

'Reducing the loss': Using high-resolution vulnerability assessments to enhance tsunami risk reduction strategies

Using Manly, Sydney as a case study, Dall'Osso and Dominey-Howes explore the implications for enhancing tsunami risk management based upon high-resolution assessments of building vulnerability.

ABSTRACT

Australia is at risk from tsunamis and recent work has identified the need for detailed models to assess the vulnerability of buildings to damage during tsunamis. Such models will be useful for underpinning the development of land-use zoning regulations, the identification of appropriate design standards and construction codes and in outlining community relevant tsunami disaster risk reduction strategies by local emergency managers. Such strategies might include the identification of coastal areas that require evacuation, the identification of specific buildings that might be the focus of search and rescue efforts, and the demarcation of 'safe' evacuation areas and structures within expected tsunami flood zones. We use the results of a very high-resolution assessment of building vulnerability to tsunami (using the PTVA -3 Model) at Manly, Sydney to illustrate how vulnerability assessments could be used to enhance tsunami risk reduction.

For the coast of New South Wales (NSW) (Figure 1a), tide-gauge records show that historically, only small tsunamis have occurred (Dominey-Howes, 2007). Reported geological evidence however, suggests that megatsunami many times larger than the 2004 Indian Ocean event may have occurred many times during the last 10,000 years – a period in earth history called the Holocene (for original references, see the reviews of Dominey-Howes, 2007 and Dominey-Howes *et al.*, 2006). This geological work has led to the development of what has been referred to as the 'Australian Megatsunami Hypothesis' or 'AMH' (Goff *et al.*, 2003; Dominey-Howes *et al.*, 2006). The evidence for the 'AMH' is very controversial (Felton and Crook, 2003; Goff and McFadgen, 2003; Goff *et al.*, 2003; Noormets *et al.*, 2004). First, some of the proposed evidence for megatsunami has clearly been incorrectly interpreted (Dominey-Howes *et al.*, 2006). Second, there appears to be a 'disjunct' or mismatch between the historic record of small frequent events and the Holocene record of large infrequent tsunami (Dominey-Howes, 2007; Goff and Dominey-Howes, 2010). Last, no independent verification of the sources of these events has been undertaken—a vital component for understanding risk (Dawson, 1999). Bryant (2008) however, advocates a cosmogenic source for these events although this hypothesis also remains to be proven.

If the 'AMH' can be independently validated, it has profound implications for the coastal vulnerability of NSW and government agencies (such as the NSW State Emergency Service (NSW SES)) are very likely and understandably, completely unprepared for such events. Further, it indicates that we should not be complacent about the potential magnitude of future tsunamis even though only small events have occurred in the past. For example, the proposed Holocene megatsunami occurred in coastal areas of NSW where more than 330,000 people now live within 1 km of the coastline and at no more than +10 metres above sea level (m asl) (Bird and Dominey-Howes, 2006; 2008). More than 20% of these people are over the age of

