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# Analysis of damage to buildings following the 2010–11 Eastern Australia floods

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# ANALYSIS OF DAMAGE TO BUILDINGS FOLLOWING THE 2010–11 EASTERN AUSTRALIA FLOODS

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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# Glossary of terms and abbreviations

| | |
|---|---|
| ABCB | Australian Building Codes Board |
| AEP | Annual exceedance probability. The probability a specified value will be exceeded in any given year. |
| ALR | Adjusted loss ratio. Insured loss ratio adjusted for demand surge and underinsurance. |
| ASCE/SEI | American Society of Civil Engineers, Structural Engineering Institute |
| BCA | Building Code of Australia |
| BoM | Commonwealth Bureau of Meteorology |
| CMA | Catchment Management Authority |
| Defined flood event | The flood event selected by the flood management authority having jurisdiction to be used for development controls |
| Defined flood level | Flood level associated with a *defined flood event* relative to a specified datum |
| FEMA | Federal Emergency Management Agency (USA) |
| Flood depth | Depth of water above ground level during the *defined flood event* |
| Flood hazard area | The area inundated during the *defined flood event* |
| Flood hazard level | *Defined flood level* plus the *freeboard* |
| Freeboard | Height above the *defined flood level* typically used to provide a factor of safety |

| | |
|---|---|
| GA | Geoscience Australia |
| GABT | Geoscience Australia building type |
| Habitable floor level | Floor level of a room used for typical domestic activities |
| HNFMSC | Hawkesbury-Nepean Floodplain Management Steering Committee |
| ICA | Insurance Council of Australia |
| Inundation depth | Depth of flood water above the floor level of a building [m] |
| Loss ratio | The cost of flood-induced damage to an asset divided by the total value of the asset |
| LSIO | Land subject to inundation |
| NCC | National Construction Code |
| Non-habitable floor | Floor of rooms other than *habitable floors* |
| QDC | Queensland Development Code |
| QFCI | Queensland Floods Commission of Inquiry |
| QFRS | Queensland Fire and Rescue Services |
| QRA | Queensland Reconstruction Authority |
| RDA | Rapid Damage Assessment |

| | |
|---|---|
| SBT | Simplified building type |
| SBT1 | Simplified building type 1: Single-storey, raised floor, weatherboard cladding (Queenslander style) |
| SBT2 | Simplified building type 2: Single-storey, brickwork cladding (notionally slab-on-ground) |
| SBT3 | Simplified building type 3: Two-storey all wall types (this type includes elevated and built-under Queenslanders) |
| SBT4 | Simplified building type 4: Type 3 but with the lower storey partially built under or used as a garage |
| SPP | State Planning Policy |

# Abstract

This research quantifies the extent of damage to buildings in Queensland and Victoria following the 2010–11 Eastern Australia flooding. From the perspective of building inundation, the worst affected areas in Queensland were the Brisbane and Ipswich City Councils as well as the Lockyer Valley, Central Highlands and Rockhampton Regional Councils. In Victoria the Buloke, Campaspe, Central Gold Fields and Loddon Councils also reported significant levels of inundation. In all, insured losses reached $2.5 billion and many thousands of homes and businesses were inundated.

This research also explores the mechanisms by which flood waters can damage buildings, and highlights the role building and planning controls can play in exacerbating or mitigating this damage. It highlights weaknesses in the current systems and reviews proposed changes to the Building Code of Australia aimed at minimising future damage under current or future climates.

Utilising observations of damage to buildings in Brisbane, Ipswich and Grantham, the project developed a predictive model for estimating flood loss and occupant displacement with regards to residential property. This model can be used for flood risk assessments or rapid assessment of impacts following a flood event.

# EXECUTIVE SUMMARY

Late 2010 and early 2011 saw major flooding throughout much of Eastern Australia. Queensland and Victoria were particularly hard hit, with insured losses in these states reaching $2.5 billion and many thousands of homes inundated. The Queensland cities of Brisbane and Ipswich were the worst affected; around two-thirds of all inundated property/buildings were in these two areas. Other local government areas to record high levels of inundation were Central Highlands and Rockhampton Regional Councils in Queensland, and Buloke, Campaspe, Central Gold Fields and Loddon in Victoria. Flash flooding was a problem in a number of Victorian councils, but the Lockyer Valley west of Ipswich suffered the most extensive damage with 19 lives lost and more than 100 homes completely destroyed. In all more than 28,000 *properties* were inundated in Queensland and around 2,500 *buildings* affected in Victoria. Of the residential properties affected in Brisbane, around 90% were in areas developed prior to the introduction of floodplain development controls, with many also suffering inundation during the 1974 floods.

Utilising observations of damage to buildings in Brisbane, Ipswich and Grantham, a predictive model for estimating flood loss and occupant displacement has been developed. This model can be used for flood risk assessments or rapid assessment of impacts following a flood event.

The loss prediction model consists of four semi-empirical total loss (i.e. building and contents) vulnerability curves developed for different residential building types subject to riverine flooding. These curves relate over-floor inundation depth to the mean observed loss and use a beta distribution to quantify the spread of individual building losses about the mean. Vulnerability curves relate to housing types found in Queensland, with further work required to investigate their applicability to other parts of the country. A methodology for including the impact of high velocity flooding (i.e. flash flooding) into the predictive model is proposed, but requires substantially more work before it can be used with confidence.

The proposed occupant displacement model uses the total loss curves to estimate the proportion of homes requiring occupants to be accommodated elsewhere following a flood event. This model assumes an implicit relationship between the likelihood of displacement to the estimated Loss Ratio for a given building. The model was used to simulate displacement probability curves for short- and long-term displacement based on inundation depth. Qualitative comparisons with existing data suggest the model is plausible, but further work is required to validate the methodology.

## Recommendations

1. Future research should assess the performance of the semi-empirical vulnerability curves derived here against other (past or future) flood events to ensure their applicability across the country. Update if required.

2. Undertake further research into the correlation between flow velocity and observed damage to buildings. Incorporate this information into a vulnerability curve – along the lines of that proposed in this report – so it can be used for flood risk assessment.

3. Validate the proposed method for estimating occupant displacement against international practice and compare the resulting probability curves with displacement experienced in other (past or future) flood events.

Most observations of damage to individual components of the building system were similar to those seen previously following extensive flooding events. However, the extent of silt infiltration into cavity brick, internal walls and plumbing systems, as well as damage to around 30% of building foundations, are major issues needing to be addressed.

Development controls in Australia are regulated by each state through land planning and building controls but are enforced through local government approval systems. For land considered at risk of flooding, standard practice allows land use planning controls to determine minimum floor elevations and set a minimum freeboard. Building controls are used to determine how buildings on this land should be constructed. Issues arise in areas where flood mapping has not been undertaken or no existing flood information is available. Since recent flooding, the Queensland Government has introduced a temporary planning policy (TSPP 2/11: *Planning for stronger, more resilient floodplains*) (Queensland Reconstruction Authority, 2011) that attempts to address this issue by allowing local councils to specify *natural hazard management areas* based on existing information or a set of interim overlay maps developed by the Queensland Reconstruction Authority. At the local level, some councils have invoked temporary local planning instruments to enforce construction above flood levels experienced during recent floods.

In Victoria, the Victorian Planning Provisions are used to control development on floodplains. As in Queensland, hydrological models are in principle used to determine land subject to inundation, but again studies of this kind have not been conducted throughout the whole state. Unlike in Queensland, however, decisions on the suitability of land for development in Victoria are deferred to the relevant independent Catchment Management Authority (CMA), with legislative power to approve or deny applications. These CMAs are technically skilled in flood risk analysis and able to give an impartial assessment of the risk of flooding at a site. This system potentially provides better and more independent outcomes than a council-based approval system.

## Recommendations

4. Responsible bodies should continue development of accurate flood maps in Queensland and Victoria (and other states) that aim to identify multiple flood hazard layers (e.g. 0.2%, 1%, 5% annual exceedance probability [AEP]), and a range of flood characteristics. These should include flood depth, flow velocity, rate of rise, and origin of flooding (e.g. riverine flooding, high velocity flooding, flash flooding, and coastal inundation).

5. State governments could assess the viability of introducing independent flood assessment bodies similar to Catchment Management Authorities in Victoria to assess development proposals with respect to flood risk in other states.

The principal document for controlling construction practice in Australia is the Building Code of Australia (BCA). At present the BCA has no specific requirement for flood-resistant design when building on land subject to inundation. However, the Australian Building Codes Board (ABCB) has recently developed a draft Flood Standard to address this shortcoming. This draft Standard is currently proposed for adoption into the BCA in early 2013 and is a performance based design manual. It is not a technical Standard along the lines of AS/NZS1170.2 or AS1170.4 but instead sets a number of performance requirements closely following what is specified in the US equivalent ASCE/SEI 24-05.

The Standard itself is limited in its application to residential construction in areas where flow velocities are less than 1.5 m/s and where inundation of non-habitable floors is less than 1 m. No inundation of habitable floors is permitted. Where velocities or inundation depths are greater than these thresholds, a ‘first principles’ engineering approach must be adopted to ensure construction will satisfy the performance requirement. Unfortunately, no additional requirements above what currently exist are made in respect of commercial or industrial buildings constructed in these areas. Moreover, performance requirements need not be satisfied for construction in areas prone to coastal inundation.

Both Queensland and Victoria will adopt the proposed Flood Standard as a design manual if approved for inclusion in the BCA. Going further, Queensland has drafted amendments to the Queensland Development Code (QDC) that would effectively adopt the performance requirements in the Flood Standard prior to BCA adoption. In this amendment a number of specific solutions are provided for broad performance requirements within the Flood Standard (and BCA) and the applicability of several performance requirements are extended to commercial or industrial buildings when their immediate use after a flood is required. These are seen as positive improvements over the draft Flood Standard. Unfortunately, proposed changes would preclude application of performance requirements to homes being rebuilt following flooding. We strongly oppose this move.

## Recommendations

6. The ABCB should consider including some level of flood-resistant design requirements for commercial and industrial buildings within proposed changes to the BCA. Proposed changes to the QDC could be used as a basis from which to work.

7. Areas prone to storm surge and coastal wave actions should be included in the proposed BCA amendment. To facilitate design for these actions, include provisions similar to those in ASCE/SEI 24-05 in the Flood Standard.

8. The Flood Standard should specifically set a minimum freeboard of at least 300 mm.

9. Remove *raising existing building* and *repairing existing building* from exclusion in proposed changes to the QDC.

10. The handbook *Reducing Vulnerability of Buildings to Flood Damage* (HNFMSC, 2006) should be reviewed and if necessary updated to ensure that it is applicable to all building types throughout Australia. This should form the basis of a prescriptive technical design manual to be called upon by the Flood Standard. The responsibility for undertaking and maintaining such a document should fall to a national body, e.g. ABCB, Engineers Australia, Standards Australia.

Looking to international experience, building-level improvements to existing buildings that reduce the impacts of flooding are only deemed beneficial, from a cost–benefit perspective, when the AEP of inundation was greater than 2–4%. Detailed cost–benefit analysis of retrofit methodologies should be carried out for flood-prone cities in Australia with possible funding mechanisms for uptake explored.

Finally, the proposed Flood Standard appears to be in line with practice in other countries that mandate design for flood actions. However, the use of multiple flood levels based on floods of differing AEPs, as used in Wales, is worth further consideration in Australia.

## Recommendations

11. Cost–benefit analysis of the application of flood-aware design to new construction and retrofit methodologies to existing buildings should be carried out for flood-prone cities in Australia. Possible funding mechanisms to entice people to undertake these actions should also be explored. These could be done through case studies, with Brisbane being a good first choice.

12. The Flood Standard should consider using multiple *design flood levels* so a performance- and risk-based engineering approach can be adopted for design of structures.

# 1. INTRODUCTION

Over the 2010–11 summer, Eastern Australia experienced multiple heavy rainfall events that flooded parts of Queensland, New South Wales, Victoria and Tasmania. Queensland and Victoria were the worst affected states, with 58,600 insurance claims now topping $2.5 billion in losses (ICA, 2012). This figure ranks the 2010–11 floods at number 5 on the top 10 list of most costly (normalised) natural disasters to have affected Australia since 1967 (Crompton, 2011). The overall financial impact – considering damage to uninsured infrastructure and buildings, lost productivity and post-disaster financial aid – will exceed this value many times. By any measure the impact of the summer floods of 2010–11 (hereafter simply *the floods* or *flooding)* were significant.

The aims of this report are as follows:

1) Report the number of flood-damaged properties/homes in Queensland and Victoria for the period between December 2010 and late January 2011. These reports will largely be made on a Local Government Area (LGA) basis so the planning and building controls of those regions can be studied.
2) Outline the multiple ways floodwaters can damage buildings and the approaches to mitigate these damages. Reference is made to engineering/construction standards, guidelines and handbooks that will practically aid this analysis without explicitly specifying new methods.
3) Collate and analyse flood-damage data collected by multiple agencies following the Queensland floods in order to develop damage (stage-damage) and fragility functions for a number of building classes. Data sources for analysis are a) the Geoscience Australia damage assessment database, 2) the Queensland Fire and Rescue Services rapid assessment database, and 3) an adjusted insured-loss database from a major national insurer.
4) Review building controls in Queensland and Victoria. Comment on observed shortcomings and proposals for change. This will include a review of flood resistant/resilient guidelines and handbooks as well as identification of international equivalents.

A number of these points are broad, so to ensure project work could be completed in a timely manner a number of limitations were imposed. First, numerous types of flooding are possible, for example, riverine flood, flash flood, flooding from failure of internal building plumbing, and coastal inundation (including storm surge). This report discusses riverine and flash flooding only, as these were the predominant flood types during recent flooding. Storm surge is briefly mentioned as it shares some similarities to flash flooding. Second, the primary focus of this work is on assessing damage to buildings and methods (regulatory or otherwise) for reducing this. By virtue of data availability much of this report relates to residential buildings, but many concepts are equally applicable to commercial buildings. Contents damage during flooding events is costly but what people do with their belongings during a flood event is almost impossible to regulate, so while contents damage is discussed it is not analysed to the same extent as building damage.

The report layout is as follows. A brief overview of the flooding event is given in section 2.1, with section 2.2 addressing aim 1. Sections 3 and 4 address aim 2, while section 5 contains the analytical methodology and results addressing aim 3. Aim 4 is addressed in section 6, with section 7 concluding the report and outlining recommendations for future work.

# 2. 2010–11 EASTERN AUSTRALIA FLOODING EVENT

Eastern Australia experienced prolonged periods of extreme rainfall between late November 2010 and mid-January 2011, resulting in severe flooding in much of the region. Several individual major rain events coupled with significant rainfall totals prior to November 2010 led to major flooding (riverine and flash) in Queensland, New South Wales, Victoria and Tasmania (National Climate Centre, BoM, 2011). Heavy rainfall in February 2011 compounded problems, with repeat flooding of some areas. Primary flooding in Queensland and New South Wales occurred during December and January, while major flooding in Victoria and Tasmania began in January 2012.

## *2.1 Meteorological drivers and rainfall*

This section is predominantly based on observation and analysis of rainfall data by the Bureau of Meteorology (BoM, 2011a; National Climate Centre, BoM, 2011; Victorian Climate Services Centre, 2011) and these sources should be considered as references unless otherwise noted.

For the period *28 November to 22 December*, passage of upper-level troughs associated with persistent surface troughs were responsible for much of the measured rain. For the first week a surface trough sat over inland Eastern Australia, pulling warm moist air down from the tropics. Bands of heavy rain fell between Mackay and Emerald in Queensland and over the eastern portion of New South Wales (Figure 1a). The second week saw an easterly moving cold front generate an upper-level trough that moved slowly across northern New South Wales and southern Queensland. Rainfall in excess of 50 mm was widespread across the region over the week (Figure 1b). On 14 December a monsoon low developed off the west coast of Australia, and as it moved eastward a monsoon trough developed across the country and into Queensland. Associated with this trough were severe convective storms that generated large hail, damaging winds and torrential rain over parts of south-east Queensland. A northerly moving trough on 19–20 December coupled with a low pressure system east of Tasmania added to the rainfall total in Victoria, New South Wales and Queensland (Figure 1c).

For the period *23–28 December* a moisture-laden easterly flow covered most of Queensland. Adding to this was the landfall of Tropical Cyclone Tasha on 25 December, causing heavy rainfall along the coast. Ex–Tropical Cyclone Tasha proceeded to move inland and developed into a large-scale monsoon low, dumping rainfall over southern Queensland for the next two days. Interaction with a north-easterly moving trough prolonged the low's influence over rainfall in the area. Figure 2 shows the rainfall totals for the 7-day period ending December 30. Totals in excess of 100 mm for the period are evident from the New South Wales–Queensland border to just north of Cairns.

The cumulative result of the above rainfall events was the wettest December on record for Queensland, the sixth wettest for Victoria and the eighth wettest for New South Wales. For Australia as a whole it was the third wettest December, but for Eastern Australia, the wettest. These falls were on top of an exceedingly wet spring (wettest on record for Queensland and New South Wales) meaning that leading into 2011 many catchments were already sodden and rivers full. Figure 3 shows the total rainfall for December and the totals for the spring season (September–November). Of particular interest in Figure 3b are the high totals in the areas of high altitude in Victoria that led to riverine and flash flooding throughout the state (Comrie, 2011).

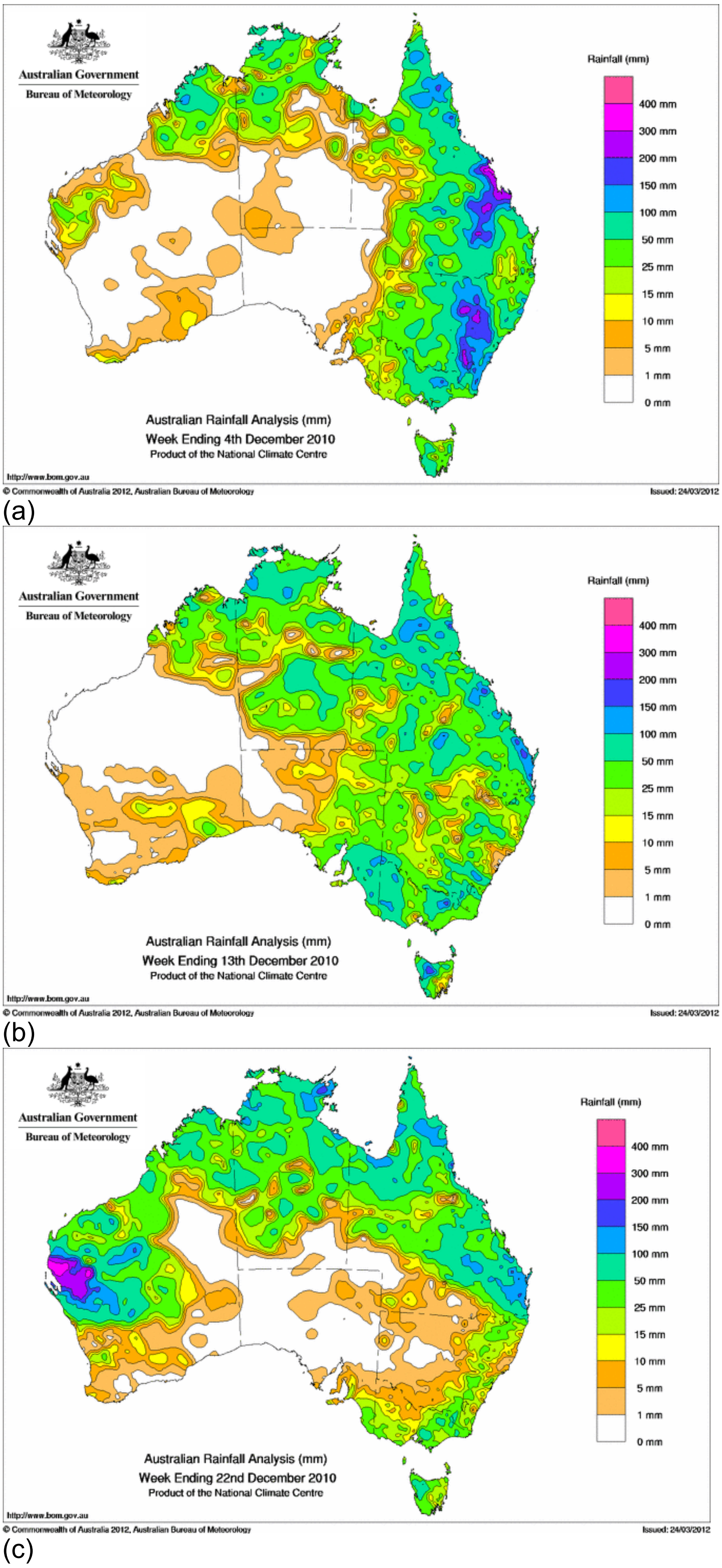

**Figure 1: Total rainfall for the 7-day periods ending, a) 4, b) 13 and c) 22 December 2010**

Source: http://www.bom.gov.au/jsp/awap/rain/

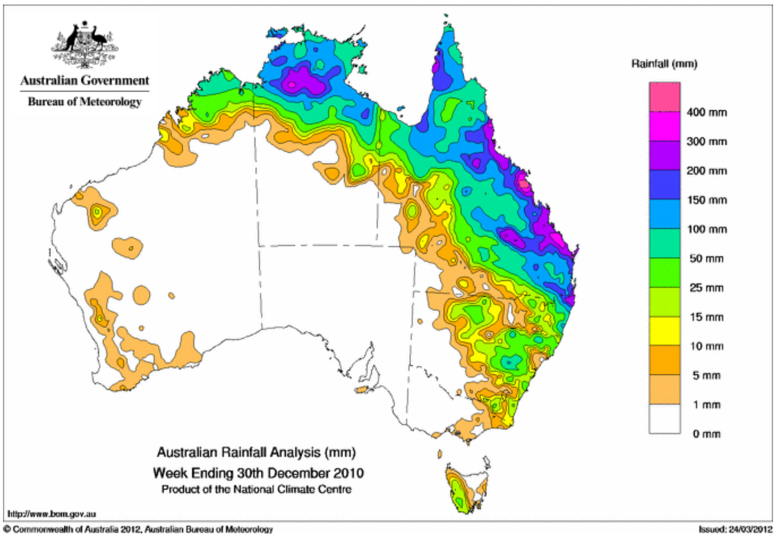

**Figure 2: Total rainfall for the 7-day period ending 30 December 2010**

Source: http://www.bom.gov.au/jsp/awap/rain/

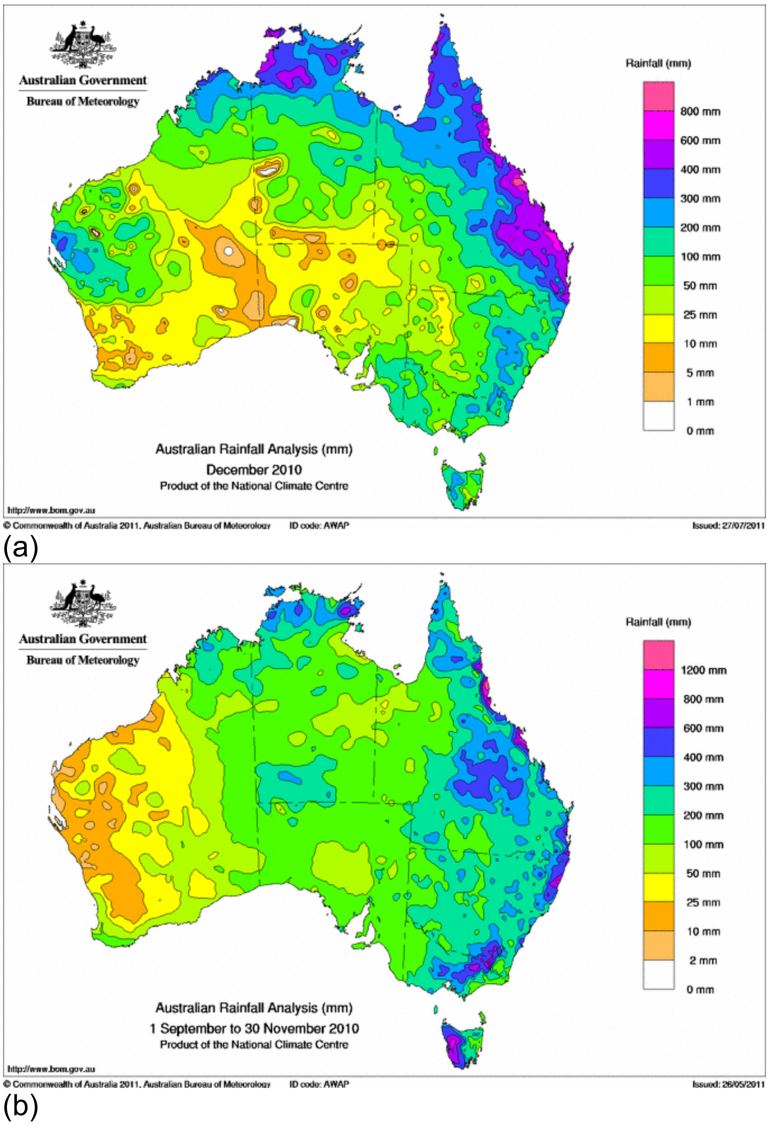

**Figure 3: Rainfall totals for, a) December 2010 and b) September–November (spring) 2010. Note the differing scales.**

Source: http://www.bom.gov.au/jsp/awap/rain/

Rains that instigated major flooding in south-east Queensland (riverine and flash flooding) fell over the three-day period *10–12 January 2011*. An upper-level low combined with humid easterly flow generated a 'classical' east coast rainfall pattern that led to major flooding over a scale of several hundred kilometres. Embedded within the easterly flow were a complex of severe thunderstorms that caused flash flooding in Toowoomba and the Lockyer Valley on the afternoon of 10 January. Three-day rainfall totals exceeding 200 mm were recorded for much of the region bounded by Brisbane, Gympie and Toowoomba, with the area south to Coffs Harbour and inland to Dalby recording in excess of 100 mm (Figure 4). Totals exceeding 600 mm were recorded at a number of stations north and west of Brisbane (Mount Glorious, Peachester). Sixty-minute totals in excess of 60 mm were also recorded in these broad areas. Given the small spatial extent of severe thunderstorms that drive short-duration rainfall peaks, it is possible that rainfall in some areas that did experience these events was not recorded by the Bureau of Meteorology's monitoring network.

At approximately the same time, tropical air was being drawn south into a trough sitting near the South Australian border, putting much of western New South Wales and Victoria under a moist air mass. On January 12 a low pressure system developed near Mount Gambier, within this mass, and moved southerly producing large rainfall totals throughout the region until January 15. Four-day totals exceeding 100 mm occurred in much of western New South Wales, Victoria and northern parts of Tasmania (Figure 4).

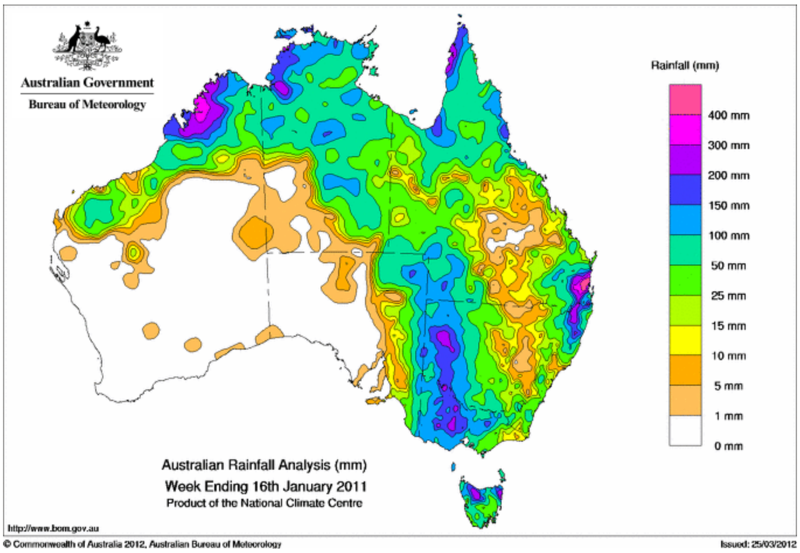

**Figure 4: 7-day rainfall totals for the period ending 16 January 16 2011. Note that the period does not exactly align with the periods discussed; however, rainfall outside the periods of interest – i.e. 10–12 January for south-east Queensland and 12–15 January for Victoria – were relatively small and trends are still evident.**

Source: http://www.bom.gov.au/jsp/awap/rain/

The above events all took place during a period of highly positive Southern Oscillation Index (SOI) characterising a strong La Niña climate phase (Figure 5). It is well established that the El Niño Southern Oscillation (ENSO) phenomenon plays a moderating role, with Australia receiving below average rainfall during these phases over a seasonal time scale, though the exact mechanism by which this occurs is less clear. During La Niña events, Eastern Australia typically has higher than average rainfall; the La Niña phase in place over the period of the floods was one of the strongest on record, and high seasonal rainfall was forecast (QFCI, 2011).

On a sub-seasonal time scale the Madden Julian Oscillation (MJO) plays a moderating role in the generation of rainfall. When the MJO is in phases 4, 5 or 6 (active) the probability of rain over the northern parts of Australia is increased. For the periods 3–14 December 2010 and 9–17 January 2011 (Figure 6), the MJO was active and may have contributed to the rainfall over these periods.

