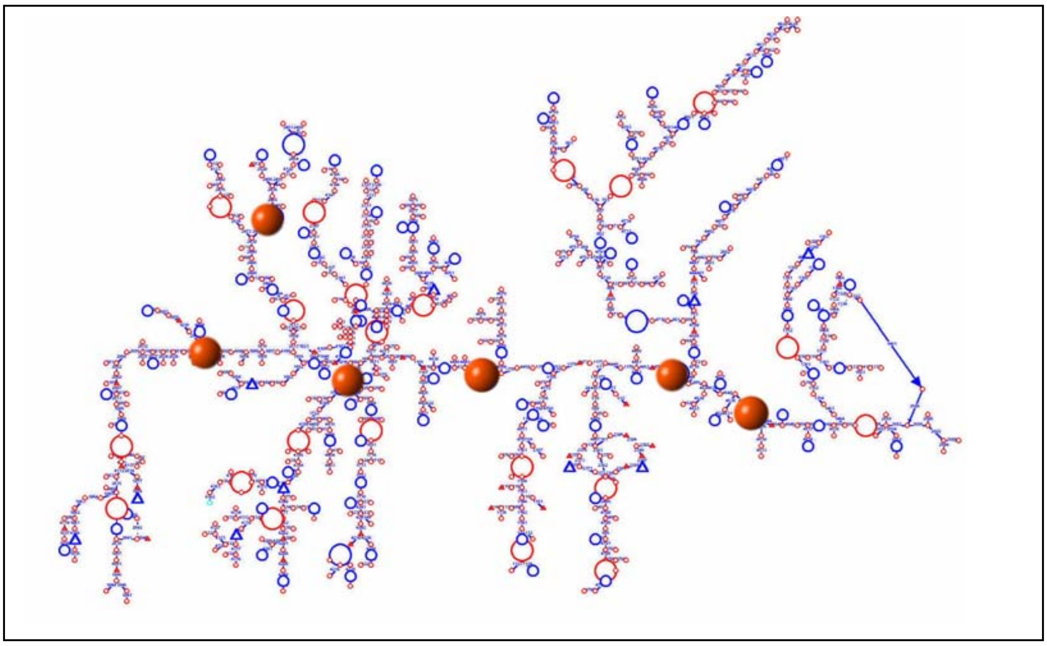

Fig. 7 Schematic plan of catchment RAFTS-XP layout showing representative locations. The table shows the area draining to each location.

OUTCOMES

Allan Goyen's research (and that undertaken by Dr Brett Phillips and others after Allan's retirement) showed that the PSD of 80 l/s/ha was still a critical parameter. However, the corresponding storage requirement could be significantly reduced for the 1 in 100 year storm if a small amount of spillage was permitted. The detailed model was able to show that such spillage was attenuated (slowed down) by travelling overland and did not worsen flooding at any points downstream.

However, the volume of storage required when detaining more frequent storms, pushed the total site storage requirement (the SSR) back up again. A critical factor proved to be the pre-burst rainfall.[1] For large storms, the percentage of pre burst rainfall is generally not critical to the total flows generated. However, the modelling showed that, when very small outflows are being controlled, the pre burst rainfall fills a significant part of the available storage. It turned out that the volume of storage required to control the 1 in 1.5 year storm is two thirds of the volume needed for the 1 in 100 year storm.

The modelling was also able to directly determine the reduction in OSD storage (SSR) that could be obtained by using different size rainwater tanks. Furthermore, it was able to compute the maximum percentage of a site that could be allowed to by-pass the OSD facility without worsening flooding downstream.

Overall, the modelling showed that it would be feasible to control both the 1.5-year flow as well as the 1 in 100 year flow. The total volume of storage (SSR) was still slightly less than that required under the current OSD policy. New parameters would be needed and some significant changes required to the discharge control structure. In place of the current OSD policy's off-line storage, single orifice and high early discharge - giving a constant discharge for most of the storm - there would be an on-line storage with twin orifices and discharges from the site that vary with the depth of water in the storage. The design would be slightly more challenging, but the site discharges would become much closer to the natural flows from an undeveloped site.

Following the completion of these studies, the Trust and four catchment councils decided to adopt the new policy. However, it was recognised that a completely revised Handbook would be needed to guide OSD designers and council staff in applying the new rules. Cardno Willing were engaged to produce the fourth edition of the OSD Handbook, with assistance from a prominent local OSD designer, Steve Arraj, of Haddad, Khalil, Mance Arraj Partners.

Once site flows are reduced to a trickle in smaller events, there is a great opportunity to achieve water quality benefits because these frequent flows are the primary vehicle for pollutant transport into local drainage systems and watercourses. So the Trust asked Cardno Willing to include Robert Peterson of Brown Consulting (NSW) in the project team, so that the Handbook could include some simple water quality measures to treat the trickle flow leaving the OSD system.

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[1] The 1987 Australian Rainfall and Runoff recommends that drainage design use the rainfall intensity of the critical storm burst for the appropriate recurrence interval storm. This ensures that the maximum rainfall intensity is catered for in sizing drainage pipelines etc. Storms of varying lengths can be broken into rainfall intensities for specified time intervals to reflect historical rainfall data for the area in question. Typically, the critical rainfall burst occurs some way into the storm and varying amounts of pre-burst rainfall will occur before that time.

The revised OSD Handbook includes a Microsoft Excel spreadsheet that is downloadable electronically. This allows OSD designers to input site characteristics and their design features in order to determine the volume of storage required and any offsets for rainwater tanks. This spreadsheet can be readily checked by Council staff and could easily become the basis of a similar spreadsheet likely to be required when Stormwater BASIX is introduced in coming years.

The Fourth Edition of the OSD Handbook was completed in December 2005 and a free electronic copy can be downloaded from the Trust's web site www.uprct.nsw.gov.au . A hard copy manual is being printed and will be available for purchase shortly.

CONCLUSION

The new catchment OSD policy and OSD Handbook reflect a major innovation in stormwater management in this catchment. No longer will the OSD simply reduce flooding in major storms. By controlling flows from the 1.5 year storm right through to the 1 in 100 year event, post-development flows will virtually mimic pre-development flows from the site. An opportunity will be available to add some simple water quality improvements. As more and more areas are redeveloped, the risk of councils' local stormwater drainage pipelines surcharging will be progressively reduced. Furthermore, by controlling runoff in the smaller more frequent storm events, bank full flows in local watercourses will become less frequent, leading to reduced bank erosion.

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Improving the Management of Urban Runoff using On-Site Detention

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NARRABRI – WEE WAA FLOODPLAIN
RURAL AND URBAN FLOODPLAIN MANAGEMENT COMBINED

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ABSTRACT

Since the completion of Keepit Dam in 1960, the Namoi River floodplain between Narrabri and Wee Waa has experienced a significant change in agriculture from low intensity to high intensity landuse. This change(s) was largely the result of the introduction of surface irrigation to produce high-value crops such as cotton, which results in a combination of irrigation structures for water supply and levee banks to ensure crop protection during flood events.

The early construction of rural levee banks occurred prior to present government regulations, and with the flood events of the 1960s and early 1970s, the erection of levee protection was largely un-coordinated and did not consider the needs for orderly passage of floodwaters.

The Wee Waa township is located in the middle of the floodplain irrigation development and is also subject to significant flooding. During the 1970s, following a number of devastating flood events, a levee bank was constructed around the perimeter of the town. This levee was erected without the detail presently afforded to levee design and construction. While improvement works have been undertaken, recent investigations have found that the height of the levee may not meet community expectations.

Over the past 30 years, a number of studies have been undertaken and a number of legislative changes have occurred. This paper outlines –

- The history of development in the Narrabri to Wee Waa floodplain area;
- The recent studies which have been undertaken in an attempt to improve flooding patterns within the area and improve the protection level afforded to Wee Waa by the levee; and
- The implication of recent legislative changes.

Management of the floodplain has progressed significantly in the past 30 years with respect to both the technical aspects and legislative controls. The Narrabri to Wee Waa floodplain is a good example of how previous management, legislative and resourcing issues are now being addressed and where necessary rectified. It also illustrates the connection between urban and rural floodplain management.

1.0 INTRODUCTION

As illustrated on Figure 1, this paper is concerned with the floodplain of the Namoi River in the Lower Namoi Valley between the towns of Narrabri and Wee Waa. This area is characterised by very flat terrain, with elevations dropping approximately 1 metre per 1500 metres (0.067%) generally in an east to west direction.

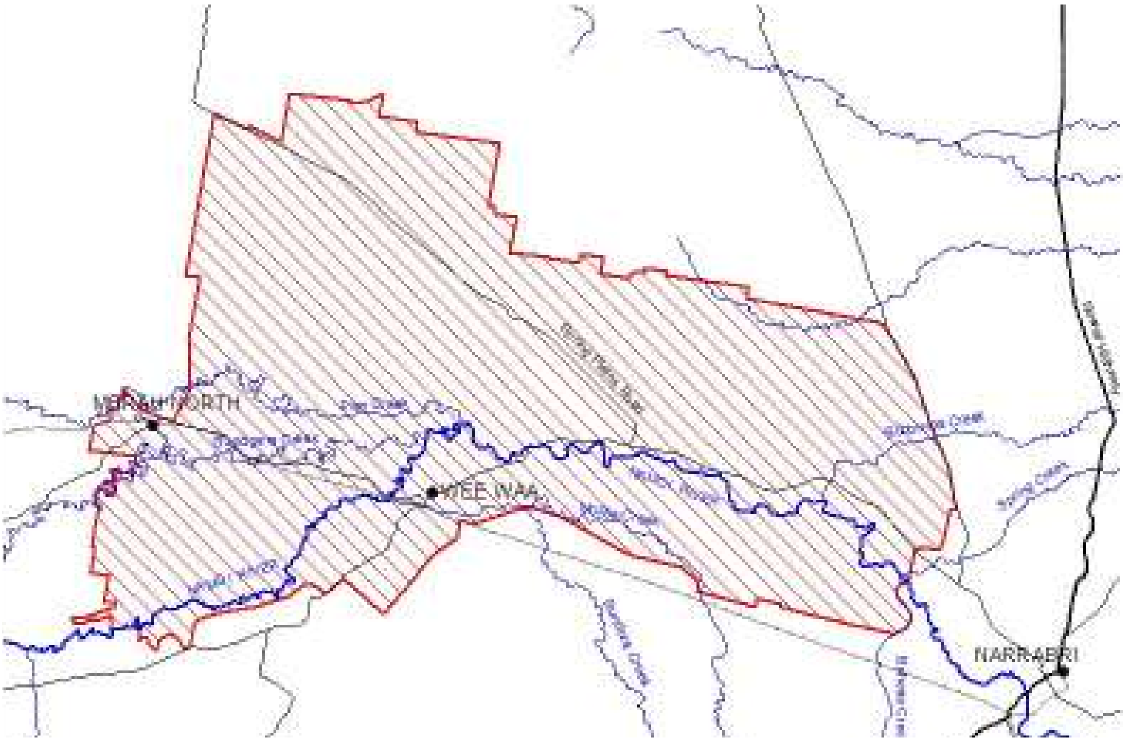

Figure 1 – Narrabri to Wee Waa Floodplain Area

While the majority of flood flow emanates from the Namoi River as it overflows downstream of Narrabri, local flows originating from Nandewar Ranges and Pilliga Forest can also contribute to flooding.

Following the construction of Keepit Dam in 1960 and the introduction of cotton, the Namoi River Valley experienced a major shift in agriculture from low intensity to high intensity landuse. This change was largely the result of the introduction of surface irrigation, which results in a combination of irrigation structures for water supply and levee banks to ensure crop protection during flood events.

The area of irrigated cotton in the valley has expanded from 25 hectares in 1961 to approximately 30,000 hectares in 1984 to around 45,000 hectares in 2004/2005. The majority of landholders in the Narrabri - Wee Waa area now practice cropping, with the dominant system being cotton and cereal crop rotation.

To give you some idea of the monetary importance that irrigated cotton has in the community within and around the Narrabri to Wee Waa area, during the 2004/2005 financial year the study area produced around 30,000 hectares of cotton which is equivalent to over $100 million.

The early construction of rural levee banks to protect the high-value cotton crops occurred prior to present government regulations, and with the flood events of the 1960s and early 1970s, the erection of levee protection was largely un-coordinated and did not consider the needs for orderly passage of floodwaters.

Figure 2 illustrates part of the Narrabri to Wee Waa area during the 1998 flood event. The level of floodplain development (crop protection) is evident.

Figure 2 – Aerial Photography of 1998 Flood Event

In addition to the issues resulting from un-coordinated rural floodplain development, the Wee Waa township with a population of around 2300 is located in the middle of the floodplain and is also subject to significant flooding. During the 1970s, following a number of devastating flood events, a levee bank was constructed around the perimeter of the town. While improvement works have been undertaken, recent investigations have found that the height of the levee may not meet community expectations.

A number of studies have been undertaken in an attempt to improve the overall flood flow distribution throughout the Narrabri to Wee Waa system. However it was not until 1984, when the Narrabri to Wee Waa area was gazetted as a floodplain under Part 8 of the *Water Act 1912,* that the government had some control over the location of earthwork construction.

2.0 HISTORY

2.1 Rural Development

During the flood events of 1964, 1971 and 1974 the Narrabri to Wee Waa area suffered several major setbacks during its period of growth with large crop and stock losses, as well as significant damage to irrigation infrastructure. This, along with impacts experienced by farmers from altered flood flow patterns caused by irrigation earthworks, triggered the then *Water Resources Commission* (WRC) to develop guideline documents in an attempt to coordinate the construction of flood control works. In 1976 the final document titled 'Restoration of the Namoi River Floodplain Waterways: Final Proposal' was released.

However floodplain development was not always undertaken in accordance with the Final Proposal document and the flood flow paths identified. At this point in time there was no legislation that enabled the then WRC to impose conditions on the location and nature of flood control works, it was purely by negotiation with the landholders (voluntary).

During late January & early February 1984, a major flood event occurred in the Namoi River causing significant damage to maturing cotton crops. Most of the damage resulted from levee systems being overtopped by floodwaters.

As evident from Table 1, the 1984 event had an Annual Recurrence Interval (ARI) of around 20 years at the Mollee Gauging Station which is around 15 kilometres downstream of Narrabri.

Flood	Danger Height (m)	Maximum Gauge Height (m)	Gauge Height > Danger Height (days)	Approximate Peak Discharge (ML/d)	Approximate ARI
2000	5.8	7.97	**	187,000	20 years
1998	5.8	8.01	**	197,000	20 years
1984	5.8	8.06	7.5	194,000	20 years
1976	5.8	8.02	7.0	189,000	20 years
1974	5.8	8.14	9.25	205,000	22 years
1971	5.8	8.43	19.5	246,000	25 years
1964	5.8	7.47	**	122,000	8 years
1955	5.8	8.94	9	326,000	50 year

** No data available

Table 1 - Significant Flood Events in the Namoi River at the Mollee Gauging Station

Soon after the 1984 event, a subsequent investigation by the then WRC led to the report titled 'Proposed Modifications to Narrabri – Wee Waa Floodway Restoration Scheme'. This investigation revealed the following -

- On the basis of data collected during the passage of the 1984 flood, it appeared that if all the recommendations in the original 1976 investigation had been undertaken in their entirety, the actual flood damage to cotton crops would have been substantially reduced; &
- The 1984 flood flow distribution caused nearly a 35% increase in the expected peak discharge for a flood of that magnitude in the Wee Waa Lagoon which runs directly adjacent to the Wee Waa levee.

2.2 Wee Waa Levee

The town of Wee Waa, with a population of around 2300, is located on the floodplain and is subject to major flooding from the Namoi River system. Upstream irrigation development has the potential to significantly affect flow distribution and therefore the flooding characteristics around Wee Waa.

As previously stated, a levee bank was constructed around the town perimeter following a number of devastating floods during the 1970s. The levee was completed soon after the 1976 event, with a nominal design crest elevation of 900 mm above the 1955 flood level.

Figure 3 – Aerial View of Wee Waa During the 1998 Flood Event

The levee was erected without the detail presently afforded to levee design and construction, and since its completion, the levee has undergone two (2) upgrades, being –

- After the 1984 flood event; and
- After a *Public Works* audit in 1992. This upgrade was designed and carried out adopting a levee crest elevation of the 1971 flood event level plus a one (1) metre freeboard.

2.3 Legislative Changes

(a) Pre 1983

Prior to 1983 legislation under which the then WRC carried out floodplain investigations (*Water Resources Commission Act 1976)* did not provide the authority to approve and/or impose conditions on the location and nature of earthwork construction on the floodplain.

A paper published in 1977 by the then WRC details some of the problems encountered during formulation of inland flood control schemes such as the 1976 'Restoration of the Namoi River Floodplain Waterways: Final Proposal' mentioned above. The paper described how development was based on cooperation between landholders in the development scheme area, implementation and subsequent maintenance of the scheme. In addition it stated that implementation was voluntary & at the landholders cost.

The papers went on to say that "legislative powers should be extended to the flood plain, to enable any authority involved in flood plain studies to implement a project accepted by a majority".

(b) 1983

Part 8 of the *Water Act 1912* was enacted in 1983 to provide control over private works that were affecting flood flow behaviour on rural floodplains where local council consent was not required and help implement management strategies to coordinate rural floodplain development. Under the Act it is an offence to construct a levee or embankment within a designated floodplain, such as the Narrabri to Wee Waa area, without prior approval.

A review of Part 8 licensing procedures in the late 1990s by the then *Department of Land & Water Conservation* (DLWC) revealed them to be limited in effectiveness and resource intensive. A more proactive regulatory approach to the control of illegal/unauthorised works was therefore required. The major problems encountered are summarised below -

- The onus was on the then DLWC to undertake all the necessary analyses to determine whether individual works could be licensed despite the existence of published floodplain guidelines. In this regard Part 8 was totally out of line with other development legislation where the onus of proof is paced on the developer; and

- The restrictive basis on which the then DLWC could make its determination as its jurisdiction was limited to considering whether a work would have "a material and prejudicial effect on the distribution of floodwaters". This was usually taken to mean localised impact rather than the overall flood flow distribution pattern. As a result the majority of the then DLWC's resources were directed to the detailed localised assessment of individual works rather than considering the impacts of floodplain structures in the context of strategic floodplain management plans.

(c) 1999

In 1999 amendments to Part 8 of the *Water Act 1912* were introduced in order to enable the control of rural floodplain works to be dealt with at a strategic level and in a more streamlined and resource efficient manner. The key elements of the legislative reform included -

- Developing strategic floodplain management plans which address ecologically sustainable development and have statutory recognition;

- Replacing the localised hydraulic assessment of proposals with a public interest test that looks at development and ecological matters on a long-term strategic basis with compliance based on statutory floodplain management plans;

- Streamlining the procedures for dealing with applications, including placing the onus of proof on applicants or objectors, compulsory mediation and one forum for appeal; &

- Strengthening the Departments ability to prosecute or otherwise deal with unauthorised works or proposed building of works.

(d) 2000

In 2000 the *Water Management Act* was enacted after the State Government initiated wide-ranging reform of water legislation. While the water licensing and flood control provisions of the Act are not yet in operation, it will eventually replace the *Water Act 1912.*

3.0 PRESENT

Even after the 1984 investigations and the Wee Waa levee upgrade in the mid 1990s, there was still community concern regarding the impact of rural levees on flood flow distribution and the integrity of the Wee Waa levee. The need for a study was confirmed during more recent floods, particularly the 1998 event where it was evident that significant flood flow redistribution was occurring with flows being restricted to the north-west.

With improvements in computer simulation it was decided to undertake an investigation of the area using the fully-dynamic, one-dimensional network hydraulic model known as MIKE 11 to effectively analyse flooding characteristics and flow distribution during a number of flood events. The MIKE 11 modelling involved two phases -

(i) Flood Study Modelling -

- Pre-Development Conditions - modelling of the floodplain system prior to the commencement of landuse change from grazing to cropping and development; and
- Existing Conditions - modelling of the floodplain system after the area had experienced significant irrigation development.

(ii) Floodplain Management Study Modelling - areas with flood-related issues were modelled with various modifications in order to determine potential and optimised solutions. In most instances, issues were treated collectively in order to determine the impact on surrounding areas and any cumulative impacts.

The models each comprise a network of around 42 branches that describe the flow along the major watercourses as well as the numerous overland flow paths. The collective total of branches adds up to approximately 340 kilometres in waterway length, with around 285 survey cross-sections.

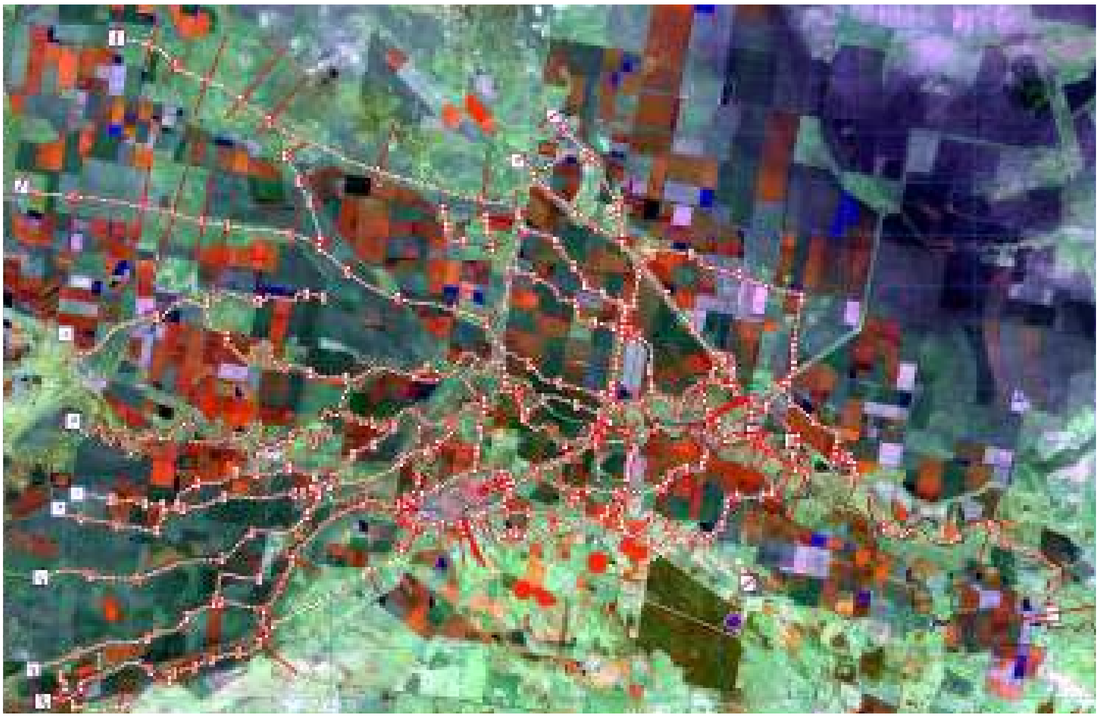

Figure 4 – Narrabri to Wee Waa Floodplain Hydraulic Model Network

To encourage community involvement and develop a Floodplain Management Plan (FMP) with local knowledge and ownership, the investigation was overseen by the *Narrabri to Wee Waa Floodplain Management Committee.* This committee comprises representatives from the community, various stakeholder groups and government agencies.

The investigation and comparative hydraulic modelling found that the system is experiencing significant flood flow redistribution (compared to the pre-developed distribution) due to existing flood control works that block or restrict natural flood flow paths. In particular the investigation confirmed that under existing floodplain conditions the Wee Waa Lagoon, which runs directly adjacent to the Wee Waa levee, is experiencing considerably more flood flow than under pre-development conditions due to upstream flows being restricted to the north-west.

As evident from Figure 5, the results indicate that the one (1) metre freeboard would likely be breached during a 1971-type event and that the levee would likely be overtopped during a 100-year ARI event.

It is apparent that a section of the levee, which even though was constructed as designed, does not meet the crest elevation of one (1) metre above the 1971 flood level.

As the MIKE 11 was a broad-brush approach, the local results around Wee Waa levee were questioned. However anecdotal information and observations indicate that the results are more than likely to hold true.

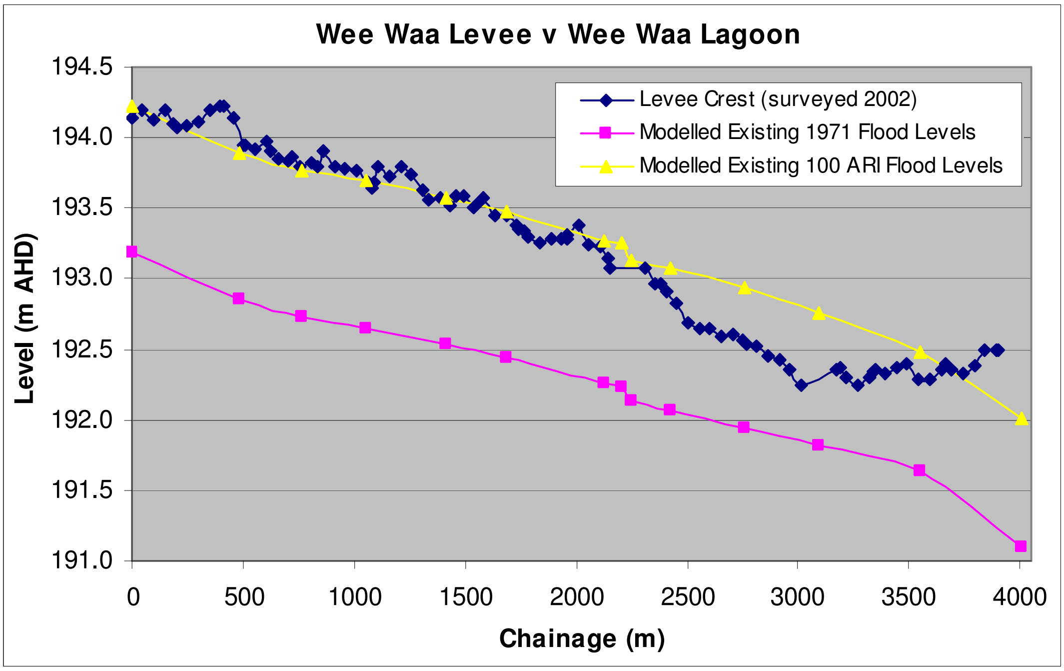

Figure 5 – Wee Waa Levee v Wee Waa Lagoon

The results presented in the *Narrabri to Wee Waa Floodplain Management Plan* have prompted further investigations to assess the need for remedial works to existing flood control development and re-assessment of the adopted flood planning level (FPL).

These investigations are in essence the second (2nd) stage of the Floodplain Management Plan and will focus on reviewing Wee Waa levee, as well as three (3) rural sub-areas. It will involve the development of detailed two-dimensional models and the formation of local working groups comprising landholders directly affected by any proposed modifications.

The fact that the majority of rural levee banks in the area have been authorised by the Department under Part 8 of the *Water Act 1912,* means that landholders have the expectation that the location and nature of existing flood control works will not be modified. This, along with the fact that irrigated cotton has demanded relatively significant financial commitments, makes the community consultation process vital.

In the process of setting the second phase, debate occurred as to the recommended course of action. A common response to the problems encountered was to simply raise the height of the Wee Waa levee to compensate for the redistribution. However this was seen as a typical "band-aid" solution. Increasing the height of the levee raises several other issues including -

- The potential hazards of emergency evacuation and vehicular access in the vicinity of Wee Waa;
- Continued risk and damage in downstream areas where increased flood flow is experienced; and
- Continued reduced flood flows in some rural areas and ecologically sensitive environments, such as wetlands, where flooding is seen as beneficial.

4.0 ISSUES TO BE RESOLVED

Problems that are envisaged during the second stage of the *Narrabri to Wee Waa Floodplain Management* Plan include –

- **Co-ordination -** while the rural areas investigation and the Wee Waa levee investigation should result in consistent outcomes, the timing of implementing the recommendations may create some social issues. In other words, the timing between finalising recommendations and actually implementing them may differ significantly between rural areas and the Wee Waa levee.
- **Funding** – it is doubtful that landholders will perceive an individual benefit to modify their existing flood control works. This will inherently raise the issue of funding and compensation resources.
- **Monitoring –** based on current resourcing levels and the fact that there is around 2 million hectares of designated floodplain area within the Barwon Region, it is extremely difficult to ensure that –
  - All existing flood control works are approved under Part 8 of the *Water Act 1912;*
  - All existing works have been constructed in accordance with their Part 8 approval, including conditions relating to location, heights, floodway widths, maintenance, etc; &
  - Recommendations made as part of the *Narrabri to Wee Waa Floodplain Management Plan* process are carried out in a timely and appropriate manner.

  Verifying the above points requires field survey work to accurately measure the location and constructed height of flood control works.

5.0 CONCLUSION

The first stage of the *Narrabri to Wee Waa Floodplain Management Plan* aimed to demonstrate the need to –

- Provide a floodway network that will improve the current flow distribution of the floodplain system and allow for the orderly passage of flood flows;
- Balance the expressed requirements of landholders with the requirement to minimise the impact of development on natural flood flow patterns and ecological functions of the floodplain; and
- Improve the security of Wee Waa during flood events.

The second stage of the floodplain management plan will aim to develop an on-ground implementation strategy that has stakeholder consensus and outlines specific modification works determined necessary to improve the current flood flow distribution.

Cost-benefit assessments will be undertaken in order to establish whether the various options for modification works are justifiable. Once consensus among stakeholders has been reached, DNR will prepare submissions to the relevant government agencies seeking funding to undertake the preferred modification works.

The Narrabri to Wee Waa area is a classic example of where the lack of legislative and planning control in the past has lead to uncoordinated rural floodplain development, which has resulted in both rural and urban flood flow problems. These problems are significant and require addressing in order to improve current flow distribution throughout the floodplain system and reduce the risk to Wee Waa levee.

The legislative changes, which have occurred over the past 20 or so years, will enable the *Department of Natural Resources* (DNR) to adopt a floodplain management plan for the study area that has statutory recognition and addresses the floodplain environment on a strategic or holistic level.

Under the 1999 amendments to the *Water Act 1912,* the adopted floodplain management plan must be considered by DNR when reviewing and determining approval applications for flood control works under the Act or its forthcoming replacement the *Water Management Act 2000.*

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MANAGING IMPACTS OF STATE SIGNIFICANT MAJOR ROADS WITHIN THE RICHMOND RIVER FLOODPLAIN

PACIFIC HIGHWAY UPGRADE – WOODBURN TO BALLINA

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Abstract

The Richmond River floodplain is one of the largest on the eastern coastline of northern New South Wales, Australia. The planning for critical national infrastructure, such as main roads, along the north-coast needs to recognise and manage the unique flooding regimes that occur in this floodplain.

As part of the planning for the Woodburn to Ballina Pacific Highway Upgrade being undertaken on behalf of the Roads & Traffic Authority (RTA), hydraulic modelling of the Richmond River was required to aid in the selection of route options, flood mitigation options and ultimately a preferred route. The hydraulic modelling utilised a fully integrated 1D/2D hydraulic model (SOBEK). Prior 1D and 2D modelling undertaken within the Richmond River floodplain was integrated into the SOBEK hydraulic model to form a 'whole of river' model that extends for approximately 100 km inland from the confluence with the Pacific Ocean at Ballina.

This approach has proven to be highly effective, allowing the rapid assessment of route options and detailed hydraulic modelling of the preferred route to meet the project timeframe. The results of the study concluded that substantial capital works are required to mitigate flooding impacts and could have a wide application to any major road construction within large floodplains.

Key Words: hydraulics, major roads, levees, floodplain, mitigation, SOBEK

1. Introduction

The planning process associated with the construction of major roads within the floodplains of major rivers can be significantly influenced by the need to minimise impacts on existing flood behaviour. To identify the potential impacts on flood behaviour and associated mitigation works requires the use of hydraulic models with the capability to model two dimensional (2D) solution schemes over all of the floodplain.

Fully 2D solution schemes and quasi 2D representations of the floodplain using a 1D model have inherent disadvantages within this application, given the large model area to be covered and the significant setup time involved in representing the river channel adequately within the model. In comparison, fully integrated 1D/2D models such as SOBEK allow a much coarser model to be used in the planning process while still adequately resolving the hydraulics of major hydraulic controls, the river and its floodplain.

2. Overview of the Pacific Hwy Upgrade – Woodburn to Ballina

Planning for the proposed Woodburn to Ballina highway upgrade is being undertaken by the Roads and Traffic Authority on behalf of the NSW State Government, as part of the Pacific Highway Upgrading Project. The study area identified for the Woodburn to Ballina upgrade is a 32 km section of the highway which extends from the southern side of the point where the existing highway crosses the Tuckombil Canal (just south of Woodburn) to intersection of the Pacific Highway and the Bruxner Highway (just south of Ballina).

Within the study area, the existing highway generally runs parallel with the Richmond River. From a flooding perspective a primary design objective of the upgrade project is to provide a minimum of 1 in 20 year ARI flood immunity to the highway. This would then require the highway to be raised up on embankments. As a result the proposed highway upgrade has the potential to have major impacts on the floodplain.

3. The Richmond River Catchment

The Richmond River Catchment covers an area of approximately 6,850 square kilometres, extending from the Nightcap, McPherson and Richmond Ranges to the ocean at Ballina. The Richmond River itself (often referred to as the main arm) is 170 km in length, with the tidal limit being 90km from the ocean, extending past Lismore on the Wilsons River to beyond Tatham on the Richmond River.

4. The Route Option Development Process & Objectives

The Pacific Highway upgrade project has a number of objectives at different levels; National, State and local. From the range of objectives the principal flood management objectives are to provide 1 in 100 year ARI flood immunity where practical or as minimum provide 1 in 20 year ARI immunity to the road carriageway and the proposed highway is to minimal change on existing conditions.

The hydraulic modelling objectives for the route options, included:

- Ensuring flood level increases during a 100 year ARI flood were restricted to 50mm.
- Limit the effects on flood inundation times across the floodplain – this is particularly relevant to sugar cane farmers where inundation time causes more crop damage than flood depths.
- In areas outside of the floodplain, cross drainage is to convey the 100 year ARI peak flow.

5. Community Consultation for the Route Option Development

The community and stakeholders have been involved in an extensive consultation program. The key part of the consultation process was the formation of a Community Liaison Group (CLG). The CLG provided the opportunity for the two way exchange of information between the project team and the community.

From the CLG three smaller groups were formed to focus on specific issues. One of these groups was a flooding focus group. In addition to community members representatives from other stakeholders were invited to join the group. The focus group met on several occasions during the process which allowed detailed presentation and discussion of the flooding issues in the valley.

6. Hydraulic Modelling of the Route Options

6.1 SOBEK

The hydraulic modelling of the route options was undertaken using SOBEK, an integrated 1D/2D fully dynamic hydraulic model developed by Delft Hydraulics. This model enables efficient integration between river hydraulics, where flow can be considered 1D, and the floodplain where flows are best described by a 2D model (see Plate 1). The hydraulic model uses a grid based solution scheme (finite difference) for the 2D component and both the 1D and 2D components use the complete de Saint Venant Equations.

6.2 Development of a 'Whole of River' Integrated 1D/2D Hydraulic Model

The hydraulic modelling of the route option development process required the integration of existing site specific flood studies undertaken along the Richmond River. These studies included:

- Cabbage Tree Island Flood Study (Patterson Britton & Partners, 2005) – undertaken in RMA2 between Broadwater and Pemlico Island. Although the use of a pure 2D model may have had application to this study, the vast amount of effort and hence time required to establish the grid (particularly for the river) over such a large study area excluded the use of this model, or any other pure 2D model. In addition, their were concerns regarding whether the 2D elements would satisfactorily model conveyance within the river channel given that most of the discharge in the Richmond River lies within the river banks where flow can effectively be described as one-dimensional.

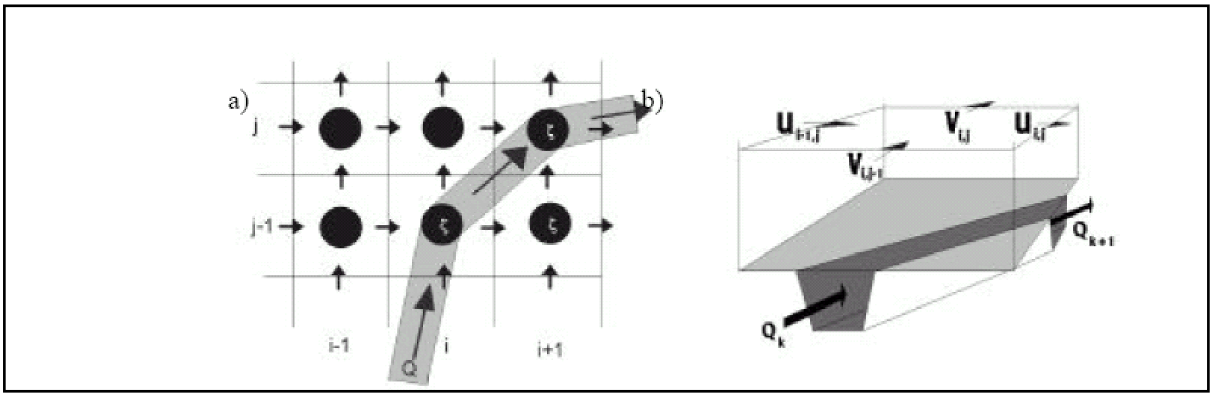

Plate 1. SOBEK 1D-2D Schematisation Source: WL Delft

- Mid Richmond Flood Study (WBM, 1999) – A Mike11 model setup as a quasi 2D to represent breakouts over levees etc. This is the only other 'whole of river' model that currently exists, extending from Coraki to Ballina. This model was not used for the route options assessment due to the inherent difficulty of cross sectionally averaged flow and velocity within a 1D model that would provide little information in regard to the effects of floodplain modification. In addition, modification of the model to examine all of the route options would require more set-up time comparative to altering a 2D surface.

- Ballina Floodplain Management Study (WBM 1996) – ESTRY 1D model – This study was undertaken from Pemlico Island to Ballina using ESTRY, a 1D model. Due to the overlap with the Mid-Richmond Flood Study, only the hydrology was used from this study for the major creeks entering around Ballina towards the downstream end of the study area.

The various base survey sources used to originally establish the above mentioned hydraulic models were integrated along with additional photogrammetry into a TIN representing the terrain using ArcGIS. This TIN was used as the base for developing a raster grid, often referred to as a digital elevation model (DEM).

6.3 ArcGIS Spatial Analysis

The primary objective at the route option development stage was to develop an alternative to the coarse quasi 2D Mid Richmond Mike-11 model, from which large scale changes to floodplain hydraulics and preliminary mitigation options could be estimated.

The Spatial Analyst component of ArcGIS was utilised to aggregate a relatively coarse raster grid from a much smaller raster resolution, which resolved hydraulic controls. This spatial analysis function ensured that the maximum cell height of a hydraulic control was translated to the larger 'aggregated' grid cell. In selecting the final raster grid size (resolution) a quantitative assessment was undertaken using the GIS to select the largest grid size possible which would still resolve the hydraulic controls such as the Pacific Highway and other roads acting as levees. This involved extracting cross sections for various grid sizes over various major levees and comparing the estimated heights. Where necessary, raster cells were manually lifted to provide an adequate representation of hydraulic controls.

A final raster grid size of 100m x 100m was adopted for the modelling of the route option development, resulting in a raster surface containing 418,914 cells of which 53% are active. The result was a hydraulic model that broadly depicted major hydraulic controls and resulted in manageable model run-times, given the large number of model iterations required to model mitigation measures for each proposed route option in the short timeframe available.

It should be noted that for the concept design of the selected preferred route the SOBEK model will use a finer 2D grid of approximately 60m resolution.

7. Hydraulic Modelling Results – Key Findings

7.1 Comparison to Existing Studies

Flood level differences between the *Mid Richmond Flood Study* (WBM 1999) and the SOBEK model within the study area are shown in *Plate 2*. In general, flood levels are similar to the *Mid Richmond Flood Study* (WBM Oceanics Australia 1999), with a mean difference between estimated 100 year ARI flood levels of 23mm and standard deviation of ±160 mm. Differences are attributable to the fact that the SOBEK model is most likely representing floodplain storage more accurately, as it is currently the only integrated 1D/2D model used within the entire study area.

7.2 Boundary Conditions

Selection of boundary conditions can have significant impacts on the level of flood mitigation works required. The boundary condition used in this study was a 100 year ARI storm tide boundary condition at Ballina, as that used for the Mid Richmond Flood Study (WBM 1999). This boundary consisted of a stage vs time boundary offset sufficiently so that the storm tide peak occurred approximately 3 days prior to the river peak at Broadwater (approximately half way through the study area), as shown in Figure A1.

This boundary condition is conservative in that much of the low lying areas within the study area, many of which are below 1 m AHD, are inundated before the flooding occurs in the Richmond River. This effective reduces available floodplain storage, which in turn influences the extent of flood mitigation works required and their relative capital costs.

7.3 River versus Floodplain Discharge

The Richmond River floodplain is extensive, comparative to the river itself. However, within the study area much of the discharge from the river is conveyed within the river banks, as shown in Figure A2.

As a result, models which incorporate a 1D component for the river sections are likely to accurately model flood behaviour. More importantly, an integrated 1D/2D model can also describe floodplain behaviour adequately.

8. SOBEK Modelling of the Route Options

The advantage of using an integrated 1D/2D hydraulic model is that the route options were able to be analysed with minimal model modification by inserting the proposed horizontal alignments of the routes options into the 2D component of the model. The route options and existing 100 year ARI flood depths are shown in Figure A3.

Flood mitigation options were modelled by incorporating viaduct areas along the route at strategic locations (i.e. by lowering the cells to match the surrounding surface) such as within low lying areas that provided active floodplain storage, or where major drains passed through the road alignment.

Each viaduct was represented in the 2D surface only, as all routes provided for 100 year ARI flood immunity. For lower flood immunity standards, the viaduct would be modelled in the 1D component, while the road weir flow represented in the 2D surface.

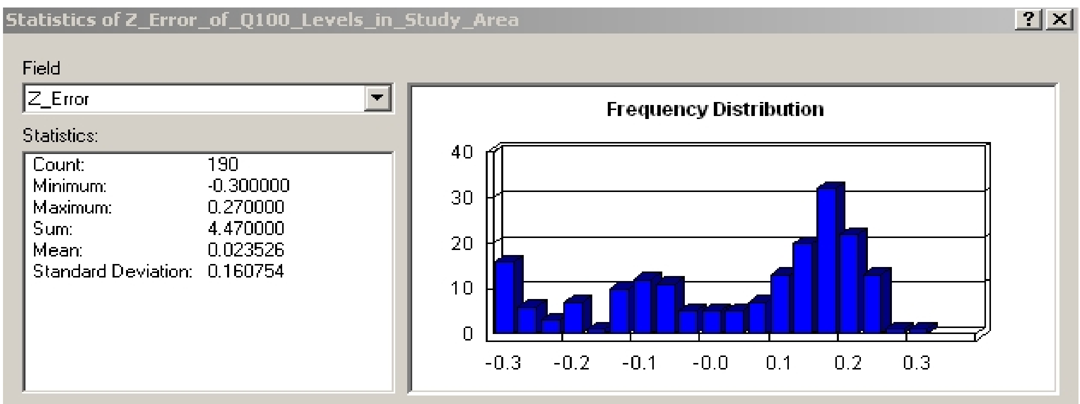

Plate 2. Standard Deviation of Error Between Mid Richmond River Flood Study (WBM 1999) Flood Levels

9. Floodplain Mitigation Requirements for Route Options

For the route options the following flood mitigation scheme has been developed to ensure that the objectives of the project were met:

Richmond River Bridge Crossing – in the modelling of the route options development a bridge span of approximately 720m to 850m was required to minimise afflux. This allowed some encroachment into the Richmond River floodplain. However, geotechnical and highway design issues will result in the bridge spanning all floodplain areas (approximately 1,000m span).

Tuckombil Canal Bridge Crossing – a 350m span bridge was proposed for all route options along this crossing to facilitate conveyance of Richmond River flows through to Evans Head along Tuckombil Canal and the Evans River.

Floodplain Viaduct – between 880m (Option1c) and 1350m (Option 1a) of viaduct was required for the section of floodplain between Woodburn and Broadwater Towns.

10. Conclusions

Important outcomes from the SOBEK modelling are:

- Significant benefits of using an integrated 1D/2D modelling approach for the route options development in terms of number of options that could be examined in the short timeframe.
- Pure 2D models are often associated with slow simulation times, where this approach provides shorter simulation times.
- Quicker setup time than using a quasi 1D model approach, and produces a more reliable estimation of impacts of the proposed routes on the floodplain hydraulics.
- Integrated 1D/2D models appear at the very least to be able to generate similar results to existing 1D and 2D models given similar base survey, hydrology and downstream boundary conditions.
- Issues of scale in relation to a 'significant impact' – 50mm allowable afflux results in a significant change in storage volume, but has little impact on floodplain hydraulics, planning and development.
- Choice of boundary conditions can affect the extent of mitigation options required (increase capital costs) due to pre-filling of floodplain storage areas.
- Development of a whole of river model allows various areas to be readily modelled in much finer detail, while integrating hydrology from the larger base model.
- Where full 100 Y ARI flood immunity is desired the extent of capital works required for flood mitigation is substantial. It has been estimated that the capital works for viaducts alone would be in excess of $35 Million.
- Lower standards of flood immunity may provide significant cost savings both in terms of embankment fill depths and capital works (viaducts).
- The level of model detail will be increased for modelling of the preferred route, as more information is required around viaduct areas ect. This can be facilitated by using nesting of finer resolution grids.