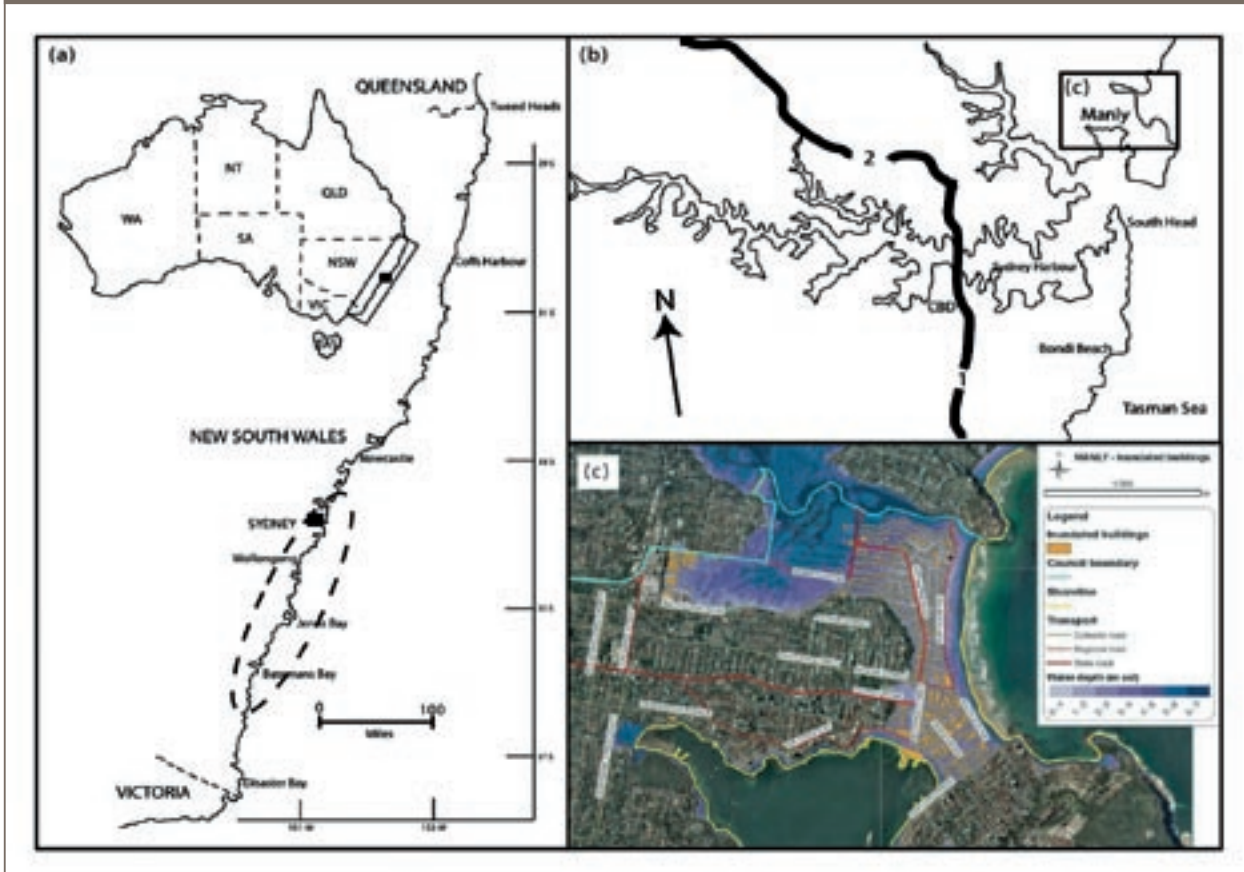
Introduction

The coasts of Australia are at risk from tsunamis. Dominey-Howes (2007) indicates that more than 40 tsunamis have affected Australia since 1788. The 2004 Indian Ocean and 2006 Java tsunamis both resulted in flooding of low-lying coastal areas of NW Western Australia. More recently, the 2007 Solomon Islands and 2009 New Zealand tsunamis were both recorded on tide gauges along the eastern seaboard of Australia although there was no significant inundation associated with these events.

FIGURE 1. (a) Broad location of the study region of Sydney located in New South Wales, SE Australia. The hatched oval encompassing the region north of Sydney south to beyond Batemans Bay is the region reported to have been affected by Holocene megatsunamis. NSW = New South Wales, NT = Northern Territory, SA = South Australia, TAS = Tasmania, VIC = Victoria, WA = Western Australia.

(b) Simplified map of the Sydney Harbour region with Manly located NE of the CBD. Highways 1 and 2 are shown.

(c) Detailed GIS map of Manly. Area of inundation (including relative water depths above land surface) associated with the tsunami referred to are shown in blue. Principal features are highlighted and buildings inundated by the tsunami are indicated in orange.



65 (Opper and Gissing, 2005). Furthermore, within the Sydney region, approximately 400,000 property addresses are located less than 3 km from the coast and about 200,000 are less than +15 m asl (Chen and McAneney, 2006). These properties have a combined value of more than \$150 billion. Given this massive exposure, it is of concern that our understanding of the regional tsunami risk remains limited and unverified and that no work has been undertaken to assess the 'vulnerability' of coastal buildings.

