TSUNAMI HAZARD AND RISK IN NEW SOUTH WALES

Supplementary Document to the NSW State Tsunami Plan

January 2024

CONTENTS

FIGURES

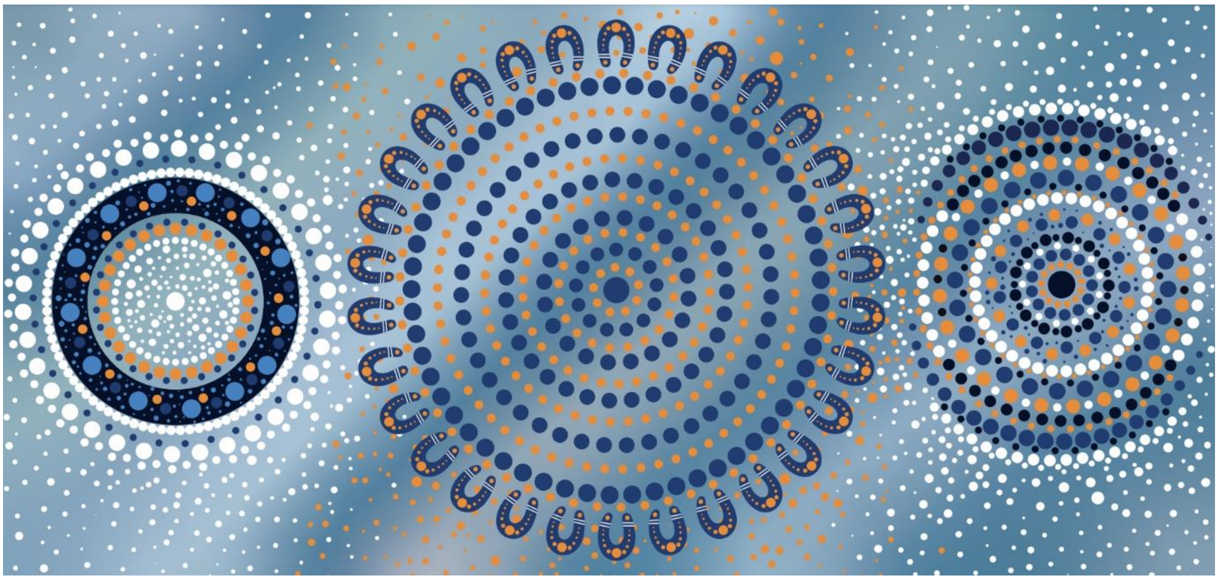
TABLES

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENT OF COUNTRY

The New South Wales State Emergency Service (NSW SES) acknowledges and pays respect to the traditional owners and custodians of the land on which we work, volunteer and live. NSW SES recognises the diversity of Aboriginal and Torres Strait Islander peoples and their ongoing culture and continued connection to lands, waters, and the greater communities throughout Australia.

NSW SES appreciates the value of traditional knowledge held by Aboriginal and Torres Strait Islander peoples and its significance in understanding Australia's natural landscape to perform the emergency management procedures detailed in this supporting document.



'Journey after the storm' by Lani Balzan

STATEMENT ON CLIMATE CHANGE

NSW SES understands that the effects of climate change will continue to increase the severity of disasters including storm, flood, and tsunami disasters and its impacts on life and property in NSW.

It is understood that the changes to natural climate processes, oceanic climate systems, temperatures, and weather pressure systems will affect the extremity of Australia's weather systems and ocean hazards. (1) The increased risk of severe thunderstorms and storm surges (1), flash flooding and large flood events (1), and the possibility of higher levels of tsunami inundation from sea level rise (2) have potential to have a higher impact on communities when they occur.

NSW SES in the management of flood, storm, and tsunami risk must consider the effects of climate change in all phases of Emergency Management. The NSW SES has an important role in planning, preparing for, responding to, and initiating recovery from the environmental impacts of severe weather-related incidents, emergencies, and disasters.

WHAT IS A TSUNAMI?

A tsunami is a series of ocean waves with very long wavelengths (typically hundreds of kilometres) caused by large-scale disturbances of the ocean, such as earthquakes, landslide, volcanic eruptions, explosions, or meteorites.

The following terminology is used when describing what a tsunami is and how it behaves:

- **Wave type:** Tsunami waves involve movement of all water from the seabed to the surface and differ to wind waves which only move the surface of the water (3). It is this volume of water under the surface, moving as part of a tsunami that generates larger force and subsequent damage.

- **Arrival:** Natural warning signs of an approaching tsunami may be provided by:
    - Ground shaking – this may be felt prior to a tsunami due to an earthquake.
    - Ocean withdrawal – depending on the direction the sea floor moves during the earthquake; the sea may appear to retreat from the coastline before returning with the first crest of a tsunami.
    - Roaring sounds – noise may be heard with tsunami wave arrival (4).

- **Behaviour**: Tsunamis usually involve multiple waves. The first wave may not be the largest. Tsunamis can wrap around headlands or islands and damage coasts which do not directly face the tsunami wave. Tsunamis impacting on harbours and bays can create damaging wave activity and currents (5).

- **Inundation and Run-up**: Tsunami inundation 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 funneling effects that increase the inundation area. The combination of these factors means that the inundation produced by a tsunami can vary greatly from place to place over a short distance. It also means that predicting the extent of inundation is exceedingly difficult. Run-up is defined as the highest point (maximum elevation) that becomes inundated by the tsunami (5).

- **Speed and Height:** Tsunami speed is dependent on water depth and wave period. In deep water and in the open ocean, tsunami waves can reach speeds of 900 kilometres per hour (3). Heights of tsunami waves in deep water are only slight and may go unnoticed by marine vessels. Tsunami waves increase in size and reduce speed as they approach the shore (known as shoaling). The first wave in the series may not be the largest (5).