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Appendix A

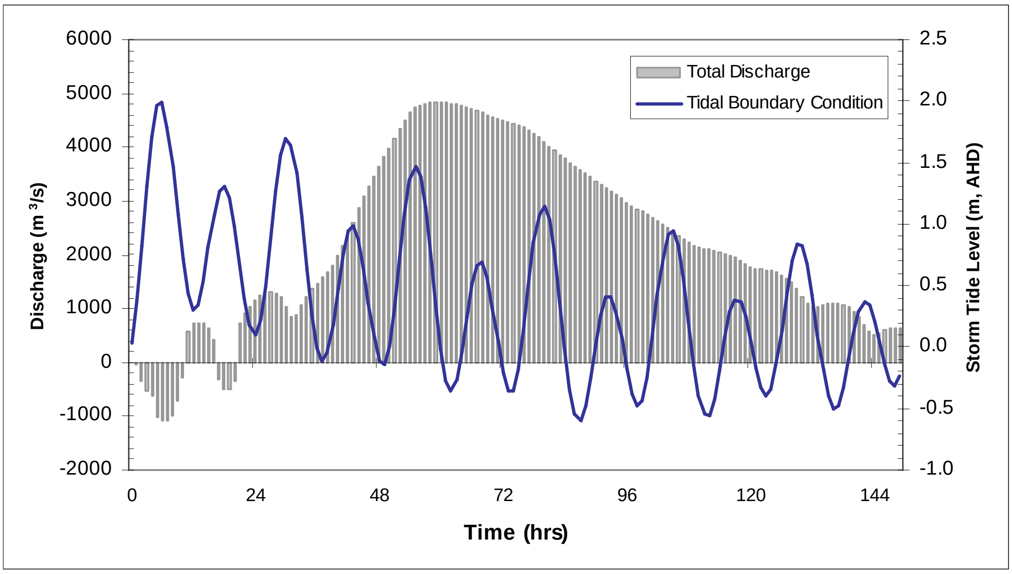

Figure A.1 **Discharge at Broadwater -100 year ARI flood**

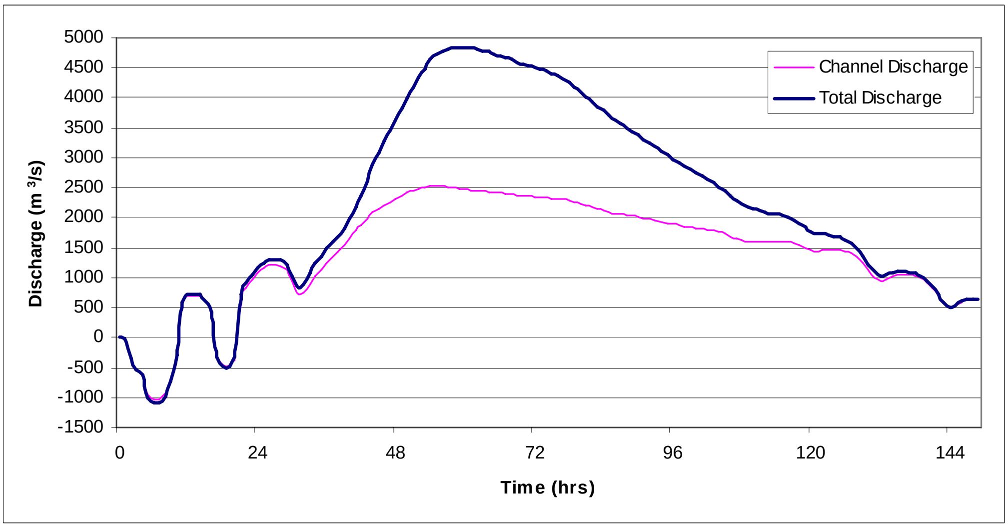

Figure A.2 **Richmond River 100 Y ARI Discharge Downstream of Broadwater/Tuckean**

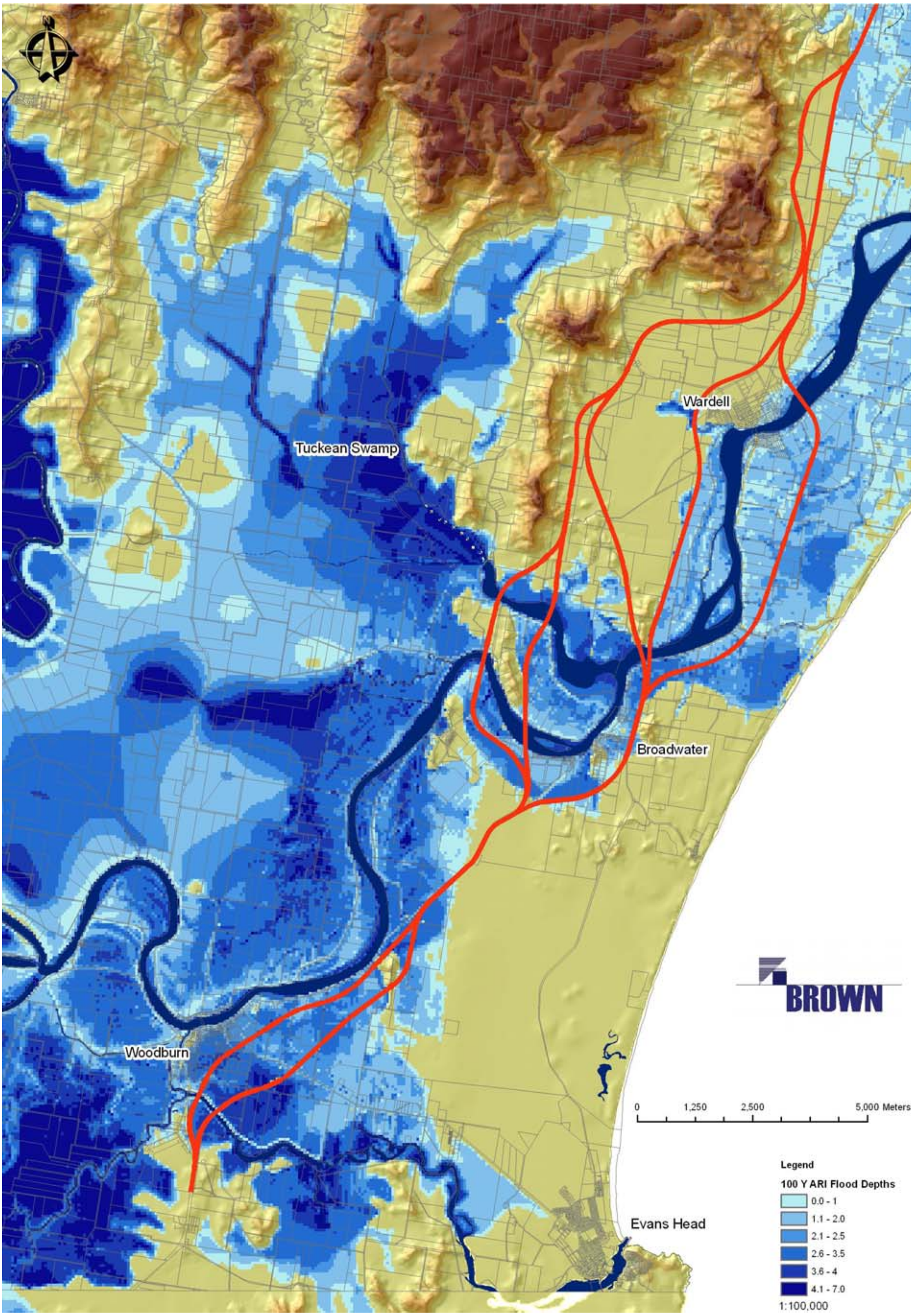

Figure A3 - 100Y ARI Flood Depths & Route Options - Southern to Mid Section

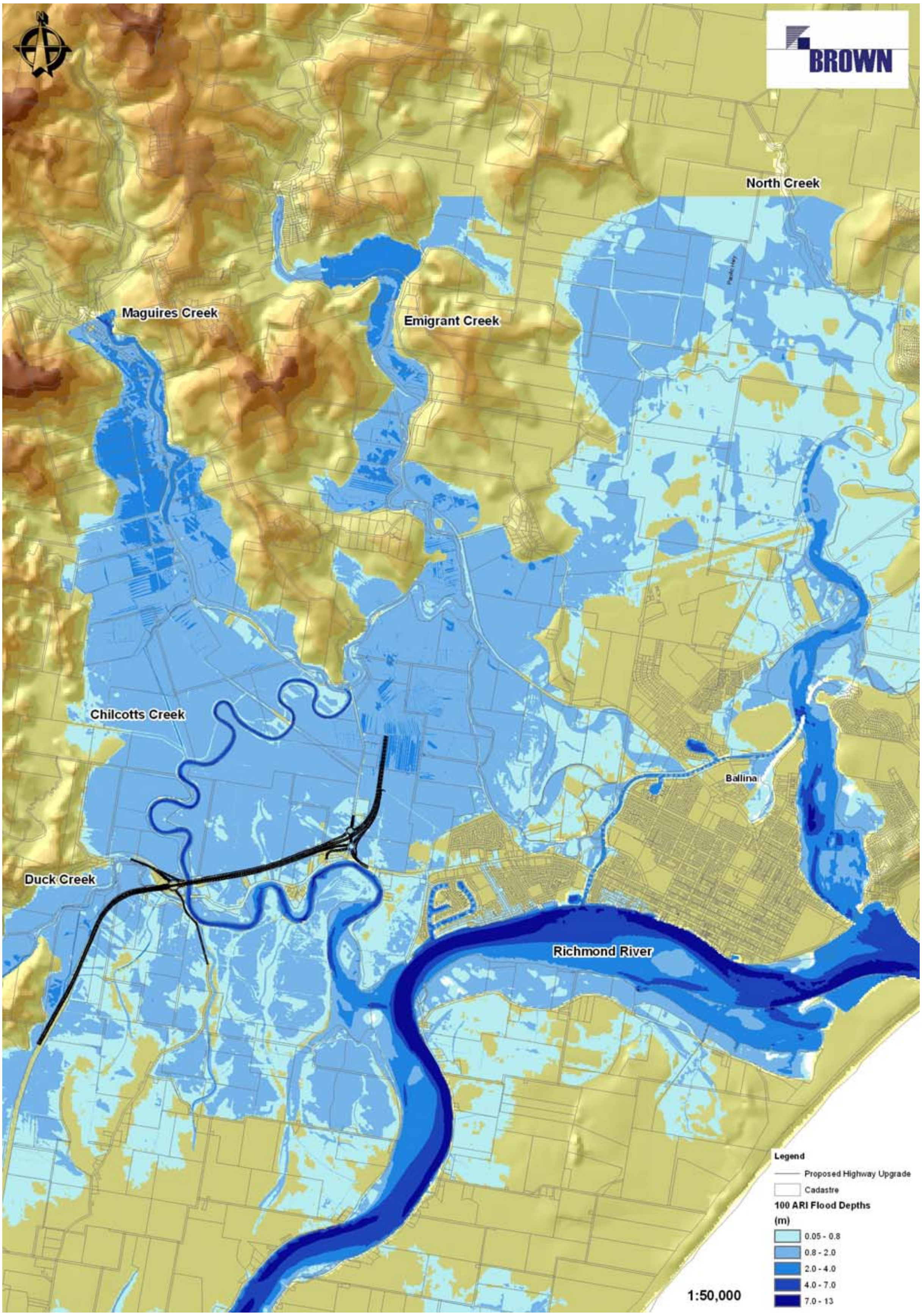

Figure A4 - Northern Section of the Preferred Route & Bruxner Hwy Interchange – 100Y ARI Local Flood with 10Y ARI Ocean Storm Tide

Modelling Overland Flows and Drainage Augmentations in Dubbo

by

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ABSTRACT

Dubbo has experienced a number of overland flooding problems at several locations within the city. Council had formulated possible augmentation works to address the problems and was keen to confirm that the proposed works would address the local flooding problems. The drainage system in Dubbo faces a number of challenges due to the relatively flat grades on stormwater drainage lines and the possibility that overland flows from a local drainage catchment may flow into an adjacent catchment via the road system. It has also been found that minor works like a roundabout can also initiate flooding of local properties.

Council had previously commenced the assembly of XP-SWMM model(s) of some of its drainage systems. Council also had available Aerial Laser Scanning (ALS) of the city.

In view of the sensitivity of overland flows to modest changes in intersection geometries and the problematic issue of the magnitude and direction of overland flows at many intersections in the city an XP-SWMM2D model of subcatchments 102, 103, 104, 105 and Boltje Street was assembled comprising the existing drainage piped system and 2D description of the roads based on available ALS data. The advantages of this modelling approach including the possibility of including roundabouts and other modifications of kerb-lines in the model and to assess the impacts on overland flows are discussed.

The modelling of the interaction of Council's piped drainage system and overland (road) flows is overviewed and the assessment of Council's proposed augmentation works is discussed.

It is concluded that the increasing consideration of extreme flooding in urban areas and the growing availability of aerial laser scanning of urban catchments is leading to the growing adoption of 2-D models as the new benchmark for urban flood studies in NSW and elsewhere. It was also concluded that:

- the combined 1-D/2-D modelling capabilities in the XP-SWMM2D package offers Dubbo City Council and others new opportunities to undertake more detailed investigations of urban drainage systems and of overland flows;
- the modelling completed to date has highlighted the interconnection of local drainage subcatchments and confirms observed overland flow problems in several areas in Dubbo;
- the assessments have highlighted the value of ALS data.

Keywords: Drainage, Overland Flow, 1-D/2-D modelling, Urban flooding

1. INTRODUCTION

Dubbo is a city of 38,000 people located 400 km north-west of Sydney. The City Council administers both the urban centre of Dubbo and a surrounding rural area in excess of 3,300 square kilometres. The city is bisected by the Macquarie River, one of the major tributaries of the Murray/Darling Drainage Basin.

The City of Dubbo lies within a transition zone between the ranges and tablelands of the Great Dividing Range to the east and the Darling Basin plains to the west. The topographical characteristics of the Dubbo include (Willing & Partners, 2000):

- Broad (up to 4 km wide) alluvial flood plains of the Macquarie and Talbragar Rivers;
- Extremely gentle grades across valley floors (around 1(v):100(H)), into which the rivers themselves are incised between steep (1(v):5(H)) banks up to 10 - 15m high; and
- Valley sides generally of 1(V):20(H) to 1(V):50(H) slope, with localised steepening associated with resident geology;

Dubbo also lies in the transition between the southern winter rainfall area and the northern summer rainfall area. It is also the transition area between the tablelands and the plains. The effect of this is that rainfall is distributed fairly evenly throughout the year. Dubbo has an average annual rainfall of 587 mm (based on records from 1870 to 1996). Pan evaporation averages 1,560 mm per year and whilst this varies slightly year to year because of differing wind and cloud cover conditions, average evaporation constantly exceeds average annual rainfall by almost 3:1.

1.1 Mainstream Flooding

Dubbo City Council (DCC) prepared a floodplain management plan (FPMP) which was adopted by Council in 1993. This FPMP (and its supporting Floodplain Management Study prepared by PPK, 1991a, b, 1992) was largely based on a Flood Study (DWR, 1988) that only considered flooding from the Macquarie River and did not explicitly consider the interaction between the Macquarie and Talbragar Rivers. Since the adoption of the FPMP, DCC has undertaken a number of other studies to investigate flooding in the vicinity of Dubbo (Rust PPK, 1995, PPK Environment & Infrastructure, 1996, 1999).

1.2 Local Drainage and Flooding

The Dubbo stormwater drainage network presently discharges at over 40 different locations. Twenty of these are into the Macquarie River itself and the remainder into three creeks which are tributaries of the Macquarie River. The connected stormwater drainage network includes 156 kilometres of conduits, 4,100 structures and 71 retarding basins, with a total replacement value of $118 million.

The oldest schemes located in Central Dubbo date back to 1873 and include brick arched structures to convey the stormwater flows draining to the Macquarie River.

Dubbo has experienced a number of overland flooding problems at several locations within the city. Council had formulated possible augmentation works to address the problems and was keen to confirm that the proposed works would address the local flooding problems.

The drainage system in Dubbo faces a number of challenges due to the relatively flat grades on stormwater drainage lines and the possibility that overland flows from one local drainage subcatchment may flow into an adjacent subcatchment via the road system. It has also been found that minor works like a roundabout can also exacerbate flooding of local properties.

Council had previously commenced the assembly of 1-D XP-SWMM model(s) of some of its drainage systems. Council also had available Aerial Laser Scanning (ALS) of the city.

2. MODELLING OF LOCAL FLOODING AND OVERLAND FLOWS

2.1 1-D and 2-D Modelling Approaches

As discussed by Goyen and Phillips, 2003, the approach that has routinely been adopted for Council drainage and overland flow investigations has comprised:

- Creation of a model of all pits and pipes and overland flows (typically 200 – 3,000 pits at a time);
- Overland flows only are calculated and are hydrologically routed (ie. overland flows are lagged to the destination downstream node); and
- Hazard assessment is based on the consideration of flows in comparison with the safe carrying capacity of roads and/or overland flowpaths.

Models that are typically used include DRAINS, PCDRAINS, and XP-RATHGL.

In the past Council flooding investigations in NSW have been typically based on the assembly of hydraulic models of all major watercourses and open channels but not routinely for overland flow paths. The challenge posed by the 2005 NSW Floodplain Development Manual (NSW Government, 2005) is to hydraulically model overland flow paths as well.

Models that have been used for flooding investigations include:

- 1-D flood profile: HEC-RAS,
- 1-D flood routing: MIKE-11, XP-UDD/XP-SWMM, RUBICON (SOBEK)
- 2-D flood routing: TUFLOW, SOBEK, MIKE-21, SMS, RMA-2)

At the same time the increasing collection of aerial laser scanning (ALS) across whole local government areas (LGAs) including the City of Dubbo is providing detailed survey levels capable of supporting 2-D terrain and hydrodynamic modelling and detailed floodplain mapping. The increasing availability of ALS has ramifications for modelling systems used to characterize flooding in urban areas. The trend in NSW and elsewhere has been for the growing adoption of 2-D models as the new benchmark for flooding investigations.

However a number of challenges exist when attempting to apply 2-D modelling systems to local drainage systems. These include being able to:

- interface the hydraulic model with a hydrological model and digitally input hydrographs at many locations from subcatchments that may be each only 0.1-2 ha in area;
- model the interaction between pipe drainage systems (with their associated inlets, pit losses, etc) with overland flow paths particularly where the two do not coincide; and
- start with dry overland flow paths that wet as the capacity of the piped drainage system is exceeded and then dries as the runoff recedes.

As part of the on-going development of the XP-SWMM modelling system to enhance its capability to model urban drainage systems, the TUFLOW 2D “engine” has been incorporated into the XP-SWMM package as a new 2-D hydrodynamic layer. It interfaces with the other layers in XP-SWMM to facilitate the modelling of the interaction of storms conveyed by conduits with 2-D overland flows. This new capability offers opportunities to model:

(i) Urban watercourses and floodplains in 2-D; and/or
(ii) Urban watercourses and floodplains using a combination of 1-D (watercourse) and 2-D (floodplain) elements; and/or
(iii) Urban drainage systems using a combination of 1-D (piped drainage) and 2-D (overland flow) elements.

Two recent case studies that demonstrate the new 1-D/2-D modelling capability of XP-SWMM2D (incorporating TUFLOW) are described by Phillips et al, 2005. The first case study was of a reach of Prospect Creek in the City of Fairfield. A 2-D model and a combined 1-D/2-D model of the floodplain were assembled and run. A comparison of 1-D, 1-D/2-D and 2-D results was given. The second case study was of a local drainage subcatchment that demonstrates the interaction between the piped drainage system and 2-D surface overland flows.

2.2 Modelling Overland Flows in Dubbo

There are a number of trade-offs when adopting a 1-D or a 2-D approach to the modelling of overland flows at subcatchment scales in urban areas including Dubbo. A characteristic of many streets in Dubbo is that there is significant cross falls from road centre-lines such that the road centre-lines can be higher than the ground level at property boundaries. This can give rise to a "quilted" terrain where the centre-lines of a rectilinear road network controls the spill of overland flows from one side of a road and/or an intersection to the other. If footpaths and properties are lower than the road centre-lines then they can be subject to inundation by overland flows that are ponded until they can either: enter the piped drainage system, flow around a corner or eventually overtop the road centre-line.

A 2-D model can account for the "quilted" terrain but may not fully represent all kerbs and gutters due to limitations on the smallest grid spacing that can be achieved for a large study area. Alternatively a 1-D model representation of the overland flowpaths would require 1-D links to be created for each side of the road centre-line with overflows across a road centre-line represented by a weir. At each intersection there would need to be four weirs to represent the possible overflows from one side of a road to the other side. This would give rise to a very complex 1-D model with each section of road being represented by two parallel links and a weir cross connection. A further challenge is representing a sloping road centre-line as a horizontal weir and deciding the appropriate length of the weir.

In view of the sensitivity of overland flows to modest changes in intersection geometries and the problematic issue of the magnitude and direction of overland flows at many intersections in the Dubbo, an XP-SWMM2D model of subcatchments 102, 104 and 105 comprising the existing drainage piped system (as partially described in Council’s existing model(s)) and 2-D description of the roads based on available ALS data. In December 2005, Dubbo City Council requested the assessment include two additional stormwater subcatchments, namely subcatchment 103 and the Bultje Street subcatchment (refer **Figure 1**).

Council has identified three hot spots where it proposes to implement drainage augmentation works to reduce overland flows preferably up to the 100 year ARI event. These hot spots include the intersections of:

(i) Fitzroy Street and Wingewarra Street,
(ii) Brisbane Street and Church Street, and
(iii) Talbragar Street and Carrington Avenue.

Council supplied concept drainage augmentation works at each location that were tested using the XP-SWMM2D model.

3. THE MODELLING APPROACH

The existing topographies of subcatchments 102, 103, 104, 105, and Bultje Street consist of roads, streets, lanes, pedestrian walkways, kerbs and gutters, roundabouts, carparks and residential, commercial and industrial developments. Each of the subcatchments is serviced by a piped drainage system. The sizes of stormwater pipe diameters vary from 200 mm to 1350 mm. A series of junction pits and inlet pits are also present in each drainage system.

The area of the local catchment draining to each inlet pit and its associated local catchment imperviousness was estimated by Council and input into XP-STORM models of subcatchments 102, 103, 104, 105 and Bultje Street created by Council. The overall area of the five modelled subcatchments is approximately 289 ha.

In accordance with previous assessments undertaken in Dubbo a “split subcatchment” modelling approach was adopted to separately estimate runoff from directly connected impervious areas and pervious subareas within each local catchment. This also allowed different rainfall losses to be applied to impervious and pervious areas respectively.

Based on a review of hydraulic conductivities for soils in Dubbo (including the Troy Gully catchment just north of the subcatchment 102) reported in the “Estimation of Soil properties using the Atlas of Australian Soils” prepared by CSIRO in 2000, the initial and continuous rainfall loss rates adopted for pervious surface were 35 mm and 10 mm/hr respectively. For impervious surfaces, the adopted initial and continuous runoff loss rates were respectively 1 mm and 0.05 mm/hr. The runoff routing method in the XP-SWMM2D model that was selected was the Laurenson (RAFTS) routing method.

The supplied XP-STORM models were converted into XP-SWMM2D models for the purposes of this study.

Existing inlet pits are typically grated pits with or without a lintel. There is a total of 909 pits in the five stormwater subcatchments of which 305 pits are inlet pits. The inlet level at inlet pits were estimated from a digital terrain model (DTM) that was generated from supplied aerial laser scanning (ALS) data for each subcatchment.

Council photographed each inlet pit in subcatchments 102, 104, 105 and Boltje Street. Based on the photographs, inlet pit types (lintel plus grate, lintel only, grate only, etc) were identified, and an inlet capacity rating curve was assigned to each inlet pit. Photographs of the inlet pits for subcatchment 103 were not available. For assessment purposes al inlet pits in these subcatchments were assumed to have no limitations ie. the hydraulic capacity of the piped drainage system could be fully utilised.

The Manning roughness values were defined for overland flow paths as well stormwater conduits. For paved areas such as roads, streets, and lanes, a roughness value of 0.020 was adopted. For pervious areas such as parks, and ovals, a roughness value of 0.060 was adopted. A roughness value of 0.012 was adopted for all existing concrete stormwater conduits including pipes and box culverts.

In the XP-SWMM2D model, the existing underground drainage system was represented in the 1-D layer while overland flows were modelled in the 2-D layer. The 1-D and 2-D layers were connected at inlets to allow overland flows to enter the piped drainage system and for the piped drainage system to surcharge onto roads as appropriate.

The 2D model of overland flowpaths was based on a rectilinear 2.5 m grid (the minimum grid size that could be adopted for the 289 ha study area).

4. EXISTING CONDITIONS

The XP-SWMM2D models for subcatchments 102 to 105 and Bultje Street were run for the 100 year ARI and 20 year ARI events under existing conditions. The hydrological analysis disclosed that critical storm burst duration varies between 30 minutes and 120 minutes depending on location within the catchments and the event ARI. However, a review of the estimated peak flood levels indicated that the critical storm burst duration for flooding in the subcatchments is 60 minutes in both the 100 year ARI and 20 year ARI events.

After each model run, spatial plots of the overland flow depth and velocity were generated at each hot spot intersection. The estimated 100 yr ARI flood depths and extents under existing conditions are given in **Figure 2**. The estimated 100 yr ARI flood depths and extents under existing conditions at one of the intersections of interest (Church Street and Brisbane Street intersection) are given in **Figure 3**.

The 100 yr ARI existing condition assessment disclosed in particular:

(i) Ponding south of Cobra Street on the former RAAF lands and overland flows through residential areas north of Cobra Street;
(ii) Shallow overland flows through Elston Park;
(iii) Flooding of the intersection of Fitzroy Street and Wingewarra Street with only the roundabout remaining dry;
(iv) Overland flows through southern sections of the Showgrounds and Paceway;
(v) Overland flows through the Dubbo High School and Victoria Park and flooding of Talbragar Street opposite Victoria Park; and
(vi) Major overland flows in Brisbane Street between Church Street and Talbragar Street. The flooding also extends back up Talbragar Street to the Carrington Ave intersection;
(vii) Peak overland flow velocities are higher in the upper (eastern) areas of the study area and tend to align with road kerb lines;
(viii) The peak velocity of overland flows in Brisbane Street between Church Street and Talbragar Street are low

The 20 yr ARI existing condition assessment disclosed in particular:

(ix) A similar pattern of overland flows to the 100 yr ARI event but with a reduced extent of inundation eg. Victoria Park;

(x) Reduced overland flows in Talbragar Street between Carrington Ave and Brisbane Street;

(xi) Inundation of the northeast, southeast and southwest corners of the intersection of Fitzroy Street and Wingewarra Street;

(xii) A similar pattern of overland flow velocities to the 100 yr ARI event.

5. IMPACT OF AUGMENTATION WORKS

The XP-SWMM2D model for subcatchments 102 to 105 and Bultje Street were then modified to reflect the proposed drainage augmentation works at the three hot spot intersections and the model was re-run for the 100 year ARI and 20 year ARI events. Details of the proposed augmentation works at the three road intersections namely at the junction of Talbragar Street and Carrington Avenue, Brisbane Street and Church Street, and Wingewarra Street and Fitzroy Street were supplied by Council. The concept upgrade includes the addition of new pipes and inlet pits as well as enlarging existing inlet pipe size(s).

After each model run, spatial plots of the overland flow depth and velocity were generated at each hot spot intersection.

The estimated 100 yr ARI flood depths and extents with the augmentation works are given in **Figure 4**. The estimated 100 yr ARI flood depths and extents with the augmentation works at one of the intersections of interest (Church Street and Brisbane Street intersection) are given in **Figure 5**.

The 100 yr ARI post augmentation works condition assessment disclosed in particular

(i) The overland flows in Brisbane Street between Church Street and Talbragar Street are markedly reduced. Likewise the flooding back up Talbragar Street from Brisbane Street to the Carrington Ave intersection is noticeably reduced;

(ii) The depth of overland flows in Brisbane Street are reduced by more than 0.01 m north of Church Street. The reduction in depth of overland flooding in Brisbane Street south of Church Street and in Church Street west of Brisbane Street is around 0.01 to 0.05 m;

(iii) There is only a minor reduction in the overland flow depth in Carrington Ave south of Talbragar Street. There is a reduction in overland flow depth in Talbragar Street south of Carrington Ave of 0.01 m or more; and

(iv) There is a minimal reduction in overland flood depths at the intersection of Fitzroy Street and Wingewarra Street;

The 20 yr ARI post augmentation works condition assessment disclosed in particular:

(v) The depth of overland flows in Brisbane Street are reduced by more than 0.01 m north of Church Street. The reduction in depth of overland flooding in Brisbane Street south of Church Street and in Church Street west of Brisbane Street is around 0.02 to 0.05 m;

(vi) There is a reduction in the overland flow depth in at the western corner of Carrington Ave and Talbragar Street. Of around 0.05 m There is a reduction in overland flow depth in Talbragar Street south of Carrington Ave of 0.01 m or more; and

(vii) There is a minimal reduction in overland flood depths at the intersection of Fitzroy Street and Wingewarra Street.

Further options that might improve the flooding at the Fitzroy Street and Wingewarra Street intersection include:

(i) Collecting overland flows south of Cobra Street and east of Fitzroy Street and discharging them into Cobra Street west of Fitzroy Street ie. a catchment transfer of overland flows. The potential transfer of a problem from one subcatchment to another subcatchment may not be viewed favourably by the community, and/or

(ii) the construction of a shallow basin in Elston Park to retard overland flows from Cobra Street and Fitzroy Street thereby reducing overland flooding at the intersections of Fitzroy and Wingewarra Streets and Gipps and Wingewarra Streets, possibly in combination with

(iii) a retarding basin south of Cobra Street in the RAAF land.

It was concluded that the modelling completed to date has highlighted the interconnection of local drainage subcatchments and confirms observations of overland flow problems in several areas in Dubbo. The analyses completed to date have assessed the reductions in overland flows and flood extents at intersections of interest to Council. It also provides an opportunity for Council to further refine the possible augmentation options to overcome the residual flooding problems.

6. CONCLUSIONS

It is concluded that the increasing consideration of extreme flooding in urban areas and the growing availability of aerial laser scanning of urban catchments is leading to the growing adoption of 2-D models as the new benchmark for urban flood studies in NSW and elsewhere.

It was also concluded that:

- the combined 1-D/2-D modelling capabilities in the XP-SWMM2D package offers Dubbo City Council and others new opportunities to undertake more detailed investigations of urban drainage systems and of overland flows;
- the modelling completed to date has highlighted the interconnection of local drainage subcatchments and confirms observations of overland flow problems in several areas in Dubbo; and
- the assessments have highlighted the value of ALS data.

7. ACKNOWLEDGEMENT

The support of Dubbo City Council for the assessments described herein through its provision of extensive ALS data and detailed drainage system data is gratefully acknowledged. The views expressed in this paper are those of the authors and are not necessarily the views of Dubbo City Council.

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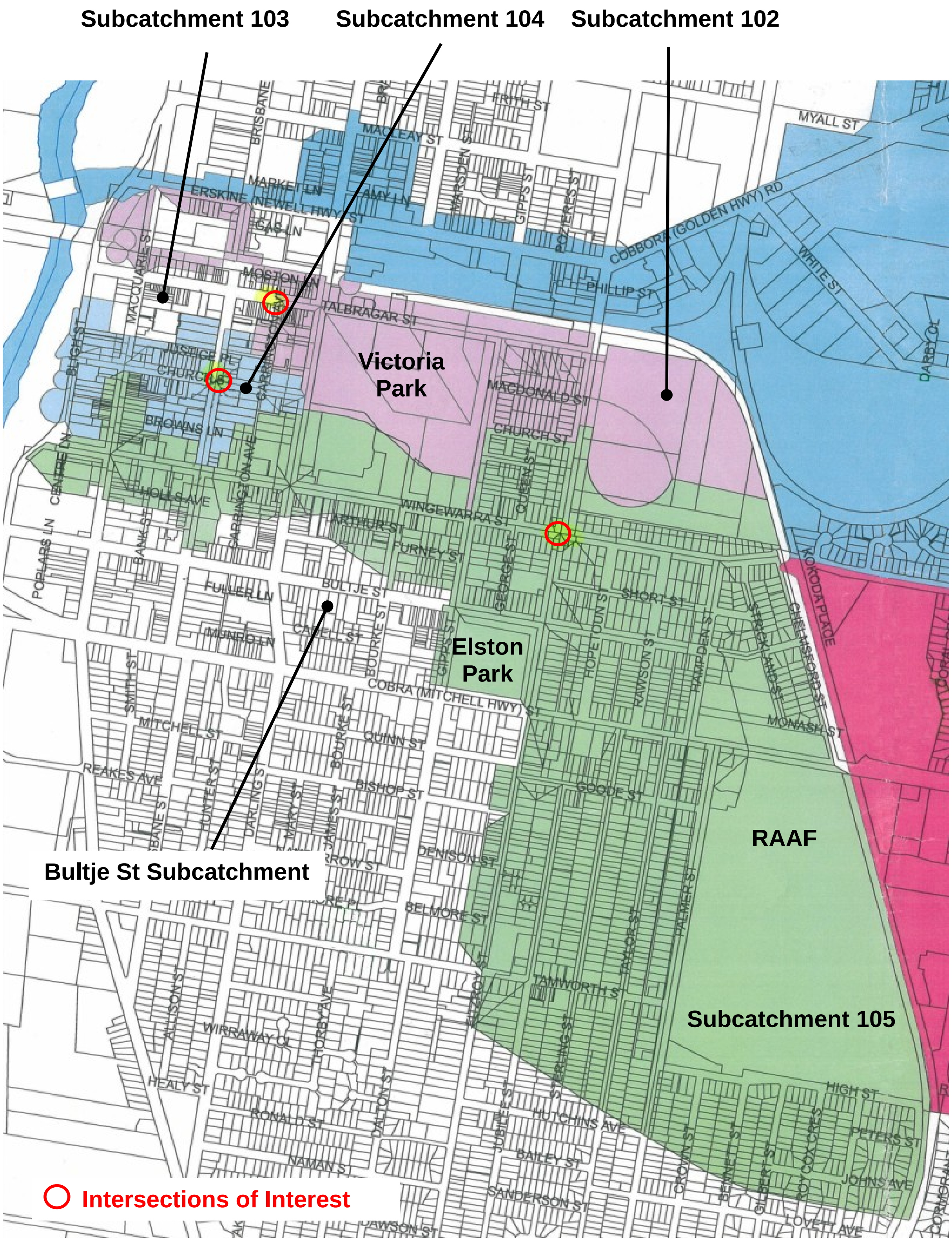

Figure 1 Dubbo Local Drainage Subcatchments

Figure 2 Estimated 100 yr ARI Flood Depths and Extents – Existing Conditions

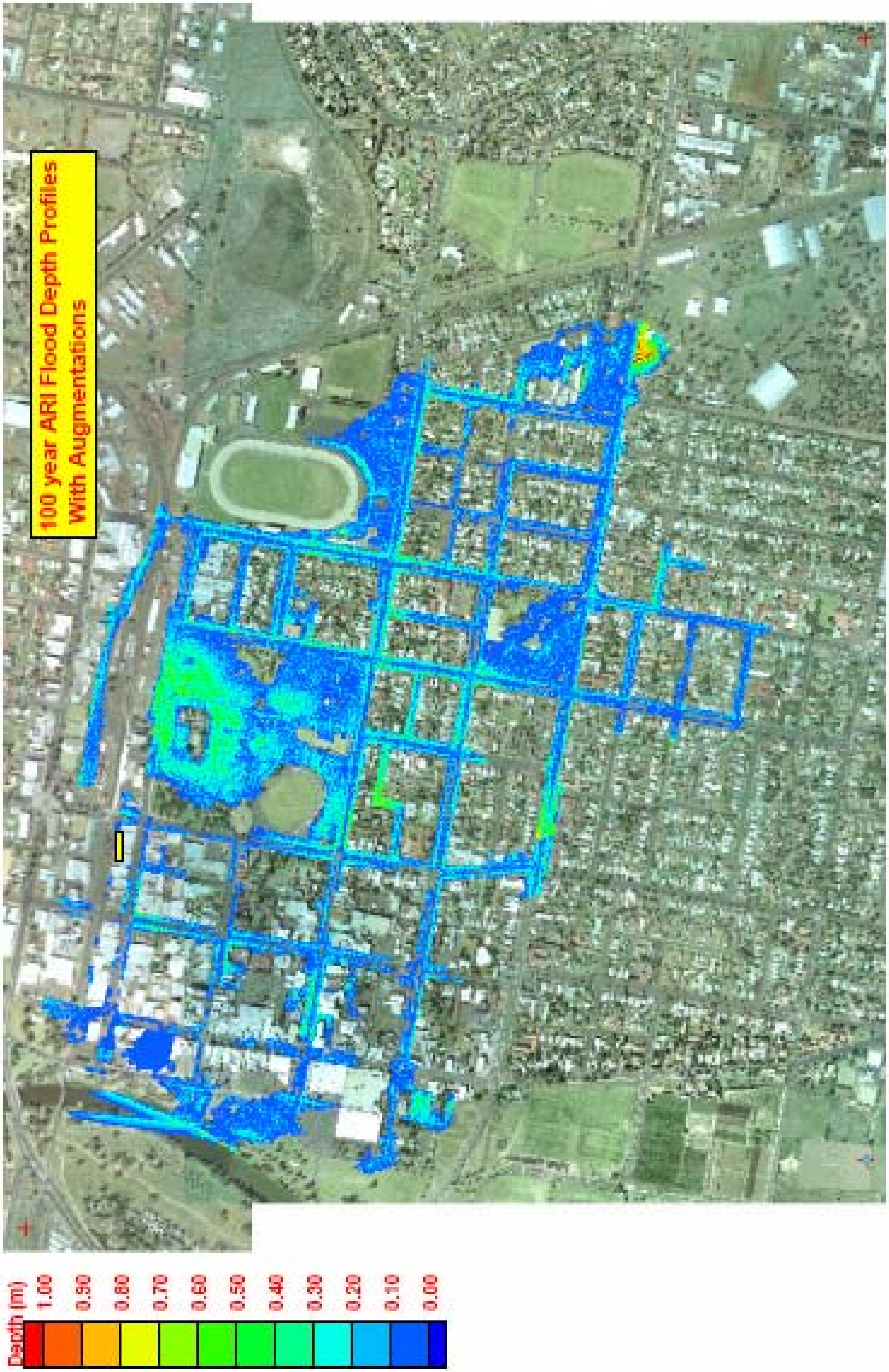

Figure 3 Estimated 100 yr ARI Flood Depths and Extents – With Concept Augmentation Works

Figure 4 Estimated 100 yr ARI Flood Depths and Extents at Brisbane Street & Church Street Intersection – Existing Conditions

Figure 5 Estimated 100 yr ARI Flood Depths and Extents at Brisbane Street & Church Street Intersection – With Concept Augmentation Works

Modelling Overland Flows and Drainage Augmentations in Dubbo
by J. Smith, Dr BC Phillips and S. Yu

Author Bio Data and Contact Details:

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Are the Poor more at Risk in Flood-prone Communities?

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Summary

The relationship between socio-economic factors and vulnerability to natural hazards is well documented in the literature [3]. In addition, it is often hypothesised that communities living in hazard-prone areas are dominated by those of lower socio-economic status, who are less able to cope with a crisis. This study tests the hypothesis using several flood-prone urban areas of eastern Australia as sample communities. For each urban area, flood-prone and non flood-prone areas were determined using flood risk ratings calculated for individual addresses and derived using Risk Frontiers' flood inundation risk model, FloodAUS. Socio-economic indicators are available from the Australian Bureau of Statistics (ABS), at the finest resolution of Collection Districts (CD). To determine socio-economic status, four indexes from "Socio-Economic Indexes for Areas 2001" (SEIFA) [2] and two census derived indicators extracted from CDATA 2001 [1] have been used. Six of the seven flood-prone urban areas have been found to essentially support the above hypothesis.

1. Introduction

The average annual cost of flooding in Australia is estimated by the Bureau of Transport Economics to be $314 million [4], making it the most costly of all natural hazards in this country. Identifying the communities vulnerable to floods, both in terms of their exposure and the underlying socio-economic factors which will determine a society's ability to prepare for, react to and recover from a crisis, is vital for emergency planning and disaster mitigation and recovery.

It is often hypothesised that communities residing in flood-prone areas tend to have lower socio-economic status. To test this hypothesis, two types of information are required to determine a flood-prone area: (1) the geographic classification of flood-prone and non flood-prone zones; and (2) socio-economic data for each of these two zones. This paper uses flood risk ratings that are available from FloodAUS [8] for classifying flood-prone zones, in conjunction with the four socio-economic variables extracted from the ABS Socio-Economic Indexes for Areas 2001 [2]. For each of the flood-prone urban areas in eastern Australia, the socio-economic variables for flood-prone and non flood-prone zones are compared.

2. Flood Risk Ratings

Risk Frontiers has completed flood inundation risk assessments for 26 urban areas in eastern Australia, covering approximately 1.18 million addresses in 174 postcodes. FloodAUS is a GIS-based model developed to estimate mainstream flood risk on an address-by-address basis. Using best quality digital terrain models, flood surfaces from the most recently available hydrological studies and most recently, the Geocoded National Address File (G-NAF) street address databases [7], FloodAUS thus provides estimates of the Average Recurrence Interval (ARI) of inundation for each address. This enables easy delineation of flood-prone zones with a specified

ARI. This is the first time in Australia that flood risk in a significant number of areas has been assessed. The presentation is limited to 7 regions, where our flood risk analysis has been re-analysed using the G-NAF database. The areas are: Georges River, Hawkesbury-Nepean River, Lismore, Murwillumbah, Macksville, Maitland and Queanbeyan.

3. Socio-economic Variables

Traditionally, measures of vulnerability have taken into account variables which are representative of the physical properties of the hazard, its likelihood and the exposure of a population. A recent study by Geoscience Australia [5] identified that damage to property and likelihood of injury were the two most important factors to influence vulnerability. However, more recently considerations of what may be used to calculate vulnerability and risk have moved away from simple cause and effect hazard models towards more complex types which take into account human systems and their influence on the ability to cope with and recover from an event [6]. The value of such an interpretation of vulnerability is demonstrated by a social mapping project carried out by Louisiana State University's Coastal Studies Institute (LSU CSI) [12]. Prior to Hurricane Katrina the CSI was in the process of mapping New Orleans with a Geographic Information System database that included variables such as income level and access to transportation, to determine which neighbourhoods were likely to have the most flood victims [9]. The study, correctly predicted that those most vulnerable in the event of a hurricane were those unable to leave the city due to financial restrictions, poor access to transportation and those suffering from depression, disabilities and other life stresses. Unfortunately their study was not yet finished by the time Katrina struck.

Vulnerability to floods may be interpreted in different ways. A recent paper produced by Geoscience Australia [5] on Social Vulnerability tends to focus on the ability to recover from an event. Damage to property and likelihood of injury, are the 2 major factors that Geoscience Australia found influenced vulnerability. The research undertaken by Risk Frontiers assesses the financial vulnerability of the Insurance Industry to floods, and as such, is focused on the likelihood of damage to property. Being able to identify areas that are vulnerable to tangible asset damage can assist communities prepare both physically and financially for flood events, thus increasing their resilience.

The Australian Bureau of Statistics has developed a set of Socio-Economic Indexes [2] based on the information from nearly 50 questions collected in the 2001 Census. The indexes are constructed using statistical techniques that combine information on related items to produce summaries. This information is used by government departments to allocate resources. Information provided in SEIFA is superior to direct census data as it combines information, this provides greater number of cross-tabulated variables. For example: two sets of census data - population over 40's and number of unemployed are combined within the one SEIFA index using the number of unemployed over 40 years of age.

The indexes are a combination of 3 levels of variables

- Level 1 – Education, Income and Occupation
- Level 2 - measure of aspects of disadvantage (eg living conditions, wealth, access to services etc)
- Level 3 – relates to disadvantage generally rather than specific aspects of disadvantage – eg percentage of non-English speaking households may generally be a signal that the area has some disadvantage.

Table 1: *Six variables used to investigate vulnerability to floods*

Category	Use	Description
Disadvantage	Reflects areas disadvantage	Uses all 3 levels of variables
Advantage/ Disadvantage	Ranks CD in terms of both advantage and disadvantage	Advantage may offset disadvantage in this measure
Education and Occupation	Target specific area of disadvantage	Uses only level 1 variables
Economic Resources	Reflect economic disadvantage	Uses level 1 and 2 variables
*Residency Time	Previous exposure to hazard	Census
*Vehicle Ownership	Ability to evacuate	Census

* To better assess vulnerability to floods the following statistics from the Census Data have been included:

- the percentage of households with a motor vehicle – the availability of a motor vehicle is important in the ease and speed of evacuation and
- the percentage of persons that have lived in their usual address for more than 5 years – as an indicator of the level of past experience of flooding. Having experienced recent flooding, a community may better prepared and therefore less vulnerable.

4. Selection of Flood-prone and Non flood-prone CDs

Whilst flood risk ratings from FloodAUS are based on individual addresses, socio-economic variables more generally describe CDs, which contain an average of 220 dwellings in urban areas. To reconcile the data discrepancy, we classify the CDs as flood-prone or non flood-prone using a specified Average Recurrence Interval (ARI) threshold or cut-off.

Accepted zoning guidelines restrict development below the level of an ARI of a 100 years event. In order to assess the flood-proneness of a CD, the percentage of addresses with an ARI of less than 100 years has been calculated (using FloodAUS). This threshold is an arbitrary choice, so to investigate the significance of this choice, the values of 20% and 60% of addresses with ARI below 100 years have been analysed. A value of 20% of addresses below ARI 100 years indicates more CDs will be flood-prone than the 60% value.

The area of non flood-prone CDs surrounding the floodplain are selected based on the distance from the river and flood prone CDs. Within the smaller towns, the whole of our flood study area was used (usually the town area) but within Sydney (Georges River and Hawkesbury Nepean River) the area includes a border of CDs that do not have any addresses with an ARI of less than 100 years.

Levee protection was been taken into account when the FloodAUS risk ratings were calculated. Therefore, in areas such as Murwillumbah, with levee protection to just above the ARI 100 year event, there would be a dramatic increase in the number of flooded properties if an ARI of 250 years (the ARI used for reinsurance purposes) were to be used.

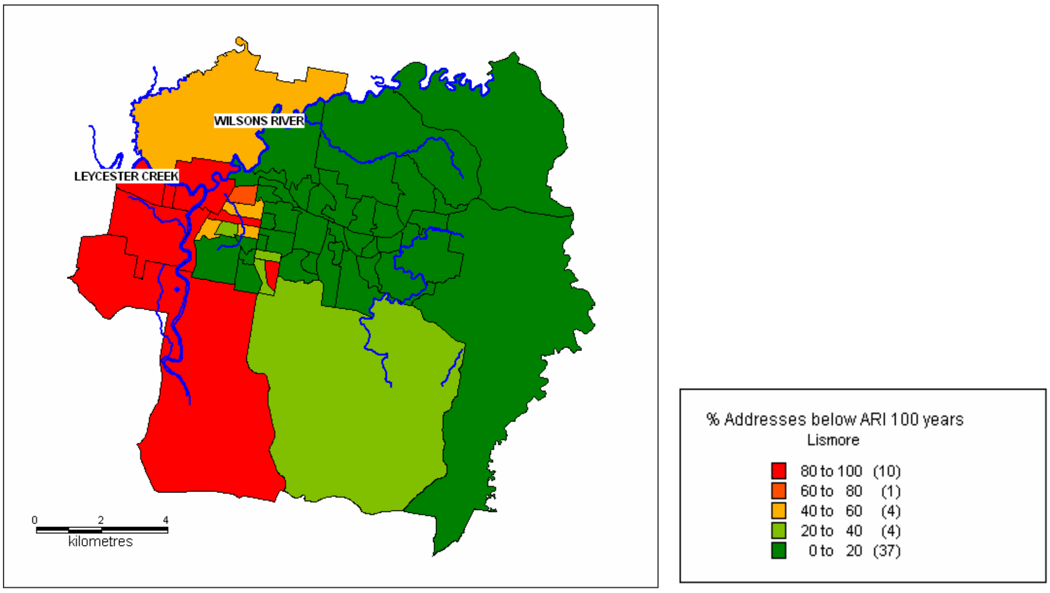
5. Analysis and Results

Socio-economic variables of flood-prone and non flood-prone CDs were compared for each of the 7 urban areas listed. Lismore, NSW, is used as an example to illustrate the analysis process and relevant results. The City of Lismore, located at the confluence of Leycester Creek and the Wilson River, is one of the most flood-prone towns of its size in Australia [8]. The largest floods since European settlement occurred in February 1954 and March 1974. The most recent damaging floods occurred in April 1989 and February 2001. Flood study estimates by Sinclar Knight and Partners [11] suggested that a 1-in-100 year flood would inundate approximately 1,200 properties in the town to above floor level.

In order to define flood-prone and non flood-prone CDs, the percentage of addresses with an ARI of less than 100 years was calculated for each CD, as shown in Figure 1. Using a threshold of 20%, 19 of the 56 CDs covering the Lismore study area are categorised as flood-prone. A threshold of 60%, results in 11 CDs being defined as flood-prone. The CD average SEIFA indexes and Census variables were calculated for flood-prone and non flood-prone areas.

Figure 2 shows a comparison of the average Socio-Economic indexes for flood-prone and non flood-prone CDs. Figure 2a uses the 20% addresses below ARI 100 year threshold and Figure 2b, the 60% threshold. Both thresholds show that the socio-economic indexes for flood-prone CDs is significantly lower than for those defined as non flood-prone. Figure 2c compares the two Census variables, (1) households with at least one car and (2) percentage of residency longer than five years. When the flood-prone threshold is set at 20% flood-prone areas had higher percentages for both variables but with a more restrictive threshold for being flood-prone (60%) the flood-prone areas were more vulnerable.

Figure1: *shows CDs by percentage of addresses with ARI of less than 100 years.*



The same analytical procedure was applied to other urban areas, and the results of a comparison of flood-prone CDs to non flood-prone CDs are shown in Table 2, where "Low" indicates that the index for flood-prone areas is lower than the corresponding non flood-prone areas. For all but the Georges River area, the average disadvantage index for flood-prone CDs is less than that for non flood-prone areas. This indicating that flood prone CDs generally are more disadvantaged. The other socio-economic disadvantage index –Disadvantage/Advantage shows a similar trend.

