Australian Disaster Resilience Handbook Collection

MANUAL 46

Tsunami Emergency Planning in Australia

Australian Institute for Disaster Resilience

AUSTRALIAN DISASTER RESILIENCE
HANDBOOK COLLECTION

Tsunami Emergency Planning in Australia

Manual 46

Australian Government
Attorney-General's Department

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History of the Australian National Disaster Resilience Handbook Collection

The first publications in the original Australian Emergency Manual Series were primarily skills reference manuals produced from 1989 onwards. In August 1996, on advice from the National Emergency Management Principles and Practice Advisory Group, the Series was expanded to include a more comprehensive range of emergency management principles and practice reference publications.

In 2011, Handbooks were introduced to better align the Series with the *National Strategy for Disaster Resilience*. Compiled by practitioners with management and service-delivery experience in a range of disaster events, the handbooks comprised principles, strategies and actions to help the management and delivery of support services in a disaster context.

In 2015, the Australian Institute for Disaster Resilience (AIDR) was appointed custodian of the handbooks and manuals in the series. Now known as the Australian Disaster Resilience Handbook Collection, AIDR continues to provide guidance on the national principles and practices in disaster resilience in Australia through management and publication of the Collection.

The Handbook Collection is developed and reviewed by national consultative committees representing a range of state and territory agencies, governments, organisations and individuals involved in disaster resilience. The Collection is sponsored by the Australian Government Attorney-General's Department.

Access to the Collection and further details are available at www.knowledge.aidr.org.au.

Australian National Disaster Resilience Handbook Collection (2011 –)

Handbook 1 Disaster health

Handbook 2 Community recovery

Handbook 3 Managing exercises

Handbook 4 Evacuation planning

Handbook 5 Communicating with people with a disability – National Guidelines for Emergency Managers

Handbook 6 National Strategy for Disaster Resilience – community engagement framework

Handbook 7 Managing the floodplain: a guide to best practice in flood risk management in Australia

- **Guideline 7-1** Guideline for using the national generic brief for flood investigations to develop project specific specifications
- **Guideline 7-2** Technical Flood Risk Management Guideline: flood emergency response classification of the floodplain
- **Guideline 7-3** Technical flood risk management guideline: flood hazard
- **Template 7-4** Technical project brief template
- **Guideline 7-5** Technical Flood Risk Management Guideline - flood information to support land-use planning
- **Guideline 7-6** Technical flood risk management guideline: assessing options and service levels for treating existing risk
- **Practice Note 7-7** Considering flooding in land-use planning activities

Handbook 8 Lessons management

Handbook 9 Australian Emergency Management Arrangements

Handbook 10 National Emergency Risk Assessment Guidelines *(plus supporting guideline)*

Guideline 10-1 National Emergency Risk Assessment Guidelines: practice guide

Handbook 11 *renamed Guideline 10-1 National Emergency Risk Assessment Guidelines: practice guide*

Handbook 12 *Spontaneous volunteer management*

Australian Emergency Management Manual Series

The most recent list of publications in the Manuals series includes 46 titles.

The manuals have not been reviewed since 2011 or earlier and the Manual Series is undergoing a review which will see relevant Manuals move into the Handbook Collection. Current and past editions of the Manuals will remain available on the AIDR Knowledge Hub at www.knowledge.aidr.org.au.

Manual Series Catalogue: 2004 - 2011

Manual 1 Emergency management concepts and principles (2004)

Manual 2 *Australian Emergency Management Arrangements (superseded by Handbook 9)*

Manual 3 Australian Emergency Management Glossary (1998)

Manual 4 Australian Emergency Management Terms Thesaurus (1998)

Manual 5 *Emergency risk management – applications guide (superseded by Handbook 10)*

Manual 6 *Implementing emergency risk management – a facilitator's guide to working with committees and communities (superseded by Handbook 10)*

Manual 7 Planning safer communities – land use planning for natural hazards (2002, currently under review)

Manual 8 *Emergency catering (2003, archived)*

Manual 12 Safe and healthy mass gatherings (1999)

Manual 13 Health aspects of chemical, biological and radiological hazards (2000)

Manual 14 Post disaster survey and assessment (2001)

Manual 15 Community emergency planning (1992)

Manual 16 Urban search and rescue – capability guidelines for structural collapse (2002)

Manual 17 Multi-agency incident management (replaced by AIIMS)

Manual 18 Community and personal support services (1998)

Manual 19 *Managing the floodplain (superseded by Handbook 7)*

Manual 20 Flood preparedness (2009)

Manual 21 Flood warning (2009)

Manual 22 Flood response (2009)

Manual 23 Emergency management planning for floods affected by dams (2009)

Manual 24 Reducing the community impact of landslides (2001)

Manual 25 Guidelines for psychological services: emergency managers guide (2003)

Manual 26 Guidelines for psychological services: mental health practitioners guide (2003)

Manual 27 Disaster loss assessment guidelines (2002)

Manual 28 Economic and financial aspects of disaster recovery (2002)

Manual 29 Community development in recovery from disaster (2003)

Manual 30 Storm and water damage operations (2007) (information may not be appropriate to all situations)

Manual 31 Operations centre management (2001)

Manual 32 Leadership (1997)

Manual 33 National Land search operations (2014) (refer to the Land Search Operations Manual website)

Manual 34 Road rescue (2009)

Manual 35 General and disaster rescue (2006)

Manual 36 Map reading and navigation (2001)

Manual 37 Four-wheel-drive vehicle operation (1997)

Manual 38 Communications (1998)

Manual 39 Flood rescue boat operation (2009)

Manual 40 Vertical Rescue (2001)

Manual 41 *Small group training management (1999, archived)*

Manual 42 *Managing Exercises (superseded by Handbook 3)*

Manual 43 Emergency planning (2004)

Manual 44 Guidelines for emergency management in culturally and linguistically diverse communities (2007)

Manual 45 Guidelines for the development of community education, awareness and education programs (2010)

Manual 46 Tsunami (2010)

Contents

Preface

The purpose of this manual is to enhance capacity and knowledge regarding the emergency planning for tsunami in Australia and to provide emergency managers with a guide to the key principles of tsunami preparedness.

The manual is the initiative of the Australian Tsunami Working Group (ATWG), a subordinate forum of the National Emergency Management Committee. ATWG membership comprises of all Australian States and Territories, Bureau of Meteorology, Geoscience Australia, Attorney-General's Department and Surf Life Saving Australia.

The manual is designed for use by all those who have roles to play in preparing communities for tsunami, whether in lead or supporting agencies. These people will include emergency management practitioners and members of agencies and organisations that will be involved in tsunami response operations, including staff and volunteers in the State/Territory Emergency Service organisation which, in most jurisdictions in Australia, have a lead role in the emergency planning for tsunami.

The document is intended to provide broad guidance on all the important aspects of tsunami preparedness. It incorporates best practice approaches developed over many years of tsunami planning and other facets of tsunami preparedness in the Australian states and territories.

Like other documents in the Australian Emergency Manual series, this guide focuses on defining 'best practice' as this is presently understood in Australia. It does not seek to define or describe current practices, which may vary considerably between jurisdictions.

Every attempt has been made to use neutral terminology. As a result, the guide does not use specific terminology (for example in relation to officers, programs and management structures) or refer to the particular arrangements for tsunami management in the various states and territories.

Mike Norris
Acting First Assistant Secretary
National Security Capability Development Division
Attorney-General's Department

CHAPTER 1

Introduction

1.1 Purpose of the Manual

This manual is an initiative of the Australian Tsunami Working Group (ATWG). A subordinate forum of the National Emergency Management Committee, the ATWG comprises all Australian States and Territories, Bureau of Meteorology (the Bureau), Geoscience Australia (GA), Attorney-General's Department and Surf Life Saving Australia (SLSA). The working group collaborates on tsunami management initiatives including warning systems, community education, capacity building activities, risk assessment and emergency planning in attempts to further enhance the nation's capability to plan for and manage tsunami emergencies.

The purpose of this manual is to enhance the capacity and knowledge of emergency managers regarding emergency planning for tsunami in Australia. This manual provides emergency managers an easy to read guide on the key principles of tsunami science, tsunami risk assessment, warning systems, emergency planning, community education, response management and recovery. The guide may be used to assist emergency and coastal managers when developing emergency risk management strategies to deal with the threat of tsunami.

Further information about the emergency management of tsunami in individual jurisdictions is available from the tsunami control agency in each state or territory.

1.2 What is a Tsunami?

The name *tsunami* is derived from the Japanese words 'tsu' meaning harbour and 'nami' meaning wave. The word tsunami is now used internationally to describe a series of long period, full depth waves travelling across the ocean.

In the past tsunami have been referred to as "tidal waves" or "seismic sea waves". However, the term "tidal wave" is misleading and should not be used to describe a tsunami event. Even though a tsunami's impact upon a coastline is dependent on the tidal level at the time a tsunami strikes, tsunami are unrelated to the tides. Tides result from the gravitational influences of the moon, sun, and planets.

Similarly, the term "seismic sea wave" is also misleading. "Seismic" implies an earthquake-related generation mechanism. An earthquake is one of several ways that a tsunami can be generated.

1.3 How are Tsunami Generated?

The most common cause of tsunami is an undersea earthquake that results in a sudden rise or fall of a section of the earth's crust under or near the ocean. Typically tsunami are generated by earthquakes that occur along subduction zones. A subduction zone is an area on the earth where two tectonic plates meet and move towards one another, with one sliding underneath the other down into the earth at rates typically measured in centimetres per year.

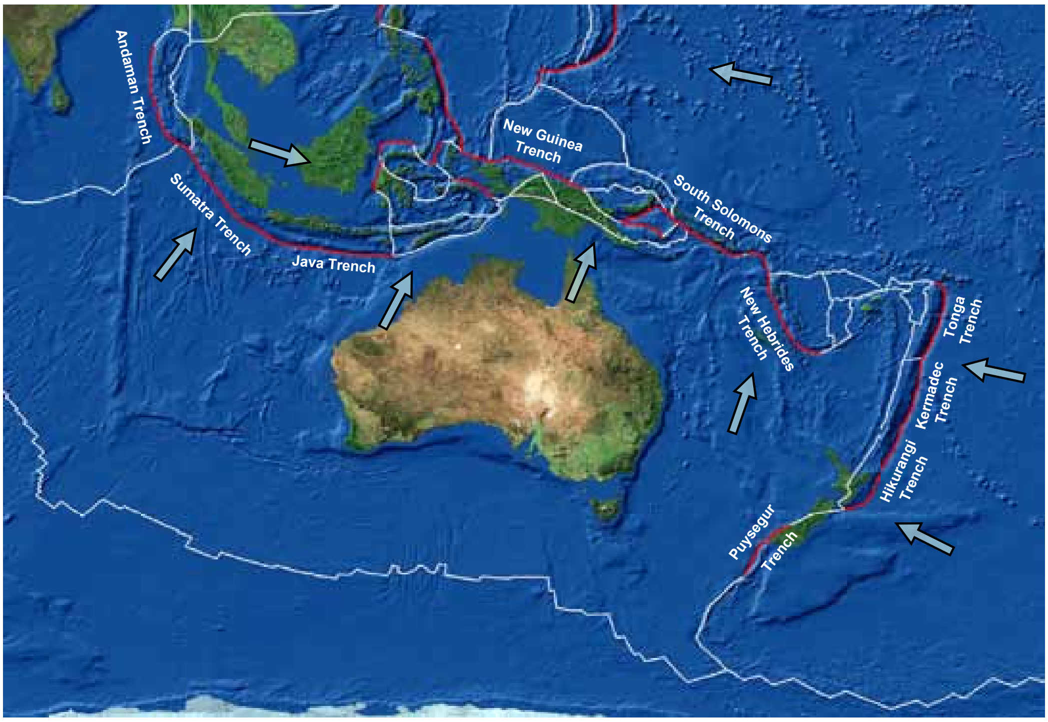


Figure 1.1 Subduction Zones surrounding Australia.

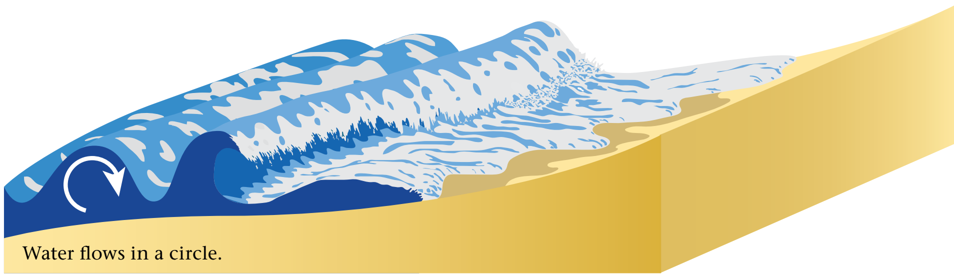
Source: Geoscience Australia

An earthquake creates an explosive vertical motion between the two plates that can displace the overlying water column, creating a rise or fall in the level of the ocean above. This rise or fall in sea level is the initial impulse that generates tsunami waves. It should be noted that the Australian Tsunami Warning System only monitors and detects tsunami generated by undersea earthquakes.

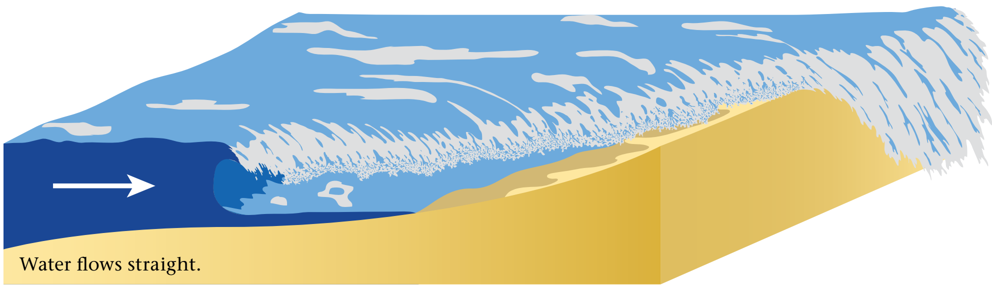
Tsunami can also be caused by events such as underwater landslides, volcanic eruptions, land slumping into the ocean (typically from the face of a continental shelf), meteorite impacts and even the weather when the atmospheric pressure changes very rapidly.

1.4 What are the Characteristics of a Tsunami?

A tsunami is different from a normal ocean wave. The effects of wind-driven ocean waves are seen only near the surface of the ocean, however tsunami waves involve the movement of water all the way to the seafloor. Additionally, in the deep ocean tsunami waves have extremely long wavelengths. In comparison to wind driven waves, tsunami waves may have wavelengths up to hundreds of kilometres between wave crests. Tsunami are therefore much more destructive than normal waves because the huge flooding body of water can continue to rush onto land for an extended period of time. This may be anything from a few minutes to up to an hour, compared to seconds for wind driven waves.



Wind waves come and go without flooding higher areas.



Tsunami run quickly over the land as a wall of water.

Figure 1.2 Tsunami waves versus wind generated waves

Source: University of Washington

The speed and size of a tsunami is controlled by water depth. In the deep ocean, tsunami waves may be unnoticed by ships or from the air. As the wave approaches land it reaches shallow water and slows down. Compared to the front of the wave, the rear is still in slightly deeper water (so it is going slightly faster) and catches up. The result is that the wave ‘bunches up’, the wavelength becomes shorter and the body of water becomes much higher. This effect is called shoaling.

In the deep ocean, a tsunami can travel at more than 900 kilometres per hour, similar to the speed of a jumbo jet. In shallow water, the tsunami waves slow down and can be compared to roughly the speed of a fast cyclist. As well as travelling at high speeds, tsunami can also travel large distances with limited energy losses. Tsunami can have sufficient energy to travel across entire oceans.

The path of a tsunami is never symmetrical – the waves do not radiate out uniformly in all directions from the earthquake hypocentre like ripples from a rock thrown into a pond. Tsunami predominantly propagate out at right angles to the orientation of the subduction trench on which the earthquake occurred. The finer details of the path are determined by a number of factors, including the bathymetry of the seafloor. Bathymetry is the measurement of the depth of the ocean floor from the water surface and is the oceanic equivalent of topography. A tsunami travels faster through deep water and slower through shallow water, which influences how the waves travel along undersea valleys. The size and shape of the earthquake are also factors influencing where a tsunami will propagate.

As mentioned, a tsunami generally consists of a series of waves. The amount of time between successive wave crests is known as the wave period. Wave crests can be a few minutes to over two hours apart. In most cases, the first tsunami wave is not the largest. Subsequent waves, sometimes the fifth or sixth, can be many times larger.

The impact of a tsunami can vary widely. A small tsunami may result in unusual tides or currents that can be dangerous to swimmers or cause damage to boats and marinas. A large tsunami can cause widespread flooding and destruction, such as that seen off the west coast of Northern Sumatra on 26 December 2004. Large tsunami can cause strong rips and currents in oceans around the world for up to a few days after the initial earthquake.

With the arrival of a tsunami, natural signs may sometimes, but not always, be experienced near the coast. Natural warning signs that may be observed include:

1. Evidence of a large undersea earthquake, which may be felt prior to a tsunami with shaking of the ground in coastal regions.
2. As a tsunami approaches shorelines, the sea may sometimes withdraw from the beach (like a very low and fast tide) before returning as a fast-moving tsunami.
3. A roaring sound may precede the arrival of a tsunami.

Tsunami magnitude at the coast is dependent on the configuration of the coastline, the shape of the ocean floor, reflection of waves, tides and wind waves. Narrow bays, inlets and estuaries may cause funnelling effects that enhance tsunami magnitude. The combination of these factors means that the flooding produced by a tsunami can vary greatly from place to place over a short distance.