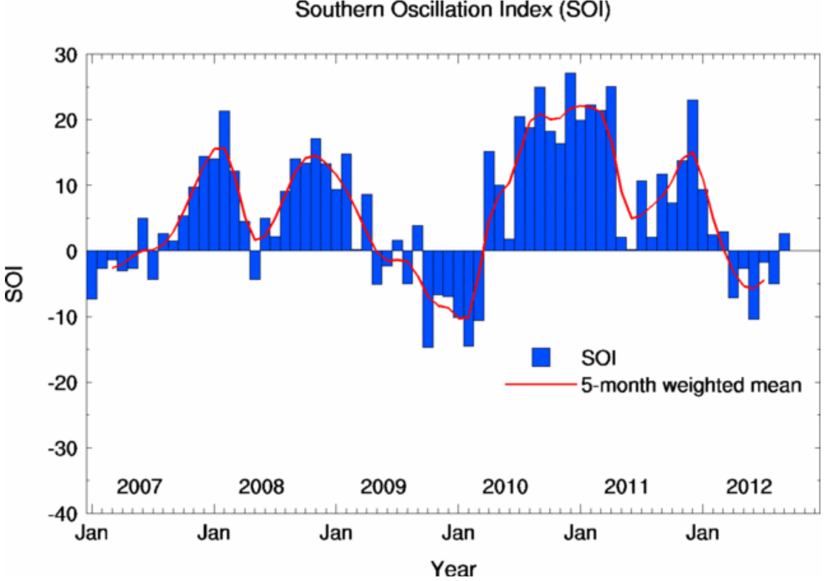

Figure 5: Southern Oscillation Index

Source: http://www.bom.gov.au/climate/glossary/soi.shtml

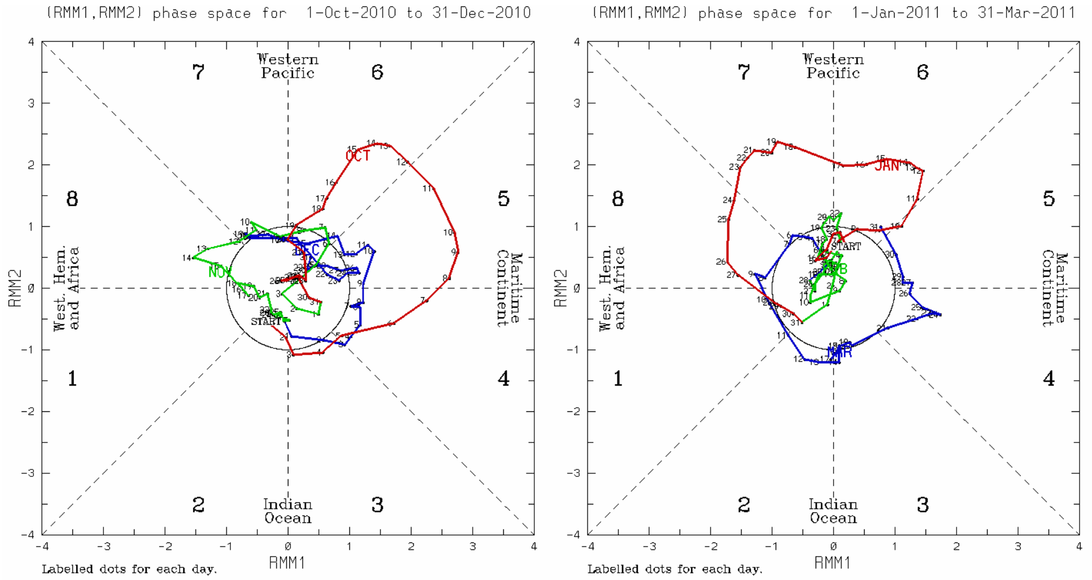

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Figure 6: Madden Julian Oscillation for (left) October–December 2010 and (right) January–March 2011

Source: http://reg.bom.gov.au/climate/mjo/

## *2.2 Observed major flooding and building inundation*

During the period of heavy rainfall, flooding of rivers and streams in all eastern states were reported. Given that the primary focus of this report is the flooding in Queensland and Victoria, only these areas are subsequently discussed. In addition, given the building controls focus of this work, reporting is primarily aggregated to Local Government Areas (LGA) as this is predominantly the scale on which these controls are applied.

Rainfall during early December 2010 led to major[1] flood peaks on the Balonne River at St George (Balonne Shire Council) and the Dawson River at Theodore (Banana SC). Later in the month major flood levels were again recorded in St George, leading to inundation of some of the town's buildings (QFCI, 2011). On Christmas day Theodore again experienced a major flood peak, inundating homes and instigating evacuations. Before the end of December major flood peaks were recorded on Charleys Creek in Chinchilla (South Burnett Regional Council), the Comet River at Rolleston (Central Highlands RC), the Condamine River at Warwick (Southern Downs RC), Myall Creek at Dalby (Western Downs RC), Dawson River at Taroom (Banana SC), Burnett River at Bundaberg (Bundaberg RC) and the Nogoa River in Emerald (Central Highlands RC). At the same time the Fitzroy River at Rockhampton was rising above its major flood level, a threshold it would not fall below for approximately two weeks (National Climate Centre, BoM, 2011). Properties were also flooded on the Jordan River and Alpha Creek in Jericho and Alpha (Barcaldine RC) and on the Burnett River in Gayndah and Mundubbera (North Burnett RC).

Into January 2011 the Condamine and Dawson Rivers remained above major flood levels. Within the first week the Fitzroy River at Rockhampton and Yaamba (Rockhampton RC) as well as the Balonne River at Surat (Maranoa RC) peaked, inundating buildings (QFCI, 2011). Over the next few days riverine inundation of homes was reported in the Balonne Shire, Southern Downs Region (Stanthorpe) and Toowoomba region (Oakey).

Severe localised rainfall that fell on the afternoon of 10 January led to flash flooding in the Toowoomba city centre, rapidly inundating numerous homes and businesses. Stream flow data at the Cranley Stream gauge (a few kilometres downstream of the city) show a stream depth increase of approximately 2.5 m in less than 1 hour (ICA Hydrology Panel, 2011). Further downstream the Lockyer Valley suffered even worse impacts. Flash flooding of the Lockyer Creek and its tributaries inundated buildings in Spring Bluff, Murphys Creek, Postmans Ridge, Withcott, Flagstone Creek, Helidon, Grantham, Gatton, Forest Hill, Mulgowie, Laidley, Mount Silvia, Black Duck Creek, Junction View, East Haldon, Glenore Grove, Crowley Vale, Brightview, Regency Downs and Lockrose. Grantham, Murphys Creek, and Postmans Ridge bore the brunt of the damage, with around 120 homes structurally destroyed and thousands of properties inundated (Lockyer Valley Regional Council, 2011a). Reports suggest that the Lockyer Creek at Helidon rose approximately 9.5 m in less than 1 hour (BoM, 2011b). This flow will have spread out over the flood plain in areas such as Grantham, so the inundation depth was not of this order. Damage assessment carried out by the first author suggests a depth of 1.5–2.5 m is of the order experienced through that

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[1] Flood levels are assigned a category by the Bureau of Meteorology – Minor, Moderate or Major – based on the expected impact to the community. A Major flood classification suggests that extensive rural areas and/or urban areas will be inundated. Properties and towns are likely to be isolated and major traffic routes are likely to be closed. Evacuation of people from flood-affected areas may be required. http://www.bom.gov.au/hydro/flood/flooding.shtml

town. Nineteen lives were lost in the Lockyer Valley flooding (Lockyer Valley Regional Council, 2011a).

On 11 January the major flood peaks occurred in the Southern Downs, Somerset, Moreton Bay and Gympie Regional Councils, inundating homes and businesses in the towns of Warwick, Lowood, Caboolture and Gympie. January 12 saw further flooding of Charleys Creek, inundating buildings in Chinchilla.

The bulk of damage to Queensland buildings occurred with the flooding of the Bremer (Ipswich City Council) and Brisbane Rivers (Brisbane CC) between 12 and 15 January. At Ipswich the Bremer River peaked at its highest level since 1974, inundating more than 1000 homes and affecting over 7000 properties (including businesses) (QFCI, 2011). Early on the morning of 13 January, flood levels peaked downstream at the Brisbane City gauge, also at its highest level since the 1974 floods. In Brisbane and surrounds, more than 14,000 properties were flood-affected, with thousands of homes suffering some level of inundation and greater than 2000 businesses suffering the same fate. Fortunately, power to much of the city was turned off prior to the flood peak, minimising potential damage through water contact with electrical systems (QFCI, 2011). On 15 January, nearly 6000 Brisbane properties were still inundated to some extent.

As floodwaters in Brisbane and Ipswich began to recede, flooding in Victoria was on the rise. The heavy rains over much of western Victoria between 12 and 15 January led initially to localised flash flooding affecting properties in Beaufort (Pyrenees SC), Halls Gap (Northern Grampians SC) and Ballarat (Ballarat CC) (Burin, 2011) with more extensive river flooding from 14 January onwards (National Climate Centre, BoM, 2011). Over the next few days the towns of Bridgewater (Loddon SC), Carisbrook (Central Goldfields SC), Charlton (Buloke SC), Clunes (Hepburn SC), Echuca and Rochester (Campaspe SC), Horsham (Horsham RCC), Shepparton (Greater Shepparton CC) and Warracknabeal (Yarriambiack SC) all had inundation of buildings to some extent (Australian Broadcasting Commission, 2011; Burin, 2011; Comrie, 2011; Fogarty, 2011; Tippet, 2011; Turnbull, 2011; Victorian Climate Services Centre, 2011). In all, approximately 80 towns were affected by flooding, though given the largely rural nature of the area not all experienced building inundation.

A map showing flood peak river conditions for Eastern Australia river gauge stations over the period 26 November 2010 to 20 January 2011 is presented in Figure 7. The spatial extent of flooding that affected communities is evident. Further, state government maps of flood-affected cities in Queensland and Victoria are included in Appendix 1.

A complete list of LGAs that reported flooding during the December 2010 – January 2011 period is provided in Table 1. Where information was available, an estimate of the number of inundated buildings (in some instances only information on number of properties was available) and a list of impacted towns are reported. Inundation numbers should be considered approximate, and in all likelihood represent a lower bound estimate of affected properties/buildings. Data were collated from a range of sources, but the Queensland Floods Commission of Inquiry (QFCI, 2011) and the Victorian State Emergency Services (2011) *Rapid Damage Assessment Report* should be considered the primary references. These documents are themselves, in fact, collations of data from multiple other sources.

The worst affected areas in Queensland included the Brisbane and Ipswich City Council areas as well as the Lockyer Valley, Rockhampton and Central Highlands Regional Councils. Flooding in Victoria affected fewer buildings, but the Buloke, Campaspe, Central Gold Fields and Loddon Shire Council areas still suffered significant impacts. In total it is estimated that Queensland had greater than 28,000 properties inundated, while in Victoria nearly 2,600 buildings were inundated.

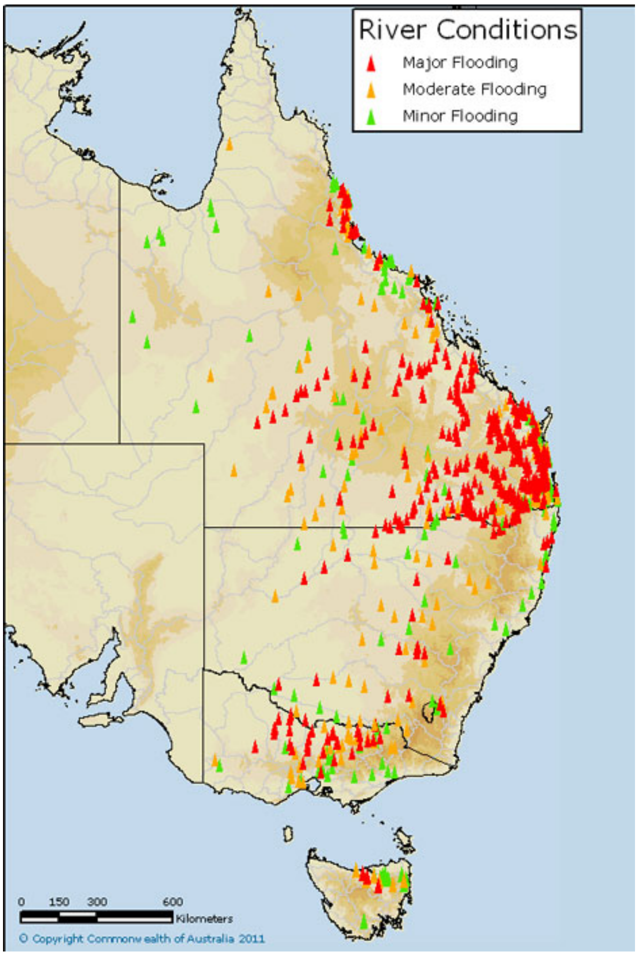

**Figure 7: Peak flood conditions 26 November 2010 – 20 January 2011**

Source: (National Climate Centre, BoM, 2011)

**Table 1: Local Government Areas affected by the Eastern Australia flooding event**

| State | LGA | No. of properties or buildings inundated[2] | Towns worst affected |
|---|---|---|---|
| **Queensland** | Balonne Shire Council | 25 | St George |
| **Queensland** | Banana Shire Council | > 100 | Theodore, Taroom, Jambin, Biloela |
| **Queensland** | Barcaldine Regional Council | > 80 | Alpha, Jericho |
| **Queensland** | Brisbane City Council | > 14,000 | 94 suburbs |
| **Queensland** | Bundaberg Regional Council | 208 | Bundaberg |
| **Queensland** | Burdekin Shire Council | NA | Giru |

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[2] Numbers reported for Queensland are for inundated properties, while those for Victoria are inundated buildings.

| State | LGA | No. of properties or buildings inundated[2] | Towns worst affected |
|---|---|---|---|
| **Queensland** | Cairns Regional Council | NA | Gordonvale |
| **Queensland** | Central Highlands Regional Council | > 1200 | Emerald, Rolleston |
| **Queensland** | Fraser Coast Regional Council | 31 | Maryborough |
| **Queensland** | Gympie Regional Council | NA | Goomeri, Gympie, Kilkivan, Woolooga |
| **Queensland** | Ipswich City Council | > 7,200 | |
| **Queensland** | Lockyer Valley Regional Council | 2,290 | Gatton, Grantham, Helidon, Laidley, Withcott |
| **Queensland** | Maranoa Regional Council | NA | Roma, Surat |
| **Queensland** | Moreton Bay Regional Council | 300 | Caboolture |
| **Queensland** | North Burnett Regional Council | 23 | Gayndah, Mundubbera |
| **Queensland** | Rockhampton Regional Council | 1,000–2,000 | Rockhampton, Yaamba |
| **Queensland** | Somerset Regional Council | NA | Esk, Fernvale |
| **Queensland** | Southern Downs Regional Council | 200 | Killarney, Warwick, Stanthorpe |
| **Queensland** | Toowoomba Regional Council | 100–200 | Toowoomba, Oakey |
| **Queensland** | Western Downs Regional Council | > 200 | Chinchilla, Condamine, Dalby, Jondaryan |
| **Victoria** | Ararat Rural City Council | 30 | Ararat, Wickliffe |
| **Victoria** | Ballarat City Council | 24 | Delacombe, Miners Rest and Mount Rowan |
| **Victoria** | Buloke Shire Council | 420 | Charlton, Culgoa, Donald, Nullawil, Coonooer Bridge, Nandaly |
| **Victoria** | Campaspe Shire Council | 419 | Echuca, Rochester, Colbinabbin |
| **Victoria** | Central Goldfields Shire Council | 345 | Carisbrook, Dunolly, Maryborough |
| **Victoria** | Corangamite Shire Council | 47 | Skipton |
| **Victoria** | Gannawarra Shire Council | 172 | Capels Crossing, Dingwall, Kangaroo Lake, Kerang, Kerang East, Kerang West, Koroop, Lake Charm, Lake Meran, Marcorna, Milnes Bridge, Murrabit, Murrabit West, Mystic Park, Quambatook, Tragowel, Westby |
| **Victoria** | Golden Plains Shire Council | 10 | Cressy, Haddon, Inverleigh, Ross Creek, Shelford |
| **Victoria** | Greater Bendigo City Council | 1 | Bendigo |
| **Victoria** | Hepburn Shire Council | 156 | Clunes, Creswick |
| **Victoria** | Hindmarsh Shire Council | 7 | Dimboola |
| **Victoria** | Horsham Rural City Council | 189 | Horsham, Quantong, Dadswells Bridge, Natimuk |

| State | LGA | No. of properties or buildings inundated[2] | Towns worst affected |
|---|---|---|---|
| **Victoria** | Loddon Shire Council | 418 | Appin South, Benjeroop, Boort, Bridgewater, Dingee, Durham Ox, Inglewood, Jarklin, Mitiamo, Mologa, Newbridge, Prairie, Pyramid Hill |
| **Victoria** | Macedon Ranges Shire Council | 1 | Darraweit Guim |
| **Victoria** | Maribyrnong City Council | 1 | Maribyrnong |
| **Victoria** | Mildura Rural City Council | 3 | Mildura |
| **Victoria** | Mitchell Shire Council | 9 | Seymour, Cloverdale |
| **Victoria** | Mount Alexander Shire Council | 50 | Campbells Creek, Newstead |
| **Victoria** | Moyne Shire Council | 17 | Hexham, Woorndoo |
| **Victoria** | Murrindindi Shire Council | 1 | Yea |
| **Victoria** | Northern Grampians Shire Council | 167 | Campbells Bridge, Glenorchy, Great Western, Halls Gap, Navarre, Marnoo, Stawell |
| **Victoria** | Pyrenees Shire Council | 72 | Beaufort, Trawalla, Avoca |
| **Victoria** | Yarriambiack Shire Council | 32 | Rupanyup, Warracknabeal, Beulah |

# 3. FLOOD ACTIONS ON BUILDINGS

Flooding can affect buildings in numerous ways. In many instances the impacts of flooding are made worse by the fact that buildings, particularly houses, are seldom designed to withstand any form of flood action. Indeed, in Australia traditional residential building practice ensures that much of the housing stock is vulnerable to component damage and possible structural failure when exposed to floodwaters (HNFMSC, 2006).

The impacts of flooding can be divided into two distinct categories: direct and indirect impacts. Direct impacts are those that occur when floodwaters come into contact with a structure. Indirect impacts occur spatially or temporally separated from a building itself but influence how that building/owner responds to a flood event (Thieken, Müller, Kreibich, and Merz, 2005). Given that this report is primarily focused on building controls, direct impacts are of greater relevance and are discussed throughout this section. That said, indirect losses such as interrupted access, reduced housing availability, lack of easily accessible building material or contractors and the overall extent of impact to other buildings can contribute to levels of damage to a building if rapid clean-out following an event is not possible. The above may also serve to prolong periods a building occupant must remain away from their home or business, thus increasing the financial impact that must be borne. Further, financial impacts at an individual property level may result at the point of any future sale where the stigma of a 'flooded' home or property may influence sale prices. It is relatively difficult to control indirect impacts through individual building controls, but regional planning regulations can be imposed that help minimise their impact on people. This point is discussed further in section 6.2.

The remainder of this section outlines direct actions that can influence the extent and severity of damage to a building during a flood event. It should be borne in mind throughout that in almost all instances these factors will not be acting in isolation, so their interrelationships are also important (Kelman and Spence, 2004).

## *3.1 Hydrostatic actions*

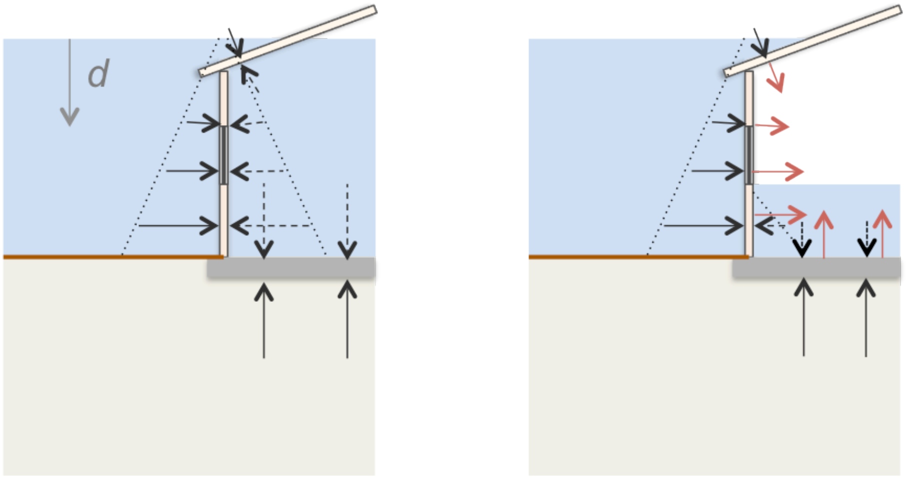
Hydrostatic pressure forces are imposed upon a structure, or component of a structure, by a depth of water contacting it. These pressures occur as a response to the mass of fluid above a specified point and therefore increase linearly with depth as the amount of overlying liquid increases. At any point hydrostatic pressure is equal in all directions. Therefore, irrespective of building or component orientation, hydrostatic pressure forces will act perpendicular to a submerged surface. Force diagrams shown in Figure 8a give an example of how hydrostatic forces can act on a typical building. Pressures on vertical walls act horizontally, trying to push the wall inwards, and if inundated above the roof-line, water forces act to push the roof down and into the building. The omnidirectional hydrostatic pressure, $P_s$ [Pa], can be calculated at any depth, $d$ [m], from the surface using Equation (1) when $\rho_w$ is the density of water [kg/m$^3$] and $g$ is gravitational acceleration [m/s$^2$]. The force acting on a surface at a given $d$ is equal to the hydrostatic pressure multiplied by the width of that surface. These are the force vectors shown in Figure 8.

$$P_s = \rho_w g d \qquad \textbf{(1)}$$

For the most part hydrostatic forces equate across building surfaces when the rate of flood water rise is slow enough for the inside of a building to fill at the same rate as external waters rise (internal pressure forces are shown as dashed arrows in Figure

8a). This occurs because flood waters typically rise over a period of hours to days and small openings in standard buildings, such as gaps beneath doors or weepholes in brickwork, allow flood waters to enter a building at a similar rate. If, however, external water levels rise more quickly than openings allow water infiltration into the building (e.g. when owners actively try to stop water entry), a differential pressure over a surface or component ensues. Given the high density of water (approximately $\rho_w$ = 1000 kg/m$^3$), even small differences in water level inside and outside a building can generate loads large enough to cause damage. Figure 8b gives an example of a differential pressure scenario, with the red arrows showing the resultant forces – that is, the difference between internal and external forces – the building is required to resist. Water that fills a building acts to oppose forces generated by the external loading and reduces the overall loading on a structure. In the differential pressure scenario shown in Figure 8b, given the internal water depth is below the window frame but the external depth is above, the full water load must be carried by the fixings between the window frame and the wall structure. These loads will more than likely be greater than the wind loads this framing is designed for and failure would ensue.

Examples of the relatively small pressure differentials required to fail a typical US style residential structure are given in USACE (1988). This work shows only 0.75–1.0 m of differential water depth is required to cause gross failure of a brick veneer style wall. Kelman and Spence (2003) suggest a depth difference between the inside and outside water levels ranging between 0.8 m and 2.0 m will fail most unreinforced masonry walls on a range of typical UK style homes. Similar depths could be expected to induce failure on unreinforced masonry homes in Australia (HNFMSC, 2006).



(a) (b)

**Figure 8: hydrostatic force diagrams for a) partially inundated building with equalised water levels inside and outside, and b) partially inundated building where inflow into the building is at a slower rate than external water rise. Solid black arrows signify external water loading, dashed black arrows internal, and red arrows show the resultant forces.**

Capillary action can also damage components of a building even if water does not come into contact with it (Kelman and Spence, 2004). This can occur when floodwaters do not recede quickly and buildings remain partially inundated for an extended period. When this happens capillary rise within say, plasterboard, can damage material above the water line. Capillary action within partially saturated soils can also bring water into contact with the sub-surface structure, potentially causing damage. From a review of literature, Kelman and Spence (2004) suggest approximate upper limits for capillary rise of 0.45 m within building materials and up to 10 m within soils. The extent of rise is, however, very dependent on material/soil type and duration of inundation.

An example from recent floods of the impact equalised hydrostatic actions have on a home is shown in Figure 9. In this example the home was completely inundated, but because waters were able to enter and recede, the home suffered little overall structural damage. Few reports of damage due to differential water levels were found during this project.

**Figure 9: Home following full inundation by waters without a significant velocity component**

### 3.2 Hydrodynamic actions

As well as static contact pressure, flowing water applies additional 'hydrodynamic' forces to a structure. During flash flooding, where water velocities can exceed several metres per second, major structural damage can occur at depths where inundation actions alone would be structurally inconsequential. Two main categories of hydrodynamic actions are as follows:

1) Dynamic pressures imposed through the interaction of flowing water with a stationary object: to a first approximation the dynamic pressure, $P_d$ [Pa], applied at the middle of the upstream face of a building by water flowing at a velocity, $v$ [m/s], can be calculated using Equation (2). In most cases, given the flood surface is free to move up and down, these dynamic pressures result in an increase in water depth and an increased inward load on that wall (Figure 10). Around a building, however, the dynamic pressure is highly variable – dependent on factors such as building shape, size and orientation – and negative dynamic pressures and a drop in flood surface are typically associated with the side and leeward walls (HNFMSC, 2006). Figure 10 gives an example of the potential change in water level around and within a typical home as water moves past and through it. Given that internal waters of a notionally closed home only see a filtered version of the actual flow, water levels inside will not typically match that on the outside. Non-stationary load effects due to flow turbulence can also act to either increase or decrease dynamic pressure loads and therefore water levels.

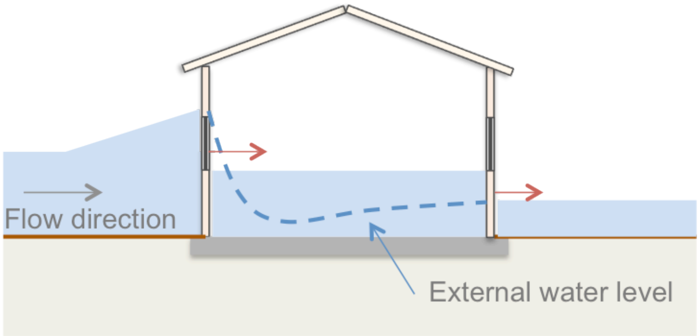


**Figure 10: Representative flood levels around and through a building subject to flowing water (after (HNFMSC, 2006)). Red arrows indicate resultant force direction on walls.**

A number of design guidelines (ASCE, 2005; HNFMSC, 2006) approximate the hydrodynamic loading on a wall through calculation of afflux, A, (i.e. the increase in depth on the upstream wall) (Equation (3)). This equation is simply the velocity head multiplied by a shape factor, *C*, and is only applicable for slow velocity flows.

$$P_d = \frac{\rho_w v^2}{2} \qquad (2)$$

$$A = \frac{Cv^2}{2g} \qquad (3)$$

2) Dynamic loading due to wave actions: not all flood events have associated wave actions, but when they do the impact can be substantial. The impact of non-breaking waves is a cyclic increase/decrease in water levels adjacent to a structure. These peaks (troughs) increase (decrease) applied pressures by up to 100% (40%) of hydrostatic (Kelman and Spence, 2004). The result of this dynamic loading could be short periods of substantial differential pressures across a wall. The impact of breaking waves is potentially even worse, with a possible increase in dynamic pressure loads of the order of 10–20 times (Kelman and Spence, 2004) the hydrostatic pressure. Fortunately river flooding is seldom coupled with breaking waves, and indeed no reports of this action were found during the 2010–11 Eastern Australia flooding.

During recent flooding, significant hydrodynamically induced damage was reported in the Lockyer Valley. An example of gross structural failure, where an elevated home has been washed from its piers, is shown in Figure 11a. An example of hydrodynamic damage to a newer slab-on-ground home is shown in Figure 11b. The latter avoided displacement from its foundation but some level of façade and window/door failure did lead to extensive internal damage. In both instances the maximum external water depth was of the order of 2.0 m with an maximum average flow velocity of approximately 1.5 – 3 m/s (SKM, 2011).


(a)


(b)

**Figure 11: Flood damage to homes in Grantham. Considerable hydrodynamic actions played a role in the damage shown.**

## *3.3 Buoyancy actions*

Buoyant forces are vertical (uplift) loads applied to a structure or component when submersion occurs. Buoyant forces are a function of the volume, $V$ [$m^3$], of water displaced by an object, Equation (4).

$$F_B = \rho_w g V \tag{4}$$

If a lightweight building is sealed – that is, water cannot enter – small depths (tens of centimetres) of floodwater can generate uplift forces in excess of a building's weight, resulting in floatation. Figure 11a is an example where buoyant forces could have potentially reduced the capacity of gravity to hold the building to its piers, making displacement by hydrodynamic actions easier. Buoyancy is particularly an issue for elevated weatherboard style homes (HNFMSC, 2006), even in areas of relatively slow flow. Slab-on-ground brick homes are also subject to buoyant forces, but their weight generally ensures survivability. Indeed, the Hawkesbury-Nepean Floodplain Management Steering Committee (HNFMSC, 2006) suggests that differential hydrostatic pressure-induced failure of walls, doors and windows of double brick or brick veneer homes will likely occur before buoyant forces exceed structural weight.

When water levels are similar on the inside and outside of a building, buoyant forces become relatively small because the volume of displaced water is now only equal to the volume of building material. They can still be an issue for components though, with water and gas tanks being particularly susceptible if not appropriately anchored.

Buoyancy is in large part a hydrostatic action, but because it often requires hydrodynamic actions for the impacts of buoyancy to be detrimental it is included here as a separate action.

### *3.4 Debris actions*

Moving water can carry with it debris ranging from individual grains of soil to cars or even buildings. Three forms of debris action exist: static actions, dynamic actions and erosion (Kelman and Spence, 2004). The first two are discussed here, with the third covered in the following section.