- **Wavelength:** Tsunami waves are characterised by their long wavelength, which may be up to hundreds of kilometres between waves (or the wave crests) (3). The wavelength is the average horizontal distance between successive crests or troughs of a wave pattern. (6)

- **Wave period:** Wave period (or time between wave crests) is dependent upon the mode of propagation (relative velocity and magnitude of the disturbance, the water depth in which the wave is generated, and the volume of water displaced by the event generating the waves). The wave period usually lasts between a few minutes to a few hours (5) (3).

TSUNAMI GENERATION

A tsunami may be caused by any one or combination of the following:

- Vertical movement of the sea floor because of a large earthquake.
- Submarine or coastal volcanic eruptions.
- Meteor impacts.
- Coastal landslides and slumps, either land-based or sub-marine.
- Rapid changes in barometric pressure such as moving storm fronts; these are known as meteotsunamis.
- Any other major disturbances to ocean water columns that may cause a tsunami.

Earthquakes are the most common cause of tsunamis (3). However, not all earthquakes generate tsunamis.

To generate a tsunami, the fault where the earthquake occurs must be underneath or near the ocean, and the earthquake must cause significant vertical movement of the sea floor over a large area.

The most destructive tsunamis are generated from large, shallow earthquakes which usually occur in areas of tectonic plate subduction. (5)

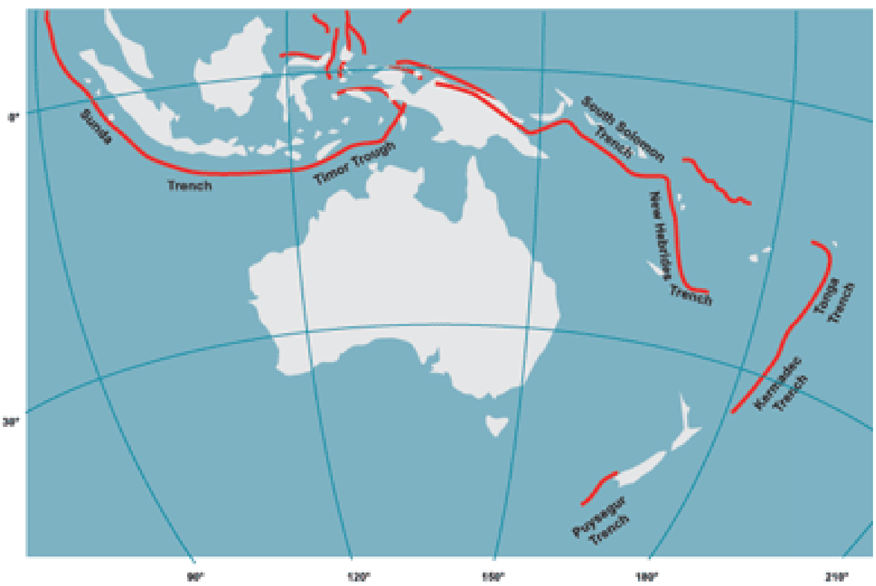
Tsunamis can be classified as either local, regional, or distant, depending on the distance of generation from the coastline (5):

a. **Local tsunamis** are generated close to the NSW coast. Time between generation and arrival can be around 20 minutes for submarine landslides, or as little as 5 minutes for coastal landslides. Hence it is unlikely that areas at the initial point of impact would receive any effective warning other than environmental signals, such as strong ground shaking, unusual rumbling noises, elevated water levels or drawdown at the coastline.

b. **Regional tsunamis** are generated within the southwest Pacific Ocean. Potential sources are in subduction zones along the Indian-Australian and Pacific tectonic plate boundary (Figure 1). This boundary runs through Macquarie Island, New Zealand, Tonga, Vanuatu, Papua New Guinea, the Solomon Islands, and the Kermadec Islands (1000 km northeast of Auckland). From these locations travel time to the NSW coast is in the order of 2 hours to several hours. The recent Tongan tsunami generated from a volcanic eruption in January 2022 is also considered from a regional source.

c. **Distant tsunamis** are generated by subduction zone boundaries as far away as North America, South America, and Asia or in divergent boundaries located between

Figure 1 - Subduction Zone



Subduction zone along tectonic plate boundaries (shown in red) around Australia that have the potential to generate a tsunami that may impact on Australia's coast. (31)

Australia and Antarctica. An example is tsunamis generated from earthquakes off the west coast of Peru. Travel time to the NSW coast may be in the order of several hours to days.

CONSEQUENCES OF TSUNAMIS

Destruction from tsunamis are the direct result of inundation, currents, waves, erosion, and debris impact on coastal structures.

Floatation and drag forces can move buildings and over-turn vehicles. Tsunami associated wave forces can demolish buildings. Considerable damage is also caused by debris, including boats, up-rooted vegetation, structural materials, and vehicles that are swept along by the force of the water. Even small tsunamis can generate currents strong enough to cause damage to boats and associated facilities. Destructive waves may continue for several hours, and several days may pass before the sea returns to its normal state (5).

The consequences of a tsunami can include:

a. Loss of life, often by drowning.

b. Inundation – damaging property, farmland, infrastructure, and roads (leading to a need for evacuation, property protection, and/or rescue).

c. Property damage or destruction (including vessels, buildings, and vehicles).

d. Infrastructure damage, particularly marinas, moorings, ports, and coastal infrastructure such as beach access, but also land-based infrastructure leading to loss of services and transport access - such as airports, roads, bridges, downed power and telephone lines, water, and sewerage.

e. Isolation of properties and/or communities due to flooding of access roads, with the additional risk of secondary emergencies (creating risk to life and the need for resupply and/or rescue).

f. Coastal erosion (including beaches and associated dunal systems) which may result in high unstable (near vertical) erosion escarpments and loss of sand that might lead to the undermining of infrastructure, building collapse or the trapping of persons.

g. Economic losses (for example impacts to maritime industries, local businesses, infrastructure loss, tourism, and agricultural damages).

h. Environmental losses, particularly in the coastal zone and the marine environment (for example impacts to water quality, soil erosion, animal habitat, cultural heritage, and generation of waste that is potentially hazardous.

i. Indirect effects such as disruption to community activities and ongoing psychological issues. The broader community can be affected by infrastructure damage, disruption of essential services and disruption to transport and shipping routes.