CHAPTER 2

Australian Tsunami Hazard

Key Points

- ***The main source of Australian tsunami hazard is subduction zone earthquakes to the north and east of Australia.***
- ***Australia's highest tsunami hazard is in northwest Western Australia, where the coast is exposed to tsunami generated off the coast of Indonesia.***
- ***The largest historical tsunami run-ups have occurred in northwest Western Australia.***
- ***Geological investigations of tsunami deposits (palaeotsunami) suggest larger events than those historically observed may have occurred in the past.***

2.1 Introduction

Australia has never experienced a catastrophic tsunami disaster on the scale of the Indian Ocean tsunami of 2004. However, tsunami have impacted Australia during historical and prehistorical times, showing that a real tsunami threat exists. Australia is surrounded to the north and east by some 8000 kilometres of active tectonic plate boundaries capable of generating tsunami that would reach Australia within two to four hours. Furthermore, 50% of Australians live within 7 km of the shoreline, meaning that a considerable proportion of Australians are exposed to tsunami hazard. The population exposed can swell during peak holiday periods, with nearly two-thirds of international and a quarter of domestic tourists spending time at the beach (Tourism Research Australia 2006, 2007). Understanding tsunami hazard in Australia allows steps to be taken to mitigate against it.

This chapter discusses the sources of tsunami hazard in Australia, the present understanding of the threat posed by these sources, and steps that can be taken to mitigate the hazard. Evidence for historical and prehistorical tsunami in Australia is also discussed.

2.2 Potential Sources of Tsunami Hazard in Australia

Earthquake

Australia is surrounded by an 8000 kilometre system of subduction zones in the Indian and Pacific Oceans to the north and east. Large earthquakes along these subduction zones have produced most of the significant tsunami recorded in the region, and nearly all tsunami historically recorded to reach Australia. As such, these subduction zones are considered the most likely source of tsunami that may impact Australia (Burbidge et al., 2008), and thus have received the most attention in hazard and risk assessments.

Our understanding of tsunami generated by earthquakes is more advanced than for other sources due to their relative frequency. However, the long return periods for large earthquakes means there is still significant uncertainty regarding the frequency and maximum magnitude of earthquake generated tsunami.

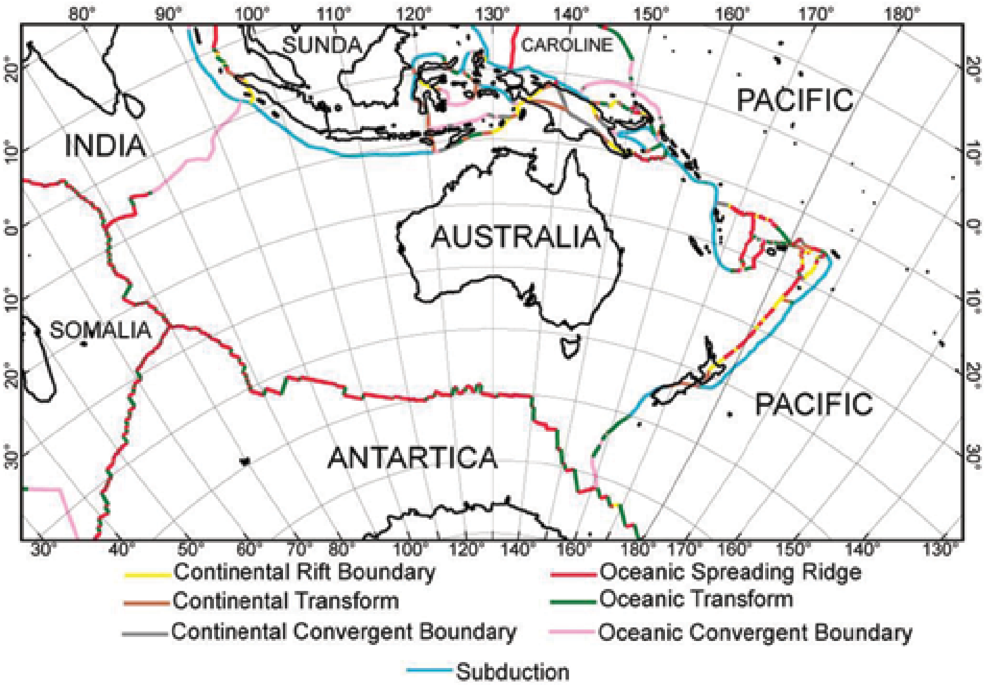


Figure 2.1 Active tectonic plate boundaries that surround Australia

Source: Geoscience Australia.

Tsunami that have historically created the largest run-ups in Australia have been generated by earthquakes off the south coast of Indonesia and have inundated parts of the Western Australian coast. Earthquakes above magnitude 7.5 have created several tsunami over the past few decades, particularly those from eastern Indonesia, such as the Java tsunami in 2006.

East of Australia, earthquakes from the subduction zones stretching from Papua New Guinea through the Solomon Islands and Vanuatu to New Zealand have generated several historical tsunami that have been observed on the east coast, however none have been large enough to create substantial inundation. These subduction zones are considered the main sources of tsunami hazard for eastern Australia. Of particular note, the Puysegur Trench, extending southwards of New Zealand, is considered to be a significant source of tsunami hazard for South East Australia, particularly Tasmania.

Further afield, large earthquakes have been known to occur in the eastern Pacific off South America. The magnitude 9.5 Chile earthquake in 1960 was far away, and most of the tsunami did not head in Australia's direction. Although this event did not create any major inundation on the Australian coast, it did create currents strong enough to tear boats from their moorings in several harbours along the east coast (Lynam et al.,1988).

Landslide

Less is known about the magnitude and frequency of tsunami generated by submarine landslide (slope failure) around the Australian coast. A recent survey along the New South Wales continental slope identified several potential sources of slope failures (Glenn et al., 2008). Multiple landslide scars were located along the continental slope, several of them adjacent to population and critical infrastructure locations. As more surveys are conducted around the world, it is increasingly recognised that slope failures are common along many continental margins. It is also thought that an ocean-wide tsunami can be produced by massive collapse of a part of a volcano (Ward and Day, 2001).

Anecdotal evidence exists of freak waves having swamped the coast on clear, calm days at several Australian locations (see box text). These freak wave events may represent tsunami generated by small, localised submarine landslides (Middelmann, 2007).

1. 'Black Sunday' drownings at Bondi beach

The event known as 'Black Sunday' occurred on 6 February 1938 at Bondi Beach, New South Wales (PMSEIC 2005). This event was characterised by three successive waves that piled water on the beach and returned as backwash, sweeping swimmers out to sea. Five people were drowned. The waves were not restricted to Bondi Beach; they were reported on adjacent beaches and as far north as Newcastle. It has been suggested, although not proved, that this event may have been a tsunami generated by a localised submarine landslide.

Volcanic eruption

There are at least five regions that have volcanoes capable of generating a tsunami with the potential to affect Australia (Rynn and Davidson, 1999):

- Eastern Indonesia (including Krakatau)
- Papua New Guinea (New Britain–New Ireland)
- The Kermadec Islands region
- The Tonga–Samoa volcanic arc
- The South Fiji basin.

The eruption of Krakatau on 26–27 August 1883 generated a tsunami that affected Australia and is the only documented example of its kind (Gregson and Van Recken, 1998). It caused 36,000 deaths in Indonesia and generated a tsunami in the Indian Ocean that was more extensive than the 2004 Indian Ocean tsunami. Within four hours of the final eruption, a tsunami reached several locations along the coast of Western Australia, with a maximum run-up of 1.8 metres above sea level (Hunt, 1929). The recurrence time for major eruptions at Krakatau is thought to be 21,000 years (Beauregard, 2001). The likelihood of other volcanic centres triggering the generation of a tsunami that would impact Australia is not known. Historical records suggest these events are rare.

There are 137 volcanic centres known to have erupted in the last 10,000 years in the region between New Zealand and Papua New Guinea (Smithsonian Institute, 2007). While a number of these volcanoes are too small or are located too far inland to produce tsunami, a surprisingly large proportion has some tsunamigenic potential. Large scale collapse of volcanic edifices outside or our region are well known. Perhaps the best understood of these are the Hawaiian chain of volcanoes which experience repeated failures with a suspected frequency of around 1 in 100,000 years. Slope failures have been of the order of up to 2-3,000 km^3 and capable of generating Pacific-wide tsunami. It is also likely that seamounts and guyots spread across the ocean floor of the Pacific are capable of generating landslides that could also produce tsunami.

An understanding of the frequency of the resultant wave height at source is required to estimate the potential impact at the Australian coastline from these volcanic sources. An assessment conducted as part of the NSW Tsunami Risk Assessment Scoping Study (Somerville et al, 2009) estimated that the chance of a volcanic source generating over a one metre wave height at the NSW coast would be rare. Regional sources are estimated to generate a tsunami with less than a one metre wave height at the NSW coast.

Meteorite or Comet Impact

The hazard posed by tsunami generated from meteorite or comet impact is insufficiently understood. Meteorite impacts have been suggested as sources for several palaeotsunami deposits in Australia (Bryant et al. 2007; Scheffers et al. 2008). However, confirmation of meteorites as the source is difficult due to the often circumstantial nature of the evidence. Although, such events are considered very rare, they are potentially the source of the most catastrophic tsunami.

2.3 Potential Warning Times

A key design standard of any tsunami warning system is the definition of the amount of time between the publication of a tsunami warning and the arrival of the first tsunami at a threatened coastline. The most significant threats to Australia are from the subduction zones that surround Australia to the northwest and northeast around to the southeast. The shortest tsunami arrival times from the closest of these source zones (the Puysegur Trench, south of New Zealand, and the Java Trench, south of Java) are approximately 2 hours. So allowing for an overall time of 30 minutes for detection and assessment of the earthquake, determination of potential tsunami threat and preparation and dissemination of a tsunami warning, the maximum possible warning time for tsunami coming from the nearer sources to the Australian mainland or Tasmania would be 90 minutes. Accordingly, the standard defined for the Australian Tsunami Warning System is to provide a minimum of 90 minutes warning to Australian coastal communities for tsunami generated earthquakes occurring on tectonic plate boundaries in the Indian, Pacific and Southern Oceans. For tsunami coming from sources other than the nearest sources Australian coastal communities will receive longer warning times.

The Joint Australian Tsunami Warning Centre has a demonstrated capability of consistently issuing initial tsunami warning bulletins within 30 minutes of the origin time of earthquakes within the Australian region.

2.4 Current Knowledge of Australian Tsunami Hazard

Due to the absence of any significant tsunami disasters from the historical record, tsunami hazard in Australia has traditionally been assumed to be relatively low. However, palaeotsunami investigations suggesting significant prehistorical tsunami and mega-tsunami (see section 2.6), followed by the catastrophic events of 26 December 2004, have focussed attention on the problem of properly understanding Australia's tsunami hazard.

Recently Geoscience Australia completed a probabilistic tsunami hazard assessment (PTHA)for events generated in subduction zones (Burbidge et al., 2008) as part of the Attorney-General's Department capacity building initiatives. This assessment estimates the likelihood of a tsunami wave of a given amplitude occurring at offshore locations. These probabilities are shown graphically in Figure 2.2. It must be noted that tsunami generated from sources other than subduction zones are not included in this hazard assessment. The focus on subduction zones in the southeast Indian and Pacific Oceans is justified because these are known to have produced major historical tsunami and are considered the most likely sources of future events. Sources not considered in this assessment include:

- Non-seismic tsunami sources (e.g. submarine landslides, volcanoes or meteorites); and
- Earthquakes that do not occur on a subduction zone. Examples of these earthquakes include those that occur on plate margins or within the plate itself (intra-plate earthquakes).

The results of the hazard assessment can be summarised as:

- The highest offshore hazard is the northwest coast of WA;
- The offshore hazard on the eastern and northern coasts of Australia is significantly less than it is for northwest Australia;
- The offshore hazard on the southern coasts of Australia is much lower than the rest of the Australian coast;
- The majority of the offshore hazard is sourced from the subduction zones closest to Australia, i.e. eastern Indonesia, particularly Java and Sumatra, and the southwest Pacific near New Zealand, Vanuatu and the Solomon Islands; and
- The offshore hazard from other subduction zones is low.

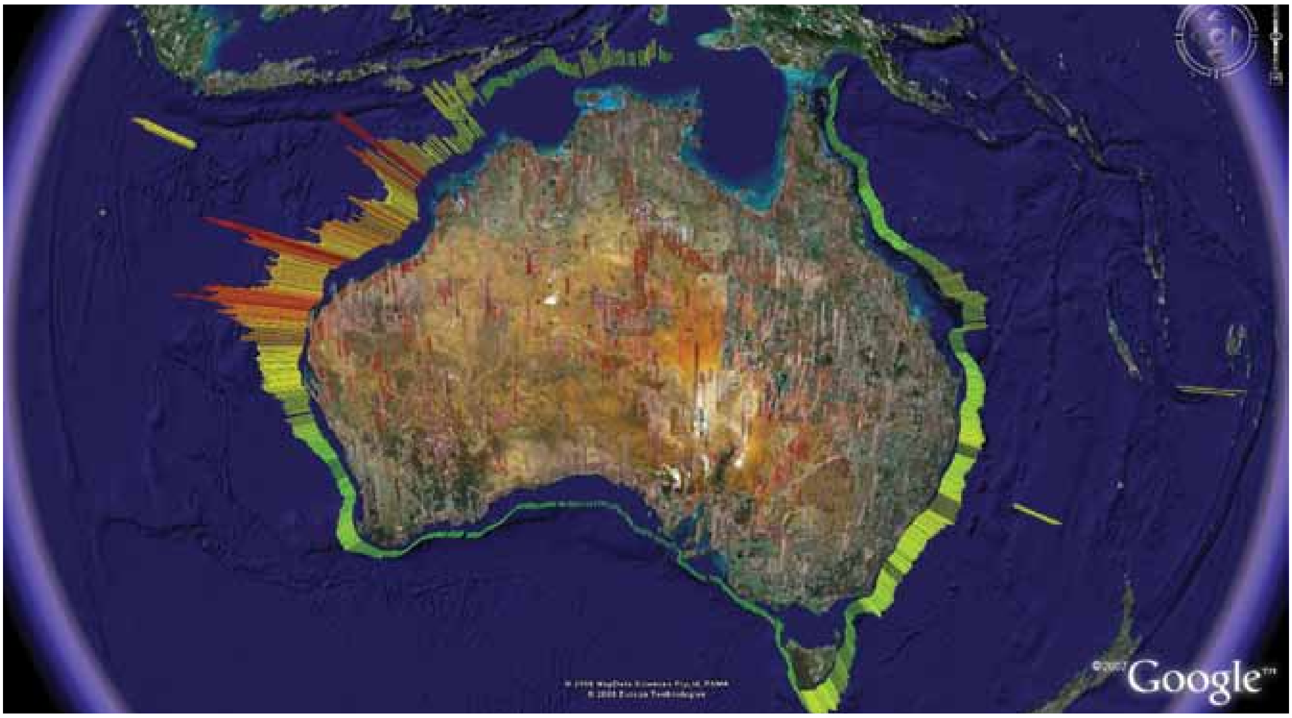


Figure 2.2 An example Australian tsunami hazard map at the 100m water depth contour.

Source: Geoscience Australia

The PTHA was reported at the 100m depth contour and therefore was not able to resolve questions regarding the effect of the continental shelf on tsunami or the extent to which the Great Barrier Reef altered the tsunami behaviour. As part of the Attorney-General's Department capacity building initiatives, Geoscience Australia then conducted a nearshore assessment to address these questions (Fountain et al, 2009). The study added interpretative value to the deep water assessment by estimating the amplification factor that can be applied to convert the deep water hazard (PTHA at 100m depth contour) to the nearshore tsunami hazard (at the 20m depth contour) at a number of Australian communities and thereby assist the Jurisdictions in prioritising communities for further detailed studies. The key generalisations that could be made include:

- Areas with narrower shelves tend to result in an increase in wave height between deep water and nearshore areas. Wider shelves may act to attenuate tsunami, reducing wave heights.
- Offshore islands and reefs appear to provide significant protection to the mainland from tsunami, though this may have implications for communities living on these islands not investigated here.

- The protective effect of smaller islands is more variable, and in some cases can lead to locally increased wave heights. This behaviour is highly sensitive to the particular tsunami characteristics.
- The response of tsunami to areas of complex seafloor features is variable and less predictable, demonstrating the need for accurate bathymetry data to underpin tsunami modelling.

The nearshore assessment did not change where the highest hazard occurs, that is Western Australia. The key change in hazard characteristics from the PTHA is that the hazard increases for the majority of communities in New South Wales, Victoria and South Australia due predominantly to the narrower shelf in those area. The hazard mostly decreases for communities within Queensland, Tasmania and Northern Territory due predominantly to the presence of the Great Barrier Reef and wide continental shelves that act to attenuate the tsunami.

It is important to emphasize that these hazard maps **cannot** be used directly to infer inundation extents, run-ups, damage or other *onshore* phenomena. To estimate the tsunami onshore impact, the following are required:

- detailed bathymetry and topography of the region concerned. The shape of the seafloor near the coast has a significant effect on the size of a tsunami reaching the coast (see box text 2); and
- a more sophisticated scientific process than that used for this assessment.

2.5 Historic Tsunami in Australia

The first tsunami historically recorded to affect Australia occurred in Tasmania in 1858, and there has been close to 50 tsunami events recorded since (Blong and Allport, 2007). The largest historical run-up observed was in northwest Western Australia, with a run-up height of 8m recorded at Steep Point in 2006 (see box text). This tsunami was generated by a subduction zone earthquake near Indonesia. The largest recorded run-up on Australia's east coast was 1.7m at Eden during the 1960 Chile earthquake and tsunami (Blong and Allport, 2007). Where information on tsunami source is known, nearly all were generated by earthquakes. The one exception is the 1883 tsunami observed in Western Australia generated by the eruption of Krakatau in Indonesia.

Historically recorded tsunami provide us with an understanding of events that are known to occur. Data collected from historical events can be used to test tsunami hazard and risk models, e.g. can the model simulate the observed inundation? However, the historical record is short compared to the return period of large tsunami, meaning that events larger than previously witnessed may be possible.

2. Steep Point, 2006

In 2006 a magnitude 7.7 undersea earthquake south of Java generated a tsunami that reached much of the coast of Western Australia, although did not cause significant inundation. However, at Steep Point a run-up height of 8m was experienced, the largest for any historical tsunami in Australia. It appears that the shape of the seafloor, a narrow channel between the beach and an offshore island plus a very large sandbar near the affected beach, acted to focus the tsunami's energy there. Several campers were lucky to escape after the tsunami flooded their campsite, in the process picking up their four-wheel drive and washing it 10m up the beach. Fish, starfish, corals and seas urchins were deposited on roads and dunes well above high tide level. As sandbars move with time, a similar event in the future is likely to have a different effect at Steep Point.