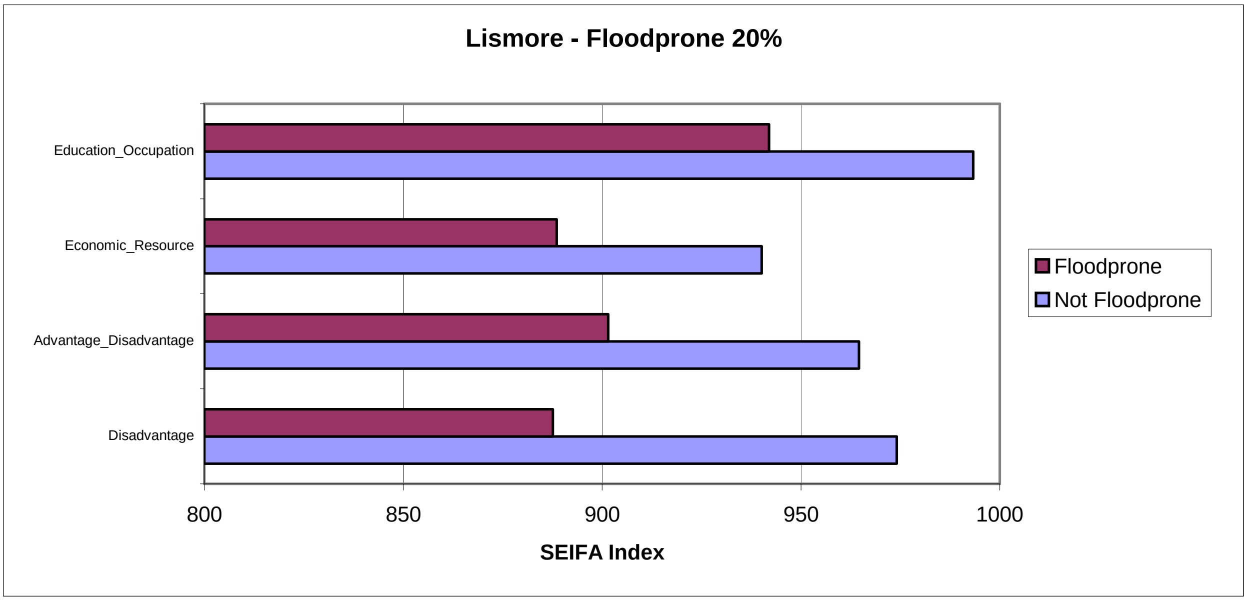
The Economic Resources Index gives an indication of the financial resources available to a household and is an important measure of the ability to take precautionary measures or recover from an event. Generally, flood-prone areas have lower Economic Resources Indexes indicating fewer resources available, and this may indicate a need for government sponsored mitigation and post event assistance. The Education/Occupation Index, along with car ownership and length of residency varied across the study area. Education/Occupation and length of residency are important factors when planning community education programs, and local variations must be assessed. Of most importance is the influence of flooding experience on risk perceptions and preparedness. Although experience of a flooding event is likely to increase preparedness for future events it can also have a negative effect known as “normalisation bias” [10], where individuals’ experience of coping with a flood may condition them to be complacent.

Table 2: Relative Difference of Flood-prone vs non flood-prone CD averages for SEIFA Indexes, Car ownership and residency of greater than 5 years. (High/Low ≈20% threshold/60% threshold – using 2.5% significance level).

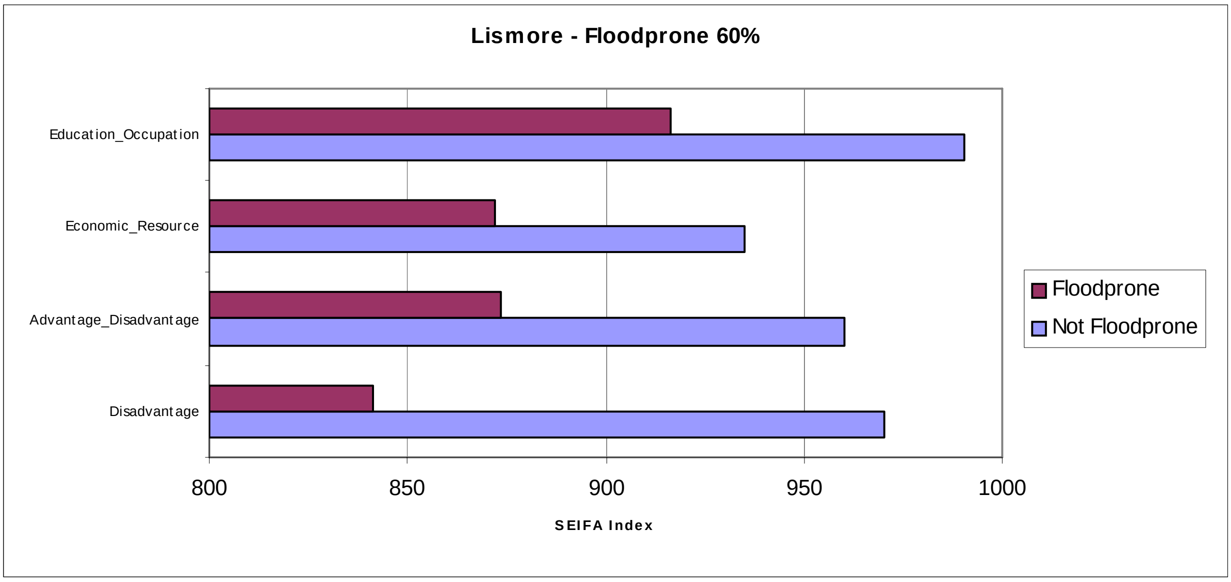
Area	Disadvantage	Disadvantage/ Advantage	Economic Resources	Education /Occupation	Own Car	Resident >5 years
Georges R	High	High	High	High	High	Low
Hawkesbury-Nepean	Nil/Low	Low	Nil/Low	Low	Nil/Low	Nil/Low
Queanbeyan	Low	Nil/High	Low	High	Low	Low
Lismore	Low	Low	Low	Low	High/Low	High/Nil
Murwillumbah	Low	Low	Low	Low	Low/Nil	Nil/Low
Macksville	Low	Low	Low	Low	Low	Nil
Maitland	Low	Low	Low	Nil/Low	Low	Nil

Figure 2: *Comparison of socio-economic characteristics for flood-prone and not flood-prone CDs (Lismore, NSW).*

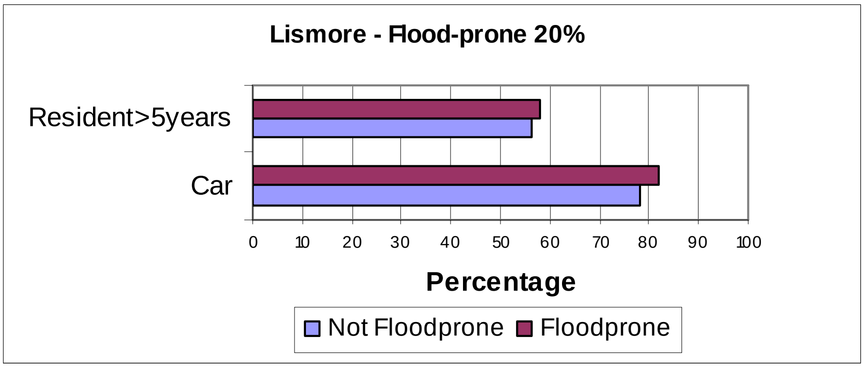
a) With 20% below ARI 100 year as flood-prone



b) With 60% below ARI 100 year as flood-prone



c) % of households with at least one car and % of population resident for more than 5 years



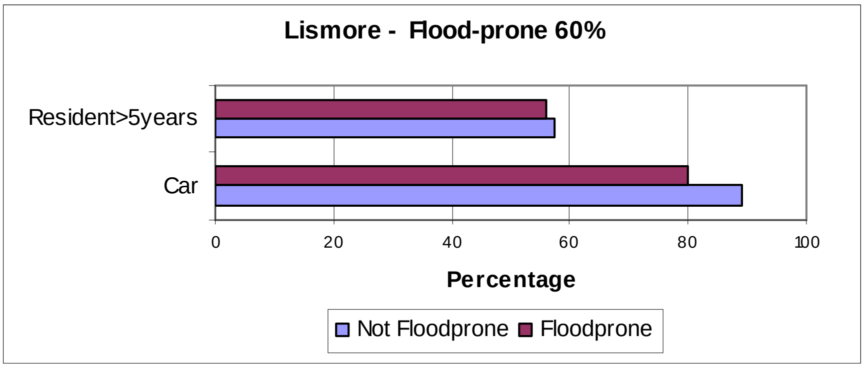
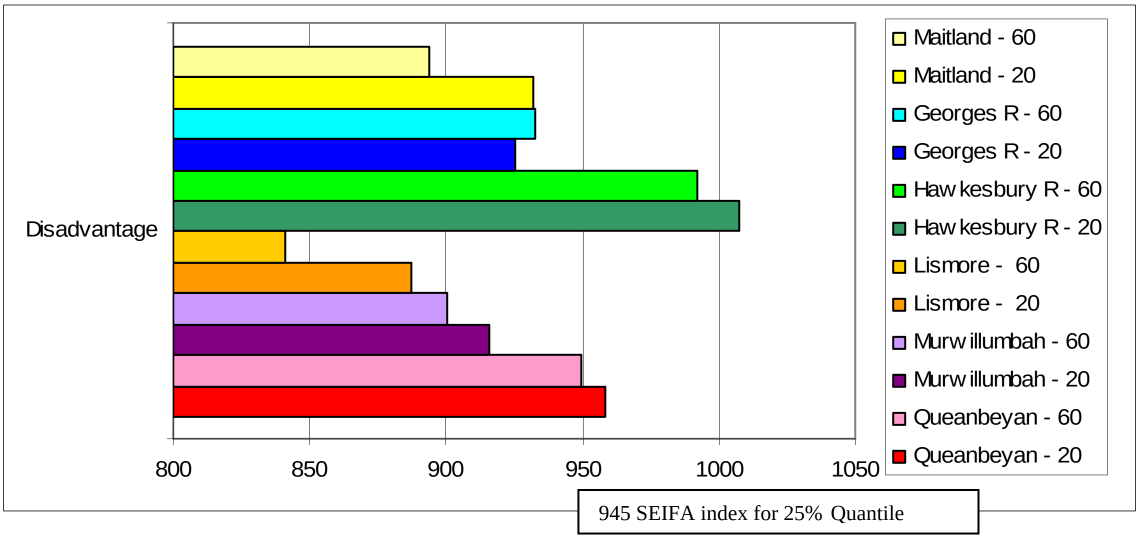


Figure 3 shows that for all study areas, with the exception of Georges River, increasing the threshold for defining flood-proneness increases the level of social disadvantage seen (lower Index value). Figure 3 also shows the variation in the level of disadvantage across the study areas. Table 3 lists the quantile index values for the disadvantage index. Although the relative level of disadvantage within the Hawkesbury Nepean area is greater with the higher flood-prone threshold, this level of disadvantage is lower than any other regions non flood-prone areas. However, in the Georges River, flood-prone CDs appear less socio-economically disadvantaged. In comparison with the State averages they score below the 25% quantile, whereas for Hawkesbury Nepean the most vulnerable (60% threshold flood-prone CDs) score towards the 50% quantile. With the exception of the Hawkesbury Nepean area all areas score less than the 50th percentile score – indicating a higher than average level of disadvantage.

Table 3: *Quantiles for Disadvantage (lower index value indicates increased disadvantage)*

Quantiles	10%	25%	50%	75%	90%
Index Value	876	945	1011	1073	1119

Figure 3: *SEIFA Disadvantage Index for flood-prone thresholds of 20% and 60%*



Although the use of averages is an accepted method of comparison, this may result in a loss of information. An alternative analysis is show in Figure 4, where the relationship between the percentage of properties below ARI 100 and the SEIFA disadvantage index is explored. All plots show a significant variation within the index for CDs that are not flood-prone (percentage equal to zero) and only Lismore showed any significant relationship between flood-proneness and disadvantage. However, generally, with the exception of Georges River, there is a slight negative relationship for all locations.

Figure 5 shows the relationship for flood-prone addresses only. For the five regional areas, there is a decline in the disadvantage index (increase in level of disadvantage) with increasing percentage of addresses with a risk rating below ARI 100 years. This trend is not seen in the Sydney urban area river systems. Within the Georges River the trend may be slightly positive but the Regression Coefficient ($R^{2)}$ values for both areas indicate a very weak relationship.

***Figure 4:** Relationship between Disadvantage Index and the percentage of addresses with a Risk Rating less that ARI 100 for all CDs*

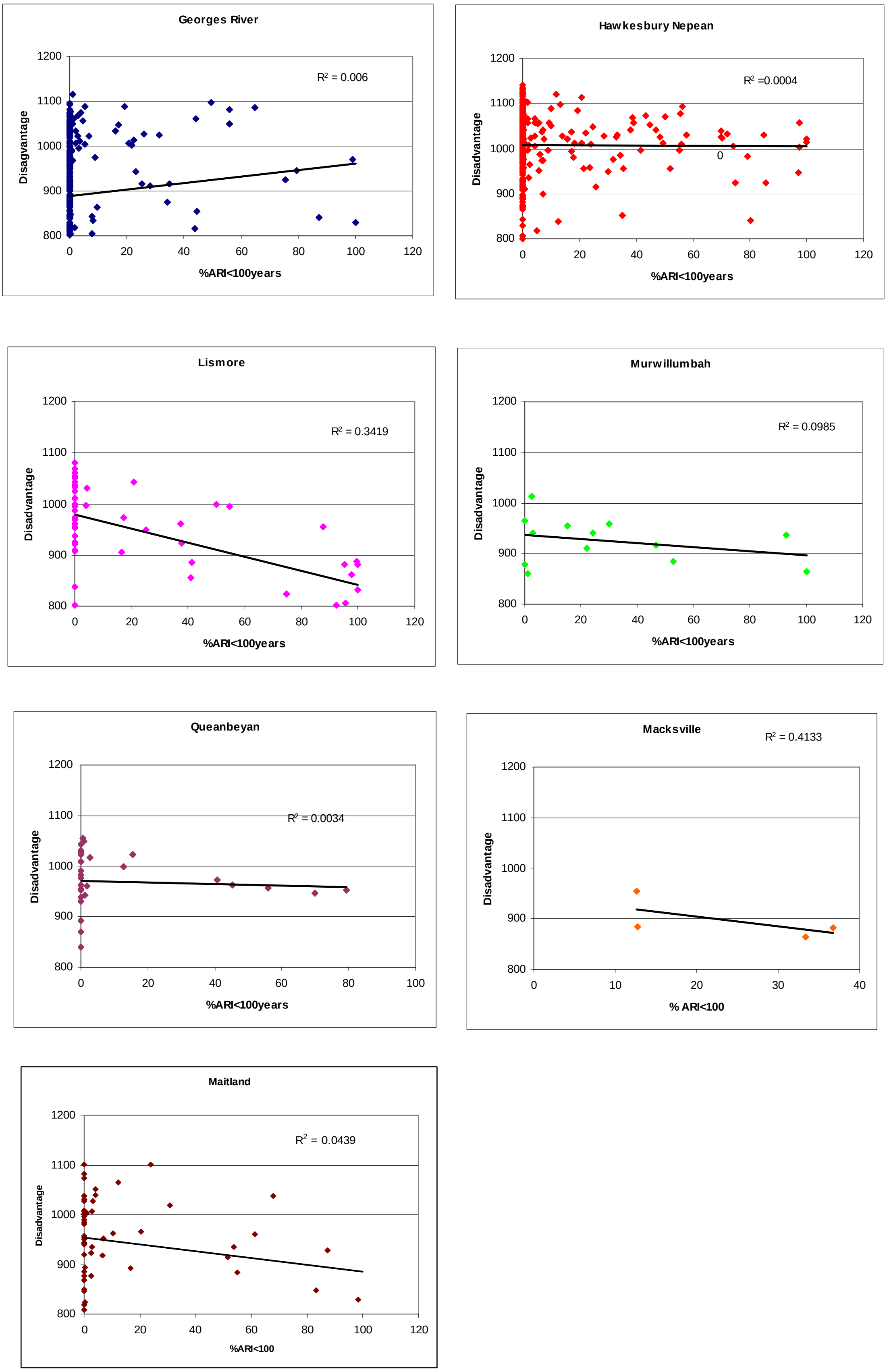
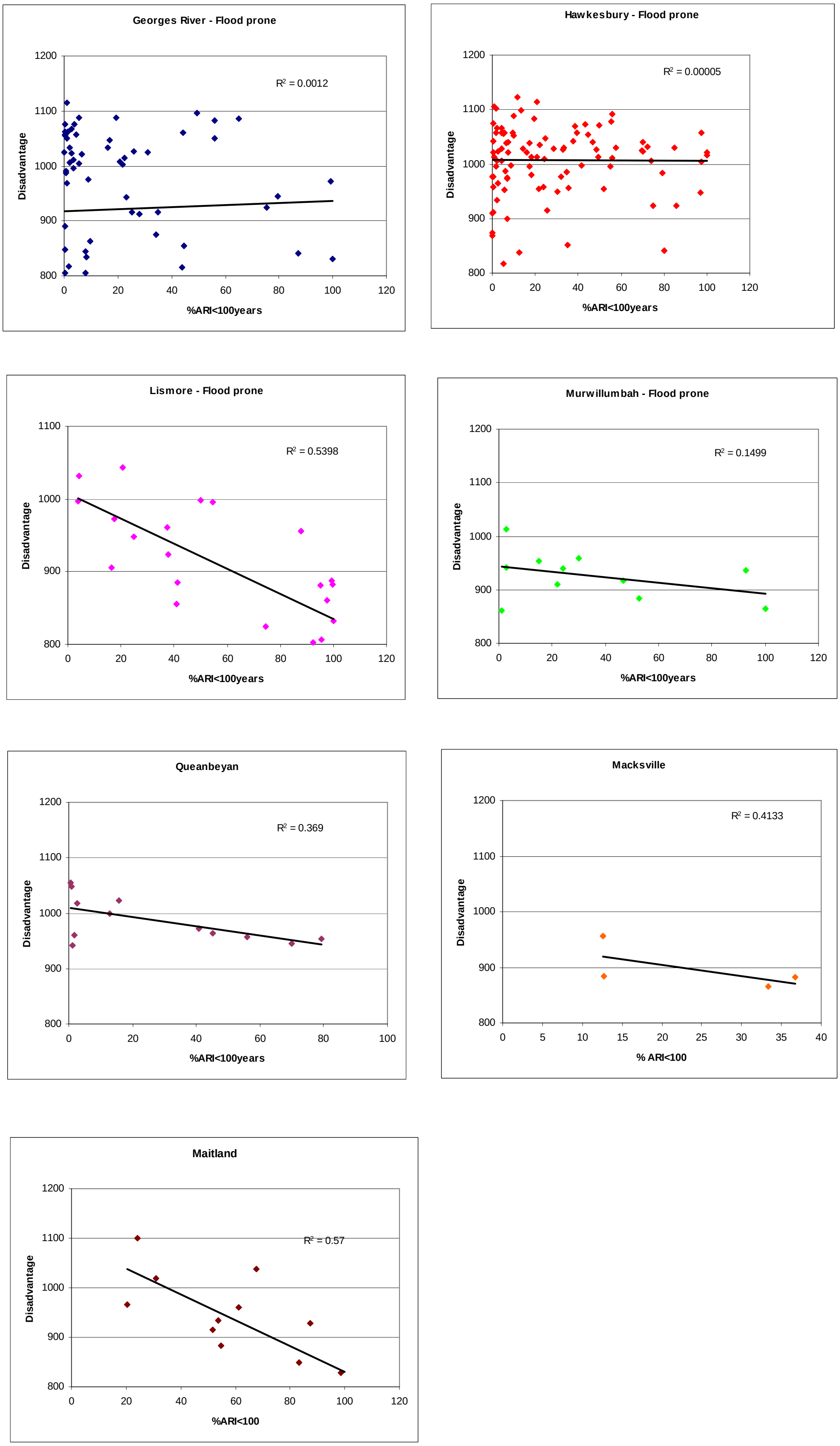


Figure 5: *Relationship between Disadvantage Index and the percentage of addresses with a Risk Rating less than ARI 100 for flood-prone CDs (percentage greater than zero)*



6. Discussion

The seven communities studied generally support the hypothesis that "poorer people within a community are more at risk from flooding". This result differs from a previous investigation by Risk Frontiers where no clear relationship was identified from the pair-wise analysis of census socio-economic variables (income, education, tenancy, age, race etc) for all 26 urban area assessed by FloodAUS [8]. Although this current study is limited to seven areas, the use of indexes involving weighted and cross-tabulated variables is considered a refinement over the use of simple census data analysed in a pair-wise fashion. It is therefore considered that this study has allowed a more detailed exploration.

The results show that generally, with increasing risk of flooding, there is an increase in social disadvantage, albeit a sometimes weak relationship. The definition of flood-prone did have an influence on the results as the percentage of properties in a CD with an ARI below 100 years increased the Disadvantage Index decreased, indicating a higher level of disadvantage. It should also be noted that the level of disadvantage of the base (non flood-prone) populations varied across the areas. Although the Hawkesbury-Nepean area was subject to the general trend, all the Socio-Economic Indexes where higher than for CDs in other areas. The Georges River area, where the trend was reversed, had a base Socio-Economic Index considerably lower than the Hawkesbury-Nepean and Queanbeyan areas, but similar to Maitland. Social disadvantage is not influenced by being flood-prone but being flood-prone is related to social disadvantage.

In part, these differences may reflect true differences between the communities. On the other hand, as with other studies of environmental justice, some of the differences may stem from aggregation bias or choice of spatial analysis units. The use of different spatial units may result in conflicting interpretations and outcomes. Whilst the hypothesis raised in this paper may be better tested at an individual household level, the fact that socio-economic data are only available at aggregate CD level restricted our analysis to CDs as the smallest areal unit. The introduction of mesh-grids in the 2006 Census will provide a finer geographic resolution for future work. Depending upon the spatial distribution of flood-prone addresses and the threshold value used to determine flood-prone CDs, the number of flood-prone CDs could be very small as was the case with Macksville with no flood-prone CDs using 60% threshold and 2 of the 4 CDs flood-prone using a 20% threshold.

Although all four Socio-Economic Indexes represent social disadvantage, not all indexes revealed the same relationship. The focus here was on the "Disadvantage" index as it used all three levels of variables in its calculation. Levels of car ownership, length of residency and Education/Occupation varied across study areas, indicating that these factors and local knowledge need to be assessed for local level implementation of mitigation and disaster preparedness programs. This study was designed to provide an overview and indicates that generally flood-prone areas are comprised of more socio-economically vulnerable communities.

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FLOOD MODELLING THE COMPLEXITIES OF URBAN ENVIRONMENTS
MEETING THE CHALLENGE IN NEWCASTLE

Bill Syme
Associate, WBM Pty Ltd

David Gibbins
City Strategist – Integrated Flood Management, Newcastle City Council

Presenters: ***Bill Syme and David Gibbins***

Presenters' Profiles

Bill has over twenty years experience in computer modelling, mostly within the floodplain management fields. He is the primary author of the TUFLOW modelling software, which is now widely used within Australia and the UK for flood modelling. Bill's experience includes numerous flood investigations within Australia and overseas, including recent visits to the UK where the TUFLOW software has been selected for the Thames Embayments Inundation Study in London, and for modelling the London 2012 Olympic Site.

David holds a degree in Civil Engineering from the University of Newcastle and has worked in a diversity of roles with Newcastle Council. After the devastating flash flooding in Newcastle in 1988 he became part of a group seeking to find ways to manage these risks. He now heads the development of Council's integrated citywide flood management strategies. Hobby's include a recent attack on kayaking.

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Flood Modelling the Complexities of Urban Environments Meeting the Challenge in Newcastle

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Abstract

Large urban catchments can present extraordinary challenges to both flood simulation software and modellers. A little more than a decade ago software and computing power was stretched "to the max" to confidently simulate comparatively simple riverine flood behaviours in floodplains. Today this level of complexity equates to just a small element in a remarkable mosaic of multilayered complexity which forms the Throsby, Cottage and CBD flood model in Newcastle. The community's and the development industry's expectations have increased to the point where models need to predict flood levels to the highest standard. Given the density of urbanisation, understanding the train of causes and affects is paramount. A major step towards this challenging goal was the development and calibration of a high-resolution computer flood model across the 42 sq km study area and some 19,000 flood affected properties. Recent advances have offered the opportunity to develop a confident and useable model. An unusually comprehensive historical data set for the 1988 and 1990 floods provided a solid base for validating the model's predictions. This paper presents the need for the approach adopted, the TUFLOW model developed and its rigorous calibration. Challenging and interesting aspects to the model's development and validation are discussed. The benefits of taking on a challenge and successfully applying recent advances in technology were realised.

Key Words: Technology Advances; Flood Modelling; Urban; Newcastle; TUFLOW

1 Introduction

The Throsby, Cottage and CBD catchments contain much of Newcastle's urban expansion since the mid 1800's. Creeks were realigned, covered and replaced by concrete channels and large box culverts. Wetlands and estuarine areas were filled. Flood behaviour was changed dramatically, and made far more difficult to model than in their natural state.

The Throsby and Cottage Creek catchments, and to a lesser extent the CBD, have an established history of flooding. The catchments are steep around their perimeter, but drain onto low-lying, flat areas, where it is difficult for floodwaters to escape. Some of the low-lying areas are subject to tidal and other ocean influences.

Beginning in the late 1800's in response to the flooding and health problems, the creeks have been heavily engineered into concrete lined stormwater channels, or replaced by underground pipes and box culverts. In a number of areas, the creek lines have become non-existent, with the pipes and culverts being relied upon to carry the floodwaters.

Roads also act as flow paths once the capacity of the channels and culverts is exceeded. A number of rail, road and other embankments exacerbate the flood problem by diverting and blocking floodwaters. Continued urbanisation has also increased the rate and quantity of runoff, further worsening the flood risk.

While the drainage engineering works have reduced the flood risk in some areas, problem areas remain and it is not unfeasible for floods to massively exceed the capacity of the channels and culverts. The potential for widespread flooding, risk to life-and-limb and damage to buildings and infrastructure is an on-going issue for Newcastle City Council.

These risks were amply demonstrated during the April 1988 and February 1990 flash floods. Simulations of more extreme floods reveal an even greater and wider level of risk.

2 Background

The coastal location and flashy nature of the catchments combine to give a susceptibility to intense but very localised flooding forced by thunderstorms over sections of the three catchments. Historically in the last twenty years this spawned a series of isolated and reactive small investigations across the study area in what were perceived to be localised 'hot spots'.

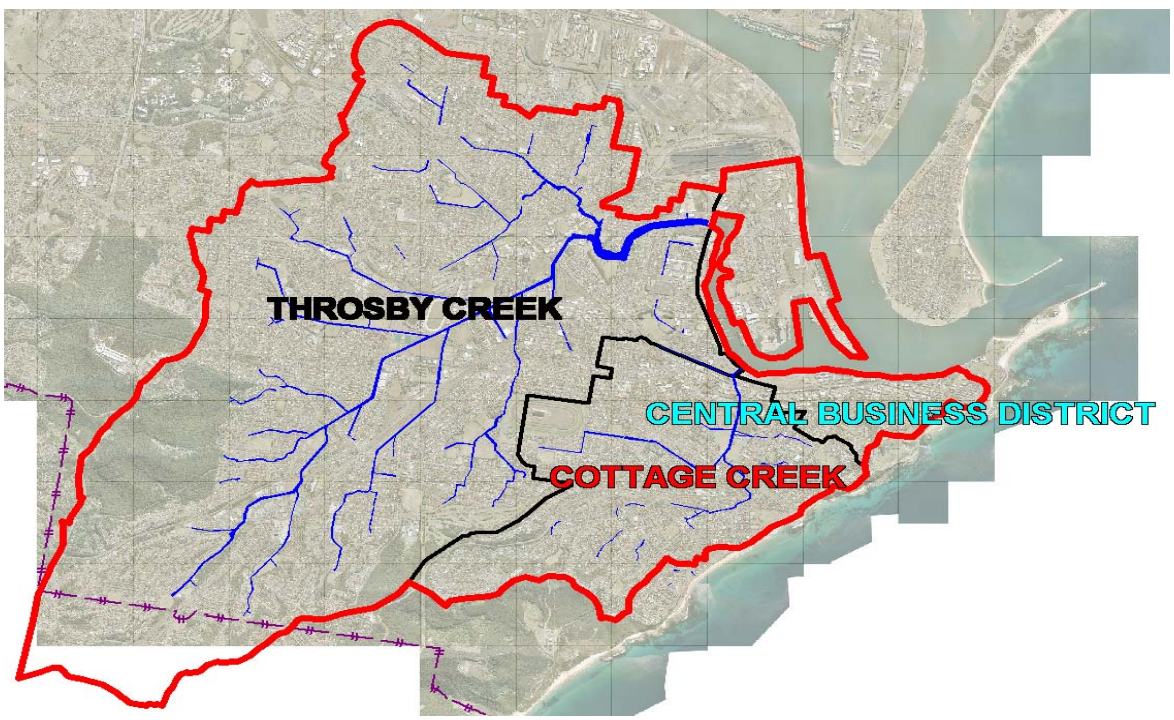
Research into available flood records from Newspapers since early European settlement gave a perspective that flooding in the three catchments was a much broader risk and a more strategic approach would be required.

In the late 1980's an attempt to derive a computer flood model by the Total Catchment Committee through the local Water Authority was launched. Maps were produced, but these had to be highly qualified and restricted in their application. While the attempt was genuine, time and resource constraints in addition to limitations of computer power, available software at the time and topographic data, resulted in flood information that was not confident enough to apply to individual properties.

The lack of a confident flood model translated into developments having floor levels set by Council staff after field inspections and an examination of broad-scale historic flood maps compared with the results of the above broad-scale flood model (where output was available in a useable form). This is a time consuming, frustrating and stressful method, contributing to a high turnover of Council staff.

3 Setting the Bar

The bar was raised and set when the Building Better Cities program initiated an inner city revitalisation program in the early 1990's. This major redevelopment that would take place over more than a decade was pivotal from a flood management-planning viewpoint.



Study Area

The redevelopment would skirt the majority of Newcastle Harbour frontage at the bottom of the three catchments of Throsby Creek, Cottage Creek and the CBD. The revitalisation authority (The Honeysuckle Development Corporation) and Council carried out a series of studies that defined floodways, set floor levels and found that the extreme flood events of the three catchments crossed over in the lower reaches.

The Honeysuckle studies were of necessity somewhat generalised and significant differences in design water levels (up to nearly one metre) were detected with a later flood study in Cottage Creek. This was an unsatisfactory position.

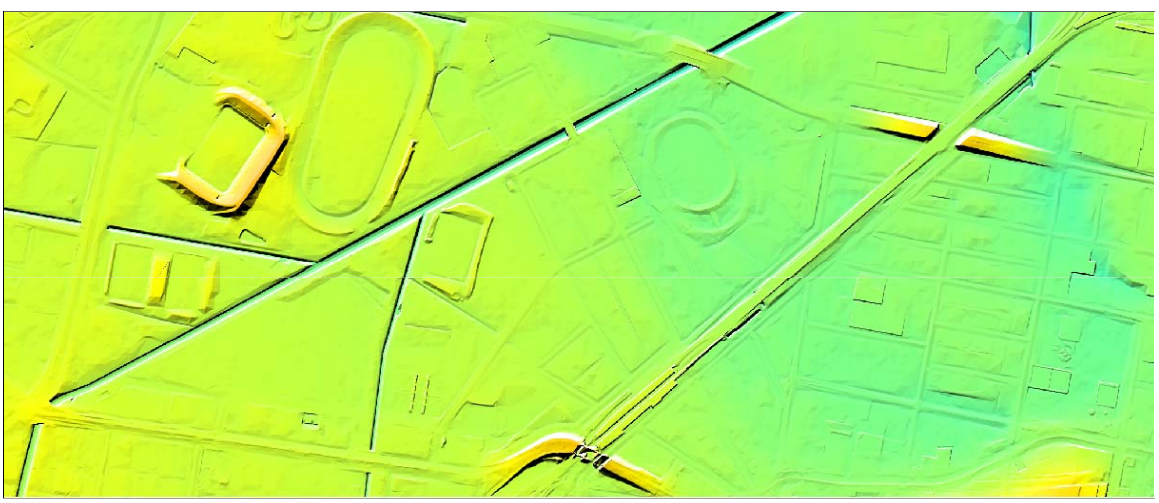
The need for an integrated flood study across all three catchments of the highest accuracy possible became apparent to the Committee in the new millennium. Useable results for thousands of individual properties (where levels could vary within individual properties) were required. There was significant questioning if such a study would be achievable over such a complex and large area. With some risk taking and enterprise the bar was set and the present study commissioned.

4 Defining the Flood Risk

The Throsby and Cottage Creek catchments, and the CBD Flood Study, is being carried out to meet the objectives described above, leading to a much improved and better understanding of the flood behaviour and the risk to the community. It is producing leading-edge computer based models that simulate the flooding processes of the whole catchment, and also the potential interaction between catchments in the low-lying areas, hence the combining of the three catchments into one study.

The study is being carried out in preparation for a Flood Risk Management Study that will investigate options and planning strategies for reducing the flood risk and minimising damage to buildings and infrastructure. It is noted that the Flood Risk Management Study will be simplified by the fact that for all practical purposes the catchments for the Study Area are in a single (Newcastle City) Local Government Area

The Study is being carried out through the Newcastle Flood Risk Management Committee with Grant assistance from the NSW Flood Program, which includes Commonwealth assistance.



The above image shows the DTM generated by the 12D software then converted to Vertical Mapper. The 12D DTM triangulation is a combination of photogrammetry and ground survey for the open channels. The final DTM is an excellent example of a good DTM for flood modelling and floodplain management. It does not have any of the data "noise" and vertical accuracy and triangulation issues associated with ALS data.

5 Topographic Data

Even before the commissioning of the Study, it was apparent that a high quality representation of the topographic and built environment would be a fundamental foundation to all efforts. Without such a representation no simulation of flood behaviours would be successful as the flow patterns were completely dependent on ground levels and the shape of the built environment. Even if flood surfaces could be derived without this detailed topographic information it not be possible to map the results and determine which properties were affected without such data.

Gathering this information is impractical by conventional land survey because of the sheer scale – there was about 25 square kilometres of detailed topography to be represented. After intensive investigation of options under expert guidance commissioned through the University of Newcastle, including the emerging technology of air borne laser scanning, it was decided to commission conventional but very low-level photo-grammetry.

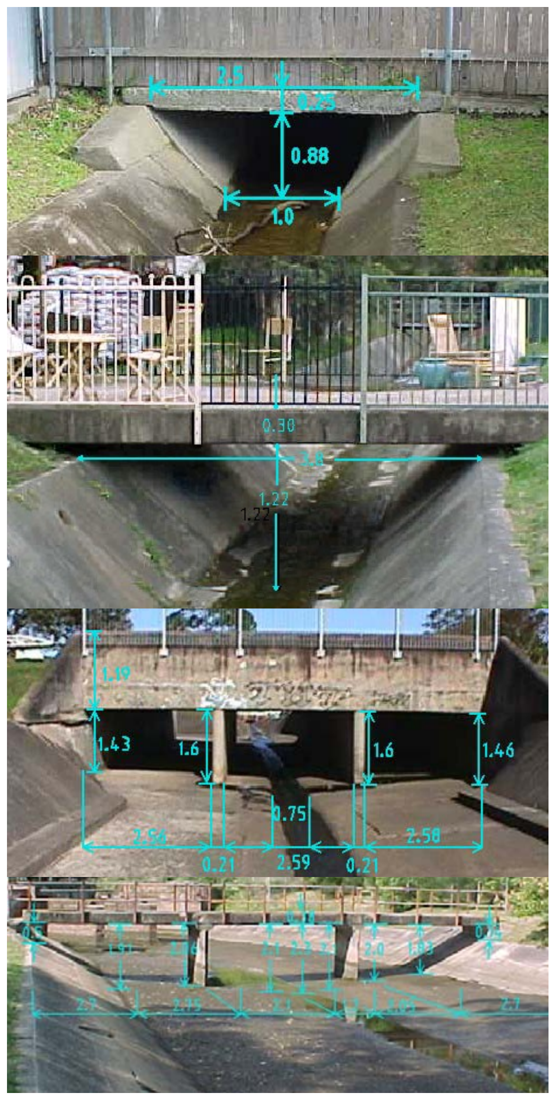
The photogrammetric vertical accuracy was independently assessed with thousands of ground truth random test points required to be within +/-0.1 metre (85% confidence). The final digital elevation model resulting in millions of triangular elements.

Of critical importance was the representation of the numerous concrete lined channels, which even in large events carry the bulk of the floodwaters. In endeavouring to minimise uncertainties, it was paramount that these critical flow paths were ground surveyed and 'cut in' to the overall DTM. Rather than carry out the conventional cross-section survey approach, the channels were surveyed as 3D breaklines along their banks, sides, low drainage sections, etc. This approach provided a more cost effective and accurate approach, and greater ease when cutting into the photogrammetric DTM.

This work was completed before the present flood study was commissioned. (The photogrammetry was carried out by QASCO P/L, and the building of the DEM by WBM P/L with independent assessment and guidance carried out the University if Newcastle (Fryer 2001). The University of Newcastle review commented that one reason for the success of the DEM was the ever-present human control of the derivation and data processing, rather than being an automated process.

In addition to the DTM, NCC collected the following topographic data:

- Bathymetric (depth) surveys of tidal areas were also stamped into the DTM;
- Surveys of hundreds of stormwater channel crossings (eg. bridges); and
- Dimensions and levels of the underground pipe system (down to 900 mm diameter).



Examples of a few of the many structures.

6 Hydrographic Data

Council surveyed several hundred flood heights reported by residents as part of a previous study. The types of information sought included:

- local knowledge and personal experiences in flooding and flooding patterns; and
- any flood marks or recollections of flood heights.

Flood marks were graded in terms of their reliability to represent the flood peak, and have been an invaluable source of data for calibrating the computer models.

Other hydrographic data collected are:

- Rainfall data from seven pluviographs within the study area;
- Harbour tide levels;
- Several water level gauges within the open channel system; and
- Flood extent surveys from past flood events.

The study is very data-rich in historical information compared with most flood studies carried out, and offers the challenge of a rigorous model calibration within a complex urban flooding problem.

7 Flood Behaviour

In minor rainfall events, floodwaters generally remain contained within the pipes, creeks and stormwater channels, with little or no overland flooding. Streets (gutters) may also act as a pathway for overland flows.

In larger events, the capacity of the stormwater drainage system can be exceeded. This occurs where pipes are too small to carry the floodwaters; pits and manholes are surcharged; and water starts to flow out of a stormwater channel and onto neighbouring streets and property. When this occurs, roads in particular become important secondary flow paths. In recent times, this occurred during the April 1988 and February 1990 floods where some thousands of properties were affected.

For very large rare and extreme floods, the floodwaters would continue to extend overland, causing major flooding and severe risk to the community.

The occurrence of elevated ocean levels from a large high tide, an intense low-pressure system and/or general sea level rise from global warming will further exacerbate flooding in the low-lying areas.

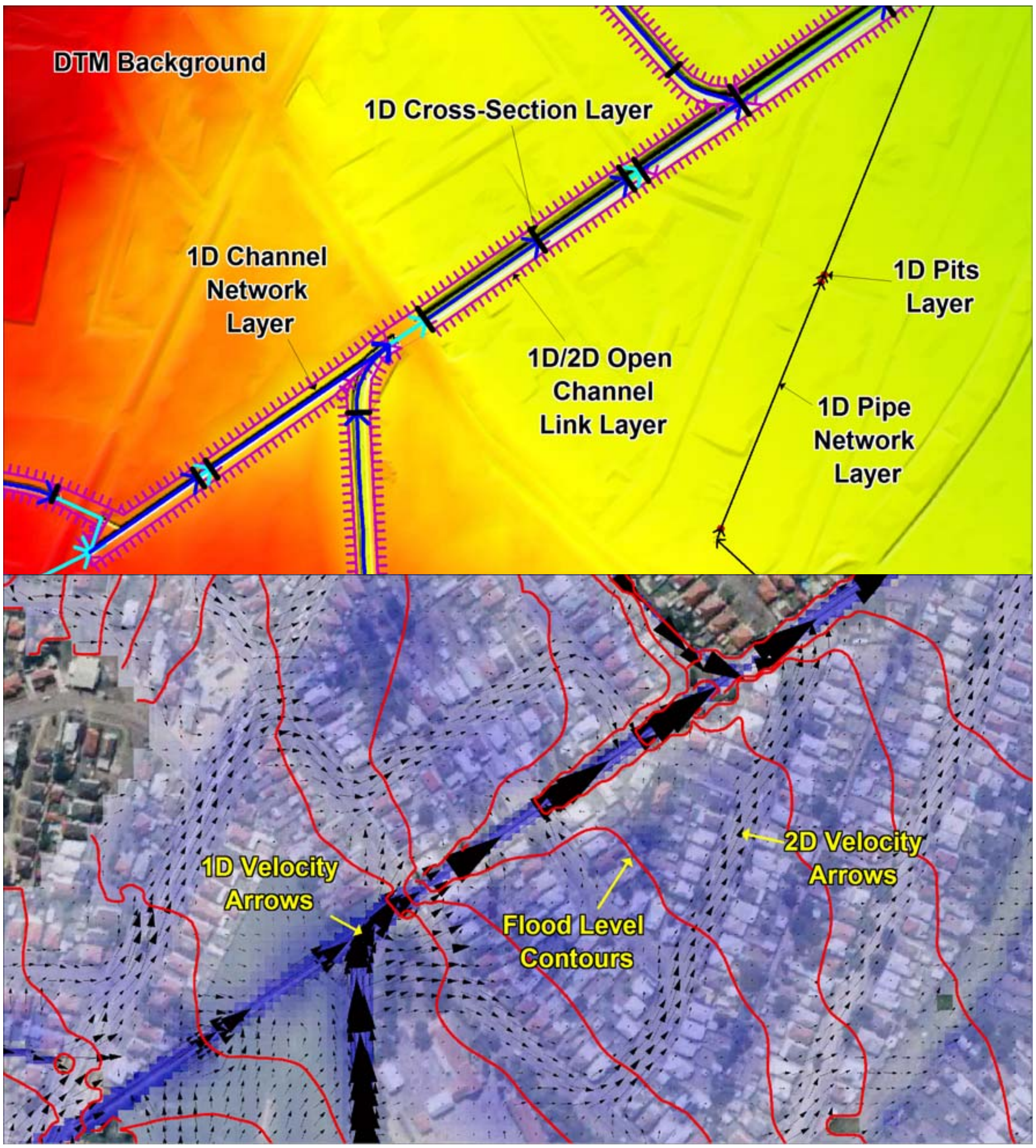
The above photo of the February 1990 flood, taken after the flood peak, illustrates the high velocities experienced, and reproduced by the TUFLOW model, in the concrete lined channels.
The floodwaters entering from the left as the flood receded was also reproduced by the model.

The computer models developed aim to reproduce the various physical processes described above for a range of flood severities.

The first process is that of converting rainfall to the flow of water in pipes and down streets, creeks and gullies feeding into the stormwater drainage system. This is referred to as hydrologic modelling.

The second process is to take these flows and simulate their passage down the larger creeks and stormwater channels all the way through to the harbour. This is referred to as hydraulic modelling. The hydraulic model also simulates the tidal conditions in the harbour.

The hydrologic and hydraulic models were calibrated to the most data rich floods of April 1988 and February 1990.



The top image shows the DTM in background with several TUFLOW GIS layers.
The bottom image shows the TUFLOW model output over the same area.

8 Hydrologic Model

The hydrologic modelling was carried out using the WBNM software over the entire catchment. To expedite the process, two hundred sub-catchments were automatically delineated from a catchment wide DTM using the StreamBuilder software.

Land-use categories, digitised for the entire catchment, were used to assign proportions of pervious and impervious fractions to the sub-catchments. The resulting GIS layers of sub-catchments and streams, along with GIS layers of rainfall distribution and pluviograph proximity, were then processed using in-house software to automatically generate the WBNM input data files.

9 Hydraulic Model

The study area presents a range of challenges for the hydraulic modelling, including:

- Several hundred rectangular culvert sections (one reach which exceeds 1.6km in length);
- Over a hundred bridges of many shapes and designs;
- Several hundred circular underground pipes;
- Steep concrete lined open channels that experience velocities up to 6m/s, and both sub-critical and super-critical flow regimes;
- Complex and variable overland flow along streets and through properties.

The first four dot points above are best represented using a 1D scheme as the flow is essentially in one dominant direction (eg. in the direction of the pipe), rather than spreading out over a floodplain.

The last dot point is most accurately modelled using a 2D solution as the flow paths often vary in direction as the floodwaters rise, spread out and then recede. 2D solutions allow floodwaters to vary in direction, and are ideally suited to modelling overland areas.

A TUFLOW 1D/2D model was therefore adopted as the best option for representing this array of 1D and 2D flow patterns. Its powerful 1D/2D linking options were critical to easily setting up the model, especially given that the several thousand 1D elements nearly all needed to be linked into the surrounding 2D domain.

The ability to develop a model of this complexity also benefited from TUFLOW's GIS layering of various types of data. This allows pipes, bridges, open channels, etc to be stored and managed in separate GIS layers.

Flooding with in the study area.
The top photo shows a hydraulic jump that has formed in an open channel. Review of the flow regimes in the model shows that a hydraulic jump would occur in the same vicinitv.

10 Model Calibration

The hydrologic and hydraulic models were calibrated to the data rich floods of 1988 and 1990.

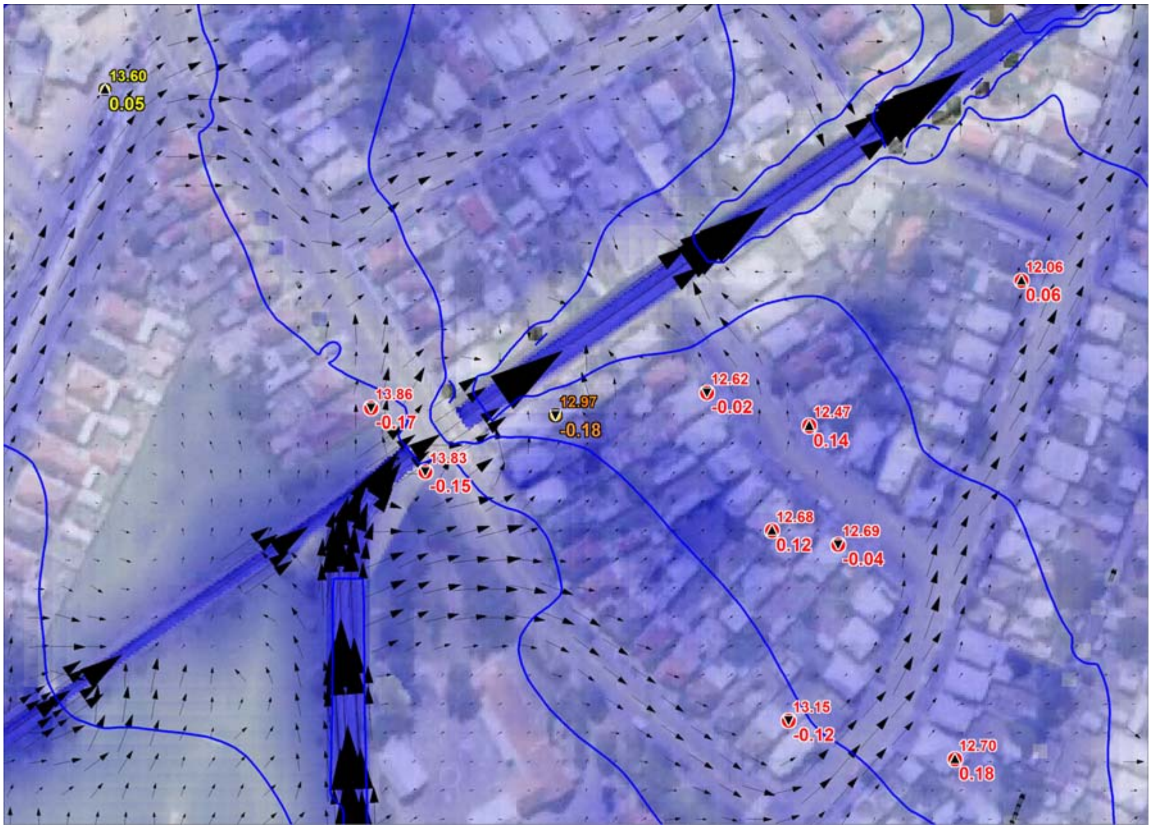
On the 2nd and 3rd of February 1990, around 300mm in a 48 hour period fell over the study area in several bursts. Five reliable pluviograph recordings within the study area were available, and five flood height gauges recorded the rises and falls of the flood within the stormwater channels. The first and largest peak caused the worst overland flooding around 3pm on the 2nd of February.

Previous investigations commissioned by Council identified around 160 sites within the study area provided information on the 1990 flood. Of these, around 70 identify a potential flood height to assist in the model calibration. These flood marks provide valuable information on flood levels away from the stormwater channels. In addition, there are a number of photographs and recollections that also assist in the model calibration process.

A similar, but lesser, data set was retrieved for the 1988 flood. As the 1990 flood was more widespread, had a greater and higher quality data set, it was chosen as the primary calibration event, while the 1988 flood was used as a secondary calibration event.

During the previous data collection study, the flood marks were graded according to their perceived accuracy. For example, a Grade 1 flood mark is a reliable representation of the flood peak (eg. watermark), while Grades 2 to 4 were progressively less reliable. Grade 5 was assigned to observations that could not be translated to a flood height.