THE TSUNAMI HAZARD

NSW TSUNAMI SOURCES

Tsunamis are known to be generated by vertical movement of the sea floor caused by a large earthquake, sub-marine or coastal volcanic eruptions, meteor impacts, or coastal landslides and slumps, either land-based or sub-marine (5).

EARTHQUAKE SOURCES

The majority of tsunamis are caused by earthquake-induced movement of the seafloor typically along subduction zones of tectonic plate boundaries. This includes the world's largest tsunami caused by the 1960 Chile earthquake (moment magnitude, Mw, 9.5), the 1964 Alaska earthquake (Mw 9.2), the Sumatra–Andaman Islands earthquake of 26 December 2004 (Mw 9.1) and the Japan earthquake of 11 March 2011 (Mw 9.0).

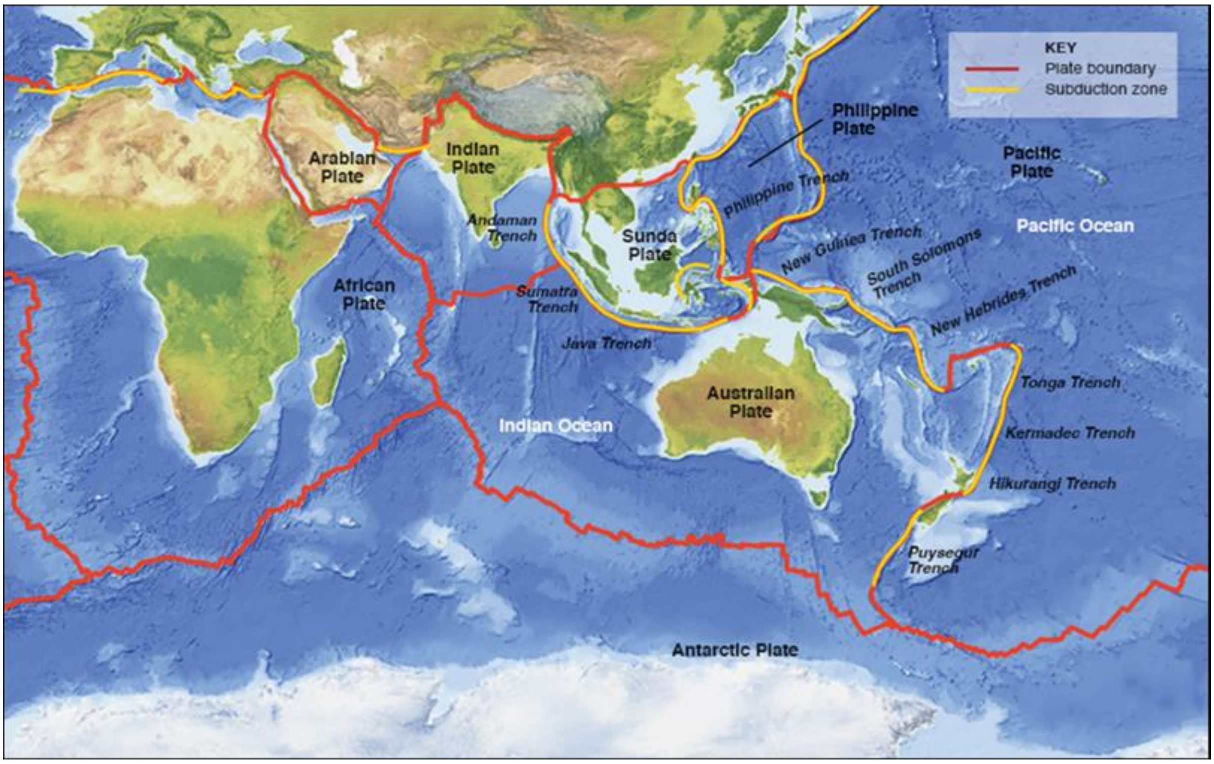
Smaller earthquakes can cause significant tsunamis as well; however, their impact tends to be more localised (7) (8).

At average recurrence intervals (ARIs) of above 500 years (unlikely events) only a few potential earthquake sources contribute to the tsunami hazard in NSW. These sources include the regional plate boundaries of the New Hebrides (Vanuatu), Kermadec and Puysegur (New Zealand) trenches. This is because only a few sources can generate tsunamis having a large near shore wave amplitude.

At an Average Recurrence Interval (ARI) of less than 100 years (possible events) however, many potential sources contribute to the tsunami hazard in NSW.

These include both regional and distant plate boundaries and include the regional subduction zones off New Hebrides (Vanuatu), Kermadec and Puysegur, as well as distant sources off Peru, Chile, and Indonesia (8).

Figure 2 - Tectonic Plate Boundaries



Location of Plate Boundaries and Subduction Zones (supplied by Geoscience Australia)

VOLCANO SOURCES

There are at least five active volcanoes capable of generating a tsunami that could affect Australia. The Krakatau eruption, in Indonesia, of 26–27 August 1883 generated a tsunami that affected Australia and is recorded in the NSW record. 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 (8).

The Hunga Tonga-Hunga Ha'apai volcano (near Tonga) erupted on 15 January 2022, resulting in tsunami waves to impact Tonga. (9) The size of these waves also resulted in a marine threat warning to Australia's east coast, and a land threat warning to Lord Howe Island and Norfolk Island. (9) There were no significant impacts to Australia.