Static debris actions occur when sediment is moved by floodwater and deposited in contact, internally or externally, with a building. A prominent type of static debris action is due to deposited soil loading left behind as floodwaters recede (Figure 12). This deposited soil will apply a vertical and lateral load to a building and its components. Non-kinetic actions associated with contaminants in deposited sediment are also of concern and discussed further in section 3.6. A further type of static debris action occurs when an accumulation of debris mass (e.g. tree branches) pushes against or becomes fixed to a building and increases its drag resistance to flowing water (HNFMSC, 2006). This can act to increase the loads on the structure as a whole or upon an individual component.

**Figure 12: Soil and other debris items deposited inside a flood-affected home in Grantham.**

Dynamic debris actions occur when floodwaters propel items onto a building. Dynamic loading can occur externally by, say, a floating tree or car, or internally by a couch or table impacting walls and ceilings. An example from Grantham of dynamic debris impact is shown in Figure 13, where a piece of timber fencing has been carried by floodwaters and impacted a home. The impact force is evident in Figure 13b where the support pier is shown to have moved in the order of 200 mm.

**Figure 13: Dynamic debris impact of a fence paling on a home. Right image shows the resulting lateral displacement of a pier foundation.**

## *3.5 Geotechnical actions*

Floodwaters can undermine the capacity of soils to effectively support building foundations. Geotechnical actions can occur through the processes of erosion, collapse of poorly compacted soils and swelling/shrinking of soils (HNFMSC, 2006). For new construction, issues resulting from the latter two are largely avoidable when appropriate construction practices are followed. However, for some older homes built prior to modern construction practice, some issues may exist.

Erosion actions can be detrimental when moving water scours soil around or underneath a foundation. This is particularly a problem when floodwaters are moving and soils are non-cohesive. A number of factors influence whether erosion will occur, but the main factors are soil grain size, flow velocity, flow depth, and potentially building shape and orientation. Erosion occurs when local flow velocities near the surface are large enough to pick soil particles off the ground and entrain them in the moving flow. The interaction between a moving fluid and building can induce local erosion as waters speed up as they are moving around the structure. An example of erosion around a house slab is shown in Figure 14. Seepage of water through soils or the impact of bouncing debris may also initiate erosion.

**Figure 14: Erosion around corner of foundation. Note the debris caught in the palings suggest a decrease in water depth and therefore an increase in water velocity around the edge of the home.**

### *3.6 Water contact actions*

One of the major sources of flood damage is the decay of building materials when they come into contact with water (HNFMSC, 2006). The extent of damage is linked to the depth of above-floor inundation, the duration of contact, the type of building material used and the presence of contaminants.

Depth of inundation is important because the greater the depth the more material is in contact with water. The link between this variable and damage costs, however, is not linear. HNFMSC (2006) gives the example that for a completely inundated single-storey slab-on-ground brick veneer home, up to 45% of damage costs are incurred before floodwaters reach 0.5 m of over-floor inundation. This occurs because damage to the floor and sub-floor structure, floor coverings, skirting boards, electrical outlets and wall framing will all have been initiated by this stage. A further 25% occurs as waters rise to the ceiling, and the remainder when floodwaters rise above this point and wet the ceiling and roof structure. The accumulation rate of damage costs is not identical for all building types, but the important point this example makes is that as soon as *any* over-floor inundation occurs, damage costs rise rapidly. The relationship between damage costs and inundation extent is explored further in section 5.3.

Some building materials are impervious to prolonged immersion, while others suffer irreparable damage after only short durations. A prime example of the latter is plasterboard. Selection of flood-resilient building materials can significantly minimise the extent and cost of damage incurred during flooding events. Several handbooks suggest types of material and specific building techniques that can be employed so as to reduce the likelihood of damage, but often they are not utilised because of their cost implications. A number of these methods are discussed further in section 4, and a list of relevant handbooks is given in section 6.3.6.

Floodwaters can be contaminated by sewage, petrol, industrial and household chemicals or fertilisers. When these substances come into contact with building materials they may cause chemical reactions that deteriorate the strength of the building materials. An example of a consequence of chemical actions is the rusting of connections. It is also possible for fumes from contaminated waters to deteriorate structural components. Interviews with a number of insurance cost assessors revealed widespread contamination (to varying degrees) during flooding in the Brisbane area.

## 3.7 Relative importance of actions

Kelman and Spence (2004) suggest the most important actions driving flood damage to a large population of buildings are inundation depth, differential hydrostatic pressure loading and hydrodynamic loading. Where internal flood depths rise at the same rate as external depths, inundation depth assumes more prominence because structural failure is unlikely. However, where differential hydrostatic or hydrodynamic loadings are present, their impact quickly supersedes inundation depth as structural failure ensues. Buoyancy can also be a factor affecting large populations of buildings but is highly dependent on building type. For older style ‘Queenslander’ homes, buoyancy is a significant issue. Contaminant actions could also be an issue for large populations of buildings should large volumes of sewage or other chemicals make their way into major waterways. Thieken et al. (2005) highlight an example of this in Germany, where large volumes of oil impacted buildings, subsequently increasing damage cost by approximately 300%. Soetanto and Proverbs (2004) also believe contaminant actions are important, as is the duration of inundation.

In practice, any of the actions discussed in this section could be the factor that drives damage on the level of an individual building. Therefore all must be considered in the design process. For estimating or predicting damage to a population of buildings, those actions listed in the previous paragraph will be of greatest assistance.

# 4. METHODS FOR PROTECTING BUILDINGS FROM FLOOD ACTIONS

Numerous guidance documents or handbooks exist to assist people wanting to build structures with some level of flood resilience or resistance (FEMA, 2009; HNFMSC, 2006; USACE, 1997, 1993, e.g., 1988). These documents, in essence, provide three philosophical approaches to minimising flood impacts: displacement, barriers and wet flood proofing (USACE, 1997). These are briefly discussed in the following three sub-sections, with reference given to appropriate documents for sourcing further information. Whether a given building owner would implement any of these would be dependent on the owner's financial situation, use of building (e.g. residential or commercial), lifestyle concerns (e.g. aesthetics of mitigation works) and the severity of the flood problem at their location (e.g. 1% risk of 10 cm flood depth or 1% chance of 2 m flood depth). A prudent cost–benefit analysis of different mitigation options would aid decision making on the most appropriate method for any given situation (USACE, 1993).

## *4.1 Displacement*

This methodology involves elevating or relocating a structure so floodwaters cannot reach damageable areas. It could involve lifting or building a structure with the lowest floor level above the height to which floodwaters have risen or are expected to reach. If the site is at risk of flash flooding or other high velocity flows, special care must be taken that these waters can pass underneath the building relatively unimpeded. To what elevation a building is lifted is often dictated by local planning authorities, who will set a minimum floor level based on the highest recorded flood level or a flood with a predefined annual exceedance probability (AEP) (typically 1%). Although any increases in the elevation of a building will minimise its flood risk, unless lifted to a suitable height, say beyond the 1% AEP, the financial benefit of construction work may not exist. Cost effectiveness also varies between building types, with lightweight timber clad and framed housing much cheaper than slab-on-ground brick buildings to lift. Some examples of lifting the latter do exist (USACE, 1990), but in most instances this work would not prove economically beneficial. Figure 15 shows an example of a home in Emerald (Queensland) being lifted above the recent flood depth. Lifting of a home similar to this in Brisbane would typically cost in the order of $30,000–$50,000 (Chi-Hsiang Wang 2012, Commonwealth Scientific and Industrial Research Organisation, pers. comm. 8 October).

**Figure 15: Example of elevation as a method of flood proofing**

Relocating a building to a part of the property where floodwaters are not expected to reach is another displacement technique. In some instances relocation could also mean moving a building to another property. Relocation is often extremely costly, requiring new foundations, new connections for building infrastructure (i.e. plumbing and electricity), new landscaping, and many other issues. Internationally, a number of government-funded relocation programs exist (USACE, 1997) to encourage relocation from flood-prone land, and following the flash flooding in Grantham a land-swap program was initiated to move people from the worst affected area (Lockyer Valley Regional Council, 2011b). For relocation to dramatically reduce the risk of flooding to a community, significant government intervention and funding is required. A number of government-funded schemes do exist around the country, for example, Brisbane City Council, but have been met with limited success, high costs and long lead times.

## *4.2 Construction of barriers*

Barriers can be used to stop floodwaters reaching a building. Barriers can either be freestanding and built away from the protected building (structural flood defence), or can be built as seals on the home itself (dry flood proofing). The idea behind both systems is to keep water outside of a building while having the habitable floor level below the expected flood height.

### *4.2.1 Structural flood defence*

Permanent freestanding barriers can be in the form of berms, levees or floodwalls. Berms and levees are compacted earthen structures constructed around a building or near rivers with the goal in both cases to keep floodwaters away from buildings. USACE (1997) suggests that given the land requirements to build these structures, if expected flood levels are above 6 ft (1.8 m) these mitigation devices are not suitable.

Non-earthen, temporary levee systems can also be constructed given suitable warning time and labour (e.g. Figure 16). These are potentially a cost-effective method for protecting large areas, or individual homes, while still maintaining current land use in non-flood times. While these mitigation devices are relatively new to Australia, they have been used successfully throughout Europe and the UK.

Permanent floodwalls are typically anchored reinforced concrete structures built to surround a building. These barriers take up less room than berms and are less susceptible to erosion, but do have associated aesthetic disadvantages and greater costs. In all instances sewage and plumbing systems with connections to external networks must be fitted with cut-off or reflux valves (or similar) to ensure backflow flooding does not initiate through these systems. An example of a floodwall built by a homeowner in Emerald (Queensland) is shown in Figure 17. This wall was built to 0.5 m above the 2011 flood depth and came at an estimated cost of $100,000. As could be expected, a cost–benefit analysis of individual residential property floodwall construction would in most instances suggest an overall cost to the owner. This may not be the case for commercial or industrial buildings, where the value of contents is significantly higher.

**Figure 16: Temporary flood levee in Charleville, Queensland**

Source: (Knowles, 2011)

**Figure 17: Example of floodwall built around a home in Emerald**

### *4.2.2 Dry flood proofing*

The process of sealing a building to water entry is known as dry flood proofing. All openings such as doors, windows, vents, weepholes and drainage systems below a specified expected flood level require permanent or removable water barriers. In instances where wall materials are permeable (e.g. brick), wall linings would also be required. These may not be needed if flood duration is expected to be short. By its basic principle, dry flood proofing ensures a hydrostatic pressure difference across all external walls will occur (section 3.1). To avoid structural failure USACE (1997) suggests this method only be used on residential buildings where the expected flood level is below 0.9 m and suggests a structural engineer be engaged to assess the ability of an individual building to withstand these loads. An engineer would also likely need to be engaged following a significant flood event to ensure structural integrity had not been compromised. In the Hawkesbury-Nepean region, the HNFMSC (2006) recommends dry flood proofing not be used on residential buildings because expected flood levels are in excess of the limits mentioned above. CSIRO (2011) suggests a shallower maximum flood depth of 0.5 m for Australian brick homes if dry flood proofing is to be implemented. In practice, dry flood proofing is only possible in areas where flood warnings provide enough time for erection of all non-permanent sealings. This means dry flood proofing is not suitable for areas susceptible to flash flooding. FEMA (2009) also highlights the inability of most dry flood proofing techniques to account for the impacts of hydrodynamic or debris impact loading and suggests prolonged periods of inundation would likely fail some components of the system. One of the simplest forms of non-permanent dry flood proofing is sandbagging, which is widely practiced throughout Australia. However, many people interviewed for this project felt sandbagging was not particularly effective and the time spent preparing this defence could be better spent relocating contents.

Following the 2002 Elbe flooding in Germany, Kreibich, Thieken, Petrow, Müller and Merz (2005) report a 29% decrease in damage to homes that successfully implemented temporary local water barriers.

## 4.3 Wet flood proofing

Wet flood proofing involves the modification of a building to allow floodwaters to enter during a flood event while minimising the impact to the structural system and, where possible, contents. Unlike dry flood proofing, wet flood proofing is designed to avoid the detrimental impacts of differential hydrostatic pressure loads. Therefore, it is imperative that in wet flood-proofed buildings, suitable provision be made to ensure water can enter at a rate commensurate with external water rise. With specific reference to housing, HNFMSC (2006) suggests that a differential depth no greater than 300 mm should be allowed at any time during the flood rise and fall to ensure structural safety. To do this, specific care must be taken in designing openings for the water to enter. HNFMSC also suggests that for slab-on-ground type housing the most efficient method for achieving suitable inflow rates is through floor drains in ‘wet areas’ such as bathrooms and laundries. Additionally, increasing the number of external and internal wall vents, adding weepholes, or the inclusion of hinged ‘pet doors’ are suggested as further measures for increasing flow rates of water into and out of a home.

While wet flood proofing reduces loading of a building’s structural system, more elements are wet during a flood event than in the barrier or displacement methods. Those components (e.g. framing, flooring, cabinetry) expected to be in contact with water should therefore be constructed using flood-resilient materials to minimise the financial impact and ensure their continued structural capacity. Examples of typical Australian housing material performance under four days of inundation are given in HNFMSC (2006) and replicated in Appendix 2; tables such as this can be used as a guideline for designers. A further consideration during wet flood proofing is to ensure that electrical, services equipment and contents are above the expected flood depth unless designed for submersion. Moveable objects can be placed on tables or in overhead storage spaces, but all permanent items, for example circuit boards, should be built as high as reasonably (and legally) possible. Protection of commercial and industrial building contents under a wet flood proofing scenario will likely require special consideration.

A final consideration for wet flood proofing is the clean up. Whenever floodwaters enter a building there will be associated clean-up cost and potential relocation required depending on the severity of flooding.

If considered at the time of design, HNFMSC (2006) suggests an additional cost of between $4,000 and $17,000 (2006 estimate) is required to wet flood proof a typical New South Wales single- or double-storey brick veneer home. In the event of a 1.2 m flood, these works are expected to reduce damage by between $7,000 and $50,000 respectively. This level of damage reduction was indeed observed by Kreibich et al. (2005) for flooding in Germany, where homes suitably constructed with water ingress and egress in mind suffered around 50% less damage to the building and contents than similar homes not designed for these actions.

Where expected flood levels are greater than the thresholds given in section 4.2.1, wet flood proofing will more than likely be the most cost-effective option for protecting a home. Depending on the contents, this may not be the case for a commercial building.

# 5. ANALYSIS OF DAMAGE DATA

## *5.1 Introduction*

The recognised standard for analysing potential direct flood impacts on urban structures is through families of stage-damage, or vulnerability, curves (Smith, 1994, 1981). These curves relate specific flood characteristics, typically water depth, to a mean expected damage, that is, financial impact, to a given structure or region. This approach can be extended to analysis of damage to building contents, infrastructure, agricultural crops or even societal impacts, and can be aggregated to larger geographical areas for estimates of regional damage/loss. Two approaches exist for development of vulnerability curves: synthetic and empirical development.

The ***synthetic*** approach involves the theoretical summation of potential damage costs to a given structure and its contents for a range of different inundation depths. This generally involves cost assessors evaluating and summing potential imposed costs room-by-room and element-by-element. The advantage of this approach is that no flood event is needed for vulnerability curve development, and the methodology can readily be extended to an almost infinite range of building and occupancy types; the latter is especially important for assessment of commercial and industrial assets. In practice, however, a finite number of building and occupancy types have to be chosen and some approximations are required. Synthetic vulnerability curves also reflect the 'potential' damage, where issues that can affect losses – such as flood warning, flood history, precautionary measures – are not incorporated. To account for this deficiency, additional multipliers are often used to adjust potential to actual loss (McBean, Gorrie, Fortin, Ding, and Monlton, 1988; Penning-Rowsell and Chatterton, 1977; Smith, 1994; Thieken et al., 2005).

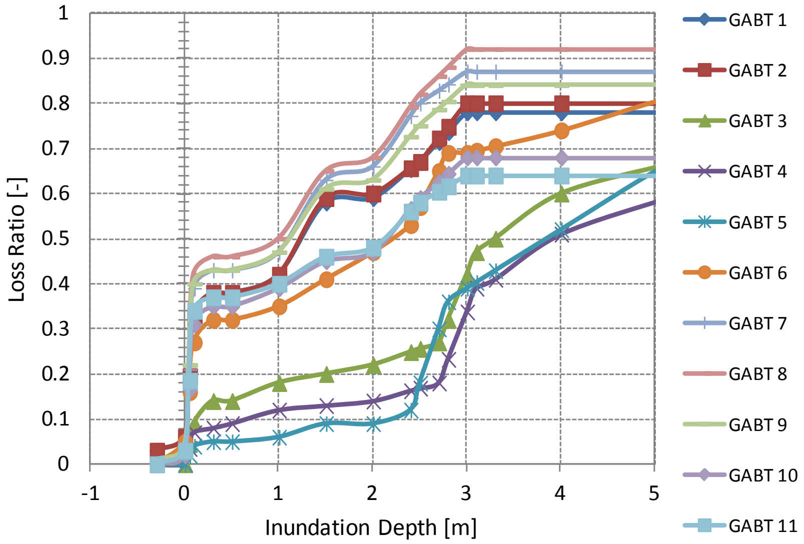
Within Australia the most widely cited example of synthetic vulnerability curve development is that embodied within the ANUFLOOD model built during the 1980s at the ANU (Smith and Greenway, 1988). This model was based on that developed in the UK by Penning-Rowsell and Chatterton (1977) and includes synthetic potential loss curves constructed based on valuation surveys in flood-prone areas of the country and has been extended from exclusive use in the residential sector to incorporate commercial premises. More recently Geoscience Australia (GA), funded by the Department of Climate Change and Energy Efficiency, has embarked upon a project to develop a range of synthetic vulnerability curves for contemporary Australian residential buildings and their contents (Martin Wehner 2012, Geoscience Australia, pers. comm. 14 April). These GA curves are used for potential damage assessment in this report and are briefly described below.

The GA synthetic damage curves were developed to assess the impact of riverine flooding on Australian residential building types. A quantity surveyor was used to estimate damage costs to 11 generic house types for 10 different inundation depths (Table 2). For each generic building type the structural system was broken into its constituent parts, and repair work was priced per component and then summed per building for each inundation depth. Similarly, generic residential contents were catalogued and priced for replacement or repair at each level. In a further step, additional curves were developed for insured and uninsured buildings on the assumption that home owners would act differently to save or repair more items if they were uninsured, thus reducing the vulnerability at any given flood level. For contents damage yet another set of curves was developed to account for moral hazard, where it was deemed that owners may act opportunistically to increase damage by placing items at elevations with greater risk of flooding. All vulnerability curves are directly related to above-floor inundation depth and no other flood characteristic.

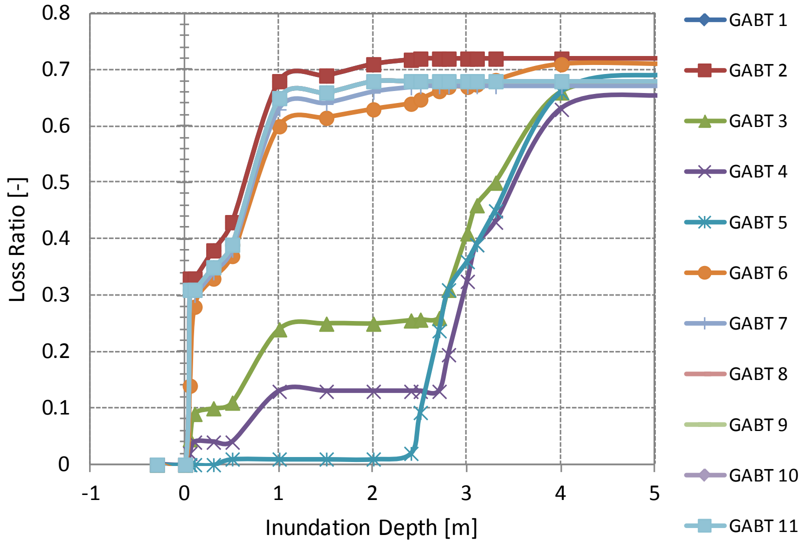
The set of synthetic curves describing insured damage to building and contents where no action was taken to either save or destroy contents was chosen for use in this report. These curves are shown in Figure 18a and 18b as ratios of damage cost to repair/replacement cost for building and contents damage respectively. Distinct groupings of curves are evident for similar building types.

**Table 2: Geoscience Australia general building types and descriptions**

| GA Building Type (GABT) | Attributes |
|---|---|
| **1** | Single storey, raised floor, weatherboard cladding (Queenslander style), no garage, hard board internal lining |
| **2** | Type 1 with timber internal lining |
| **3** | Two storey, slab on ground, concrete masonry lower storey, weatherboard upper storey, no garage, plasterboard internal lining |
| **4** | Type 3 with garage |
| **5** | Two storey, slab on ground, weatherboard cladding, partial lower storey, plasterboard internal lining |
| **6** | Two storey, raised floor, weatherboard cladding, no garage, plasterboard internal lining |
| **7** | Single storey, slab on ground, brick veneer, garage, plasterboard internal lining |
| **8** | Type 7 with no garage |
| **9** | Type 8 with raised floor |
| **10** | Single storey, slab on ground, concrete masonry cladding, no garage |
| **11** | Type 10 with raised floor |



(a)



(b)

**Figure 18: Geoscience Australia synthetic vulnerability curves for a) building damage and b) contents damage**

***Empirical*** vulnerability curves show the relationship between flood characteristics – again, typically inundation depth – and actual loss incurred during actual flood events. The use of actual damage data offers benefits over synthetic damage assessment (Merz, Kreibich, Schwarze, and Thieken, 2010) in that estimations as to what, and to what degree, elements will be damaged for a given inundation depth are not required. These data also allow an estimate of inter-type (say within building type 1) variability to be quantified in a manner that accounts for true variations that exist within a population, for example variability in building size and shape, without having to explicitly define their origins, magnitudes or correlations. This said, detailed damage surveys following flood events are often not undertaken or are not extensive (Smith, 1994). This means that vulnerability curves are frequently built from small datasets and extrapolated beyond observed flood heights when used to estimate the impact of greater floods. The transferability of these curves in time and space is also an issue, but this can be minimised if care is taken when characterising building type, and recording damage extent.

There are benefits to both synthetic and empirical approaches to assessing damage, so the use of one to extend or validate the other presents the optimal approach (Merz et al., 2010). Smith (1981) used this combined approach following flood events in Lismore (1974) and Forbes (1974), and it is used here for this analysis.

The aim of this section is to develop a set of vulnerability relationships, based on observations following the floods, applicable to typical Queensland residential buildings. In practice these curves may be transferrable to homes in other areas with similar building types. This will be particularly true for single storey slab-on-ground homes, which appear to be the standard ‘new home’ construction type throughout much of Australia. Curves may also be applicable to similarly typed buildings of differing use (e.g. commercial), but contents damage relationships are considered strictly residential (Gissing and Blong, 2004).

## 5.2 Data

Three main datasets were made available for this research: GA Damage Assessment Database; Queensland Fire and Rescue Services (QFRS) Rapid Damage Assessment Database, and Insurance loss (IL) data made available through a major national insurer. A subset of the GA and IL databases was used to adjust the Geoscience Australia synthetic vulnerability curves, and a subset of the QFRS database was used to proof these curves against independent damage data. Information within the QFRS database and developed vulnerability curves were then used to develop a displacement fragility curve that can be used as a baseline to predict the number of households that will require short- and long-term accommodation following a future flood event.

These datasets were originally compiled for different reasons and therefore have differing spatial and temporal extents and are comprised of differing attributes and perceived levels of accuracy. Components of these data important to the current research are discussed in the following sub-sections with possible limitations highlighted where relevant.

### 5.2.1 Geoscience Australia Damage Assessment Database (GA)

Teams of researchers compiled the GA Damage Assessment Database over two deployments to flood-affected areas of Brisbane, Ipswich and Grantham between 28 January and 10 February 2011. Team members were drawn from natural hazard researchers and assessors at GA, the National Institute for Water and Atmospheric Research (NIWA) (New Zealand), Risk Frontiers, Insurance Australia Group, the Queensland Government and the Indonesian Government. The primary objective of these assessments was to collect information on flood impact characteristics to a representative portion of the residential building stock affected by both slow rise and flash flooding for the development and refinement of a series of synthetic vulnerability curves (section 5.1) under development by the agency (Martin Wehner 2012, GA, pers. comm. 23 May).

Assessments were reported for 817 buildings: 514 in Brisbane suburbs, 265 in Ipswich and 38 in Grantham. Information was gathered either as a street-side survey with impact characteristics estimated by an assessor from the exterior of the building, or where possible, by internal and external examination. In the latter case interviews with property owners or occupants were often possible. All assessments were geo-referenced and multiple photographs were taken of each surveyed building.

Of the data collected, those characteristics utilised in the current study included (example characteristics are shown in parenthesis):

- Building address
- Building type (detached house, townhouse, duplex, elevated floor, single or multi-storey)
- Period of construction (Prior to 1950, 1950–1980, post 1980)
- Building dimensions
- Construction material (external walls: brick veneer, weatherboard; floor type: timber, concrete slab)
- Lowest storey floor height above ground
- Maximum flood inundation depth
- Flow velocity category (none, slow, fast)
- Signs of damage (settlement, scour, displacement, wall, window or door failure)
- Inundation of air conditioning, hot water system or fuse box.

Additional information on damage to internal materials was recorded but in many instances was incomplete so was not used for this analysis. Each assessor also assigned a level of confidence (high, medium, low) to each damage record and this information was used to assign possible errors to inundation depth measurements.
Some cleaning of inundation depth records was required where the assessor did not enter data. New depth data were entered if they could be inferred from neighbouring buildings or imagery. Where this was not possible a record was discarded. In all, the cleaned database is considered to have high accuracy, with an estimated error bound on maximum inundation depth of +/- 0.2 m if the assessor assigned a medium level of confidence and +/- 0.1 m if a high level of confidence was assigned.

Based on the building information listed above, each entry in the database was assigned a representative Geoscience Australia Building Type (GABT), as described in Table 2, so the appropriate synthetic GA vulnerability curves (Figure 18) could be used to estimate potential loss values. Assigned GABTs were cross-validated against photographs in an attempt to minimise categorisation discrepancies between assessors.

In addition to the GABT, each assessed property was assigned a Simplified Building Type (SBT), which is the more generic building classification system used for development of semi-empirical vulnerability curves in this report. SBT descriptions and corresponding GABTs are outlined in Table 3.

**Table 3: Simplified Building Type (SBT) attributes (residential) and equivalent GABT**

| Simplified Building Type (SBT) | Attributes | GABT |
|---|---|---|
| **1** | Single storey, raised floor, weatherboard cladding (Queenslander style) | 1,2 |
| **2** | Single storey, brickwork cladding (notionally slab on ground) | 7–11 |
| **3** | Two storey all wall types (this type includes elevated and built-under Queenslanders) | 3,6 |
| **4** | Type 3 but with the lower storey partially built under or used as a garage | 4,5 |

Using the GABT, synthetic vulnerability curves and recorded inundation depth, an estimate of potential loss to building and contents was calculated for surveyed buildings. A subset of these data is presented in Figure 19 and by definition follows the range of curves presented in Figure 18. It is evident that the assessment database covers a wide range of inundation depths, allowing a full analysis of the assumptions used to derive the synthetic curves.

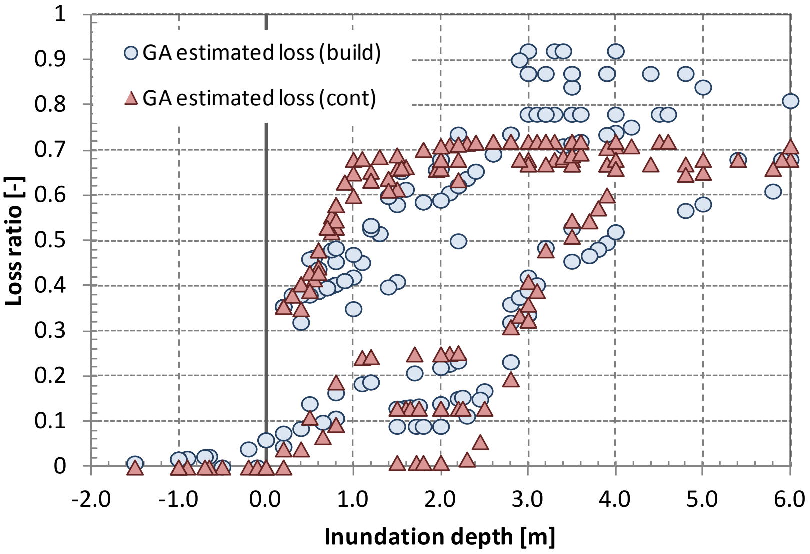


**Figure 19: Estimated potential losses to a subset of surveyed buildings based on measured inundation depths and the application of GA vulnerability curves (Figure 18)**

### *5.2.2 Queensland Fire and Rescue Services Rapid Damage Assessment dataset (QFRS)*

The QFRS rapid damage assessment (RDA) data were compiled in the week following the floods (largely undertaken 14–17 January 2011) to assess the immediate and long-term safety and needs of affected communities (Queensland Government, 2011). Flood impacts were assessed on a property-by-property basis by trained assessors from the Queensland Fire and Rescue Service and the Queensland Reconstruction Authority (Peter Timmers 2012, Department Community Safety, pers. comm. 18 May). The aim of these assessments was to rapidly provide information on damage to housing, infrastructure and property to support disaster declaration, response and recovery decisions to be made by government and its agencies.