The processing and presentation of TUFLOW model's calibration performance was greatly enhanced through using the flood mark grading and GIS. Figure ??? shows the recorded flood levels (smaller numbers) and the difference between the modelled and recorded level (larger numbers). Red fonts are



The above image shows how the TUFLOW model calibration to recorded flood marks was presented to Committee members in addition to the more traditional longitudinal profiles and time-series graphs. The red marks are Grade 1 marks, orange Grade 2 and yellow Grade 3.

the Grade 1 marks, orange Grade 2 and yellow Grade 3. Through displays such as this, the presentation of the model's calibration and general dissemination of material to the Flood Study Committee was very much enhanced.

Key observations from the calibration process were:

- Parameters adopted for both the hydrologic and hydraulic models fell within conventional bounds.
- Initially, the TUFLOW model was setup and calibrated using a coarse 20m resolution 2D grid, with the final calibration shifting to a 10m grid. This greatly expedited the calibration process as the 20m grid model had significantly shorter simulation times allowing quick turnover of the numerous model runs carried out.
- The video animations and GIS mapping of TUFLOW output was of significant benefit for the Committee to understand and comment on the computer modelling. Importantly it highlighted areas of concern. In one instance, the model predicted overtopping of a railway line and substantial inundation on the downstream side of the embankment. After ground survey of the railway embankment and tracks, this was subsequently shown by the model not to be the case (as previously indicated by several Committee members and local residents), highlighting the need for ground survey in critical areas where uncertainties in the DTM can have a significant influence on model predictions (it's amazing what a difference of 0.2m can make in a flat urban environment!).
- The absence of pipes less than 900mm in diameter causes excessive inundation in some of the lower-lying, flat, areas of the study area that rely on these pipes for stormwater drainage. As the costs of surveying these pipes were prohibitive within the study's budget, there therefore needed to be an appreciation of this issue by committee members and the community when reviewing predicted flood inundation maps.
- The modelling of large buildings remains a difficult issue. The options examined were: completely removing 2D cells within the building outlines; or allowing water through the buildings but applying a very high Manning's n roughness. The latter approach was adopted, but further research in this area would greatly benefit urban flood studies.
- In a similar vain, fences also pose a significant dilemma in urban hydraulic models. Of particular mention in this study was the delineation of fence lines using high resolution aerial photography along the open channels. The 1D open channel cross-sections extracted from the DTM also incorporated a third column representing the variation in roughness across the channel. Between the fences lower Manning's n values representing concrete and mown grass were used, while a much higher n value was used where the 1D cross-section extended into gardens due to the numerous and "impenetrable" fences both parallel to the open channel and between properties.

11 Onwards to Managing the Flood Risk

Some tasks remain in managing the flood risk. The Study will deliver to Council velocity and depth data for the entire study area for all design events. This will enable Council to map velocity depth products and determine provisional flood hazards in accordance with the NSW Floodplain Development Manual. This information will then determine final flood hazards in accordance with Council's currently adopted Flood Policy that very much recognises the unique challenges of urbanised flash flood catchments. Provisional flood-ways and storages will be determined in collaboration with the Committee as part of this study.

The foreshadowed separate Floodplain Risk Management Study will have a confident baseline set of design floods and a robust model that will enable a full suite of scenarios to be tested, analysed, and simply yet powerfully displayed to the community.

12 Community Consultation

The model calibration that used the historic data previously gathered was placed on public exhibition with the intention of clarifying the model's performance, and to seek any other data not previously collected to further improve and/or confirm the models' calibration. However, there was a surprisingly small attendance. We are unsure as to whether this is because of: the extensive resident surveys previously carried out; that there have been no floods of great concern since the 1990 event and therefore it is not a pressing issue within the community; poorly advertised; that it was just awful weather on the night (which it was!).

Council carried out a phone survey for some "hot spot" areas in the calibration using Council records of those residents whose property had not been sold since 1990. This helped resolve some issues in the calibration where no data on whether the land flooded or not in these events was otherwise available.

13 Conclusions

In conclusion, the challenges laid down to develop detailed and reliable flood management modelling tools for the Newcastle urban area have largely been met. The TUFLOW computer model is considered to be leading edge in its complexity, size and capabilities, and more than adequately meets the high standards and expectations laid down for the study. There are some weaknesses in the model such as not having pipes under 900mm in diameter due to the cost of surveying. These issues can be readily resolved in the future with further funding if required.

The study has demonstrated:

- The excellent detail that 1D/2D models can now represent complex urban areas.
- The fundamental importance of calibration data, and the need to manage data (much of the hydrographic data used in this study was officially lost, and only found by contacting a former employee of the local water board who had a 5¼" floppy diskette and obscure software to extract it!).
- The power of GIS to present and disseminate large amounts of information to committee members and other stakeholders.
- Persistence in seeking to resolve anomalies can pay off, but some things may never be explained where there are uncertainties.
- The confidence that one may now have in computer modelling of this nature.
- The benefits of taking on a challenge, innovating and succeeding.
- Australian products such as TUFLOW are at the technological leading edge.
- No matter how much you advertise, it's hard to get the community interested in a meeting on a cold, rainy night!

14 References

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TUFLOW References: www.tuflow.com

SUSCEPTIBILITY TO BROADSCALE RISK OF INUNDATION: A NEW APPROACH TO CATCHMENT-WIDE RISK MAPPING

Michael Barry
Associate, WBM Oceanics Australia
Bill Syme
Associate, WBM Oceanics Australia

Presenter: *Michael Barry*

Presenter's Profile

Michael Barry is an Associate of WBM and has experience across a range of environmental engineering disciplines, especially 1, 2 and 3 dimensional hydrodynamic and water quality modelling and integrated water cycle management. Michael also has skills in software development and has constructed standalone distributable packages for the assessment of floodplain related issues, including the impact of failing onsite sewage disposal systems on areas of environmental sensitivity.

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Author's Profile

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Michael Barry and Bill Syme

Abstract

Estimation of the areas likely to be at risk of flood inundation often forms an important part of the strategic planning framework of local governments. For example, planning for future urban development, provision of public amenities and services and development of maintenance regimes all require some understanding of the likely flood extents within a municipality. Traditional approaches to meeting this requirement would most likely involve one- or two- dimensional flood model construction, calibration and validation, and subsequent execution of particular ARI events within the model. Flood mapping based on model results would then provide local governments with an indication of likely flood extents. Whilst being a reliable and tried process, it is also potentially expensive and time consuming. This paper describes a relatively fast approach that also informs council planning but does not require detailed hydraulic modelling. Rather, it employs a novel technique that requires only good quality digital elevation model data of the region of interest. This technique is not a substitute for hydraulic modelling, but a method that can be used at the broad scale, catchment-wide strategic planning stage, prior to area-specific hydraulic modelling.

Key Words: broad scale, inundation, risk, mapping

Introduction

Flood extent mapping comprises an important part of most local government planning frameworks. Such information is typically required to inform the selection of future urban development areas, as well as the distribution and maintenance of other council services. Typically, significant effort and expertise is required to develop, calibrate and validate hydraulic models which then, when subject to hypothetical flood events of specific magnitude and duration, predict likely flood extent zones.

In an effort to reduce the reliance of local government on this lengthy (and often expensive) process, we have developed a technique to estimate the susceptibility to broadscale risk of inundation (SBRI) within a catchment of interest. This approach does not involve dynamic numerical modelling, but only requires sufficient quality digital elevation model (DEM) data, and a processing tool that has been developed in-house. This paper describes this approach.

Methodology

The methodology for computing and reporting the SBRI information was developed as part of a study commissioned by the New South Wales (NSW) Department of Infrastructure, Planning and Natural Resources (DIPNR). DIPNR required 100-year flood maps of the entire Far North Coast (FNC, see Figure 1) region of NSW, including the Tweed, Richmond and Clarence River catchments, together with a series of smaller coastal catchments from Bogangar to Byron Bay. Given the scale of the area, it was identified that insufficient time and data were available to successfully undertake the considerable volume of numerical modelling required to provide these maps using traditional approaches. As such, the SBRI technique was developed, and adopted by NSW DIPNR, to provide broadscale information regarding the likely susceptibility to inundation across the entire region. It is stressed that the SBRI data generated does not correspond to a particular ARI event or PMF.

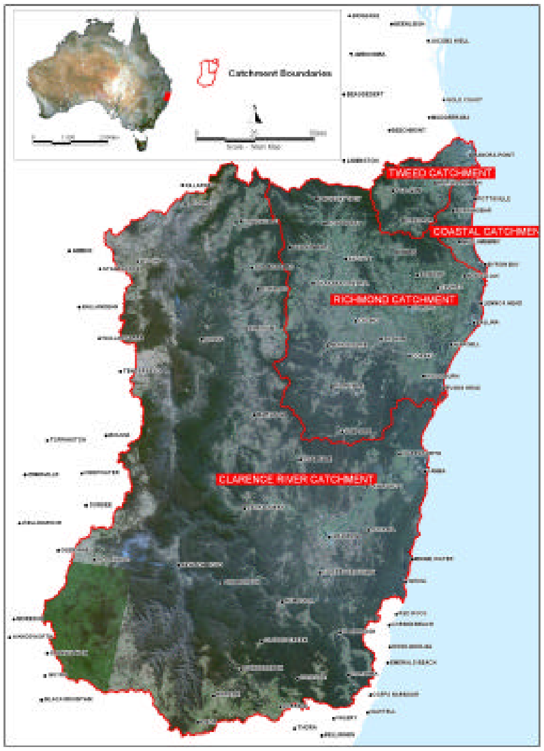


Figure 1: FNC Region where SBRI approach was applied

The production of SBRI maps developed for DIPNR was a five step process:

1. Collection and collation of input data
2. DEM pre-conditioning
3. Computation of SBRI
4. Interpretation and recasting of SBRI
5. Map production

These steps are described below.

Collection and collation of input data

The only input data requirement for successful application of the SBRI technique was the DEM of the entire catchment area of interest. It is noted that the SBRI technique requires specification of a complete catchment; use of the approach to partial catchments will result in erroneous outputs. The DEM used for DIPNR was a 25m cell size, except in the Clarence, which used a slightly larger cell size. It is shown in Figure 2, together with the Strahler ordered stream network of the region.

DEM Pre-conditioning

The SBRI technique relies on analysis of the flow routing properties of a DEM. As such, the DEM needs to be hydrologically sound. This requirement necessitates that all 'pits' (e.g. grid cells that do not drain) are removed from the DEM. This was easily achieved in the case of the FNC mapping using commercially available software packages. Similar software was also used to ensure that drainage from extensive flat areas was appropriately routed.

Computation of SBRI

Following production of a hydrologically sound DEM, the SBRI was calculated at each cell location within the DEM. This calculation used drainage properties and catchment characteristics at each DEM location. In-house software was developed to facilitate this analysis. A new data set of the SBRI values corresponding to each DEM cell was produced and constituted the SBRI grid, that was then submitted to further analysis.

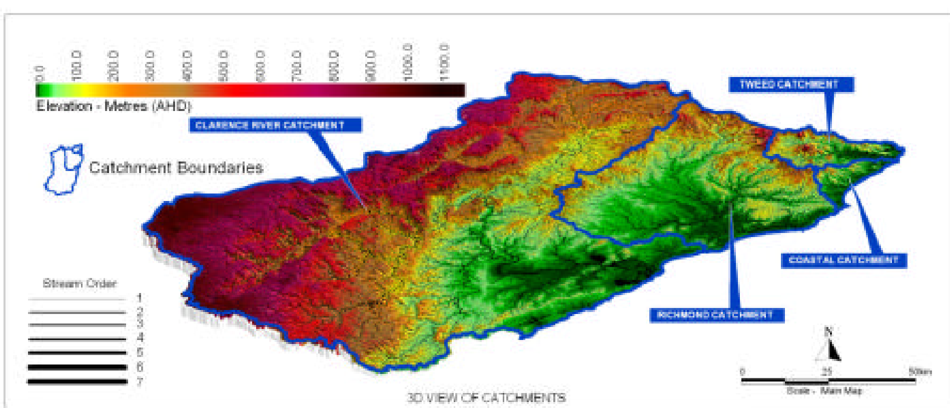


Figure 2: FNC region DEM

Interpretation and recasting of SBRI

The SBRI computed for each grid cell was a single number. These numbers, in themselves, did not directly correlate with areas susceptible to inundation. Rather, the SBRIs needed 'calibration' to provide this information. To do this, the SBRI distribution was compared to known flood extents (i.e. those predicted by a two-dimensional model) in a catchment proximate to the NSW FNC. In particular, the normalised SBRI histogram distributions computed from data both the entire ('parent') catchment and within ('interior') the known flood extents were examined, and a relationship developed between the two. The normalisation was relative to the maximum SBRI (x-axis) and mode (y-axis) of each histogram. These histograms are shown in Figure 3.

This relationship between the normalised histograms of the entire and flood-prone regions was then used to determine the extents within each NSW FNC catchment that were likely to be susceptible to inundation.

It is noted that in applying this relationship to other catchments, it was assumed that all considered catchments possess similar SBRI distributions, notwithstanding their different areas, shapes and elevation ranges. In order to test this assumption, the normalised SBRI distributions of all catchments (including the calibration catchment) were computed and plotted. These are shown in Figure 4. The figures demonstrate that indeed the normalised SBRI parent distributions across all catchments are similar, lending confidence to the application of the SBRI technique outside of the calibration catchment.

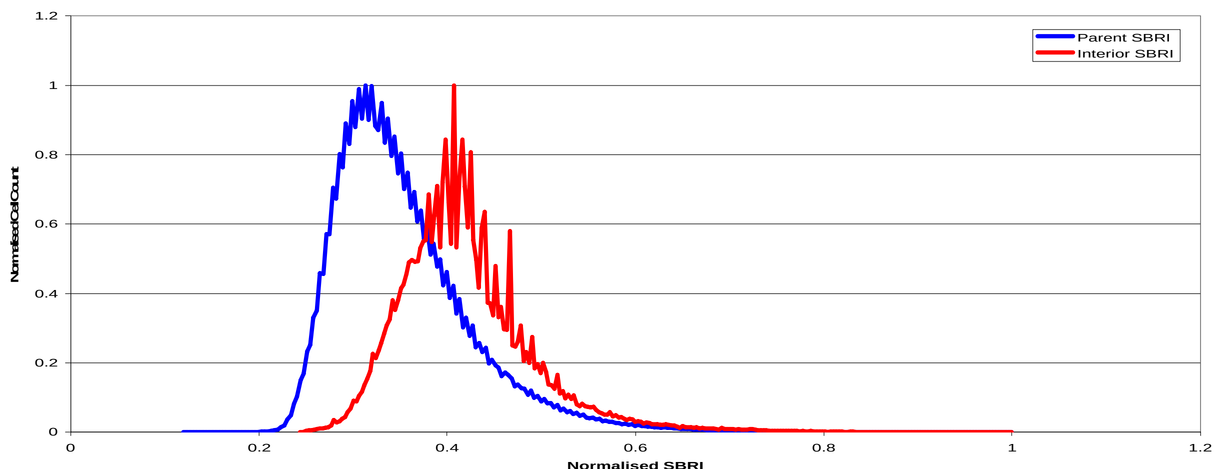


Figure 3: Calibration histograms

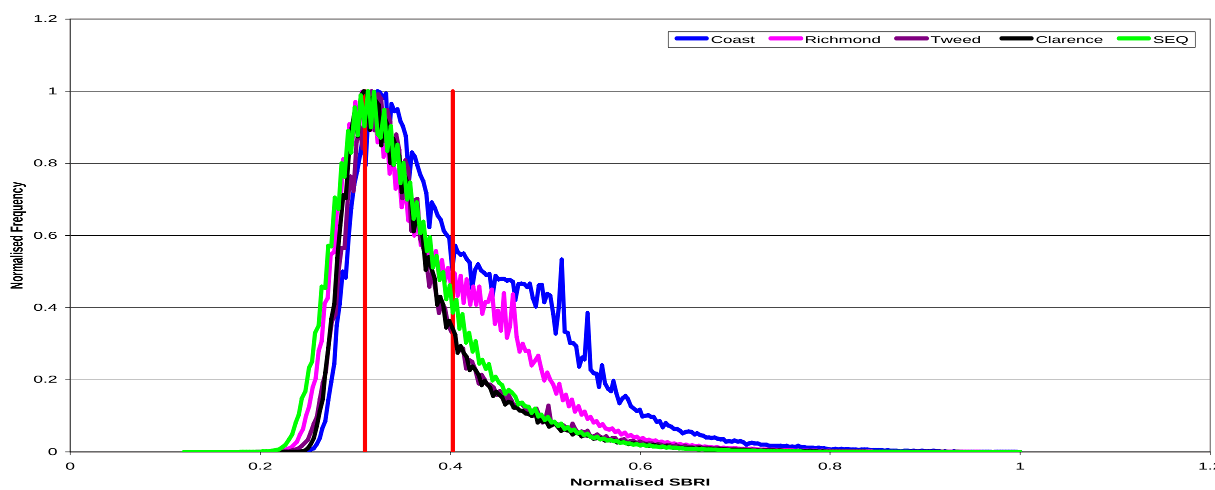


Figure 4: All normalised SBRI histograms

Map Production

Following the calibration and assumption checking described above, the SBRI approach was used to delineate the likely areas susceptible to inundation within the NSW FNC.

Results

The SBRI map computed for the entire NSW FNC region is shown in Figure 5.

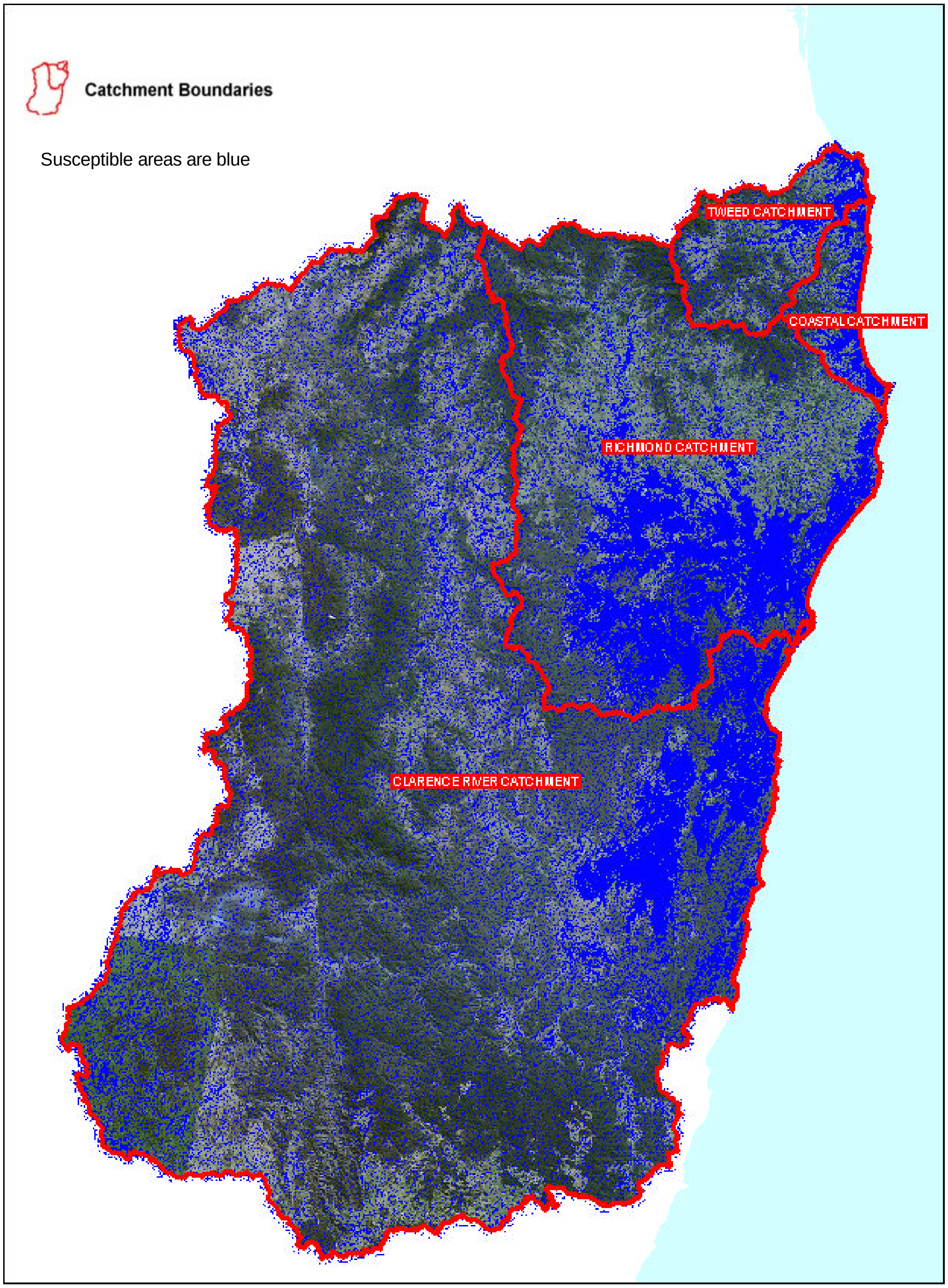
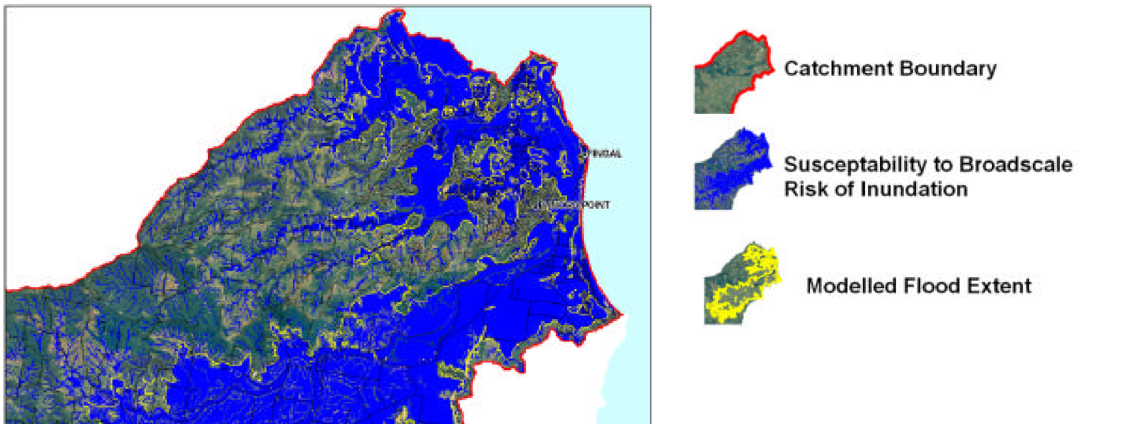


Figure 5: SBRI for entire NSW FNC.

In order to investigate the applicability of the SBRI approach to the NSW FNC, the calibrated SBRI predictions for the Tweed catchment were compared to results from two-dimensional modelling previously undertaken in the area. This comparison is shown in Figure 6, where the SBRI results are in blue, and the modelled flood extents are yellow lines. The agreement is generally very good.



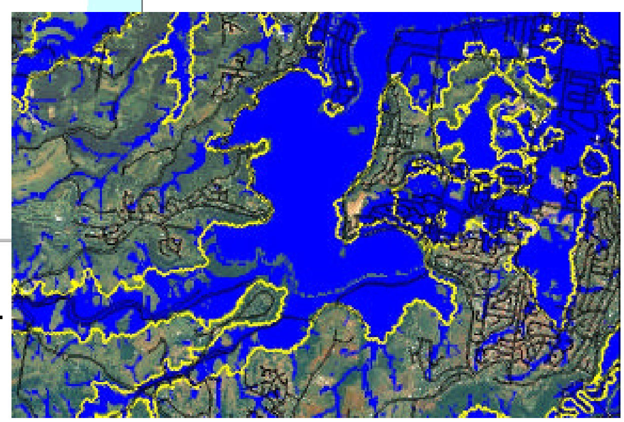


Figure 6: (a) Comparison of SBRI and two-dimensional model predictions, Tweed catchment (b) Zoomed area within (a). SBRI output is shown in blue while the flood extent from a 2D hydraulic model is indicated by the yellow line.

Conclusion

This paper has described a new technique for estimating the broad scale risk of inundation across an entire catchment of interest. This technique does not employ the traditional approach of numerical flood modelling, but rather uses comparatively quicker and less data intensive computations based on flow characteristics and catchment properties to estimate susceptibility to inundation. It has been shown that this technique produces results that agree well with those derived from more traditional modelling studies.

Whilst being a useful tool for consideration in informing the planning process, the SBRI approach does have limitations. Importantly, this process produces information that should only be used at a broad scale (i.e. should not be compared to cadastre, for example), and it delineates regions that are likely to be susceptible to inundation only. Further, it does not predict flood extents corresponding to a particular ARI event, and should not be interpreted as such.

Acknowledgements

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How many flood-prone properties are there in Australia?

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Abstract

Because flood studies and floodplain management studies are generally commissioned by Local Government Authorities and there is no central national repository for the studies, or the data contained therein, it is not easy to develop a picture of the total flood risk in Australia. One way of representing flood risk is the number of residential properties susceptible to inundation by a flood with an average recurrence interval of 100-years. While this may not be the ideal measure of risk it is a statistic that is almost universally available. In this project we identified 300 flood-prone regions/towns and obtained this statistic for each. This allows us to compare states and towns using a common basis. Such information can inform resource allocation for emergency management organisations and help insurance companies quantify their exposure to residential flood risk.

Key Words: flood, flood-prone, risk assessment

Introduction

Most natural hazard mitigation activities are implemented at the Local Government Authority or State level. National risk assessments for natural hazards are fairly rare (with the notable exception of some studies by Geoscience Australia). A reason for this may be the difficulty in obtaining the required data. Whatever the reason, questions such as that posed in the title of this paper aren't easy to answer.

Even before attempting to answer the question "How many flood-prone properties are there in Australia?" the question itself raises a couple of other questions:
"What does flood-prone mean?"
"What does property mean?"
"Who cares?"

This paper reports on research undertaken to estimate the number of flood-prone residential properties in Australia and in so doing also attempts to answer the supplementary questions posed above.

But first some context.

How damaging is flood compared to other natural hazards?

One way to get a feel for this is to examine historic records of natural hazards that caused damage to buildings. Risk Frontiers' *PerilAUS* database contains records of almost 5,000 events that occurred in the 20th century, 1,200 of these have building damage information (Blong and Chen, 2000). By converting the building damage caused by each event to a common base we can compare different events that occurred at different times without having to adjust for inflation etc. The common base used was Equivalent Houses destroyed, where, for example, 5 partially damaged houses were deemed equivalent to one destroyed house, or one damaged hospital was deemed equal to 8 destroyed houses. Refer to Blong (2003) for more details of the fairly complex methodology underlying this.

When building damage was summed over the approximately 100-year period and disaggregated by peril it was found that tropical cyclone had contributed the most building damage and flood came second (Figure 1). Bushfire accounted for a similar proportion to flood and combining gust, hail and tornado into “storm” also yields a similar proportion. So from a building damage perspective it seems that flood is at least as important as bushfire or storm, but perhaps not as important as cyclone.

Figure 2 shows the same result for New South Wales and we can see that the decreased importance of tropical cyclone elevates flood to the top position. The difference between cyclone and flood induced damage becomes vague in NSW because ex-tropical cyclone rain depressions are a significant source of flooding. Flooding is also a threat to life safety. Between1788 and 1996 at least 2213 persons were killed by floods in Australia, with almost half occurring in NSW. The death rate however is decreasing over time (Coates 1999).

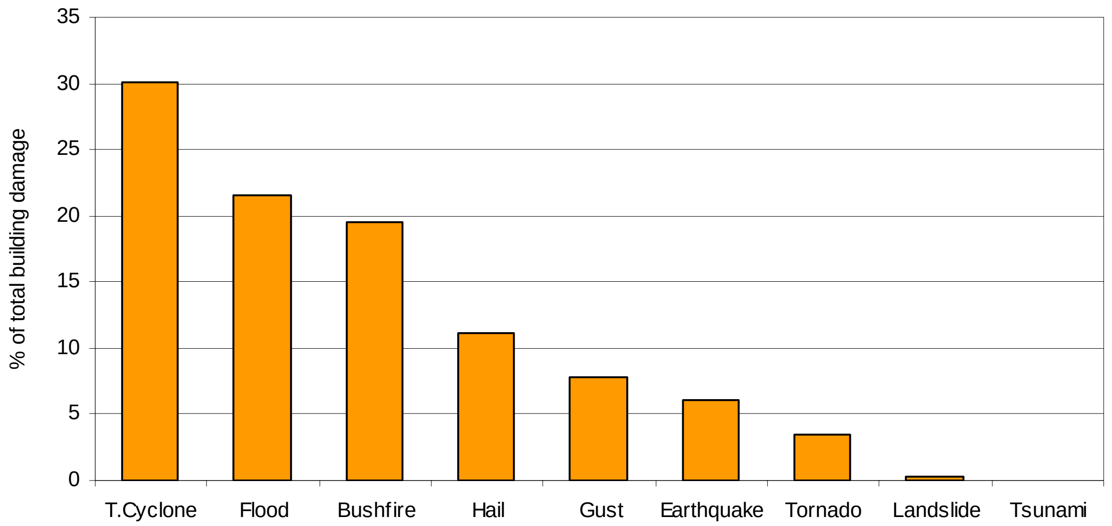

Figure 1: Relative proportions of building damage in Australia from 1901 to 2003 by peril type

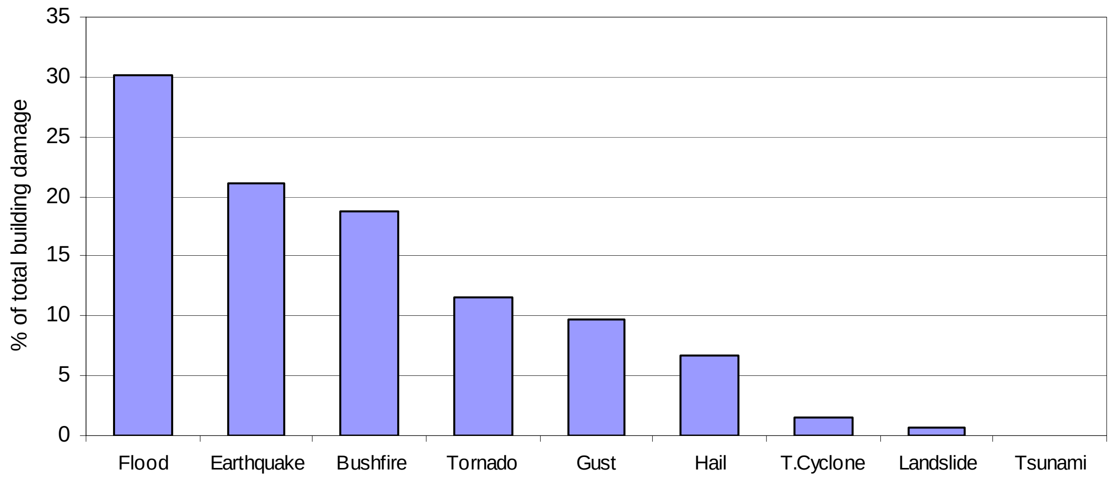

Figure 2: Relative proportions of building damage in New South Wales from 1901 to 2003 by peril type

Another way of looking at this is a Catastrophe Modelling approach as used by many insurers and reinsurers. In this example we consider a synthetic portfolio of approximately 90,000 houses in the Sydney Basin. By using average values to represent the value of both the buildings and contents we calculate the total damage cost using Risk Frontiers' loss estimation software for the following hazards:

- Earthquake (*QuakeAUS*)
- Hail (*HailAUS*)
- Flood (*FloodAUS*)

The relationships between the modelled damage and the probability of that damage amount occurring or being exceed in a given year (expressed as return period) are indicated on Figure 3. The flood curve is based on the Hawkesbury-Nepean, the Georges and the Upper Parramatta Rivers.

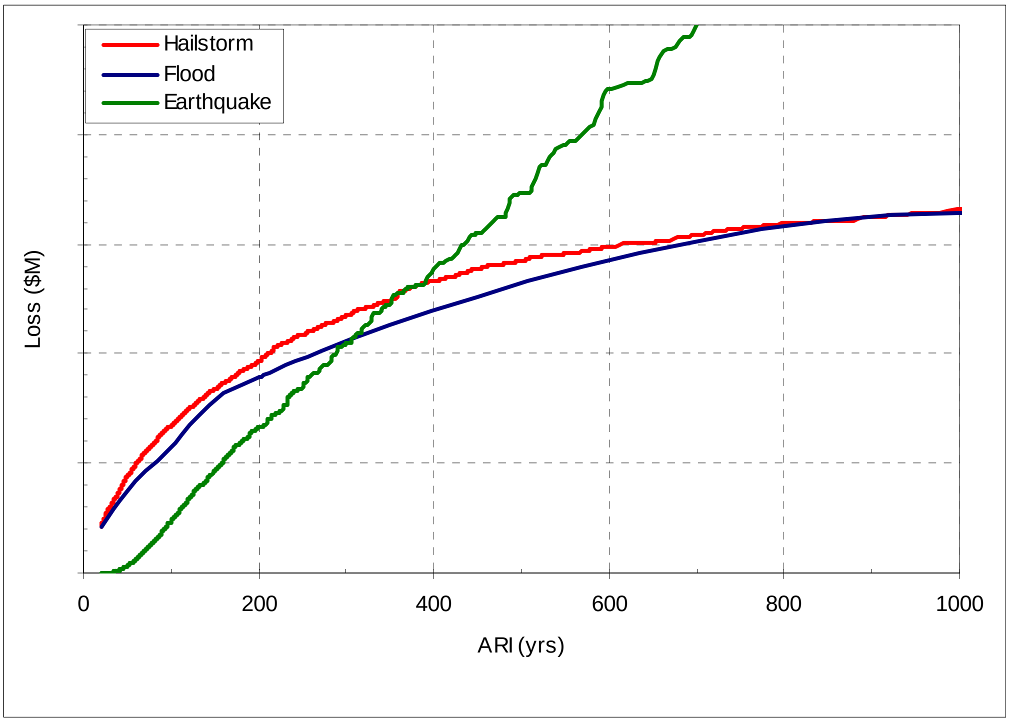

Figure 3: Modelled damage vs. return period curves for a synthetic portfolio of houses in Sydney

Although this is a city-specific study it supports the thesis that storms and flood are about equally damaging, and both are more damaging than earthquake, except for very rare events.

How many flood-prone properties are there in Australia?

The work reported here was performed by Risk Frontiers primarily for the Insurance Council of Australia (ICA), with the NSW component being performed jointly with NSW State Emergency Service as part of a strategic risk assessment. This rather innocent-sounding question was posed by the ICA as part of their investigations into residential flood insurance. The question raises at least two sub-questions:

- What does flood-prone mean?
- What does property mean?

It was agreed that a reasonable picture of national flood risk could be obtained by estimating the total number of residential properties in urban communities that are liable to river inundation by a flood with an average recurrence interval (ARI) of 100 years, that is, a flood that has a 1% chance of occurring in any year. The number of properties liable to inundation by an ARI 100-year flood is not an ideal measure of flood risk (risk metric) because:

1) It tells us nothing about the distribution of properties below that flood level or the water depth at those properties during an ARI 100-year flood (or any flood).
2) It takes no account of properties above that level - just because a property is located higher than the ARI 100-year flood level does not mean it is flood-free.
3) It doesn't allow for the damaging and dangerous effects of water velocity or duration.

However this statistic or metric has one inarguably redeeming feature – it is by far the most widely used and readily available piece of macro flood data for Australian catchments.

The second sub-question alludes to the wide variation in exposure metrics published in flood studies, floodplain management studies etc. This is far from consistent between studies. Common examples include:

- The number of buildings flooded over ground
- The number of buildings flooded above floor level
- The number of residential (or commercial) properties flooded over ground
- The number of residential (or commercial) buildings flooded above floor level
- The number of addresses flooded over ground

The most relevant measure for insurance purposes is over-ground flooding, since this can result in a claim for damages to fences, sheds, gardening equipment, swimming pools and spas even if water doesn't rise above floor level of the main dwelling. Over-ground flooding is also most important to emergency managers as actions such as property protection and evacuation are likely to be necessary and access to properties problematic. For this study we selected the number of residential properties inundated (above ground but below floor) by the ARI 100-year flood as the most appropriate risk metric, and used this wherever it was available. Because of the remarkable variation between floodplain management studies, we use substitute measures when the preferred one was not available. This adds some uncertainty as some of these measures will overestimate the risk vis-à-vis the base measure and some will underestimate; however two thirds of the identified properties are defined by the base measure.

National Results

The study considered residential properties in urban settlements and addressed mainstream riverine flooding only. Storm water flooding from overflowing drainage systems and coastal inundation from tsunami and storm surge were excluded (except where storm surge was modelled coincident with river flood). We considered all major flood-prone areas and covered regions that contain approximately 75% of Australia's population. Over 90% of urban residential properties flood-prone to the ARI 100-year level are located in Queensland, New South Wales and Victoria (Table 1). In theory there are no dwellings in ACT flood-prone to the ARI 100-year level. In practice some may suffer over-ground flooding to this level and some will be certainly located between ARI 100-year level and PMF.

State	**Number of residential properties**	**Proportion of total**
Queensland	62,130	36%
New South Wales	55,677	33%
Victoria	42,376	25%
Western Australia	1,142	1%
South Australia	6,582	4%
Northern Territory	990	1%
Tasmania	723	<0.5%
Australian Capital Territory	0	0%
TOTAL	**169,620**	**100%**

Table 1: Number of urban residential properties susceptible to mainstream riverine flooding with an ARI of 100years

The seven most flood-prone areas account for just over 40% of the total number of identified properties flood-prone to the ARI 100-year level. The evident corollary to this is that roughly 60% of flood-prone properties lie outside of these 7 areas. The worst 60 areas contain 80% of the flood-prone properties. About 22% of the identified flood-prone properties are located in Brisbane city, Ipswich and the Gold Coast.

Region or City	**State**	**Number of residential properties susceptible to over-ground flooding**	**Proportion of national total**
Gold Coast	Qld	20,128	12%
Brisbane & Ipswich	Qld	18,010	10%
Sydney	NSW	10,139	6%
Shepparton	Vic	6,572	4%
Melbourne	Vic	6,000	3%
Mackay	Qld	5,924	3%
Brown Hill & Keswick Creeks (Adelaide)	SA	5,000	3%

Table 2: The seven most flood-prone regions in Australia based on an ARI 100-year flood

New South Wales Results

A list of identified flood-prone regions/towns in New South Wales is given in Appendix A. We are aware that this is not a comprehensive list, so as Appendix B we have attached a list of areas that we believe contain flood-prone properties but for which we couldn't locate data. Any feedback or assistance regarding the database would be most welcome. As noted earlier, locating and compiling this data is not an easy task for an "outsider" – primarily because the information isn't held at one central location.

The locations of the flood-prone areas/towns are indicated in Figure 4. The dominance of coastal rivers is obvious and to some extent the map is a reflection of population distribution. Also a number of creeks, lagoons and rivers in Sydney have been amalgamated for mapping purposes.

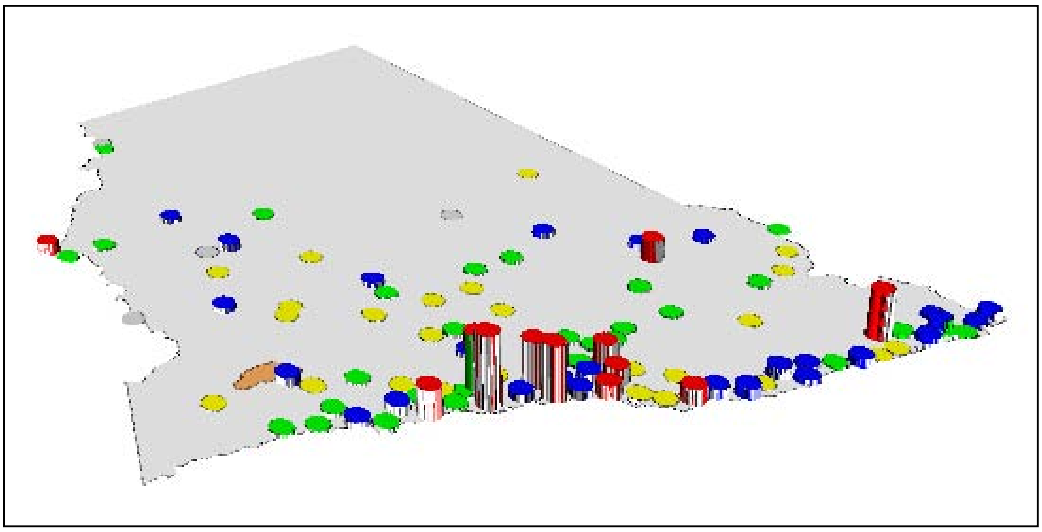

Figure 4: Location of areas/towns with residential properties susceptible to flooding by an ARI 100-year flood (height of column is proportional to number of properties)

The current inconsistencies in the risk metrics in the database are a little problematic when it comes to ranking areas for flood-proneness. Nevertheless it is clear that the following areas should be near the top of a list of most flood-prone areas in NSW at a 1% AEP level:

- Hawkesbury-Nepean River
- Wyong and Tuggerah Lakes
- Wollongong
- Gosford
- Grafton
- Singleton
- Upper Parramatta River
- Newcastle
- Georges River
- Forster/Tuncurry

Discussion

This research has produced a comprehensive and up-to-date snapshot of flood risk in Australia. Unlike other recent national assessments (e.g. Smith 2002) each identified flood prone area is listed and the risk quantified (generally in terms of exposed residential properties) for design floods. The last comparable study was carried out 14 years ago (AWRC 1992). The strong focus on quantifying the risk in terms of exposed properties also differentiates this work from Geoscience Australia's flood studies catalogue (Middlemann et al. 2005) and the Bureau of Transport Economics assessments (BTE 2001, 2002). However, GA's catalogue was an important source of data for this project.

The project drew together and summarised quantitative data from a range of disparate sources. It has produced a defensible and robust estimate of the number of residential properties in Australia liable to inundation by an ARI 100-year flood. A drawback from a risk assessment perspective is the lack of a universally applicable risk metric; this is a reflection of the inconsistency in data contained in floodplain management studies around the country. The accuracy of the estimates that make up the database is also dependent on the quality of the modelling underlying the floodplain management studies. For the majority of flood-prone properties in the database risk is expressed in terms of over-ground flooding of residential properties. Using a mix of risk metrics is likely to have little impact on the overall results, but care should be exercised when comparing different areas that may have different risk metrics. It is hoped that the quality and consistency of data in floodplain management studies will improve over time.

National and state-based estimates of flood risk such as these are likely to be useful for policymakers. This work was commissioned by the Insurance Council of Australia as part of its investigations into the feasibility of introducing residential flood insurance in Australia – a good example of using quantitative risk data in policy making. As mentioned previously part of the data is feeding into a NSW SES strategic risk assessment. Notwithstanding the issue of the risk metric, the information is potentially useful for risk differentiation between other between spatial units. For example, with some effort the data could be summarised at Local Government Area or State Emergency Service operational zones.

Conclusions

Our best estimate of the number of residential properties in Australia liable to inundation by an ARI 100-year flood is 170,000. This is based on consideration of 300 of the most flood-prone regions across the country. Flood risk information was provided for each of these areas, making this the most detailed study of its type for Australia.

Nevertheless, it would be imprudent to consider this a definitive answer. There is considerable uncertainty around the estimate because of the different risk measures used, the accuracy and currency of the data sources, and the impact of recent mitigation work and urban development.

While all the most flood-prone areas have certainly been included, there are areas for which we could not obtain data. Similarly there are likely to be some flood-prone areas that we didn't identify.