LANDSLIDE SOURCES (LAND AND SUBMARINE)

Tsunamis caused by submarine landslides tend to be more localised. However, major submarine landslides have potential to generate giant tsunamis that can devastate coastal regions even thousands of kilometres away from its origin.

Off the NSW coast, numerous submarine landslide scars can be seen on the continental slope, with several significant ones lying adjacent to Sydney (8).

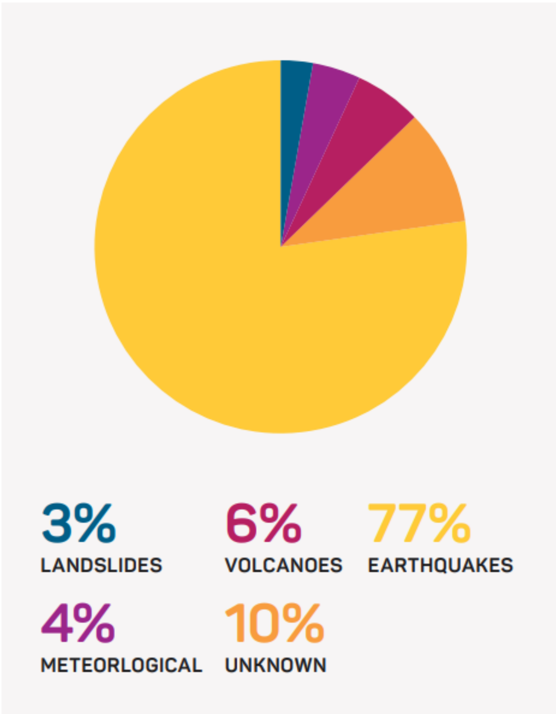
One of the largest landslides occurred off Bulli (near Wollongong) and was 10km wide and 20km long and is considered large enough to have generated a significant local tsunami (8). Clarke et al. (2014) examined morphologic characterisation of five distinct, eastern Australian upper continental slope submarine landslides and modelled their tsunami hazard (10).

Their analysis suggests that the reoccurrence of submarine landslides with similar characteristics to those in the recent past would be expected to generate a tsunami with a run-up of up to 5m and inundation distances of up to 1km (8).

METEORITE SOURCES

Tsunamis can also be generated by meteorite impact on the ocean. Modelling completed in 2000, extrapolated to NSW suggests the return period for a meteorite-generated tsunami with a wave amplitude of 1m at a water depth of 15m is approximately one thousand years (unlikely). However, several other recent studies suggest this may be too frequent and an ARI for an event this size may be more likely to be around 10,000 years (rare) (8).

Figure 3 - Historical Sources



Tsunami event sources based on historical tsunami event database. (33)

TSUNAMI HISTORY

Over fifty incidents of tsunamis have been recorded in Australia's written history (11), although many have been too small to produce noticeable effects.

At least 7 marine-threat tsunamis originating from earthquakes and 1 from a volcanic source have impacted NSW since 2007. These include earthquake-sourced tsunamis occurring in the Solomon Islands (2007), Puysegur (2009), Chile (2010), Japan (2011), New Hebrides (2021), Kermadec (2021), New Hebrides (2023), and a volcano-sourced tsunami occurring in Tonga (2022). (12).

The most recent land-threat tsunami occurring in NSW was recorded at Lord Howe Island in January 2022 from a tsunami generated from a volcanic eruption in Tonga.

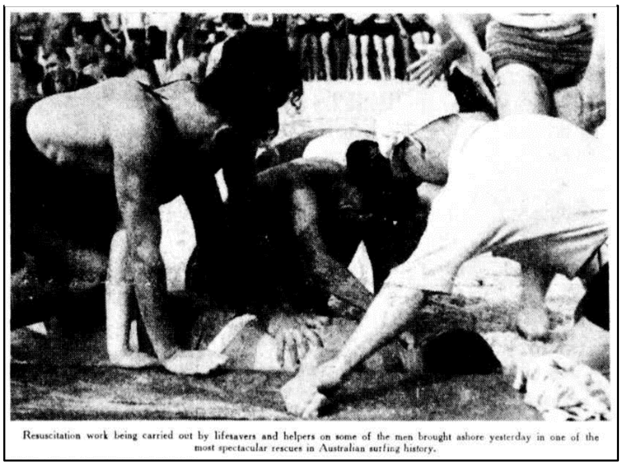
A notable tsunami impact on the NSW coast also occurred in Eden in 1960. The maximum run-up for this tsunami was 1.71m at Eden which was generated from the Chilean earthquake (13). Resulting damage was limited primarily to vessels and moorings, as well as the local oyster industry which suffered some losses. There were two unconfirmed reports of minor injury and some reports of people having to flee beaches and tidal rock shelves, indicating that the tsunami event did create a risk to life (13).

Other historic records have indicated potential tsunami impact on the NSW coast. For example, the Black Sunday event of February 1938 at Bondi Beach may have been tsunami generated by a localised submarine landslide, although this has not been verified. (4). The event produced several large waves in quick succession, with waves reported on adjacent beaches. Reports at the time indicated that around 250 people required assistance with 35 near drownings and 5 fatalities (14).

Geological studies (8) also suggest that tsunamis have impacted along the NSW coast, with the oldest event dated at 105,000 years ago and reported to have been generated by submarine sediment slides off Lanai, Hawaii. The six youngest paleo-tsunami events all occurred during the Holocene (10,000 years ago).