RDAs were conducted following all major flooding events throughout Queensland in early 2011. As may be expected, this generated a dataset covering an exceedingly large geographical area, so given the foci of this analysis are the Brisbane and Ipswich areas, only these portions of the supplied QFRS database were considered. There were 5221 RDA reports available for Brisbane suburbs and 678 for Ipswich. Around 75% of records had at least one photograph and/or additional assessor comment associated with the assessment.

Given the rapid acquisition and large sample size of the QFRS database, the level of detail and expected accuracy in each record is less than in the GA dataset. Despite this, the following information was extracted from these data:

- Building address
- Building use (residential, commercial)
- Number of storeys
- Floor area (estimated and not consistently recorded)
- Construction material (external façade and roof materials only)
- Highset or lowset
- Flood inundation depth above lowest floor
- Damage state (not damaged, minor, medium, severe, destroyed)
- Habitability (whether the building is habitable at the time of assessment)
- Potential hazards (e.g. biological, electrical, collapse)

From these data a Simplified Building Type (SBT) could be assigned (Table 3). Above-floor inundation depth was highlighted as a possible source of uncertainty as there was some reported misunderstanding between assessors as to whether depths were measured above floor or above ground level (Peter Timmers 2012, Department Community Safety, pers. comm. 18 May). It is evident when comparing measured inundation depths at the same buildings within both the GA and QFRS databases (Figure 20), that there is significant scatter between datasets but no clear positive or negative bias.

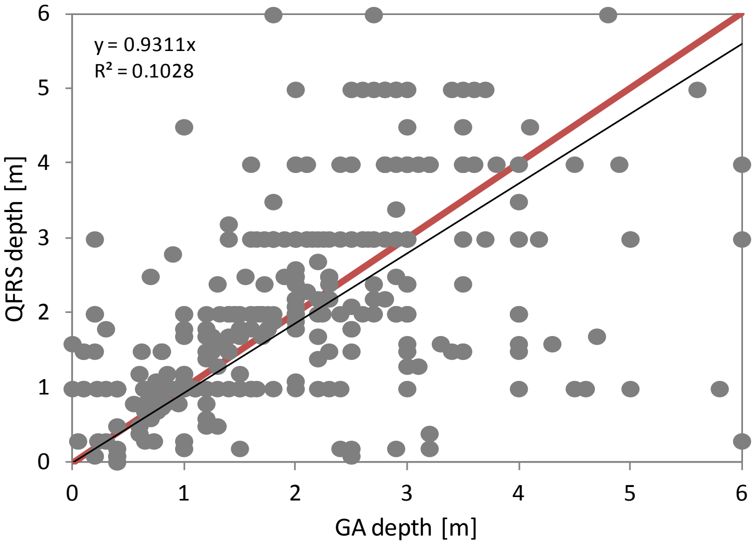


**Figure 20: Above-floor inundation depths recorded for buildings with entries in both the Geoscience Australia and QFRS databases**

### 5.2.3 *Adjusted Loss Ratio (ALR)*

Insurance claims data were provided for residential policies in suburbs of Brisbane, Ipswich and the Lockyer Valley. Loss information was available for several thousand locations within these regions. Information available for each policy was:

- Policy address
- Total sum insured (TSI)
- Value claimed to date (April 2012; assumed to be completed)
- Policy type (building only, contents only, building and contents) was available for a portion of the database. Where this information was not available a policy type was assumed based on the TSI.

Given that the portion of each claim attributed to building and contents (within a building and contents policy) was not available, a statistical distribution taken from historical flood loss experience was used to apportion these data.

The value claimed divided by the TSI is a standard measure of reporting a normalised *Loss Ratio* as a metric for describing the proportion of damage incurred at a given location (be that an individual property, suburb, etc.). This approach is largely followed here because a non-dimensional reporting method provides greater transferability of results across space and time than the more direct method of working in true dollar values (Merz et al., 2010).

It is, however, important when considering normalised insured losses to appreciate that these values are not truly representative of actual loss ratios. One reason for this is that while the value claimed is subject to any post-event inflation (often referred to as demand surge) the TSI is not. This means that loss ratios calculated simply on the raw values are possibly an overestimation of the impact, in relative terms, the flood had on a building. In an attempt to remedy this, an *Adjusted Loss Ratio* (ALR) is developed using loss values modified to account for post-event inflation in building labour and material costs. Further, the ALR makes use of adjusted TSI values to account for the acknowledged issue of underinsurance (ASIC, 2005). These adjustments are described in the following paragraphs.

Construction industry reports suggest an increase in construction costs of between 2% and 5% (Awad, 2011; Brandtman, 2011; Brisbane Business News, 2011; Rider Levett Bucknall, 2011) in the Brisbane area during early 2011. There will have been some localised variation upon this range, with more remote areas typically experiencing greater increases (e.g. Emerald), but in general this increase is considered relatively uniform for the Brisbane and Ipswich areas. Accordingly, a 4% reduction is applied to the loss value for each building policy. No increase is applied to contents policy values, though it is acknowledged that there may have been increases to the cost of purchasing and installing carpets that are generally considered under these policies.

Underinsurance is an acknowledged by-product of an insurance system based on ‘sum insured cover’ (NDIR, 2011). Most homeowners are unaware of the true value of their home or contents and systematically underestimate, and therefore underinsure, their value. ASIC (2007) suggest this issue is improving, but acknowledge it is still substantial. Referring to work by Reed Business Information Systems (unpublished) and the Insurance Council of Australia, ASIC (2005) report that during the early 2000s between 27.5% and 81% of the insured population were underinsured on their building policy to a level of 10% or greater. The mean level of underinsurance, based on the Reed work, is reportedly 34%. The Insurance Council of Australia values imply a mean level of underinsurance less than 10%. No single definitive or justifiable level of underinsurance exists and the disparity between these two studies simply exemplifies the difficulty in estimating a value.

The uncertainties expressed in the previous paragraph notwithstanding, in order to represent a ‘true’ loss ratio an adjustment is made to both building and contents TSI values. Considering reports that the level and extent of underinsurance is improving (ASIC, 2007), and validating this with increases in relative average TSI for the current insurance loss database (adjusted with a measure of increased building value over time, Crompton and McAneny (2008)) when compared with the Reed average TSI for 2000 of approximately $192,000, the average level of building underinsurance is set to 15%. Given the reported wide bandwidth of underinsurance levels it is unrealistic to apply this adjustment as a fixed value to all reported TSI values, so reported building TSI values are divided by a randomly sampled multiplier taken from a normal distribution with a mean value of 0.85 and a standard deviation of 0.18 (on top of the demand surge increase discussed above). This distribution implies that 60% of building policies are underinsured by greater than 10%, and 20% are underinsured by greater than 30%.

Even less information is available for underinsurance of contents policies, but it is widely accepted that homeowners severely underestimate (more so than for their buildings) the value of their contents (ASIC, 2007; Dr George Walker 2012, Aon Benfield, pers. comm. May). To account for this, the underinsurance divider for contents polices is a normal distribution with a mean of 0.65 and a standard deviation of 0.2. There is considerable uncertainty in the setting of the building and the contents underinsurance levels and a sensitivity analysis in section 5.3.1 investigates the implications for the resulting vulnerability curves.

Some of the claims data will include a component of accommodation costs incurred while a home is being repaired. Unfortunately, no information on the number of policies or proportion of claims including this was available so no adjustment has been made. Consequently, ALR values may include some component of this cost.

In effect, the process described generates a set of ‘possible’ loss data based on an assumption (drawn from a normal distribution) made as to the level of underinsurance at each property. To account for the fact that this randomly sampled assumption will almost certainly be incorrect, 99 further realisations are generated to create an ALR dataset that consists of 100 ‘possible’ losses for each property.

Privacy constraints restrict the reporting of actual loss data in this report.

### 5.2.4 Other data sources

For assessed buildings in Grantham, flow velocity information was estimated using output from a numerical model (TUFLOW) simulation of the flash flooding event of 10 January 2011 by the consulting firm Sinclair Knight Mertz (SKM) undertaken for the Lockyer Valley Council (SKM, 2011). These data were extracted from grid cell and depth-averaged peak velocity maps within that report. An average of the upper bound of velocity contours within a 20–50 m radius was used as the estimated velocity for each entry.

There is little scope for validating simulated velocity results against actual measurements – none were taken – but when comparing simulated maximum inundation depths with measured depths at a range of locations throughout Grantham, SKM (2011) report an accuracy of within 0.3 m. This gives some insight into the accuracy of their model output. For further details of the hydraulic model setup the reader is referred to the original SKM report.

### 5.2.5 Data intersections[3]

For the analysis in section 5.3 an ALR value is required for coupling with each synthetic GA loss ratio. Using address information, intersection of the GA and ALR databases produces 192 independent entries spanning Brisbane and Ipswich suburbs.

Table 4 shows the number of independent entries in each GABT category. The most populous GABTs are 1 (37%) and 4 (17%), which represent the typical ‘Queenslander’ home, with the latter being those homes raised and built under. GABT 7 and 8 represent single storey slab-on-ground homes and comprise 19% of the population. Of the population, 40% were two-storey buildings. All records from Grantham were removed for the analysis in section 5.3 because the high velocity flows will have instigated different damage modes than the slow rising floods considered in the synthetic curve development by GA.

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[3] Mathematically, the intersection of two databases is a database made up of entries common to both. That is, the intersection of the GA and ALR databases is a list of buildings that have information contained in both.

**Table 4: GABT and policy type counts for independent intersections between ALR and GA databases**

| GABT | SBT | Policies |
|---|---|---|
| **1** | 1 | 71 |
| **2** | 1 | 0 |
| **3** | 3 | 16 |
| **4** | 4 | 33 |
| **5** | 4 | 16 |
| **6** | 3 | 12 |
| **7** | 2 | 20 |
| **8** | 2 | 16 |
| **9** | 2 | 8 |
| **10** | 2 | 0 |
| **11** | 2 | 0 |

For the vulnerability curve validation in section 5.3.4, an independent subset of data is generated through the intersection of the ALR and QRFS datasets. This subset is also used for developing the displacement fragility curves in section 5.4.

## *5.3 Developing and validating simplified vulnerability functions*

As outlined in section 5.1, adjustment factors accounting for warning time, the community's flood experience and preparatory behaviour are typically used to transform potential loss values to actual losses. Examples of the structure of these factors are given in Smith (1994), highlighting the loss dependence not only on warning time and experience but also flood depth; less reduction in losses is possible as the mean flood depth increases. Read Sturgess and Associates (2000) summarised available adjustment information for 11 Australian floods (based on Smith et al. 1990) and show a range of mean overall adjustment values between 0.35 and 0.9 (the uppermost value is for historical flooding in Brisbane). Figure 21 plots these mean factors against warning time. The proposed *Experienced Community* and *Inexperienced Community* curves are those recommended for adjusting potential to actual damage in flood loss analysis of Queensland homes (NRM, 2002).

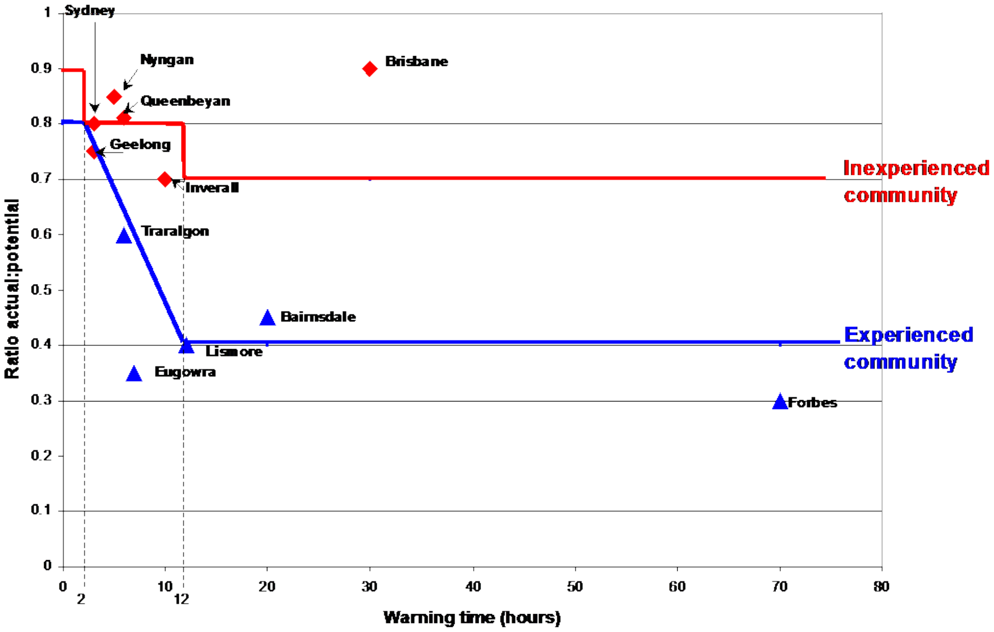


**Figure 21: Adjustment factor for converting potential to actual loss**

Source: (Read Sturgess and Associates, 2000)

### *5.3.1 Synthetic curve adjustment factors*

By comparing Estimated Loss Ratios based on measured inundation depth and the GA synthetic vulnerability curves with actual loss ratios taken from the ALR database, a set of adjustment factors can be derived. The methodology chosen for estimating these factors was to plot ALR values against estimated synthetic GA loss ratios and fit a linear regression to these data. This process was repeated for all 100 realisations of the ALR data and the optimal fit was chosen as the realisation that maximised the $r^2$ fit parameter. The validity of this fitting procedure is based on the premise that the GA synthetic curves are inherently representative, even if not precisely so, of the damage that is truly occurring. The random sampling process is then searching for the *true* combinations of measured depth, underinsurance, and so on, to optimise each fit.

Where limited data exist it is possible the proposed methodology may artificially generate a good fit to an unrepresentative realisation. To overcome this the top five regression fits were studied in each case and if not all similar the most appropriate (similar intercept and gradient to a linear regression through an aggregate dataset of all building types) of the five was chosen. Linear regressions were fit for the entire loss ratio range (i.e. 0 to 1; therefore all depths) and over inundation depth, *d,* subsets ($d < 0.5$; $0.5 \leq d \leq 1.5$; $1.5 \leq d \leq 3.0$, $d > 3.0$) to ensure that the assumed single linear fit was reasonable. Regression fits for the four simplified building types and both building and contents data were carried out. GA loss ratios are calculated using vulnerability curves for the 11 different building types (GABTs) but are aggregated as in Table 4 to the four simplified building types (SBT) to maximise the number of data points. Derived adjustment factors are assumed to be applicable for each of the GABTs that make up the SBT.

A representative example of the analysis methodology is shown in Figure 22 for a subset of the building data. Individual points show the relationship between the estimated synthetic GA loss ratio and the ALR for a single realisation of data. This figure exemplifies three characteristics common to fits irrespective of building or damage (building or contents) type:

1. The GA potential damage functions overestimate actual losses (ALR) when they exceed approximately 0.2 but underestimate those below this point.
2. A single linear fit does reasonably well at describing the mean relationship between potential (GA) and actual (ALR) loss ratios when the GA estimate is greater than approximately 0.2. Below this value a line of steeper gradient and smaller intercept is sometimes more appropriate.
3. Significant scatter exists about the mean regression line. This scatter is, however, reasonably uniform over all loss ratios.

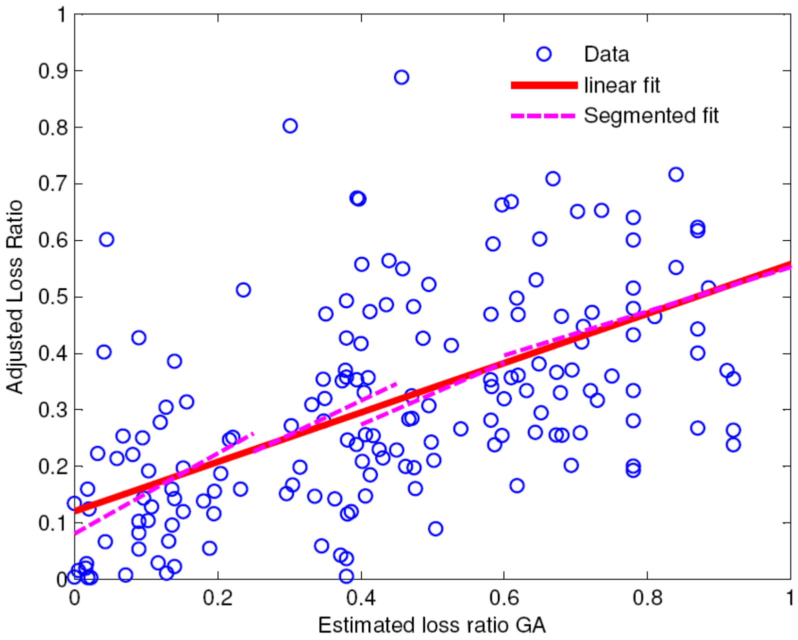


**Figure 22: Relationship between potential (Estimated Loss Ratio GA) and actual (Adjusted Loss Ratio) loss ratios for building damage**

Considering point 1, both observations are expected. The overestimation of actual losses is a feature of all potential loss estimates because by definition they assume no mitigation efforts take place. Some level of damage minimisation will almost inevitably occur in all instances where some level of warning exists (Smith, 1994). For minimising contents damage this could be raising or removing items, and for building damage this could be sandbagging entry points, thus minimising damage to internal wall, flooring or cabinet material. The underestimation at low loss ratios occurs because insurance policies, as used to derive ALR, include payouts for damage to items external to the home such as fences and driveways. Damage to these items was not considered during the development of the potential GA curves. It is expected that losses due to this type of damage will accrue at small inundation depths and will therefore increase losses above those of a synthetic derivation.

The appropriateness of a linear regression over much of the loss ratio range implies the potential damage curves are suitably capturing the damage process, if not the magnitude, observed in the field. The level of scatter is relatively uniform between building types but is greater for contents than building damage. This is expected given that there will be variability within the amount and value of contents people own within, say, a single building type. The fact that a finite number of building types are chosen means there will always be some level of scatter within any damage data because each building type includes homes of differing age, shape, size and flood preparation/experience, so there will always be some inherent difference in flood resistance. Quantifying this variance is therefore an important part of describing vulnerability but, unfortunately, is seldom done in flood risk studies (de Moel and Aerts, 2010; Merz and Thieken, 2009).

The chosen best-fit linear equation for mean regression lines relating potential (Estimated Loss Ratio GA) to actual building and contents loss ratios (ALR) for the four SBTs is given in Equation 5. In this equation $m$ is the gradient and $C_1$ and $C_2$ the intercepts. Fitting variables are given in Table 5.

$$ALR = m \cdot Estimated\ Loss\ Ratio\ GA + C_1 \qquad \text{for Loss Ratio GA} > 0.2$$

$$ALR = C_2 + \frac{ALR(0.2) - C_2}{Estimated\ Loss\ Ratio\ GA} \qquad \text{for Loss Ratio GA} \leq 0.2 \qquad \textbf{(5)}$$

**Table 5: Best-fit equation parameters**

| | SBT | m | $C_1$ | $C_2$ |
|---|---|---|---|---|
| **Building** | 1 | 0.60 | 0.07 | 0.05 |
| | 2 | 0.55 | 0.00 | 0.00 |
| | 3 | 0.55 | 0.10 | 0.05 |
| | 4 | 0.73 | 0.05 | 0.05 |
| **Contents** | 1 | 0.81 | 0.05 | 0.05 |
| | 2 | 0.80 | 0.00 | 0.00 |
| | 3 | 0.80 | 0.10 | 0.05 |
| | 4 | 0.85 | 0.10 | 0.05 |

The scatter of data around mean regressions is relatively uniform within building and contents datasets (i.e. across building types) and can be defined by a standard deviation of $\sigma = 0.15$ for building damage and 0.25 for contents damage. Given the relatively small sample sizes it is difficult to conclusively determine the most appropriate distribution for this scatter. De Moel, Asselman and Aerts (2012), based on Egorova, van Noortwijk and Holterman (2008), suggest a depth-dependent beta distribution is most suitable for describing damage estimates. The limited available data suggest this is reasonable for the current analysis and is recommended.

As discussed earlier, ALR derived from insurance loss data will include damage to landscaping, fences, driveways, and so on, and will manifest as rapidly accrued losses at small inundation depths. This is not accounted for in the synthetic derivation of potential loss curves and is believed to be one of the primary reasons the intercept values given in Table 5 are greater than zero. Therefore, in order to compare actual to potential loss ratios with those of previous work (Smith, 1994, e.g. 1981), these offset losses can, to a first approximation, be ignored and the gradient alone considered as the ratio between actual and potential losses.

Across building types, the building damage actual to potential ratio is between 0.55 and 0.73. Comparing this range with ratios shown in Figure 21, and considering more than 12 hours warning was available to all Brisbane and Ipswich suburbs, a greater loss reduction is generally seen than for the events in *inexperienced communities* (0.7 in Figure 21) but is less than for *experienced communities* (0.4 in Figure 21)*.* These reductions are certainly greater than the 0.9 reported for previous Brisbane flooding. For contents damage, the actual to potential ratio is somewhat greater and ranges from 0.8 to 0.85. This is closer to historical Brisbane experience and representative of an inexperienced community.

The magnitude of reduction in building damage (~0.6) is greater than expected given that little can be done to minimise damage to the building structure itself in the near-term prior to an event. This could occur because the general building stock in Brisbane/Ipswich is more resilient to flooding than the generic building types considered during the synthetic curve derivation. It may also suggest an overestimation of rebuilding labour and material costs following this event or an underestimation of the ability of current structural materials to resist flood impacts. Peculiarly, the adjustment factor for contents damage (~0.8) is greater than for building damage. The similarity between this value and ratios for other inexperienced communities shown in Figure 21 lends some confidence to the derivation of potential values. Further, the relatively high ratio, suggesting little remediation action was taken to reduce damage to contents, is perhaps not surprising given the vast area flooded and the focus of the survey on areas with relatively deep flood depths. It may be reasonable to assume that areas with only very shallow flooding were able to save relatively more contents.

Before reading too much into these comparisons it should be stated that all historical ratios were derived using ANUFLOOD potential loss estimations, while for the present work the GA potential loss methodology is used. There are differences between the two estimation techniques and therefore it is expected that there may be some variability in the ensuing levels of reduction. In addition, the transformation process used to convert actual insured losses to more *realistic* ALRs has some uncertainty. In an attempt to quantify this potential error, sensitivity tests were run where the level of underinsurance (the most uncertain component of the adjustment process) assumed for both building and contents policies was moved to what were considered their realistic upper and lower limits and the resulting impact on fit parameters analysed. These tests suggest potential errors in actual to potential ratios due to an inappropriate assignment of underinsurance range between +/- 10%.

### 5.3.2 Simplified vulnerability functions

Using adjustments outlined in section 5.3.1, a set of simplified vulnerability curves was developed for use in estimating the direct tangible economic impacts of future flood events. Prior to flood events, floodplain planners and managers could use these curves, together with hazard and exposure information, to estimate their community flood risk. Or, in the immediate aftermath of an event, emergency services could use them to rapidly estimate the economic impact or help determine levels of assistance required in affected areas.

The simplified vulnerability curves presented here are in essence adjusted versions of the GA synthetic vulnerability curves based on the damage experience in Brisbane and Ipswich. This means that they embody the theoretical structure and progression of damage contained in the theoretical derivation while tempering final damage values with empirical observations. Inherent in these curves, therefore, is an account of present day warnings, evacuation and resident behaviour in Brisbane/Ipswich, or indeed in any other similarly inexperienced flood community. The transferability of these curves to external communities without further adjustment has not been tested but will be in the future.

Vulnerability curves are presented as normalised total loss curves; that is, they include building and contents damage presented as a proportion of their total combined value, for the four SBTs outlined in Table 3. The full 11 GABT categories used by GA are not used because it is rare that this level of building information is available to a risk assessor. Similarly, the division of building and contents on an individual home or community level is unlikely to be available so a range of potential combinations have been considered in the development of total loss curves. Finally, replacement cost and not depreciated asset costs (Merz et al., 2010) are used for curve development as this is more representative of the true cost to the community of reinstating life to its pre-flood state following an event.

Figure A3-1 (Appendix 3) shows the adjusted (section 5.3.1) mean building damage loss ratio curves for the 11 GABTs grouped into their four SBTs. Figure A4-2 shows similar curves for mean contents damage. In both figures the overlain red curve is a simplified fit used to represent the subset of curves making up each SBT. These red curves are the building and contents components of the total loss vulnerability curve for each SBT. The empirically adjusted curves within SBT 1, 2 and 4 are shown to be reasonably similar and can confidently be represented by a single curve (in SBT 2

GABT 10 and 11 are largely ignored because these are rare building types). For SBT 3 an average between GABT 3 and 6 is used despite their apparent differences. Further interrogation of the ALR for these two GABTs suggests this is reasonable given the adjusted synthetic curves (both modified using the same adjustment curves and therefore unable to move in relation to each other, as explained in the previous section) on average overestimate losses for GABT 6 and underestimate losses for GABT 3. For simplicity it is assumed that the averaging process adds no further uncertainty to the distribution of damage values about these mean curves and those presented in section 5.3.1 are again adopted.

To build the total loss ratio curves, the representative SBT curves (mean and uncertainty) for building (B) and contents (C) were combined through simulation using Equation (6) and assuming (perhaps naively) no correlation between random variables. *R* represents the distribution of possible combinations of building value/contents value ratios derived from the ALR database and expert judgment (Blong, 2002). A mean value of *R* = 0.7 is chosen. Resulting mean total loss curves are presented in Figure 23 using Equation (7) to develop an easily codable fit ($r^2 > 0.99$) to the combined multi-linear curves shown in Appendix 3. Although the final distribution about each curve is not truly beta, it is still reasonably represented by such an approximation. For simplicity, the approximations to the beta distribution constants α and β proposed by Egorova et al. (2008) can be used. A constant *k* value of 0.14 is proposed to reasonably represent σ = 0.14 to 0.18 as observed in the loss data.

$$Total\ Loss\ Ratio = R \cdot B + (1 - R) \cdot C \qquad \textbf{(6)}$$

$$\begin{aligned} Total\ Loss\ Ratio &= \Delta + \alpha_1 {d_1}^{\beta_1} + \alpha_2 {d_2}^{\beta_2} && \text{for } d_1 \geq 0 \text{ m} \\ &= \Delta + 0.01 d_1 && \text{for } d_1 < 0 \text{ m} \qquad \textbf{(7)} \end{aligned}$$

where: Δ = total loss ratio at d = 0 m.

$d_1$ = above ground floor inundation depth. $d_1$ is truncated at 3 m for single-storey buildings (SBT 1 & 2) and $d_1$ = 2.6 m for two-storey buildings (SBT 3 & 4).

$d_2$ = above first floor inundation depth. Second-storey floor is assumed (following the GA curves) to be 2.6 m above the ground floor. $d_2$ has a fixed minimum of 0 m.

$\alpha_1$, $\beta_1$, $\alpha_2$, $\beta_2$ = fitting constants with values given in Table 6 for each SBT.

**Table 6: Fitting variables for Equation (7)**

| | SBT 1 | SBT 2 | SBT 3 | SBT 4 |
|---|---|---|---|---|
| **Δ** | 0.060 | 0.030 | 0.030 | 0.030 |
| **$\alpha_1$** | 0.350 | 0.345 | 0.240 | 0.100 |
| **$\beta_1$** | 0.300 | 0.310 | 0.260 | 0.400 |
| **$\alpha_2$** | - | - | 0.140 | 0.240 |
| **$\beta_2$** | - | - | 0.270 | 0.330 |

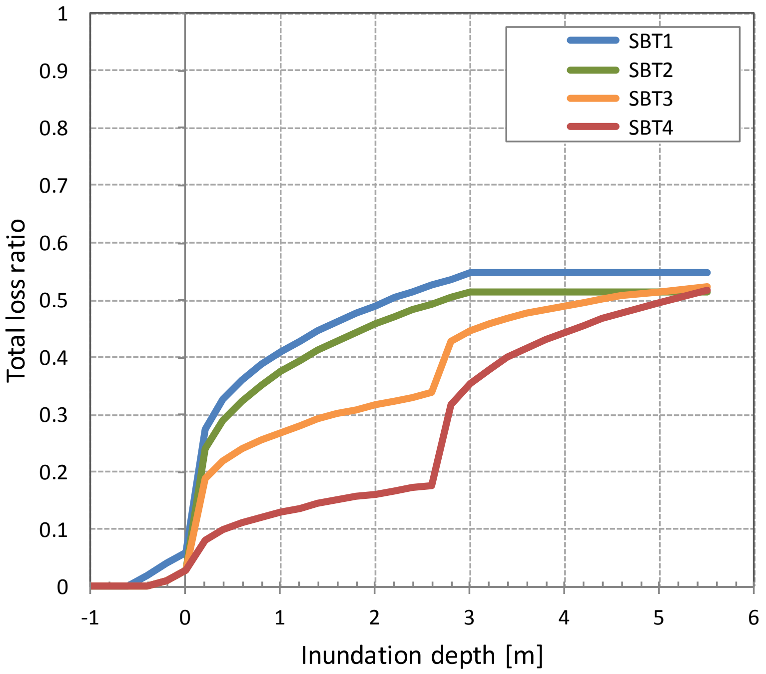


**Figure 23: Total loss ratio vulnerability curves for the four classes of simplified building type**

Despite the simplifications made to develop the total loss curves, their general form maintains some important physical characteristics noted during damage investigations, loss analysis and embodied in the synthetic potential damage curves.