Hall *et al.*, (2008) outlined an extremely useful 'step-by-step scientific process' to gather information useful for assessing the risk to Australia's coasts from tsunamis. The first part of this process defines all likely sources of tsunamis, estimates their frequencies and then propagates tsunami waves from these sources to shallow water adjacent to the coast providing a probabilistic wave height for any particular return period of interest. The second step of the process utilises inundation modelling to examine exactly how far inland and to what elevation above normal sea level a particular tsunami might flood. At the present time, in Australia, Geoscience Australia is the agency that undertakes these tasks.

The final step in the scientific process described by Hall *et al.*, (2008) is to map the 'exposure' of (for example) buildings within the expected inundation zone and then assess the 'vulnerability' of those structures to damage associated with that event. So far though, this last step has not been undertaken by any official government agency or emergency service.

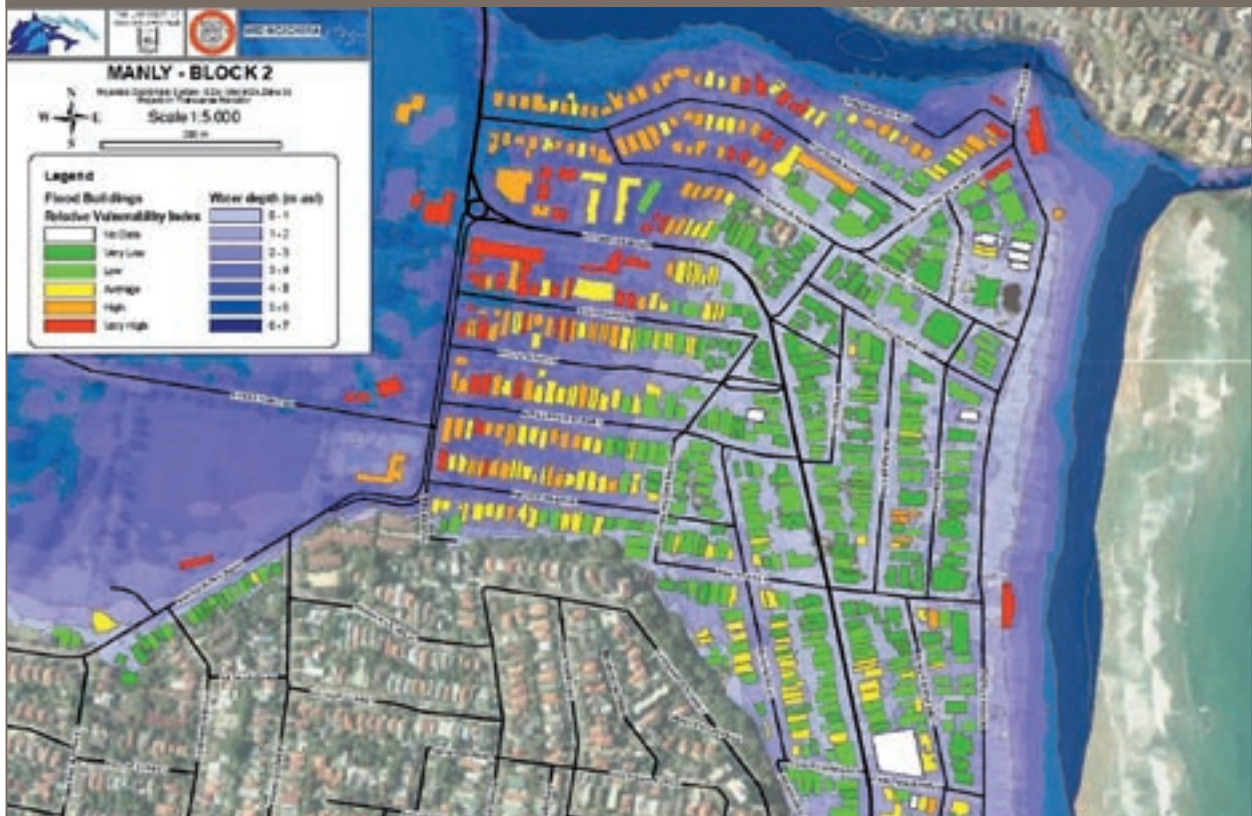
Assessing the vulnerability of buildings to tsunami damage using the PTVA Model