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Appendix A - Identified flood-prone areas in NSW (with data)

River Catchment	City or Region	Local Government Area
Murray R.	Albury	Albury City
Dumaresq Creek	Armidale	Armidale Dumaresq Council
Macintyre R.	Ashford	Inverell Shire
Careel Ck	Avalon	Pittwater Council
Richmond R.	Ballina	Ballina Shire
Macquarie R.	Bathurst	Bathurst City
Bellinger R.	Bellingen	Bellingen Shire
Bellinger R.	Bellingen East	Bellingen Shire
Bellinger R.	Bellingen North	Bellingen Shire
Bellinger R.	Bellingen Rural	Bellingen Shire
Bellinger R.	Bellinger Keys	Bellingen Shire
Wingecarribee Ck.	Berrima	Wingecarribee Shire
Shoalhaven R.	Bomaderry	City of Shoalhaven
Mittagong Ck.	Bowral	Wingecarribee Shire
Barwon R.	Brewarrina	Brewarrina Shire
Clarence R.	Brushgrove	Clarence Valley Council
Myall R.	Buladela	Great Lakes Shire
Hewitts Ck	Bulli and Thirroul	Wollongong City
Bundeena Ck	Bundeena	Sutherland Shire
Turallo Ck.	Bungendore	Yarrowlumla Shire
St Georges Basin	Callala Beach / Callala Bay	City of Shoalhaven
Hawkesbury-Nepean R.	Camden	Camden Council
Camden Haven R.	Camden Haven	Hastings Council
Richmond R.	Casino	Richmond River County Council
Clarence R.	Chatsworth	Clarence Valley Council
Tweed R.	Chinderah	Tweed Shire
Clarence R.	Clarence River (Lower)	Clarence Valley Council
Bonville and Middle Creeks	Coffs Harbour	Coffs Harbour City
Coffs Ck	Coffs Harbour	Coffs Harbour City
Murrumbidgee R.	Cooma	Cooma-Monaro Shire
Castlereagh R.	Coonamble	Coonamble Shire
Muttama Ck.	Cootamundra Shire	Cootamundra
Richmond R.	Coraki/Woodburn	Richmond River County Council
Lachlan R.	Cowra	Cowra Shire
Murrumbidgee R.	Darlington Point	Murrumbidgee Shire
Hunter R.	Denham	Musswellbrook Shire
Edward R.	Deniliquin	Deniliquin Council
Macquarie R.	Dubbo	Dubbo City
Mandagery Ck.	Eugowra	Carbonne Shire & Forbes Shire
Cabramatta Ck	Fairfield	Fairfield City
Lachlan R.	Forbes	Forbes Shire
Wallis Lake	Forster / Tuncurry	Great Lakes Council
Macleay R.	Frederickton	Kempsey Shire
Castlereagh R.	Gilgandra	Gilgandra Shire
Macleay R.	Gladstone	Kempsey Shire
Gloucester R.	Gloucester	Gloucester Shire
Hawkesbury R.	Gosford	Gosford City
Avoca, Cockronw, Wamberal and Terrigal Lagoons	Gosford	Gosford City
Narara Ck, Erina Ck, and others	Gosford	Gosford City
Wollondilly R. and Mulwaree Ponds	Goulburn	Goulburn City
Clarence R.	Grafton	Clarence Valley Council
Shoalhaven R.	Greenwell Point	Shoalhaven City
Mirrool Ck. Canal	Griffith	Grifith City

River Catchment	City or Region	Local Government Area
Namoi R.	Gunnedah	Gunnedah Shire
Clarence R.	Harwood	Clarence Valley Council
Murrumbidgee R.	Hay	Hay Shire
Lachlan R.	Hillston	Carrathool Shire
Hunter R.	Horseshoe Bend	Maitland City
Clarence R.	Iluka	Clarence Valley Council
Macintyre R.	Inverell	Inverell Shire
Macleay R.	Jerseyville	Kempsey Shire
Macleay R.	Kempsey	Kempsey Shire
Macleay R.	Kinchela	Kempsey Shire
Lake Conjola	Lake Conjola	Shoalhaven City
Lake Macquarie	Lake Macquarie	Lake Macquarie City
Dora Ck.	Lake Macquarie	Lake Macquarie City
Cockle Ck.	Lake Macquarie	Lake Macquarie City
Clarence R.	Lawrence	Clarence Valley Council
Wilsons R.	Lismore City	Lismore
Hawkesbury-Nepean R.	Lithgow	Lithgow City
Cabramatta Ck	Liverpool City	Liverpool
Hunter R.	Lorn	Maitland City
Hunter R.	Lower Hunter R.	Newcastle City & Port Stephens Council
Nambucca R.	Macksville	Nambucca Shire
Clarence R.	Maclean	Clarence Valley Council
Hunter R.	Maitland	Maitland City
Manly Lagoon	Manly	Warringah Council
Murray R.	Moama	Murray Shire
Molong Ck.	Molong	Cabonne Shire
Gwydir R.	Moree	Moree Plains Shire
Hunter R.	Morpeth	Maitland City
Moruya R.	Moruya	Eurobodalla Shire
Cudgegong R.	Mudgee	Mudgee Shire
Brunswick R.	Mullumbimby	Byron Shire
Pages R.	Murrurundi Shire	Murrurundi
Tweed R.	Murwillumbah	Tweed Shire
Hunter R.	Muswellbrook	Muswellbrook Shire
Bellinger R.	Mylestom	Bellingen Shire
Namoi R.	Narrabri	Narrabri Shire
Murrumbidgee R.	Narrandera	Narrandera Shire
Cottage Ck.	Newcastle	Newcastle City
Bellinger R.	Newry Island	Bellingen Shire
Shoalhaven R.	Nowra	Shoalhaven City
Bogan R.	Nyngan	Bogan Shire
St Georges Basin	Old Lake Tabourie	Shoalhaven City
Shoalhaven R.	Orient Point / Culburra	Shoalhaven City
Clarence R.	Palmers Island	Clarence Valley Council
Paterson R.	Paterson	Port Stephens Council
Hawkesbury-Nepean R.	Penrith Richmond Windsor	Penrith City, Blacktown City, Hawkesbury City, Baulkham Hills Shire
Queen Charlottes Vale Ck.	Perthville	Bathurst City
Stonequarry Ck.	Picton	Wollondilly Shire
Queanbeyen R.	Queanbeyan	Queanbeyan City
Bellinger R.	Raleigh	Bellingen Shire
Shoalhaven R.	Riverview Rd Estate (Nowra)	Shoalhaven City
St Georges Basin	Sanctuary Point	Shoalhaven City

River Catchment	City or Region	Local Government Area
Parsons Gully, Kingdon Ponds and Middle Brook	Scone	Scone Shire
Shoalhaven R.	Shoalhaven Heads	Shoalhaven City
Hunter R.	Singleton	Singleton Shire
Macleay R.	Smithtown	Kempsey Shire
Bland Ck.	Stockinbingal	Cootamundra Shire
St Georges Basin	Sussex Inlet	Shoalhaven City
Cooks R.	Sydney	Canterbury City, Marrickville Council, Rockdale Council, Strathfield Council
Georges R.	Sydney	Liverpool City, Fairfield City, Bankstown City, Sutherland Shire
Upper Parramatta R.	Sydney	Blacktown City, Holroyd City, Parramatta City, Baulkham Hills Shire
Powell's Ck.	Sydney	Strathfield City
Muddy Ck.	Sydney	Rockdale City
Haslams Ck.	Sydney	Auburn City
Narrabeen Lagoon	Sydney	Pittwater Council & Warringah Council
Newport Beach Catchment, McMahons Creek, Farrels Lagoon	Sydney	Pittwater Council
Upper Prospect Ck.	Sydney	Fairfield City
Kemps Ck.	Sydney	Liverpool City
Peel R.	Tamworth	Tamworth Regional Council
Manning R.	Taree	Greater Taree City
Shoalhaven R.	Terara	Shoalhaven City
Tweed R.	Tumbulgum	Tweed Shire
Lachlan R.	Ungarie	Bland Shire
Bellinger R.	Urunga	Bellingen Shire
Bellinger R.	Valery	Bellingen Shire
Hastings R.	Wauchope	Hastings Council
Murrumbidgee R.	Wagga Wagga	Wagga Wagga City
Namoi R.	Wee Waa	Narrabri Shire
Macquarie and Bell R.	Wellington	Wellington Council
Murray R	Wentworth	Wentworth Shire
Wooli R.	Wooli	Clarence Valley Council
Wollongong Creeks	Wollongong	Wollongong City
St Georges Basin	Woollamia	Shoalhaven City
Woronora R.	Woronora	Sutherland Shire
Wyong R.	Wyong / Tuggerah L.	Wyong Shire
Clarence R.	Yamba	Clarence Valley Council
Bellinger R.	Yellow Rock	Bellingen Shire
Macintyre R.	Yetman	Inverell Shire

Appendix B – Identified flood-prone areas in NSW without data

River Catchment	City or Region
Murray R	Balranald
Darling R.	Bourke
Brunswick R	Brunswick Heads
Murrumbidgee R	Carathool
Barwon R.	Collarenabri
Lachlan R.	Condobolin
Murray R	Corowa
	Garah
Murrumbidgee R.	Gundagai
	Kiama
Barwon R.	Mungindi
Macquarie R.	Narromine
Brunswick R	Ocean Shores, New Brighton, South Golden Beach
Gwydir R.	Pallamallawa
Hastings R.	Port Macquarie
	Pottsville
Quirindi Ck.	Quirindi
Tumut R.	Tumut
Tweed R.	Tweed Heads
Gwydir R.	Uralla
Macleay R	Walcha
Namoi R.	Walgett
Macquarie R.	Warren
Hastings R	Wauchope
Gill Gill CK	Wemelah
Murrumbidgee R	Yass

Long-term Planning for Flood Management – a Comparison of Australian and United Kingdom Approaches

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Abstract: *In recent years there has been a movement internationally towards longer term catchment scale flood planning. This has been necessitated by a range of environmental, social and economic issues, including the effects of climate change, increasing public awareness and sensitivity to flood risk, the need for land use planning consistency, changes in the insurance industry, and improvements in flood prediction technology. These issues are driving development of catchment scale plans which try to anticipate the effects of these issues, and which develop long term land and flood management policies to address them. The United Kingdom has recently started a programme to develop such plans for the whole of England and Wales, to be completed by 2008. The development of these plans is discussed, and contrasted against common practice within Australia.*

1 INTRODUCTION

Flooding is the most manageable of all natural disasters; relative to the uncertainty of other natural disasters, such as drought, earthquakes and bushfires. It is easy to determine how and why a flood occurs, and where it will happen. Flooding can be planned for, its effects can be mitigated and regulations can be put in place to address the residual problem remaining after mitigation. The only parameters we do not know are when, and how large the flood will be.

As floodplain management professionals, we are responsible for managing the risk posed by this uncertainty. Our approach is guided by our experience, reasoning and diligence. However, our approach is also determined by implicit factors such as legislation, the structure of government, government policy initiatives and improvements in technology.

In this paper we have two aims:

- to compare the governmental structures of Australia and the United Kingdom which support flood management, and discuss the effect this has on long-term planning
- to outline the current Catchment Flood Management Plan system in England and Wales, and compare it with Australian practice

2 WHAT IS FLOODPLAIN MANAGEMENT

2.1 GENERAL

In the context of this paper, **Floodplain Management is the management of the flood risk associated with the human occupation of the floodplain** for both urban development and agricultural production. That risk is addressed through management decisions that satisfy the social and economic needs of the community, the constraints that flooding imposes and being compatible with the maintenance or enhancement of the natural ecosystems that the floodplain sustains.

An integrated, catchment-based approach to floodplain management features not only a consideration of flood characteristics but also a variety of other interrelated issues such as community desires, and the ecological and economic impacts of various land use and flood mitigation measures. In other words, development on flood prone land is considered across the broad spectrum of issues.

Such an approach to floodplain management recognises that:

- Flood-prone land is a valuable resource that should not be sterilised by unnecessarily precluding its development; and

- If all development proposals for flood-prone lands are assessed according to rigid and prescriptive criteria, some of them may be unjustifiably disallowed or restricted.

- Based on these considerations there are three main principles that are applied:

- Three types of flooding problems affect flood-prone areas: the existing problem, the future problem and the residual problem, and that the most effective means of floodplain management is through the development of a comprehensive Floodplain Management Plan.

2.2 OBJECTIVES

The primary objective of floodplain management is to reduce the impact of flooding and flood liability on individual owners and occupiers, and to reduce private and public losses resulting from flooding.

2.3 FACTORS FOR EFFECTIVE FLOODPLAIN MANAGEMENT

The principal requirements for effective floodplain management, identified in Floodplain Management in Australia: Best Practice Principles and Guidelines, (SCARM 2000) are:

- An authority with the primary responsibility for floodplain management policy and practice;

- Appropriate and effective legislative powers for the responsible authority, with powers applied on a catchment-wide basis;

- Appropriate mechanisms for coordination of land use planning and floodplain management on a catchment wide basis;

- A community awareness of the flooding problem and the planning/management process, and a willingness to become involved;

- Completion of flood studies and floodplain management studies overseen by a steering committee representing all interested or affected parties;

- Provision of adequate resources to undertake studies and implement measures;

- Access to technical advice, standards and guidelines for the authority responsible for floodplain management;

- Legal provisions ensuring that the responsible authority exercises its powers responsibly, such as legal liability for the consequences of decisions; and

- Provision for intercession by a Central Authority when necessary.

We will return to these requirements when discussing the roles of various stakeholders and the comparison of approaches below.

3 GOVERNMENT FRAMEWORKS FOR FLOOD MANAGEMENT

3.1 THE NATURE OF GOVERNMENT

In both Australia and the United Kingdom environmental management is regulated at state or constituent country level. In Australia, each state has its own approach to environmental management, and there are different internal structures within state governments. In the United Kingdom, Scotland and Northern Ireland have independent environmental management organisations, which are controlled by local devolved government. However in England and Wales, which constitutes 88% of the United Kingdom population, the

Environment Agency is the sole environmental management body.

Table 1: Structure of government

Australia	**United Kingdom**
Australia is a federation of individual states and territories. At federation, the Federal Government gained powers over defence, foreign affairs and taxation. The States retained powers in relation to the provision of services to their populations, such as health, education and transport. The provision of these services is supported financially from both Federal and State taxation funds. Local government is principally charged with provision of local services, such as local roads, waste disposal, and, of particular importance in floodplain management, vested powers over land use management.	The United Kingdom is the political union of four constituent countries. In 1998, the United Kingdom devolved a range of powers from central United Kingdom government to Scotland, Wales and Northern Ireland. The Scottish Executive, National Assembly for Wales and Northern Ireland Assembly assumed responsibility for a range of activities, including environmental management and flooding. In England, central government retains direct responsibility for these functions. Funding for devolved governments is largely from central government taxation. United Kingdom local government has a similar role to that of Australian local government, including planning authority and development control. Provision of local government services is funded mostly by central government grants and local taxation.

3.2 BROAD ROLES OF GOVERNMENT IN FLOODPLAIN MANAGEMENT

State government in Australia provides the policy and technical framework within which floodplain management planning is carried out. The same is true within the United Kingdom within the devolved countries. In Scotland and Northern Ireland this framework is provided by the Scottish Environmental Protection Agency and Northern Ireland Department of the Environment. In England and Wales, this is provided by the Westminster government department Defra and Environment Agency. The Environment Agency is a statutory organisation, created in 1996 and funded and managed by Defra.

As might be expected, local authorities in both the United Kingdom and Australia have similar roles in managing the floodplain to ensure sensible land use planning and development. However, while Australian local authorities are responsible for preparing floodplain management plans for all aspects of planning control and risk management, this is not the case in England and Wales. The Environment Agency is responsible for flood risk management on watercourses designated ‘Main Rivers’. Local authorities retain planning control along these watercourses, with the Environment Agency a (non-binding) consultee on development applications.

In a broad sense, the allocation of roles looks roughly similar in terms of a central government - state/devolved government – local government model. However, as the next section illustrates, there are significant differences in the allocation of roles due to the statutory definitions of the organisations involved.

Table 2: Broad roles of government hierarchy

Role	Australia	United Kingdom
Central (federal) government	Provision of funds for floodplain management measures and flood relief. This is done through programmes such as the Natural Disaster Mitigation Programme, which fund studies and measures to address all natural disasters except droughts.	Provision of overall operating budget to devolved authorities, for them to allocate. In England direct management through provision of funding, research and policy by the Department of Environment, Food and Agriculture (Defra), and to local authorities
State Government / Devolved Government	The principal floodplain management role of State and Territory Governments has been stated as follows (DPIE, 1992): "....to develop appropriate standards and strategic approaches for floodplain management and to ensure that they are applied in a coordinated and integrated fashion across the State. This role encompasses the provision of expert technical support via a principal water resources authority(s), of planning advice through a State Planning Agency and of effective counter-disaster and welfare services".	Devolved governments and Defra fund and manage flood policy development. They carry out flood management activities through their respective environmental management bodies : England and Wales: Environment Agency Scotland: Scottish Environment Protection Agency Northern Ireland: Department of the Environment. Through these environmental management bodies, government also: • directly carries out floodplain management of 'Main' watercourses*; • has broader scale floodplain management responsibility across local authority boundaries
Local government	Implement floodplain management strategies through land and development control plans and building regulations, and through flood mitigation measures. Floodplain management strategies devised by local government are defined in partnership with State Government, balancing local community aspirations with statewide consistency and standards.	Implement floodplain management strategies through land and development control plans and building regulations, and through flood mitigation measures on 'Ordinary' watercourses*. Local plans should be developed to take account of regional planning and the views of government environmental management authorities, which have a wider view of regional flood management

* Watercourses in England and Wales are categorised as either 'Main Rivers' or 'Ordinary Watercourses'. Main Rivers are larger watercourses or those important for drainage, and the Environment Agency maintains flood defences on these watercourses. All other watercourses are Ordinary Watercourses, and are maintained by either Local Authorities or Internal Drainage Boards.

3.3 ALLOCATION OF ROLES WITHIN GOVERNMENT

All tiers of government and the community at large have an obligation to ensure that the local community is adequately protected from flood risk, both now and in the future. However, there is necessarily a formal allocation of roles within government. The following table outlines how this allocation varies between Australia, and England and Wales.

Table 3: Allocation of responsibility within government

Flood Management Action	Australia	England and Wales
Developing floodplain management plans	Local authority	Local authority (planning emphasis) Environment Agency (risk emphasis)
Developing flood emergency plans	Local authority / State Emergency Service	Local authority (emergency response) Environment Agency (awareness raising, flood warning and defence structure management)
Implementing flood management plans (planning control)	Local authority	Local authority
Implementing flood management plans (flood defence maintenance and construction, flood warning equipment installation and operation)	Local authority / State Emergency Service / Bureau of Meteorology / Water Resources Agency	*Ordinary Watercourses*: Local authorities and Internal Drainage Boards *Main Rivers*: Regional Flood Defence Committees*
Setting floodplain management policy, regulation and standards	State Water Resource Agency	Environment Agency
Providing expert technical advice	State Water Resource Agency	Environment Agency
Promoting best practice in flood management	State Water Resource Agency	Environment Agency
Advising central government agencies on flood forecasting, flood warnings and natural disaster and flood relief needs of the affected community.	State Water Resource Agency / State Emergency Service / State Community Services Agency / Bureau of Meteorology	Environment Agency
Regional planning control, providing advise to local authorities, ensuring regional plans taken into account in floodplain management plan development	State Planning Authority	Regional Assemblies (regional planning bodies formed from local authority representatives, and community, business and environmental group representatives)
Increasing awareness of flooding matters at local authority and community level	Local authority	Environment Agency
Ensuring special environmental issues taken into account in flood management plan development	Local authority on advice from State Planning Authority	Environment Agency
Preparing plans for the management of flood events	State and Territory emergency planning agencies	Local authorities

Flood Management Action	Australia	England and Wales
Managing and conserving the soil, mineral, water and vegetation resources, including resources on floodplains. Protecting fauna and protecting and enhancing riverine corridor, riverbank, wetland and floodplain habitats and water quality.	Natural resource management agencies and environmental protection agencies	Environment Agency
Incorporating environmental issues into floodplain management plans	Advise from Natural Resource and Environmental Protection Agencies to local authorities	Environment Agency indirectly through provision of advice to local authorities, and directly within its own floodplain management plans.
Encouraging the development of effective long-term strategies for the sustainable management of the nation's floodplains.	Federal government / State government	Environment Agency
Funding floodplain management studies	Federal, State and local government	Central and local government
Providing flood forecasting services	Federal Government Bureau of Meteorology	Environment Agency

* Regional Flood Defence Committees are composed of representatives from central government, the Environment Agency and local authorities

For England and Wales, the Environment Agency manages flood risk from 'Main Rivers' and the sea, and is responsible for spending 80% of the total government funding for flood defence under the direction of Regional Flood Defence Committees. The Environment Agency is also responsible for flood forecasting, flood warning, nation-wide floodplain mapping, public awareness raising, and acting as a development control consultee. It also has a general supervisory role with respect to flood defence and strategic floodplain management planning.

Local authorities have powers to provide flood defences on 'Ordinary Watercourses'. They also develop local plans and regulate floodplain development. They do this by incorporating floodplain management controls into their plans, often developed based on their own floodplain management plans, or through reference to Environment Agency floodplain mapping studies.

Internal Drainage Boards are independent bodies which manage drainage in areas with special drainage requirements. As part of their role they have powers to provide flood defences on 'Ordinary' Watercourses.

3.4 FUNDING FOR FLOODPLAIN MANAGEMENT

There is a range of funding programs that are applied to floodplain management throughout Australia; again each State seems to have adopted a different approach and accepted differing levels of funding.

In essence, the Federal Government provides for funding through specific programs within the annual budget cycle. These programs are considered on a three-year cycle (the nominal term of a government) and while there are forward estimates, these are not always fixed and may vary from time to time. This funding is provided on the basis that the State or Territory matches the funds allocated.

The States have programs that are either based on the matching of Federal funding or, as is the case in NSW, contains additional funding that is over and above the Federal funding. The cycles of funding and budgetary allocations again reflect the variations across States.

The most consistent application of funding is that the local agency must also contribute to any studies, works or measures that are implemented under these funding programs. The funding ratio is usually on a 1:1:1 (Federal:State:Local) basis and while this may create financial issues for smaller local agencies, it reflects the shared responsibilities for floodplain management.

In the United Kingdom, Defra provides funding for flood defence through grant aid through Regional Flood Defence Committees to the Environment Agency, local authorities and Internal Drainage Boards. This covers activities such as maintaining and improving watercourses, sea defences, installing and operating flood warning equipment, and controlling the action of riparian land owners. Grant aid will cover a proportion of the total Flood Defence Committee expenditure. The proportion will vary from year to year, and according to the level of funding requirements relative to local resources.

4 THE FLOODPLAIN MANAGEMENT PROCESS

4.1 THE NSW APPROACH

Floodplain management is ideally achieved through the formulation and implementation of a strategic **Floodplain Management Plan** by a local authority. This plan forms part of a Local Environmental Plan, which controls land use and provides procedures for obtaining consent and environmental assessment for development. This Local Environmental Plan is then implemented through a Development Control Plan, which gives a detailed description of the controls on permitted development.

The floodplain management process is the responsibility of the relevant local authority. Specialist technical assistance and advice are provided by government authorities with the relevant skills.

To assist local authorities, the NSW Government has published a Floodplain Management Manual that not only describes the process, but also gives detailed appendices on a broad range of floodplain management issues. Victoria and Western Australia are in the process of developing similar Manuals. The State Planning Authority also ensures that the regional planning objectives are taken into account in the development of the local plan.

LOCAL STEERING COMMITTEE

The formation of a local Floodplain Management Steering Committee is the first step in the Floodplain Management Process. Its main function is to assist the local authority in the development and implementation of a floodplain management plan for the area(s) under its jurisdiction.

FLOOD STUDY

The Flood Study consists of a detailed technical investigation of flood behaviour. It defines the flood hazard by providing information on the extent, level and velocity of floodwaters and the distribution of flood flows across various sections of the floodplain. It does this for a range of floods up to the Probable Maximum Flood.

FLOODPLAIN MANAGEMENT STUDY

The Floodplain Management Study brings together flood risk, economic, social and ecological facts so that, with input from the community, a balanced sustainable solution to the flood issue can be achieved. Amongst other things, the Study identifies appropriate management options and assesses their effectiveness in mitigating the social, economic and ecological impacts of flooding. Often, no single floodplain management option will be sufficient and determining the optimum combination of measures requires complex investigations, wide ranging consultation with the community and the exercise of professional judgement.

A detailed appraisal of proposed management measures needs to be undertaken to ensure that costs are justified by associated benefits. This analysis usually follows conventional cost-benefit procedures. It is not unusual however, to proceed with urban flood mitigation schemes on largely social or environmental grounds and, schemes are now often designed to enhance the local environment.

It may be impractical on a broad range of grounds to adopt the PMF as the design flood or development flood. It is essential however to know where such a flood may effect and what peculiar conditions may apply, especially from the emergency management context and the need to ensure that essential services and specific properties are not within the PMF extent.

FLOODPLAIN MANAGEMENT PLAN

A Floodplain Management Plan is a strategic plan for the management, development and control of flood liable land in both the short and long terms. It is based on the results of the above studies, and provides a common rationale for both site specific and general development decisions, and a sound basis for decision making regarding mitigation works and measures. It is essential that local authorities actively involve the community and emergency managers in the preparation and review of the management plan. The plan, therefore, is initially prepared in draft form and exhibited. Public comment is actively sought and taken into account before the plan is finalised and adopted.

IMPLEMENTATION

Implementation of a Floodplain Management Plan involves civil engineering works, where viable, and the application of planning controls by the local authority. Successful implementation means that development is now controlled and conditioned to minimise flood damage and to remove adverse environmental and social impacts. The adoption of a Floodplain Management Plan does not mark the completion of the Floodplain Management Process. Over time, more flood data will become available that, particularly where the original plan had to be prepared on the basis of limited data, may show that some aspects of flood behaviour are, in reality, not quite as anticipated. Some issues may also emerge during implementation of the original plan that were not foreseen.

4.2 ENGLISH AND WELSH APPROACH

In recent years the United Kingdom has been moving towards more strategic flood management, over a longer term and at a broader scale. This is product of a mixture of experience, governance, law and politics, specifically (ICE, 2001):

- the impact of recent flooding such as the Autumn 2000 floods, and the extent of damage and disruption this caused;
- good practice identified in other countries ;
- the formation of the Environment Agency in 1996, a statutory organisation responsible for flood management at a range of scales, in addition to its role in environmental management;
- legislation which requires consideration of the wider effects of floodplain management activities, particularly European Directives such as Habitats and Species Directive, Birds Directive, Water Framework Directive, Strategic Environmental Assessment Directive, and the forthcoming Flood Directive; and
- Political drivers such as dealing with climate change and national and regional land use planning.

A critical factor in the success of this strategic approach is the interaction of different levels of government, and the production of floodplain policies which can be implemented in regional and local plans. In England and Wales, this has led to a tiered approach to flood management planning. Different scale flood risk assessments are used to guide the planning process, control proposed development, create flood management plans and develop flood defences.

In England and Wales, there is a distinction between flood risk assessment for development planning, and flood risk management. Development studies concentrate on designating areas for development, and setting constraints within these areas. Flood risk management studies consider long term management of the flooding problem, and measures to address this.

Despite this, Catchment Flood Management Plans (CFMPs) will be common to both the planning and the flood management process. Their aim is to draw together the long-term interaction of planning and flood management, which then helps govern plan development at local scales, as well as guiding the improvement of flood defences and flood management practices.

In carrying out flood studies to guide development planning, four different levels of study are used (Defra/EA, 2005):

- **National Flood Risk Assessments**: Studies to gain better understanding of the existing fluvial, tidal and coastal flooding risk and required investment levels at national or regional scale. These studies are used by central government to help plan the quantity and location of new housing and other development within England and Wales. (*undertaken by the Environment Agency*)
- **Catchment Flood Management Plans** (CFMPs) and Shoreline Management Plans: High level strategic planning studies of entire river catchments or groups of catchments to explore and define long-term sustainable policies for flood risk management. These are intended to mesh into general regional and local plans. CFMPs will allow planning to take account of long-term flood risk, and help guide strategic land development and land use within the catchment in future. (*undertaken by the Environment Agency*)
- **Strategic Flood Risk Assessments**: Local scale studies used to develop spatial plans, in a similar way to Australian Floodplain Management Plans. These studies identify present and future flood risk, both with and without development. Their outcomes are used to set planning constraints within a local plan area. (*undertaken by local authorities*)
- **Site specific Flood Risk Assessments**: Studies to determine the actual flood risk to a development site and surrounding area, for the purposes of development consent approvals. (*undertaken by developers*)

For flood management and defence, studies are also carried out using a tiered approach. This approach aims to ensure any proposed flood defence measures are consistent with planning aims and flood management aims in the wider catchment. The key flood management studies, all carried out by the Environment Agency, are:

- **Catchment Flood Management Plans**: In addition to their role shaping development plans, CFMPs will also guide future flood management and defence. They will decide flood management policies within different parts of the catchment – for example whether any intervention should take place, whether the effectiveness of existing management measures (including defences) should be preserved, increased or decreased. CFMPs will identify where more detailed Strategic Flood Studies should be undertaken.
- **Strategic Flood Studies**: Local scale studies which determine the flood management approach in detail for a specific part of a catchment. Once the flood management policy for an area has been determined by the CFMP, a strategic flood study may be carried out to determine the best way to implement this policy. The strategy will identify site specific measures that will be carried out, such as building a flood warning model, or constructing a particular flood defence.
- **Site specific measures**: Implementation of measures identified by the strategy. This includes feasibility assessment, securing funding, consultation, design and construction of flood defence measures.

This split structure reflects both the nature of government and the complicated allocation of roles in flood management in the United Kingdom. The Environment Agency's responsibility for flood management along 'Main Rivers' and its overall interest in flood management intersects with local authorities role in development planning and smaller scale watercourse flood management.

4.3 THE CATCHMENT FLOOD MANAGEMENT PLAN PROCESS IN ENGLAND AND WALES

4.3.1 OBJECTIVES OF THE CATCHMENT FLOOD MANAGEMENT PLAN PROCESS

Catchment Flood Management Plans (CFMPs) are the means by which the governments of England and Wales are attempting to ensure consistent and sustainable long-term flood management planning. The key objective of the CFMP process is:

'*To develop complementary policies for long-term management of flood risk within the catchment that take into account the likely impacts of changes in climate, the effects of land use and land management, deliver multiple benefits and contribute towards sustainable development.*'

Specific stated objectives of the CFMP process are to:

- undertake high level strategic assessment of current and future flood risk
  - from all sources (although coastal flooding and erosion is considered under separate plans)
  - in terms of both probability and impact
  - including the effect of current risk reduction measures
  - quantified in broad economic, social and environmental terms
- identify opportunities and constraints for reducing flood risk through strategic responses, such as changes in:
  - land use
  - land management practices
  - flood defence infrastructure
- identify opportunities to maintain, restore or enhance the total stock of natural and historic assets
- identify priorities for studies, actions or projects to manage flood risk and assign responsibility for them

4.3.2 DRIVERS

CFMPs are required to identify the best ways of managing the risk of flooding within the catchment over the next 50 to 100 years. The objectives stated above reflect a number of the key drivers which have led to the CFMP process in its current form. Of particular importance are climate change and development control.

CLIMATE CHANGE

Climate change is expected to significantly increase flood risk in the United Kingdom within the 50 to 100 year CFMP policy horizon. A key study shaping policy is the UK Government Office of Science and Technology Flood and Coastal Defence 'Foresight' Flood and Coastal Defence project, completed in 2004. The study aimed (Foresight, 2004):

'*to produce a challenging and long-term (30-100 years) vision for the future of flood and coastal defence in the whole of the UK that takes account of the many uncertainties, is robust, and can be used as the basis of policy and its delivery*.'

The study identifies potential scenarios and uses these to identify long-term flood risk. It considers factors increasing flooding probability such as climate change and development encroachment, as well as socioeconomic and environmental factors that determine the severity of flood damage. Combinations of probability and consequence scenarios give a picture of how the picture might develop by 2080.

Key findings of the study were:

- Under every scenario considered, flood will increase substantially by 2080. Average annual damage from flooding could rise from the present level of GBP 1 billion ($2.4 billion AUD) to between GBP 1.5 billion ($3.5 billion AUD) and GBP 23 billion ($54 billion AUD) in the worst case
- Climate change is an important factor in increasing flood risk
- Land use, increased urban development and effects of increased wealth and higher standards of living are also important factors
- The number of people at high risk from flooding could rise from 1.5 million to 3.5 million
- More effective land management will help reduce the risk in most scenarios. However, in the worst case scenario these are of little benefit and greater use of flood defences and coastal re-alignment will be required
- Increased flooding could bring both opportunities and threats to the environment.

These findings directly relate to the stated objectives and scope of CFMPs. CFMPs are intended to consider a planning horizon of 50 to 100 years, a period over which significant changes will occur in the climate and the socioeconomic state of England and Wales. The Foresight study noted that these factors are highly uncertain, and that future policies will need to be flexible enough to work under a wide range of possible outcomes.

DEVELOPMENT CONTROL

As discussed earlier, different scale flood risk assessments are used to guide the development planning in England and Wales. CFMP development attempts to take existing and future land use plans into account, considering how catchment response and flood risk might change as development occurs. Representatives from planning bodies are included in the CFMP development process, and have the opportunity to shape the policies the CFMP produces.

In addition, outcomes of the CFMP process will help shape future land development plans, and ensure flood risk management is taken into account. Regional Assemblies and local authorities will use CFMP outcomes to guide planning. This will form the basis of development planning and regulation. Drainage boards and water companies will also use CFMP to plan their activities within the catchment.

4.3.3 CFMP PROCESS AND MANAGEMENT

CFMP development is managed by the Environment Agency. The Environment Agency is funding their development, and outputs are produced in its name. A Project Board generally oversees project resources and programmes. It consists of senior strategic flood management Environment Agency staff, as well as the Environment Agency Project Manager.

A Steering Group will develop CFMP objectives and policy outcomes, and ensure wider ownership and acceptance of the CFMP. The group may include representatives from the Environment Agency, regional and local authorities, water companies, farmers unions, fishing and environmental organisations. It is important that this group takes an active interest in the project, so that stakeholders buy into the CFMP process, and that the outcomes can be used in wider planning activities. They also assist in gaining a wider picture of the catchment, and ensuring comprehensive data collection.

The CFMP process consists of the following stages:

1. Project start-up: forming a Project Board and Project Team
2. Inception Stage: Establishing a Steering Group, collating catchment information and developing an initial catchment understanding
3. Scoping Stage: Identifying flood risk and relevant economic and social issues, identifying future scenarios, opportunities and constraints, and producing draft objectives for flood risk management in the catchment(followed by a 3 month public consultation period on the outcomes)
4. Draft CFMP stage: Finalising scenarios and future flood risk assessments following consultation, identifying and appraising flood risk management policies (followed by a 3 month consultation period on the draft policies)
5. Final CFMP stage: review of the CFMP following consultation and final production

It is intended that CFMPs will each take between one and two years to produce, depending on the size and complexity of the catchments involved. Each CFMP will be reviewed and updated on a six year cycle. CFMP production will be timed to link in with other related initiatives, such as the production of River Basin Management Plans required by the European Union Water Framework Directive.

5 COMPARISON OF THE TWO APPROACHES

As a means of comparing the NSW and English and Welsh approaches, we identified a number of issues affecting floodplain management plan development. Table 4 summarises how the two systems deals with each of the issues.

Table 4: Approach to selected issues in long term floodplain management

Issue	**NSW**	**England and Wales**
Flood Management Plan procedures		
National / state guidance on flood management planning	Floodplain Development Manual agreed as appropriate standard. Some site specific issues require approaches not necessarily covered by Manual. Manual concentrates on site specific studies; catchment wide approach needs to be further investigated and implemented. Broad scale "rural" situations not well covered.	CFMP production is supported by purpose written guidance, as well as technical resources including templates, project examples and specialised mapping and damage assessment software. Guidance on CFMP development is high level, as it is being applied to all English and Welsh catchments, with widely varying level of data, different levels of historical flood knowledge, and different flooding mechanisms. Aspects of the process are still being clarified, including the detail of scenario modelling, report length, style and amount of technical information, and the type of policy outcomes.
Procedural consistency	The NSW Manual applies across the State so basic procedure is consistent. Application across DNR Regions may not be consistent.	The CFMP process is being applied across the whole of England and Wales. The national management of the process by the Environment Agency will ensure relatively uniform development.
Level of detail of floodplain management plan	Level of detail varies, usually due to supposed budgetary constraints. Smaller Councils unable to cover all issues due to competing demands for limited finances.	The tiered approach to flood management provides varying levels of detail. CFMPs are broad scale studies, which do not make assessments of flood risk at specific locations. They are intended to identify flood management issues, and recommend smaller scale flood risk studies. In practice, this approach is still being implemented, and consensus is still emerging about the appropriate level of detail in a CFMP.
Ensuring floodplain risk is taken into account in plan development	Local authority is responsible for managing floodplain risk and plan development.	Environment Agency has extensive role in dealing with floodplain risk. However, it only acts as a consultee in local and regional plan development. CFMPs aim to address this by making a direct connection between long term flood risk, land use and development.
Ability to produce consistent 'whole catchment' planning	Where local authorities encompass specific catchments, they are responsible for floodplain management and development control. In larger catchments containing more than one authority, agreement must be reached on consistent planning and flood management within the catchment.	The development of Catchment Flood Management Plans (CFMPS) in England and Wales will give direction to catchment wide flood management and planning control. The national extent of the Environment Agency allows it to deal effectively with whole catchments, groups of catchment and river basins in a unified way. A part of CFMP development is attempting to agree long term planning priorities between different authorities within each catchment.

Issue	NSW	England and Wales
Consultation		
Stakeholder engagement	There is an emphasis on stakeholder and community consultation within the Manual, but there are widely divergent views about what this may mean and what it really costs.	There is an emphasis on stakeholder steering groups driving flood management policy selection in CFMPs. In some areas, good working relationships have developed between key government and private stakeholders.
Consultation 'fatigue'	Some key stakeholders are becoming wary of detailed or on-going consultation, and may be becoming reluctant to be involved in the process. The increase in consultation in recent years, while positive, has placed additional demands on stakeholders' resources and community patience.	Similar to Australian experience. Some attempts to address this through coordination of consultation with other activities such as abstraction planning, and through the use of regional groups instead of catchment specific ones.
Raising public awareness about flood risk and the planning/management process	This issue is sporadically addressed, depending on the processes adopted in the Floodplain Management plan. Occasional special events undertaken, usually to commemorate major flood events. Public exhibition of Plans usually only of interest to those with a vested interest. Requires considerable effort by local authority and priority may not be there for major effort.	As part of its role, the Environment Agency raises public awareness about flooding and flood management. It provides an internet and telephone based public flood warning system. The Environment Agency also makes considerable effort to publicise individual studies and projects, and their objectives and outcomes. Consultation on flood management plan development is a legal requirement in England and Wales.
Public understanding of the flood risk planning/management process	Rarity of flood events and / or rarity of need to utilise Plan can reduce community interest to minimal levels, or below. Those directly affected (or potentially directly affected) are the most interested.	Community awareness of the flood management process is poor in England and Wales, partly due to complexity of the allocation of roles, and partly by the way flood management is presented to the public. There is relatively little publicly accessible information explaining the difference between the roles of the organisations, and how their studies and plans relate to each other.
Timeframes		
Programme of flood risk management plan development	No timeframe for completion of studies and construction of measures. Totally dependent on funding.	The Environment Agency has committed to a deadline of completing all CFMPs in 2008. Meeting this will require considerable effort, especially given shortages of suitable staff.
Staffing and knowledge		
Depth of technical skills and availability of suitable staff	There is a serious shortage of flood engineers in the relevant NSW Agency. Other skills needed for the floodplain management process are spread through a number of disparate agencies and there is no clear mechanism for co-ordination. Very dependent on consultants for some specialist skills.	The Environment Agency has a large number of skilled technical and managerial staff, including specialists in ecology, fisheries, water quality and groundwater, making this knowledge more readily available to inform the flood management process. However, there is a serious shortage of flood engineers in the UK.

Issue	NSW	England and Wales
Sharing knowledge and experience between technical and management staff in different catchment	No formal knowledge sharing between DNR, Regions, Councils and consultant staff.	Knowledge is shared between different regions, as Environment Agency and consultant staff discuss different approaches and techniques in formal workshops and through informal contact.
Technical approach		
Ability to incorporate future land use changes and climate change scenarios	The ability to identify future flood risk is limited by uncertainties or insufficient information about the effects of climate change and land use changes. Climate change and land use change risk analysis has not been translated into specific or even regional guidance for the process. No specific planning horizon specified, though review recommended every five – ten years.	In many catchments, climate change is expected to be the key driver for changes in future flood risk. CFMPs must consider this, given their intended planning horizon of 50 to 100 years. In practice, effect of climate change is currently being incorporated as a 20% peak flow increase. Information on regional variation in future flood risk, or the effect of specific land use changes has not been incorporated into CFMP procedure yet.
Accurate flood damage assessment	Wide range of methods employed and no centralised data repository to add to and review damages estimates.	A flood damage estimation methodology and estimation guidelines has been distributed by central government as the standard approach. Social, economic and environmental effects of flooding are still only partially quantified by the CFMP process. Process does not take into account indirect economic costs, infrastructure damage and environmental costs.
Data management and purchasing	Stream flow data collected and managed by DNR. Flood data collected on relatively ad hoc basis with limited streamlining, consistency of quality and distribution.	Initiatives in the Environment Agency are leading towards nationally consistent datasets of information subject to controlled update, verification and distribution. National data purchase agreements in place for a range of environmental data.
Level of technical innovation in the process	Technical innovation mainly generated from consultancies as technical work within DNR limited. Limited technical expertise may result in inconsistent production standards.	Flood research is funded by Defra and the Environment Agency. A range of technical measures have been implemented to try to streamline CFMP production and ensure consistent production standards. This includes GIS based software to automate broad-scale flood mapping and damages estimation.

6 CONCLUSIONS

Comparing the floodplain management planning process in different countries helps identify strengths and weaknesses of each system. Often, the approach to floodplain management planning is determined by the structure of each level of government, and the allocation of roles within them. This affects the development of methodology and technology, types of plans produced, ability of plans to address different issues, and regional consistency of plan outcomes.

In New South Wales, local authorities carry out both plan development and floodplain risk management. This gives them the opportunity to ensure floodplain management issues are fully recognised in the development of local plans. By comparison, in England and Wales, the Environment Agency has responsibility for flood management on most watercourses with substantial flood risk, while local authorities are responsible for plan development. This complicates plan development, and central government has developed policy guidance specifically for local authorities to encourage better floodplain management. Shared responsibility for flood management between the Environment Agency, local authorities and Internal Drainage Boards also confuses the public.

As Table 3 illustrates, the Environment Agency has a broad range of roles over all of England and Wales, including conservation, fisheries, abstraction management, air quality, groundwater and waste management. This has encouraged development of broad scale long term floodplain management planning which takes into account a range of environmental effects. CFMPs, which aim to provide catchment wide sustainable management, are currently being developed for all of England and Wales. This approach will offer a more consistent approach to flood management, once the CFMP development process has been rigorously tested and improved.

The national extent of the Environment Agency also offers potential advantages in innovation, sharing knowledge, and data gathering and management. Centrally funded technical research and tool development is helping to improve and standardise methodology, and the development of standard data formats and national data storage. There is also a pool of expertise and information sharing on a regular, formalised basis.

This is the major contrast with New South Wales, and other States in Australia. Floodplain Management has become a “poor relation” – the responsible State Agency is losing expertise and the ability to centrally organise and control the standards within the process. Expertise at the local level is falling, and without a strong and consistent application of policy from the State, standards will fall, data collection and management will become more burdensome and long-term planning and management of flooding will become very much a niche issue, only relevant when another disaster occurs.

Does it need a disaster such as the English and Welsh floods of 2000 to again make New South Wales serious about the management of floods? We have experienced more than enough flood disasters to know it is not a matter of if, it is a matter of when. The more the expertise is cut back, the more data that is lost, the more flood plains are developed ad-hoc, the more difficult it will be to recover and to achieve the objective of floodplain management:

> **The reduction of the impact of flooding and flood liability on individual owners and occupiers, and the reduction of private and public losses resulting from flooding.**

Future generations will not thank us if we do not act now.

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LOCAL FLOOD PLAN FOR SMALL COASTAL CATCHMENTS

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Presenter's Profile

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Urban modelling projects have included a variety of flood studies, which have required detailed investigation and design of culverts, bridges and other hydraulic structures for flood management. Habib has worked on a number of RTA projects in preparing concept designs of cross drainage infrastructure and evaluating its flood impacts on the neighbouring properties. His expertise also includes groundwater modelling and total catchment management studies.

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LOCAL FLOOD PLAN FOR SMALL COASTAL CATCHMENTS

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Abstract

A Local Flood Plan is generally a sub-plan of the Local Disaster Plan (DISPLAN) which is prepared by the Local Emergency Management Committee in coordination with the State Emergency Services (SES). The plan covers the preparedness measures, the conduct of response operations and coordination of recovery measures in the event of flood emergency in a Local Government Area (LGA).

The operational procedures set out in the flood plan are often biased towards the large creek or river flooding in the LGA and ignore the specific requirements of small catchments where the nature of flooding is substantially different to that in a major creek. In addition, the coastal catchments are likely to experience sea level rise as a consequence of climate change and as such require special provisions for flood emergency management in the Local Flood Plan.

This paper presents the issues related to flood emergency management in small coastal catchments and how Local Flood Plans can ensure special provisions for such catchments. A case study is presented for the Turo Creek, Pretty Beach catchment in the Gosford LGA.

Key Words: Flood Emergency, Flood Plan, Flash Floods, Coastal Catchments, DISPLAN.

Introduction

Managing flood hazard in catchments is challenging and can be resource intensive for a particular LGA. A part of the hazard management strategy is to plan for managing flood emergencies when they happen. The NSW State Flood Plan provides guidelines for preparing a Local Flood Plan with responsibility for the plan placed with the State Emergency Service (SES).

Often Local Flood Plans are biased towards major creek or river systems in the LGA and fail to provide planning measures for the small catchments. The failure to address creek flood hazard in these catchments can be more perilous for small coastal catchments, which are subjected to additional flood threat from the ocean.

This paper discusses various aspects of the Local Flood Plan that need to include special provisions for small coastal catchments. A case study is provided for the Turo Creek catchment in Gosford LGA.

Flooding Characteristics of Small Coastal Catchments

A large number of coastal catchments in NSW are subjected to flash flooding. The nature of the catchment in terms of its flood generation capacity is determined based on the time it takes from the rainfall event to complete inundation of the floodplain. The catchment is generally considered ‘flashy’ in nature if the time taken for the flooding process is less than 6 hours. The flood hazard associated with this type of flooding is generally high and can result in significant loss of life and property. In United States, most flood related deaths are reported to be from flash flooding (NOAA, 1992).

Flash floods occur as a result of high precipitation rates over a relatively long period of the order of few hours. Majority of flash flood producing rainfall is convective in nature (Doswell, 1997), since such a rainfall system generally results in high precipitation rates. The other important factor is the duration of convection, as only high intensity rainfall sustained over a substantial period would result in flash flooding. In addition, hydrological conditions of the catchment such as antecedent wetness play an important role in generating flash flooding.

Catchments prone to flash flooding give little or no warning of the impending flood. Rapid urbanisation of the coastal areas has also magnified the flashy nature of these catchments as times to flood have been reduced with increased impervious areas in the catchment.

Additionally, the coastal catchments are subjected to met-oceanic processes that can add significantly to the flood hazard.

Local Flood Plan

These plans are based on standard emergency principals of Preparedness, Response and Recovery. Given the short timeframes for flooding in small catchments, preparedness is vital in managing the flood hazard. Adequate response measures are generally not feasible for very small catchments whereas the recovery phase of the flood event can generally be coordinated with other measures undertaken LGA wide. This paper concentrates on various aspects of preparedness required for small coastal catchments.

Preparedness for a flood event involves developing flood intelligence, development of an effective flood warning system, public education and clear definition of the roles to be played by various agencies. All these aspects of preparation for flood events are discussed in reference to a small coastal catchment in Gosford LGA. Description of the catchment and discussion on flood preparedness for this catchment is provided below.

Turo Creek Catchment

The Turo Creek catchment is a small catchment of Brisbane Water that discharges at Pretty Beach (Figure 1). The catchment has an area of 44 hectares and consists of forested and urban residential areas. The headwaters of this creek lie in the Bouddi National Park. The creek traverses through a number of private properties before discharging into Brisbane Water.

The Turo Creek catchment is very steep with an escarpment to the south in Bouddi National Park. Flash flooding occurs as a result of intense rainfall on steep upper portions of the catchment. During rainfall events, waterfalls can be observed over the escarpment.

Existing Flood Behaviour

Each property traversed by Turo Creek has a pedestrian bridge in the backyard. These bridges on the creek act as hydraulic controls during significant flood events and have a tendency to block during the flood events. The rate of rise of floodwaters in the creek is high due to the steep catchment. For a 100 year ARI event, the peak discharge is 20 m^3/s and the time to flood peak is less than an hour. The existing creek has an approximate capacity to carry a 5 year ARI event.

Fourteen properties in the catchment are flood prone with above floor flooding ranging from 0.2m to 0.77m. The Annual Average Damage for the catchment is $62,342.

The main access road to the catchment, Pretty Beach Road, is flooded in a range of design flood events. The depth of flooding ranges from 0.1m for the 5 year ARI event to 0.5m for the PMF.

Figure 1: Turo Creek Catchment

Flood Intelligence

The core requirement for combating floods is to have an in-depth knowledge of the local flood behaviour. Such knowledge is generally based on historic data gathered over a period as the catchment is subjected to flooding and flood records are preserved. Generally, historic river gauge data is available which can be related to actual flooding in the catchment for any future events. However, such data is almost non-existent for small catchments where resident surveys need to be carried out along with the use of catchment modelling tools to analyse the flood behaviour.

Hence a detailed flood analysis for the small catchments is required before any meaningful Local Flood Plan could be prepared.

For the Turo Creek catchment, the flood behaviour was established using hydrologic and hydraulic modelling. This process was assisted by the valuable historic flooding information provided by the residents.

Flood Warning

A national workshop held in November 2002 by Emergency Management of Australia highlighted the need for a separate approach for effective flood warning for flash flooding (Elliott et al, 2003). The workshop noted that the current flood policy generally recognises flash flooding as separate to other forms of flooding such as in NSW (SEMC, 2001), the application of this policy has not been consistent at the implementation stage. Elliott et al. note that

"*The current flood warning policy treats warning for flash flooding in a different manner to other forms of flooding …….. There has been an uneven adoption of this policy and the institutional arrangements for flash flooding are not as formalised as for other forms of flooding …… The workshop felt that the review was needed into the limitations and deficiencies of the current policy in each state with the aim of developing an improved approach".*

NSW State Flood Plan notes that flash flooding warning systems have been installed in only two Councils in the State (Byron and Hastings) and recommends the provision of such systems for the larger Sydney basin.

The flash flood warning systems are generally based on telemetry systems where rainfall or gauge height is read remotely through an automatic system in the upper parts of the catchment. This data is relayed to the SES where it is used in conjunction with look up tables to forecast the extent of flooding at the areas of interest.

Such systems are not feasible for small catchments like Turo Creek. An innovative methodology is required to provide effective flood warning for these catchments. Based on the existing technology and institutional set-up this can be a daunting task.

Flash Flood Warning System

The first and the foremost requirement for an effective warning system is the development of flood intelligence for the catchment. Such intelligence in most cases would need to be developed from flood analysis carried out using modelling techniques. The crucial piece of information with regard to flood warning that comes out of this flood analysis is the capacity of the creeks in the floodplain ie magnitude of the flood that results in overbank flooding of the creeks. For the Turo Creek catchment, overbank flooding would occur for an event greater than 5 year ARI. This equates to an approximate rainfall measurement of 30mm in an hour.

Thus if the timely rainfall information could be made available to the community, they can be better prepared for the oncoming flood. A methodology to communicate this information is described below.

Rainfall Data Acquisition

Provision of rainfall information would require a reliable rain gauge near the catchment, located in a strategic position in terms of the prevailing weather pattern in the area. The available rain gauge network in the area may not be suitable for this purpose. It is also likely that the owner of the gauge is not able to provide the required information in time. As such a separate gauge would be required for a particular catchment.

Since, a rain gauge for a single catchment may not be economically justifiable, clustering of adjoining catchments for this purpose would be more feasible. Thus based on BOM advice, the gauge can be located strategically to provide the rainfall information for a number of catchments in the area. The purpose of such a flash flood warning system would be well served if the ownership of the gauge rests with the local Council. The gauge needs to be of telemetric type with the relay of information in real time.

Communication of Rainfall Data

Before the flood warning could be relayed to the community, the rainfall data would need to be interpreted. Ideally, SES should carry out this interpretation and issue the appropriate flood warning. However, given the short time frame of flooding, it may not be possible for SES to warn the community in time. In order to expedite this process, the rainfall information would need to be relayed to other relevant agencies/groups. The Local Emergency Management Officer can play a role by receiving this information and taking appropriate actions. However, for the prompt delivery of the warning, the information would need to be relayed to a local community group directly. This would require that a few community members be trained to interpret the rainfall information.