- For SBT 1 (single-storey, raised floor, weatherboard 'Queenslander') loss ratios begin to increase before water reaches floor level. This is expected because damage to sub-building piles and foundations, as well as damage to contents stored under these homes, often occurs. For SBT 2–4, notionally all slab-on-ground homes, damage prior to over-floor flooding is less.
- For SBT 1–3 the most rapid accumulation of loss occurs during the first 0.5 m of over-floor flooding. For SBT 4 the worst accumulation occurs in the first 0.5 m above the second-storey flooring, as much of the home contents are expected to be on this level.
- Total losses in the absence of flowing water plateau at around 50% of the total value of home and contents. This occurs because slow rising floods and relatively 'leaky' homes generally result in almost no hydrostatic or hydrodynamic loading of buildings, leaving its structure relatively intact even after total submersion. Since modern flood warning systems for the type of flooding observed in Brisbane and Ipswich are good, many residents had the opportunity to save their most valuable items. This upper bound is in line with observations in other studies (Blong, 2002; Pistrika and Jonkman, 2010).

These vulnerability curves represent the mean expected loss to a population of buildings, not the expected loss to any individual building. While the distribution of losses about the mean can be used to estimate the proportion of buildings with loss ratios above or below a specified limit, losses to any given building cannot be estimated without further engineering analysis.

### 5.3.3 Influence of flow velocity

It is generally accepted that when buildings are loaded by moving flood waters the extent of damage will be greater than for slow rising floods (Soetanto and Proverbs, 2004). This is because flowing water can apply hydrodynamic loads to a building, its sub-structure and foundations, and can increase the probability of hydrostatic loading across structural members (sections 3.1 and 3.2). In its simplest terms, flowing water has the ability to instigate additional building failure mechanisms that stationary water cannot generate. In addition, flash flooding – the usual instigator of flow velocity – is generally associated with short warning times, giving the population less time to minimise potential damage to building and contents (Kreibich et al., 2009).

Significant flow velocities occurred during the flash flooding in Grantham. The extent of damage to this area was proportionally greater than to other flood-affected areas of Queensland, with 119 buildings suffering major structural failures and more than 2000 further homes inundated in the surrounding rural area (Lockyer Valley Regional Council, 2011a). This section summarises previous Australian work in the area of high-velocity flood loading of buildings and proposes a methodology for updating the damage function developed in section 5.3.2 to include this loading action.

Some of the earliest work on flow-induced damage to buildings was conducted by (1975) where the depth-velocity (*dv*) thresholds for failing a range of typical US-style timber-framed homes were theoretically generated. Dale, Edwards, Middelmann and Zoppou (2004) extended this work to Australian timber-framed homes, generating a similar set of failure curves for four different building combinations. The latter work considers the role of gravity and buoyancy forces as well as the transfer of momentum from flowing water to the home in order to determine the depth-velocity threshold at which loading actions would exceed structural restraint. This work assesses the ability of buildings to resist failure provided all components remain undamaged, but they do not investigate the possibility of failure to any individual component (e.g. walls). For double-brick and brick-veneer homes, failure of components is probably a more likely failure scenario than sliding or floating. HNFMSC (2006) – citing work by the University of Newcastle – does investigate thresholds for failure of typical Australian brick-wall systems and, as expected, suggests failure at lower depth-velocity combinations than proposed by Dale et al. (2004), as shown in Figure 24. Similar work has been carried out in the USA (USACE, 1988) and the UK (Escarameia, Karanxha, and Tagg, 2006) and guidelines set for typical buildings in those countries.

To assess empirically how buildings performed during recent flooding with respect to specified failure thresholds, an analysis was undertaken of damage to buildings in Grantham assessed during the GA damage survey. Figure 24 plots in a depth-velocity space the observed extent of damage to SBT 1 (raised floor, weatherboard clad) buildings along with a representative failure threshold from Dale et al. (2004) (Fibro clad, steel roof) and the recommendation for light-framed building within the New South Wales Floodplain Management Manual (NSWFMM) (NSW State Government, 2005). Damage extents are broken into three categories based on a mixture of photographic evidence and/or insurance loss information. Damage categories are chosen as follows: *Total damage* when losses exceed 80% of the building and contents value or photographic evidence show gross displacement or failure; *Partial damage* when the GA damage database indicates observed flow-induced damage or the ALR is greater than one standard deviation above the expected mean ALR value for the recorded inundation depth; and *Inundation only damage* to all other buildings. The first two categories signify some level of flow-induced damage. Figure 25 plots the much smaller subset of damage data for slab-on-ground brick-clad housing (SBT 2) along with representative thresholds from HNFMSC (2006) and Dale et al. (2004).

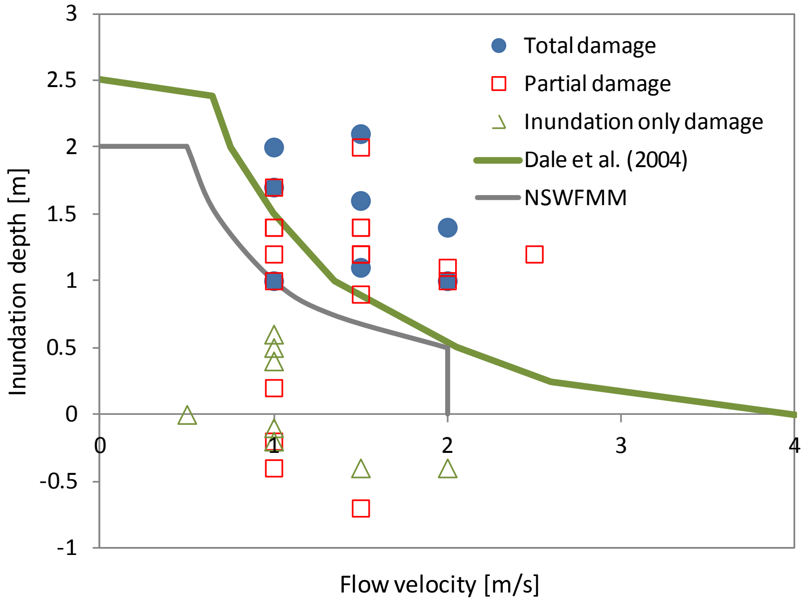


**Figure 24: Damage extents for raised-floor timber-clad buildings (SBT 1) assessed in Grantham compared with predicted failure thresholds**

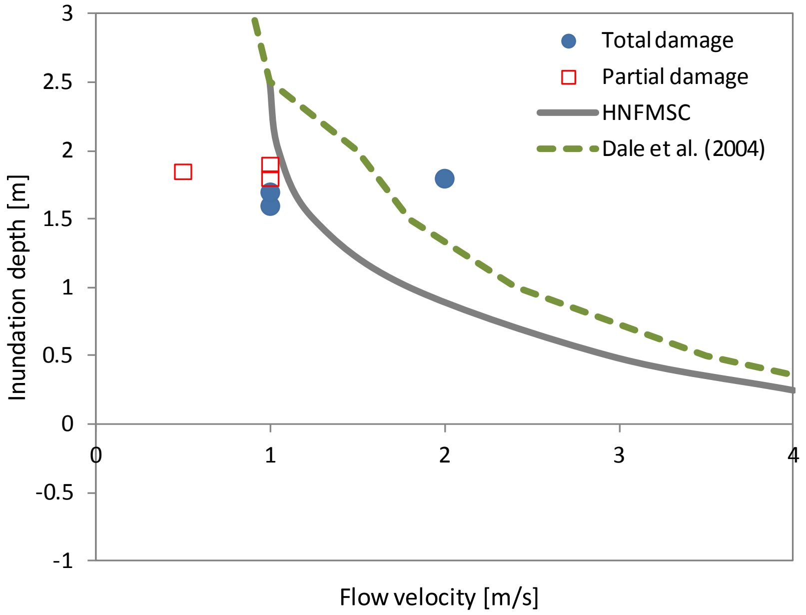


**Figure 25: Damage extents for slab-on-ground brick buildings (SBT 2) assessed in Grantham compared with predicted failure thresholds**

Keeping the flow velocity estimation limitations in mind (section 5.2.4) and the relatively small sample set, the following observations are made. Figure 24 suggests that both thresholds perform reasonably in separating those buildings with some level of flow-induced damage (to the right of the curve) from those without. The several partial damage points to the left of the threshold curves were instances where the home itself sustained no flow-induced damage, but instead damage was noted to portions of the sub-structure. Some total and partial damage has occurred for buildings that the Dale et al. (2004) threshold would suggest should not sustain damage, but their threshold was developed based on a larger home (area = 193 $m^2$) than those of the average assessed home in Grantham (average area = 130 $m^2$). Reducing building size in the

Dale analysis is expected to move the threshold curve to the left. The velocity-depth product threshold of 1.0 specified in the NSWFMM appears to be a reasonable lower bound for flow-induced damage to SBT 1 type buildings. Some potential for damage through scour or erosion to sub-structure piers and foundation does, however, appear to be possible below this limit.

Very little can be said with confidence about the data shown in Figure 25 because of the small sample size. That said, it is evident that total damage is possible for a depth-velocity product of 1.5, a value similar to that predicted by the HNFMSC (2006) threshold.

Further to providing thresholds for damage, a number of researchers have investigated methods for incorporating flow velocity into damage/loss estimates (Kreibich et al., 2009; McBean et al., 1988; Middelmann-Fernandes, 2010; Pistrika and Jonkman, 2010). Based on limited data, McBean et al. (1988) suggest that at a depth of 2.4 m the influence of flow velocity can increase losses by 2–5 times that observed in its absence. Kreibich et al. (2009) investigated the relationship between three key flow parameters – energy head ($d + v^2/2g$), indicative flow force ($dv^2$) and the depth-velocity product ($dv$) – and reported damage following severe flooding in Germany during August 2002. They find that beyond a specified lower bound, flow velocity has a significant influence on observed structural damage to residential buildings. Surprisingly, however, no significance was found in their analysis relating financial loss (to these same structures) and flow velocity. Of the flow parameters studied, Kreibich et al. (2009) suggest energy head has the greatest explanatory power when this value is in excess of 2 m. They do, however, highlight the need for further research on the topic and suggest their findings are only preliminary. Using aggregated damage data from flooding in New Orleans following Hurricane Katrina, Pistrika and Jonkman (2010) find a relatively strong relationship between depth-velocity product and total damage ratios. Further, they show the ability of this product to better predict damage than depth alone. Results for the Lower Ninth Ward region of New Orleans suggest losses can double when flow velocity is significant, but show little increase in losses when depth-velocity is less than around 1.0.

The depth-velocity product ($dv$) is chosen as a possible methodology to extend the vulnerability functions developed in section 5.3.2 as shown in Equation (8). The scaling factor $\alpha_v$ is preliminarily proposed to be 0.1 and $v$ [m/s] is the maximum velocity estimated to have impacted a building over the duration of flooding. In most instances $v$ will be estimated from a hydrodynamic model. All other variables are as previously specified. The flow-induced damage term (right-hand term in Equation 8) should be set to 0 for $dv < 1$.

$$Total\ Loss\ Ratio = \Delta + \alpha_1 {d_1}^{\beta_1} + \alpha_2 {d_2}^{\beta_2} + \alpha_v d_1 v \qquad \textbf{(8)}$$

Figure 26 shows the additional flow-induced losses (delta LR) for all the assessed homes that also had insurance loss information (adjusted to ALR) plotted against their depth-velocity product. Open circles show loss increases for SBT 1 buildings, and filled circles show SBT 2. Increases in loss ratios were calculated by subtracting the estimated mean inundation loss (Equation 7) from the ALR recorded for each home. The dashed line shown signifies mean inundation loss plus 1 standard deviation, below which around 85% of all losses would sit in the absence of velocity affects. Finally, the solid line shows the proposed trend in increased mean total loss due to flow velocity. This appears to loosely represent the observational data but is only preliminary and warrants further analysis. It is expected that scatter of individual losses around the mean will increase beyond the suggested value in section 5.3.2 when flow velocity is significant, but no estimate as to its value can be made at this point.

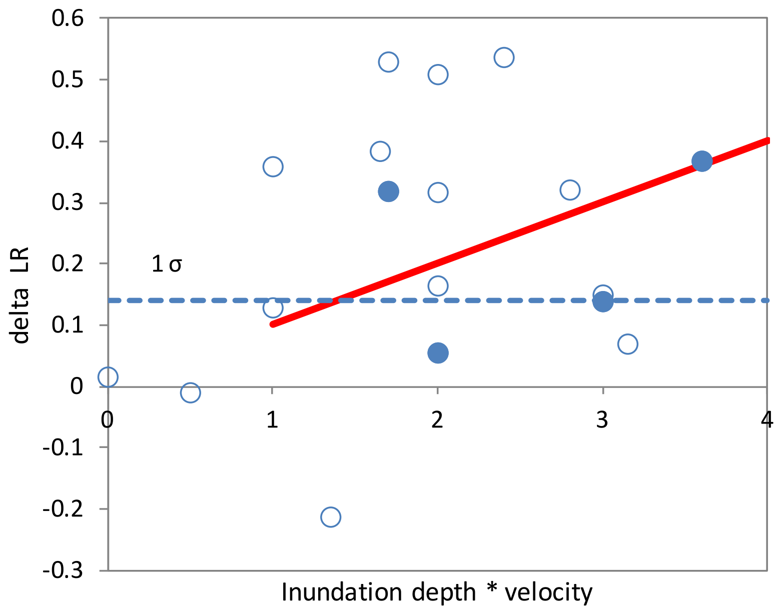
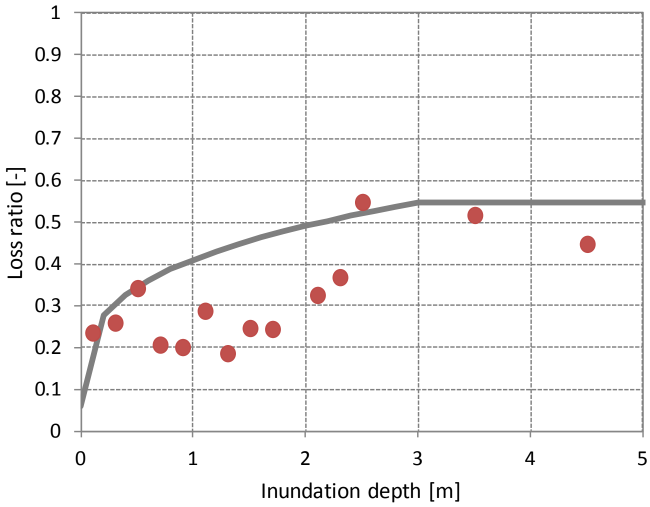


**Figure 26: Relationship between depth-velocity product and increase in ALR**

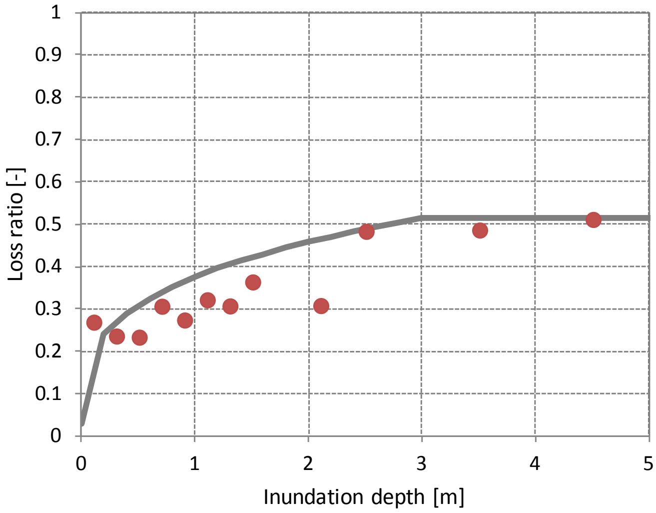
### *5.3.4 Validation*

To validate the simplified vulnerability curves proposed in section 5.3.2, built on the intersecting data within the GA and ALR databases, the intersection of QFRS and ALR databases was used. Using available data in the QFRS database, a simplified building type was assigned to all intersecting points. Unfortunately, it was not possible to segregate between SBT 3 and SBT 4 (two-storey fully built under and two-storey partially built under) so these were aggregated. Data on the inundation depth were available for most, but not all, intersection points. The total number of intersections with an identifiable building type and a valid flood depth entry was 599: 135 in SBT 1, 150 in SBT 2 and 314 in the aggregated SBT 3 & 4 group. ALRs were binned and averaged over depths of 0.2 m.

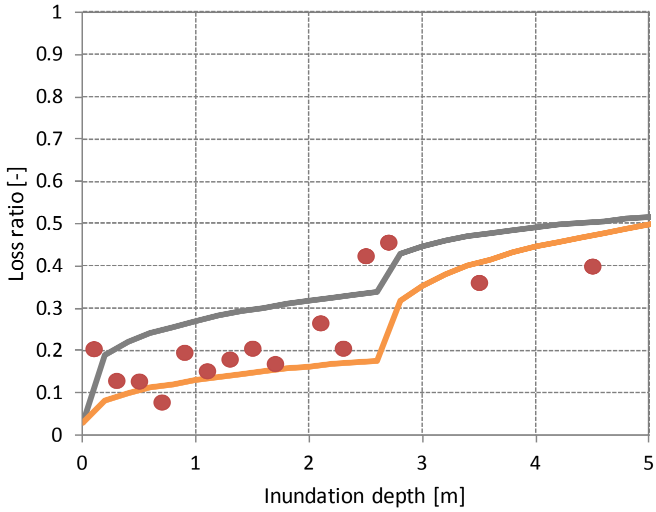
Figure 27 shows the comparison between proposed vulnerability curves and average ALR results using the QFRS data. Results for SBT 1 shown in Figure 27a suggest reasonable performance at shallow above-floor flooding depths and also at the level of full building inundation where a truncating loss ratio in the vicinity of 0.5–0.55 appears to be reasonable. The predicted curve appears to perform less well over the partial inundation depths of 0.5–2.5 m. It is expected that part of the reason for overestimation of losses for this range has to do with the measurement of depth for this building type (recalling the misunderstanding between assessors over measurement of depth from floor or ground height, section 5.2.2). Figure 28 indeed shows that when plotting recorded above-floor inundation depths for intersecting SBT 1 points in the GA and QFRS databases, a systematic overestimation of depths is seen in the QFRS database for GA flood depths between 1 and 2.5 m. This would be expected if a portion of assessors were measuring inundation depth from ground level instead of above-floor height. The manifestation of this recording error will be most pronounced for SBT 1 buildings, as these have the greatest difference between ground and floor heights. A realignment of depths would bring the QFRS validation data closer to those estimated using the proposed vulnerability function.



(a) SBT 1



(b) SBT 2



(c) SBT 3 & 4

**Figure 27: Comparing proposed vulnerability curves for (a) SBT 1, (b) SBT 2, (c) SBT 3 (grey curve) and SBT 4 (orange curve) with averaged mean ALR values from the intersection of ALR and QFRS databases (red circles)**

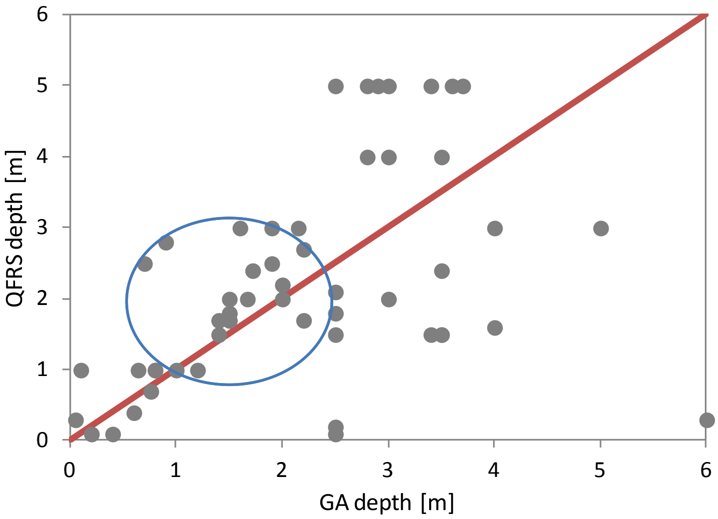


**Figure 28: GA above-floor depth measurements against QFRS above-floor depth measurements for SBT 1**

Validation for SBT 2 buildings shows much better agreement. Only a small overestimation is seen over the range of flood depths with the upper truncation value of 0.5 shown to be reasonable. As with SBT 1 buildings, there may be some underestimation of ALR in the validation dataset because depth measurements were taken from ground level and not floor level. This discrepancy, however, is expected to be only small for these buildings, as slab-on-ground homes tend to only be 0.1–0.3 m above ground level. When considering transferral of these curves to other parts of the country, the good performance of the proposed vulnerability curve for this building type is encouraging, given – much more than SBT 1 – it is common throughout Australia.

Validation data for two-storey buildings generally sit between the two proposed vulnerability curves. This is the optimal situation given that the population will consist of both SBT 3 and SBT 4 buildings. Further, the apparent step rise in losses at the point of complete ground floor inundation supports the approach taken for these building types. The upper level of loss of 0.5 again appears to be a reasonable approximation.
Looking at the variance of individual ALR records around mean values shown, values ranging between 0.13 and 0.18 were typical for 0.5 m depth bins of data. This bandwidth was again largely uniform across all building types, validating the proposed simple method of considering a uniform variance for all flood depths.

Unfortunately, the available information on increases in loss due to flow velocity is not substantial or extensive enough for any meaningful validation of the methodology proposed in section 5.3.3 to be undertaken. However, Pistrika and Jonkman (2010) do show that for the Lower Ninth Ward in New Orleans depth-velocity products ranging between 2 and 5 $m^2/s$ increased loss ratios by between 0.1 and 0.5. This is in line with predictions of the model proposed in section 5.3.3. A field survey of residents in Grantham to ascertain insurance claim or rebuilding cost information would serve to increase the analysis sample size and could potentially allow a much better validation of the proposed methodology.

## *5.4 Estimating displacement*

For emergency management it is important to quickly estimate the number of people that will be displaced by a given flood event. This can be done, in part, through a set of fragility curves that relate displacement to a given flood parameter. Using the damage curves developed in the previous sections it is possible to develop such a set of fragility curves if some assumptions are made relating loss ratios to the potential for occupants to be displaced from their damaged homes.

The QFRS database includes a recorded damage state for each entry based on the following list (Queensland Government, 2011):

- No damage: No observable damage or inundation
- Minor damage: Water just entered building, new floor coverings may be needed
- Moderate damage: More extensive inundation with replacement of gyprock and possibly kitchen and bathroom
- Severe damage: Not liveable but structurally sound
- Total damage: Not structurally sound and most likely requiring demolition.

Using these definitions, it is expected that the first two states (no and minor damage) would not require any significant period of occupant displacement once waters recede. For buildings assigned a moderate damage state it is assumed that a short period of displacement would be required while some structural 'drying out' or reconstruction occurs. If a building is assigned either a severe or total damage state, a long period of occupant displacement is expected. Coupling this information with ALR data at the points of intersection between the QFRS and ALR databases, relationships can be drawn between incurred loss (ALR) and the expected damage states assigned to a population of buildings. These data are shown graphically in Figure 29 for buildings throughout Queensland.

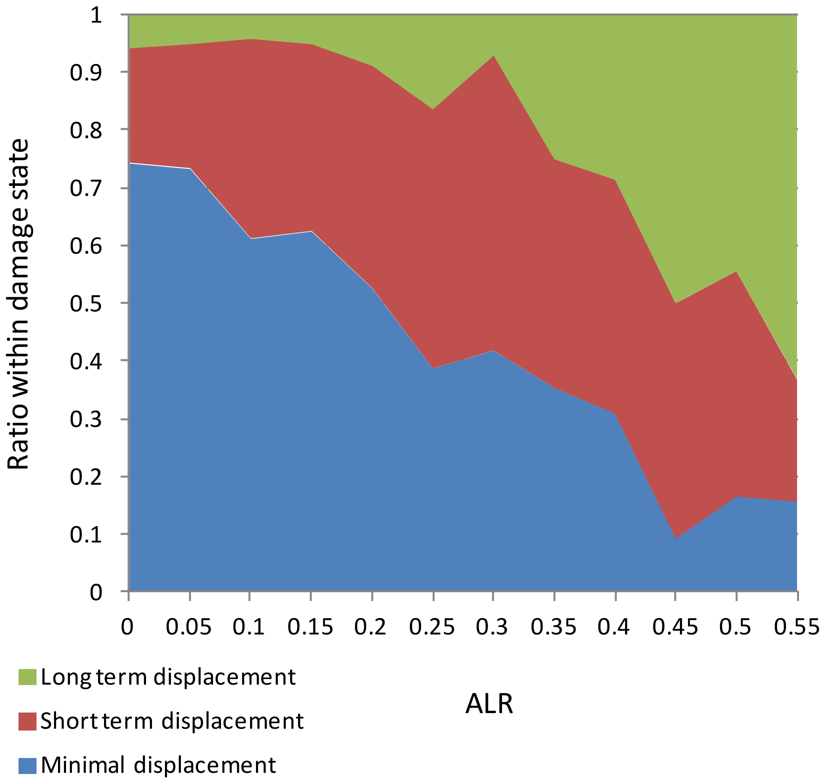


**Figure 29: Relationship between Adjusted Loss Ratios and ratio of building population within given displacement states for buildings throughout Queensland. A *minimal displacement* state is assigned to buildings with recorded damage states of no or minor damage, *short-term displacement* to those with moderate damage, and *long-term displacement* to those with severe or total damage.**

For buildings with low ALR values, a minimal displacement state would typically be expected. Considering, however, that not all buildings will be damaged in the same manner while reaching a given loss value, some potential for short-term displacement is expected. As loss ratios increase, the proportion of building population with expected minimal displacement falls, and those with expected long-term displacement rapidly rises. By an ALR of around 0.5, near the mean expected loss for complete inundation (and the loss ratio below which a suitable dataset was available for statistical analysis), only around 10% of buildings would be expected to be quickly occupied, while occupants from 60% should be expected to require long-term alternative accommodation.

Fitting smoothed curves to data presented in Figure 29 and extrapolating to greater loss ratios, Figure 30 presents the expected relationship between loss ratio and percentage of building population within given damage states. The proportion of population expected to have minimal, if any, displacement drops to zero when loss ratios reach 0.5. This is marginally less than observed in field data but was reduced to ensure a conservative estimate. Long-term displacement is expected to rise rapidly after loss ratios increase beyond around 0.2 and is expected for all buildings within a population when loss ratios reach 0.75.

Relating displacement to loss ratios as opposed to depth itself is thought to be an optimal approach as it negates the need for multiple relationships to be built across different building types. A strong conceptual argument could also be made that this link should be strong.

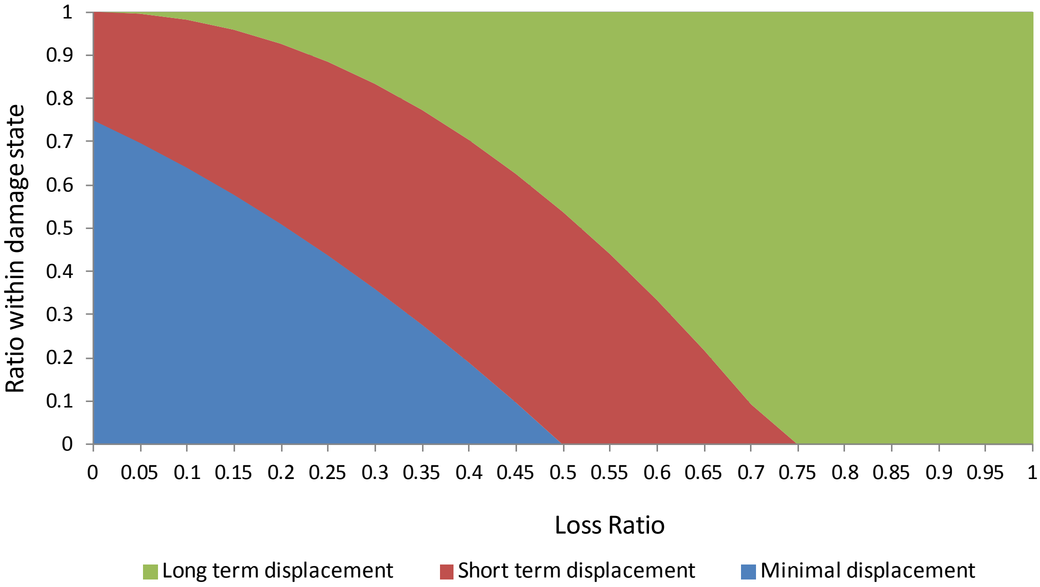
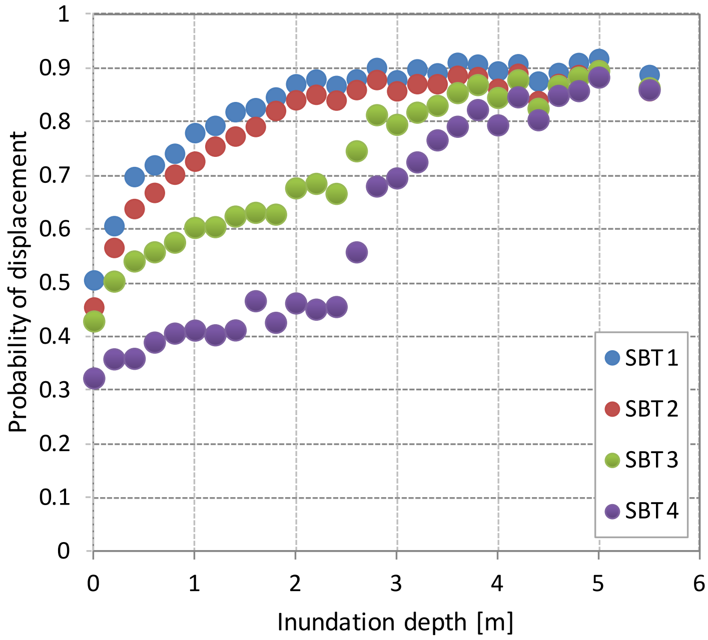


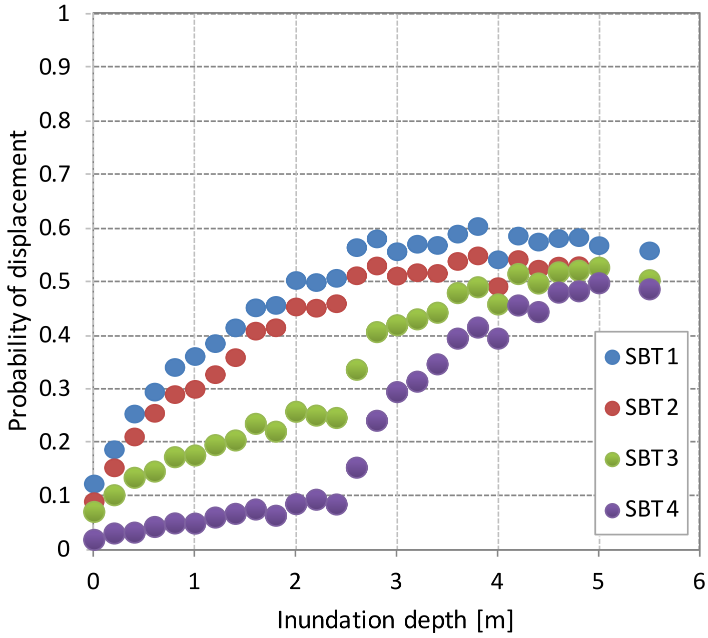
**Figure 30: Smoothed and extrapolated relationship between Adjusted Loss Ratios and ratio of building population within specified displacement states**

Using these data coupled with vulnerability functions developed in section 5.3.2 (including uncertainties), expected proportions of building population within each displacement state can be calculated with respect to building type and inundation depth. Figure 31 presents the expected proportion of building population for each building type whose occupants are expected to suffer (a) at least short-term displacement, and (b) long-term displacement. These figures were developed by randomly sampling 10,000 inundation depths for each building type, estimating a loss ratio by sampling from the beta distribution about each mean expected total loss ratio, then randomly choosing a damage state based on this loss ratio and proportion of buildings within each damage state given in Figure 30. These figures could be used by aid or emergency services agencies to quickly estimate expected housing needs during future flood events. Similarly, they could be used in flood risk assessments to forecast these needs.