CHAPTER 3 – APPLICATION

2.6 Palaeotsunami Evidence

Geological evidence for tsunami has been reported from several areas on the Australian coast (Bryant and Nott, 2001; Switzer et al., 2005). Most evidence has been from the southeast and northwest of the continent, where depositional and erosional features provide evidence for tsunami occurring prior to recorded history. Some features interpreted as tsunami deposits suggest tsunami much larger than have occurred historically. While the interpretation of many deposits as tsunamigenic is controversial, if confirmed it has significant implications for our understanding of the Australian tsunami hazard.

East Coast

On the east coast, evidence has been presented for at least six large tsunami in the last 10,000 years. Much of the evidence consists of large boulders and erosional features. Some of the largest features are attributed to 'mega-tsunami', tsunami with wave heights of 10s of metres, and run-up heights of greater than 100m and distances of 10 km. If such tsunami events have occurred in the past, then tsunami hazard on the east coast is much higher than the historical record suggests. However, there has been controversy regarding whether such features are really generated by tsunami. Recent research has focussed on finding more typical palaeotsunami deposits, such as sand sheets in coastal swamps, in areas adjacent to these features. Extensive deposits have not been found, challenging the evidence for prehistoric mega-tsunami (Prendergast, 2008).

West Coast

Boulder and erosional features found in northwest Australia have also been interpreted as tsunami and mega-tsunami deposits, giving run-up heights of greater than 25m (Nott and Bryant, 2003; Scheffers et al., 2008), much larger than the largest historical run-up of 8 m. Again, the evidence is contentious and it is not clear whether such features have been deposited by tsunami. This region is also impacted by severe tropical cyclones and storm surges, which can leave similar geological features to tsunami, making it difficult to determine the causal agent. Geoscience Australia has been conducting field work to investigate the geological record of tsunami in this region. Such work is expected to provide valuable information on the size and frequency of tsunami reaching this region.

CHAPTER 3

Understanding Tsunami Risk: Undertaking Tsunami Risk Assessments

Key Points

- ***Tsunami risk assessments allow us to estimate the tsunami risk faced by Australian communities.***
- ***Conducting tsunami risk assessments requires knowledge of the sources that generate tsunami; simulation of the propagation of tsunami through the ocean and onshore; and information about particular communities to assess the potential impact of an event***
- ***Several different sources of data are required for each stage of the tsunami risk assessment process***
- ***The quality and coverage of data used in the risk assessment process will affect the accuracy and utility of the results***
- ***Palaeotsunami studies can improve tsunami hazard and risk assessments***

3.1 Introduction

While the overall risk from tsunami to the Australian population is lower than it is for many parts of the world, assessments by the Australian Government indicate that the north-west and east coast have the potential to be affected by a damaging tsunami resulting from a large earthquake.

To gain an estimate of risk to Australia from tsunami we need to consider plausible tsunami together with their probabilities and how they might impact Australian communities. This is the goal of the risk assessment.

This chapter describes the components of the risk assessment methodology and the associated data requirements. The benefits and limitations of the approach and the importance of data are also discussed. Finally the approach is illustrated through two case studies.

3.2 Risk Assessment Methodology and Data Requirements

Conducting a tsunami risk assessment typically relies on understanding the sources that generate tsunami, the propagation of tsunami through the ocean, and their behaviour as they reach the coast and flow onshore. This is then combined with information about particular communities to assess the potential impact of an event. This methodology can be described by six key components, each of which requires a number of different data types.

Step 1: Define a source model

The first step involves identifying potential tsunami sources – earthquake, landslide, volcano or meteorite – and modelling the magnitude and frequency of tsunami they generate.

At present the only tsunami sources considered in tsunami risk assessments for Australia are earthquakes generated in surrounding subduction zones. These represent the majority of tsunami sources for Australia (See Chapter 2). Consideration of other source types may occur in the future.

Data requirements: The history and physical properties of the subduction zones, which generate the source earthquakes is used to provide estimates of the initial size of the tsunami, its location, frequency and other relevant properties. Historical data, such as instrumental records of tsunami from tide gauges and tsunameters, comprising a bottom pressure sensor which detects the tsunami and a surface communication buoy, is used to validate these models. Evidence of tsunami before the keeping of instrumental records can also be obtained from palaeotsunami deposits (see Section 3.4 Palaeotsunami Methods).

Step 2: Simulate the tsunami using a deep-water propagation model

Once a tsunami is generated it often has to travel across an expanse of deep water to reach the coastline of interest. This process is simulated by a deep-water propagation model, which simulates the tsunami from the source to the shallow water off the coast of interest, typically 100m water depth. If the tsunami source is very close to the community of interest, this step may be omitted.

Data requirements: As the tsunami travels through the ocean, it is strongly influenced by the water depth and shape of the seafloor (the bathymetry). Sensitivity to details in the bathymetry is moderate in the deep water between the source and the shallow water off the coast, and therefore moderate resolution bathymetry data (on the order of 250m for intermediate water depths and 1-2km for the deep ocean) is needed to accurately simulate the propagation for earthquake-generated tsunami.

Step 3: Simulate the tsunami in shallow-water and onshore using an inundation model

Once the tsunami enters shallow water, typically defined as water 100m or less deep, an inundation model is used to simulate the tsunami as it approaches land and comes onshore. These models are normally mathematically identical to deep-water propagation models; however, they are designed to capture the complications associated with flow from offshore to onshore. These models are also able to capture the complexities associated with flow in the near shore environment, such as reflections off headlands, refraction around islands etc as well as the interaction with the multitude of waves that make up the tsunami wave train. Depending on the actual model used, Step 2 and 3 may be achieved using one model. Due to the distance of earthquake sources from the Australian coastline, it may be more typical to use two models.

The model results can be used to produce maps showing the maximum inundation depth (i.e. the maximum water level reached on the land) and the maximum flow speeds across the community of interest, throughout the duration of a given tsunami. Inundation maps can be used as a planning tool by emergency managers to understand, for example, what infrastructure and services would be potentially damaged during a given tsunami; what roads can be used for evacuation etc. Maps of maximum flow speed can also be used to assist the marine community in preparing for tsunami events.

The inundation model can also provide the maximum height above sea-level reached by the tsunami (often referred to as the run-up height) and the maximum distance from the coast reached by the tsunami (often referred to as the inundation distance). These features are often measured during post-tsunami surveys and so offer data for validation of modelling results.

Data requirements: In shallow water, tsunami are more sensitive to finer scale variations in seafloor bathymetry than in deeper water. Therefore, higher resolution bathymetry and onshore elevation (topography) data – on the order of 10m – are needed close to specific communities or infrastructure to attain reliable estimates of wave height and speed from tsunami modelling. Any limitations in the resolution, accuracy and coverage of the data will introduce errors to maps of inundation and flow speed (see Section 3.3 Benefits and limitations of risk assessments).

Step 4: Define structural and community vulnerability models

Vulnerability is a broad measure of the susceptibility to suffer loss or damage. Structural vulnerability models describe the type and amount of damage that a particular type of structure may experience from a given tsunami. They are typically represented as a series of curves, which relate damage to a building (usually as a percentage of its total replacement cost), to characteristics of the hazard, such as water height and speed for tsunami.

Community vulnerability is far more difficult to define, and is an area of ongoing research. A number of complex issues surround definition of community vulnerability, such as which factors contribute to vulnerability; the dynamic aspects of communities over time; the scale at which vulnerability is examined (i.e. individuals, households, streets, neighbourhoods, municipalities, demographic groups etc); variation from community to community; and issues related to specific hazards (Buckle et al., 2001). Also see Community Vulnerability Analysis section below.

Community vulnerability models aim to identify people in the community who are most likely to suffer loss or injury during a hazard event. The general methodology for defining community vulnerability is to identify a number of social indicators, which are combined to identify community members that are vulnerable to particular hazards. Some of these factors may include: households with access to a car, those aged over 65 years or under 5 years, people from different cultural or language backgrounds, and those who have moved into the community within the last 5 years.

Data requirements: A significant contribution to our knowledge of building vulnerability comes from conducting damage surveys of buildings following hazard events. These surveys collect information about the degree and type of damage sustained by different buildings, with each structure located using GPS. This allows the spatial distribution of damage to be related to the measured (or simulated) characteristics of the hazard, such as the water height and speed in the case of tsunami.

As they are largely based on observational data, structural vulnerability models are by definition empirical. As tsunami impact is relatively infrequent (when compared with impact of other hazards such as severe wind), tsunami offers little opportunity for data collection; therefore the structural vulnerability models for tsunami are relatively simplistic.

Data requirements for assessing community vulnerability are extensive and will depend on the situation. Community vulnerability is assessed along a number of dimensions, with relative vulnerability measured on each dimension. It may be just as appropriate to simply understand the sheer numbers of people that are considered high risk. Local information sources to identify vulnerable groups include: police, schools, fire services, Meals on Wheels, hospitals, libraries, local media, government agencies, storekeepers and publicans, banks, real-estate agents, doctors and other health and welfare workers. Other more general data sources include: Home and Community Care databases, people at risk registers held by hospitals and utility companies, Australian Bureau of

Statistics Census data, and Human Service Agencies. People requiring life support systems are particularly at risk. People in this group may be registered with local utility companies. For a more comprehensive list of data sources, refer to Buckle et al 2001.

Step 5: Combine with an exposure database for the area of interest

To understand the impact a tsunami may have on a community, it is necessary to know what resources and infrastructure are potentially exposed to the tsunami. This information is held in an exposure database.

Data requirements: The exposure database should include information about residential and commercial buildings, as well as critical infrastructure. Details should include information such as: the building type, construction type, building materials, number of floors and floor height, typical number of inhabitants, demographic data replacement value and contents value. This information should be as current and accurate as possible and therefore requires continual updating.

Step 6: Build community resilience

Early stages of risk management programs invariably involve developing an understanding of the nature of the potential hazard. However it is only through comprehending the functioning of the community that the impact of the hazard can be fully understood. Invariably the community does not present a static target for research, but functions with dynamic inter-relationships exhibiting attitudes and behaviours on both individual and collective levels. Emergency managers need to influence these attitudes and behaviours in order to increase resilience and reduce vulnerability to risks, but their influence is rarely isolated to one hazard. Community interactions with emergencies, emergency procedures and emergency managers may have developed over many years and can become part of the environment which will influence community reactions when programs to address the tsunami risk are introduced.

Data requirements: Community interaction with the land-based and maritime communities to communicate the elements likely to be at risk (see Community Vulnerability Analysis section below).

Summary of the tsunami risk assessment process

Combining the results of the hazard modelling (which tells us which areas of the community get wet, how deep the water is and how fast it moves) together with the vulnerability models (which tell us how buildings and people will respond to the water) with the exposure database (which tells us where buildings are, including their characteristics as well as people) allows estimates of the number of people and buildings affected by the tsunami. Increasing community resiliency to reduce community vulnerability is also a crucial part of the risk management process and involves significant engagement at the community level. The outputs from the modelling process are important inputs to this component and the communication strategies should also be case in an all-hazards approach.

The majority of the tsunami hazard and risk assessment modelling for Australian communities up until 2010 has been done by the Australian Government in partnership with state government agencies. A number of hazard and risk products have been developed over the life of the ATWS following the assessment steps described here. They include:

- National scenario offshore tsunami hazard assessment (step 1 and 2),
- National probabilistic offshore tsunami hazard assessment (PTHA, using step 1 and 2),
- National nearshore tsunami hazard map (combined with the PTHA and modelled to the 20m depth contour), and
- Inundation models for a number of communities (steps 1 - 5).

How these outputs relate to emergency management planning and preparation activities will be described in Chapter 5.

3.3 Benefits and Limitations of Risk Assessments

Tsunami risk assessments require a collaborative approach to integrate data and expertise across the emergency management, scientific and government sectors. Where successful they can inform tsunami preparation and emergency response plans to build safer communities (See Case Study – Risk assessments assist tsunami planning in Western Australia, below).

It should be kept in mind however, that the understanding of tsunami and their effect is an evolving science. Key limitations/approximations of the risk assessment approach include:

Validation

Individual components of the hazard modelling methodology have been validated using e.g. wave tank experiments and tide gauge data where available. Validation results against the 2004 Indian Ocean tsunami impact at Patong Beach, Thailand, using Geoscience Australia's tsunami risk modelling methodology, are very promising. Validation is an on-going activity and is conducted as data becomes available.

Elevation data

As outlined in Section 3.2, a tsunami is strongly influenced by the seafloor bathymetry as it travels through the ocean, and the topography onshore. Therefore, the predicted tsunami impacts are sensitive to variations in quality and coverage of elevation data input into the model.

Model output interpretation

Individual tsunami risk assessments are generated for a limited number of tsunami events only, and do not necessarily represent all possible scenarios in which a tsunami event may impact a community. Therefore results of the risk modelling approach are indicative and should not be relied upon solely for making any decision.

The importance of data

The predicted tsunami impacts are sensitive to variations in elevation data and the tsunami source. This is an open area of research and as described above, the required resolution is not yet fully understood.

Validation and sensitivity analysis is currently being conducted in order to improve the accuracy and reliability of tsunami risk estimates in Australia. Importantly, while many of these improvements will come from national scale research, there is a crucial need to incorporate all available State datasets that could support this work. This includes up to date bathymetry and topography, which is invaluable for refining models as well as high resolution exposure data, which ultimately describes the tsunami impact to individual communities. The range of coastal issues, including climate change, has prompted many State governments to acquire LiDAR (Light Detection and Ranging) data to support coastal vulnerability studies. This data is high resolution (now under 1m), highly accurate and it can also provide offshore data (limited to 20m water depth and water quality). It is becoming increasingly available around Australia.

3.4 Palaeotsunami Methods

Historical and instrumental records of tsunami have been gathered for a much shorter period than the recurrence intervals of large tsunami. Studying the geological evidence of past tsunami therefore extends the tsunami record by thousands of years, leading to a better understanding of tsunami frequency, magnitude and dynamics, and a greater appreciation of tsunami hazard and risk. Palaeotsunami studies can identify previously unknown areas at risk (see box text).

As a tsunami impacts on a shoreline it may erode existing soil and deposit new sediment, from coarse sand to large boulders. The most common tsunami signatures are sand sheets deposited by fast moving currents, preserved within layers of finer sediment deposited in lower energy environments, such as swamps and lagoons. This characteristic layering of coarse and fine deposits, aids identification of tsunami deposits (see Figure 3.1).

Detailed study of tsunami deposits can provide constraints on tsunami behaviour, such as flow depth and speed, while mapping their geographical extent can contribute to hazard maps, and to calibration, testing and enhancement of tsunami run-up modelling. If several tsunami deposits occur in sequence, dating of the deposits allows estimates of tsunami frequency (Cisternas et al 2005).

Individual tsunami deposits may contain features, which allow specific waves in the tsunami wave train to be identified. The composition of the tsunami deposit, including fossils of tiny organisms, can help to locate the source of the sediment, which may come from tidal, deepwater or terrestrial environments, indicating that the tsunami has carried sediment during inundation and backwash.

Geological evidence identifies tsunami threat to west coast of North America

The Cascadia Subduction Zone off the west coast of North America had been thought incapable of hosting great earthquakes capable of generating large tsunami. Although indigenous oral history hinted at the possibility, there was no documentary evidence of such events. Since the 1980s however, geological investigations have found palaeotsunami signatures along much of North America's west coast. Evidence includes tsunami sand sheets and submerged forest. The most recent event was dated at 1700 AD. This date corresponds to the 'orphan tsunami', a tsunami that impacted Japan on 26 January 1700 without any accompanying earthquake being felt. This evidence suggests the Cascadia region can host earthquakes large enough to generate ocean-wide tsunami. Such tsunami would be devastating to the adjacent North American coastline, and identification of the threat has allowed steps to be taken to mitigate and plan for the possibility of a similar event occurring in the future.

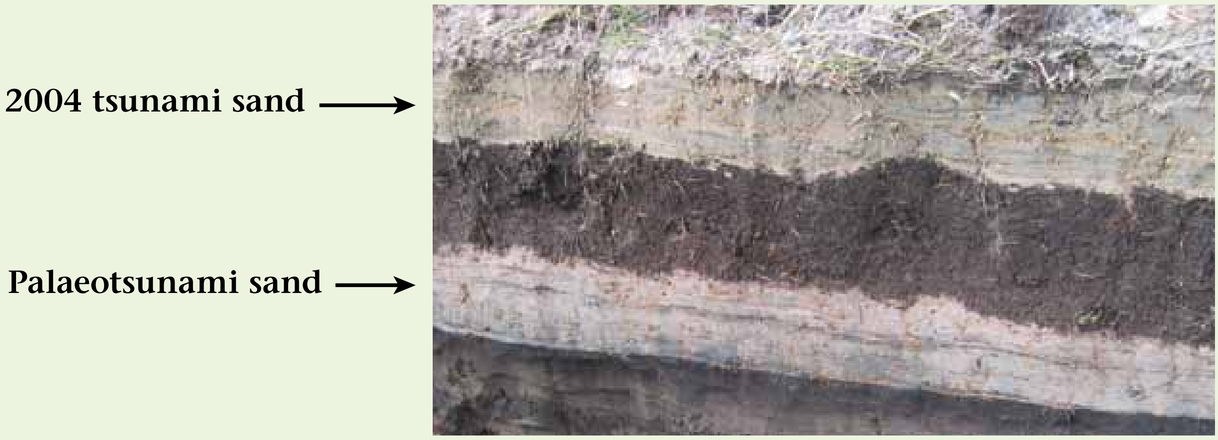


Figure 3.1 Palaeotsunami deposits from Koh Phra Thong, Thailand. Visible is the 2004 deposit and an earlier deposit dated at ~600 years ago.

Source: Geoscience Australia

3.5 Community Vulnerability Analysis

Introduction

Major emergencies can have a variety of devastating effects on the community and often we only measure the aftermath in terms of costs to property, business and infrastructure. While these indicators can be valuable, major emergencies around the world in the last decade have highlighted the vulnerability of modern communities to social dislocation and have emphasized the social aspects of disaster. World events ranging from the 9/11 terrorist attacks and Hurricane "Katrina" to the 2004 Asian Tsunami have shown the paramount position that social effects have had in influencing emergency management (EM) priorities for both affluent and poor nations and communities.