Communication of Flood Warning

Once the flood warning has been issued, it can be communicated in various means such as radio, TV, telephone, e-mail/internet etc. However these media of communication are not likely to be effective for catchments with very short lead time to flooding. In such a case, like Turo Creek catchment, the local community group would need to play an important role in communicating the flood warning. This could be through telephone or simply door knocking.

Automated Warning Systems

Another automated system that can be deployed is to sound an emergency siren located at an appropriate location, say on a telephone pole, in the catchment that is directly triggered by the telemetric rain gauge once the critical rainfall has been recorded. The authors are not aware of such a system in place anywhere and would recommend testing it in a pilot project for a small catchment or any catchment with telemetric rain gauges.

Such a warning system is likely to minimise the communication delays, however, may need extensive maintenance to ensure its proper functioning.

Use can also be made of installing flood sensing devices that can alarm residents in a small catchment. Although such devices have been tested for road overtopping (NRC, 2001), they can probably be used at critical creek locations in the catchment. In the case of Turo Creek, such a sensor can be located upstream of the urban area. The sensor can then remotely trigger a siren in the area or may possibly trigger alarms in individual properties.

Community Education

The need to educate the community about the existing flood hazard can not be over emphasised. For catchments subjected to flash flooding it is important that the community is able to play an active role in the flood management since lead times for flash flood warning are generally small and effective dissemination of flood warning may not be feasible for the state or local agencies. However, the community would need to be thoroughly educated about the flood hazard and the community groups trained to help manage the flood threat to their catchment.

Key elements of the community education in a small catchment are

- Providing a clear understanding of the flood hazard that exists in the catchment
- Community is prepared to contribute to the flood warning process
- Community is able to manage the aftermath of the floods with assistance from state and local agencies

Impact of Climate Change

Current studies on climate variability indicate significant changes over the last century. Most authorities on climate change agree that the recent changes, by and large, have been brought about by human activity, which has increased atmospheric emissions thereby creating the greenhouse effect. A comprehensive report prepared by the Australian Greenhouse Office (DEH, 2003) indicates that the following changes are likely to occur with regard to flooding of the coastal catchments:

- Increase in the rainfall intensity
- Increase in the number of extreme events
- Increase in storm surge flooding due to meteorological activity
- Rise in sea levels

The above changes are predicted to occur over the next 50-100 years. As such all development along the coast with expected life of similar duration would need to address the increased flood hazard. A comprehensive impact assessment of climate change on flooding of coastal catchments is therefore required as part of the floodplain management process in order to develop the necessary flood intelligence for the Local Flood Plan.

Conclusion and Recommendations

A large number of small coastal catchments are subjected to flash flooding. However, Local Flood Plans generally do not address the issues related to managing flash flooding in an LGA. The current flash flood warning systems are not suitable for small catchments and hence some innovative approach is required to manage the flash flooding hazard.

This paper presents an approach that focuses on quick transmission of flood warning to the community in case of impending flood hazard. In summary, this approach has the following key elements

- Flood Intelligence needs to be established through the floodplain management process whereby a detailed flood analysis of the floodplain is required.

- Innovative flood warning systems are required for small catchments subjected to flash flooding. Some ideas have been presented in this paper in developing such a system.

- Involvement of community is of paramount importance. The community not only needs to be thoroughly educated about the flood hazard but also trained to help manage the flood hazard in the catchment.

- A comprehensive impact assessment of climate change on flooding of coastal catchments should be undertaken as part of the floodplain management process in order to develop the necessary flood intelligence for the Local Flood Plan.

This paper provides a discussion on flash flooding in the hope that industry wide dialogue may start into the importance of flood warning for small catchments. Needless to say, further research is required to establish key elements of an effective flash flood warning system.

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THE JUNE 2005 LISMORE FLOOD –LESSONS FOR THE FUTURE

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Abstract

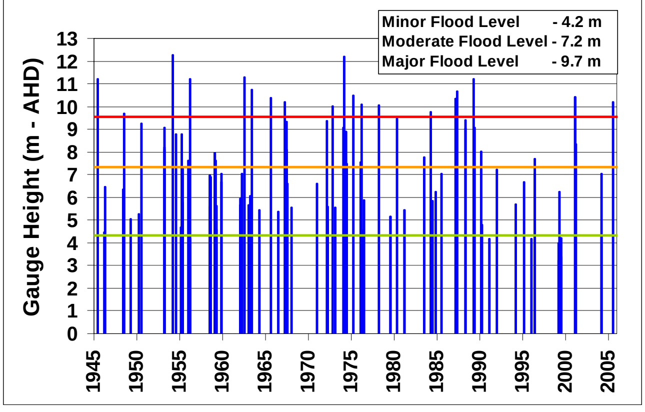
The Flood Warnings issued for the June 2005 flood at Lismore utilised modern technology such as Numerical Weather Prediction model outputs of forecast rain, automated radio telemetered field data, weather radar and the Internet. This technology allowed the Bureau's flood forecasters to make a rapid assessment of flooding in the Wilsons River catchment and provide accurate and timely forecasts for Lismore. Despite accurate and timely flood warnings for the peak, the rapid evolution of the flood at North Lismore was different to other recent events and the response of several people was started too late in the event to achieve the maximum possible reduction of risk to life and property damage. A public meeting held after the flood also showed that many did not understand how flood levels vary across the floodplain. The paper will describe the flood forecasting process used for Lismore and the lessons learnt from this flood, which has implications for other flood prone areas in NSW.

Key Words: Flood Watch, Flood Warning, flood response, Lismore

Introduction

Since 1945 Lismore has experienced over 100 floods greater than the minor flood level of 4.2 metres measured to Australian Height Datum (AHD) at the Lismore (Rowing Club) flood gauge, shown in Figure 1.

Figure 1: Floods at Lismore since 1945



During this 60 year period 19 of these 100 floods were greater than the major flood level of 9.7 metres AHD. However, over the past 16 years Lismore has only experienced 2 relatively small major floods of 10.4 and 10.2 metres AHD in February 2001 and June 2005 respectively. Both of these floods were preceded by Flood Watches, issued well before the flood producing rain fell, and had early Flood Warnings that utilised quantitative predictions of overnight rainfall, from Numerical Weather Prediction models, in hydrological models to develop quantitative flood forecasts. This approach was used to provide longer warning lead times during daylight hours for predicted overnight rainfall and flooding to facilitate a more effective community response to the threat.

Public meetings and discussions with individuals held at Lismore after these floods indicated that there was little community understanding or use made of the Flood Watch service and that there was a mixed response to the early Flood Warnings based on forecast rainfall that were issued before there were obvious signs of flooding at Lismore.

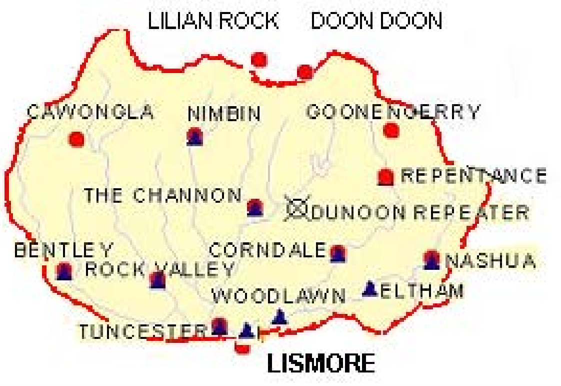
The 2005 flood was also much different to 2001, or other recent floods, and many residents at North Lismore were caught out by the rapid river rises in their area. This was despite the predicted peak flood levels at North Lismore, based upon forecasts for the Lismore flood gauge, being on target.

The Lismore experience in the June 2005 flood is not unique and this paper aims to develop a better understanding of the Bureau of Meteorology's flood warning services to help improve future flood warning system outcomes, the key one being to minimise the potential risk to life and property from a flood threat.

Lismore Flood Warning Network

The Bureau has provided Lismore with a flood warning service since 1967. Until 1990 the service relied on a system of manually-read rainfall and river level gauges until the formation of the NSW Flood Warning Consultative Committee which coordinated funding for the automation of the network utilising radio communications.

Fig. 2 : Lismore (Wilsons River) Catchmment



The Lismore catchment now has a network of 13 rain and 11 river gauges, shown in Figure 2. The blue triangles represent river stations and the red dots are rain gauges. This network is co-operatively maintained by Lismore City Council, Department of Natural Resources and the Bureau. Data is received in real-time by Lismore City Council, the State Emergency Service (SES) and the Bureau. The data is also available in near real time on the Internet which is updated hourly.

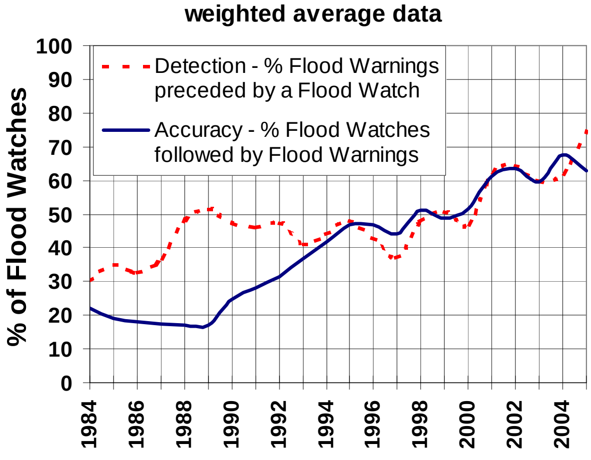
Flood Watches

Flood Watches are typically issued 24 to 48 hours ahead of flood producing rainfall and are based upon forecast rainfall and catchment wetness. Depending upon the confidence the meteorologist has in forecast rainfall, these values may be quoted in Flood Watches. For example, "50 to 100 millimetres" or "up to 150 millimetres", along with the degree of flooding that can be expected, such as "minor", "moderate" or "major", or a range, are routinely quoted in Flood Watches. Unless significant localised flooding is possible, Flood Watches are generally not issued for the very large catchments where several days, or longer, warning is available.

Flood Watches are being increasingly used by the NSW SES for their strategic planning and community flood education. In particular, Flood Watches are seen as being vitally important for the smaller catchments, including flash flood catchments, as well as for very flood vulnerable areas, such as caravan parks, where the available warning time is a critical limiting factor for a successful community response to flooding. The SES aims to disseminate Flood Watches to the community, along with locally based flood advice and education material, via the local media within 1 hour of their issue by the Bureau. They area also published on the Bureau's Internet site www.bom.gov.au .

The improvement in the performance of Flood Watches for NSW shown in Figure 3.

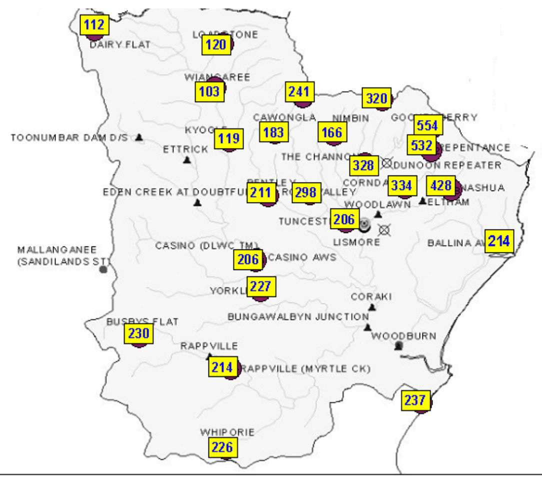
Fig. 3: FLOOD WATCHES - NSW - 5 year weighted average data



Since 1984 over twice as many floods are now preceded by Flood Watches and their accuracy has improved more than threefold. Around 70% of Flood Watches are now followed by flooding in NSW. Importantly, during the last 10 years, over 90% of major floods have been preceded by a Flood Watch (McKay 2005).

A Flood Watch for minor to moderate flooding was issued for the NSW North Coast from the Bellingen to the Tweed Valleys at 10.20 am on 29 June 2005. This Flood Watch was based upon predicted rainfalls of between 100 to 250 millimetres over a 48 period 29 to 30 June 2005. Whilst this predicted rainfall was fairly accurate on a regional basis, the Numerical Weather Prediction (NWP) models did not pick up the rainfall maximums of over 500 millimetres that fell in the north eastern half of the Wilsons River catchment shown in Figure 4.

Fig 4 : Rainfall over the Richmond-Wilsons Valley 29-30/6/05



However, for the purpose of issuing a Flood Watch for the region, the NWP models provided reasonable guidance.

As was the case with the February 2001 flood, there was no evidence to suggest much use was made by the community of the extra lead time afforded by the Flood Watch in June 2005. For example, a discussion with the manager of a caravan park, who responded to the Flood Warnings that were issued in the afternoon and evening of 29 June, revealed that he was unaware of what a Flood Watch meant. As the park is particularly vulnerable to flooding the manager could have utilised his staff during the day to prepare for the flood instead of needing to recall them after normal working hours and having to respond in a relatively tight time frame due to the nature this particular flood (discussed later).

For properties which are less vulnerable to flooding, the Flood Watch can be used as a trigger to plan and/or physically prepare for possible evacuation.

Using Forecast Rainfall Quantities in Flood Predictions

A Preliminary Flood Warning was issued for Lismore at 3.47 pm on 29 June 2005 warning that river levels at the Lismore flood gauge could reach 9 metres, with moderate flooding, around midday 30 June based on predicted heavy rainfall. This predicted river level meant that areas of North Lismore would be flooded. Figure 5 shows the key river level predictions and rainfall pattern for the June 2005 flood.

The predicted rainfall quantity used in the hydrological model was determined from studying rainfall predictions from a number of different international NWP models as well as the Bureau's meso-scale model, from which the forecast rainfall pattern was determined.

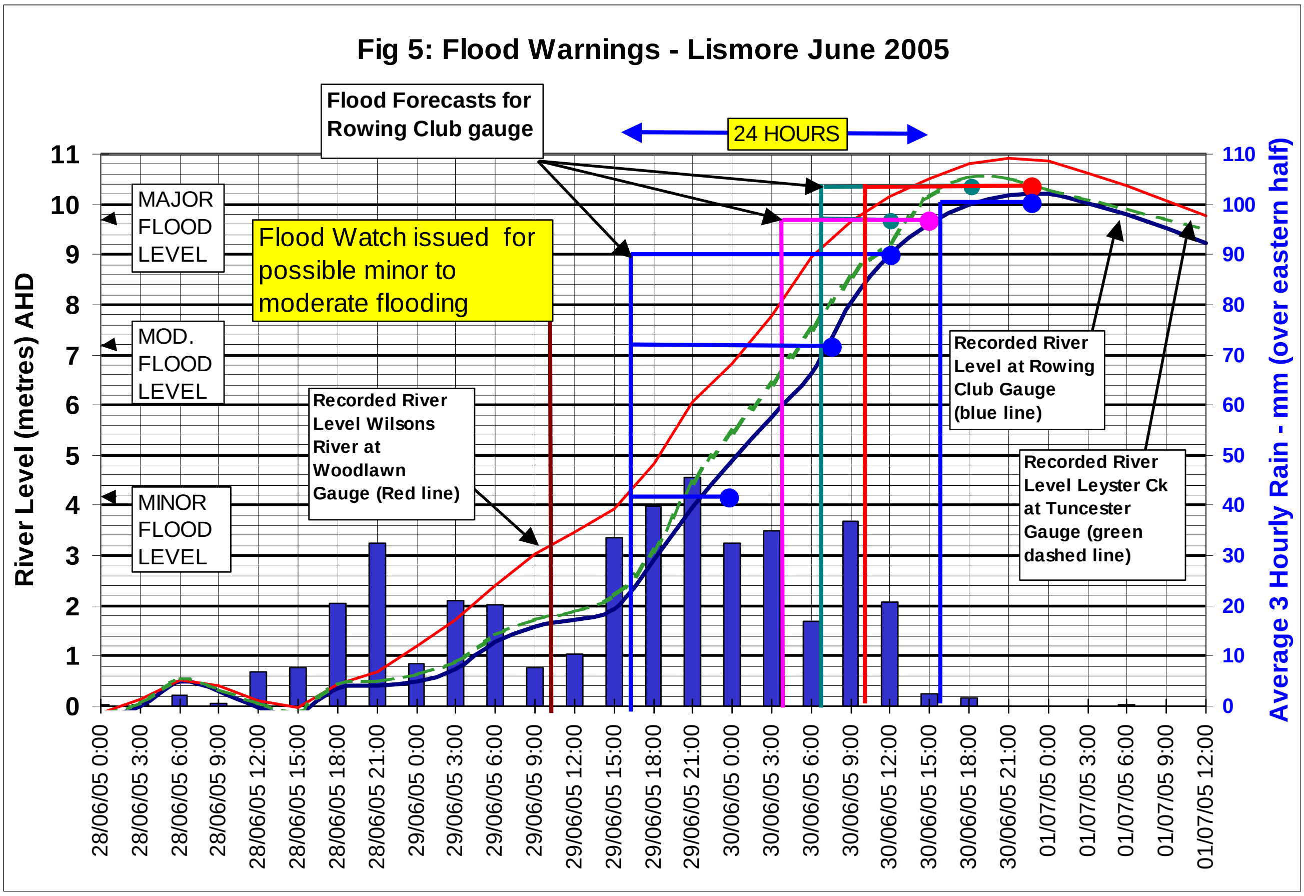
The use of qualitative, or generalised, rainfall forecasts in flood warnings has occurred since the Bureau was established in the early 1900s. However, even with recent improvements in NWP models, the use of forecast rainfall values in quantitative flood forecasting is a higher risk approach as the scale of most NWP models is relatively large compared to the scale of catchments that are being hydrologically modelled. Even slight differences in the location of rainfall maximums on a synoptic scale can have a profound effect on the amount of rainfall and flooding that is experienced in even medium sized catchments of 5,000 to 10,000 square kilometres. The difficulties are more so for smaller catchments, such as the Lismore catchment, with an area of only 1,400 square kilometres. The present resolution of the Bureau's meso-scale model is 12.5 kilometres, which means that about 9 model grid points define the rainfall distribution in the catchment. On the other hand, the larger scale global NWP models, with 50 to 100 kilometre resolutions, may only have only 1, or even zero, grid points in the Lismore catchment.

Therefore, forecast rainfall quantities from NWP models are not taken literally as experience has shown that it is rare for the precise amount, location and timing of heavy rainfall to all be simultaneously captured by the NWP models. Instead, the use of NWP model output is presently based more on a visual interpretation of graphical products, rather than direct use of modelled grid data points, to determine which areas are likely to receive heavy rain recognising that there will be variations from the predicted rainfall scenario (McKay 2005).

would have been available and the forecasts would have been issued around 9pm, thereby limiting the effectiveness of the dissemination of and response to the warning.

Flood Behaviour

A feature of the June 2005 flood was relatively high rainfall in the eastern (Wilsons River) part of the Lismore catchment compared to the western (Leyster Creek)



part from which most of the total volume of runoff usually comes as it represents 65% of the total catchment area to Lismore.

The recorded rain exceeded the total predicted rain by 3am on 30 June 2005 (see Figure 5) and forecasts were revised upwards until the rain eventually eased. Final peak predictions were accurate to within 0.2 metres with over 15 hours warning lead time.

Although the predicted rainfall quantities were not high enough to initially capture the peak of the flood in the very early Flood Warnings, they did allow the Bureau to provide 14 hours notice before flooding reached 9 metres AHD at the Woodlawn gauge at North Lismore and to issue this warning at 3.47pm. Without the use of forecast rain only about 9 hours notice

This rainfall pattern resulted in a very steep flood slope of about 2 metres difference between the Woodlawn gauge, at North Lismore, and the Lismore flood gauge during the rising stages of the flood (see Figure 5). What this meant on the ground was that flooding at North Lismore started some 6 hours earlier than usual using the Lismore flood gauge as a reference point. By comparison, the height difference between the two gauges during the rising stage of the February 2001 flood was only 0.5 metres.

This faster than usual rate of river level rise at North Lismore confused a number of people who used their own past experience of floods to calculate how much time they had to respond based upon the rate of river level rise at the Lismore flood gauge. In one case, a small business owner, who based his judgement upon past flood behaviour, delayed his response until it was too late and lost some $40,000 in flood damage to stock and equipment. Worse still, he was almost swept away by the flood water.

Despite the difference in the major source of flood water compared to other recent floods, the final peak flood height at North Lismore was consistent with that recorded at the Lismore flood gauge. At both locations the flood peak was about 2 metres below the 1974 flood. The 1974 flood is used as a reference point for flood level markers that are located throughout Lismore.

Lismore Flood Meeting

A public meeting was held at North Lismore on 27 July to discuss the June 2005 flood. The meeting was attended by some 100 people and was opened by the Lismore City Council Mayor, Clr. Merv King. Speakers were from the Bureau of Meteorology, NSW State Emergency Service and the Richmond River County Council.

The meeting was well managed by Lismore City Council staff and the overall tone was positive with only a couple of interjections. At the opening, the audience was notified that the speakers would be available after the meeting to discuss any details not covered during the talks and this helped keep the proceedings to schedule.

Some key issues raised during the meeting included :

- Confusion in the community over the relationship between their floor levels, measured to AHD, and the recorded river levels at the Lismore flood gauge, which are also measured to AHD. Many people wondered why their properties in North Lismore were flooded when their floor levels were considerably higher (in absolute terms) than the 10.2 metre AHD peak at the Lismore flood gauge located downstream. Many believe the recently completed CBD levee caused these higher flood levels. The floodplain is not a level pool of water. For water to move there needs to be a height difference between upstream and downstream water levels, called the “hydraulic gradient”. The greater this height difference is, the faster the flood waters flow. The previous section on flood behaviour referred to water levels at the Woodlawn river gauge being 2 metres higher than the Lismore flood gauge during the rising stages of the flood. This steeper than usual gradient was why the floodwaters were higher (and faster) than usual when using the Lismore flood gauge as the reference point. Similar flood behaviour was noted at South Lismore during the 1989 flood, when most water came from the (larger) western part of the Lismore catchment, and their levee was overtopped much earlier than expected.

- Many people did not prepare to evacuate early enough. Several only started to prepare when the evacuation order was issued by the SES, rather than when an earlier “prepare to evacuate” instruction was issued.

- The decision to evacuate the Lismore CBD was questioned as the predicted flood levels were below the levee spillway levels. The SES responded that the predicted river heights were close enough to critical levels to be concerned over possible flooding of the CBD given the usual degree of uncertainty over flood predictions and levee levels.

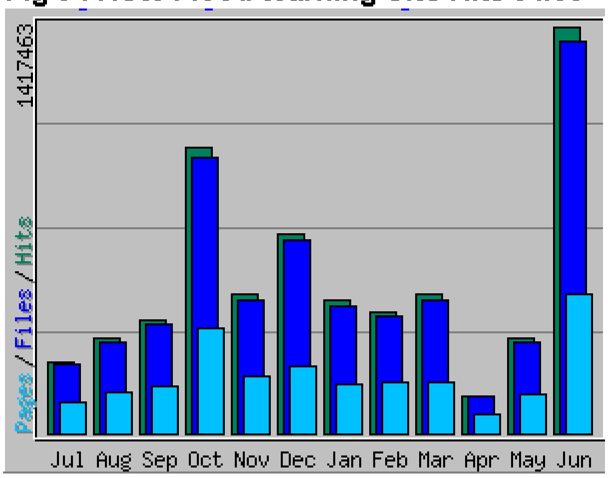
- There was some confusion over reported river heights and manual versus automatic readings. There will always be some inconsistency between quoted river levels, particularly during the developing stages of a flood, depending upon the time the reading is taken. It is also not unusual for there to be slight differences between manually read values and readings from an automatic gauge. For example, there was a 0.1 metre difference between the recorded peak and surveyed peak at the Lismore flood gauge. For the purpose of flood warning and response, however, this difference is usually insignificant.

Use of the Internet

Following public feedback after the 2001 major floods on the NSW north coast the Bureau accelerated the upgrade of its Flood Warning Internet site to provide near real time public access to rainfall and river level data (Robinson and McKay 2003).

Figure 6 shows a spike in the number of hits for June 2005 indicating that a lot of people are now using this service. Given that flooding only occurred during 29 to 30 June, it is estimated that the NSW Flood Warning site had about 1 million extra hits over these two days. The other spike, in October 2004, also coincided with flooding on the north coast.

Fig 6 : NSW Flood Warning Site Hits 04/05



For people without Internet access, all NSW warnings, including Flood Warnings, can be obtained on 1300 659 218 for the cost of a local call.

Lessons for the Future

Given the timely and accurate Flood Warnings for the June 2005 flood at Lismore, there should have been virtually zero avoidable flood losses. Unfortunately this was not the case for several reasons. The lessons from this flood include:

- To have any hope of achieving the key flood warning system outcome of reduced risk to life and property the community must have at least some basic information such as to what extent their property is affected by floods and what they need to do when a flood occurs. This information needs to be specific for each property. For example, a resident or business owner needs to know whether they need to lift their furniture or goods to a certain height, or whether flood waters will be so deep in their premises that they need to move items to a second storey or to a flood free location. They also need to know whether it is safe to remain at the premises or if they need to evacuate.

- Floor level information given to the public needs to be related to the equivalent height at the nearest flood gauge for which predictions are provided, recognising that there may be some variations in flood gradient and timing between different floods. Only with this "translation" of levels can people understand to what extent their property will be affected by predicted heights for a particular flood. Lismore City Council is one of the few in Australia to publish this information on the their Internet site. See http://www.lismore.nsw.gov.au/ then click on Council Services – Emergency Information – Lismore Flood Heights and Floor Levels links. The flood height and floor level tables in this site do, however, still need to be converted from the predicted Lismore flood gauge heights using the equivalent 1 in 10 or 1 in 100 year floods heights that are quoted for the property location to which the floor level is then compared. This involves a 3 step calculation that may be beyond the technical capability of many people. The site also contains other vital flood information to help the community prepare and respond to floods. This is an excellent initiative and the Council has received a national award for their pro-active approach to flood education.

- Once a flood threshold is predicted to be exceeded, people should be encouraged to respond as quickly as possible. There is often a "wait and see" attitude which wastes the valuable opportunity afforded by the additional warning lead times available through Flood Watches and the use of quantitative rainfall forecasts from NWP models in Flood Warnings.

- Local flood evacuation plans need more community input to ensure that local people are committed to the plan when flood thresholds are exceeded. In the case of the Lismore CBD, the SES calls for evacuation during the June 2005 flood were largely ignored. This could lead to credibility problems for future larger floods that will pose a greater risk to life and property. It is recognised that it is difficult to attract much community interest before a flood strikes. However, after a major flood it is usually easier to elicit community engagement in such a consultation process.

- Like any other form of training, message repetition and practice are needed to reinforce the lessons from past floods. Because there are often several years between major floods there are few opportunities to practice a response at a specific location. The problem of lack of flood knowledge is also exacerbated by the large number of people who now live on flood plains and have never experienced a major flood. The experience at Lismore for the 2001 and 2005 floods indicated that the community's response may not be as sharp as it was, say, during the 1980s, when the city experienced more frequent major flooding. The SES, in collaboration with local councils, is trying to fill in these gaps of flood knowledge and experience with flood education pamphlets geared to local areas, flood commemorations and other flood education initiatives. A problem with these activities is that there is often general apathy amongst the community over flooding, particularly during relatively dry periods. There is also the issue of what people can remember from such education campaigns when a flood does eventuate after several months, or even years. It has been suggested that the Flood Watch be used as a trigger to launch a local flood education campaign as people are likely to be more receptive if there is a threat and the time difference between receiving this information and applying it may be less than a couple of days.

Conclusion

The experience of the Lismore June 2005 flood shows that even in a relatively flood aware community there is still scope for improvement to fully achieve the potential reductions in risk to life and property from flooding.

The lessons learnt from this flood are important if communities are to maximise the benefits from a flood warning service which is now capable of delivering more timely and accurate flood forecasts than was previously possible.

It is also recommended that other flood prone communities learn from Lismore's recent experience rather than waiting for their own next major flood as an opportunity to "reinvent the wheel".

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Between a tidal barrage and a hard place: developing a management plan for the Tuckombil Canal - North Eastern NSW

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ABSTRACT

The Tuckombil Canal was constructed in the early 1900's as a flood escape to convey a portion of floodwaters from the mid Richmond area through Rocky Mouth Creek and into the sea via the Evans River. The canal was widened and deepened in 1965 to provide direct connection to the main water body of the Evans River. Although providing some flooding relief for the mid Richmond the artificial connection of the highly saline waters of the Evans River (> 30 mS) to the predominantly freshwaters of the mid Richmond River (< 3 mS) presented an additional management challenge.

To prevent salt incursion an inflatable tidal barrier was installed and replaced in the 1980's. This second barrier locally known as the 'Fabridam' failed in 2001 and a temporary fixed weir was installed to prevent saltwater incursion into the mid Richmond River system. A long-term management plan is now being developed for the Tuckombil Canal.

The challenge is to balance the competing interests and perceptions of the many stakeholders and develop a management plan that addresses social, economic, environmental issues and provide flood mitigation outcomes. This merit-based approach, espoused by State Government, ensures that the resulting management plan is appropriate and sustainable.

In January 2004 Council formed a Community Consultative Committee to provide advice to Council in the development of the plan. The committee has representation from the local community, local government, relevant state agencies and industry groups. Broad community involvement in the plan preparation, right from the beginning, should produce the best prospect for community acceptance of, and commitment to, the management plan.

WBM was engaged to investigate the hydraulic impacts of a variety of structures that are placed within Tuckombil Canal. These impact assessments go as far upstream as Swan Bay and Broadwater in the Richmond River and downstream to Evans Head. A key aspect arising from the community consultations was the influence of future works not on peak flood heights, but on the duration of inundation. Prolonging inundation on the floodplain was viewed as highly undesirable within the farming community, with any reduction, a key benefit. To better understand this issue, photogrammetry of the floodplain was commissioned and a TUFLOW hydraulic model developed that reproduces the local flood behaviour. The effects of different mitigation options on flood inundation are presented.

GHD was engaged to investigate the salt intrusion, environment, economic and social issues.

Background
Following major flooding in the Richmond River in the mid 1900's the state government and local councils began investigating strategies to mitigate flooding impacts. In 1958 the Richmond Valley Flood Mitigation Committee (RFMC) submitted its report to the then Minister for Conservation That report presented mitigation options and strategic locations where state and local governments could invest in hard works to mitigate flood impacts.

These strategies included:

1) the construction of seven dams in the upper catchment to store and stall flood waters with the intension of reducing down stream flooding.
2) regulating tributaries of the Richmond River with barrages and floodgates to prevent back up waters from the river flooding sub catchments on the floodplain and estuary
3) containing minor floods within the river with levees
4) the construction of flood mitigation canals to convey the surface tail waters from the floodplain and
5) the formation of the Richmond River County Council (RRCC) to carry out the works

The dam retention option was not adopted but strategies 2, 3, 4 and 5 were. With the formation of RRCC the Woodburn area was one of the first considerations for the implementation of the recommendations of the RFMC (Patterson, Britton and Partners 1992).

One of the strategies to alleviate flooding in the mid Richmond was to increase the discharge capacity of floodwaters into the Evans River by enlarging an existing flood escape constructed in 1895. This flood escape initially was a small canal breached through the bank of Rocky Mouth Creek with a sandstone causeway constructed at roughly the high tide level to prevent tidal exchange between the two river systems (Patterson, Britton and Partners 1992). The construction of the Tuckombil Canal was completed in 1965.

The new canal was now 50 metres wide, deepened by 2.1 metres and flanked by a levee on the northern bank to protect the town of Woodburn. Mind full of the problem of tidal exchange an inflatable tidal barrage locally known as the Fabridam was installed (Figure 1). To compliment this work Rocky Mouth Creek was floodgated and mitigation canals constructed to prevent flooding from the main river.

The Fabridam could be deflated during Richmond River flooding to allow a more direct route to the ocean via the Evans River and inflated during non-flood periods to exclude salt water from the Evans River. This operation provides benefits to the Richmond River farmers. Prolonged inundation of sugarcane by floodwaters or salt waters could seriously affect the viability of the crop.

Figure 1: Tuckombil Canal and tidal barrier 'Fabridam'

Between a tidal barrage and a hard place

The concept of the environment or natural resources last century was not what the community understands today. The thinking of the time was purely aimed at reducing the threat of flooding on the community with engineering solutions being the obvious means to achieve this objective. The community still seeks to mitigate flooding impacts and maximising agricultural production but now under the concepts of the 'triple bottom line' approach, by considering the social, environmental and economic aspects along with the pure engineering solutions as well as the intra and inter generational equity that guides floodplain managers today.

The infrastructure and strategies of yesteryear and their legacy and the triple bottom line sets the stage for a seemingly impossible challenge to balance the multi stakeholders perceptions and needs.

Developing a long-term sustainable management plan for the Tuckombil Canal

In July 2001 the inflatable tidal barrier the Fabridam failed. The result was tidal mixing of highly saline waters (>30 mS) of the Evans River with the predominantly freshwater (<3 mS) of the Mid Richmond River system. The impacts of this unchecked tidal exchange was quite dramatic with riparian users, irrigators, stock water all affected. The artificially high salinity levels also has environmental impacts such as the queuing for fish like Bass to spawn and changes in aquatic species assemblages in effect moving the intermediate zones of the estuary further up River.

With state government assistance RRCC installed a temporary concrete modular barrier. This had the desired outcome of checking the free tidal mixing between the two rivers but the long term sustainable management of the Tuckombil system was now the most important priority.

Community consultation: RRCC formed a community consultative committee to assist Council and the then Department of Infrastructure, Planning and Natural Resources to develop a solution for the canal. This committee is comprised of state agencies, the cane and grazing industries, commercial fishers, community and environmental representatives. The committee also considered the Mid Richmond Flood Study which identified flood mitigation options and the recommendations of the Evan's River Estuary Management Plan, which included reducing the impact of increase flows from the Richmond into the Evans River estuary. The stakeholder groups vary in their perceived management for the Tuckombil Canal and have a complexity of issues shown below in Figure 2.

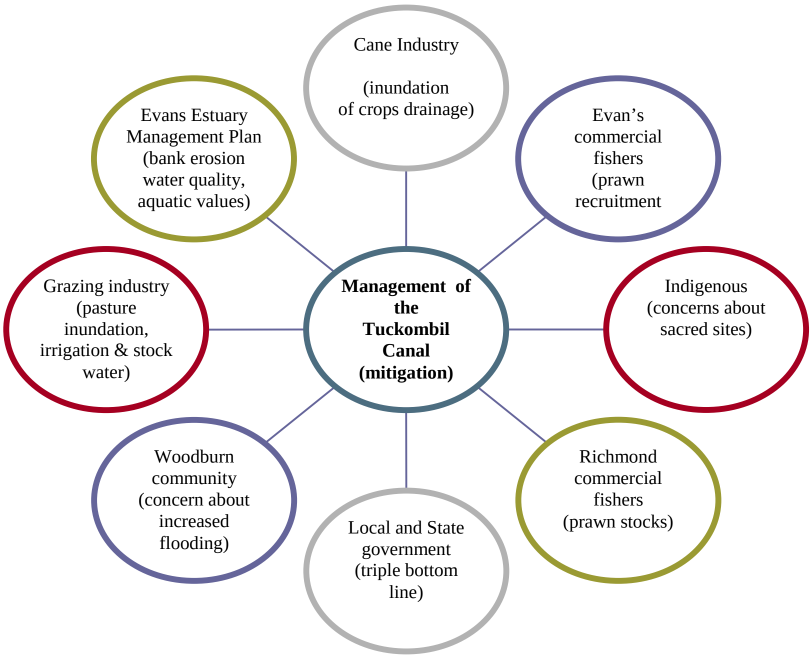


Figure 2: Mind map of stakeholder concerns and issues

Flooding Issues

A long term management plan dealing with Tuckombil Canal specifically is being developed to guide the future management of the canal and any permanent structure that is placed within it. In developing strategies, the plan will need to consider the hydraulic, environmental, economic and social implications of the proposed works.

WBM has extensive knowledge of the study area because of its involvement in studies undertaken between 1998 and 2002 and has set up a broad-scale hydraulic model for the entire study area. The model was not set up to model the drainage of farm drains as the focus was on larger floods. However, with smaller floods the floodplain storage, drainage of farm drains and floodgate structures become prominent in influencing hydraulic behaviour. The model was therefore upgraded to a finer-scale model. Because of the complexity in the hydraulic behaviour, a 2-dimensional model was set up to undertake the hydraulic assessment for this area.

2D and 1D Flood Modelling using MIKE 11 and TUFLOW

The first step was to survey and model flood behaviour and predict the effects on flood behaviour in the mid Richmond area. As part of this process a flood impact assessment into alternative weir options was carried out. The aim of this assessment was to assess the effect of the fabridam/weir structure on flooding by quantifying its effect on:

- peak levels in the Richmond River, Evans River, Rocky Mouth Creek and adjoining floodplains;
- frequency of flood intrusion from Rocky Mouth Creek and its floodplains into Tuckombil Canal; and
- detention of floodwaters on the Rocky Mouth Creek/Swan Bay floodplains.

A 2D/1D (two-dimensional/one-dimensional) hydrodynamic model was developed for the study area using the TUFLOW software (www.tuflow.com). The more advanced 2D/1D approach was adopted for the following reasons:

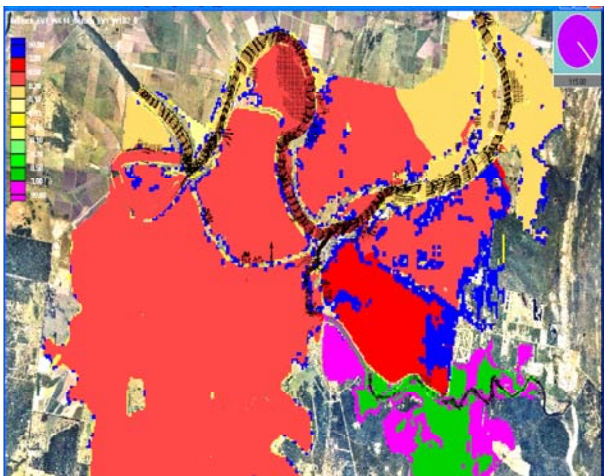
- The 2D approach provides superior representation of the complex flow patterns that develop within the study area.
- The photogrammetric survey of the study area does not cover areas below water. This includes the Richmond River, Rocky Mouth Creek, Tuckombil Canal and the Evans River. These areas were therefore modelled as 1D elements using the cross-section data available to prior studies in the mid-Richmond area
- Areas outside the photogrammetric data were modelled using a 1D approach based on the mid-Richmond MIKE 11 model data. The extent of the 1D component was taken sufficiently far away from the area of interest to remove any significant effects resulting from assumptions at the model's boundaries.

The TUFLOW model was validated to results from the 1954, 1974 and 1988 historical events (used for calibrating the previous MIKE 11 model), and the 1, 5 and 20 year ARI design flood events, as carried out for the Mid-Richmond Flood Study. The hydraulic conditions (flows and water levels) at the 2D/1D boundaries were extracted from the MIKE 11 model and applied to the TUFLOW model. A form of model validation was made by comparing the results of the two models to check that similar flow conditions occur in both.

Peak levels between the two models were nearly all within 0.1m, except where the effects of having an improved topographic representation in the area of the photogrammetric survey. Within the floodplains, the 2D representation provides a much better depiction of the flow patterns and effects of storage, partly due to the availability of the photogrammetric DEM, and partly due to the more accurate solution offered by the 2D approach.

Investigations were also made into calibration of the model to 2001 flood event. After review of the data available, this was not carried out due to the lack or shortage of rainfall and other data to warrant a worthwhile calibration exercise. The rainfall data in particular was problematic with insufficient pluviograph data in the southern catchments and major variations in daily totals over the Richmond River catchment.

The TUFLOW model was used to assess the effect on flood behaviour of different weir heights and structural options. The effects of the different weir options on flood levels and duration of inundation are being quantified to help understand the pros and cons of the different options. An example of the preliminary findings are presented in the images below.



Social, Economic and Environmental issues
With the flood modelling completed the next stage in the process was to evaluate the triple bottom line of Social, Economic and Environmental issues. GHD were engaged to drive this study.

Review of Existing Data
The first step in this process was to review the data and associated reports that had been undertaken in the area to date. These included, the Mid Richmond River Flood Assessment, The draft Richmond River Process Study, the Evans River Process Study and Evans River Estuary Management Plan and the numerous reports for which they refer. Within each of these reports varying assessments and assumptions have been made regarding Tuckombil Canal. In many instances the reports had conflicting views on the Canal and it's impacts.

The main issues found to be associated with Tuckombil Canal in these reports include:

- Water quality, particularly Salinity increases in Rocky Mouth Creek and the Mid Richmond River
- Bank Erosion, accretion and siltation in the Evans River
- Loss of terrestrial vegetation and fauna habitats
- Change in aquatic flora and fauna
- Increase in Fish deaths and fish diseases
- Social implications (up stream and down stream)
- Economic implications

The significance of impacts to these factors from Tuckombil Canal however varies within reports and definitive data has not necessarily been, or can be collected to determine the actual impacts Tuckombil Canal has on these factors. Therefore an assessment of data in terms of what is known and what can likely be attributed to Tuckombil Canal and its management was undertaken A summary is outlined below:

<u>Salinity</u>
Several water quality sampling programs have been undertaken within the Richmond River, Rocky Mouth Creek and or the Evans River, each program has had different parameters and characteristics and therefore comparing programs as well as comparing water quality in relation to structure management must be undertaken with a degree of caution. However we know that based on the water sampling undertaking by RRCC in Rocky Mouth Creek salinity levels in Rocky Mouth Creek are high when there is no tidal structure in Tuckombil Canal.

Salinity in Rocky Mouth Creek (2000 – 2004)

Time Line	Structure Details	Salinity in Rocky Mouth Creek Range (ppt)	Salinity in Rocky Mouth Creek Average (ppt)
2000	Fabridam in Place	0.6 – 1.2 ppt	0.77 ppt (0.76)
Jan - July 18 2001	Fabridam in Place	0.3 – 2 ppt	0.7 ppt (0.70)
18th July – December 2001	Fabridam Split no structure in Place	1.7 –16.2 ppt	6.2 ppt (6.23)
2002	Concrete weir in place	0.5 – 8.4 ppt	2.5 ppt (2.46)
2003	Concrete weir in place	0.6 – 9.8 ppt	3.3 ppt (3.2)
2004	Concrete weir	0.2 – 2.5 ppt	1 ppt (1.07)

Information based on data supplied By Richmond River County Council (RMC Salinity).

Salinity data from other studies parts per thousand (ppt)

Time Line	Structure Details	Salinity in Tuckombil Canal (down stream)	Salinity in Rocky Mouth Creek	Salinity at Woodburn
1990	No structure in Place	27 – 30*	5.2 – 20 ppt 12 – 20 10 – 30 $	2.5 - 7.7 between Woodburn to Swan Bay*
1994	Fabridam replaced		1 - 4 ppt+	
1995	Fabridam in place		0.6 – 5 ppt +	
1997	Fabridam in place	20-25 #		

*Referenced in PBP 1991 and Evans River North Coast Estuaries Sedimentologist Studies

$ Referenced in PBP 1991 and Estuary management Group Report 1997 the different ranges reflect the fact that the creek is stratified and therefore readings varies based on depth of the sampling as well as ebb or flood tide situations.

+Referenced in MHL Report 748, # Referenced in Estuary Management Group Report 1997

We also know that the tidal flows and range are diminished in an upstream direction from the ocean entrance. A tidal plane analysis was undertaken which gives a mean High High Water Spring Tide level of 0.78 m AHD and a mean Mean High Water Spring Tide level of 0.45 m AHD at the Tuckombil Floodgate site (down stream end of Tuckombil Canal).

Bank Erosion and Sedimentation

Studies to date have found that on average 5,000 tonnes/year of fines sediment currently enters the Evans from the Richmond River. This compares to the likely former sediment inputs (i.e. pre Tuckombil Canal) which is in the order of 500 tonnes/year.

Air photo analysis undertaken for the Evans River Processes Study shows that a proportion of the sediment entering the Evans River from Tuckombil Canal is being deposited within the river between the downstream end of Tuckombil Canal and Brandy Arm Creek.

The construction of Tuckombil Canal is estimated to have approximately doubled the volume of freshwater being discharged into the Evans River each year (Patterson, Britton and Partners, 1999)

Mathematical model studies *(MHL, 1997 and Wainwright 1997*) have shown that Tuckombil Canal has no impact on the peak tidal discharge through the entrance of the Evans River.

Terrestrial flora and Fauna

Vegetation mapping undertaken by Biogreening for the Evans River Processes Study identified nine main vegetation types encompassing 14 recognisable vegetation communities along the Evans River.

These vegetation communities included rainforest, wet sclerophyll forest, dry sclerophyll forest, swamp sclerophyll forest, heathland complex, mangrove complex, saltmarsh complex, reed swamp and grasslands.

Biogreening found that vegetation communities of the highest conservation significance to be the rainforest communities, followed by the wet sclerophyll forests north of Brandy Arm Creek and in the vicinity of Iron Gate.

The main fauna study undertaken for the Evans River have been those undertaken for the Processes Study in 1999 these found that fauna habitats generally correspond with the vegetation occurrences.

The lower reaches of the catchment, while experiencing some disturbance are in a fairly natural state with the greatest flora and fauna significance being associated with these areas, including the National Parks.

The Upper Reaches of the Evans River Catchment and in Rocky Mouth Creek have however experience extensive clearing associated with flood mitigation as well as agricultural pursuits.

Aquatic Flora and Fauna

A survey of water quality and benthic organisms at eight representative sites in the Evans River estuary were undertaken on 18th of June 1999 as part of the Evans River Processes Study. The study found that:

Water quality and benthic communities varied considerably along the river.

Rocky Mouth Creek had poor water quality, with acidic fresh water (pH 4), and low levels of dissolved oxygen,

Water quality was good in the middle and lower reaches of the Evans River.

The benthic communities in the river reflect the water quality and varying salinity.

A total of 15 invertebrate taxa were present in the grab samples at eight sampling sites along the river system.

Benthic macrofauna present in the Evans River estuary is similar to that found in benthic communities along a similar salinity gradient in the Richmond River estuary. The abundance and diversity of benthic macrofauna recorded in the Evans River was relatively low.

Freshes in Rivers can cause substaintial reductions in diversity and abundance of benthic organisms in estuaries, and can have long-term impacts on benthic communities.

Poor water quality such as low oxygen and acid runoff along with a lack of sediments as a result of flood induced scouring reduces the health of the system and therefore benthic communities.

Fish kills

Numerous fish death events have been recorded in the region.. Significant fish and invertebrate mortalities have occurred periodically in the Evans River.

The largest fish and invertebrate kill recorded occurred in March 1999, where thousands of fish and invertebrates died throughout the length of the Evans River and in Rocky Mouth Creek (*Patterson, Britton and Partners, 1999*).

Most fish death episode have been attributed to low dissolved oxygen conditions throughout the river system, and may also have been exacerbated by acid sulphate soils runoff.. Rocky Mouth Creek Catchment is and Acid Sulphate soils priority Area and acid sulphate runoff is generated from the catchment.

During floods inundated vegetation rots depleting oxygen levels in the water (Black Water). Black water is generated in RMC during prolonged floods especially in summer.

Social and Cultural

Both upstream and down stream communities have varying opinions of the impacts and benefits of the structure in Tuckombil Canal.

The Evans River contains numerous sites, which are considered valuable to the local Aboriginal Culture. There are several Non Aboriginal Heritage sites in the region

Economic

Limited detailed studies have been undertaken on the economic implications of the Management of Tuckombil Canal however, it has been suggested that it can cause agricultural losses (associated with flood inundation), fishery losses and gains (associated with prawn recruitment through the Richmond River) and tourism impacts. The cost of a range of structures have been debated by different groups over recent years.

Technical

The 2nd Fabridam appeared to have been vandalised, leading to a reduced life. The Fabridam and the Rocky Mouth Creek Floodgates were operated in conjunction. The operation of a structure may cause time delays in responding to floods and preventing black water egress.

Social Perception

The next step was to gain an understanding of the different community perceptions of Tuckombil Canal and its management. There are polarised views within the community on the benefits and impacts of Tuckombil Canal. Many of these views have been recorded within existing reports. Meetings with the Community Consultative Committee where undertaken to provide an outline of these concerns and varying views. Given the varied nature of community concerns and the polarised views between up stream and downstream, and within down stream community. A number of interviews and discussions were held with different community representatives and key interested parties to gain a better understanding of the issues and where possible clarify these conflicting views and the associated impacts which can realistically be attributed to Tuckombil Canal. These included discussions with:

- Southern Cross University aquatic researcher regarding fish passage, prawn seeding, fishing pressures, fish kills and impact of sedimentation on aquatic species.
- NSW Farmers Association regarding impacts of salinity on agricultural pursuits.
- Cane Growers Association regarding impacts of inundation on cane growing and the susceptible periods within the growing season and salinity tolerance for watering in of sugar cane.