Only one model has been developed that assesses the vulnerability of buildings to damage from tsunamis. This model – the Papathoma Tsunami Vulnerability Assessment (or PTVA) Model has been described in detail in Papathoma *et al.*, (2003) and Papathoma and Dominey-Howes (2003). It was then validated by Dominey-Howes and Papathoma-Köhle (2007) and Dall'Osso *et al.*, (2010) and applied to different case studies by Papathoma *et al.*, (2003), Papathoma and Dominey-Howes (2003) and Dominey-Howes *et al.*, (2010). Broadly speaking the model collects and

FIGURE 2. The Manly study area divided in to four (4) 'Blocks' for ease of results presentation. This paper just deals with Blocks 2 and 3.



FIGURE 3. Tsunami inundation and water depth in Block 2, Manly. The RVI scores of every building of all classes located within the inundation zone are indicated.



integrates engineering attributes about buildings together with information about the tsunami and the natural environment in order to calculate a 'Relative Vulnerability Index' (RVI) score or rank for each building.

Recently, Dall'Osso *et al.*, (2009a) presented a newly revised and improved version of the model – PTVA-3. Further, Dall'Osso *et al.*, (2009b) applied the PTVA-3 model to a case study in Manly, Sydney (Figure 1b, c). They undertook an assessment of 1100+ individual buildings located within the expected flood zone associated with a particular tsunami scenario. The scenario is fully described in Dall'Osso *et al.*, (2009b) and the area of Manly forecast to be inundated is shown in Figure 1c. Since the area inundated was large, they presented their assessment of building vulnerability in four separate blocks (referred to as 'Manly, Block 1 to 4) (Figure 2).

For a full description of the results of the case study, see Dall'Osso *et al.*, (2009b). However, their main findings are shown in Table 1. They divided the buildings in to nine classes and assessed the RVI scores of each building in each class. Table 1 indicates that of the 1100+ buildings they assessed, the majority of the building stock is residential followed by commercial. The absolute number of buildings in each class assessed as having a particular RVI score are indicated in columns 3 to 7 of Table 1. An example of the spatial distribution of all buildings in Block 2 of different classes, together with their RVI scores is shown in Figure 3. It is clear therefore, that the application of the PTVA-3 Model to individual buildings located within an expected inundation zone can provide very high-resolution information about the spatial vulnerability of buildings and by analogy, the population in that area.

Enhancing tsunami risk reduction strategies using high-resolution vulnerability assessments

Many different stakeholders will be interested in the management of risk associated with tsunamis. However, here we focus on Australian Local Government Authorities (LGA's) (including their Local Emergency Management Officers (LEMO's)) together with their local units of the State Emergency Service (SES) who are at the sharp end of dealing with hazardous events such as tsunamis.

Local government planners will be interested in a number of questions that include (but are not limited to):

- Which low-lying areas of coastal land are 'safe' to permit new and/or re- development?
- Are there any low-lying parcels of coastal land that are simply too 'unsafe' to permit any form of development?
- If development and/or re- development is permissible, should there be any forms of restrictions and if so, what?
- What building standards, codes and regulations should be applied to new development (and re- development) proposals to minimise the vulnerability of new structures built at the coast?
- For existing structures, what is their vulnerability and how (if at all) can that vulnerability be reduced?
- For any buildings assessed as having "High" or "Very High" RVI, what (if any) liability is faced by Local Government?

Local Government LEMO's and Emergency Service personnel will be interested in (amongst others) questions such as:

- Which areas of the coast are likely to experience flooding associated with a tsunami of a particular magnitude/return period?
- Which areas of low-lying coastal land will need to be evacuated in the event of a tsunami of a particular magnitude/return period?
- What areas can be identified as 'safe zones' to which people may be moved during an evacuation?
- What are the best routes to 'safe evacuation areas'?
- Which buildings are likely to be the most problematic or will require special attention or response (e.g., search and rescue) during a tsunami event of a particular magnitude? For example, where are the schools and nursing homes?
- In the event that it is not possible to move all people located within the expected inundation zone into 'safe' evacuation areas, which buildings provide the best options for 'vertical evacuation' above the maximum expected flood level?