Early stages of risk management programs invariably involve developing an understanding of the nature of the potential hazard. However it is only through comprehending the functioning of the community that the impact of the hazard can be fully understood. Invariable the community does not present a static target for research, but functions with dynamic inter-relationships exhibiting attitudes and behaviours on both individual and collective levels. Emergency managers need to influence these attitudes and behaviours in order to increase resilience and reduce vulnerability to risks, but their influence is rarely isolated to one hazard. Community interactions with emergencies, emergency procedures and emergency managers may have developed over many years and can become part of the environment which will influence community reactions when programs to address the tsunami risk are introduced.

There has been abundant material written on the conduct of a community analysis as part of the risk management process for natural hazards. It is not the intention of this section of the manual to cover the entirety of community analysis techniques but rather to focus on some aspects of the process that are either unique or important to the tsunami risk.

The Land-Based Community

In viewing the tsunami risk to Australia an initial hazard analysis will usually identify two broad areas of risk and lead to consideration of two broad "communities" within the elements which are likely to be at risk.

The first broad area sidents, commerce and industry who have the potential to be exposed to the flooding and on-shore effects of a tsunami.

The land-based community groups are easily integrated into conventional risk management initiatives and because the groups are relatively static, a good deal of data about them is available through such sources as the Australian Bureau of Statistics (ABS), local government records, academic research and publicly available data sources. It is possible to analyze such data as a broad indicator of demographic or socio–economic factors which can give an insight into potential vulnerabilities at an individual or household level. When used alongside hazard data such as inundation and flow-rate mapping, the community data can assist in guiding priorities for development of risk treatment options. This is particularly valuable in developing emergency management strategies for the more catastrophic tsunami events involving significant inundation of the built environment. Such a technique has been used effectively by Geoscience Australia in partnership with emergency management agencies for such projects as the Cities Project Perth (Jones et al 2005) and more recently for the tsunami program outlined in Chapter 3 of this manual.

Catastrophic events are also characterised by a breakdown of a large number of cohesive factors within the community. Normal local government services, for example, may not be available; sporting and social clubs may not function; family and neighbourhood networks may become dysfunctional; shopping, banking and fuel supplies may be disrupted. Community morale and functioning is invariably lowered and the support networks normally available to a community become fractured. These collective or networking vulnerabilities start to affect the community's ability to cope with the effects of an emergency and, in larger events, may drive media and political imperatives which can effect EM priorities The techniques for identifying and analysing collective vulnerabilities are more complex than those used to analyse individual vulnerabilities but may have a greater influence on the emergency management priorities.

The Maritime Community

The hazard analysis is likely to identify a second tsunami risk associated with exposure to fast running tides and currents or significant wave action on and near beaches. In many parts of Australia this exposure to the marine risks of tsunami can occur quite frequently (every few years) and may become the key focus of EM programs. The marine tsunami risk is likely to affect different parts of the community from those affected only by a tsunami causing land inundation. It is convenient to classify this group as a maritime community. The maritime community is more mobile and elusive than the land-based "community" and consists of groups which are predominantly associated with marine activities including tourists, recreational fishers, boaters, yachties, swimmers, surfers, foreshore fossickers and beach campers.

Analysing the maritime community presents some challenges. In particular, the sourcing of data is problematic due to the highly mobile nature of the community. It is possible to engage with yacht clubs, fishing clubs, surf life saving clubs and sea rescue groups, but the results may only reflect a limited sample of the target audience. Techniques need to be developed which capture the views, attitudes and likely behaviour of campers, surfers and similar informal groupings. A number of social science techniques such as focus groups may be useful, but invariably there will need to be resource intensive research such as on-beach interviews in order to obtain data which is reliable enough to be useful in driving effective EM strategies. This type of research has been used effectively by fisheries authorities and coastal planners, and liaison with these organisations can be fruitful when conducting a community analysis.

Engaging the Community

Contemporary risk-management philosophy emphasizes the need to engage with the community at all stages of the risk-management process. When developing community engagement strategies for tsunami there are some considerations which are unlikely to be encountered with other hazards.

One of these considerations is the difficulty of communicating the risk of a rare, high consequence event. It is not unusual for a severe natural hazard to be considered an event which occurs with a statistical likelihood of once in a hundred years. This is a figure which is frequently used to plan for and describe a major flood or wind event. When identifying the recurrence interval for a tsunami causing land inundation it is probable that rare events with statistical likelihoods in the order of once in 10,000 years will be used.

The environment in which one will be engaging the community for tsunami risk management will be effected by community engagement strategies already adopted for more frequent events and, in turn, will influence those strategies. The process of determining community vulnerability is an interactive process with the community. If the community is going to be able to make an informed decision about tsunami it is important to keep the risks in perspective. This can be done by engaging the community in consideration of risk frequencies and consequences for a range of hazards at the same time. Similarly, risk treatment strategies should be appropriate to the risk, and community information programs conducted solely for infrequent events may not be as sustainable as programs targeting multiple risks.

In summary, it is recommended that emergency managers develop a range of community engagement strategies to reinforce the effects and responses to a range of emergencies, rather than addressing the tsunami risk in isolation. This will retain relevance and plausibility for the community and lead to provision of quality data for a community vulnerability analysis.

3.6 Case Study – Risk Assessments Assist Tsunami Planning in Western Australia

The tragic events of the 2004 Indian Ocean tsunami, highlighted shortcomings in the response and alert systems for the threat of tsunami to Western Australia's (WA) coastal communities.

To improve community awareness and understanding of tsunami hazard and impact for Western Australia, the Fire and Emergency Services Authority WA (FESA) established a partnership with Geoscience Australia (GA) to utilise their scientific expertise to develop numerical modelling capabilities, three-dimensional visualisations and GIS-based decision making tools for tsunami impact on selected WA coastal communities.

Tsunami impact assessments have been completed for the north-west communities of Broome, Port Hedland, Dampier, Karratha, Exmouth and Onslow. These locations were selected following a probabilistic tsunami assessment for WA conducted by Burbidge et al, 2007 and combined with anecdotal evidence of community impact experienced during the 2004 Indian Ocean tsunami. A second phase is now focussed on selected coastal communities from Carnarvon to Busselton including a number of Perth metropolitan coastal locations, has been completed.

Outputs

The information requirements of emergency managers and local land-use planners were identified during workshops across the State and these drove the scientific process. Specific questions relating to impact included:

- What is the time between the earthquake event and arrival at the location?
- What is the extent of inundation from the tsunami impact?
- What damage is expected?
- What differences are expected if the tsunami arrives at the location at different tide levels?

Based on these questions, the following outputs were produced utilising Geoscience Australia's tsunami risk modelling methodology for a number of "worst-case" scenario events:

- Time of tsunami arrival;
- Maximum inundation maps (Figure 3.2), and;
- Estimates of number of inundated houses.

Maximum flow speed maps (Figure 3.3) can assist in understanding the threat of tsunami in the offshore environment. These maps can be derived from the model and are now being recognised as important planning outputs.

Risk assessments help make safer communities

Tsunami planning and preparation in Western Australia (WA) has been shaped by this collaborative project between FESA and GA. The project has led to the development of tsunami impact assessments in communities identified as at risk to tsunami inundation.

Tsunami preparation and emergency response plans have been initiated based on community engagement workshops to increase stakeholder awareness of the science and risk of tsunami. The project has integrated data and expertise across Australian and State government bodies to build safer communities in WA.

This project demonstrates the advantages of combining science, emergency management and spatial data to achieve a leading edge risk assessment

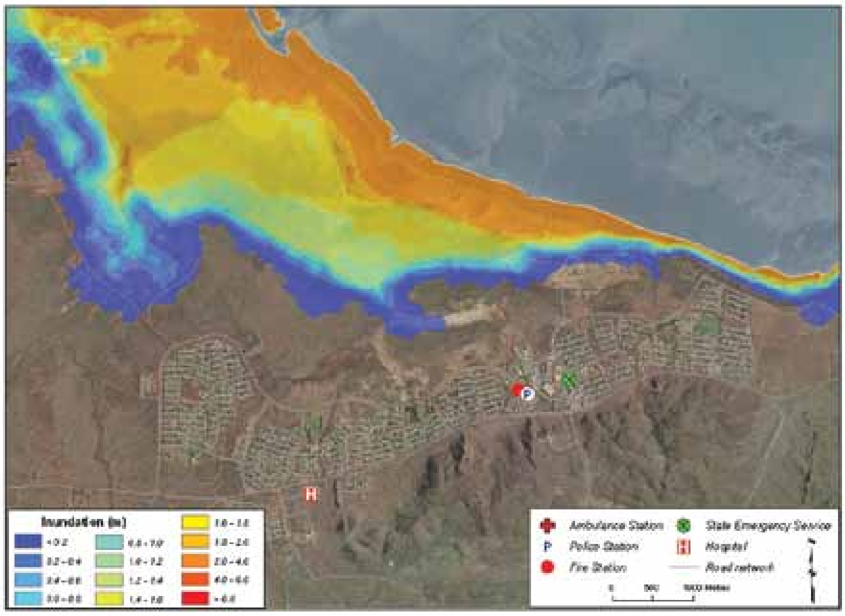


Figure 3.2 Maximum inundation map

Source: Fire and Emergency Services Authority, Western Australia and Geoscience Australia

[1]Geoscience Australia's tsunami risk modelling methodology consists of the coupling of an earthquake generation and tsunami deep-water propagation model (URSGA) with a free and open-source hydrodynamic model (ANUGA, Nielsen et al, 2005) that estimates tsunami inundation and flow speed at the location of interest.

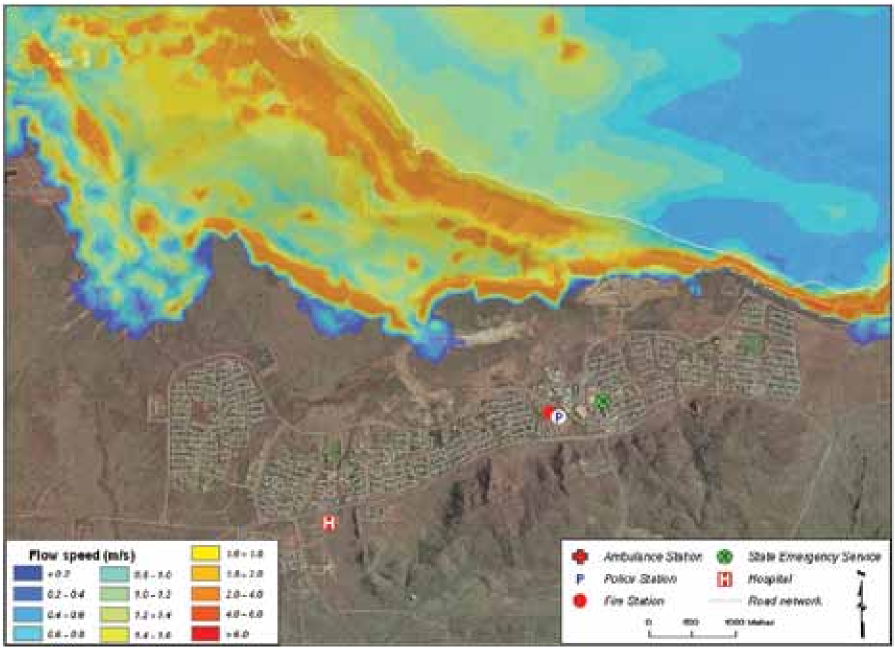


Figure 3.3 Maximum flow speed map.

Source: Fire and Emergency Services Authority, Western Australia and Geoscience Australia

Conclusion

The FESA – GA tsunami risk assessment has improved community safety in WA, by raising community awareness and providing a solid platform of knowledge on which emergency managers can base plans. It allows emergency managers to prioritise planning and mitigation activities for communities that are identified at greater risk and provides initial estimates of tsunami impact based on a selection of representative "worst-case" scenarios. FESA can now gain a picture of how a tsunami could affect the length of the WA coastline and also identify potential implications that may compromise emergency response infrastructure.

Emergency management planning is now based on a realistic understanding of the likely consequences of a tsunami in WA. This project has served to emphasise and highlight phenomena associated with tsunami that must be managed for an effective response, Stevens et al (2008).

3.7 Case Study – Tasmania Palaeotsunami Research

In 2006/07, a palaeotsunami study was conducted in Tasmania involving Tasmania State Emergency Service (SES), Mineral Resources Tasmania (MRT) and Geoscience Australia. In collaboration with the steering group, GNS Science carried out the fieldwork, and the analysis, interpretation and reporting for the palaeotsunami project. Taking into consideration the lack of any previously published palaeotsunami records, the project was designed to address the following questions:

- Which sites are most suitable for the preservation of Holocene[2] tsunami deposits?
- Do tsunami deposits or possible tsunami deposits exist at such sites; if not, why not?
- What are their characteristics, approximate age and frequency?

The scope of the project was set to focus on a maximum of three coastal sites in the vicinity of Hobart. Sites were chosen to encompass a range of water body types with a variety of coastal aspects in order to maximise the likelihood of finding a palaeotsunami record. Two fieldtrips were undertaken by steering group members and GNS Science – one to carry out a reconnaissance of potential sites and one to sample the selected sites using hand-operated coring devices. Cores were documented and sub-sampled in Tasmania and sample analysis was undertaken in New Zealand. Analysis included basic sedimentology, radiocarbon dating to establish a chronology for the cores, and macro- and microfossil analysis to reconstruct past environments at each site.

Inundation modelling was not available at the time of site selection. Of 26 sites considered, 11 were visited during reconnaissance fieldwork and ranked according to their tsunami preservation potential and accessibility. Three preferred sites – South Neck Beach (Bruny Island), South Arm Beach and Primrose Sands (Fig. 3.4) were selected. During fieldwork at South Neck Beach, the steering group was also able to collect two cores at Dunkels Beach. The four sites represent a variety of aspects such as east, west and south facing beaches and covered a range of exposure from open to the Tasman Sea near the mouth of Storm Bay to shelter at the head of Frederick Henry Bay. The sites encompassed as much variety as possible to increase the chances of finding any evidence of palaeotsunami that may exist in the region.

At the three main study sites a transect of cores perpendicular to the beach was collected. The aim of this was to ascertain seaward to landward changes in sediments, and potentially determine tsunami run-up distances. Cores were also collected in a line approximately parallel to the beach to maximise the spatial extent of sample collection. Twenty-two short cores were collected in total. At all sites, penetration to 2-3m depth was sufficient for sampling back through to the early Holocene.

8000-9000 years before present

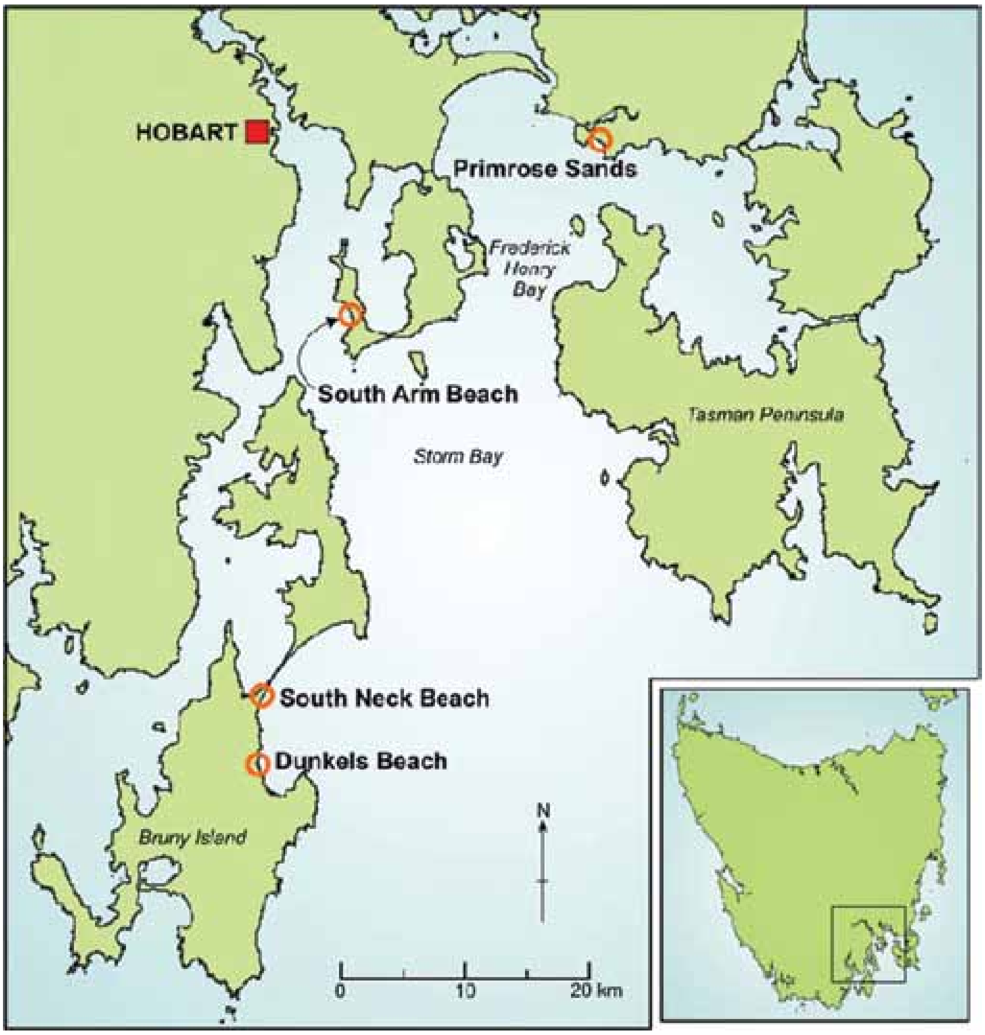


Figure 3.4 Map of the coastline in the vicinity of Hobart. Red circles show the location of palaeotsunami study sites. Inset map shows the coastline of Tasmania with a box highlighting the Hobart region.