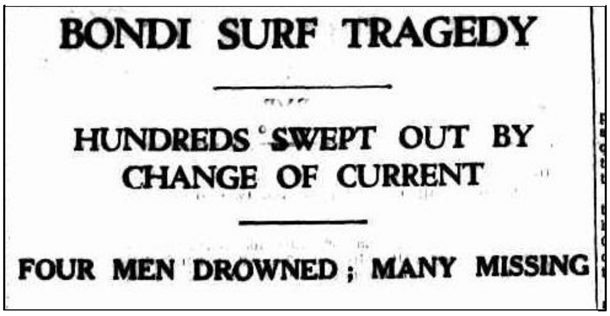
The maximum run-up for a paleo-tsunami is reported at possibly as much as 130 m above sea level at Steamers Beach, Jervis Bay, NSW, while another event is reported to have inundated the coast to distances of 10 km inland. There is scientific conjecture about evidence supporting paleo-tsunamis and the accuracy of these records.

Figure 4 - BONDI DEATH WAVE



1938 'BONDI DEATH WAVE', The Canberra Times (29)

Figure 5 - BONDI SURF TRAGEDY



BONDI SURF TRAGEDY

HUNDREDS SWEPT OUT BY CHANGE OF CURRENT

FOUR MEN DROWNED; MANY MISSING

1938 'BONDI SURF TRAGEDY', The Canberra Times (30)

TSUNAMI HAZARD ASSESSMENT

In 2008 Geoscience Australia (GA) completed an Offshore Probabilistic Tsunami Hazard

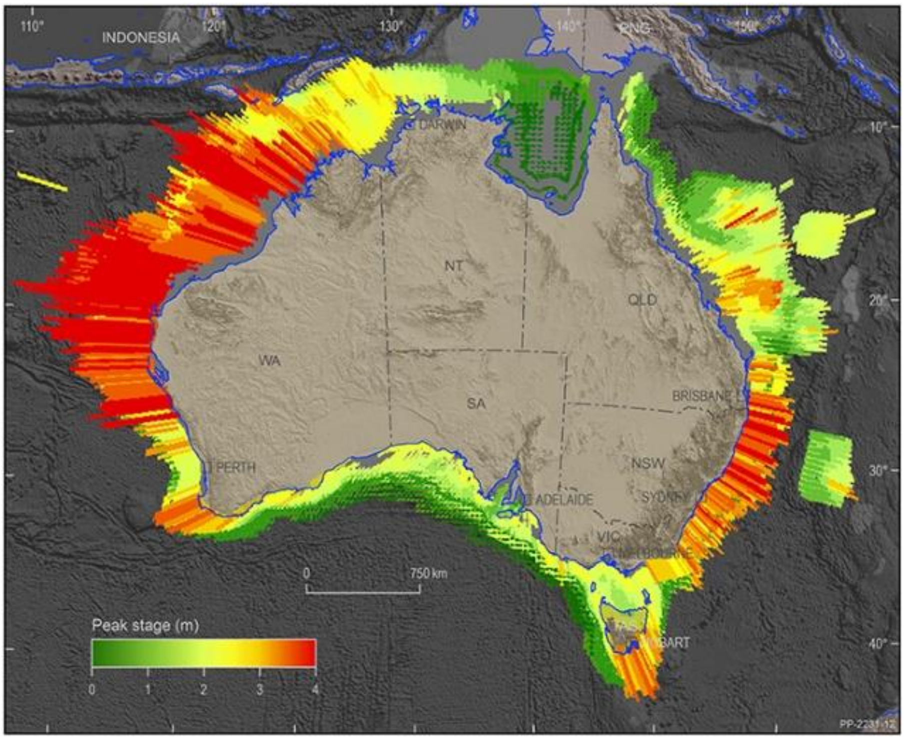
Assessment (OPTHA). The OPTHA estimated the likelihood of a tsunami wave of a given height occurring at offshore locations (100m water depth). Results indicated that the highest offshore hazard is in the northwest of Western Australia (WA).

Offshore hazard on the eastern and northern coasts of Australia is significantly less than the northwest of WA (4). NSW is considered to have a moderate hazard and is similar along the entire coast for a 2000-year (unlikely) ARI (15).

The PTHA18 provides modelled tsunami data that can be used for detailed analysis of locations around the Australian coast and across its offshore islands and territories. (17)

PTHA18 provides an analysis of offshore tsunamis, focusing on the inundation hazard of sites of interest. It does not define the onshore tsunami impact, nor the effects of tsunamis on communities. It is also exclusive to earthquake sources and does not include other sources that can cause a tsunami, such as landslides, volcanic activity, or meteorological events (17).

Figure 6 - Hazard Assessment



Probabilistic Tsunami Hazard Assessment (PTHA18) (32)

For each offshore location, data exists for: (17)

- Hazard curves (stage vs exceedance probability).
- Hazard disaggregation for scenarios and exceedance rates.
- Time series for each possible scenario at that site.
- Initial ocean uplift/subsidence for each scenario.

On average tsunami wave heights at the 20m water depth are twice that at the 100m water depth. (16)

In 2018, GA developed the 2018 Australian Probabilistic Tsunami Hazard Assessment (PTHA18) to better understand Australia's tsunami hazard due to subduction earthquakes in the Pacific and Indian Oceans.

TSUNAMI RISK AND VULNERABILITY

TSUNAMI RISK ASSESSMENT

GA has previously undertaken detailed tsunami inundation modelling for Batemans Bay and several sites in the Gosford area.

The NSW SES and Office of Environment and Heritage also commissioned additional studies to build on the tsunami understanding for NSW. These include:

a. Development of Information for a Tsunami Risk Assessment of the NSW Coast 2008 (18).
b. NSW Tsunami Inundation Modelling and Risk Assessment 2013 (report, figures, appendix) (19).

The report on Development of Information for a Tsunami Risk Assessment of the NSW Coast 2008 summarised knowledge on tsunami sources and history and provided a general assessment of tsunami risk on the NSW coast.