We are not qualified to address these questions but it is clear that the approach we have developed and tested and which is detailed in Dall'Osso *et al.*, (2009a, b) does provide the sort of high-resolution data needed by decision makers to tackle these important questions.

Maps displaying 'exposure' during inundation such as Figures 1c and 3, will be useful for guiding decision making processes related to land-use zoning. It is apparent that having accurate information about flood depth above ground surface will be useful for those organisations who make decisions about development proposals, building design and regulation. We are aware that prohibiting development of coastal landscape areas is neither desirable or in many cases, practical. However, data generated by models and approaches like ours certainly can help to guide decision making to ensure new, and re- developed, structures are constructed to a standard that reduces risk to an affordable minimum.

Some of the individual buildings located in Block 2 (Figure 3) are directly owned and managed by the Manly LGA. Table 1 indicates that some seven (7) LGA buildings in the whole Manly area that would be affected by a tsunami are assessed as having "High" or "Very High" RVI scores. In many ways, local taxes and environmental levies paid by residents in this LGA are

FIGURE 4. Evacuation areas and 'safe' buildings for evacuation, Block 2, Manly.

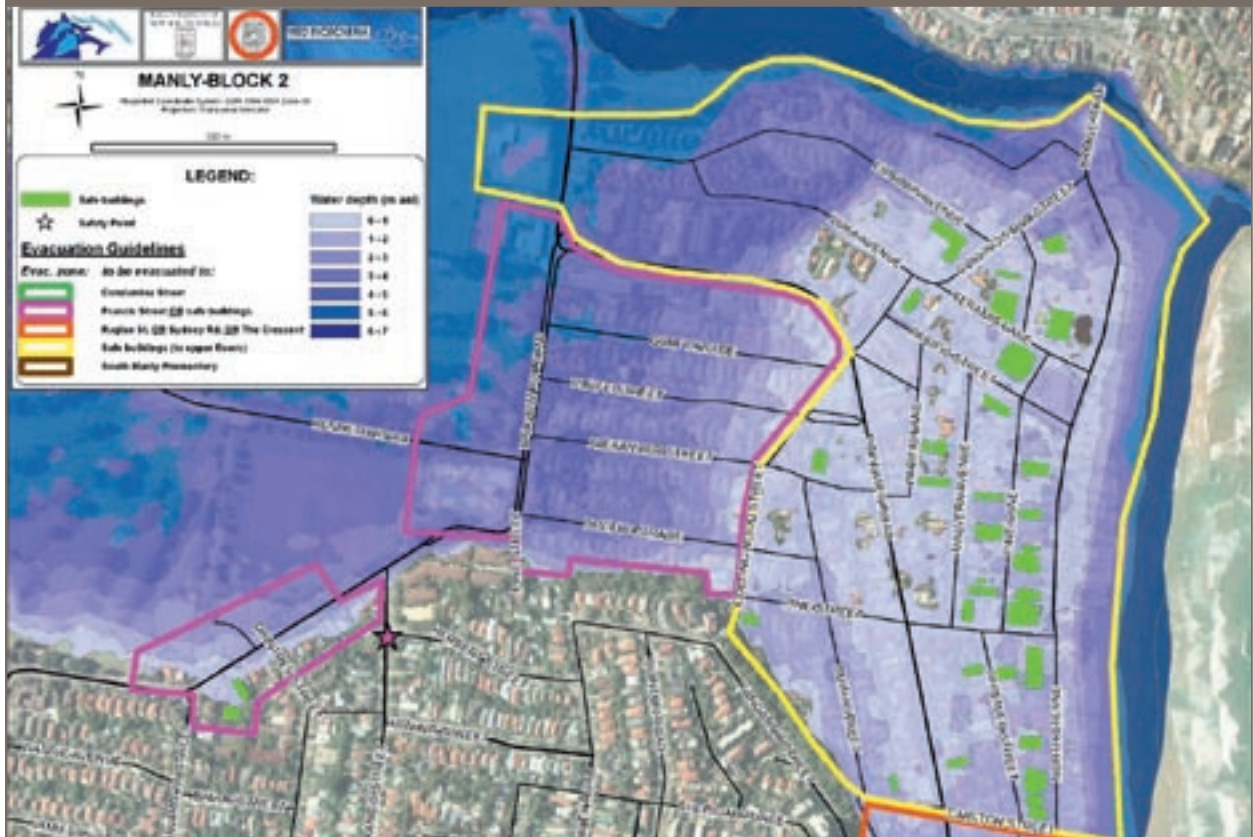


FIGURE 5. Evacuation areas and 'safe' buildings for evacuation, Block 3, Manly.