Source: Tasmania State Emergency Service and Geoscience Australia

The findings of the sample study indicated that there are several deposits that are candidates for tsunami deposits. In total these may represent three tsunami events during the last four thousand years. The size of the tsunami cannot be easily judged from the GNS study until inundation modelling with appropriate topographic data is undertaken. However, the possible tsunami deposits identified have required waves to exceed 3-5m in elevation in order to overtop the sand dunes between the ocean and the sample locations.

Tsunami inundation modelling was conducted in 2008/09 using newly acquired LiDAR data and based on three maximum probability event scenarios. It was confirmed that such events are likely to inundate the areas where the palaeotsunami deposits were located.

CHAPTER 4

Tsunami Warning Systems

Key Points

The instrumental detection capability of the Australia Tsunami Warning System is made up of three key components. These components include:

- ***A network of seismometers to detect and assess undersea and coastal earthquakes;***
- ***A network of deep ocean buoys or tsunameters to detect and measure tsunami amplitudes in the deep ocean; and***
- ***A network of coastal sea level gauges to detect and measure shallow water tsunami amplitudes once they reach the coast.***

4.1 Key System Components

Tsunami Earthquake Detection with Seismometers

A seismometer is a device that measures the vibrations of the earth at a single location over time. The vibrations caused by an earthquake are called seismic waves. These waves have distinguishable patterns that are recorded by a seismometer and allow for the determination of the size or magnitude of an earthquake and the time that the earthquake began to rupture. With a minimum of three appropriately positioned seismometers, the location of the initial point of earthquake rupture can also be computed. This point is called the epicentre on a map, or hypocentre if the depth of the point is also depicted.

The speed of the fastest seismic wave through the earth is approximately 8 kilometres per second. Thus, a network of seismometers that are placed at close distances surrounding the seismically active zones, complemented by a seismometers at regional distances to detect tsunami generating earthquakes, can be used to determine the preliminary earthquake characteristics within approximately 10 minutes of the initial earthquake rupture.

These seismometers need to have broadband measurement capabilities and a wide dynamic range, which means that they will be able to record earthquakes from a wide range of magnitudes and distances. The data measured by the seismic network is also required to be communicated quickly to a central processing facility so that the earthquake details can be quickly computed.

Tsunami Detection with Tsunameters

Once the seismic waves (which move at more than 30 times the speed of a tsunami) are detected by distant seismometers, Geoscience Australia will analyse the data and determine if the earthquake has the potential to generate a tsunami.

The Bureau of Meteorology uses its deep ocean and coastal sea-level network to confirm the existence of a tsunami. Data taken from tsunameters (deep ocean tsunami detection sensors) and coastal tide gauges are analysed by the Bureau to verify whether a tsunami has actually been generated.

The use of sea level observation instruments, as compared with reliance on seismic observations alone, helps to significantly reduce the risk of false tsunami warnings being issued. Information from the sea level network is transmitted via satellite communication to the JATWC.

Tsunameters observe and record changes in sea level out in the deep ocean and confirm the existence of tsunami generated by undersea earthquakes.

Each tsunameter consists of a sea-bed bottom pressure recorder which detects the passage of a tsunami and transmits the data via sonar to a surface buoy. In order to detect tsunami in the deep ocean, which are typically only 5 to 10cm in height, the instrument is capable of detecting changes of 1mm in approx 5km of ocean where the effects of surface wind waves and swell are not observed. The surface buoy then radios the information via satellite to a global network of tsunami warning centres including the JATWC.

The system has two operating modes – 'standby and 'event'. The system generally operates in standby mode which routinely collects sea level information and reports to the satellite every 15 minutes. The tsunameter goes into event mode when the pressure sensor first detects the faster moving seismic wave travelling through the water. The device then commences reporting sea level information at one minute intervals to enable rapid verification of a possible tsunami. For distant sources tsunameters can be electronically switched to event mode.

Figure 4.1 The surface component of an operational deep-ocean tsunami detection buoy

Source: Bureau of Meteorology

The tsunameter needs to be placed far enough away from any potential earthquakes epicentre to ensure there is no confusion between the earthquake signal and the tsunami signal, and to avoid being damaged by the earthquake. Ideally, tsunami bottom pressure sensors should be placed in water 3000m to 5000m deep to ensure the signal is not contaminated by other types of waves.

International maritime boundaries must also be considered when deploying tsunameter systems. The life cycle of a tsunameter (bottom pressure sensor and surface communications buoy) is approximately 2 to 4 years. The Bureau's maintenance program involves the replacement of the surface buoy and the sea-floor pressure sensor every one to two years.

To offset the effects of the harsh environment the network has built in redundancy to insure availability of vital information. The Australian network operated by the Bureau currently has approximately 40 Coastal Sea Level stations and six tsunameters strategically placed to the east and west of Australia and its offshore territories.

Australia also accesses data from other countries participating in the Indian Ocean Tsunami Warning System (IOTWS) and the Pacific Tsunami Warning System (PTWS). In turn, data from Australia's tsunameters are made freely available to the international community and the tsunami warning centres of other countries in real time using the World Meteorological Organisation's dedicated Global Telecommunication System (WMO GTS).

Tsunami Detection with Tide Gauges

Coastal sea level gauges consist of sensors (acoustic, radar and/or water pressure) to measure variation in the water level at strategic locations around the Australian coastline and offshore regions.

New stations complement existing climate monitoring sea level gauges, which have had satellite communications installed to also make the information useful for tsunami warnings. Observations from sea level gauges verify the existence and local effects of a tsunami and also assist in the cancellation of the tsunami threat by providing information to determine when conditions have returned to normal.

4.2 Methodology of Evaluating a Tsunami Threat and Issuing Warnings

In the majority of cases, the first indication that a tsunami may have been generated in the ocean is the detection of a large undersea earthquake. The internationally recognised criteria for issuing warnings for tsunami generated by earthquakes is that for all earthquakes located under the ocean or near the coast that are greater than or equal to a magnitude of 6.5 and with a depth no greater than 100 kilometres a tsunami warning bulletin must be issued. The standard time to issue the first earthquake alert is within 15 minutes of the time of the initial earthquake rupture. This is followed by an initial tsunami warning within another 15 minutes.

Evaluating a tsunami is the focus of the JATWC - providing an accurate and rapid threat assessment. In the assessment process, seismic input from the earthquake detection phase (as described above) is utilised to select a scenario from a library of pre-computed scenarios that have been generated from a deep ocean wave model. The Bureau uses the MOST (Method Of Splitting Tsunami) forecast model. Assessment is also based on sea level monitoring of information from sources such as coastal sea level stations and deep ocean sensors, otherwise known as tsunameters. However, this information is more likely to be used for re-assessment, that is, it is looking at the observed sea-level response to verify that a tsunami has been generated and to refine the assessment if necessary.

Requirements for evaluating a tsunami threat and issuing warnings include:

- The assessment must be able to determine the tsunami threat (existence, extent, magnitude and timing) to the Australian coastline. As a minimum, the earliest arrival time for the first tsunami wave and the maximum amplitude for a wave (noting the two may not coincide) are required.
- The coastal threat assessment supports the requirement to issue Bulletins, Watches and Warnings based on No Threat, Marine Threat and Land Inundation Threat (refer to Stratification below).
- Threat assessment defines the response level that then guides message development, issuance and staffing within the JATWC and the Bureau's Regional Forecasting Centres.
- Initial assessment is carried out rapidly to allow for the issue of a first Tsunami Bulletin, Watch or Warning within 30 minutes of the earthquake event.
- Assessment also determines expected timings and magnitudes at sea-level detection stations (whether deep-ocean or coastal) so that verification or confirmation can be sought and analysed. Model outputs are able to be adjusted for observed sea-level data if available and appropriate.
- Assessment includes a determination of when the threat is over so cancellations may be issued

Stratification

The issued warning products will reflect the severity, certainty and urgency of a potential tsunami. To simplify the number of variations that can exist with these three variables, a simple three tiered *stratification* or categorisation is used. In addition to No Threat, the three tiers use simple intuitive phrases based on end customer needs. The three tiers are:

- Low Level Effects   Below warning requirement
- Marine Threat   Warning for marine areas (No SEWS)
- Land Threat   Warning for land and marine areas (Use SEWS)

SEWS - Standard Emergency Warning Signal

Assessment must identify which tier the threat is aligned to and is based on tsunami amplitude thresholds. The area of Low Level Effects is not mentioned in the texts of tsunami watches or warnings, but will be indicated on graphical products on the web.

Australian Offshore Island Territories

Australian offshore island territories are considered separately from the mainland because (a) bathymetry effects may be different from the mainland (e.g. no continental shelf and hence have characteristics more like open ocean source tsunami) and the closest MOST model grid point can be at substantial depth; and (b) the geographical distance to these island territories warrant a separate warning for each of them. Island territories, and the Regional Forecasting Centres with ATWS responsibilities for them include:

- Willis Island (Coral Sea) – QLD Regional Forecasting Centre
- Lord Howe Island (Pacific Ocean) – NSW Regional Forecasting Centre
- Norfolk Island (Pacific Ocean) – NSW Regional Forecasting Centre
- Christmas Island (Indian Ocean) – WA Regional Forecasting Centre
- Cocos Islands (Indian Ocean) – WA Regional Forecasting Centre
- Macquarie Island (Antarctica) – TAS Regional Forecasting Centre

Note: the continental Antarctic stations (TAS Regional Forecasting Centre responsibility) are treated as the mainland from an assessment perspective (continent rather than island), but as offshore territories from a product issue perspective. These products are not issued publicly because each Antarctic station is a closed community.

Tsunami Threats and Tide Levels

For Land Inundation threats, tide levels may affect the extent of inundation. However, the complexity and variability of tidal effects are such that it is not practical to include them in the standard tsunami bulletins. Accordingly, at this stage no adjustments are made to account for tides. In those parts of Australia where there are large tidal ranges it would be appropriate for emergency response agencies to provide some guidance to the public about the effects of the tides. How this might be done is discussed in the box to follow.

Effect of Tides on Tsunami

Tsunami bulletins contain threat levels which have been determined by comparing predicted tsunami amplitudes against the pre-determined method of assessing tsunami threats. However, this pre-determined method does not take account of tide levels in the overall calculations.

Emergency services agencies need guidance on the effects of tides on the tsunami threat. The difficulties in providing any real time advice are logistical rather than scientific. There are just so many variables in both times and locations that it is not practical to incorporate any real time advice in tsunami bulletins.

Tide times and tidal ranges vary every day for any location, and on any day there is a variation of both range and times along the coast. During each monthly tidal cycle there are periods of several days when tides are neap with only a very small variation between high and low tides. For these periods it is sufficient to say that there is no significant effect of the tides on a tsunami. To provide information on the effect of the tide on tsunami at other times the JATWC would have to prepare separate messages for relatively short stretches of coast – at least one for each warning zone, and possibly two for some zones. And it would be necessary to describe the tidal effects in short time periods of a few hours - probably something like two hours either side of high tide time, one hour either side of mean tide time, and two hours either side of low tide time.* And all of that for however many hours or days the tsunami effects were expected to persist, since even at one location each tidal cycle is different from the last.

The only realistic approach to the problem is to provide generic guidance notes to support either state agencies or more realistically local authorities in determining the tidal influences for themselves at the local level. The guidance would need to be based on the pragmatic development of a reference table based on the predicted tidal range on the actual days of tsunami threat. A realistic approach would be:

Daily tidal range	2 hours either side of high tide*	1 hour either side of mid tide*	2 hours either side of low tide*
Less than 3m	Minor increase of tsunami	No effect on tsunami	Minor reduction of tsunami
3m to 5m	Moderate increase of tsunami	Minimal effect on tsunami	Moderate reduction of tsunami
Over 5m	Major increase of tsunami	Minor effect on tsunami	Major reduction of tsunami

Table 1 Effect of tides on tsunami for different daily tidal ranges (* See Figure 1)

Term	Effect
Minimal	Less than 0.1 m
Minor	0.1 m to 0.5 m
Moderate	0.5 m to 1.0 m

Table 2 Definition of terms used in Table 1

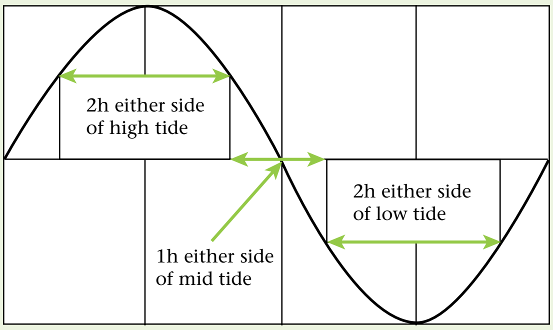


Figure 1 Daily tidal cycle

In theory coastal zones would need to be subdivided into relatively homogeneous sections where the variation in tide times was less than 1½ hours and the variation in tidal range for the day was less than 1 metre. This subdivision of a zone would need to be done if either criterion were reached. In practice, the only realistic and manageable approach is to accept that there is unlikely to be a need to subdivide any coastal zones around Australia, so local authorities would simply use the table above for each zone.

By way of illustration, consider the tidal variations at Hay Point on the north central Queensland coast over a six week period.

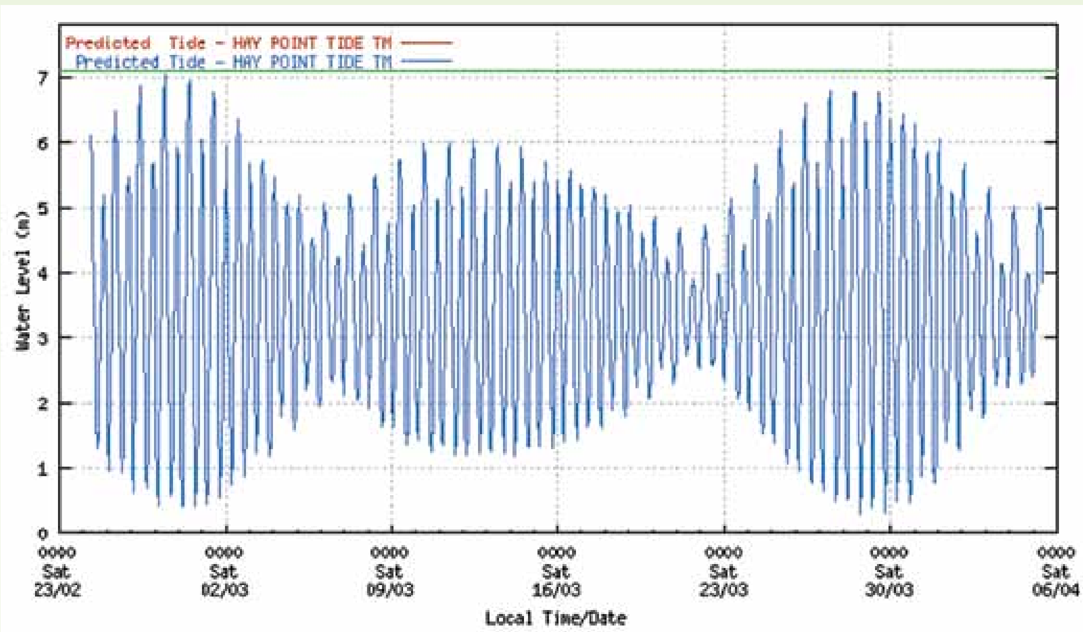


Figure 2 Tidal variations - Hay Point Queensland

For different days during this period the local authority would need to use different lines from Table 1 to determine the effect of the tide for any particular day.

It would not be practical or realistic to expect local authorities to predetermine tidal ranges for all zones for all days into the future. What is essential though is that appropriate officers within local authorities have a basic understanding of tidal variations, have copies of tide tables, and know how to use them. Then when a tsunami is predicted for their area they can fairly quickly determine the likely effects of the tides on the tsunami in their area.

4.3 Methodology for Communicating Warnings to the Public

JATWC Tsunami Warning Product Suite

The product suite for an Australian tsunami event include three primary product types: Bulletins, Watches and Warnings. Key aspects of each are described below.

Bulletins

Purpose of the tsunami 'No Threat' Bulletin is to ensure people and organisations know the JATWC is aware of the earthquake and that it has been assessed as no threat potential to Australia.

These bulletins provide positive assurance that implications have been assessed and determined to be of no threat, rather than leaving doubt in the minds of the Australian community. The 'no threat' bulletin is targeted at audiences who may have heard possibly erroneous unqualified warnings from other sources (such as global media) or who may have interpreted a tsunami impact on another country as having potential impact on Australia and/or its territories.

Watches

In an event where an earthquake may have generated a tsunami and is yet to be confirmed, the National Tsunami Watch allows people and organisations to plan for the future and monitor the situation for any subsequent warnings; this 'heads-up' provides detail on the hazard and guidance to people and organisations on how they should respond to the possible threat. Recipients should also prepare for further more specific information as it comes to hand. Watches also allow for the emergency management authorities to begin planning and preparation should a hazard eventuate.

Warnings

Warnings are issued for each affected state/territory (Regional Tsunami Warnings) rather than at a national level in order to allow for more detailed information and liaison between RFCs and relevant State and Territory emergency management authorities. Warnings can convey the severity of the threat for different coastal zones, including a Marine threat or a Land Inundation threat. The Australian offshore territories are to be treated individually as separate territories. Warnings convey whether or not the existence of a tsunami has been confirmed.

Some states/territories may be on Warnings whilst others remain on Watches. Some may have no threat at all. A consolidated National Tsunami Warning Summary of the status of state-based Watches and Warnings is produced for each issue cycle of the individual Watches and Warnings. The JATWC web site provides a freely accessed coastal threat graphic indicating the regions currently under threat. Watches and Warnings require Cancellation and a final Event Summary when the tsunami threat has passed.

Key success factors in disseminating tsunami warnings are the speed and accuracy of the issue. The information contained in a JATWC Tsunami Warning includes:

- Media Instructions, including whether or not to use SEWS and how urgently this message should be broadcast
- Type, date/time and number sequence of Message and issue time
- Headline Message
- Summary: level of threat, coastal areas affected, time of arrival
- Community Response Instructions (action prompts)
- Detailed information on extent of threat
- Web and telephone details for further/latest information
- When the next update will be issued

Issue of tsunami warning products

Following development of the Bulletins, Watches and Warnings, these are issued or disseminated by the Bureau on behalf of the JATWC. Key requirements for issuing products are:

- JATWC provide Regional Forecasting Centres with a 'heads-up' that a Watch or Warning will be issued and Regional Forecasting Centres pass this on to the relevant Emergency Management authorities.