Further work will be required to validate these estimates, and in practice factors such as age and wealth of populations may also influence displacement numbers.



(a)



(b)

**Figure 31: Expected proportion of building stock whose occupants will suffer (a) at least short-term displacement, and (b) long-term displacement**

## *5.5 Damage to individual building components*

Little assessment data were available in the datasets outlined in section 5.2 detailing the flood impacts to individual building components. To explore this further, information was sourced through EAA (2011), in their report that summarised observations of common damage to homes in Brisbane and Ipswich based on 220 in-home damage assessments by engineers or architects (unfortunately, individual damage reports were not available for analysis). Supplementing this, interviews were carried out with a group of insurance assessors and builders to determine the most common types of damage observed in Queensland homes and potential issues with the rebuilding effort.

Key findings from EAA (2011) and conducted interviews are summarised in the points below. Note that the EAA report is based on an average inundation depth of between 2.5 and 3 m with two-thirds of assessed homes being single storey. This implies that most assessed homes suffered close to, if not, total inundation.

- Most buildings performed structurally well, but around 20% of EAA-inspected homes had some level of damage to a structural member. Insurance assessors concurred that structural framing consistently performed well under riverine flood conditions and that complete 'write-offs' were exceedingly rare.
- Hardwood materials performed better than softwood, with noticeably less warping. This would include framing, flooring and cabinets/cupboards.
- Galvanised steel framing proved better than timber framing with respect to water resilience. Use of steel framing did not, however, act to reduce insurance claims but did reduce the drying time required before subsequent work could be carried out. It was highlighted that many builders steer clear of steel framing because of the additional labour and material costs required during construction.
- Around 10% of structural bracing was removed by floodwaters, with almost 50% left damaged by water and potentially requiring replacement.
- One-quarter of brick homes had visible cracking, with 10% having mortar washed out from between bricks.
- Around one-quarter of EAA-inspected homes had issues with their sub-structure, be that shifting, cracking or subsidence. Scouring was not a major issue. Insurance assessors estimated that around 30% of their claims had some component of sub-structure damage.
- For completely inundated homes, roof trusses largely remained structurally sound, but 5% showed signs of movement.
- Two months after the floods, most timber frames had not dried adequately. Despite this, most had been re-sheeted with plasterboard after only 2–3 weeks (EAA, 2011). This could potentially lead to bacteria issues. Insurance assessors reported instances of masonry walls causing wetting issues up to 12 months after previous flood events. These assessors have said, however, that all their builders sanitise wall cavities and conduct moisture tests prior to re-sheeting. Around 2–3 weeks seemed to be the minimum amount of drying time reported by assessors in the absence of additional aggressive drying techniques (e.g. fans). Interviewed builders reported using drying fans in some instances.
- Cavity wall or unfilled block work construction retained large amounts of silt after floodwaters receded. This may lead to ongoing issues with smell and bacteria. Weep holes in cavity walls were a major source of this problem.
- Damage to sarking was observed on a number of homes. Remediation will require removal of external cladding.
- Insulation in roofs and walls must be replaced after any wetting occurs. EAA report that this was not always done. For insured homes it was suggested that all insulation be replaced if wet.

- Single-skin housing (e.g. Queenslanders) was easier to clean, dried out quicker and suffered less damage than cavity wall construction.
- Tiled floors performed well, with almost all left unaffected. Timber floors performed poorly, with around 80% of EAA-assessed homes suffering some level of swelling, warping or other damage. Insurance assessors said that in some instances complete retiling of rooms was required if cracking of tiles occurred (often driven by something falling onto the floor), substantially increasing losses to those homes. They did agree, however, that tiled floors performed better than most other floor coverings.
- Sediment infiltration into plumbing systems was common. This extended to guttering and downpipes for homes with inundation above the roofline.
- Backflow flooding through sewage and plumbing systems is relatively common.
- Almost all cabinetry had been removed or was judged to need removal because of swelling. Insurance assessors report that almost all cabinetry is replaced as soon as any part of it is wet.
- One-quarter of inspected homes could not salvage any of their bench tops, sinks, etc.
- More recently constructed homes performed **worse** than older homes but in many instances are easier to repair because little needs to be done to them to align with current building regulations.
- Homes inundated for several days suffered more damage than those inundated for only a few hours.
- Sediment-laden floodwater (e.g. in Brisbane) caused more damage than equivalent ‘clean’ floodwater (e.g. in Emerald).

From a safety standpoint it is encouraging to note the good performance of most homes’ structural systems. Given the majority of these will have been inundated with relatively slow-rising floodwaters, this is perhaps to be expected and is in line with comments from insurance assessors. EAA do, however, note that they found a correlation between flow velocity and structural damage, which may explain why some level of damage to structural members was noted. The relative performance of hardwood, softwood and steel structural members is as expected.

It appears that damage to bracing material is an issue of concern. This is particularly worrisome given that it may go unchecked unless a qualified builder or engineer inspects a flood-damaged home. The level of damage to building sub-structure is also an issue that needs to be addressed. Observed increases in the level of damage/loss with increased inundation time and sediment loading is in line with observations from previous floods (Smith, 1994; Thieken et al., 2005).

# 6. ROLE OF DEVELOPMENT CONTROLS

Kelman (2003, pp 1) suggests that in the UK '[w]hen flood disasters occur, a traditional reaction is to suggest the straightforward, obvious, simple solution of not building on floodplains.' Reactions are similar in Australia. Unfortunately, the solution to minimising the impact of extreme floods is not quite that simple. While it is true that removing buildings from, or not allowing any future construction in areas exposed to flooding will reduce their toll, it is in most instances not a realistic response. Reasons for this include (after Kelman, 2003):

1. Australia was developed on floodplains, so a large number of people live or work in areas with some level of flood exposure. Indeed, according to the National Flood Information Database, in Queensland and Victoria alone there are more than 80,000 properties within the 100-year flood extent. To remove these people, buildings and associated infrastructure would be immensely expensive and in most instances politically impossible. Clearly, some level of residual flood risk will remain even if no new development is allowed in flood hazard areas.
2. Defining an area that is 'at risk' of flooding is a non-trivial task. Even if the hazard is well defined, what threshold (i.e. 20, 50 or 100-year flood extent, highest historical flood level) should be used to determine areas that can and cannot be built upon? Further, what type of flood events should be considered: riverine flooding, flash flooding, coastal inundation? Further still, flood risk is not a stationary metric. An area that may be outside the flood-risk zone today may be inside tomorrow because of development, urbanisation in surrounding areas/properties or changing climatic conditions.
3. Living on floodplains has many advantages. Some people enjoy the lifestyle associated with close proximity to waterways. Despite the risk of inundation, and in full appreciation of this risk, some residents will feel they have the right to live or continue to reside in these at-risk areas.
4. It is possible to build flood-resilient structures that minimise the impacts of flooding to a building and its occupants. Indeed, Australian standards exist that allow people to safely build in areas of the country prone to cyclone (AS/NZS1170.2), earthquake (AS1170.4) and bushfire (AS3959).

The counterargument to these points is that it is irresponsible to allow people to build in areas that will potentially increase the burden on emergency services, increase the economic impact to building owners and the community, and potentially endanger the lives of building owners and emergency service personnel during flood events. The answers to these questions are therefore not simple, and what is appropriate in one area may not be so in another. What is clear, however, is that the problem cannot be solved with planning controls alone (e.g. do not build new structures within the 100-year flood extent), but involves the interplay of these regulations with building controls that ensure when buildings are built, rebuilt or retrofitted in an area with some level of flood risk, it is done so in a manner that minimises future impacts.

## *6.1 Development framework overview*

The process for approving and constructing new developments in Australia is regulated by each state through land planning and Building Acts. The actual task of approval is generally passed down to local council bodies and not handled directly by the state. With respect to flood hazard, the general process followed is that the planning Act, through some form of regulation, will be used to assess the probability of flooding at a given site and determine whether it is suitably low for safe development to occur. If a given site is approved for construction, building controls determine how each building on that site must be built, assessed and approved. If planning controls determine the flood hazard at a given site to be too high, development proposals can be denied or conditions can be placed upon their application, such as defined minimum floor levels, to minimise the risk to building and occupants.

This process works to protect new developments. However, it is much more difficult to implement flood protection measures in established communities (Comrie, 2011) and address what is termed ‘existing risk’ (BTRE, 2002). Planning and building controls are not retrospective and will only be invoked upon an existing structure if redevelopment or major renovation is undertaken. Typically for these areas, flood-flow modification techniques (e.g. levees) or buy-back schemes are used to minimise risk, with the costs borne by the greater community. Building modifications, where the cost is borne by those exposed to flood hazards, can play a role in aiding this risk reduction but are often expensive, and while unregulated or subsidised their implementation will only ever be ad hoc and done by those with the financial means to do so. No regulations currently exist that require buildings with existing flood risk to do anything to minimise it.

## 6.2 Planning controls

The aim of this section is to briefly outline the planning controls in place throughout Queensland and Victoria with respect to minimising flood damage. Given that the focus of this report is largely on building controls, we have not analysed planning controls in detail but instead, and as outlined in the previous section, have viewed them as an integral part of the construction process that determines where, and in some instance how, construction will occur. In particular, we focus on the use of flood maps to zone at-risk areas and the level of risk chosen to define these zones.

### 6.2.1 Planning controls in Queensland

The Queensland Floods Commission of Inquiry (QFCI, 2012) summarises the planning framework throughout Queensland and makes several recommendations as to its improvement. Much of this section is based on the QFCI summary and should be considered referenced as such unless sourced otherwise. The reader is directed to that document for a more detailed analysis of Queensland planning policy.

The principal piece of planning legislation in Queensland is the *Sustainable Planning Act 2009*, which replaced the now repealed *Integrated Planning Act 1997*. The Act provides for land-use planning at the state, regional and local council levels through *planning instruments*. State planning instruments are applicable across the state, while local planning instruments are applicable only to the local government area within which they are developed.

The State Planning instrument of most importance to minimising flood impacts is State Planning Policy (SPP) 1/03: *Mitigating the Adverse Impacts of Flood, Bushfire and Landslide* (Queensland Government, 2003). This policy enforces upon local councils the Queensland Government’s position that ‘development should minimise the potential adverse impacts of flood, bushfire and landslide on people, property, economic activity and the environment‘ and requires that flood be adequately considered when assessing development applications. SPP 1/03 is called upon when a development application is lodged for land that lies within a designated *defined flood extent* (referred to as a natural hazard management area in Queensland) specified by local council. Notionally this extent covers the area that is believed to have a 1% annual exceedance probability (AEP) of inundation. However, where considered justified some scope for setting *natural hazard management areas* based on a flood event with higher AEP is provided. Unfortunately, in areas where local councils have not undertaken flood mapping to determine their *defined flood event* and do not designate a flood-specific *natural hazard management area* (or choose not to use flood mapping information to specify this area), no scope for considering flood hazard in a development application exists. SPP 1/03 provides two possible designations of land (overlays) within a natural hazard management area, 'flood and inundation' or 'overland flow paths', but local councils can choose to create more. These designate differing levels of risk within the flood hazard area, but it is unclear how often more than a single designation is used. SPP 1/03 will be superseded in 2013 and is currently under review.

Following recent flooding the Queensland Government, through the Queensland Reconstruction Authority (QRA), released Temporary State Planning Policy (TSPP) 2/11: *Planning for stronger, more resilient floodplains* (Queensland Reconstruction Authority, 2011), that supersedes portions of SPP 1/03 and allows local councils to specify natural hazard management areas based on existing 1% AEP flood information **or** by using interim overlay maps and a Model Code generated by the QRA. These overlay maps were developed using information that included topography, land use, drainage information and interpreted or recorded flood extents from the 2010–11 events, to estimate regions at risk of flooding (Queensland Reconstruction Authority, 2012). For areas without existing flood maps these interim maps allow local councils to include some level of flood information in their planning schemes. However, these are not necessarily maps that represent a single identifiable level of flood hazard and are only proposed as an interim measure. This TSPP will expire in late 2012 and any useful information within (or reference to) these overlay maps needs to be included into local planning policies before this point.

Approvals for development applications are granted at the local council level. SPPs are used by councils to develop their own *Local Planning Instruments* (LPIs) that must reflect the overall goals of the SPP. It is within an LPI that the *natural hazard management area* must be defined to invoke SPP 1/03. At this point there is no explicit requirement within the *Sustainable Planning Act* that suggests LPIs **must** include information on flood hazard. When LPIs do invoke SPP 1/03 it is suggested they use flood information to specify minimum floor levels for proposed developments. This can be done for habitable or non-habitable floor levels and is generally set to the expected flood depth at a given site during the *defined flood event* (i.e. the flood event that defines the natural hazard management area) plus a factor of safety called the freeboard. Typically, freeboard is used to account for uncertainty in flood modelling results, possible wave action and unforeseen flood actions and is set between 300 mm and 500 mm. In many instances non-habitable floor levels have relaxed elevation requirements and can potentially be below the *defined flood level*.

As with the TSPP, Temporary Local Planning Instruments (TLPI) can be used as temporary planning mechanisms to override an existing planning scheme. For a TLPI to be implemented, approval must be sought from the Minister for Local Government and evidence must be produced to suggest that delaying implementation of the change will adversely increase the risk to the community. These changes are certainly warranted when significant reconstruction efforts are required following severe flooding. TLPI can be written to be applicable to all or part of an LGA.

TLPIs were used by a number of the worst affected LGAs (Table 1) throughout the state following the 2010–11 floods. As an example, the QFCI reported that the Central Highlands Regional Council, Brisbane City Council and Ipswich City Council adopted TLPIs to, among other things, adjust the *defined flood event* used to set their planning levels (and therefore lift minimum floor levels), using flood information from the 2010–11 events. Ipswich City Council and Brisbane City Council TLPIs expired in mid-2012 but have been extended for a further year. Instead of developing their own TLPIs, councils can also choose to adopt recommendations made in TSPP 2/11 by the QRA, that is, use the QRA maps. The Somerset Regional Council is an example of a council that did this.

Unlike other states, TLPIs in Queensland have the ability to impose requirements on building work within a designated area. As an example, the Ipswich City Council TLPI 01/2012 requires any construction with greater than 1 m of inundation at the defined flood level to be designed to withstand hydrostatic, hydrodynamic and debris actions. Further, it requires habitable floor levels (e.g. bedrooms, living areas) to be a minimum of 500 mm (freeboard) above the regulated flood line with building material and surface treatment below this level to be resistant to water damage. Brisbane City Council TLPI 01/12 requires similar elevation of habitable floor levels and use of flood-resistant materials below this point, but in that instance provisions are only applicable to residential construction. Many of these interim building requirements are embodied with the Australian Building Codes Board draft Standard, *Construction of buildings in flood hazard areas*, which is expected to be introduced into the National Construction Code in early 2013 (section 6.3).

### *6.2.2 Planning controls in Victoria*

The *Review of the 2010–11 Flood Warning and Response – Final Report* (Comrie, 2011) summarised the planning process with respect to flood impacts in Victoria. This section is largely based on that report or the State Government of Victoria Department of Sustainability and Environment website (Victorian State Government, 2012) and should be considered referenced as such.

Land use planning in Victoria is regulated by planning schemes established under the *Planning and Environment Act 1987*. The Act allows municipal councils to introduce planning schemes to control land use within their boundaries. For floodplain management this control is through a set of Victoria Planning Provisions (VPPs) zones and overlays. As a general rule, zoning provisions control the use of land, and overlays control the development of land. One zone and three overlays exist that relate to flooding:

- Urban Floodway Zone (UFZ). The primary function of land designated as UFZ is to convey active riverine flood flow within urban areas. The consequences of flooding in UFZ areas are considerable because of the high potential for deep, high-velocity flows. The UFZ restricts land use to agriculture and recreational activities. All other land uses are prohibited. This zonation reflects the land at highest risk of flooding, but it is unclear if any specific exceedance probability is assigned to its zonation.
- Floodway Overlay (FO). The FO applies to areas prone to riverine flooding in rural and urban areas. The risk of flooding to FO regions is high but deemed of lesser risk than the UFZ. Some level of urban or public use development is permitted. Again, no explicit exceedance probability is assigned to the determination of this overlay extent.
- Land Subject to Inundation Overlay (LSIO). This overlay designates land considered to have some level of riverine flood risk, lower than embodied in the FO but greater than 0. If no flood mapping exists, the LSIO is used to describe all land considered to have some level of flood risk until such time that mapping is available and a floodway overlay (FO) can be identified.
- Special Building Overlay (SBO). The SBO applies to areas prone to stormwater overflow flooding in urban areas.

Zone and overlay maps for each municipality are available online through the State Government of Victoria Department of Sustainability and Environment website (Victoraian State Government, 2012). Where hydrological flood mapping studies have been carried out, these are used to inform the UFZ, FO and LSIO extents. The latter overlay is notionally in line with the 1% AEP flood. Where flood mapping has not been undertaken, existing flood experience or anecdotal evidence is used to prescribe the LSIO.

Decisions about land development fall to local councils. If an application for development is registered for land that lies within any of the zones or overlays above, under the *Water Act 1989* the council must refer it to the relevant authority with floodplain management function, that is, a Catchment Management Authority (CMA) or Melbourne Water. CMAs are independent authorities with the technical capability to assess flood risk and suggest provisions that alleviate unacceptable risks. CMAs have the ability to require councils to decline development applications unless these provisions are adhered to. In some instances CMAs will also have the ability to incorporate projected climate change impacts on flood risk into their assessments.
Generally, CMAs will have a greater capacity to assess flood risk than the council themselves, and as independent bodies are, in principle, free to subjectively assess an application's flood risk solely on its merits. If a development application is submitted for land outside the flood zones or overlays, no referral to a CMA is required.

Under the *Water Act* CMAs are required to use the best available information to estimate the flood level at a proposal site that has a risk of 1% AEP in any given year. By default this becomes the minimum floor level required for approval of new developments. Requests are often made to relax this level for commercial and industrial buildings, with permission often granted under the provision that additional flood proofing measures be undertaken (Victorian Government, 2000).

Using the Victorian Department of Sustainability and Environment's Victoria Flood Database (VFD) and referencing VPP maps, flood-affected LGAs (Table 1) were studied to determine whether planning overlays were available in those areas. In almost all instances, LSIOs covered parts of the town with only a few, predominantly the larger towns (e.g. Horsham, Charlton, Donald, Echuca), also having floodway overlays. Without knowing exactly which buildings were inundated, it is unclear whether affected buildings were within these bounds. However, considering the data source metadata entries in the VFD, it is evident that many areas affected had LSIO based only on historic flooding or otherwise subjective information. The Victorian Flood Review (Comrie, 2011), based on a submission by the Department of Sustainability and Environment, suggests that 80% of Victoria's floodplains have information on what is considered the 1% AEP extent available for planning use. This said, within the same document the North Central CMA suggests that many of these extents are inadequate and need updating. The North Central CMA exemplifies their point by highlighting Carisbrook and Creswick, two towns that were flood-affected and have flood information developed on anecdotal evidence alone. Fortunately, following the flood events the state government is funding the improvement of mapping in a range of areas that will eventually filter through to better zonation and overlays.

Use of an independent body (CMA) to assess flood risk, free from developer or economic pressures, is expected to lead to positive outcomes when it comes to alleviating the impacts of flooding (we make no comment on the economics of sustaining such an agency). This is considered a more optimal solution than that used in Queensland. Further, the use of multiple overlays to designate differing levels of flood risk (i.e. FO, LSIO and SBO) also offers greater flexibility over use of a single 1% AEP flood extent. The QFCI (2012) suggests a ranked set of possible flood mapping scenarios for the optimisation of flood risk in planning practice. These are listed below with the most desirable (and most expensive) first, and the last being the least desirable but still better than no flood information at all.

1. Use of flood maps that depict both the likelihood of flooding and the characteristics (i.e. velocity, rate of rise, etc.) of flooding
2. Use of flood maps that depict a number of different levels of flood likelihood, e.g. probable maximum flood, 0.2% AEP surface, 1% AEP surface, 5% AEP surface
3. Use of flood maps that depict only the 1% AEP surface
4. Use of historical flood maps
5. Use of flood prediction maps based on topography.

Aiming to include the information embodied within points 1 and 2 will improve the flood information in many planning schemes around the country. Having multiple flood depths and associated exceedance probabilities at a given location will also aid performance-based engineering design of the structure on that site and will allow better decisions to be made on potential alleviation methods.

## 6.3 Building controls

In principle, building controls regulate the structural form of buildings and other developments. Despite this, using land-use planning mandates to disallow construction in areas prone to flooding is in most cases the easiest and cheapest method for avoiding flood damage to new structures (BTRE, 2002). However, where planning approval is given for construction within flood hazard areas, or indeed dealing with existing structures within these zones, building controls play a vital role in minimising flood impacts when flooding events occur.

Building controls include legal *Acts* and *Regulations* as well as the design *Codes* and *Standards* they call upon.

### 6.3.1 Building controls in Australia

The primary tool for controlling the quality of new construction in Australia is the Building Code of Australia (BCA). The BCA makes up two of the three parts of the National Construction Code Series and is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of all State, Territory and Federal governments (ABCB, 2011a). ABCB (2011a) states:

> The BCA is a set of technical provisions for the design and construction of buildings and other structures throughout Australia whilst allowing for variations in climate and geological or geographic conditions.
>
> The goal of the BCA is to enable the achievement of nationally consistent, minimum necessary standards of relevant health, safety (including structural safety and safety from fire), amenity and sustainability objectives efficiently.
>
> This goal is applied so–
>
> - there is a rigorously tested rationale for the regulation;
> - the regulation generates benefits to society greater than the costs (that is, net benefits);
> - the competitive effects of the regulation have been considered and the regulation is no more restrictive than necessary in the public interest; and

- there is no regulatory or non-regulatory alternative that would generate higher net benefits.

In general terms the BCA sets out guidelines for those designing and constructing buildings so that minimum levels of health, safety, amenity and sustainability are embedded into buildings across the country. The performance requirements of most relevance to flood loading are BP1.1 in BCA Volume 1 (ABCB, 2011a) and P2.1 in BCA Volume 2 (ABCB, 2011b), which state that under all expected conditions, including frequently repeated and extreme actions, a building or structure must be designed to remain structurally stable and not instigate damage to other properties. An extensive list of actions to be resisted is provided, but those of importance to flooding are:

- liquid pressure actions
- ground water actions
- rainwater actions (including ponding action).

It should be noted that the BCA does not require the designer to minimise damage to non-structural components of a building (e.g. wall linings, cabinets, floor covering, etc.) provided this failure will not endanger life or structural integrity of the building under consideration or that of any neighbouring buildings.

By itself the BCA has no regulatory power. Given that building practice is mandated at the State government level, the BCA is only given legal effect when called upon by the relevant regulatory legislation in each State or Territory. State/Territory relevant additions or deletions of specific provisions can be made to the national code, but in principle it is written to minimise these amendments. All States and Territories have adopted the BCA.

The BCA will not always specify design provisions or load calculation methodologies explicitly but will call upon *Technical Standards* to set deemed-to-satisfy provisions for the resistance of specific actions or combinations thereof. This practice allows technical committees to develop detailed documents that reflect ‘best-practice’ methods of designing structures resistant to a range of actions. With regard to natural hazard actions, AS1170 and its subsidiary documents (AS/NZS1170.2 – wind actions; AS/NZS1170.3 – snow and ice actions; AS1170.4 – earthquake actions) are called upon to determine the likely magnitude of individual actions, and a range of other Standards are called upon to determine structural resistance. For wind, snow and earthquake, depending on the type of building under consideration, an annual exceedance probability (AEP) is specified for the magnitude of that action to be resisted. For housing, an AEP of 0.2% (1:500) is specified for wind and earthquake, with an AEP of 0.67% (1:150) specified for snow loads. For the flood-related actions listed above no design methodology or associated AEP are specified or referenced. Some provisions for designing for surface water runoff are specified, requiring runoff from a 5% AEP rainfall event to be removed from the property without adversely impacting neighbouring properties and the requirement that runoff from the 1% AEP event not enter the building. These provisions are written explicitly for runoff and do not include water from rising rivers. Although not mentioned in the BCA, the Australian Rainfall and Runoff (ARR) Guidelines published by Engineers Australia (Institution of Engineers Australia, 1999) are widely used for runoff design throughout Australia.

Based on the current BCA, it is questionable whether designing for riverine flood is required. Although the effect of flood waters impacting a building should be accounted for (because it is reasonable to expect floods will impact buildings in areas exposed to this action), if it is not expected that these actions will instigate structural failure then the BCA performance requirement does not require action. As observed during recent flood damage assessments, even when complete inundation occurs structural failure is rare. For flash flooding events, however, structural and life safety issues are common and the BCA requires appropriate design if the hazard is known. Unfortunately, regions of flash flooding are not systematically identified throughout the country and inappropriate construction in these areas, as evidenced in Grantham, is common.

Even if the sentence leading the previous paragraph is correct, the BCA offers no methodology or reference to Technical Standards that would allow a designer to determine whether potential flooding at a site, riverine or flash, will impact the structural integrity of a proposed building. To remedy this, in July 2010 (i.e. prior to the flooding events) the ABCB began developing a Standard for *Construction of buildings in flood hazard areas* and an accompanying handbook with the goal of incorporating it into the BCA (ABCB, 2012a). At the time of writing, both documents were in draft form and the mandatory performance requirements necessitating the consideration of flood actions have been drafted into the proposed 2013 BCA. Pending ABCB Board agreement and compliance with COAG regulations, inclusion of design provisions for flood actions will come into effect in early 2013. The following section discusses the draft Standard and Handbook in further detail.

The proposed performance requirement in volume 2 (P2.1.2) of the BCA is quoted below (performance requirement BP1.4 in volume 1 is identical). The ABCB Standard *Construction of buildings in flood hazard areas* is proposed to be called upon by the BCA in clauses B1.6 and 3.11.7 in volumes 1 and 2 respectively as an acceptable construction manual.

> *P2.1.2 Construction of buildings in flood hazard areas*
>
> (a) A building in a flood hazard area must be designed and constructed, to the degree necessary, to resist floatation, collapse or significant permanent movement resulting from the action of hydrostatic, hydrodynamic, erosion and scour, wind and other actions during the defined flood event.
>
> (b) The actions and requirements to be considered to satisfy (a) include but are not limited to-
>
> I. Flood actions; and
> II. Elevation requirements; and
> III. Foundation requirements; and
> IV. Requirements for enclosures below the flood hazard level; and
> V. Requirements for structural connections; and
> VI. Material requirements; and
> VII. Flood proofing; and
> VIII. Requirements for utilities; and
> IX. Requirements for egress; and
> X. Impacts to other structures and properties.
>
> *Limitation: P2.1.2 only applies to a Class 1* [for volume 1 this includes Class 2, 3, 4, 9a, 9c] *building in an area that is not subject to landslip, mudslide, storm surge or coastal wave actions.*

The limitation excluding the application of design requirements to areas exposed to storm surge or coastal wave action means that these homes, if approved for construction, can in effect be designed to a lower structural capacity than those exposed to riverine flooding. This is disappointing, given the hydrodynamic and hydrostatic loadings applied during these events are significantly greater than would be experienced during river flooding. It is expected that this limitation has been included because surge and inundation zones are not readily mapped (or at least available) for most coastal communities across the country. Requiring these areas to be included would have meant that individual home builders would need to source (or at least pay for) information on potential loading characteristics during surge or inundation events. This would be cost restrictive to most homeowners. This said, many surge or inundation areas would by default be included in the prescribed *flood hazard area* so at least some level of flood protection may be required.