The study identified NSW as having moderate tsunami hazard level and suggested sites for future inundation modelling based on a broad-based risk assessment methodology incorporating offshore hazard levels, coastline shape and elevation-based address data (15).

Key findings of the NSW Tsunami Inundation Modelling and Risk Assessment 2013 (19):

a. NSW coast has a medium exposure to tsunami (local and regional context).
b. Calibrations found that the modelling reasonably simulates historical tsunami and replicates inundation extremely well.
c. Tides were not found to influence wave shoaling (the increase in height as the tsunami approaches the shore) but do affect wave crest levels and run-up.
d. Embayment (coastal bay) shape was found to have less influence than it was previously though to.
e. Land inundation becomes significant, particularly at the (unlikely) 1,000-to-2,000-year ARI level (and greater).
f. There was potential of inundation and exposure of people and property even at the lowest ARIs examined (likely 200-year ARI) particularly at Swansea.
g. Low lying estuary foreshores are more vulnerable.

a. Further research is required (including further investigation of tsunami impacts in estuarine areas).

The NSW Tsunami Inundation Modelling and Risk Assessment 2013 study (19) produced inundation modelling for five sites identified as being potentially more vulnerable to tsunami:

a. Swansea / Lake Macquarie
b. Manly
c. Botany Bay / Cronulla / Kurnell
d. Wollongong / Port Kembla
e. Merimbula

The study considers the areas of 'high hazard' to allow for an improved understanding of the tsunami risk to the NSW coastline, enabling future consideration of tsunami impacts in coastal zone management and planning. (19)

The study recommended that further work be undertaken to consider other potential tsunami sources, tsunami behaviour within estuarine / coastal river systems, and coastal vulnerability based on the information provided in the study to improve current vulnerability rankings of those identified sites. (19)

The Bureau of Meteorology (the Bureau) have compared potential tsunami warnings issued by the Joint Australian Tsunami Warning Centre (JATWC) against the inundation modelling results in the 2013 report, with particular focus on the JATWC's pre-defined warning threshold levels. The results at the time indicated that the thresholds used by the JATWC warning scheme have been in general set conservatively and should not be modified on the basis of these results alone (8). Further research on tsunami threshold levels will be continued by JATWC.

JATWC warnings do not include mapped areas that may be inundated as a result of tsunamis. In 2023, Geoscience Australia proposed to undertake spatially extensive earthquake-tsunami inundation modelling for the NSW coast, in partnership with the NSW SES. The modelling will correspond with JATWC marine-threat and land-threat categories against a range of earthquake scenarios and be used by the NSW SES to define actionable zones.

Whilst known historical impact of tsunami inundation in NSW has been relatively minor, and generally restricted to marine based events, the modelling of selected earthquake-generated events indicates the potential for land inundation, particularly at high (unlikely) return periods. Low lying populated communities around estuary foreshores are particularly at risk, although results also indicate there is potential for inundation of open coast sites at very high (rare) return periods (8).

TSUNAMI COMMUNITY VULNERABILITY

Tsunami vulnerability is greatest between Wollongong and Newcastle, due to the high population density in this area. Vulnerability is also likely to be greatest in many regional areas of the NSW coast during the summer months, especially during the school holiday period from December through to the end of January (5).

Both marine, land-based assets and coastal populations are vulnerable to tsunamis. It is likely that all significant tsunamis will affect marine based assets and populations, whilst larger tsunamis will cause damage to land-based assets and populations. The JATWC warnings are based on land or marine threats.

WARNING AND ARRIVAL TIMES

Further information on the development of tsunami warnings systems and the issuing of associated warning products for NSW can be found in *Tsunami Warning Arrangements* (a supplementary document to the NSW State Tsunami Plan).

Tsunami warning and arrival times are dependent on both tsunami proximity and source.

Examples include:

- **Local Sources** – Travel time from a local source could be within minutes.
- **Regional Sources** - Travel time from regional sources to the NSW coast varies but is in the order of several hours.
- **Distant Sources** - Travel time from distant sources to the NSW coast varies but is in the order of several hours to days.

Lord Howe Island will generally have shorter warning time than the NSW coast for tsunamis generated closer to the island than the NSW coast (5).

Figure 7 - Lord Howe Island

Table 1: Number of addresses (GURAS) located within modelled tsunami inundation extents.

ARI	Post Code							
	2281	**2095**	**2231**	**2230**	**2500**	**2505**	**2548**	**2549**
	Reference							
	Swansea	**Manly**	**Kurnell**	**Cronulla**	**Wollongong**	**Port Kembla**	**Merimbula**	**Pambula**
200	428	100	68	386	0	3	80	1
500	1158	262	97	476	0	4	369	1
1000	2121	479	236	625	12	7	465	1
2000	2974	1867	321	836	74	7	667	4
5000	3956	4686	485	1884	259	7	738	5
10000	4271	8515	556	2630	943	8	1179	8

Current to 2018 (19). GURAS is the NSW Geo-coded Urban and Rural Address System which may contain multiple points for cadastral land parcels (e.g. for multi-storey buildings).

Table 2: Examples of land and marine based assets and users vulnerable to tsunamis.

Marine Based Assets and Users	Land Based Assets and Users
• Boats and their crew in shallow water. • Beach and rock platform users, including swimmers, surfers, sunbathers, and fishers. • Divers and snorkelers. • Aquaculture industries. • Submarine power, telecommunications, fuel, and water supply lines. • People and facilities in ports, harbours, and marinas. • Boat ramps and jetties. • Sewerage outfalls. • Coastal infrastructure such as seawalls, groynes, training walls and ocean promenades.	• People and property in caravan parks and camping areas in low-lying coastal areas or on floodplains in tidal river areas. • Coastal infrastructure including roads, bridges, power, water, gas, sewerage, and telecommunications. • Residential, commercial, and industrial buildings and their occupants in low-lying coastal areas or on floodplains in tidal river areas. • Motorists and vehicles on low-lying coastal roads. • Low-lying coastal farmland including animals and crops. • Institutions such as schools and hospitals located in low-lying coastal areas. • Walkers in coastal parks and reserves.