- A Bulletin is to be issued when there is no tsunami threat. The No Threat Bulletin provides recipients with confirmation that the hazard has been assessed and no threat is considered appropriate for Australia and its territories.
- Bulletins are to be issued within 30 minutes of earthquake origin time.
- The first stage of the tsunami warning process is a 'tsunami watch' phase, where seismologists have determined that there is the potential for an identified undersea earthquake to cause a tsunami threat to Australia.
- The National Tsunami Watch may be reissued if a tsunami remains unconfirmed by sea level observations and if any potential first point of impact on Australia is more than 90 minutes away.
- Warnings are to be issued if sea level observations confirm the tsunami threat or if any potential first point of impact is less than 90 minutes before arrival of the first tsunami wave to the Australian mainland coast.
- Subsequent Watch/Warning updates are issued 30 - 60 minutes after the initial Watch/Warning.

Communication methods

Tsunami warnings can be communicated to the public using a variety of different methods including:

- Emergency Alert (Telephone based warning system)
- Radio
- Television
- Two-way radio
- Mobile and fixed public address systems/sirens
- Doorknocking
- Internet
- Information hotlines
- Variable message signs
- Bells

Dissemination Protocols

Dissemination of JATWC Bulletins, Watches and Warnings are subject to the following protocols;

- Tsunami No Threat Bulletins and initial National Tsunami Watches are issued nationally which includes offshore territories.
- Tsunami Warnings are issued to national bodies (eg. federal government entities) and 'at threat' regions only. Warnings also describe which other regions are subject to tsunami warnings.
- Follow-up National Warning Summary Bulletins are issued and upon Cancellation of all Warnings an Event Summary is issued.
- Messages are posted on the JATWC web site http://www.bom.gov.au/tsunami to provide consolidated overview of the status of current warnings.

4.4 Key Public Safety Advice Messages

Different Threat Levels within Tsunami Warnings

In order to assist the community, tsunami threats in Regional Tsunami Warnings are categorised into two levels that have associated community response requirements. Relating advice and community response instruction provided within Tsunami Warnings have been determined in consultation with emergency management authorities. As the earlier section on Stratification suggests, these two key threat levels include **Marine threat and Land inundation threat**.

Marine Threat will be the most frequently experience tsunami warning level for Australia. While major evacuations of land areas would most likely not be required for this warning type, the danger of Marine threats should not be underestimated particularly by those who spend time in the ocean. Marine tsunami can cause dangerous waves along with strong and unpredictable ocean currents and rips posing a threat to swimmers, surfers, people in small boats and anyone else inhabiting the water close to shore. This type of warning will advise of potentially dangerous waves, strong ocean currents in the marine environment and the possibility of some localised overflow onto the immediate foreshore.

An Example of Community Response Advice that would be found in a Marine and Immediate foreshore Tsunami Warnings;

Community Response Advice from the State Emergency Service

Evacuations from communities are not required, but people are advised to get out of the water and move away from beaches, harbours, marinas, coastal estuaries, and rock platforms

Boats in harbours, marinas, estuaries and in shallow coastal water should return to shore. Secure your boat and move away from the waterfront

Vessels already at sea should stay offshore in deep water until further advised

Do not go to the coast to watch the tsunami

Check that your neighbours have received this advice

CAUTION:
Tsunami waves are more powerful than the same size wind waves. There will be many waves and the first wave may not be the largest. Take care in other coastal areas where low-level effects may be observed.

Land Inundation Threat may be a less frequent threat but extremely dangerous. In this type of event the SEWS would need to be broadcast notifying the public to tune in for emergency response advice.

In a Land Inundation event it is likely that evacuation of low lying coastal areas would occur. Evacuation advice would vary within the individual warnings for each State and Territory as pre-determined by regional emergency management authorities. This threat type would result in a warning for low-lying coastal areas of major land inundation, flooding, dangerous waves and strong ocean currents.

An Example of Community Response Advice that would be found in a Land Inundation Tsunami Warning

Community Response Advice from the State Emergency Service for areas under threat of major flooding of foreshore and nearby land:

A threat of major flooding of foreshore and nearby land, dangerous rips, waves and strong ocean currents for the following areas at the following times:

XYZ

State Emergency Services has ordered the evacuation of low-lying parts of coastal towns and villages including XXX and XXX.

People are strongly advised to go to higher ground, at least ten metres above sea level, or if possible move at least one kilometre away from all beaches, marinas, harbours and coastal estuaries.

Take only essential items that you can carry including important papers, family photographs and medical needs.

It will be in your own interest to walk to safety if possible to avoid traffic jams.

If you cannot leave the area take shelter in the upper storey of a sturdy brick or concrete multi-storey building.

Community Response Advice for Threatened Marine Environment Areas:

State Emergency Services advises people in all threatened areas to get out of the water and move away from beaches, marinas, harbours, coastal estuaries and rock plates.

Boats in marinas, harbours, estuaries and in shallow coastal water should return to shore. Secure your boat and move away from the waterfront.

Vessels already at sea should stay offshore in deep water until further advised.

Do not go to the coast to watch the tsunami, as there is the possibility of dangerous, localised flooding of the immediate foreshore and nearby land.

Check that your neighbours have received this advice.

CHAPTER 5

Emergency Planning, Capacity Development and Preparation

Key Points

- ***Tsunami emergency plans should be developed where an identified tsunami hazard is likely to pose a risk to life or property.***
- ***When developing the plan, planners should attempt to develop an accurate understanding of the available tsunami risk information***
- ***Strategies and arrangements detailed within tsunami emergency plans should link with established warning systems***
- ***It is essential that those emergency managers involved in managing responses to tsunami have an understanding of tsunami science, tsunami risk, warning systems and tsunami emergency plans.***

5.1 Introduction

Preparations for the potential impacts of tsunami are essential to ensuring communities are ready to respond effectively to tsunami emergencies when they occur. Emergency managers can build community preparedness through emergency planning, emergency management capacity development, establishment of warning systems, exercising and community education.

5.2 Emergency Management Planning Considerations for Tsunami

Emergency Planning

An emergency plan for tsunami is a statement of intent containing an agreed set of arrangements which define the framework for the control and coordination of a tsunami emergency. In essence an emergency plan for tsunami is a script detailing the progression of emergency functions and what parts each actor must play.

Planning for tsunami enables a proactive response to tsunami emergencies, by developing an understanding of what areas are at-risk and what actions must be undertaken to reduce the risks to life and property.

Tsunami emergency plans should be developed where an identified tsunami hazard is likely to pose a risk to life or property.

Tsunami emergency plans should be holistic in their scope encompassing arrangements for all necessary activities for all magnitudes of tsunami.

The development of plans should involve all agencies likely to play some part during tsunami emergencies. People who are involved in the planning process are more likely to understand, accept and use the tsunami emergency plan. Consultation with affected communities is also vital to ensure community ownership of the plan. The establishment of a planning committee consisting of key stakeholders may assist in developing the plan in a consultative manner.

When developing the plan, planners should attempt to develop an accurate understanding of the tsunami risk information available, so as to ensure that the nature of the threat is as well understood as possible. It may be necessary to seek further information through detailed modelling before the risk can be fully understood and it is important that through the planning process that any need for further risk information is identified.

Strategies and arrangements detailed within tsunami emergency plans should link with established warning systems, to ensure that guidance is given as to how to respond to different types of tsunami warning products.

Tsunami emergency plans should cover strategies to be used in preparedness, response and the initiation of recovery for tsunami. Table 5.1 details content considerations which may be included in tsunami emergency plans.

Phase	Content
Preparedness	• Review of Plans • Establishment and review of tsunami risk assessment/intelligence • Conduct of community education • Establishment and/or maintenance of warning systems
Response	• Control and coordination arrangements • Outline of operational divisions/sectors • Location of operations centres • Warning at-risk communities • Evacuation of at-risk affected communities; including the identification of suitable evacuation routes and shelters • Provision of welfare relief • Pre-deployment of resources to staging areas outside the impact area • Protection of emergency land and marine resources by removing them from likely impact areas • Restriction of access and security of evacuated areas • Reconnaissance/monitoring of potentially affected areas and the undertaking of rapid impact assessments • Rescue of trapped and injured people • Care for sick and injured persons • Disaster victim registration • Disaster victim identification • Establishment of a public enquiry system • Issue of 'all clear'
Recovery	• Initiation of recovery • Recovery coordination • Conduct of after action reviews/debriefs
General	Description of the risk within the scope of the Plan

Table 5.1 Suggested content of plans

The use of maps to illustrate at-risk areas; the location of evacuation relief centres and assembly areas; and evacuation routes may be incorporated within Plans

Plans should be documented and distributed to relevant stakeholders. Plans need to be kept alive to ensure they remain effective and this can be done through exercising, training and community education.

Standard Operating Procedures can be developed to support emergency plans and provide further detailed guidance as to how to undertake required actions. Operations Action Plans used to communicate the operational objectives and strategies as directed by the Operations Controller of the lead agency may also be developed to guide operations. Operations Action Plans may be pre-written and modified before their release during tsunami response operations.

Exercising

Exercises provide an opportunity to ensure plans are workable and effective. They also help to educate emergency services, functional areas, supporting agencies, Local Government and the community about emergency management arrangements for tsunami. Exercises can also be used as a tool to assist in the development of tsunami emergency plans, by identifying required strategies and responsibilities.

Exercises can identify deficiencies in a Plan both in terms of its procedural adequacy and its effectiveness in communicating with those who will be managing a tsunami when it occurs. Exercising should be done regularly and be varied in its context and extent since no single test can adequately simulate all aspects of response. All agencies need to be involved in the process, practising roles which the plan details for them. However, not all agencies will need to be involved in every exercise.

Capacity Development Programs

Tsunami has largely in the Australian context until recently been an unappreciated hazard. Prior to the 2004 Indian Ocean event little was known about the Australian exposure to tsunami risk and there were few emergency plans available to specifically guide emergency response to tsunami.

After the 2004 Indian Ocean event there has been a recognised need to improve the capacity of emergency services and functional areas to manage emergency responses to tsunami.

It is essential that those emergency managers involved in managing responses to tsunami have an understanding of tsunami science, tsunami risk, warning systems and tsunami emergency plans.

Emergency Management Australia has led the development and delivery of numerous capacity development programs, two of which are described in more detail in the following sections.

5.3 Importance of Capacity Development and Principles

Capacity development is an important part of emergency management. It is the process through which individuals, the community and organisations obtain, strengthen and maintain their capabilities to set and achieve their objectives. Capacity development enables emergency managers and other response organisations to perform their functions effectively, efficiently and sustainably. It helps to build community preparedness for a natural disaster and also their ability to respond.

Some of the principle components of capacity development are assessing capacity assets and needs, defining appropriate strategies, training and education based on these strategies, monitoring and evaluating implemented strategies. These components are actioned through good organisation, best use of skilled human resources, effective networks of similar organisations and Government support.

The principle of training and education in regards to tsunami is particularly important in Australia as there has been little or poor understanding of tsunami in years prior to the Indian Ocean tsunami of 2004. The Australian Government, through Emergency Management Australia, has conducted capacity development of emergency managers through a series of tsunami awareness projects, two of which are detailed in the case studies below.

5.4 Case Study – Introduction to Tsunami for Emergency Managers

Introduction to Tsunami for Emergency Managers (ITEM) was developed as an in-service training package to increase the awareness of emergency managers and other relevant parties who play a lead role in tsunami planning and preparation within Australia.

ITEM is a comprehensive PowerPoint presentation delivered by staff from AGD, GA and the Bureau, primarily to increase emergency managers and other parties understanding of tsunami, to dispel some of the myths often associated with tsunami and accordingly enhance their capacity to effectively respond to a tsunami event. Topics presented include tsunami science, risk modelling, science of detection, warning processes including the ATWS, and jurisdictional and Australian Government emergency management arrangements relating to tsunami. There is also an optional exercise that can be carried out at the conclusion of the presentation to test emergency management arrangements.

These ITEM presentations are hosted by State and/or Territory emergency management organisations and attendance at these presentations prepare emergency managers to deliver further tsunami awareness briefings within their own jurisdictions. ITEM has been successfully presented and further disseminated amongst emergency managers and other relevant parties in all Australian States and Territories.

5.5 Case Study – Capacity Development Program for Surf Life Saving Australia

As Australia's leading water safety and rescue authority, Surf Life Saving Australia (SLSA) was identified as a key front line responder should the impact of tsunami occur on Australia's coastline. As a result, AGD in partnership with SLSA led the development of an educational interactive DVD aimed at increasing tsunami awareness amongst Surf Life Savers. The DVD aims to increase the capability of these members to adequately assist, prepare, plan and respond in the event of a tsunami. The DVD is an interactive, flexible tool which acts as a teacher's aid or independent learner guide for tsunami.

The DVD was carefully selected as the educational tool of choice due to its capacity to hold large amounts of information and associated learning aids such as illustrations, photos and animations, in a compact and easily accessible format. The educational tool was also designed into two distinct sections, one section containing information about tsunami science, behaviour and history while the other section containing information specific to Surf Life Saving and their protocols. The educational tool can also be viewed at the following web address - http://www.beachsafe.org.au/tsunami/

The advantage of this capacity development tool is its flexibility to be easily adapted by other relevant agencies and emergency management authorities who play a lead role in tsunami planning and preparation within Australia. NSW SES has modified this tool for the education of emergency managers and volunteer marine rescue agencies in NSW.

5.6 Case Study – Tsunami Hazard Assessments to Inform Planning and Preparation

Tsunami hazard information is fundamental to the development of tsunami plans. Through capacity development funding, the AGD supported GA to develop a national probabilistic tsunami hazard assessment (Burbidge et al 2008) and a nearshore tsunami hazard assessment (Fountain et al 2009) to assist the Jurisdictions in their tsunami planning and preparation activities. These assessments provided a new level of understanding of the offshore hazard and also allowed the Jurisdictions to prioritise locations for more detailed inundation studies. The key features of these assessments are outlined in Chapter 2, section 4.

AGD also supported GA to conduct detailed inundation modelling at four locations on the east coast of Australia. This then complemented the suite of modelling that was done for several communities in Western Australia that is described in Chapter 3. The outputs of this modelling provided a further level of detail to support the development of tsunami plans for those locations.

CHAPTER 6

Community Awareness Model for Tsunami

Key Points

- ***It is important to have an informed understanding of tsunami to effectively prepare community awareness tools.***
- ***It is important to have a clearly defined message or messages for communication.***
- ***It is important to identify key stakeholder groups to ensure a suite of community awareness tools effectively address the majority of the community.***
- ***It is important to evaluate community awareness tools with target audience(s).***
- ***Community engagement is essential to building community awareness. Where appropriate, community awareness materials should be developed with stakeholder consultation.***
- ***Community awareness is a crucial element in the building of community resilience.***

6.1 Introduction

Raising community awareness about tsunami in Australia is a challenging proposition due to the limited historical records and impact as compared to other natural hazards such as bushfires, floods, cyclones and drought. However, considering there is a history of tsunami in Australia (see chapter 2.5) and that Australians choose to frequent countries at risk of tsunami, education about this hazard is necessary.

It is equally important to identify and examine the cultural diversity and demographic profile of the population to be educated. In Australia, this profile is ever evolving and expanding due to social and economic conditions both domestically and internationally. These distributions should be considered highly relevant when developing education tools about prevention and preparedness in regards to tsunami.

To build community preparedness it is crucial emergency managers and the Australian public understand the potentially devastating impact tsunami can have and what action should be taken, especially when an official tsunami warning is issued.

6.2 Objective

The primary outcome of raising community awareness should always be to increase community resilience, enhanced through community understanding and preparedness.

Community awareness in regards to tsunami should be raised through the utilisation of a variety of mediums; engaging and educating emergency managers, relevant industry bodies and the general public. A further range of educational tools should also be designed for specific community groups.

6.3 Community Awareness Model for Tsunami

In Australia, AGD has led the development and delivery of community awareness programs in regards to the understanding of tsunami and risk to Australia and its offshore territories. This has been carried out in a phased approach, working with other Australian Government Departments, State and Territory governments and other industry bodies.

Approach

A key element of community awareness is to have a clearly defined message or messages for communication. Once this has been identified, the next step is to identify key stakeholders and then tailor communication style to these stakeholders.

While many community awareness materials will be aimed at the general public, it is important to address other groups of the community who may not have ready access to these materials. For example, school children, seniors, Indigenous Australians, persons from culturally and linguistically diverse backgrounds, and those with disabilities, who may require materials specifically tailored to their needs.

It might also be appropriate to target other groups who, while having access to general public materials, may require more specific information. For example, in the case of tsunami it would be more appropriate to target audiences such as recreational boat users and marine users (eg those on or near the beach, swimmers, fishers and marine industries) with specific action statements relative to their activity.

In targeting audiences it is also important to test and re-test materials, and to make changes where appropriate. Any community awareness material that does not successfully engage the proposed target audience has failed in its key objective to provide a clearly defined message or messages.

When considering the way forward for tsunami community awareness many different elements require consideration. An understanding of Australia's vulnerability to tsunami and its historical impact are important aspects, as is the importance of addressing emergency managers, other relevant industry bodies and the general public. Taking advantage of community networks, utilising focus group testing and adapting a multi-jurisdictional approach also contribute to a clear and comprehensive community awareness strategy.

Emergency manager education

The potential for tsunami to impact Australia's coastline creates the need for emergency managers and first responders to be well educated in both the nature of this natural phenomenon, and the appropriate response to an official warning issued within Australia; including agreed channels for dissemination of the warning. Therefore, before community preparedness can be built upon, emergency manager preparedness needs to be developed. This preparedness comes through understanding the science of tsunami, jurisdictional agreement and exercising of the dissemination of official tsunami warnings, and an understanding of tsunami risk to Australia. This preparedness also leads to the agreement on ways forward with public education.