### *6.3.2 Draft Standard and information Handbook for* Construction of buildings in flood hazard areas

The draft Standard (hereafter referred to as the Flood Standard) and Handbook, along with proposed changes to the BCA Volume 1 and 2 are living documents, and while the discussion in this section is appropriate at the time of writing (July 2012) changes may subsequently be made that nullify some comments.

The stated aim of the Flood Standard is to 'reduce the risk of death or injury of building occupants as a result of buildings subjected to certain flood events' (ABCB, 2012b). To do this the Standard provides 'additional requirements for buildings in flood hazard areas consistent with the objectives of the BCA which primarily aim to protect the lives of occupants of those buildings in events up to and including the defined flood event'. The requirements of the Standard are only applicable to new construction of, or significant alteration to, Class 1, 2, 3, 9a (health care) and 9c (aged care) buildings or Class 4 parts of other Class buildings (ABCB, 2011a). In practice these Classes only represent residential building types and not commercial or industrial buildings.

As with land planning practice, the Flood Standard relies on local councils to determine which areas are exposed to flood risk and should therefore apply its rules. This is done through the definition of a *flood hazard area*, which is simply the area inundated during the *defined flood event* used to generate the *natural hazard management area (flood)* in Queensland or the *land subject to inundation overlay (LSIO)* in Victoria. Notionally then, the Flood Standard will be applied to all residential developments that have an AEP of greater than 1%. Across a proposed development site the designer is required to determine the *defined flood level,* which is simply the depth of inundation during the *defined flood event*.

Where the *flood hazard area* has been developed using an AEP other than 1%, or based solely on historic flood experience, a flood load factor, $Y_F$, is used to account for the greater loading a 1% AEP event would apply to a home over that calculated for the *defined flood event* (Table 7). $Y_F$ is applied to calculated design loads alongside those currently required through AS1170. Although this method is not completely accurate in estimating loads during the 'true' 1% AEP flood event (i.e. it does not account for the larger geographical inundation area of the event or the increased depth at a given site when a greater AEP is used), it is a reasonable approach given the impossibility of accurately prescribing how, across the country, either flood area or depth will change with a change in AEP of the local *defined flood event*. As flood mapping becomes more uniform across the country, the need for these load factors will decrease.

**Table 7: Flood load factors (ABCB, 2012b). These values are applied to calculated loads in a similar manner to other load factors in AS1170.**

| Defined flood event (DFE) | Flood load factor $Y_F$ |
|---|---|
| **DFE based on AEP of not more than:** | |
| **1% (1:100)** | 1.0 |
| **2% (1:50)** | 1.2 |
| **4% (1:25)** | 1.4 |
| **DFE based on flood experience with record length of not less than:** | |
| **100 years** | 1.1 |
| **50 years** | 1.3 |
| **25 years** | 1.5 |

While the proposed BCA performance requirements will require all residential buildings in *flood hazard areas* to be constructed considering potential flood actions, the Flood Standard is only written to be an applicable construction manual where expected flow velocities during the *defined flood event* are less than 1.5 m/s. Where flood flow velocities are expected to be greater than this – which will include most areas prone to flash flooding – an alternative design solution is required. This means buildings in these areas will need to be designed from first principles considering potential hydrodynamic and other loads. Where information on expected flow velocities is not available the designer may only use the Flood Standard if the development location is known to be an area of inactive or backwater flow. While it is important that a designation be made between buildings subject to flood loads with and without significant hydrodynamic loads, where this information is not available significant costs may be required of the proponent to obtain it. This said, information on flood flow velocities is expected to be supplied by relevant councils who appear to be more readily making this information available. Lake Macquarie City Council is an example of a local council already supplying flood velocity information The exclusion of design specifications for land prone to high velocity flows is also justified, given the current lack of research on the topic and the highly variable nature of loading depending on, for example, building type, elevation, incidence angle and a range of specific flood characteristics. This is not to say there could never be a prescriptive design methodology such as that used for wind loading in AS/NZS 1170.2 included in a Flood Standard (see HNFMSC (2006) for a possible methodology), but significant investment of both time and money would be required to undertake the research required to achieve this.

Where flood information regarding the *defined flood event* is not available through other pathways, the onus of generating this information falls upon the applicant. This could potentially be a costly procedure and may limit the ability for development in some areas.

Specific clauses of the Flood Standard considered important for reducing the impact of floods on buildings, as well as achieving the desired BCA goal of ensuring life safety (if introduced), are now discussed in more detail. Instances where the introduction of a specific clause may cause conflict or be particularly onerous are outlined.

**Flood actions:** The Flood Standard requires a designer to consider hydrostatic, hydrodynamic, debris, wave, erosion and scour, and combinations of these actions upon a building.

- **Hydrostatic actions**. Balanced hydrostatic actions (lateral and uplift) can only be assumed to occur if specific provision is made for the entry and exit of water during flood events. No guidance is provided in the Standard on the size of openings or design practice required to ensure suitable transfer of water between inside and outside a home, but some information is available in the Handbook.

- **Hydrodynamic actions**: A simplified methodology for considering hydrodynamic actions is provided. Equation (3) (section 3.2) is specified with a constant, *C*, of 1.25 suggested. This is a standard method for considering hydrodynamic loading in slow-flowing floods, but does require information on flow velocity for its application. In the absence of this information the maximum possible increase in *defined flood level* of 0.14 m could be applied without significantly increasing design requirements.
- **Debris and wave actions:** The Standard requires debris and wave actions (not coastal waves) to be considered in design practice. However, the Flood Handbook (ABCB, 2012c) suggests that for buildings to which the Flood Standard is applicable, significant structural resilience is inherently present to nullify the need for further design loading requirements. Observations from damage assessments suggest this is probably a reasonable assumption. That said, debris impact is a design issue for buildings subject to fast-flowing waters (>1.5 m/s, i.e. outside the scope of the Standard) and more thorough, and complex, analysis will be required in these instances.
- **Combination of actions:** It is general practice through AS1170.0 to consider loading implications when multiple actions are applied to a building. Required combinations are specified, including load factors shown in Table 7.

**Floor height requirements:** Outside of restricting development in flood hazard areas, one of the most successful methods for minimising flood impacts is to build homes above the height of expected flooding. The Flood Standard requires all habitable floors to be built above the *flood hazard level*, which is the *defined flood level* plus an additional depth termed the *freeboard*. If planning regulations do not set a *freeboard*, the Flood Standard provides no minimum level thus potentially allowing inadequate values to be used. International practice would suggest a minimum level of 300 mm should be applied.

The Flood Standard also specifies that enclosed non-habitable floor levels can have no more than 1 m of inundation during the *defined flood event*. This means that multi-storey homes can in fact be built with their lower floor levels having an AEP of inundation greater than 1% provided only garages, laundry, toilets and so on are located on that level. From a life safety perspective, this is a reasonable requirement. For loss minimisation, however, it is somewhat less appealing. Although the damage curves developed in section 5.3 do show that when lower storeys are only partially built under (SBT 4) the level of proportional loss is less than for typical two-storey buildings (SBT 3), the losses are considerably more than for an elevated home (SBT 1) where all floor levels are raised above the *defined flood level*. This said, having the ability to build non-habitable floors below the *defined flood level* does allow greater ability to construct on land with some level of flood hazard. This is a particular example of where peoples' expectation about what building codes do (i.e. minimise damage) does not in fact align with what they actually do.

Floor height requirements are shown graphically in Figure 32.

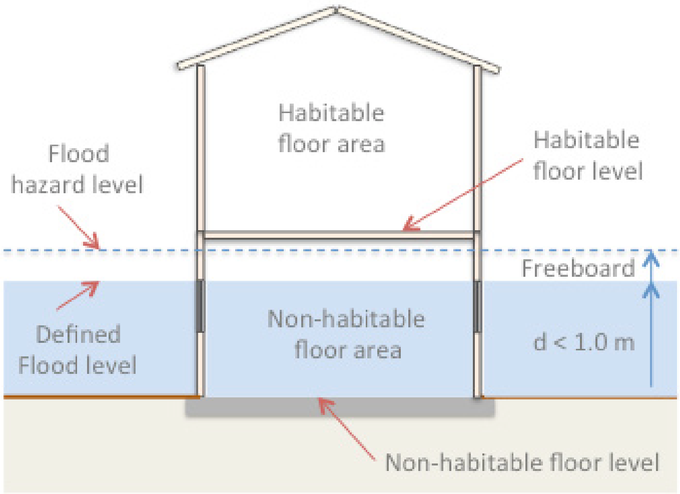


**Figure 32: Habitable and non-habitable floor level requirements in *Construction of buildings in flood hazard areas***

**Footing system requirements:** All buildings are required to have a footing system that prevents flotation of the home or permanent displacement as a result of the *defined flood event*. The design process is required to account for variability in soil properties under rapid wetting and drying conditions, possible erosion and scour, liquefaction and subsidence. Potential debris impact on piers or columns of elevated buildings must also be considered.

Mandatory reference in the Standard is made to the Technical Standard AS2870 *Residential slabs and footings* for use in design, with AS3798 *Guidelines on earthworks for commercial and residential developments* and *Reducing Vulnerability of Buildings to Flood Damage* (HNFMSC, 2006) suggested as suitable documents for design guidance in the Flood Handbook.

**Requirements for enclosures below the *flood hazard level*:** Any enclosed space below the *flood hazard level* must make provision for automatic entry and exit of floodwaters. In effect this means that the Flood Standard requires a wet flood proofing solution and does not allow dry flood proofing. This is a conservative approach that ensures additional structural loads due to differential hydrostatic pressures are not applied to a home during the *defined flood event* or from larger floods. In the instance that a homeowner decides they would prefer dry flood proofing protection, a full engineering analysis and design would be required as an alternative solution. The Flood Handbook provides a set of criteria (e.g. minimum opening sizes) that can be used to achieve automatic entry and exit requirements.

**Structural attachments:** Structural attachments, for example stairs, are permitted below the *flood hazard level* but must be designed to resist all possible flood actions and not adversely impact the resilience of the main structure.

**Material requirements:** All structural components below the *flood hazard level* must be capable of resisting damage or deterioration as a result of water contact for a period equivalent to that expected during the *defined flood event*. These components should also be designed to minimise the dry-out time following the *defined flood event*. This requirement necessitates water resilient design of (for example) framing, bracing, connections and fasteners, but does not require wall cladding, floor covering or cabinetry to have water-resistant properties. On decisions about which materials to use to fulfil these material requirements, Appendix C of the Flood Handbook reproduces an extract from HNFMSC (2006) for guidance (see Appendix 2). In buildings that are only rarely inundated it is in all likelihood more cost effective to replace non-structural elements, for example wall linings, following flood events than designing those elements to be flood resistant. For areas with greater probability of inundation, say every 10–20 years, a case possibly could be made that using all flood resistant materials would be cost beneficial, but this would need to be made on a case-by-case basis. Indeed, it would not improve the structural safety of a home so would be unlikely to be mandated through the BCA. For areas of such frequent flooding, however, it is likely that planning policy would not allow residential construction in the first place.

**Requirements for utilities:** Utilities may not be placed below the *flood hazard level* unless they have been designed to cope with inundation. This applies to electrical, mechanical and HVAC systems. Electrical cables running below this level need to be water proofed, and any buried systems should be deep enough so as to avoid scour or erosion impacts. A particularly significant requirement is the placement of electrical meter boxes above the *flood hazard level*. This will significantly improve amenity following flood events, as submersion of these boxes was identified as a key factor driving losses and disruption by a group of insurance assessors. Building Codes Queensland, however, raises issues about the legality of this requirement (section 6.3.3). The Flood Standard also requires all plumbing or drainage openings below the *flood hazard level* to be protected from backflow.

In its overall context, the proposed Flood Standard will address many of the shortcomings in the current design and construction process for new residential buildings developed in areas prone to flooding. It will not in all instances act to completely avoid damage or loss to a building, but in most instances it will reduce these. An example of this is the requirement that all habitable floors must have an AEP of less than 1%, meaning that the majority of expensive contents will be automatically located above expected flood levels. As a counter example, the necessity for only structural materials below the *flood hazard level* to be water resistant means that non-structural materials, such as wall linings and some floor coverings, will continue to be damaged during flood events. Allowing non-habitable floors below the *defined flood level* will also potentially expose, for example, expensive laundry equipment and contents within storage spaces to regular inundation.

If the Flood Standard is accepted in a form similar to its current draft, it is expected to improve structural performance during flood events, but it is unclear whether the cost of imposing these requirements justifies the savings in all cases. However, the potential indirect savings of minimising the number of people displaced and the duration of displacement for persons affected by a flood event may be significant. The exclusion of **any** additional flood-resistant regulations imposed upon commercial and industrial buildings is considered a missed opportunity. Although these buildings will inherently have greater capacity to withstand the actions of flood events (because they must be engineered), not explicitly specifying that flood actions should be considered in the design process does allow potential impacts to be ignored.

ABCB (2012d) has found the additional cost of implementing the Flood Standard on modern housing (assuming design for a *flood hazard level* of 1 m) would be in the order of 5% of the current home construction cost. A large component of the additional cost is driven by the need to raise habitable floor levels above where they would traditionally be. When considering damage curves developed in section 5.3, it is evident that this cost increase would be recovered easily if inundation could be avoided, or even minimised, during a flood event.

### *6.3.3 Building controls in Queensland*

The primary tools for controlling and assessing building quality in Queensland are the *Queensland Development Code (QDC)* and the BCA. The QDC consolidates many of Queensland's building Standards and includes state-specific requirements on top of those included in the BCA. The *Building Act 1975* lists the mandatory parts of the QDC that have legislative effect, with the remainder of the Code being informative only. Supporting this Act, the *Building Regulations 2006* designate what restrictions local planning schemes or temporary local planning instruments can impose upon a development. Until amendments made in early 2012, temporary local planning instruments could override some building controls regulated by the QDC, but this was amended so that the only requirements planning instruments can set are minimum floor levels (including freeboard) and the areas prone to flooding (QFCI, 2012).

As with the BCA, at present the QDC has no specific building requirements for construction within flood hazard areas. Some parts of Queensland, however, under current TLPIs (section 6.2.1) do have some level of building control requirements. Of course these were not in place prior to the 2010–11 floods.

Using the ABCB draft Flood Standard, Building Codes Queensland has proposed a new Mandatory Part (MP3.5) for inclusion in the QDC. This is proposed to be introduced prior to the inclusion of the draft Flood Standard into the BCA in early 2013 (QFCI, 2012). However, this has not yet occurred.

The proposed new Mandatory Part adopts most clauses (through referencing) of the draft Flood Standard, but does include a few additional requirements and some relaxation of others. These include:

1. Addition of two performance requirements:
    a. Utilities associated with a building, other than an electrical meter for a class 1 building, must be designed or located to reduce the effects of flood water on the utilities in the event of a flood up to a *defined flood event*
    b. A sanitary drain for a building must be protected so that in the event of a flood up to the *defined flood event* the effects of floodwater on the building are reduced.
2. Stipulation that the above two performance requirements be met for those building types included in the Flood Standard, and also new Class 5, 6, 7, 8 or 9b buildings when their use requires immediate occupation following a flood event. These latter classes include commercial and industrial buildings as well as carparks.
3. Flood provisions do not apply to existing buildings being raised, repaired or having an additional storey added.
4. More specific details of the types of utilities requiring flood protection are given. Lift motors are explicitly included, while electrical meter boxes on Class 1 buildings are excluded.
5. A specific requirement to fit reflux valves to sanitary drains is specified. This is a specific solution to the requirement in the draft Standard.

The addition of points 1, 2, 4 and 5 is considered beneficial with respect to the requirements in the draft Flood Standard (it is unclear whether the exclusion of Class 1 buildings in 4 would be required across the country). The exclusions in point 3, however, are potential areas where the QDC would be weakening the requirements of the Flood Standard in Queensland. Through discussion with Building Codes Queensland it was learnt that the exclusion of homes being raised was because the very act of raising a home was in itself felt to be reducing that building's flood risk and was to be encouraged. This may be true, but it does leave room open for owners to elevate only small amounts and still remain exposed to considerable flood risk.

The exclusion of homes being repaired seems counterproductive with respect to risk, but is to some degree understandable, as a number of difficulties surround the application of stringent construction standards upon those trying to rebuild existing homes following a natural disaster. Firstly, owners will want to return to their homes as quickly as possible and imposing improvements upon what could be very old homes will slow this process. The availability of builders and certifiers to facilitate this process, particularly following large floods (as experienced in Brisbane) where large numbers of people need work done, would add further drag to the rebuilding process. On top of this, where insurance is available it is only typically paid out to the value of the existing home, and improvements, even if done to reduce future risk of loss, cannot be claimed. All funding for flood-resilient improvements must therefore come from the homeowner.[4] Not requiring improvements to the buildings most at risk of flooding (i.e. those that have just been flooded) effectively extends the flood risk of that building to the next generation of homeowner. It is also out of line with what is required for other hazards. For example, following Cyclone Larry stringent standards for wind resistance were imposed on all homes being rebuilt after the event. In 2011 when Cyclone Yasi impacted the same area, considerably less damage was wrought on those homes (Boughton et al., 2011). It is clear, therefore, that improving buildings at the point of reconstruction does work and it is thought that some level of home improvement should be required following flood damage. How this could be funded is a more difficult proposition.

The inclusion of both the proposed national Flood Standard and additional requirements of the QDC as building controls in Queensland will act to reduce the flood risk to new developments in the state. It is unfortunate though that those who suffer damage from flooding will not be required to rebuild in a more resilient manner and reduce their future flood risk.

### 6.3.4 Building controls in Victoria

Building controls in Victoria are regulated through the *Building Act 1993* and the *Building Regulations 2006*. The only control within these documents relating to flooding is to say that buildings are required to have minimum floor levels based on the *defined flood event* (typically described by an LSIO) designated by the appropriate water authority (typically a Catchment Management Authority) plus a minimum freeboard of 300 mm. As with planning controls discussed in section 6.2.2, this requirement is not invoked unless the planning scheme has designated a site as land subject to inundation.

No regulations currently set requirements for building materials, utilities or structural resistance to flooding. If the national Flood Standard is adopted into the BCA it will automatically apply to construction in Victoria. No additional requirements appear to be forthcoming outside those proposed in the Flood Standard.

### 6.3.5 Addressing existing flood risk

Development controls are not retrospective and therefore do not decrease the flood risk to existing buildings. This will continue to be the case with the introduction of the Flood Standard. In the event of flooding this will mean a large number of people will still be flooded and governments will continue to compensate those affected.

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[4] Some insurance companies are now offering as an additional feature a premium or excess loading that would allow the owner to claim for improvements to bring their home in line with current building regulation requirements.

Physical solutions to this problem could include relocating the home to a less flood-prone part of a property, elevating occupiable floor levels above expected flood heights (as would be required if it were a new home) or retrofitting the home to be more resilient to flood impacts. The latter could include use of flood-resistant building materials or use of temporary flood barriers (e.g. on weep holes). Unfortunately, a cost–benefit analysis looking at the potential savings that remediation actions would yield over the lifetime of a structure will in most instances show a net cost to the owner of undertaking any significant action. Studies in the UK suggest that an overall benefit is typically achieved only when the home is subject to flooding with an AEP of 2%, and only significantly so when the inundation AEP is greater than 4% (Joseph, Proverbs, Lamond, and Wassell, 2011; Krebs, Fankhauser, Hall, Johnson, Parry, and Wynne, 2012; Thurston, Finlinson, Breakspear, Williams, Shaw, and Chatterton, 2008). However, Joseph et al. (2011) point out that cost–benefit analyses such as these often neglect some of the intangible benefits of mitigation such as reduced stress, anxiety and greater social cohesion. Inclusion of these may suggest benefits to homes at less risk of inundation.

In addition to considering mitigating flood damage to the entire home, Krebs, Fankhauser, Hall, Johnson, Parry and Wynne (2011) suggest that implementing some low-cost measures can act to reduce flood impacts in a cost-beneficial manner. These include installation of non-return (reflux) valves, use of temporary door guards and use of temporary air brick (weep hole) covers. These act to keep water out of a home and would only be beneficial if a home were designed to resist hydrostatic loading or if flood depths were shallow. This work also shows the benefit of implementing improvements at the point of rebuilding following a flood event, in some instances halving the cost–benefit ratio.

The exact numbers will not be the same for Australian homes because of different construction types, building materials, labour costs and available flood mitigation devices, but it is expected to be similar. Analysis by Smith and Penning-Rowsell (1982) of raising homes in Lismore showed there to be an overall benefit. The authors do highlight, however, that since most homes (at the time) were built on stumps, the elevation process was relatively cheap in this case. For slab-on-ground homes, elevation is largely impractical and other mitigation measures would be required.

It is recommended that a flood risk mitigation study be carried out for highly populated flood prone cities (e.g. Brisbane and Ipswich) across Australia using current exposure, flood hazard information and present-day pricing of mitigation strategies. This work should be studied within a cost-benefit framework considering (but not limited to) the options of:

- elevating occupiable floor levels above the *flood hazard level*
- retrofitting homes with flood-resilient materials below the *flood hazard level*
- installing non-return valves to avoid backflow flooding
- using temporary flood defences, e.g. weep hole or door covers.

Different methods will be most suitable for different types of building and should be explored separately.

This work should also look at potential funding mechanisms for retrofitting schemes. Methods for protecting homes against flood waters have been around for a long time yet there is little uptake, so it is clear that some incentives would be necessary. One such mechanism would be the supply of government grants to homeowners rebuilding following a flood event to increase their resilience to future floods. However, for this to be successful, the remediation methods that are most beneficial for a given house type would need to be known prior to flooding so that they could be rapidly implemented during rebuilding. Current insurance practice effectively discourages owners from improving their home following a flood event and so only through government intervention will there be an increased uptake of mitigation.

### *6.3.6 Relevant guidance documents and handbooks for flood-resistant design of Australian buildings*

A number of handbooks and design guidelines currently exist to assist those who want to build flood-resilient structures. Much of this work originated in the USA (through FEMA or the USACE) or the UK (through CIRIA), but some Australia-specific work has been conducted. This section lists a selection of references that could be used to improve flood performance of Australian structures. *Reducing Vulnerability of Buildings to Flood Damage*, published by the Hawkesbury-Nepean Floodplain Management Steering Committee (HNFMSC, 2006), is the most extensive design manual specifically developed for Australian buildings.

**Flood actions (General)**

- *Reducing Vulnerability of Buildings to Flood Damage* (HNFMSC, 2006)
- ASCE Standard 7-05 Flood resistant design and construction
- *Improving the flood performance of new buildings: Flood resilient construction* (Bowker, Escarameia, and Tagg, 2007)

**Foundation design**

- AS3798-2007 Guidelines on earthworks for commercial and residential developments
- AS2870-2011 Residential slabs and footings
- *Reducing Vulnerability of Buildings to Flood Damage* – 3.4 & 4.1 (HNFMSC, 2006)

**Utilities**

- FEMA 348: *Protecting building utilities from flood damage: Principles and practices for design and construction of flood resistant building utility systems*
- *Reducing Vulnerability of Buildings to Flood Damage* – 6 (HNFMSC, 2006)

**Flood resistant materials**

- *Reducing Vulnerability of Buildings to Flood Damage* – section 4.3 (HNFMSC, 2006)
- FEMA Technical Bulletin 2 on flood damage-resistant materials (FEMA, 2008)

**Repair or retrofit of flood-damaged buildings**

- BRANZ Bulletin 455 Restoring a house after flood damage (BRANZ, 2004)
- Technical Guide: *Guide to assessment and repair of flood damaged timber and timber framed houses* (Timber Queensland, 2011)
- CSIRO online flood damage and repair advisory sites. http://www.csiro.au/flood-damage-advisor/fdadvisor.html; http://www.csiro.au/Outcomes/Environment/Australian-Landscapes/Repairing-Flood-Damage.aspx
- FEMA 259: *Engineering principles and practices for retrofitting flood-prone residential structures* (FEMA, 2012)

**Flood proofing**

- *Reducing Vulnerability of Buildings to Flood Damage* – section 4 (HNFMSC, 2006)
- FEMA P-312 *Homeowner's guide to retrofitting: Six ways to protect your home from flooding* (FEMA, 2009)

- FEMA 259: *Engineering Principles and Practices for retrofitting flood-prone residential structures* (FEMA, 2012)

## 6.4 Lessons from international practice

Development controls around the world, by and large, appear to be in line with those currently in place or proposed for introduction in Australia. The primary objective appears to be to discourage new development in areas at risk of flooding using land planning policies and to build structural flood defences (e.g. levees) around areas with existing risk. Little evidence of mandated improvements to buildings subject to existing flood risk was found, but some countries do have regulated building controls for new structures built in areas of known risk (e.g. USA). This section outlines some components of development controls in countries around the world that could potentially reduce flood risk if adopted in Australia. It does not present a detailed analysis of planning or building controls in those countries but instead highlights components that are considered worth further exploration as to their applicability in this country.

### 6.4.1 Quantifying flood risk

For any sort of flood-resistant building controls to be implemented, there needs to be a method for determining which locations are at risk of flooding. The 1% AEP zone, as typically used in Australia, is relatively standard throughout the world as a tool for measuring land considered at risk of flooding where some level of intervention, design requirement or approval is required for development. From a structural design standpoint, proposed Australian practice is to consider flood loading only in zones prone to riverine flooding. Approaches in the USA and parts of the UK (for example) additionally require actions of the sea to be considered. This is beneficial as flood loading in these areas will be well in excess of loads applied to a building through riverine flooding (section 3.2). For these requirements to be applied, however, designers must be made aware of which areas are at risk of which hazard.

The provision of multiple categories of flood hazard region is recommended. Zonations similar to those used by FEMA and ASCE/SEI 24-05 (ASCE, 2005) could be used as a basis. Under these schemes areas prone to flooding are designated as *flood hazard areas* with the subregions of *high risk flood hazard areas,* and *coastal high risk flood hazard areas*. As in Australia, the *flood hazard area* can have a region designated as the floodway where almost all development is restricted; however, contrary to our system, the flood hazard area is defined based on all possible methods of flooding that may lead to inundation with an AEP of 1%. Within a flood hazard area, *high risk flood hazard areas* are specified, which include areas prone to flash flooding, high velocity flows (>10 ft/s, 3 m/s), wave (>3 ft in non-coastal area) or debris actions, alluvial fan flooding, mudslides and areas prone to high rates of erosion. Further still, *coastal high flood hazard areas* are defined which include coastal zones subject to inundation with an AEP of greater than 1% accompanied by breaking waves of greater than 1.5 ft (0.45 m).

While it is recognised that a number of local councils already define some of these areas, it should be a goal that as councils improve their flood mapping they include a nationally uniform set of differing flood zone categories along these lines. In particular, the inclusion of a coastal high flood hazard area should be a priority, as this would allow flood-resistant building controls to be applied in these areas. Although damage to buildings through actions of the sea was not observed during the recent floods, the potential impact of not designing buildings for these loads was made abundantly clear in February 2011 with the landfall of Cyclone Yasi in north Queensland (Boughton et al., 2011). Figure 33 is an example of the type of damage coastal inundation can generate. Water depth in this area was similar to that experienced during flash flooding in Grantham.

**Figure 33: Coastal inundation damage due to storm surge associated with Cyclone Yasi. Note the missing house in the foreground.**

### *6.4.2 Designing for flood actions*

The inclusion of coastal zones into design practice would need to be called for in the BCA. The required action would be to remove *storm surge* and *coastal wave actions* from the limitations within current proposed amendments. A complete set of design specifications is outlined in ASCE/SEI 24-05 (ASCE, 2005) for new buildings in these areas with guidance on siting, elevation, foundation design, design of enclosed areas, erosion control, and design of non-structural attachments. Similar documents or design approaches could be used by Australian designers in areas prone to coastal inundation instead of the current practice that if planning authority is granted for construction, the construction practice is not limited.

### *6.4.3 Use of 1% AEP*

Although the 1% AEP flood extent is almost universal across the world as the definition of an area requiring some level of planning or building intervention, there is no clear reason why this level of risk is chosen. Indeed, it is in many ways out of line with construction practice for other natural hazards in Australia. As mentioned in section 6.3.1, ultimate limit design for wind and earthquake is to an AEP of 0.2%.

The system used in Wales is to use the 1% AEP flood depth to define the habitable floor level, with the additional requirement that inundation cannot be greater than 0.6 m for the 0.1% AEP flood event. This is, in essence and in the parlance of Australian construction practice, setting a serviceability condition that flood waters should not enter a home during a 1% AEP event and an ultimate limit condition that inundation should not be greater than 0.6 m – which if a building is sealed could fail structural walls – during a 0.1% flood event. Use of multiple AEP flood depths is appealing, as it would allow design engineers to consider the entirety of the inundation exceedance probability curve in their calculations, not just a single point. Requiring multiple AEP depths at a site (as recommended in section 6.2.2) would bring flood hazard description more in line with that used for other natural hazards.

The Victorian Floods Commission (Comrie, 2011) notes that planning levels used to define habitable floor levels and design practice are moving to lower AEP flood depths in other parts of the world. For example, London is moving towards using the 0.2% AEP depth, while parts of the Netherlands are using the 0.1% depth. These changes are motivated not so much as a protection measure for individual buildings, but to mitigate the aggregate risk driven by immense exposure of a community to an event exceeding the 1% AEP flood. This thinking deviates from current design philosophy where each building's risk is considered in isolation, and begins to look at the community as a whole and how that much larger system would respond to extreme events. This philosophical approach is discussed in more detail in Walker (2011) and may be appropriate for major cities with considerable flood risk (e.g. Brisbane).