Developing Impact Criteria

Based_on the key issues identified in the reports undertaken to date along with information collected during committee meetings and key stakeholder discussions a number of management assessment criteria where developed for each of the following:

- Flood Mitigation Criteria (4)
- Water Quality - Salinity (10)
- Environmental Criteria (14)
- Erosion, Siltation and accretion
- Flora and Fauna (terrestrial)
- Aquatic Flora and Fauna

- Social Criteria (18)
    - Up Stream Impacts
    - Down Stream Impacts
- Cultural Criteria (4)
- Economic Criteria (8)
- Technical Criteria (5)

A total of 63 criteria were developed to help assess the likely impacts of a structure on the main areas of concern. The likely indicators for each criteria were also developed. For example Water Quality Criteria W2 is “To What extent does the option minimise salinity levels in Rocky Mouth Creek?”. The indicators for this criteria are as follows:

a) Height of structure in comparison to Tidal Plane Heights

b) Likely salinity concentration based on dilutions and results gained in EMG 1997 Tidal Modelling (5% exceedence at rocky mouth flood gates)

c) ANZECC water quality guidelines indicate that the salinity limit for stock consumption is 6ppt for dairy cattle & 10ppt for beef cattle.

d) Tolerance for watering in of sugar cane (after planting watering in can be undertaken with brackish water (up to 13ppt) but any additional water needs to be fresh.

Developing Management Options

A number of Management Options have been proposed in the past including

- The Fabridam
- A Fixed Weir
- A Gated Weir
- No Structure

These options were used as the basis for assessing the likely impacts of management on Tuckombil Canal. In addition a range of heights were considered for each of these options:

- 0.74 m AHD has been considered as this is the height for which the fabridam was set (inflated) and the approximately height of the High High Water Spring Tide (HHWST).
- 0.45 m AHD has been considered as this, based on tidal plane assessment, is the height of the Mean High Water Spring Tide (MHWST).
- 0.6 m AHD was chosen as this is not only between the HHWST and the MHWST, but also reflects a modelled height undertaken in 1997 (EMG) for which was modelled as a threshold level for salinity increases.

In addition to differing structure heights numerous gated versions have been proposed to include gated versions to replicate the Fabridams management. The management options considered are:

- The Fabridam
- Inflated Height of 0.74 m AHD and a deflated height of –0.86m AHD
- Fixed Crest Weirs
- Crest Height of 0.45 m AHD
- Crest Height of 0.6 m AHD
- Crest Height of 0.74m AHD

Gated Weirs

- Crest Height of 0.45 m AHD flood management level of –0.86 m AHD
- Crest Height of 0.6 m AHD flood management level of -0.86 m AHD
- Crest Height of 0.74m AHD flood management level of –0.86 m AHD

Gated Weirs

- Crest Height of 0.45 m AHD
- Crest Height of 0.6 m AHD
- Crest Height of 0.74m AHD

Gated Weirs

Crest Height of 0.45 m AHD flood management level of –0.86 m AHD

- Crest Height of 0.6 m AHD flood management level of -0.86 m AHD
- Crest Height of 0.74m AHD flood management level of –0.86 m AHD

No Structure

- Crest Height of –0.86m AHD

Economic Implications

Many of the reports undertaken to date have touched on the economic implications of Tuckombil Canal and its management but no detailed studies had been undertaken. An economic assessment of the impacts of management of Tuckombil Canal was therefore undertaken by Hassall and Associates. The assessment looked at the flooding, water quality and social, and to a limited level (based on data) environmental impacts on both up stream and down stream communities for the proposed management options. The Assessment found that the management of the canal and structures associated height could have significant effects on the economic implications to agricultural land management in up stream communities, In addition some economic implications to fishing and tourism in the downstream communities could also be effected by management of the canal and structures associated height.

In addition to the economic assessment of impacts that can be associated with the Canal management GHD undertook preliminary assessment of the likely capital, operating and management costs for the proposed structures. The option of no structure was naturally the cheapest capital followed by the fixed weirs and Fabridam. The options of no structure and fixed weirs had the lowest operating and maintenance costs and also the longest estimated structure life and therefore lowest replacement fund requirements.

Development of a Decision Matrix

A Decision Matrix was then developed which allowed each proposed option to be assessed against each criteria. The Decision Matrix allows scoring of each options with the options which obtains the highest score being the preferred option based on a scoring system as follows: The level of compliance for each of the indicators will provide a score for the Decision Criteria. The criteria will be scored based on the score applied to each criteria as per the following scoring system.

0 = no compliance

1 = Low level of compliance

2 = average level of compliance

3 = high level of compliance

The preferred option should reflect the greatest compliance, however, based on the information available the reliability and or ability to measure some indicators varies. A weighting system for the criteria categories was therefore developed as follows:

- Flooding– 25% of overall score
- Water Quality (salinity) 20% of overall score
- Economic = 20%
- Technical = 10%
- Environment = 15%
- Social and Cultural= 10%

Given that there is a varying range of questions in each section the weighted score will be a result of the scores of each section being added then divided by the number of questions in that section and then multiplied by the percentage applied to that section.

The Technical Committee will assess the options and compare their results to the Community Consultative Committees Decision Matrix outcomes. Criteria which score differently between the two assessments will be discussed and where possible resolved with the intention of determining the preferred management structure.

Developing Management Strategies

Once a decision is made on the preferred option the management strategies for implementation and if necessary appropriate management of the structure, along with other identified management requirements will be developed. This process can also be used to develop management strategies and checks against any criteria where complete consensus was not achieved via the decision matrix assessment.

The ultimate outcome is to develop a Tuckombil Canal Management Plan that will outline the management strategies and their implementation for the preferred tidal structure option and the long-term management strategies for the Canal.

Conclusion

This paper summarises the issues surrounding the development of a long term sustainable management of the Tuckombil Canal. The multiplicity of these issues presents significant hurdles before all stakeholders agree on a preferred solution. The title '*Between a tidal barrier and a hard place'* accurately reflects the challenge to floodplain managers seeking to address flood strategies undertaken in 1900's. These strategies addressed the community's concerns of the time but the complexity of addressing works in our time is seemingly an impossible task. The mind map presented in this paper graphically shows that the solution to the long term management of the Tuckombil Canal will be realised through compromise.

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MERRYLANDS CENTRE URBAN REVITALISATION PROJECT – DEVELOPING SOLUTIONS TO ADDRESS FLOODING IN THE TOWN CENTRE

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Abstract

The Merrylands centre comprises two distinct precincts, namely the Neil Street Precinct and the Merrylands Town Centre Precinct. The Neil Street Precinct is characterised by older commercial/light industrial uses and large areas of vacant land, and the Merrylands Town Centre Precinct is characterised by a "Main Street" with narrow retail shop frontages and a parallel shopping strip on which is located a shopping mall.

The Merrylands centre evolved along the course of A'Becketts Creek during the late 1800s, with the shops along Merrylands Road built during the 1920's and 1930's. As a consequence the town centre is subject to high hazard flooding which requires to be considered in any redevelopment of the centre.

The Merrylands Centre Urban Revitalisation Project commenced in 2000 (with funding received through the Urban Improvement Program) and sought to manage urban change in the town centre to ensure the long-term viability and vitality of the Merrylands CBD and adjoining areas.

One element of this project included creating site specific planning controls for both the Merrylands Town Centre Precinct and the Neil Street Precinct. Flooding was one of the major issues to be addressed in the development of these planning controls, with the solution required to address the flooding differing between the two precincts.

Key Words: Merrylands, Town Centre, Redevelopment, Development Controls, Flood Study

Introduction

The Merrylands Centre comprises a Main Street, and a parallel shopping strip on which is located a shopping mall. The town centre evolved along the course of A'Becketts Creek during the late 1800s, with the shops along Merrylands Road built during the 1920's and 1930's. The creek through Merrylands was converted to an open concrete lined channel in 1933 and as further development occurred, the majority of the channel was enclosed and the watercourses piped.

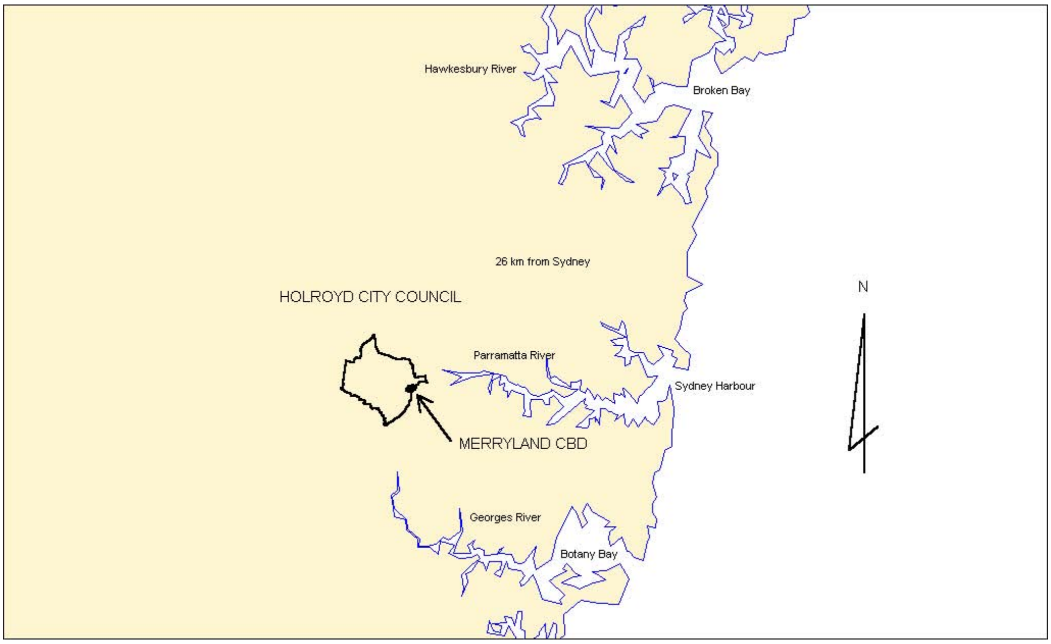

Figure 1 – Locality Map

Merrylands is Holroyd Council's largest commercial centre and is also the most accessible to the Merrylands Transport Interchange, located at the eastern side of the CBD. Merrylands is a well established shopping centre, with the main focus of the CBD being the traditional shopping strip along Merrylands Road and a large shopping mall defining the northern edge of the commercial area. The commercial area of Merrylands is in need of significant revitalisation and renewal in order to ensure the centre's viability and economic growth over the long term.

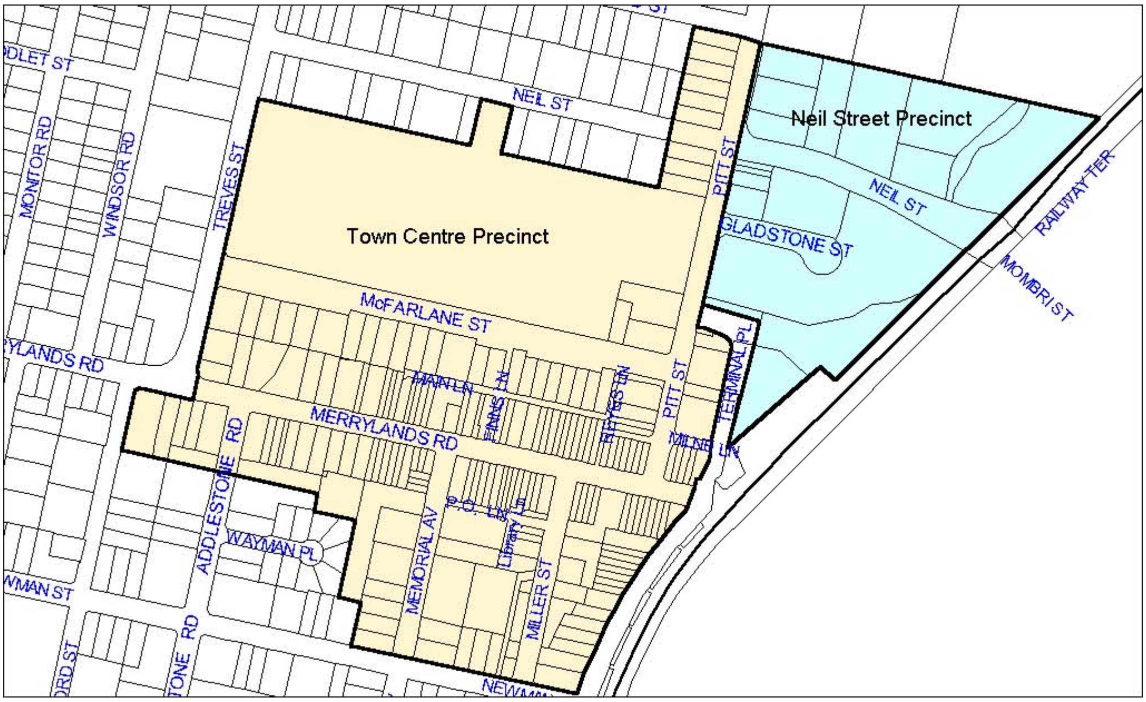

Figure 2 – Merrylands Town Centre and Neil Street Precincts

The Merrylands Centre Urban Revitalisation Project (MCURP), funded in part by both Council and the then Department of Infrastructure, Planning and Natural Resources under the Urban Improvement Program, was designed to provide long and short-term outcomes for the community and businesses of the Merrylands Centre to bring about overall revitalisation of the town centre. The aim of the project was to establish mechanisms that would ensure that future redevelopment in Merrylands would occur in accordance with well-planned urban design outcomes. One element of this project included creating site specific planning controls for both the Merrylands Town Centre Precinct and the Neil Street Precinct.

The Neil Street Precinct

The Neil Street Precinct is located immediately north of the central Merrylands Town Centre and Transport Interchange and is south of Holroyd Gardens residential estate and Holroyd Gardens Regional Park. The Precinct comprises a range of older commercial uses and light industrial uses as well as a substantial amount of vacant disused land.

Figure 3 – View of Neil Street Precinct from Terminal Place

Figure 4 – View of Neil Street Precinct from Neil Street

Due to its highly accessible location, the Precinct is considered ideal for urban renewal. Redevelopment will support the revitalisation of the Town Centre through increased residential density and provide an excellent opportunity to satisfy State Government's policy of integrating land use and transport.

The Merrylands Town Centre Precinct

The Merrylands Town Centre Precinct is the commercial heart of the City of Holroyd and is located to the west of the Merrylands Transport Interchange. The Merrylands Town Centre Precinct is comprised of a “Main Street” along Merrylands Road which is characterised by a fine grained subdivision pattern creating narrow retail frontages and McFarlane Street, a wide tree lined road on which is located a large shopping mall, but with a fine grained subdivision pattern occurring at the eastern end closest to the Transport Interchange.

Figure 5 – Merrylands Road


Figure 6 – McFarlane Street

There is a need to enhance the Main Street by focusing on facilitating mixed use development with retail development at grade that engages with the street and public domain to counterbalance the planned expansion of the shopping mall on the northern edge of the commercial centre on McFarlane Street and its expansion onto land at the western end of McFarlane Street and Merrylands Road. This is required to ensure the long-term viability of the Town Centre as a whole.

Preparation of Planning Instruments

As a means of implementing the proposed planning changes draft Local Environmental Plans (LEP) and draft Development Control Plans (DCP) were prepared by Council. The LEP and DCP for the Neil Street Precinct were finalised in 2004, whilst the LEP and DCP for the Merrylands Town Centre Precinct are nearing completion. Numerous studies were undertaken in the development of the planning instruments to respond to the identified opportunities and constraints, with one of the major constraints identified being flooding.

Flooding In Merrylands

The creek through Merrylands was converted to an open concrete lined channel in 1933. As further development occurred, the majority of the channel was enclosed and the watercourses piped. The Sydney Metropolitan area was subject to significant storm events during the late 1980s. The Sydney Water Board, under the Special Environmental Program, conducted various flood studies to assist local councils for flood mitigation options and future grant funding. Fifteen years later and after the construction of four upstream detention basins, the flood study, through the town centre, needed to be revised. A flood study was undertaken as part of the MCURP project.

Design flows through the CBD were calculated and included the impact of the Merrylands Regional Park detention basins. Computer-based hydraulic models were then developed to model the trunk stormwater system, which runs through the CBD, and to assess flow regimes through this area.

The model results indicate that the trunk stormwater system capacity is approximately $24m^3/s$ at the Addlestone Road culvert, 16 m^3/s at Treves Street and 48 m^3/s from Pitt to downstream of Neil Street. These capacities are significantly smaller than the 100-year flow magnitudes. 100-year overland flows along McFarlane Street would be approximately 35 m^3/s, with 41 m^3/s through the area downstream of Neil Street.

The hydraulic modelling of the overland flow paths shows that much of these flow paths would exhibit high hazard risks during the 100-year storm events.

To reduce these flows, it is proposed to upgrade the road culverts at Treves Street and Addlestone Road, construct a new culvert from Pitt Street to Neil Street and provide a central swale and culvert along a proposed “New Street” within the Neil Street Precinct.

Despite the proposed trunk drainage improvements, the modelling showed that overland flows in the 100-year event remain significant and hazard is often high.

To avoid increasing upstream flooding, an existing overland flow path between Merrylands Street (near Addlestone Road) and McFarlane Street needs to be preserved. Modelling showed that a width of not less than 15m wide is necessary.

To put the flooding through the CBD in perspective, the critical storm duration for this study is the two-hour storm pattern. It is expected that actual property inundation would be short and sharp, approximately 15 to 20 minutes during this event. There would be no time to warn property owners of a flood; thus alternative flood prevention measures would be required.

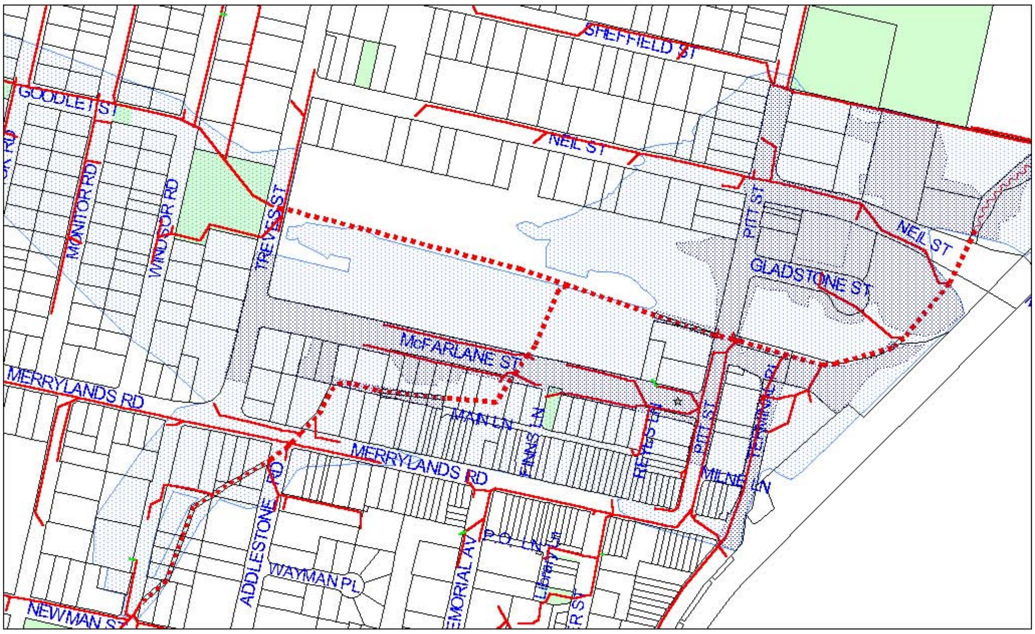

Figure 7 – Extent of 100-year Flood and High Hazard zone Through the Merrylands CBD

The Neil Street Precinct Solution

Whilst flooding was not the only constraint, it was a significant constraint. Affectation by the current 100-year ARI flood inundation means that within the Neil Street Precinct development on certain sites could not occur unless finished floor levels were up to 2 metres above natural ground level. Another constraint revolved around the subdivision pattern, such that some sites were very constrained, meaning that if they were to be developed in isolation, poor circulation and poor design would result.

The Neil Street Precinct was therefore designed so that a roadway and swale (40m wide) will carry the majority of the floodwaters. Additional under-ground trunk drainage systems will re-direct flows to the open watercourse. The proposed new road north-south will also provide for a better subdivision pattern for redevelopment and traffic circulation. These works will lower existing flood levels, in this precinct, by approximately 500-600mm.


Figure 8 – Neil Street Precinct DCP Masterplan


Figure 9 – Artists Impression of new proposed road incorporating drainage swale

New buildings and driveway entry/exit points to underground parking areas will have finished floor levels equal to or above flood planning levels.

Merrylands Town Centre Precinct Solution

Flooding of properties occurs to some extent within all streets within the town centre precinct. The flood study indicated that there is approximately 35m³/s, flowing down McFarlane Street, with a maximum depth of 1.3m.

Initially a review was undertaken into the possibility of flood mitigation works for the centre. This study identified two options, one requiring significant land acquisition (much of which is comprised of residential flat buildings) for the purpose of constructing upstream detention basins. The other option requiring a large culvert to be constructed along McFarlane Street to the watercourse. This option would require easement acquisitions, redesign of a local park, require infrastructure adjustments to sewer, gas electricity, telephone in the town centre and adjustments to existing stormwater culverts. Both options were costed as being in excess of $25 million.

With no further flood mitigation works being viable, development control solutions were required to address the flooding issue.

Two of the main options considered as part of formulating the development controls were:

- designing new buildings to be above a designated flood planning level; (in some locations as high as 1.5m above existing ground levels) or
- maintain shops at grade in order to ensure the ongoing viability of the main street.

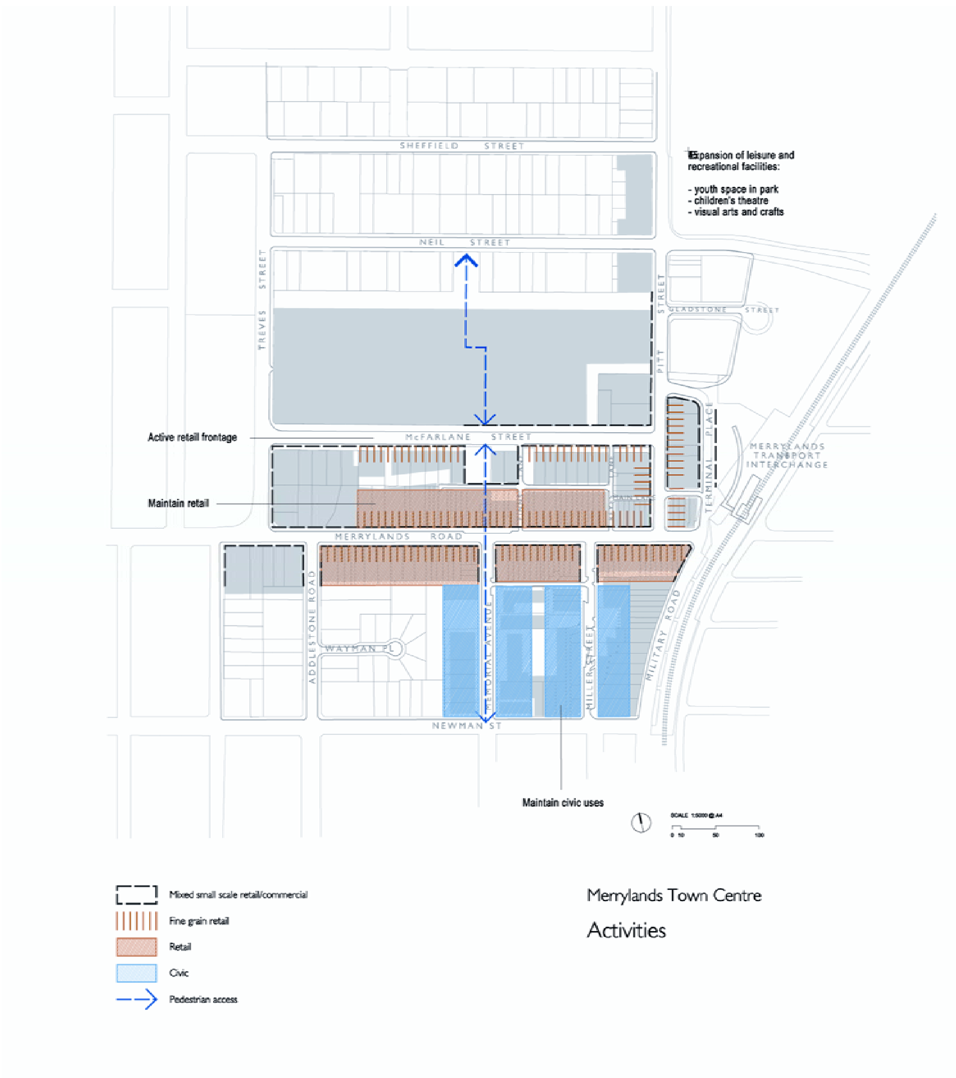

Figure 10 – Merrylands Town Centre Precinct-Activities

It was apparent from the beginning that the fine-grained subdivision pattern of Merrylands Road and the eastern end of McFarlane Street would be a major determining factor in the development of appropriate planning controls. The background studies undertaken for the MCURP identified the need to maintain and enhance the activated street front and retail edge. by facilitating retail development at grade. Clearly, this recommendation would not be consistent with a requirement to design all new buildings above a designated flood planning level, as a multiple series of steps and ramps would hinder an accessible retail strip.

Taking into account the social and economic factors associated with redevelopment of the town centre, instead of requiring all new buildings to be constructed above the flood planning level, the development controls incorporated into the draft LEP and draft DCP acknowledge the potential for inundation and requires flood proofing of buildings through the use of flood compatible materials.

Figure 11 – Artist impression of the Merrylands town Centre (in vicinity of proposed town square)

Conclusion

The Merrylands Centre Urban Revitalisation Project has resulted in the preparation of two place-based Development Control Plans for two distinct precincts in the Merrylands Centre. Each precinct is affected by flooding and the development controls prepared differ for each precinct. Within the Neil street precinct, redevelopment requires a new road north south through the precinct to facilitate not only a better subdivision pattern and traffic circulation, but to incorporate additional trunk drainage and overland flow path through the precinct. The proposed new road includes a drainage swale, with a total width of 40m. Within the Merrylands Town Centre Precinct, studies have identified the importance of the need to maintain and enhance the activated street front and retail edge. This is especially important with the proposed expansion of the shopping mall that will provide further competition to the traditional retail shopping strip. As a consequence, the planning controls permit redevelopment at grade with the use of flood compatible materials.

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SUSTAINABLE DEVELOPMENT ON A HIGH HAZARD FLOODPLAIN: SOUTH LISMORE

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1. INTRODUCTION

Central and South Lismore are protected by 1 in 10 yr levees. Large floods can overtop these levees creating overland flow conditions with a high hazard. In Central Lismore, during a 1% flood, V x D can range from 0.9 to 3m^2/s and in South Lismore it can range from 1.3 to 5.6 m^2/s *(PBP, 2001)*.

Council and the SES have developed a flood evacuation plan which aims to remove all persons from the floodplain during the early rising stages of a flood. The levee scheme facilitates the evacuation of Central Lismore by almost doubling the time before evacuation routes are cut *(PBP, 2001)*. South Lismore, however, becomes totally isolated by major floods and the levee scheme does not delay the cutting of evacuation routes from South Lismore. Hence there is the potential for people to be isolated in South Lismore and subjected to hazardous flow conditions.

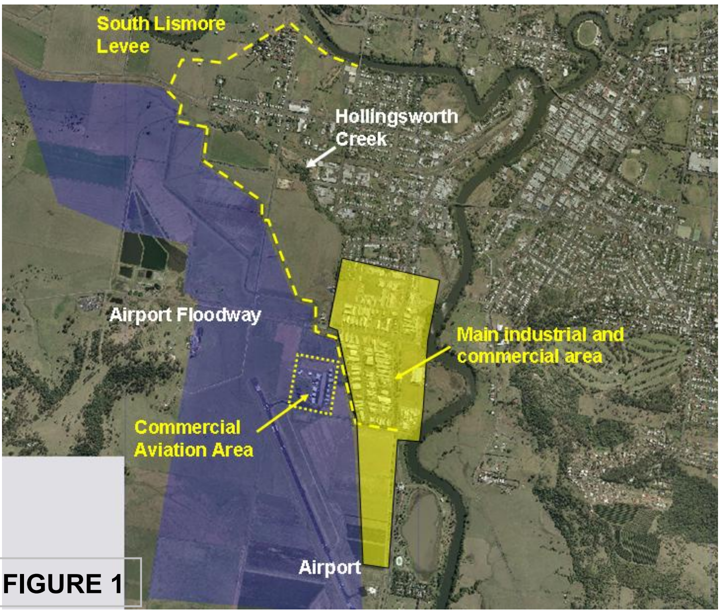

FIGURE 1

Lismore City Council has responded to these potential hazards by reviewing its Flood Policy and preparing a new development control plan *(DCP 7)* for flood prone lands *(LCC, 2003 draft)*. The thrust of these revised controls is to discourage new residential development in South Lismore and promote industrial and commercial development which is better equipped to address the flood hazards and financial risks associated with development in high hazard areas. Industrial and commercial buildings are more structurally sound and business risk can be offset through insurance. This has encouraged the continuing development of South Lismore as an important regional industrial and commercial centre.

The layout of levees, Airport floodway and industrial and commercial areas are shown in **Figure 1**.

2. HYDRAULIC SETTING

Figs 2, 3 and 4 show peak water depth, peak velocity and peak hazard *(V x D)* in South Lismore for the 1% flood. Portion of the western edge of the levee has a crest level above the 1% flood but the majority of the levee affords protection only at the 10% flood.

2.1 FLOOD DEPTHS

Water depths range from 0.5-1.6m north of the railway to around 2.3m near Hollingsworth Creek, during a 1% flood. South of Hollingsworth Creek water depths range from 1.5 to 2.5m.

FIGURE 2

2.2 FLOOD VELOCITIES

During a 1% flood, velocities range from 0.4 to 1.0m/sec north of the railway line. Close to Hollingsworth Creek, velocities get up to 1.2m/sec. Where floodwaters are forced to flow through culverts in the railway embankment, velocities can get up to 1.5m/sec. Throughout the southern portion of South Lismore, velocities are generally 0.5 to 0.7m/sec. Outside of the levee, along the Airport floodway which runs against the western edge of the levee, velocities range from 2m/sec through the narrowest section opposite the centre of South Lismore, to 1m/sec through the airport and surrounding commercial aviation precinct. Close to the Wilson River velocities on the floodplain can get up to 2m/sec.

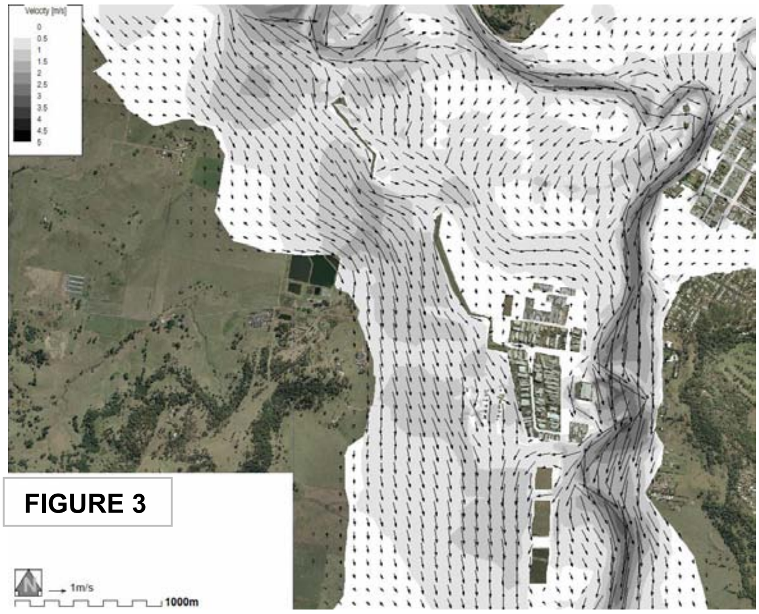

FIGURE 3

2.3 FLOOD HAZARD (V X D)

FIGURE 4

Flood hazards *(V x D)* in a 1% flood are predominantly less than 1.0m^2/s north of the railway line and 0.8 to 1.5m^2/sec immediately south of the railway line. In the vicinity of Hollingsworth Creek hazards range from 1.5 to 3.0m^2/sec and can get over 5.0m^2/sec close to the creek. South of Hollingsworth Creek, hazard is generally 0.3 to 1.0m^2/s except where flows are channelised down streets or between blocks of industrial building where they can get up to 2.5m^2/sec. Flood hazard in the airport floodway ranges from 1.0 to 2.0m^2/sec.

3. IMPACT OF DEVELOPMENT

The foregoing hydraulic setting demonstrates that a 1% flood can flow across South Lismore with significant velocity and depth. Any development of the floodplain which acts to block the free flow of floodwater will cause a change in velocity patterns as the floodwater is forced to flow around the development. A change in velocity pattern usually requires increased local hydraulic energy which is manifest as an increase in the local, upstream flood level.

As development becomes denser, the movement of floodwaters becomes progressively more confined to the narrowing gaps between buildings and the urban streetscape. Druery, McConnell, Druery and Low *(2001)* showed that if the flood flow is restricted entirely to urban streets, velocities can increase threefold as compared to those associated with the natural, undeveloped floodplain. A Study of Ironbark Creek, Newcastle *(PBP 2000)* has shown that commercial and industrial development in the Wallsend central business district has forced overbank flow down the urban streetscape. The collective impact is that flood levels are forced to build up against shops by an additional 0.4m. This additional head drives high velocities *(over 2m/sec)* along the streets as the floodwaters are forced to find a flow route through the streetscape.

The potential of buildings to increase velocities down streets has implications to potential flood damages and the risk to life, particularly in relation to evacuation planning and duration of flows considered safe for wading. This is particularly relevant to the expansion of industrial and commercial development which is occurring south of Hollingsworth Creek as well as the commercial aviation area just outside of the South Lismore levee. Hence, the cumulative impact of each development in South Lismore needs to be considered in the context of all existing development and previous approvals so that there is no net increase in flood hazards throughout South Lismore.

4. USE OF FINE SCALE HYDRAULIC MODEL

To facilitate sustainable development, Council developed a fine scale 2D hydrodynamic model of the Lismore floodplain *(PBP, 2000)*. The model is based on the finite element technique which uses a variable grid. The grid can be modified arbitrarily to simulate the exact plan shape of any proposed modification to the floodplain ie. building and/or earthworks *(fill and/or evacuation)*.

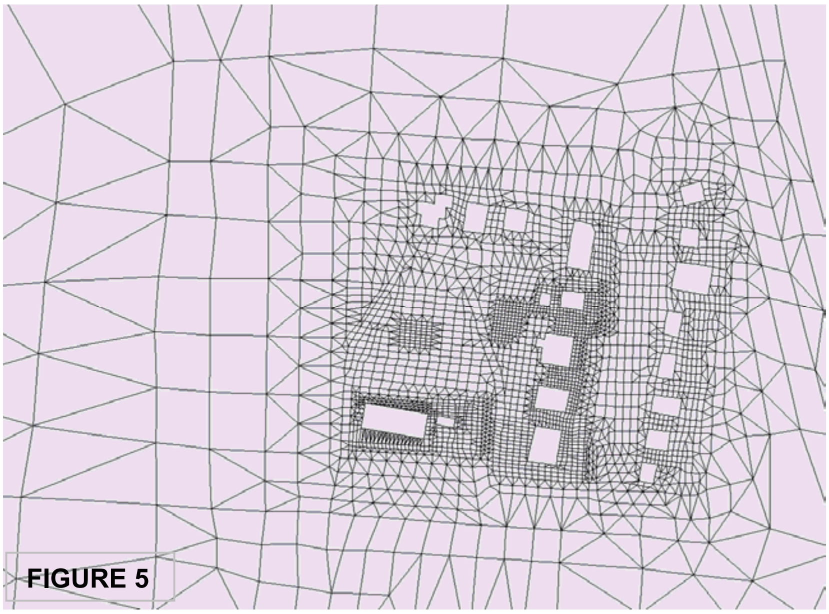

FIGURE 5

Fig 5 is an example of how the model grid can be easily varied to simulate the impact of a proposed building on velocity patterns and flood levels.

In considering the application of DCP 7, Council requires any development proposal, involving modification of the floodplain, to be simulated in the model and the detailed design of the proposal optimised until Council is satisfied that the proposed development would not escalate flood hazards. Each approved development is retained in the model so that subsequent development proposals are considered in the context of the existing and approved development. This ensures that there is no cumulative impact on flood hazards and that ongoing development is truly sustainable.

5. DEVELOPMENT GUIDELINES FOR A HIGH HAZARD FLOODPLAIN

Over the last 4 years, Council has approved a number of significant industrial and commercial developments in South Lismore. The simulation of each development proposal in the fine scale 2D model has led to design refinements. Considered collectively, these refinements provide a set of development guidelines that can be employed to avoid or minimise cumulative impacts on flood hazards.

5.1 FLOW ORIENTATION – SINGLE BUILDING ALIGNMENT

The impact of large buildings on velocity patterns and upstream flood levels can be minimised by aligning the long axis of the building parallel to the velocity vectors. This presents the smallest wall area to the flowing water. As self evident as this may be, it is only possible if the flood velocity field is well known from experience or it is defined in detail by a fine scale 2D model. Simulations in South Lismore have shown that the difference in upstream flood levels associated with building pads of approx size 200m by 100m can be as much as 0.2m if the building orientation is not optimised.

5.2 FLOW ORIENTATION – MULTIPLE BUILDING ALIGNMENT

As a corollary to 5.1, it follows that in an area of established buildings, any additional building should be situated, as much as possible, in the current shadow of the upstream buildings. This helps to reduce changes in the flood velocity patterns and the build up of floodwater against the building.

5.3 HYDRAULIC TRANPARENCY

Buildings will offer little obstruction to the movement of floodwater if the flow is able to pass under the buildings. This requires a suspended floor slab with the ground level devoted to short term parking. There is little opportunity for this in the industrial and commercial area south of Hollingsworth Creek because Council requires site filling to the 1% flood level. Hydraulic transparency is a real possibility in other sites and is included here for completeness.

5.4 ONSITE FLOOD FLOW PATH

Once a proposed building alignment/shape has been optimised as above, any residual flood impact *(ie. elevated water level and/or velocities)* can be reduced further by excavating a flow path through the site in the direction of the main velocity vectors. The flow path can be incorporated into the development as a low level carpark, grass swale or other open space landscape/site drainage feature. The creation of the flow path increases the flood discharge carrying capacity of the site so as to compensate for the residual blockage created by the building.

The dimensions of the flow path will depend upon the size and relative flood impact of the building. Assessments in respect of some development options in the South Lismore industrial area have indicated a compensating flow path up to 50m wide and 1m below grade *(ie. 1% flood level)*.

5.5 OFFSITE COMPENSATARY FLOOD FLOW PATH

Where large tracts of land are proposed for development, the economy of scale makes it more efficient to increase the discharge capacity of established floodways.

A floodway can be enlarged by excavation to accept the additional flow displaced by the proposed development without any increase in flood levels or modification of velocity patterns throughout the existing development surrounding the proposal. This can be achieved with a cut and fill strategy between the floodway and the development site. The layout of the buildings and infrastructure within the proposed development should be optimised along the lines of the guidelines set out in this paper.

5.6 VELOCITY DEFLECTION

High approach velocities can be deflected away from a proposed development by an appropriately shaped upstream embankment. The embankment causes velocities to concentrate against the upstream side and there is an increased velocity where the redirected velocities are shed from the embankment. A deflection levee or embankment is only possible if there is an area of adjacent land, such as a floodway, which is available to accept locally increased velocities. In South Lismore, a deflecting levee was simulated in the Airport Floodway within the commercial aviation area. It was found that an embankment, 86m long and built as a landscape feature approximately 1.6m in height was sufficient to deflect approaching flow 1.9m deep with a velocity of 1m/sec.

5.7 PRESERVATION OF SITE CROSSFLOW

In areas where the flood velocities run obliquely across a development site, it can become important to preserve both the longitudinal and transverse components of the flood flow. This is a variation on 5.4 where the onsite flood flow paths may need to run transverse to the direction of the main velocity vectors as well as parallel to it. In South Lismore this was found to be the case only where the proposed development was located in an area of strong oblique velocities up to 1.5m/sec.

5.8 IMPROVE LOCAL FLOW PATHS

Where the natural velocity vectors are directed onto a potential development site by the natural topography of the land, it may be possible to change the velocity field and the potential flood impact of the development by modifying the natural topography. In effect this is the same principle as 5.6 where a natural feature which is deflecting velocities onto a property can be reshaped to reduce the velocities on that property. The potential benefits of such reshaping can only be appreciated and demonstrated by the use of a fine scale 2D model. In South Lismore, it was found that the velocity across a proposed building site could be reduced from 1.5m/sec to 0.8m/sec by shaving 1m from the top of a natural riverbank levee which was causing a divergence of overtopping flow. The model simulations showed that by making the flow over the natural levee more uniform, not only would velocities on the downstream site be significantly reduced but there would be a benefit of slightly reduced flood levels upstream.

5.9 CUT AND FILL POLICY

To prevent any net reduction of the flood discharge capacity of the South Lismore floodplain, Council requires that any site filling be obtained by excavation from the site *(or approved nearby site)* or by excavation from an approved excavation area. The approved excavation area is located on the Airport Floodway. This policy aims to compensate any loss of flow area, in the development areas, with an increased flow capacity of the Floodway.

6. CONCLUSION

The availability of a fine scale 2D model of the Lismore floodplain, which is capable of simulating the detailed hydraulic impact of individual development options, has provided Council with a level of flood impact assessment was has hitherto not been available apart from the use of very expensive and very cumbersome *(time wise)* physical models. This has allowed Council to manage the growth of industrial and commercial development on the high hazard floodplain of South Lismore in a timely and strategic context which ensures that there is no cumulative impact on flood hazards.

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Hydroinformatics Support to Flood Forecasting and Flood Management

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Keywords
Hydroinformatics; flood management, flood forecasting, unsteady flow modelling; flood simulation modelling; flow resistance; data mining; Open MI; open source; proprietary software.

Abstract
This keynote lecture describes state-of-the-art hydroinformatics support to the water sector. A few examples are worked out in some detail, whereas for other examples the reader is guided to recent literature. The focus is on flood forecasting and flood management, with a brief description of the potential of changing technologies to support studies and facilities in this area. Examples are: new data collection methods; data mining from these extensive new sources of information, e.g. the use of genetic programming; data driven modelling techniques, e.g. artificial neural networks; decision support systems; and the provision of a hydroinformatics platform for flood forecasting. Particular attention is given to advances in numerical flood modelling. Over the past years the robustness of numerical models has increased substantially, solving for example, the flooding and drying problem of flood plains and the computation of supercritical flows. In addition, the emergence of hybrid 1D2D models is discussed with their different options of linking model components of flood prone areas.

INTRODUCTION

Hydroinformatics covers the application of information technology as a service to the water sector in the widest sense. The continuously increasing speed of computers and increased density of information storage, the increased communication potential through internet and the creative power of scientists have brought us rapidly forward in the way in which water related studies can be executed, currently based upon a much better understanding of underlying processes and descriptive means than some decades ago. For a better awareness of what is being opened up with these developments it is recommended to participate in the two-yearly Hydroinformatics Conferences (e.g. Nice, 2006; www.hic06.org). This paper also gives a number of references to contributions published in the proceedings of the Hydroinformatics Conference Singapore, 2004. Another recent source of information is a number of contributions related to hydroinformatics, published in the Encyclopaedia of Hydrological Sciences, e.g. Werner et al. (2005), Minns and Hall (2005), Stelling and Verwey (2005) etc. In the next paragraph we will give an outline of various interesting developments and treat in subsequent paragraphs, on a selective basis and in more detail, some more specific issues in relation to flood forecasting and flood management.

HYDROINFORMATICS TOOLS

The focus on hydroinformatics emerged from the field of computational hydraulics, when it was understood and felt desirable that around the modelling systems developed in the last three decades of the last century, a complete infrastructure of informatics support existed and that its potential had to be explored and expanded to improve service to society. It comprises data acquisition and data management techniques; new simulation techniques based upon cognitive sciences and pattern recognition, such as artificial neural networks; data mining and knowledge discovery techniques; evolutionary algorithms; decision support and management systems; forecasting and data assimilation methods; fuzzy logic; cellular automata; integration of systems and technologies; and emerging internet based technologies. A state-of-the-art description of new technologies applied in the area of ecohydraulics was given by Mynett (2004). Historically, balance equations or empirical relationships were developed by scientists, e.g. Newton, Navier, Poisson, de Saint Venant, Stokes, Darcy, de Chézy, Strickler, Manning etc., by trying to define fundamental relationships between various system state variables on the basis of observations and by setting up balance principles, partly based upon the empirical relationships found. A thorough presentation of the role of various scientists is included in the work of Chanson (1999). Hydroinformatics can now be seen as providing an extension to these developments, partly by using the computer power to guide and process new and massive data collection techniques and partly by leaving it to computational power to establish best fitting new relationships, often in areas which could not be explored before. The change that hydroinformatics really brings us, is a change in the role of scientists, from those who establish laws to those who guide the establishment of laws and relationships by mobilizing computer power.

A good example is the use of artificial neural networks (ANN), which can be seen as an extension of the traditional use of regression techniques, e.g. Minns and Hall (2005). However, whereas in regression techniques formulae have to be prescribed and parameters calibrated, ANN provides the additional flexibility that the relationships between state variables, or the formulae, are left open, in fact never defined, as all relationships established are based upon signals passed on through a sequence of (neural) cells with weightings established by the so-called learning process through numerous trials. Compared with the human mind, only one thing is missing: the ability to extrapolate the knowledge outside the range where the learning process took place and even many human beings have difficulties with such extrapolations. Although ANN's have opened up the way to new simulation techniques, the learning process shows clearly their limitation, for example in rainfall-runoff modelling, where physically based balance models, equipped with appropriate limiters, can be used more trustfully in extreme situations that go beyond earlier observations.

A step beyond ANN is the employment of sets of data to establish empirical relationships in the form of mathematical expressions by using evolutionary algorithms. Unlike ANN's, where the development process of knowledge in the human brains serves as an example for computer based knowledge development, evolutionary algorithms take the biological reproduction process as the blueprint for the derivation of mathematical relationships. By seeing state variables, operators and parameters as components of DNA strings, recombinations of sub strings, together with the process of mutation leads, in a learning process, to continuously better matching of mathematical relationships in a "survival of the fittest" process. A recent example that serves flood modelling is given by Baptist et al. (2005). For a number of years, Baptist (2005) has been working on the development of empirical relationships defining the resistance of flow, expressed as a de Chézy value as a function of flow depth and height and type of vegetation. For submerged vegetation, Baptist derived the relationship

$$C_r = \sqrt{\frac{1}{C_b^{-2} + \frac{C_D m D k}{2g}}} + \frac{(h-k)^{3/2} \frac{\sqrt{g}}{\kappa} \ln\left(\frac{h-k}{e z_0}\right)}{h^{3/2}} \qquad (1)$$

where C_r = depth dependent Chézy coefficient [$m^{1/2}$ s^{-1}], C_b = Chézy value for the bottom friction alone [$m^{1/2}$ s^{-1}]; C_D = drag coefficient for flow around the vegetation stems [-]; m = vegetation density [m^{-2}]; D = representative stem diameter [m]; g = acceleration due to gravity [m s^{-1}]; k = representative vegetation height [m]; κ = von Kármán's constant [-]; e = base of the natural logarithm [-] and z_0 = roughness height of the top of the vegetation [m]. The equation was checked on a set of 990 results obtained with a 1-DV (1-dimensional in the vertical) model based upon the Delft3D code, including a description of turbulence developed around the stems of vegetation.

Rodriguez Uthurburu (2004, and to be published further in Baptist et al., 2005) used the same set of data to train a genetic programming code and came up with the equation

$$C_r = \sqrt{\frac{2g}{C_D m D k}} + 2\sqrt{g}\,\ln\left(\frac{h}{k}\right) \qquad (2)$$

Figure (1) shows the scatter plots for both equations. Also based upon RMSE values for both sets: 1.30 for Equation (1) and 0.97 for Equation (2), respectively, it can be concluded that the data-driven discovery process has led to a better fitting equation than the equation derived on the basis of existing theoretical knowledge.