Table 3: Possible Vulnerable Population in NSW (2021 census) within 1km of coast and below the 10m contour height (AHD).

	Total Population	Dwellings	No Vehicle at Dwelling	Schools / Childcare Centres	Children Aged 14 and under	Public / Private Hospitals	Aged Care / Nursing Homes	Age >= 65	Caravan Park / Camping Grounds
Byron Coast (Tweed Heads – Wolli)	118,101	61,915	3,281	48	20.195	6	28	28,226	69
Coffs Coast (Wolli – Jerseyville)	59,065	29,425	1,589	30	11,458	2	26	14,470	37
Macquarie Coast (Jerseyville – Seal Rocks)	61,833	35,249	1,938	30	7,914	4	22	19,415	58
Hunter Coast (Seal Rock – Bouddi)	210,595	107942	5,397	73	37,486	4	38	47,383	81
Lord Howe Island	445	199	33	1	73	1	0	105	0
Sydney Coast (Bouddi – Bundeena)	520,032	242,701	25,240	172	104,526	8	58	87,885	17
Illawarra Coast (Bundeena – Ulladulla)	112,164	59,144	3,489	47	19,740	2	20	23,330	69

Batemans Coast (Ulladulla – Narooma)	16,827	10,817	389	9	1,985	2	4	4,308	20
Eden Coast (Narooma – Eden)	8,068	5,273	174	3	903	0	0	1,904	25
NSW Total	1,107,130	552,665	41,530	413	204,280	29	196	227,026	376

Note: Figures quoted are approximate. The modelling used for these figures does *not* extend 10km upstream in coastal estuaries and rivers. There may be additional areas impacted that are adjacent to tidal rivers or estuaries further than 1km from the coast.

The following table lists arrival times for five modelled sites in NSW.

Table 4: Summary List of Modelled Tsunami Scenario Arrival Times (19)

Average Reoccurrence Interval (ARI)	SOURCE	TIDE	Tsunami Arrival Time (hours:mins)				
			Site				
			Lake Macquarie	Manly	Botany Bay	Wollongong Port Kembla	Merimbula
200 (possible*)	Kermadec (1000km NE of NZ)	HAT	04:37	04:36	04:36	04:41	04:46
200	New Hebrides	HAT	03:50	03:54	03:56	04:14	04:18
200	**Puysegur, NZ**	**HAT**	**02:40**	**02:38**	**02:34**	**02:31**	**02:27**
200	South Chile	HAT	14:04	14:02	14:00	13:57	13:41
200	Tonga	HAT	05:15	05:21	05:23	05:40	05:48
500 (unlikely)	Kermadec	HAT	04:35	04:33	04:34	04:39	04:44
500	New Hebrides	HAT	03:46	03:49	03:51	04:00	04:15
500	**Puysegur**	**HAT**	**02:31**	**02:31**	**02:31**	**02:27**	**02:20**
500	Tonga	HAT	05:09	05:10	05:10	05:17	05:32
1000 (unlikely)	Kermadec	HAT	04:33	04:32	04:34	04:38	04:43
1000	New Hebrides	HAT	03:44	03:48	03:50	03:57	04:12
1000	**Puysegur**	**HAT**	**02:29**	**02:29**	**02:28**	**02:27**	**02:19**
2000 (unlikely)	Kermadec	HAT	04:32	04:31	04:33	04:37	04:42
2000	New Hebrides	HAT	03:43	03:46	03:48	03:56	04:11
2000	**Puysegur**	**HAT**	**02:29**	**02:27**	**02:27**	**02:26**	**02:18**
2000	Kermadec	MSL	04:32	04:31	04:33	04:37	04:42
2000	New Hebrides	MSL	03:43	03:46	03:48	03:56	04:11
2000	**Puysegur**	**MSL**	**02:29**	**02:27**	**02:27**	**02:26**	**02:18**
5000 (rare)	New Hebrides	HAT	03:42	03:44	03:47	03:54	04:10
5000	**Puysegur**	**HAT**	**02:28**	**02:27**	**02:26**	**02:26**	**02:17**
5000	New Hebrides	MSL	03:42	03:44	03:47	03:54	04:10
5000	**Puysegur**	**MSL**	**02:28**	**02:27**	**02:26**	**02:26**	**02:17**
10000 (very rare)	New Hebrides	HAT	03:40	03:43	03:46	03:52	04:09
10000	**Puysegur**	**HAT**	**02:28**	**02:26**	**02:26**	**02:25**	**02:17**

* Likelihood levels are from the National Emergency Risk Assessment Guidelines (20)
HAT = Highest Astronomical Tide, MSL = Mean Sea Level.

APPENDIX A - REFERENCES

1. **Adapt NSW.** Climate change impacts on storms and floods. *Adapt NSW.* [Online] 2023. https://www.climatechange.environment.nsw.gov.au/storms-and-floods.

2. **Australian Government.** Tsunamis. *Australian Climate Service.* [Online] 2023. [Cited: October 25, 2023.] https://www.acs.gov.au/pages/tsunamis#link3.

3. **Bureau of Meteorology.** Tsunami Frequently Asked Questions. *Bureau of Meteorology.* [Online] 2014. [Cited: 07 23, 2014.]

4. **Attorney-General's Department.** *Tsunami Emergency Planning in Australia.* s.l. : Attorney-General's Department, 2010.

5. **NSW State Emergency Service.** *Tsunami Emergency Sub-Plan.* 2008.