Public education

In the interest of building a resilient Australia, public education of tsunami plays a key role in communicating the real risk of tsunami for Australia, debunking tsunami-related myths, promoting the appropriate channels for receiving tsunami and official warnings information and ultimately, promoting effective response and recovery. While many community awareness materials will be aimed at the general public, it is equally important to address other groups. As there is now such a diverse culture in Australia it is more important than ever to address a wide variety of target audiences in education materials, such as remote Indigenous coastal communities, Seniors, CALD communities, school children and other special interest groups (eg the hearing and visually impaired). There is also a need for a range of diverse products that address different languages and are available via different media (eg brochures, CDs, audio, subtitled programs). This is where market and focus group testing, consultation and evaluation of tools are recognised as highly important.

Focus group testing

Community focus groups are an important stage of the research process for creating community awareness tools. Focus groups are able to establish current levels of awareness, barriers to education programs, common misconceptions, and identify opportunities to increase awareness. The outcomes of this type of testing can influence the format and content of community awareness materials and also highlight relevant target audiences. Focus group testing ensures appropriate methods of education are identified.

Consultative and multi-jurisdictional approach

A consultative and multi-jurisdictional approach should be taken to developing tsunami community awareness tools, with extensive consultation and communication taking place between key Australian Government agencies, and representatives of State and Territory governments. Should State/Territory governments be developing tools, consultation should also take place with Local Government and other relevant community representatives.

This approach aims to build a common ownership for these tools, thereby creating opportunities to effectively disseminate these tools at each level of government throughout the nation and ultimately, to the general public. These tools should also be provided to other relevant industry bodies for distribution through their key networks. For example, Surf Life Saving Australia has been recognised as potential first responders in a tsunami event. Surf Life Savers, Lifeguards and Nippers (aged 5 - 13) can be educated about tsunami and further disseminate this information to the general public.

Community networks

Utilising social networks to communicate safety information is not a new idea. For example, Rural Fire Services and volunteer groups have addressed community groups, clubs, schools and businesses regarding fire safety for decades.

Taking advantage of existing networks has been highlighted as an important part of raising community awareness and moving towards community resilience.

When individuals are directly approached by an organisation in a familiar environment, they are much more likely to quantify the risk to their area as real, and this will motivate them to take action in both preparedness for a potential emergency, and response to a real-time threat.

Engagement at this level for tsunami community awareness is managed by the relevant State and Territory governments in collaboration with their local governments who are best placed to evaluate areas of highest risk and determine the most appropriate ways to engage communities.

Community resilience

Community resilience, the concept of a community taking intentional action to enhance the personal and collective capacity of its citizens and institutions to respond to emergency, is highly promoted by all levels of Australian Government. Community awareness programs strongly aid this process as the public receive and interpret awareness materials and incorporate this new information into their understanding of tsunami. They are then more readily prepared to appropriately respond and recover from an official tsunami warning, should one be issued in Australia.

6.4 Case Study: Tsunami Education Materials and Programs

AGD undertook significant consultation and research to review and examine current practice, identify potential gaps, or areas for improvement to develop a suite of tsunami-related public awareness products and activities and capacity development service delivery programs.

The ATWG was the focal point for engagement between the Australian Government, the State and Territory Governments and other industry bodies in the process of delivering ATWS-related outcomes, ensuring coordinated and consultative engagement with the beneficiaries of the ATWS project. This group was particularly important in providing feedback and assisting in formulating bodies of tsunami awareness materials.

As part of the initial research phase for the ATWS project, Community Awareness Focus Groups were conducted. Communities, in four different states, were tested to measure their understanding of tsunami, anticipated response to tsunami warnings and appropriate methods of educating the public. The outcomes from these focus groups led to the development of several different forms of community awareness materials aimed at different members of the public including school-aged children, seniors, persons with certain disabilities, recreational boaters, Indigenous communities, and culturally and linguistically diverse (CALD) communities. It also led to the development of different mediums of community awareness materials eg brochures, audio files, information sheets, poster, action guide, DVD, CD Rom and an online web tool. These community awareness materials incorporate relevant illustrations, pictures and audio materials; and integrate relevant official tsunami warnings information.

On evaluation of this research, AGD developed a wide range of community awareness materials in close consultation with the State and Territory governments, who coordinated the dissemination of this information to the respective local governments. State and Territory, and Australian Government agencies discussed the needs and ways to build their jurisdictional ability to better respond to the threat and event of tsunami and to better prepare their communities in relation to official warnings and appropriate actions to take.

Through the multi-jurisdictional arrangement, AGD worked with State and Territory Governments as well as other Australian Government agencies to develop and implement a range of tsunami-related products, programs and services. These included, but were not limited to: tsunami education and awareness raising programs for emergency managers; tsunami planning tools, tsunami community education materials and programs; jurisdictional exercises; and children's education tools.

Development of the above mentioned activities commenced as a result of participating agencies identifying at-risk areas of Australia's coastline; investigating options to enhance or augment existing all-hazards emergency management arrangements to deal with the threat of tsunami; developing/enhancing existing State/Territory emergency response plans in relation to tsunami, and identifying appropriate programs and activities to reach the project's three policy objectives. To date, AGD and member agencies of the ATWS have developed and delivered a range of tsunami capacity building and community awareness materials.

Some of the appropriate tools developed included:

Available at www.ema.gov.au

Figure 6.1 Suite of tsunami educational brochures.

Source: Attorney-General's Department

Australian States and Territories identified a need to develop and disseminate general awareness materials to the Australian public regarding tsunami. Three educational brochures were developed during the ATWS project:

6.2.1.1 Tsunami Awareness brochure

An education tool aimed at the Australian public and containing general information about tsunami. It explains what tsunami are, how they are generated and detected, information about the ATWS and the Joint Australian Tsunami Warning Centre, natural warning signs, history of tsunami in Australia, what to do in the event of a tsunami and where to find more information.

6.2.1.2. Tsunami Information for Recreational Boaters brochure

An information resource specifically aimed at educating recreational boaters on tsunami and related information they may require. The target audience are those who own or use a boat for recreational purposes. Content within the brochure includes: what tsunami are, tsunami warnings within Australia, what to do with a vessel, (i) at sea or in the open ocean, (ii) if it is moored, (iii) in shallow water or a harbour or estuary, natural warning signs of tsunami, and where to find more information about tsunami.

6.2.1.3. Tsunami Information for Recreational Marine Users brochure

An information resource aimed at educating recreational marine users on tsunami and related issues that may affect them. Recreational marine users are those who live or spend time at or near the beach, swimming, boating or participating in other recreational marine activities. Content within the brochure includes: what tsunami are, how the public will be advised of a tsunami warning and cancellation, actions to take should a tsunami warning be issued, history of tsunami in Australia, natural warning signs of tsunami, and where to find more information about tsunami.

6.2.2 Tsunami Awareness Show – 'Questacon', the National Science and Technology Centre

Figure 6.2 Tsunami Awareness Show

Source: Questacon and Attorney-General's Department.

AGD, partnered with Questacon (National Science Museum), to develop a Tsunami Awareness Show in the Australian capital. This show ran approximately seven times per week over 13 months complementing existing community awareness tools in current use across Australia. It was aimed at educating children, teachers and the general public. This Show incorporated key messages on how tsunami can occur and included demonstrations on how to act safely when a tsunami warning is issued. There were take-home activity sheets and information brochures for audience members. The show presenters engaged audience members through the use of graphics, demonstrations and interactive activities. Featured topics include tsunami myths, causes, history, natural warning signs, the ATWS and community safety.

This Show was also developed into a DVD, including eight Frequently Asked Questions about tsunami. While it was intended to be housed on the AGD website, due to internet restrictions the Show was housed on the Questacon website and also copied for distribution to School Libraries.

6.2.3 Questacon Awesome Earth Exhibit

AGD also partnered with Questacon to develop a 'Choose your own adventure' tsunami kiosk to be housed in the National Science and Technology Centre. This kiosk was also developed into an online tool for use particularly by school teachers and children.

6.2.4 Key observations and lessons learnt in tsunami education:

- The development and delivery of bodies of work through a multi-jurisdictional arrangement with the Australian States and Territories was an effective partnership.
- The development and delivery of bodies of work through relevant industry groups proved successful and increased awareness at the both the first responder and general community level eg Surf Life Saving Australia, Questacon and Council of the Aged (COTA).
- The importance of active participation on a multi-level government approach was recognised as an extremely important step in the path of building community awareness before progressing to active participation at the community level.
- The implementation of national tsunami education and training programs such as the Questacon Tsunami Awareness Show increased awareness at the general community level.
- During the focus group testing phase it was discovered:
    - there was some confusion in the public's understanding of tsunami, tidal waves,
    - flooding and storm surge.

- there was some confusion in the public's understanding of tsunami warnings information and advice messages. Example, messages should refer to geographical descriptions such as open ocean, harbours and estuaries rather than exclusively depths.
- the public supported the idea of an education campaign about tsunami. The public thought this education should explain the risk of tsunami to specific areas and how it was derived, tell people what to do, where to go and what to take with them. They wanted an education campaign to repeat risk messages regularly throughout the year but run an education campaign more regularly through use of print media and community meetings to distribute the messages.

- To ensure a total tsunami warning system, the media need to be engaged so they are aware of tsunami, the tsunami warning system; and the role the media plays in disseminating emergency warnings to the public.

CHAPTER 7

Emergency Response to Tsunami in Australia

Key Points

- ***Tsunami operations involve a multi agency effort under the overall control of a designated lead agency or emergency operations controller***
- ***Tsunami response operations can be separated into the phases of pre-impact (warning), impact and post impact***
- ***Tsunami concept of operations should distinguish between the varying impacts of tsunami and link to the Australian Tsunami Warning System stratification levels of Marine Threat and Land Inundation Threat***
- ***The media industry is an essential component in the total tsunami warning system and it is vital that the media are aware of tsunami; the tsunami warning system; and the role of the media industry in disseminating emergency warnings to the public.***

7.1 Introduction

The emergency response to tsunami can often be challenging due to the rare nature of the hazard; its potential for wide-scale damage along an entire coastline and its potential to generate global media interest. It is essential that emergency managers have an understanding of the key phases; tasks and potential levels of impact associated with tsunami.

7.2 Concept of Operations

It must be recognised that any tsunami operation will require a coordinated multi agency effort under the overall control of a designated lead agency or emergency operations controller. Agencies with different skills and resources can be matched with tasks best suited to their capabilities.

Tsunami response operations can be separated into three key phases consisting of pre-impact (warning), impact and post impact.

The pre-impact phase is defined as the period before the impact of a tsunami and consists of precautionary tasks focused upon the protection of life and property such as warning and evacuation; operational readiness; provision of accommodation and welfare for displaced people; protection and pre-deployment of resources; and restriction of access to areas likely to be impacted. The ability of emergency services to complete these actions will be dependent upon the warning time and resources available. During this phase it will be important to prepare to undertake actions in subsequent phases in particular to ready resources involved in search and rescue and the treatment of the sick and injured if a major impact is anticipated.

The impact phase is characterised by the impact of a series of separate waves over several hours. It will be difficult to undertake many activities directly within at-risk areas due to the dangers posed by the impacts of further waves. Hence activities within this phase will be focused on warning; reconnaissance; welfare for evacuees; and preparation for response activities during the post impact phase.

The post impact phase begins upon advice that the destructive potential of a tsunami has ceased and that it is safe for emergency services to enter affected areas (if any). The scale of post impact phase activities will be dependent on the size of the tsunami event that has occurred. Some activities conducted during this phase may include reconnaissance, search and rescue, treatment of sick and injured, welfare provision, disaster victim identification, response to fire and hazmat incidents, disease control and provision of advice to the community.

Both marine and land based elements are vulnerable to the impact of a tsunami to varying degrees around Australia. It is likely that all significant tsunami will affect marine based elements. These elements may be vulnerable to the affects of unusual currents as well as variations in water level. Larger tsunami are likely to cause damage to land based elements. It is therefore important to distinguish between these two levels of tsunami impact when determining operational action plans for tsunami. The Australian Tsunami Warning System acknowledges these two varying degrees of impact and issues warnings for Marine Threat and Land Inundation Threat (see chapter 4 for more details). Table 7.1 outlines the key generic actions which may be considered in response to the different levels of threat.

Marine Threat	Land Inundation Threat
• Warning and evacuation of immediate beach and foreshore areas • Warning of marine based risk groups eg. boaters • Limited requirement for provision of welfare for evacuees • Protection and pre-deployment of marine resources • Restriction of access to beach and immediate foreshore areas • Monitoring and reconnaissance • Limited requirement for search and rescue from sea, estuaries and harbours • Limited requirement for treatment of sick and injured • Management of the media	• Warning and evacuation of immediate beach, foreshore and low-lying populated coastal areas • Provision of welfare for evacuees • Management of pets and companion animals belonging to displaced people • Traffic control • Provision of security for evacuated areas • Restriction of access to likely impact areas • Monitoring and reconnaissance • Search and rescue • Treatment of sick and injured • Damage assessment • Damage control • Resupply of isolated properties and/or communities • Management of the media • Management of a public enquiry system • Disaster victim registration • Disaster victim identification • Response to fire and hazmat incidents • Provision of mental health support to persons both directly and indirectly affected • Assessment of potential public health risks • Disease control

Table 7.1 Key actions for Marine Threat and Land Inundation Threat

Evacuation

Movement of people from at-risk areas is likely to be necessary for almost all tsunami for which warnings are issued, however the scale of evacuation necessary will vary depending on the magnitude of the tsunami anticipated. With magnitude guidance provided through the stratification of tsunami warnings issued through the Australian Tsunami Warning System.

In the case of a Marine Threat it is likely to be necessary to move people out of the water and away from the immediate water's edge of harbours, coastal estuaries, rock platforms and beaches. Such an evacuation could be undertaken with assistance of other emergency services as well as organisations such as Surf Life Saving Clubs, Port Authorities and Volunteer Marine Rescue groups. It is unlikely that there will be a major requirement to provide welfare to persons who have been evacuated from these areas.

The safety of people on boats should also be considered. Boats in shallow water are particularly vulnerable to tsunami, however, boats in deep water in the open ocean should be safe due to the tsunami wave height being only slight in deep water. People on boats in harbours, estuaries or in shallow coastal water should return to shore. Secure their boat and move away from the waterfront. Vessels already at sea should stay offshore in deep water until advised it is safe to move closer to shore. Marine based radio may be used to provide advice to boats which have this equipment available.

Where a Land Inundation Threat is likely it will be necessary to consider large scale evacuations of low-lying coastal areas. Public safety advice messages on JATWC Warnings for a land inundation threat will, with the approval of individual jurisdictions include advice to the public regarding evacuation. Commonly this may include an instruction to evacuate to higher ground, at least ten metres above sea level or if possible 1 kilometre from all beaches and the water's edge of harbours and coastal estuaries. This evacuation zone is a conservative rule of thumb only and detailed inundation modelling is required to determine more accurately areas requiring evacuation in individual communities.

In the case of a major evacuation of coastal communities it may be necessary to advise people to walk to safety to avoid traffic jams. Before giving this advice emergency managers must consider the distance required to walk and the likelihood of traffic delays being experienced.

Some people may be unable to evacuate in time or become trapped by a tsunami. These people should be encouraged to shelter in the upper storey of a sturdy brick or concrete multi-storey building.

In addition to advice contained within Bureau tsunami warnings, lead agencies may also need to prepare evacuation warnings/orders for local communities which detail locally specific information. Locally specific information will allow local community members to more easily relate to the advice given and take necessary action. Such evacuation orders can be pre-written and adjusted to suit the circumstance on the day.

Evacuation orders can be communicated to the public using broadcast media; doorknocking; public address systems (mobile and fixed); mass telephone dial systems; sirens; internet and two-way radio.

Evacuation arrangements for tsunami should be contained within plans for local communities. It is worthwhile to produce maps of likely areas to be evacuated which also define evacuation routes, assembly areas and evacuation centres.

Critical resources required for the emergency response to a tsunami may also have to be evacuated if they are located within potential impact areas. This is especially relevant to surf life saving clubs and marine rescue agencies that will need to move trailable equipment to higher ground. Assembly areas for the movement of emergency equipment should be defined in plans.

7.3 Case Study – Response to 2nd of April 2007 Event

At 6:40am AEST on Monday the 2nd of April 2007, a magnitude 8.1 earthquake located 10 kilometres below the seafloor in the Solomon Islands occurred. As a consequence of the earthquake a tsunami was generated. In the areas closest to the point of tsunami generation severe damage was experienced by the waves reported to have been several metres high. Some 52 reported deaths occurred in the Solomon Islands, with some 5,500 people displaced (Fritz and Kalligeris, 2008; OCHA, 2007).

Tsunami Bulletins were issued by the Pacific Tsunami Warning Centre, which warned of potential impacts on the Australian coast. As a consequence tsunami warnings were issued by the Bureau of Meteorology for the East Coast of Australia. (Note this event occurred prior to the establishment of the ATWS)

In Queensland the State Disaster Coordination Centre (SDCC) was activated at 7:35am. At 7:52am AEST a warning was issued for people in the coastal areas of northeast Queensland that a tsunami could start affecting these locations at the following local time: Cooktown from 9:31am, Cairns from 9:49am, Gladstone from 11:39am, and Mackay from 11:44am. Subsequent warnings extended the timings of possible impact down the coast to Sydney.

Reports between 9:15am and 9:40am from both news media and local observation confirmed that no impact had occurred in Far North Queensland. Throughout the morning a range of ad hoc responses were initiated by various agencies including: the evacuation of Cairns Hospital, the closure of several beaches, a number of disaster coordination centres were activated, and the closure of several schools.

In New South Wales public warnings were issued at 8:20am AEST and indicated that the NSW coast could be affected by 10:15 AEST. The main method of communicating warnings to the public was through the broadcast media.

As a consequence of warnings in New South Wales beaches were closed and swimmers were evacuated; some Sydney Ferry services were suspended; some vessels moved offshore from ports and a small number of schools evacuated. Throughout the morning most media agencies streamed continuous coverage of the situation until the warning was cancelled in the early afternoon.

Operations centres across coastal sections of the New South Wales were opened to coordinate the response to warnings. Operations within the State were led by the NSW State Emergency Service and were supported by numerous other emergency services and functional areas. Actions undertaken by emergency services and functional areas included enhancing operational readiness, disseminating warnings to people in or on water, closure of beaches in consultation with local government councils, monitoring and reconnaissance and management of the media.

A small tsunami was measured along the east coast of Australia, with strong currents observed at numerous sites. Fortunately no major damage, injuries or loss of life were reported.