used (in part) for the upkeep of buildings owned and managed by the authority. Therefore, the LGA might use the results of an assessment like that described by Dall'Osso *et al.*, (2009b) to prioritise actions that help to reduce the vulnerability of these buildings and enhance the capacity of the LGA to recover after a tsunami event. Once again, we are not making recommendations but are pointing towards where, and how, our work might assist local decision makers.

We have used some of the results generated by Dall'Osso *et al.*, (2009b) to explore the potential identification of areas that might be classified as 'safe evacuation areas' during a tsunami. Figures 4 and 5 display those areas we think could be the subject of evacuation orders. Where appropriate, in each area, we have identified individual buildings that could be used for vertical evacuation above the maximum expected flood level. In Figures 4 and 5, these individual buildings are coloured green. These buildings are identified from the PTVA-3 Model analysis carried out by Dall'Osso *et al.*, (2009b) because they have the lowest RVI values and because their upper floors lie well above the expected maximum flood height. That is, these buildings have at least two floors above the expected maximum flood level. Once again, it should be noted that we are not making recommendations that these specific buildings should be designated 'safe evacuation structures', merely that such analysis can lead to the identification of such buildings. It is for others to determine which are most suitable.

The type of work carried out by Dall'Osso *et al.*, (2009b) is extremely valuable. For example, Figure 4 shows that the recommended 'evacuation area' that bounds Golf Parade, Rolfe Street, Alexander Street, Pacific Parade and Pine Street does not contain a single building that would be 'safe' to evacuate in to during a tsunami associated with their scenario. That is, all buildings would be almost fully inundated and many would be severely damaged, if not completely destroyed. Therefore, people that occupy these buildings would need to fully evacuate the whole area. Having information like this means that the Emergency Services can pre-plan the best evacuation routes, implement signage at street level and develop and engage in community education and outreach programs. The value of such 'draft' evacuation maps has recently been presented and discussed in Dall'Osso and Dominey-Howes (2010). Conversely, the large evacuation area of Figure 4 parallel with the coast has many individual buildings we assess as useful for vertical evacuation (although the western ends of Eurobin Avenue and Iluka Avenue are some what problematic).

Figure 5 shows the mixed residential and commercial area of Manly CBD. Although the flow depth above ground surface is rather high in the tsunami scenario examined in this case, many individual buildings are assessed as being appropriate for vertical evacuation. Given that the ocean beach at Manly is a favourite with beach going visitors to the area and can be heavily populated on a sunny weekend in the summer, the close proximity of many buildings suitable for vertical evacuation, is somewhat reassuring.

Conclusion

As our cities expand, the exposure of our built environment to hazards such as tsunamis increases. Australia is at risk to tsunamis. The 2004 Indian Ocean tsunami was catastrophic. In some areas like Banda Aceh city, near complete devastation of the urban landscape occurred. Abandoning coastal regions affected by hazards such as tsunamis is simply not possible for a variety of reasons. Therefore, in order to enhance tsunami risk reduction strategies, high-resolution assessments of building vulnerability are required. Such assessments provide the building blocks upon which appropriate risk reduction strategies may be formulated. Recent work by Dall'Osso *et al.*, (2009a, b) using a newly revised and improved PTVA-3 Model has been shown to be useful for providing very high-resolution assessments of the vulnerability of individual building structures to tsunamis of particular magnitudes. In this paper, we have taken the outputs from Dall'Osso *et al.*, (2009b) and shown where and how they may be used to address important questions of relevance to local government and emergency services officers. We use a detailed case study from Manly, Sydney to explore these questions and options. We have not made specific recommendations since in our view, it is the role of responsible professional decision makers to best decide how such data might be used.

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