6. **Bureau of Meteorology.** Bureau of Meteorology Glossary of Terms. *Australian Government Bureau of Meteorology.* [Online] 2014. http://www.bom.gov.au/tsunami/info/glossary.shtml.

7. **USGS.** Earthquakes. *USGS.* [Online] [Cited: August 12, 2013.] http://earthquake.usgs.gov/earthquake/eqinthenews/2011/usc0001xgp.

8. *Progress Towards an Understanding of Tsunami Risk in NSW.* **Andrews, F., Beadle, C., Davies, B., Frazer, A., Garber, S., Greenslade, D., Hanslow, D., Horspool, N., Kuster, N., Opper, S., and Treloar, D.** 2013.

9. **Bureau of Meteorology.** Tsunami warnings issued for parts of east coast, Norfolk, Lord Howe and Macquarie Islands. *Australian Government Bureau of Meteorology.* [Online] January 15, 2022. [Cited: October 13, 2023.] https://media.bom.gov.au/releases/924/tsunami-warnings-issued-for-parts-of-east-coast-norfolk-lord-howe-and-macquarie-islands/.

10. *Morphology of Australia's Eastern Continental Slope and Related Tsunami Hazard.* **Samantha Clarke, Thomas Hubble, David Airey, Phyllis Yu, Ron Boyd,.** s.l. : Springer International Publishing Switzerland 2014, 2014.

11. **Bureau of Meteorology.** Past Tsunami Events. *Bureau of Meteorology.* [Online] 2018. http://www.bom.gov.au/tsunami/history/index.shtml.

12. **Davies, Gareth.** NSW Coast Tsunami Inundation Modelling Project. *Australian Government Geoscience Australia.* s.l. : Geoscience Australia, 2023.

13. **NSW State Emergency Service.** *Measurements and Impacts of the Chilean Tsunami of May 1960 in NSW Australia.* 2009.

14. **Waverley Library.** Waverley Library Black Sunday. *Waverely Library.* [Online] [Cited: 07 18, 2014.]

15. **Burbidge, D., Mleczko,R., Thomas, C., Cumminis,P., Nielsen, O., Dhu, T.** *A Probabilistic Tsunami Hazard Assessment for Australia. Geoscience Australia Professional Opinion No.2008/04.* 2008.

16. *A Nearshore Tsunami Hazard Assessment for Australia. Geoscience Australia Professional Opinion. No.2009/06.* **Fountain, L, Van Putten, K., Griffin, J., Hingee, M., Wilson, R., Burbidge.** 2009.

17. **Geoscience Australia.** Data product - Probabilistic Tsunami Hazard Assessment (PTHA). *Australian Government Geoscience*

Australia. [Online] 2021. [Cited: October 4, 2023.] https://www.community-safety.ga.gov.au/data-and-products/ptha.

18. **Risk Frontiers, Macquarie University.** *Development of Information for a Tsunami Risk Assessment of the NSW Coast.* 2008.

19. **Cardno Pty Ltd.** *NSW Tsunami Inundation Modelling and Risk Assessment.* 2013.

20. **National Emergency Management Committee.** *National Emergency Risk Management Guidelines.* 2010.

21. **Bureau of Meteorology.** Records of Tsunamis affecting Australia. [Online] [Cited: 07 18, 2014.]

22. —. Bureau of Meteorology Glossary of Terms. *Australian Government Bureau of Meteorology.* [Online] Bureau of Meteorology. [Cited: 07 14, 2014.]

23. —. Tsunami Facts and Information. *Australian Government Bureau of Meteorology.* [Online] Bureau of Meteorology. [Cited: 07 14, 2014.]

24. **Australian Bureau of Statistics.** Lord Howe Island 2021 Census All persons QuickStats. *Australian Bureau of Statistics.* [Online] 2021. [Cited: October 13, 2023.] https://abs.gov.au/census/find-census-data/quickstats/2021/10803.

25. —. Mid North Coast 2021 Census All persons QuickStats. *Australian Bureau of Statistics.* [Online] 2021. [Cited: October 13, 2023.] https://abs.gov.au/census/find-census-data/quickstats/2021/108.

26. —. Hunter Valley exc Newcastle. *Australian Bureau of Statistics.* [Online] 2021. [Cited: October 13, 2023.] https://abs.gov.au/census/find-census-data/quickstats/2021/106.

27. *Cosmogenic mega-tsunami in the Australia region: are they supported by Aboriginal and Maori legends?* **Bryant E.A., Walsh G., Abbott D.** Wollongong : University of Wollongong, 2007.

28. —.**Bryant E.A., Walsh G., Abbot D.** Wollongong : University of Wollongong, 2007.

29. **The Sun.** BONDI DEATH WAVE. *National Library of Australia.* [Online] The Sun, February 7, 1938. [Cited: November 8, 2023.] https://trove.nla.gov.au/newspaper/article/231117390.

30. **The Canberra Times.** BONDI SURF TRAGEDY. *National Library of Australia.* [Online] The Canberra Times, February 7, 1938. [Cited: November 8, 2023.] https://trove.nla.gov.au/newspaper/article/2451810.

31. **Bureau of Meteorology.** Australian Tsunami Warning System. *Australian Government Bureau of Meteorology.* [Online] 2023. [Cited: November 23, 2023.] http://www.bom.gov.au/tsunami/about/atws.shtml.

32. **Geoscience Australia.** Probabilistic Tsunami Hazard Assessment (PTHA). *Geoscience Australia.* [Online] 2023. [Cited: November 24, 2023.] https://www.community-safety.ga.gov.au/data-and-products/ptha.

33. **Australian Institute for Disaster Resilience.** *Tsunami Emergency Planning in Australia Handbook.* East Melbourne : Australian Institute for Disaster Resilience, 2018.