Key observations and lessons learnt from the event included:

- The development of tsunami planning was a big advantage and a worthwhile investment. The partnership built between agencies during the planning process ensured coordination of operations was effective.
- There was some confusion in public advice messages regarding what was meant by deep and shallow water. Messages should refer to geographical descriptions such as open ocean, harbours and estuaries rather than exclusively depths.
- A lack of consequence information available given the fact that no risk assessment work had been undertaken on the East Coast of Australia made operational decision making difficult, reinforcing the need for detailed risk assessment work to be undertaken.
- Modern communication means that information is quickly exchanged across State borders. The need for consistent messages across State borders is vital to ensure that warnings do not create confusion and are appropriately responded to.
- Although facts of the warning system were passed down by news media and through the state disaster management system effectively, recipients did not know, and did not have guidance on, what to do or what to advise their communities. Over-reaction and under-reaction were both apparent.
- The time of day – peak commuting – and interstate travel of key executives led to the passage of information upwards being fractured.

- Available staff in the SDCC were quickly overwhelmed by the volume of calls and tasks. Calls from the public were fielded across EMQ by staff that had no guidance on what to say.
- A 1800 number was activated by 9:55am, this should have happened sooner and the scripts updated more frequently.
- The message of 'no impact' took time to confirm and disseminate.
- There is a need to complete the collection of data about Queensland's coastline, reefs and near undersea bed shape.
- Improve the capability for emergency managers to pass on timely, accurate warnings.
- Once the likely effects of an event have been modelled, emergency managers must have the capability to pass on the effects to communities and authorities as fast as possible. The sudden onset nature of tsunami requires us to do this much quicker than for most other natural disasters – particularly if the tsunami is generated from an undersea landslide on our continental shelf rather than a more distant earthquake.
- The current system of an on call duty officer is insufficiently robust to guarantee a timely response. The principle of a 24/7 centre to deal with warnings such as these should be accepted, and options for its implementation explored.
- Communities must know what to do when they receive the information and be physically able to react accordingly.
- Develop the capacity of the disaster management system to help the community react appropriately.
- Those in emergency management or services responsible for supporting the community in a disaster must be aware of the nature of the threat and the actions that are appropriate in their areas of responsibility. The current program to build capacity in our disaster management system must be accelerated and appropriate infrastructure built in collaboration with local and state governments to allow communities to take action on the advice given.

CHAPTER 8

Recovery – Purpose, Principles and Concepts

Key Points

- ***Effective recovery from a disaster requires the establishment of planning and management arrangements.***
- ***The management of disaster recovery is most effective when approached from a community development perspective.***
- ***The recovery process should begin from the moment of disaster impact and run as a parallel activity to response.***
- ***Recovery should seek to develop the community rather than just return it to the previous level.***

8.1 Purpose

The purpose of providing recovery services is to assist the affected community towards management of its own recovery. It is a recognition that where a community experiences a significant emergency or disaster there is a need to supplement the personal, family and community structures which have been disrupted. Recovery can provide an opportunity to improve these aspects beyond previous conditions by enhancing social and natural environments, infrastructure and economies therefore contributing to a more resilient community.

8.2 Introduction

In 1986 the Standing Committee of Social Welfare Administrators (now the Community Services Ministers' Advisory Council) endorsed principles of disaster recovery management which have provided a successful management context for recovery managers. The key principles are:

- Recovery from disaster is an enabling and supportive process, which allows individuals, families and communities to attain a proper level of functioning through the provision of information, specialist services and resources.
- Effective recovery from disaster requires the establishment of planning and management arrangements, which are accepted and understood by recovery agencies, combat agencies and the community.
- Recovery management arrangements are most effective when they recognise the complex, dynamic and protracted nature of recovery processes and the changing needs of affected

individuals, families and groups within the community over time.

- The management of disaster recovery is best approached from a community development perspective and is most effective when conducted at the local level with the active participation of the affected community and a maximum reliance on local capacities and expertise.
- Recovery management is most effective when human services agencies play a major role in all levels of key decision-making which may influence the well being and recovery of the affected community.
- Recovery from disaster is best achieved where the recovery process begins from the moment of disaster impact.
- Recovery planning and management arrangements are most effective where they are supported by training programs and exercises which ensure that recovery agencies and personnel are properly prepared for their role.
- Recovery from disaster is most effective where recovery management arrangements provide a comprehensive and integrated framework for managing all potential emergencies and disasters and where assistance measures are provided in a timely, fair and equitable manner and are sufficiently flexible to respond to a diversity of community needs.

8.3 Concepts

Underpinning the recovery management principles are the following concepts which provide the basis for effective recovery management within Australia.

Community Involvement

Experience gained through a range of events from cyclone Tracy onwards is that the recovery process is most effective when individuals and communities actively participate in the management of their own recovery.

The involvement of the affected community in the recovery management process creates and supports community infrastructures and provides the resources necessary for successful recovery. However, recognition of the community capacity to sustain an effective recovery process will vary. Government and the wider community should complement and supplement local recovery initiatives where appropriate.

One of the most effective means of involving the community is through community recovery committees. These committees comprise representatives of government, private and voluntary agencies, as well as local councils, ethnic leaders and other representative members of an affected community.

Community recovery committees provide a mechanism through which information, resources and services may be coordinated in support of an affected community, priorities established and information regarding the progress of an affected community made available. These committees also provide a useful source of information and advice for the affected community and recovery agencies.

The advantages of community recovery committees include:

- reinforcement of local and community orientation of the recovery process;
- recognition of the common interests of members of the affected community;
- ensuring the equitable application of resources and services;
- establishing a mechanism for the identification and prioritisation of community needs;
- overall monitoring of the recovery process; and
- providing a means for identifying needs which cannot be met from within the community and which require resource support from regional/district or state/territory level.

Depending upon the scale and geography of a disaster, one or more community recovery committees may be activated. Where an event impacts upon a number of communities, it may be appropriate to activate local recovery committees for each of the affected areas. Subcommittees may also be required to meet the needs of special needs groups if a large-scale event takes place in a large urban area. In instances such as these, a central community recovery committee may also be necessary to provide an overall forum for advice, coordination and consultation.

Management at the Local Level

Management of recovery services should be devolved as much as possible to the local level. Experience has shown that when recovery programs and assistance measures are imposed upon a community, they are less effective than those that are managed at the local level.

Resource support will often be required from regional or state level. However, by maintaining participation at a local level, community input and a capacity for affected people to participate in the management of their own recovery will be maintained. In this way, state and regional recovery strategies, services and resources supplement and complement local initiatives rather than replacing local endeavour. The local authority may require additional management support following a major disaster. This should be provided through the responsible person, agency or committee at state/territory level.

Affected Area/Community Approach

Recognising that disasters rarely occur within the confines of a single local government area, management of the recovery process is generally undertaken on the basis of an identifiable affected area.

The affected area is the entire geographic area affected in any significant way by the event. It is distinguished by the losses that have resulted and by the common interests of the people involved. It may be contained within a single municipality or administrative region, or may cross municipal, regional/district or state/territory boundaries.

Affected areas are not always clearly definable and affected people may be from a dispersed population. For example, a shooting incident in a shopping centre or other public place may affect people from a range of different localities. In an instance like this, the affected community will need to be defined by other than geographic means.

Differing Effects/Needs for Different Communities/Individuals

The capacity of individuals, families and communities to restore losses and re-establish normal living patterns following emergencies or disasters will vary depending upon their own capacity, the specific circumstances of the event and its effect upon them. Consequently, assistance measures must be adapted to most appropriately meet the needs of those affected. This will require sensitivity, together with extensive consultation with affected people and communities.

Empowering Individuals and Communities

Throughout the recovery process, it is essential that affected people and communities participate in the management of their own recovery. The capacity of many individuals, families and communities to recover is likely to be diminished by the physical and emotional impact of a disaster. While assistance from outside may be required to overcome these difficulties, it is important that such assistance does not overwhelm those affected and detract from their participation in the management of their own recovery.

Emphasis should be given to supporting and maintaining the identity, dignity and autonomy of those affected by the event. Support services and assistance measures should be well advertised on a repetitive basis, and easily accessible, but allow people to make their own decisions. It should also be ensured that information be made available to CALD (Culturally and Linguistic Diverse) communities.

Recovery should be seen as a developmental process, which should seek to develop the community rather than just return it to the previous level.

This is one of the potentially positive aspects of a well managed recovery process. Community infrastructure and functioning may, in fact, be improved following a disaster, rather than just reinstated to previous levels.

Minimum Intervention

The recovery management approach should be one of minimum intervention. However, recovery services and information should always be readily available within affected communities and be responsive to the range of needs evident.

External recovery services and resources are provided as a support to an affected community, to be used if the needs following the event are beyond the capacity of existing services and resources. Wherever possible, additional resources should be under local management through the network of existing service providers.

Recognition of Resourcefulness

In successfully managing recovery, recognition needs to be given to the level of resourcefulness evident within an affected community. As with other aspects of needs assessment, the capacity of individuals and communities to participate in the management of their own recovery and the level of need for support services will only become clear as the recovery process unfolds.

Planned/Timely Withdrawal

One of the most critical aspects of the recovery management process is that of the withdrawal of outside services. If this aspect of the process is not managed successfully, the positive effect of all previous efforts may be undone. A planned withdrawal ensures community involvement, ensuring a void will not be left. This is an area in which community recovery committees have a crucial role to play.

Accountability, Flexibility, Adaptability and Responsiveness

These represent four key aspects of recovery management. As with any area of public administration, accountability is an important issue. However, the most critical element of recovery management is the speed with which events may unfold and it is in this context that managers and staff working in recovery management will need to be flexible, adaptable and responsive in a potentially ever-changing environment. The need for these skills is further accentuated by the public, media and political scrutiny inherent in large-scale disasters.

Integration of Services

One of the lessons of emergency management over recent years is that, while response and recovery activities may be separate, they are not sequential activities: they should commence and initially occur as parallel activities. Consequently, it is essential that there be an integration of all services. This is particularly important when there is an overlap between response and recovery activities, such as when an agency has responsibilities in both areas, or where response and recovery agencies both require access to limited resources. Many of these issues can be resolved through the planning process, while those that cannot will be more easily negotiated during the operational process if effective liaison arrangements and networks are in place prior to an event taking place.

There is also a need for an effective integration of recovery services. This is the basis for a coordinated approach to recovery management. Again, the establishment of networks and management arrangements during the planning process will ensure that any difficulties which arise throughout the recovery process will be resolved as easily as possible.

Coordination

The provision of recovery services is most effective when coordinated by a single agency. This agency should be represented by an identifiable coordinator who has responsibility for the full breadth of recovery activities. To ensure community input into all aspects of the recovery process, human services agencies must have a significant role in all decision-making processes.

8.4 Case Study – Australian Involvement in Papua New Guinea Tsunami Recovery

At 19:30 local time Friday 17 July 1998, two suspected earthquakes occurred within a short time of each other, producing 7-10 metre tsunami waves which impacted 50km of Papua New Guinean coast, west of Aitape. Tsunami waves travelled as far as one kilometre inland, and completely destroyed as many as 16 villages. It has been suggested the short span between the two earthquakes more accurately reflected a relatively minor earthquake followed by a major underwater landslide. Some 2,200 reported deaths occurred, with more than 10,000 persons displaced.

The tsunami occurred on the Friday evening of a holiday weekend, and this, coupled with a lack of 24-hour tsunami detection capability, saw a major delay in communication to relevant authorities.

The Papua New Guinea National Disaster and Emergency Services (NDES) requested assistance from other countries, and Australia was one of many to respond.

Australia, New Zealand and France were the primary suppliers of aircraft for the transport of emergency supplies and also contributed to the medical response.

Nineteen countries, including Australia, and 17 Non-Government Organisations contributed more than US$6 million in funds, relief and building supplies to assist in recovery operations.

Recovery activities included:

- permanent relocation of 10 villages;
- construction of homes, schools and other infrastructure;
- supplying locals with tools, building materials, canoes and fishing equipment;
- constructing water and sanitation systems; and
- repairing key roads.

Coordination of the relief efforts was complicated as more than 40 different agencies were attempting to engage the devastated area at the same time.

Key observations and lessons learnt from the event included:

- Building community awareness of tsunami is a high priority. A lack of understanding of the natural warning signs (eg earth shaking) and causes of tsunami (eg undersea earthquake, landslide) meant the entire population did not evacuate the area. Consequently, this resulted in a higher casualty rate.
- Communication networks need to be established and maintained. It was several hours before news of the destructive tsunami reached authorities outside of the affected zone.
- There must be a lead agency in response and recovery. This disaster received strong support from many nations and Non-Government Organisations, but a lack of coordination led to additional difficulties which compromised efficiency.
- Cultural awareness also needs to be considered in recovery. The affected zone was a remote area of Papua New Guinea which was not accustomed to dealing with outsiders. Within the space of a few days there were thousands of unfamiliar foreigners in their territory, which made the recovery process even more difficult for the survivors.

Glossary

ANUGA
A free and open-sourced hydrodynamic modelling software jointly developed by the Australian National University and Geoscience Australia. ANUGA can simulate the behaviour of hydrodynamic natural hazards such as floods, dam breaks, storm surges and tsunami. Coupled with a deep water propagation model, the output from ANUGA can estimate where a tsunami will go and at what speed. This information can be used to produce maps of *Maximum inundation and Maximum flow speed* that are important inputs to emergency management planning and preparation.

Bathymetry
The relief of oceans, harbours or any large bodies of water.

Continental Shelf
A gently sloping, shallow platform extending offshore from the coast to a point (shelf break) where the slope increases sharply. The width and maximum depth of the continental shelf varies around the Australian coast.

Community vulnerability model
These aim to identify people in the community who are most likely to suffer loss or injury during a hazard event. A number of social indicators are usually combined to identify community members that are vulnerable to particular hazards. See also *Vulnerability* and *Structural vulnerability model*.

Exposure
Refers to the elements at risk which are subject to the impact of a hazard event.

Exposure Database
Contains information on exposed elements, such as residential and commercial buildings, critical infrastructure and people. Details include: the building type; number of floors; typical number of inhabitants; social demographics; replacement and contents value. Information should be accurate and current. An example is the National Exposure Information System (NEXIS) developed by Geoscience Australia.

Elevation data
Refers to both offshore (bathymetry) and onshore (topography) relief or terrain data.

Geographic Information System (GIS)
An integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organising spatial data and related information so that it can be edited, displayed (in maps, for example) and analysed. (Modified from ArcGIS Online GIS Dictionary: http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=GIS)

Impact
Refers to the consequence or outcome of an event and may be expressed qualitatively or quantitatively. Impacts are generally described as the effects on people, society, the environment or the economy.

Inundation distance
The maximum distance from the coast reached by the tsunami (or modelled tsunami). See also *Maximum inundation* and *Run-up height*.

Magnitude
A single number to quantify the amount of seismic energy released by an earthquake.

Maximum flow speed
The maximum current speed at locations offshore and onshore (inundated areas) throughout the duration of a tsunami (or modelled tsunami). Maps of maximum flow speed produced from modelling can be used to assist the marine community in preparing for tsunami events.

Maximum inundation
The maximum water depth on land reached by a tsunami (or modelled tsunami) at each location across a community, throughout the duration of the tsunami. Maps of maximum inundation produced from modelling can be used as a planning tool by emergency managers to understand, for example, what infrastructure and services would be potentially damaged during a tsunami. See also, *Inundation distance* and *Run-up height*.

Model
A computational model is a computer program that attempts to simulate a natural phenomenon or system, such as a tsunami. A mathematical model is used to describe the behaviour of a system (e.g. tsunami generated from an earthquake) from a set of parameters and initial conditions (e.g. earthquake magnitude).

Probabilistic
Assessing the likelihood of certain events occurring.

Probabilistic Tsunami Hazard Assessment of Australia (PTHA)
This consists of maps which show the wave height around the Assessment of Australia
Australian coast at the 100m depth contour that has a particular chance of being exceeded per annum. The larger the wave height the greater the hazard.

Palaeotsunami
Tsunami that have occurred in pre-historical times. Geological signatures left by such tsunami allow identification of these events and provide information about the frequency and magnitude of tsunami over thousands of years and allow a greater appreciation of tsunami hazard and risk.

Post-event survey
A survey conducted following the event of a hazard, during which information about damage and endurance of the environment (e.g. buildings) and the community (e.g. casualties) may be collected. Among other things, these surveys help to develop *Structural vulnerability models* and *Community vulnerability models*.

Resolution
Refers to the level of detail contained in a spatial dataset, such as bathymetry or topography data. For example, the relative term high resolution implies greater detail than *low* or *moderate* resolution. Such relative terms should be accompanied with more quantitative measures, such as the spacing between data points, or the number of data points per unit area. Different types of data used for different purposes may require a range of resolutions.

Return period
Also known as a recurrence interval, this is an estimate of the interval of time between tsunami events of a certain size. Generally the longer the return period, the larger an event (i.e. the larger the wave height), and vice versa.

Run-up height
A single value representing the maximum height above sea level reached by a tsunami (or modelled tsunami) at any location across a community, throughout the duration of the tsunami. See also *Inundation distance* and *Maximum inundation*.

Seismometer
Seismometers are devices attached to or buried in the ground, which convert the earthquake vibrations into an electrical signal.

Structural vulnerability model
These describe the type and amount of damage that a particular type of structure may experience from a given hazard. They are typically represented as a series of curves which relate damage to a building, to characteristics of the hazard (e.g. tsunami wave height and speed). See also *Vulnerability* and *Community vulnerability model*.

Subduction zone
Collision boundary between two tectonic plates, where one plate is forced beneath the other. Large earthquakes can occur at the boundary between the two plates, and are capable of generating large tsunami.

Topography
The relief or terrain of the landscape.

Tsunameter

A deep ocean tsunami detection sensor

Tsunamigenic

1. Phenomena that generate a tsunami, e.g. undersea earthquakes;
2. Sedimentary deposit or other feature caused by a tsunami.

Vulnerability

The degree of susceptibility and resilience of the community (or individuals in a community) and environment (natural and built) to hazards. See also *Community vulnerability model* and *Structural vulnerability model*.

Wave propagation

Is any of the ways in which waves travel.

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