# 7. CONCLUSIONS AND RECOMMENDATIONS

## *7.1 Quantifying the extent of damage to buildings and properties*

Heavy rainfall during late 2010 and early 2011 caused major flooding events throughout Eastern Australia. Queensland and Victoria were particularly hard hit, with financial impacts in the billions of dollars and several thousand buildings inundated in each state. The cities of Brisbane and Ipswich were the worst affected by riverine flooding, with more rural council areas such as Central Highlands (Emerald), Buloke, Campaspe, Central Gold Fields and Loddon also suffering substantial building inundation. Flash flooding affected several areas of Victoria, but the Lockyer Valley (Queensland) was the worst affected. Flash floods driven by heavy rainfall over the Toowoomba Ranges on 10 January 2011 led to 19 deaths, the complete destruction of 119 homes and the partial damage of 2000 more.

This study found that more than 28,000 *properties* were inundated in Queensland with around half of these in Brisbane and one quarter in Ipswich. In Victoria around 2,500 *buildings* were affected throughout the state. Of the residential properties affected in Brisbane, around 90% were in areas developed prior to any form of planning or building controls relating to floodplain management (i.e. the late 1970s) and the vast majority experienced flooding during the 1974 floods (QFCI, 2012).

## *7.2 Analysis of damage to buildings*

Three datasets were used to develop a predictive model for estimating flood loss and occupant displacement based on observed damage to buildings throughout Brisbane, Ipswich and Grantham. These models can be used for flood risk assessments or rapid assessment of impacts following a flood event. Datasets utilised were 1) the Geoscience Australia (GA) Damage Assessment Database, containing 817 assessment records for damaged residential buildings in these areas, 2) the Queensland Fire and Rescue Services (QFRS) Rapid Damage Assessment Database, containing nearly 6000 records for damaged residential and commercial buildings in Brisbane and Ipswich, and 3) a dataset of insured losses for residential buildings throughout Queensland. Insured losses were adjusted to account for demand surge and underinsurance to produce an ALR database for analysis.

Using the intersection of GA and ALR datasets, four semi-empirical total loss (i.e. building and contents) vulnerability curves were developed for different residential building types subject to riverine flooding. These curves relate over-floor flood depth to mean observed loss and use a beta distribution to quantify the scatter of individual building losses about this mean. Building types included elevated homes (SBT 1), slab-on-ground homes (SBT 2), two-storey homes (SBT 3), and two-storey partially built under homes (SBT 4). These curves are empirically adjusted versions of the synthetic mean vulnerability curves developed by Geoscience Australia based on the loss experience embodied in the ALR database. Using the intersection of the QFRS and ALR databases, semi-empirical curves were validated against a (largely) independent dataset. Vulnerability curves for SBT 2 and a combined set of SBT 3 and 4 performed well, but the curve for SBT 1 homes overestimated losses in the latter dataset. Future work should further validate these curves against loss data during other flooding events to ensure the curve's applicability through space and time.

ALR data for damage to buildings in Grantham were assessed against existing thresholds for the onset of damage during high velocity floods. Output from an independently run hydrological model was used to estimate maximum flow velocities through the town. A velocity-depth product of 1m$^2$/s reasonably designated the onset of flow-induced damage to light buildings, but damage to the sub-structure was observed below this threshold. Insufficient data were available for assessing the performance of slab-on-ground homes. Using these same ALR data, a methodology was proposed to include the impacts of flow velocity into the semi-empirical vulnerability curve framework. This process involves the addition of a velocity-induced damage term to the existing model, utilising the maximum depth-velocity product expected to impact a building. Significantly more validation work needs to be undertaken before this approach can be used with any confidence.

A methodology for estimating the proportion of homes requiring occupants to be otherwise accommodated following flood events is proposed. This model relates the likelihood of displacement to the loss ratio at a given building. Using the vulnerability models (mean and scatter) developed earlier, a simulation was run to generate probability curves for expected short- and long-term displacement based on above-floor water depth. No independent data were available to validate these curves, but some qualitative comparisons suggest that results are reasonable. Further work on validating this methodology needs to be undertaken.

Interviews with insurance assessors, builders and a literature review of damage report summaries allowed an analysis of damage to individual components of the building system. Most observations were as expected from other extensive flooding events, but the extent of silt embedded into cavity brick, internal walls and plumbing systems was noted as a major issue. Further to this the occurrence of damage to around 30% of building foundations was reported. Building controls for addressing these and other observed issues are largely covered in the proposed Flood Standard, but issues will remain for existing buildings.

## Recommendations

1. Future research should assess the performance of the semi-empirical vulnerability curves derived here against other (past or future) flood events to ensure their applicability across the country. Update if required.

2. Undertake further research into the correlation between flow velocity and observed damage to buildings. Incorporate this information into a vulnerability curve – along the lines of that proposed in this report – so it can be used for flood risk assessment.

3. Validate the proposed method for estimating occupant displacement against international practice and compare the resulting probability curves with displacement experienced in other (past or future) flood events.

## *7.3 Development controls*

Development controls in Australia are regulated by each state through land planning and building controls but are enforced through local government approval systems. Generally, planning controls are used to determine whether a certain plot is suitable for a given type of development, and if approval is granted, building controls are used to determine how that development is constructed. For land determined to be at-risk of flooding, which typically means the annual probability of inundation is greater than 1%, land planning controls will determine what the floor elevation must be for approval to be granted. Once this approval is given, building controls are used to determine how each building should be constructed to ensure that life safety (and a range of other factors) is maintained during the *defined flood event*.

Land-use planning controls with respect to development on land at-risk of flooding were analysed for Queensland and Victoria. Building controls were also analysed for these states with further analysis of the proposed Flood Standard, *Construction of buildings in flood hazard areas*, undertaken. If approved, this will become the mandated Standard for constructing new buildings in areas prone to flooding.

In Queensland, the State Planning instrument of most importance for minimising flood impacts is State Planning Policy (SPP) 1/03: *Mitigating the Adverse Impacts of Flood, Bushfire and Landslide*. Under this policy local councils are required to consider flood risk at a site when assessing development applications. The policy is only enforced, however, where a local council has deemed that a site lies within a *natural hazard management area*, notionally land with an inundation AEP of greater than 1%. Issues arise in areas where flood mapping has not been undertaken and no such *natural hazard management area* has been defined.

Since the recent flooding, the Queensland Government has introduced TSPP 2/11: *Planning for stronger, more resilient floodplains* that supersedes portions of SPP 1/03 and allows local councils to specify *natural hazard management areas* based on existing 1% AEP flood information where available or by using interim overlay maps developed by the QRA. These interim overlay maps offer a short-term solution for currently unmapped areas, with the long-term goal for these to be superseded by more accurate flood mapping information. Detailed flood hazard maps should continue to be developed throughout the state. Once a site is determined to be within a *natural hazard management area,* local planning instruments will be used to enforce minimum levels for habitable and non-habitable floors based on the *defined flood level* and an additional *freeboard.* No minimum *freeboard* is required but typically it is set between 0.3 and 0.5 m. Following the recent flooding some local councils have chosen to invoke temporary local planning instruments to override clauses within their LPI. Typically this was used to change the depth of the *defined flood event* based on recent experience, to enforce minimum freeboards, or to enforce some level of building control. The ability of TLPIs to impose the latter where some specification is given by the QDC was revoked earlier this year.

Floodplain management in Victoria is controlled through Victorian Planning Provisions and the specification of flood zones and overlays. These areas designate land prone to differing levels of flood hazard. Where available, flood mapping is used to identify areas subject to inundation or within a floodway; otherwise anecdotal information is used. Unlike Queensland, when a development application is submitted for land that lies within a flood hazard area, decisions on its suitability for development are deferred to an independent body, the Catchment Management Authority. CMAs are technically skilled in flood risk analysis and able to give an impartial assessment of the risk of flooding at a site. They are also able to impose other requirements on developments, for example, elevated escape routes. Planning controls in Victoria are also used to set minimum floor levels and apply freeboards.

The principle document for controlling construction practice in Australia is the Building Code of Australia (BCA). The BCA is given legislative effect in all states and territories through reference in their respective building Acts and Regulations. At present the BCA has no specific requirements with respect to flood-resistant design, but the ABCB have recently developed a draft Flood Standard to address this shortcoming. The draft Standard is currently proposed for adoption into the BCA in early 2013 and is a performance-based design manual. It is not a technical Standard along the lines of AS/NZS1170.2 or AS1170.4 but instead sets a number of performance requirements following closely what is specified in the US equivalent ASCE/SEI 24-05.

If called upon in the BCA, the Flood Standard will require design of a structure to resist, for the *defined flood event*, all potential flood actions (e.g. hydrostatic, hydrodynamic loads); to comply with requirements for elevation and construction of adequate foundations; when parts lie below the *flood hazard level*, to consider flow of water into and out of a building and use of adequate flood resistant materials; and to comply with requirements for locating utilities and not adversely impact neighbouring buildings. The Standard itself is limited in its application to residential construction in areas where flow velocities are less than 1.5 m/s and where inundation of non-habitable floors is less than 1 m. No inundation of habitable floors is allowed. Where velocities or inundation depths exceed these thresholds, a ‘first principles’ engineering approach must be adopted to ensure construction will still satisfy the performance requirement. There are no additional requirements on commercial or industrial buildings constructed in these areas.

In general the development of a Flood Standard is beneficial and will act to improve the capacity of housing to withstand flood loads. However, the exclusion of areas prone to coastal flooding and commercial and industrial building types from any form of flood-resistant design requirements is considered detrimental and a serious deficiency.

Neither Queensland nor Victoria currently have flood-resistant design requirements in their building regulations. Both states have said they will adopt the Flood Handbook as a design manual if approved for inclusion in the BCA. Going further, Queensland has drafted amendments to the QDC that would effectively adopt the performance requirements in the Flood Standard prior to BCA adoption. In this amendment a number of specific solutions are provided for broad performance statements within the Flood Standard, and the applicability of a number of performance requirements is extended to commercial or industrial buildings, as well as carparks, when their immediate use after a flood is required. Unfortunately, proposed changes would preclude application of the Flood Standard to homes being rebuilt following flooding. Although the motivation behind this change is understandable, it is nevertheless detrimental in the view of the authors.

The vexed problem of how to address existing flood risk was considered. Looking to international examples it was found that building-level improvements to reduce the impacts of flooding were only beneficial (on average), in a cost–benefit framework, when the AEP of inundation was greater than 2%. Significant benefits were only seen when the AEP exceeded 4%. Although it is not expected that the numbers will be identical in Australia, it is felt they would be similar. Detailed cost–benefit analysis of retrofit methodologies should be carried out for flood prone cities in Australia. Possible funding mechanisms to entice people to undertake these retrofits should also be explored.

International development controls with respect to design for flood actions were assessed – predominantly for the USA and UK. Where building controls were mandated they did not differ too much from those proposed in the Flood Standard, but the use of multiple flood levels based on different AEP floods is worth further consideration in Australia.

## Recommendations

4. Responsible bodies should continue development of accurate flood maps in Queensland and Victoria (and other states) that aim to identify multiple flood hazard layers (e.g. 0.2%, 1%, 5% AEP), and a range of flood characteristics. These should include flood depth, flow velocity, rate of rise, and origin of flooding (e.g. riverine flooding, high velocity flooding, flash flooding, and coastal inundation).

5. State governments could assess the viability of introducing independent flood assessment bodies similar to Catchment Management Authorities in Victoria to assess development proposals with respect to flood risk in other states.

6. The ABCB should consider including some level of flood-resistant design requirements for commercial and industrial buildings within proposed changes to the BCA. Proposed changes to the QDC could be used as a basis from which to work.

7. Areas prone to storm surge and coastal wave actions should be included in the proposed BCA amendment. To facilitate design for these actions, include provisions similar to those in ASCE/SEI 24-05 in the Flood Standard.

8. The Flood Standard should specifically set a minimum freeboard of at least 300 mm.

9. Remove *raising existing building* and *repairing existing building* from exclusion in proposed changes to the QDC.

10. The handbook *Reducing Vulnerability of Buildings to Flood Damage* (HNFMSC, 2006) should be reviewed and if necessary updated to ensure that it is applicable to all building types throughout Australia. This should form the basis of a prescriptive technical design manual to be called upon by the Flood Standard. The responsibility for undertaking and maintaining such a document should fall to a national body, e.g. ABCB, Engineers Australia, Standards Australia.

11. Cost–benefit analysis of the application of flood-aware design to new construction and retrofit methodologies to existing buildings be carried out for flood-prone cities in Australia. Possible funding mechanisms to entice people to undertake these actions should also be explored. These could be done through case studies, with Brisbane being a good first choice.

12. The Flood Standard should consider using multiple *design flood levels* so a performance- and risk-based engineering approach can be adopted for design of structures.

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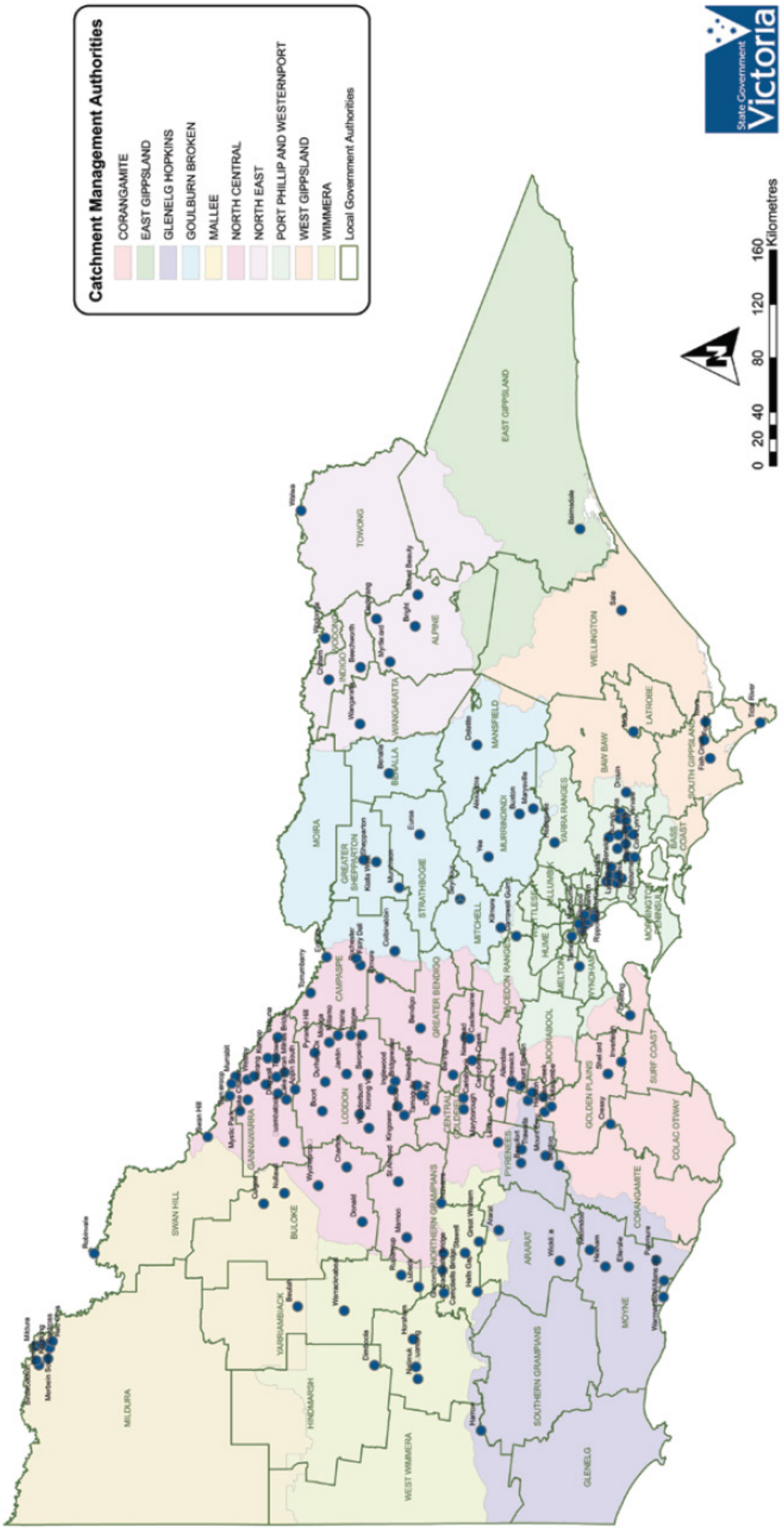
# APPENDIX 1

## *Map of flood-affected cities and towns*

(a) Flood-affected and known inundated towns/cities in Queensland. Local Government Areas also shown (BoM, 2011a).

# MAP OF AFFECTED AREAS



(b) Flood-affected towns/cities in Victoria (Victorian Government, 2011)

# APPENDIX 2

## *Building material performance for 96 hour inundation – HNFMSC 2006 pp. 59–60*

| COMPONENT | SUITABLE* | MILD EFFECTS* | MARKED EFFECTS* | SEVERE EFFECTS* |
|---|---|---|---|---|
| FLOOR, SUB-FLOOR STRUCTURE | • slab-on-ground<br>• suspended concrete | • timber T&G (with ends only epoxy sealed and provision of side clearance for board swelling) or plywood | • standard grade plywood | • timber floor close to the ground and particleboard flooring close to the ground |
| WALLS SUPPORT STRUCTURE | • reinforced or mass concrete | • full brick/block masonry cavity brick | • brick/block veneer with venting (stud frame) | • inaccessible openings<br>• large windows low to the ground |
| WALL AND CEILING LININGS | • fibre cement sheet<br>• face brick or blockwork<br>• cement render<br>• ceramic wall tiles<br>• galvanised steel sheet<br>• glass and glass blocks<br>• stone, solid or veneer<br>• plastic sheeting or tiles with waterproof adhesive | • common bricks<br>• solid wood, fully sealed<br>• exterior grade plywood<br>• fully sealed<br>• non ferrous metals | • exterior grade particleboard<br>• hardboard<br>• solid wood with allowance for swelling<br>• exterior grade plywood<br>• plasterboard | • particleboard<br>• fibreboard or strawboard<br>• wallpaper<br>• cloth wall coverings<br>• standard plywood<br>• gypsum plaster |
| ROOF STRUCTURE | • reinforced concrete<br>• galvanised metal construction | • timber trusses with galvanised connections | • traditional timber roof construction | • inaccessible flat floor<br>• ungalvanised structural steelwork<br>• unsecured roof tiles |
| DOORS | • solid panel with waterproof adhesive<br>• flush marine ply with closed cell foam<br>• aluminium or galvanised steel frame | • flush or single panel marine ply with waterproof adhesive<br>• painted metal construction<br>• timber frame, full epoxy sealed before assembly | • standard timber frame | • standard flush hollow core with PVA adhesives and honeycomb paper core<br>Note: lowest cost and generally inexpensive to replace |

| COMPONENT | SUITABLE* | MILD EFFECTS* | MARKED EFFECTS* | SEVERE EFFECTS* |
|---|---|---|---|---|
| WINDOWS | • aluminium frame with stainless steel or brass rollers | • timber frame, full epoxy sealed before assembly with stainless steel or brass fittings | | • timber with PVA glues<br>• mild steel fittings |
| INSULATION | • plastic/ polystyrene boards<br>• closed cell solid insulation | • reflective foil perforated with holes to drain water if used under timber floors | | • materials which store water and delay drying<br>• open celled insulation (batts etc) |
| BOLTS, HINGES NAILS & FITTINGS | • brass, nylon/ stainless steel, removable pin hinges | • galvanised steel, aluminium | | • mild steel<br>** see Note below |
| FLOOR COVERING | • clay/concrete tiles<br>• epoxy or cementitious floor toppings on concrete<br>• rubber sheets (chemically set adhesives)<br>• vinyl sheet (chemically set adhesive) | • terrazzo<br>• rubber tiles (chemically set adhesives)<br>• vinyl tiles (chemically set adhesive)<br>• polished floor & loose rugs<br>• ceramic tiles | • loose fit nylon or acrylic carpet (closed cell rubber underlay) | • wall to wall carpet<br>• wall to wall seagrass matting<br>• cork<br>• linoleum |

** KEY*

***SUITABLE***

***these materials or products are relatively unaffected by submersion and flood exposure and are the best available for the particular application.***

***MILD EFFECTS***

***these materials or products suffer only mild effects from flooding and are the next best choice if the most suitable materials or products are too expensive or unavailable.***

***MARKED EFFECTS***

***these materials or products are more liable to damage under flood than the above category.***

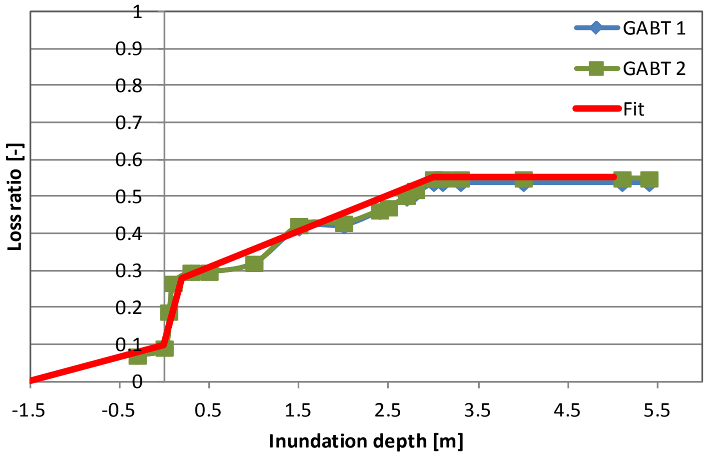
***SEVERE EFFECTS***

***these materials or products are seriously affected by floodwaters and have to replaced if inundated.***

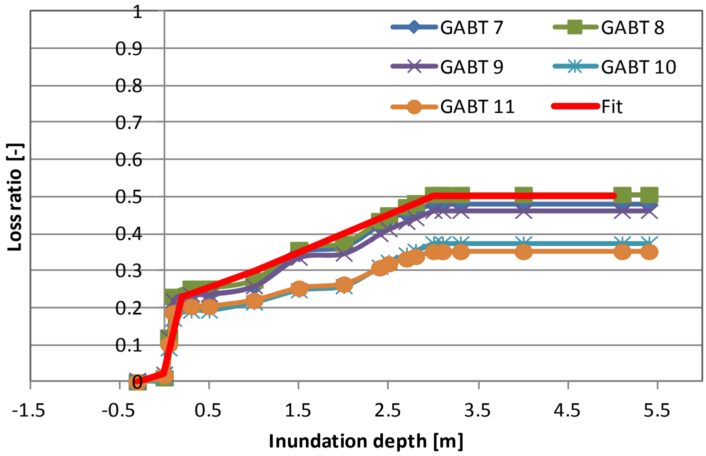
***** Note: For nominal fixings in timber framing, AS 1684.2 requires nails used in joints that are continuously damp or exposed to the weather to be hot dip galvanised, stainless steel or monel metal.***

# APPENDIX 3

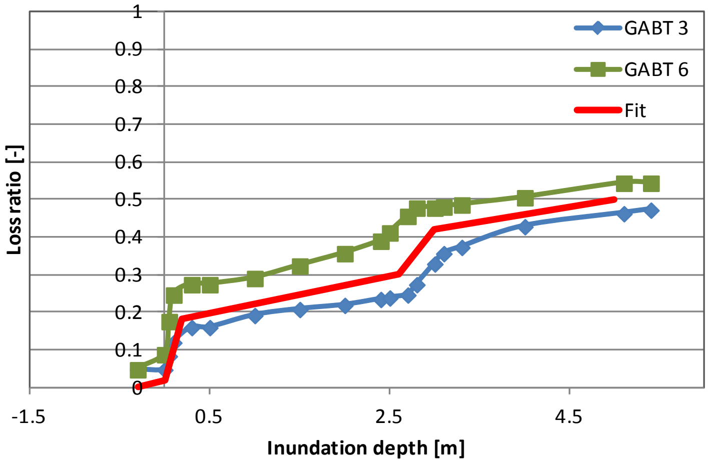
## *Empirically adjusted synthetic GA vulnerability curves*



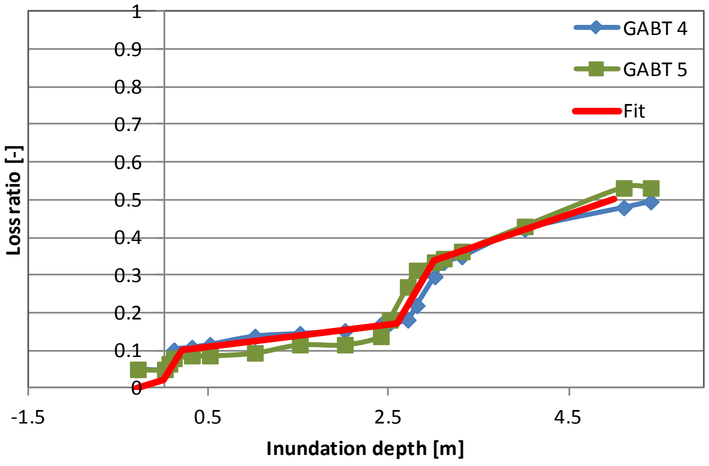
(a)



(b)

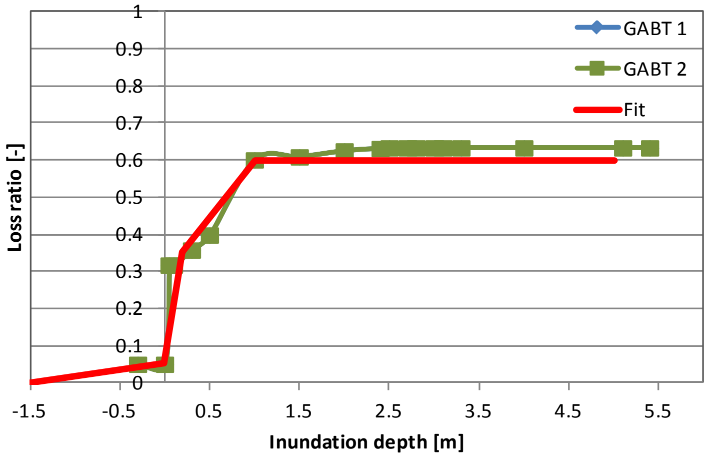


(c)

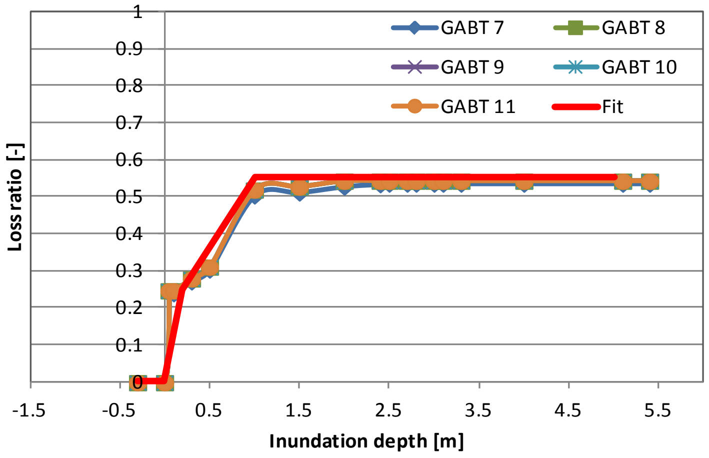


(d)

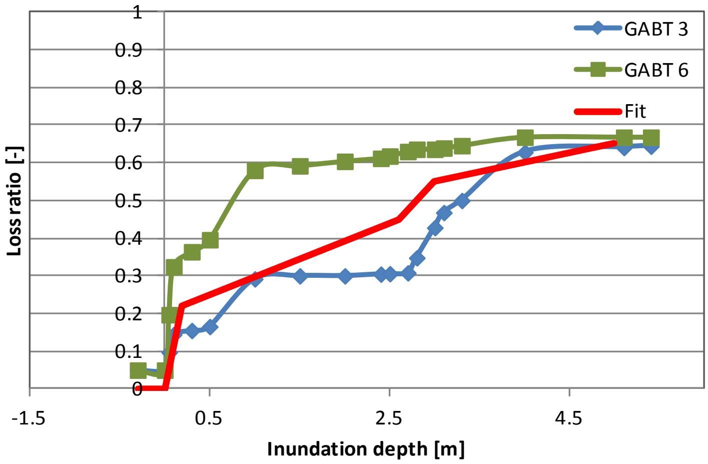
Figure A3-1 Empirically adjusted GA potential building damage curves for (a) SBT 1, (b) SBT 2, (c) SBT 3, (d) SBT 4.



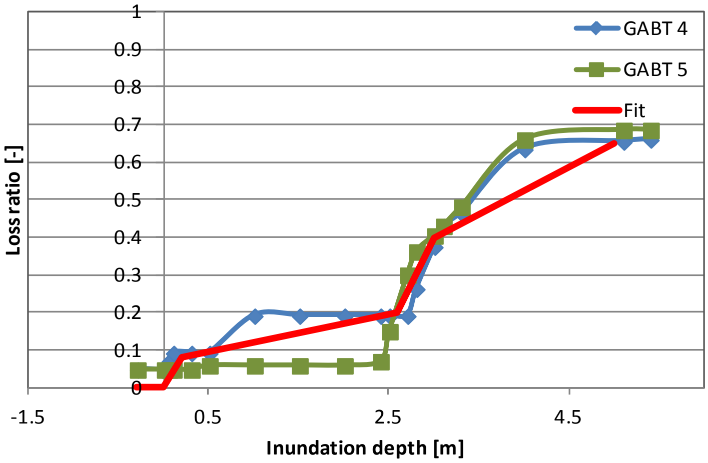
(a)



(b)



(c)



(d)

Figure A3-2 Empirically adjusted GA potential contents damage curves for (a) SBT 1, (b) SBT 2, (c) SBT 3, (d) SBT 4.

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