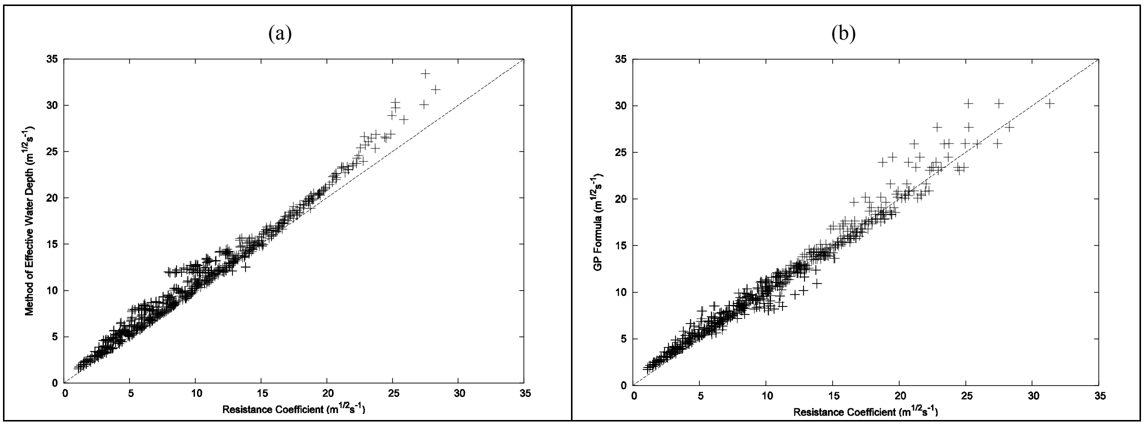

Figure 1 Scatter plots for the two equations compared with 1-DV data: (a) Method of effective water depth, Equation (1); (b) Original Genetic Programming formula, Equation (2).

In a next step, and further analyzing the descriptive nature of Equations (2) and (1), it was decided to impose the first term of the right hand side of Equation (1) and add in the data-mining process the von Kármán's constant κ to the set of parameters. Genetic programming than came up with the equation

$$C_r = \sqrt{\frac{1}{C_b^{-2} + \frac{C_D m D k}{2g}}} + \frac{\sqrt{g}}{\kappa} \ln\left(\frac{h}{k}\right) \quad (3)$$

which had an RMSE value of 1.21, between those for Equations (1) and (2), but believed to have a wider range of applicability than Equation (2). Results were also tested against 177 experimental runs based on laboratory flume experiments from 10 independent sources. In this case the RMSE values are higher, as can be expected. However, still good enough to confirm the usefulness of the data-driven equation development.

Above experiments show that computer-based technologies provide us with better means of exploring relationships in nature, either based upon large sets of measured data or upon data generated with very fine grid numerical simulations based upon existing theories. The experiment also shows that the application of these technologies merely provides an extension of our scientific minds and certainly not a replacement. With the current floods of data collected with remote sensing, for example, there must be many ways in which data-mining will assist us in deriving relationships in such complex areas as environmental process description, ecology and unsaturated ground-water zone analysis.

OPEN SOURCE VERSUS PROPRIETARY SOFTWARE

Dealing with hydroinformatics, a continuous discussion point is the question of open source against proprietary software, which is generally provided in the form of compiled executables. This form also implies that the software codes cannot be modified by staff other than that of the software vendors. Discussions on open source come down to the question of how water resources agencies are best served and how providers of hydroinformatics services are stimulated to provide the best tools. The point of view of the agency is extensively described by Khatibi et al. (2004) with inputs from hydroinformatics tool providers. A number of aspects will be presented briefly here. For water resources agencies, interested only in the use of software, the following aspects are of interest:

1. economic overall solutions for their hydroinformatics infrastructure, e.g. the overall costs for the development of a flood forecasting system, including the forecasting platform, costs for underlying software, costs for model development and calibration etc.;
2. reliability of the software products, through good development practices and maintenance of the codes, based upon extensive testing procedures;
3. openness of the software, enabling the coupling of various components;
4. reproducibility of results through good version management;
5. state-of-the-art scientific basis for the methods implemented in the software;
6. dissemination of knowledge;
7. quick response to development needs.

Most of these requirements also apply to vendors of hydroinformatics software, as it is in their interest to provide good service to clients and this in a competitive environment. Open source is definitely not in the interest of this group, unless special factors play, such as market penetration for other services (e.g. consultancy), name branding and free co-developments by third parties. This last interest sometimes leads to adopting the concept of “open source in closed community”, based upon co-development of codes by a limited group of participating organisations and the right for one or more of these partners to distribute the code commercially.

It is not the place here to draw definite conclusions on what is best practice. With a common sense mind for advantages and disadvantages, the best solution can be found for each case. However, regarding point (3) the difference between open and closed source will be reduced in the near future. Water management agencies, in general, have a strong interest in openness of software, so that various components can be linked without the need to contract the original developers of such software components. This service is now being developed through the European OpenMI concept, which facilitates coupling both of open source and proprietary software components.

OPEN MI

Dealing with water authorities, different consultants and own staff are implementing continuously bits and pieces of software and often there is neither a contractual obligation nor the means to embed these new service tools into a consistent hydroinformatics infrastructure for the organisation. For this reason, the concept of OpenMI (Open Modelling Interface) was developed through the European HarmonIT project, initiated by the Ministry of Transport, Public Works and Water Management in The Netherlands as an important stakeholder. OpenMI has been designed as a generic set of communication rules for linking all kinds of software components available to the water sector. For example, OpenMI facilitates the transfer of data in a generic way and at any moment in time, from one model, e.g. a rainfall-runoff model, to another model, such as a hydrodynamic model, vice versa. More in general, OpenMI facilitates the flexible linking of a wide variety of simulation models, generic modelling systems, databases, GIS, decision support systems, web based services etc. (Gijsbers, 2004).

OpenMI is primarily a set of rules on how to exchange data in a pre-defined way. Ideally, within an organisation, all software tools should be linkable through a common platform. With the current trend of developing integrated models of hydraulic, hydrologic and environmental systems, the development of such platforms becomes even more desirable. Currently, the definition stage of the OpenMI standard has been completed (http://www.harmonit.org) and it is expected that this initiative will lead to a European standard on data exchange. In addition, the HarmonIT project is finalizing a utility library, which is available as public domain software on http://www.OpenMI.org. This library will facilitate application builders with the responsibility of connecting various software codes via OpenMI standards. The various organisations in the HarmonIT project are also composing additional tool sets, such as event loggers and data visualizers, which will remain their own proprietary software.

In order to improve the integration of software systems, various groups have to contribute. Fortune (2004) identifies the following OpenMI user groups: non-specialist end user, specialist end user, model integrator, model builder, model coder, application builder and tool coder. In particular, it is important that the demand for better communication between hydroinformatics components is enforced in contracts. As an example, recently the Bundesanstalt für Wasserbau (BAW) in Germany demanded OpenMI compliance for the delivery of the generic Delft3D modelling system of WL | Delft Hydraulics. There is a clear trend now that the principal participants in the HarmonIT project, such as DHI, Wallingford Software and WL | Delft Hydraulics are opening up their standard software packages with OpenMI communication links. In principle, all existing modelling systems can be made OpenMI compliant. Fast connections can only be made if the source code is available. The adaptation is relatively easy if the code has been programmed in an object oriented way. Executables can be made OpenMI compliant by encapsulating them within a wrapper, a communication layer which transfers data that are accessible through the standard input- and output routines of the code. This, however, may lead to slower communication links.

The advantages of OpenMI were recently explored by Solomon (2005) for the application of ensemble Kalman filtering to reduce uncertainties in the outputs of a rainfall-runoff model. For the ensemble Kalman filtering, the EnKF code developed by WL | Delft Hydraulics was used. For the rainfall-runoff model, use was made of the five parameter, five state variable modelling system HYMOD on an existing model of the 1944 km^2 catchment of the Leaf River Watershed, Mississippi, USA (Vrugt et al., 2003). A comparison was made of connecting both software components via batch files and via OpenMI calls, respectively. Objectives of this exercise were the comparison of results obtained with both methods and the analysis of execution speed differences. It was found that both methods of coupling gave nearly the same results, whereas the OpenMI coupling proved to be 40 % faster than a batch file connection, for a simulation with updates of state variables based upon 30 ensembles (see Figure 2).

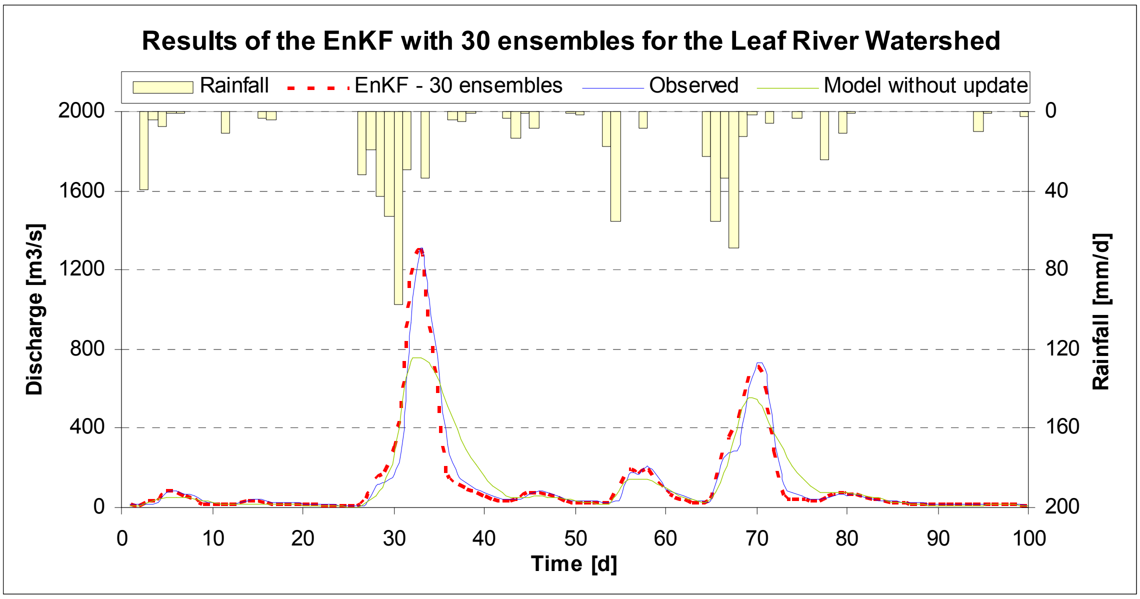

Figure 2 Observed, modelled and updated discharges for the OpenMI connection between EnKF and HYMOD

No effort was made to test the speed of a direct implementation of the ensemble Kalman filtering code inside HYMOD. This would go against the trend of designing modelling systems in a modular way by developing different functionalities in separate executables. However, other experiments with OpenMI have revealed that the speed difference between simulation with a fully integrated code and with separate codes in a modular design with exchange of data based upon OpenMI data exchange is not very significant.

FLOOD FORECASTING PLATFORM

Quoting Fortune (2004): *Perhaps the most advanced approach to flexible model integration is taken for flood forecasting applications*. This is, indeed, the area where the need of coupling of components of a hydroinformatics systems is most pronounced. As shown in the sequel, flood forecasting requires many operations between a wide variety of components to be orchestred in a short time. This leads to the explicit need to create a generic flood forecasting platform, where existing components can be connected and new components be added in a flexible manner. With this objective, the Delft-FEWS (Flood Early Warning System) was developed and implemented in various places in the world.

The Delft-FEWS system takes care of executing the following tasks:

1. import of external sources of data, such as meteorological forecasts, including those based upon numerical weather models, radar data, rainfall, discharge and water level time series from telemetric systems and data from external databases;
2. validation and interpolation of incoming data, using extensive data validation options with gap filling and hierarchy rules to allow alternative data sources to be used as a fallback for ensuring continuity in the forecasting process;
3. data transformation in order to prepare the required inputs for reporting and for the forecasting models, such as weighting of precipitation from distributed point sources, from radar and from numerical weather models, as input to rainfall-runoff modelling;
4. execution of the hydrologic and hydraulic forecasting models. These models may be provided by various suppliers and cover a wide range of methods, from simple regression analysis, lumped hydrological models, spatially distributed hydrological models, artificial neural networks, hydrological routing models to 1D and integrated 1D-2D hydrodynamic models;
5. updating the state of the models through a feedback mechanism to minimize the gap between observed and forecasted data. Delft-FEWS provides some of the possible data assimilation models, such as the ARMA error correction method and ensemble Kalman filtering. Delft-FEWS also facilitates the implementation of other updating techniques;
6. visualisation of results on maps, which can be imported from various sources, such as GIS, aerial photo's etc., including geographic navigation on these maps;

7. dissemination of forecasts through maps and HTML formatted reports, allowing easy communication to relevant authorities and public through intranet and internet.

An example of the typical requirements of a forecasting agency is described by Werner et al. (2004). In 2002, the Environment Agency in the UK commissioned to WL | Delft Hydraulics and Tessella Scientific the development of the National Flood Forecasting System (NFFS) as flood forecasting platform for the complete area of England and Wales. A requirement given was the openness of the system to allow the continued use of various calibrated models which were already operational in flood forecasting systems for a number of river catchments in the area. So far, these comprised the rainfall-runoff models based upon PDM, MRCM, TCM and NAM, the hydrologic routing models based upon DODO and KW and the hydrodynamic modelling systems ISIS and Mike11. Currently, Delft-FEWS also has links to the rainfall-runoff software HBV, Sacramento, PRMS and VFlo and the hydrodynamic modelling system SOBEK.

NFFS replaces, among others, the earlier FFS2 system developed for the UK Midlands region (Dobson and Davies, 1990). It comprises the MCRM lumped conceptional rainfall-runoff model and the DODO two layer Muskingum routing model, both equipped with updating techniques. These models had to be retained, as they have been extensively calibrated over the past years. The existing telemetry system was equipped with 124 meteorological gauges, 147 hydrological gauges and 272 forecasting points that may or may not coincide with gauge locations. The whole system represents a substantial asset value, of which many components are of great value in the newly installed Delft-FEWS. Once the new system is operational, component models can be replaced by better options if and when these will be acquired.

An immediate advantage of the new system is that forecast lead times increase through the link to more advanced weather forecasting, which is part of the overall platform. A longer term advantage is that gradually the hydrologic and hydraulic models can be replaced by state of the art products, without being bound to one single manufacturer. Similarly, with the overall platform in place, the Environment Agency can gradually increase the number of catchments where forecasting is provided.

EXAMPLE OF FLOOD MANAGEMENT DECISION SUPPORT SYSTEM

Decision support systems aim at facilitating the societal, political and managerial decision making processes with sound engineering knowledge. An interesting example is the Planning Kit, developed for supporting the decision making process of improved flood management along the Rhine branches in The Netherlands (de Vriend and Dijkman, 2003). Due to climatic and land use changes and the increased awareness of their effects, triggered by the 1993 and 1995 flood situation along the Rhine, the design discharge for the Rhine Branches has been increased by about 7 %. At the same time, a policy change was accepted by Parliament to no longer rely on heightening dikes. The new policy is to provide “room for the river”, with dike heightening only as a last resort. As a result, various measures have to be taken to achieve safety against flooding for these new criteria. In a recent study Room for

Rivers, many alternatives for flood protection were presented as an alternative to the earlier solutions of a continued raising of dike levels. Examples of such measures are presented in Figure (3).

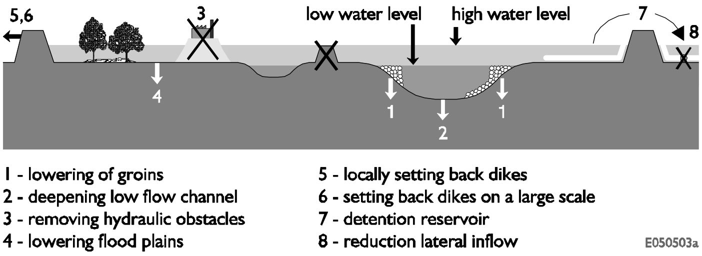

Figure 3 Flood control measures in the river bed [from Silva et al., 2000]

Many of these measures can be taken to enrich simultaneously the ecological state of the flood plain. Most of these measures, however, also have a negative impact on the population living along the rivers. This leads to a complex decision making process with many actors and stakeholders, both public and private. After an extensive investigation of possible measures, including the creative inputs provided by stakeholders and local authorities, a set of some 700 potential measures along the Lower Rhine branches emerged. The objective of the Planning Kit has been the visualisation of the effects of these measures to facilitate the participation and planning process. As a first step, these measures were implemented in a GIS environment.

Limiting ourselves here to the flood level aspects, GIS was used to compute the changes in flood conveyance. These changes were introduced in a 2D depth averaged hydrodynamic model of the entire Lower Rhine system. Subsequently, sub models were run to study the impacts of local measures on the surrounding flood levels. These impacts were stored in a database as water level changes along the river, compared to the reference situation. During public hearings and meetings with local authorities, the measures could be discussed on the basis of the presentations in GIS, combined with other database information, such as photos, visualisation of the area with and without the measures and the scores of individual measures on more than 50 criteria (costs, ecological effects, etc.). The use of the database enabled the instantaneous visualisation of the superimposed effect of any selected combination of measures on the maximum flood levels along the river. This selection could be made just by clicking on the map, in the list of measures or on a graph. Such effects could not be produced during the actual meetings by using real models. This would simply take far too much time. With the Planning Kit, a preferred set of actions could be defined by the public and decision makers who cannot be expected to have an in-depth knowledge of river hydraulics.

The question arises whether the superposition principle of measures is justified, as the hydrodynamic process is non-linear. Such justification is based upon the evaluation of measures in a relatively narrow range of water level variations around the design flood level. In addition it can be stated that rating curves, though by definition non-linear, show up as monotonically rising and rather smooth functions at these levels.

Obviously, after reaching agreement on a set of measures using the Planning Kit, a 2D calculation with all measures implemented is realised to check the combined water level effect. Figure (4) appears to justify the use of the Planning Kit, by showing that a combination of 40 measures along the Rhine branch Waal provides water level effects which differ not more than 10 cm from those obtained with a full 2D hydrodynamic model.

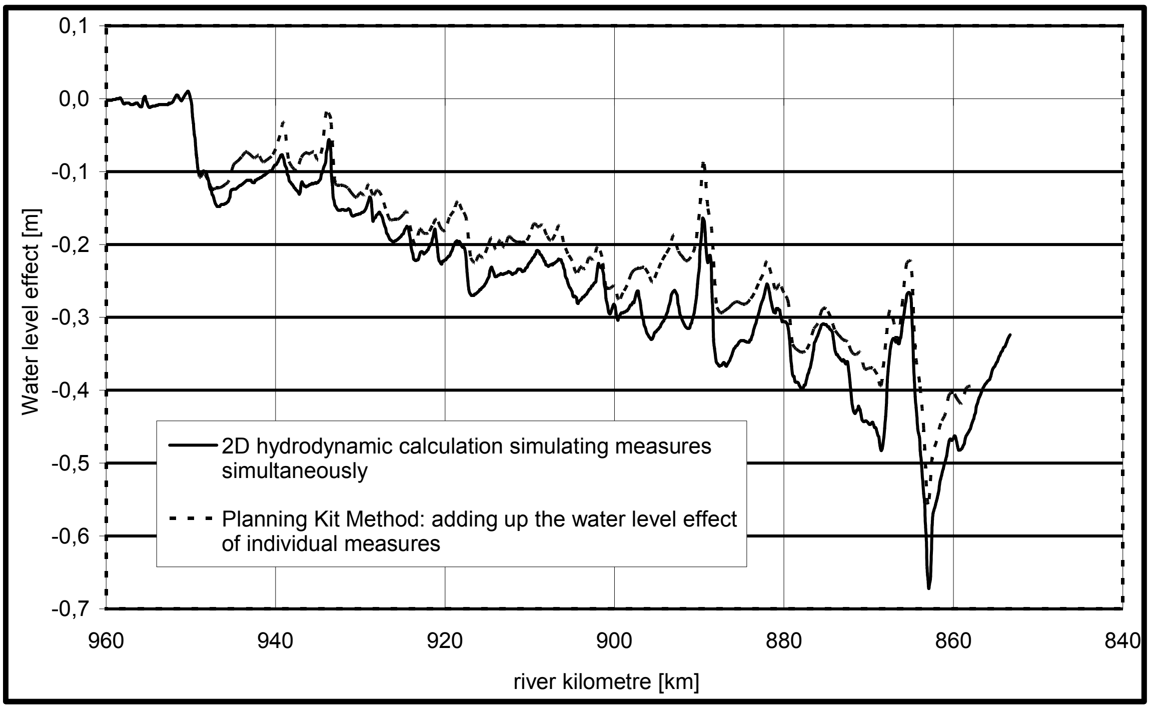

Figure 4 Water level effect of 40 measures along the Rhine Branch Waal under design flood conditions as calculated with a 2D model simulating all measures (solid line) and as a result of the Planning Kit method, in which results for individual measures are simply added up. The reference level is formed by existing dike heights.

All in all, the strength of the Planning Kit is that all stakeholders have rapid access to a common and uniform set of information on all potential measures. This provides clarity and avoids confusion, while it serves as a rapid learning tool to decision makers.

NUMERICAL FLOOD MODELS

Hydroinformatics platforms, such as a flood forecasting system and a decision support system, need models to provide relevant information on state variables and state indicators. In this contribution we will limit ourselves to numerical models based on finite difference formulations of the hydrodynamic balance equations. Progress is based upon a number of advances in the following areas: data collection (DGPS, LIDAR, multibeam echo sounding, remote sensing, radar etc.); data processing and storage (GIS and hydrological databases); and numerical speed and robustness (Stelling and Verwey, 2005). Advances in all these areas lead to more refined numerical models, higher accuracy, shorter construction times and faster model execution.

Focussing on the use of hydrodynamic flood simulation models, there is a gradual shift from the use of 1D to 2D depth averaged models and further to the integration of these two types of schematisation. Both 1D and 2D models have advantages and disadvantages, as follows:

1. in terms of model construction time, the construction of 2D models is generally faster when reliable digital elevation models are available and use can be made of land use maps to support roughness parameter estimation;
2. 1D models, on the other hand, are faster in simulation, which is of particular advantage in flood forecasting;
3. the accuracy of 1D models can be higher than that of 2D models for flow in the main river, including the flow between river embankments;
4. 2D models are usually more accurate and cheaper in construction when flow in flood plains has to be modelled;
5. 1D modelling software is generally available at lower cost than 2D modelling software, as there is more choice in the market.

The third point, in particular, requires further comments. Limiting ourselves to finite difference methods, detailed modelling of the main river bed requires at least 10 2D grid cells over the width of this bed in order to model the flow in the usually meandering channel with sufficient accuracy. For long river stretches, this usually leads to an excessive number of 2D grid cells. Although, at first sight, the 1D schematisation of a meandering river is complex, it is relatively easy to compensate for the effects of short cuts over the flood plain in the integration of the flow conveyance parameters along the 1D cross-sections. On the other hand, when large flood plain areas are to be included in the model, a 1D model schematisation becomes quite inaccurate. For a number of decades the 1D flood plain cell technique has been used. Although this technique allows for a correct schematisation of storage, it is difficult to estimate reliable conveyance parameters as the flow directions may vary significantly during the passage of a flood wave. In this case a 2D schematization is superior (statement 4), especially with the possibility to implement depth-dependent roughness descriptions based on vegetation classes.

As both 1D and 2D schematizations have particular advantages and disadvantages, an integration of both types of schematisations will be attractive. There are, indeed, numerous practical examples where flows are best described by an integration of 1D and 2D schematizations. An obvious example is the flooding of deltaic areas, often characterized by a flat topography with complex networks of natural levees, polder dikes, drainage channels, elevated roads and railways and a large variety of hydraulic structures. Flow over the terrain is best described by the 2D equations, whereas channel flow and the role of hydraulic structures are satisfactorily described in 1D. Flow over higher elevated line elements, such as roads and embankments can be modelled in 2D reasonably well by raising the bottom of computational cells to embankment level. To increase the accuracy, however, adapted numerical formulations have to be applied, such as the energy conservation principle upstream of overtopped embankments. For the hybrid 1D, 2D schematization, basically there are two approaches: one with interfaces defined between 1D and 2D along vertical planes and the other approach with schematization interfaces in almost horizontal planes.

Coupling along vertical planes, gives a full separation in the horizontal space of the 1D and 2D modelled domains. In the 1D domain the flow is modelled with the de Saint Venant equations applied over the full water depth. The direction of flow in the

1D domain is assumed to follow the channel x-axis and in the model it carries its momentum in this direction, also above bank level. Without special provisions, there is no momentum transfer accounting applied between the 1D and 2D domains. Momentum and volume entering or leaving the 2D domain at these interfaces, are generated by the compatibility condition applied. As a result, the coupling cannot be expected to be momentum conservative. Depending on the numerical solution applied, the linkage may either be on water level or on discharge compatibility.

In a model coupled along an almost horizontal plane, 2D grid cells are placed above the 1D domain. In this schematization, the de Saint Venant equations are applied only up to bank level. Above this level, the flow description in the 2D cell takes over. For relatively small channel widths compared to the 2D cell size, errors in neglecting the effect of momentum transfer at the interface are minor. For wider channels it is recommended to modify each 2D cell depth used in the momentum equation by adding a layer defined by the local hydraulic radius for that part of the 1D cross-section which underlies a 2D cell. Further refinements are possible, including terms describing the momentum transfer between the 1D and 2D domains. An advantage of this way of coupling domains is the easy extension of an existing 1D model to a fully integrated 1D2D schematization.

As an example, WL | Delft Hydraulics has developed its combined 1D2D package SOBEK for the modelling of integrated fresh water systems. The 1D and 2D parts are built upon robust implicit numerical techniques, avoiding problems with flooding and drying of channels and terrains through time step controllers and a variety of other limiters. The 1D and 2D domains are coupled implicitly via water level compatibility conditions at intersections of 1D and 2D grid cells. The system of equations is solved at each iteration and each time step with a combination of a minimum connection search direct solver and a conjugate gradient technique. With these direct solvers the traditional differences between looped and tree-like channel networks (e.g. Cunge et al., 1980) become totally irrelevant. Furthermore, the efficiency of conjugate gradient solvers has improved significantly over the past years.

CONCLUSIONS

Continuing development of the speed and the data storage capacity of computers have a large impact on the methods used to support studies in the water sector. In the first place, this potential leads to new measuring techniques providing us with large amounts of information (LIDAR, remote sensing, multibeam echo sounding, ADCP, radar technology etc.). The increased and more accurate sets of data also facilitate the construction and calibration of simulation models. In the second place, the large sets of data can be explored with new data-mining techniques to extract new knowledge from these massive sets of individual numbers or pixels, for example in the form of new empirical equations. This new knowledge, in turn, can either reinforce existing numerical models or provide an alternative to the balance equation based modelling methods, e.g. artificial neural networks. In the third place, there is a trend to use the increased computer power to achieve a better integration of hydroinformatics components, such as models for different physical subsystems, databases, GIS, telemetry etc. Especially water resources agencies feel the need to arrive at better integration of these various components. In this context, the Open MI standard developed recently through an EU initiative may prove to be very useful, facilitating the development of hydroinformatics platforms such as flood forecasting systems and decision support systems.

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A Review of Victorian Flood Warning Development Priorities – Looking into the Crystal Ball

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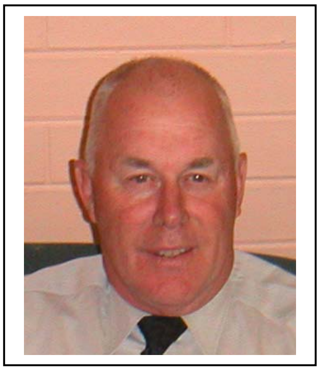

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A Review of Victorian Flood Warning Development Priorities – Looking into the Crystal Ball

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Abstract

During 1994, an assessment of flood warning service development needs across rural and metropolitan Victoria was completed by the Victorian Flood Warning Consultative Committee (VFWCC) and subsequently updated in 1997. The assessment was limited in that its focus was primarily on the technical elements of the flood warning system. A significant number of changes have occurred since 1994 including municipal and water industry restructure, the establishment of Catchment Management Authorities (CMAs) and the development of catchment and floodplain strategies. A large number of flood studies have also been completed. In the context of these changes, the increased knowledge of flooding issues and the time that had elapsed since the last assessment, the VFWCC recognised the need to reassess State-wide flood warning development priorities. Michael Cawood and Associates in conjunction with CT Management Group were engaged by the VFWCC in early 2004 to complete this review. The objectives of the review were to evaluate existing flood warning services, determine locations/catchments where there is a need for total flood warning system (TFWS) upgrades, identify the relative priority for TFWS upgrades based on a consideration of economic, social and related factors and to deliver a revised Flood Warning Service Development Plan. User input was a key determinant in identifying major issues, ensuring the accuracy of the review and maximising the potential for acceptance of review findings and recommendations. As a result, stakeholder organisations and key individuals were engaged with the study through a consultation program that involved a series of facilitated workshops, a questionnaire and one-on-one discussions. The priorities determined as a result of the project will provide the blueprint for future flood warning upgrade and development activities and in so doing facilitate the better management of identified flood risks. The new development plan will also provide a logical and consistent basis for actioning recommendations from flood and related studies calling for the development or upgrade of flood warning services in the context of State-wide priorities, broader floodplain management objectives and the status of existing TFWS elements within Victoria.

Key Words: emergency management, flood warning service priorities, community and agency engagement/consultation, total flood warning system, quantification, review

Introduction

Flooding costs Victoria at least $38.5 million on average a year in damages to property, buildings, infrastructure and agricultural production (Bureau of Transport Economics, 2001). The 1993 spring floods caused over $300 million in damages in north-east Victoria and Gippsland alone (Department of Natural Resources and Environment, 1998).

It is generally agreed that a reduction in flood impacts and associated losses can be achieved by the implementation of sound floodplain management practices that revolve around an appropriate mix of structural and non-structural flood mitigation measures. The aim of the risk based approach to floodplain management is to achieve a sustainable balance between the benefits of development and the consequences of flooding. This is achieved by trading off the economic, social and environmental costs and benefits of such development against the associated risk and adverse consequences attributable to flooding. The emphasis is now on modifying how the floodplain is used/developed rather than on modifying the floodplains so that they can be developed. This shift recognises that people's reaction to impending floods and associated warnings have a substantial effect on the losses that subsequently occur.

Flood forecasting and warning is recognised as a valuable element of any floodplain management strategy. The advantages of an effective and efficient flood warning service are well documented (Smith and Handmer, 1986; Mileti, 1975) as is their cost-effectiveness (Chatterton et al, 1979; Parker, 1981; Penning-

Rowsell, 1981). However, in order to realise these benefits, flood warning systems must consider not only the production of an accurate and timely forecast but also the efficient dissemination of this forecast to response agencies and the threatened community in a manner and in words that elicits an appropriate response. This response should be based on well developed mechanisms that maintain flood awareness within the community. Equally important to the development of flood warning mechanisms is the need for quality, robust flood awareness (education) programs to ensure the community is capable of response. Community engagement and education is therefore a critical aspect of effective flood warning system development and operation, particularly during the periods between significant flood events.

Flood warning services rely on a cooperative and partnership approach with Local Government, State Government agencies, Regional Authorities and the Bureau of Meteorology having distinct roles. A critical factor in the success of the flood warning partnership is local commitment to and ongoing responsibility for many components of the flood warning system. The ongoing health of the total flood warning system is dependent on a commitment from all of the groups involved.

The paper aims to:

- Provide an overview of the Victorian Flood Warning Development Priorities Review project;
- Outline the process developed to objectively review TFWS development priorities;
- Introduce the key recommendations stemming from the review; and
- Provide an indication of the steps that will follow delivery of the revised Development Plan.

Project Background

During 1994, an assessment of flood warning service development needs across rural, provincial and metropolitan Victoria was completed by the VFWCC and documented as the first Flood Warning System Development Plan (VFWCC, 1994). This document was updated in 1997 (VFWCC, 1997) and listed the six catchments identified as most in need of an upgraded flood warning service as the Broken, Goulburn, Loddon, Ovens/King, Barwon and Mitchell. Relative priorities were assigned to all other major catchments across Victoria.

The assessment underlying the above ranking was limited in that its focus was primarily on the hydrological data collection and flood forecasting elements of the TWFS. While the need for improvements to other elements of the TFWS was recognised, actions to achieve those improvements were not documented.

The focus and content of the 1994 and 1997 Flood Warning System Development Plans was drawn substantially from feedback generated by a questionnaire distributed by the Bureau in 1989 to all Victorian Municipalities and other organisations with a stake in flood warning service provision. While there was good return rate for this survey (43%), the distribution and quality of responses masked the potential for flood damage. For example, some Municipalities with well-known flood problems did not return the questionnaire. In addition, the response rate from areas with few flood risks was markedly higher than from those with a higher flood risk.

A significant number of changes have occurred within Victoria since 1994 including municipal and water industry restructure, the establishment of Catchment Management Authorities (CMAs) and the development of catchment and floodplain strategies. A large number of flood studies have also been completed. In the context of these changes, the increased knowledge of flooding issues and the time that had elapsed since the last assessment, the VFWCC recognised the need to identify, analyse and assess the requirements for flood warning service improvements within Victoria and to establish a revised set of State-wide TFWS development priorities. Consequently, the VFWCC applied for and was successful in 2003/04 in securing Natural Disasters Risk Management Studies Program (NDRMSP) funding to complete a project titled “Review of Flood Warning Development Priorities in Victoria”. Michael Cawood and Associates in conjunction with CT Management Group were engaged by the VFWCC in early 2004 to complete the project.

User input was a key determinant in identifying major issues, ensuring the accuracy of the review and maximising the potential for acceptance of review findings and recommendations. As a result, stakeholder organisations and key individuals were engaged with the study through a consultation program that involved a series of facilitated workshops, a targeted questionnaire and a number of one-on-one discussions.

The TFWS Concept and Flood Warning Services in Victoria

Flood warning systems are aimed at enabling and persuading people and organisations to take action to increase personal safety and reduce the damage caused by floods. They are an integral part of emergency and floodplain management. Effective flood warning systems maximise the opportunity for the implementation of response strategies aimed at enhancing the safety of life and property and reducing avoidable flood damage.

In 1995, the Australian Emergency Management Institute (AEMI) published a best practice manual titled “Flood Warning: An Australian Guide” (AEMI, 1995). The manual described a set of best practices for the design, implementation and operation of an effective (flood) warning system in Australia and introduced the concept of the Total Flood Warning System (TFWS). It formalised a re-focus on flood warning as an effective and credible non-structural flood mitigation measure and made it clear that implementing a flood warning system wasn’t just a matter of installing a data collection network, developing a forecast tool and forwarding predicted flood levels and times to key agencies. The manual also stressed the point that for a flood warning system to work effectively, all TFWS components must be present and integrated rather than operating in isolation from each other and that there must be close cooperation throughout all stages of developing and operating the system. The TFWS concept is shown in diagram form at Figure 1.

While the 1995 manual has been revised and is now known more formally as Guide 5 (Flood Warning: 2nd edition) of Volume 3 (Guidelines) of Part III, (Emergency Management Practice) of the Australian Emergency Manual Series, (EMA, 1999) the concepts and terminology introduced in 1995 remain valid.

It is apparent that the TFWS concept is well known and understood by those closely involved in flood warning matters. However, it is equally apparent that the wider community does not share this understanding and has little appreciation of the concepts and interrelationships that underpin an effective flood warning system.

Further, experience shows that in the past, flood warning systems were not generally designed in an integrated manner and over-emphasised flood forecast production at the expense of attention to message construction, warning dissemination, local interpretation and community response.

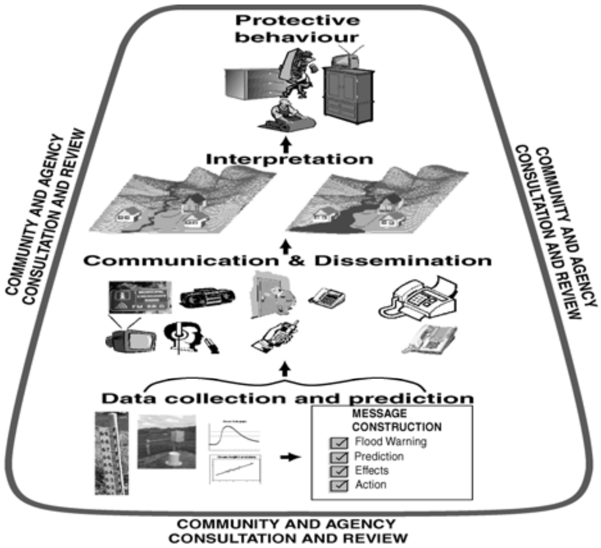

Figure 1: The main elements of a flood warning system

Arrangements for the provision of flood warning services in Victoria were formalised in working arrangements approved by the Commonwealth Government in 1987 and agreed to in-principle by the Victorian Government through the State Disaster Council in early 1988. These arrangements were reiterated and aspects clarified in Arrangements for Flood Warning Services in Victoria (VFWCC, 2001) and then endorsed by the relevant Minister at both State and Federal level. State and local entity responsibilities are also addressed in the Department of Natural Resources and Environment (now DSE) Victoria Flood Management Strategy and in the Emergency Management Manual Victoria (Department of Justice, 2005) as well as in applicable State legislation.

However, in the absence of a clear lead or ‘champion’ for flood warning service delivery in the State, it is not clear that the responsibilities that follow from the VFWCC (2001) arrangements were assigned to Local Government with adequate consultation and with due regard for available skill sets and longer term resourcing needs.

Objectives of the Review

The objectives of the review, in summary form, were to:

- Evaluate existing flood warning services;
- Determine locations/catchments where there is a need for TFWS upgrade;
- Identify the relative priority for TFWS upgrade based on a consideration of economic, social and related factors; and
- Deliver a revised Flood Warning Service Development Plan.

The project Brief also stated that "The priorities determined as a result of the project will provide the blueprint for future flood warning upgrade and development activities and in so doing facilitate the better management of identified flood risks. The new Development Plan will also provide a logical and consistent basis for actioning recommendations from flood and related studies calling for the development or upgrade of flood warning services in the context of State-wide priorities, broader floodplain management objectives and the status of existing TFWS elements within Victoria."

Consultation

Stakeholder organisations were engaged with the project through a consultation program that involved a series of facilitated ½ day workshops and a number of one-on-one discussions. A questionnaire was also developed to assist the assessment of recent TFWS upgrade projects and emailed to targeted individuals with emergency management responsibilities within each of the involved Councils.

Discussion at workshops was lively and contributions diverse with participants sharing their experiences and knowledge. The full report of each of the workshops reveals that a large number of the issues raised and discussed relate strongly to community flood awareness and alerting/warning (ie. service delivery) and that while forecasting and data collection networks were raised as issues in the some areas the State, they were generally not major concerns.

In all, there were more than 317 separate issues raised through the workshops but not all were able to be addressed through the project. Many were complex and their resolution dependent on substantial coordination across a number of areas of government.

A discussion of issues raised at the various workshops is provided in the full project report (VFWCC, 2005). It is of note that while most participants recognised alerting/warning as a fundamental component of the TFWS, it is considered to be lacking a clear "champion" or leader within Victorian legislation and supporting policy vague on the responsibilities of stakeholder organisations on the task. It was also evident that except in those areas with a strong history of flooding, there appeared to be considerable uncertainty on aspects of the roles and responsibilities of stakeholder organisations, particularly in relation to the interpretation of forecast heights. The questions of who does it, how it is done and how the resulting 'value-added' information is communicated to the at-risk community in a beneficial and digestible way were considered to be largely unanswered within Victoria.

At all workshops attendees expressed considerable concern that changes to property ownership coupled with continuing development within the floodplain is continually eroding community flood awareness and local flood knowledge. The impact this has on overall flood warning system performance and the associated risk to the effectiveness of emergency flood management activities was considered to be often overlooked.

Workshop comments indicated there is a body of opinion that the current TFWS is based on the premise that people know they live in a flood prone area and that the warning applies directly to them, not someone else. It was pointed out that in many cases this is blatantly wrong and impacts on TFWS performance, in terms of damage avoided, even though 'the system' is considered to work well.

The need for leadership to be provided on the development and maintenance of an on-going flood awareness building program targeted at communities and agencies was also raised at all workshops. The need for substantial, relevant and credible information about flood impacts and likely extents to underpin such a program was recognised at the same time as the load the collection and collation of such data currently imposes on Local Government. While it was acknowledged that outputs from flood studies provide a valuable contribution to awareness raising, it was pointed out that resource (and technical) constraints often mitigate against the full use and update over time (and after major flood) of such information. The development of flood awareness programs as well as their on-going delivery was a high priority with workshop participants. What was not clear however was where responsibility for driving, funding and delivering such a program should reside.

Questionnaire responses indicate that the recently upgraded TFWSs are valued by stakeholder Municipalities. However with some exceptions, the systems are generally not receiving all the on-going attention and support needed to deliver on expected benefits. It is equally apparent that the gap between expectations and delivery will increase as time passes.

Quantifying Existing Flood Warning Services

Under the current institutional arrangements for the delivery of flood warning services in Australia, the Bureau of Meteorology is the national lead agency, with particular responsibility for the technical forecasting role and for issuing warnings to emergency management agencies and to the public through a variety of channels including the mass media and the Internet. State and local entities work in cooperation with the Bureau and play essential roles in warning delivery and response as well as supporting the data collection networks that underpin the technical forecasting function. Appropriate responses from organisations and individuals are required to secure benefits from the service.

Further, flood warning services are provided within a wider floodplain management, flood mitigation and emergency management environment where a variety of State and local players as well as regional catchment management authorities have significant roles. The Commonwealth Department of Transport and Regional Services provide funding support for a full range of flood mitigation measures, including flood warning.

The TFWS picture at both National and State level is therefore quite complex!

In many cases within Victoria there are no specific identified TFWS requirements attached to the flood warning service currently provided. Critical levels are generally not known (other than as encapsulated in the flood class levels documented for key river gauges some of which are based in history) and few people seem to have any firm ideas on the warning lead time required in order for the at-risk population to achieve flood damage savings. This creates something of a vacuum in which to assess current TFWS performance.

In assessing (or quantifying) existing flood warning services, each element of the TFWS was considered individually in order to gain an appreciation of 'how effective' it is in contributing or delivering on overall flood warning service performance. The individual assessments were then summed to produce an overall TFWS assessment score. This score provides an initial indication of relative priorities for TFWS upgrade activity with the score from individual TFWS elements providing guidance on where effort should be best directed.

It can be argued that application of a weighting factor to each of the individual TFWS element assessments would allow accounting for the relative importance of each element within a community/social and environmental context. However, it can equally be argued that importance is implicitly factored into the assignment of the initial values for each of the components that make up the score for that TFWS element. Consequently, unweighted factors were used in the assessment.

The overall TFWS assessment score was then combined with damage data, adjusted by a measure of the population affected by flooding on an average annual basis, in order to obtain a relative ranking of "need to" versus "value of" improving flood warning services within the basin.

All catchments were then given a relative rank (from 1 to 34) on the basis firstly of the initial score and then using the adjusted score. The adjusted score when used in conjunction with the initial score provides guidance on the relative 'benefit' of upgrading elements of the TFWS.

As indicated above, rankings are relative (not absolute) and apply to the basin as a whole. Further work will be required to identify the details of where improvements are most needed (ie. the key locations and communities). Information contained in the catchment specific report cards compiled as part of the project should assist in that process.

Development and application of the quantification tool is discussed in more detail in the project report (VFWCC, 2005).

Assessment of Existing Flood Warning Services

All rivers, creeks and streams will flood if given sufficient rainfall. After all that is how they formed their floodplains. It is only human presence that creates the risk that necessitates a flood warning system. Hence, while all water courses will at some time exceed bank full capacity and flood, in many cases particularly in rural areas, there will be limited (and in some cases no) need for a formal flood warning service. The challenge is to provide services to areas and/or locations that need them and where there is genuine potential to reduce direct and indirect damages.

As outlined above, use of the TFWS element quantification tools resulted in a value (or score) and relative ranking for each basin considered. A low TFWS performance score indicates a high need for upgrade whereas a high value suggests that the flood warning service is performing reasonably soundly as it will have scored well on the individual factors. Not surprisingly, those catchments not currently serviced by a flood warning system all score very low thereby indicating a high need for a service. However, the latter is a simplistic interpretation and not a true representative assessment of need: it is more an indication of service deficiency. A deficiency that may well be totally acceptable in view of potential flood damages and impacts on the community. In other words, the "need" may not stand up to economic scrutiny.

As indicated above, a second deliberation involved a consideration of damages in order to incorporate due regard for the impact flooding would have on people. This is captured by the damages factor, which was then divided by the TFWS performance score. A higher value indicates a need for flood warning service upgrade. As potential damages have been factored into this analysis the relative rankings are not as biased to those catchments not currently covered by a flood warning service as the initial analysis. However, an accepted flaw inherent in the RAM flood damage estimates used in the analysis has caused some bias towards those catchments where flood extents are not well documented.

Nevertheless, and with due regard for information collated to the basin Report Cards during the project and the word of caution in the following paragraph, it is suggested that initial attention should be directed to the following ten catchments in priority order:

1. The Loddon catchment
2. The Wimmera catchment
3. The Campaspe catchment
4. The Goulburn catchment
5. The Broken and Boosey Creek catchment
6. The Murray
7. The Werribee catchment
8. Metropolitan Melbourne catchments
9. South Gippsland catchments
10. The Gippsland Lakes

It is at this juncture that a word of caution would be appropriate. The above list is the result of a concentration on the top ten (10) ranked catchments (out of thirty-four) and should not be viewed as exclusive and/or fixed. Issues of risk, flood damage reduction potential and thus value are at the core of assigning the relative priorities. The analysis has some weaknesses that have been partially compensated for by the application of localised experience and knowledge gained through consultation and through the consideration of available flood study and related reports. As such, all projects that look for an improvement in any element of the TFWS for any catchment should be considered in context and on its merits. The information and analyses contained in VFWCC (2005) may assist in determining those merits but should not be used in isolation to endorse or reject the project.

Recommendations

The results of recent flood and related studies confirm that many of Victoria's communities will be affected by flood at some time in the future and that the impacts will be more severe and more damaging than previous events. However, many of these at-risk communities do not appear to be (wholly) aware of the threat they face and as a result are ill-prepared. The gap between flood knowledge and preparedness is significant. Opportunities to reduce flood damages at the personal, community and State level are not being fully realised. As a result, the potential flood damage and hardship bill is growing unnecessarily.

The review described by this paper identified where improvements to the total flood warning system are warranted and presented twenty-two (22) recommendations concerning those improvements and associated matters.

The first of the twenty-two recommendations concerns improvements to flood warning services for the ten top ranked catchments most likely to show benefits from such improvements. However, the review stresses that State-wide improvements to flood awareness and preparedness, forecast interpretation, and information dissemination and communication are more important than individual warning system upgrades.

A significant outcome from the consultations that supported the review described above was a clear message that flood warning system maintenance and operation within Victoria, while involving a range of stakeholders, lacks a clear "champion" or leader with legislation and supporting policy not specific enough on the responsibilities of individual stakeholder agencies.

Further, it is apparent that by far the most important task identified as a result of this study is the need to gain clarity on responsibilities for delivering on community flood awareness raising and on the (local) interpretation of forecast flood heights into areas/assets at risk of inundation. A continuation of the current lack of clarity on this matter will prevent the full realisation of the benefits that can stem from Victoria's existing flood warning systems: the value of existing investment in flood warning systems will continue to be eroded. Conversely, resolution of the matter will have a State-wide benefit and provide a platform for the realisation of benefits stemming from future improvements to flood warning system elements.

The Next Steps

At the time of writing this paper all VFWCC member agencies had endorsed and approved the release of the final report.

A number of the more straightforward recommendations are now being addressed by various VFWCC member agencies. In addition, the Wimmera Catchment Management Authority has indicated it intends to submit (in conjunction with local municipalities) an application to the Regional Flood Mitigation Programme for funding to upgrade flood warning services throughout the Wimmera Catchment during 2006/2007.

The Victorian State Flood Policy Committee (SFPC), whom the VFWCC reports to also endorsed the report at its meeting on 28th October 2005. It was noted that a separate report prepared by the Emergency Services Commissioner for the Premier on the February 2005 Storm/Floods, also contained a number of similar recommendations with regard to flood warning services.

As a result, the SFPC agreed to develop an action plan for consideration by the Victorian Government by mid 2006 that addressed the implementation of recommendations arising from the flood warning upgrade priorities project along with relevant recommendations stemming from the Emergency Service Commissioner's review of the response to the Melbourne storm of 2-3 February 2005.

The Victorian Emergency Management Council chaired by the Minister for Police and Emergency Services endorsed the development of an action plan by the SFPC at its November 2005 meeting.

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