TSUNAMI IN NSW – THE CHILEAN WAVES OF 1960

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Abstract

An search was undertaken to examine the history of the tsunami of the 23rd and 24th of May 1960 which impacted the New South Wales (NSW) Coast. A more detailed account of the tsunami has been presented than was previously available.

The observed characteristics of the tsunami varied widely based on location although in all instances the tsunami's greatest effects did not occur until many hours after it first arrived. Wave amplitudes of up to 0.85m were recorded and potentially reached much higher, up to 4.3m in isolated locations. Damage was limited primarily to vessel moorings, although the oyster industry did suffer 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 did create a risk to life along the coast of NSW. Implications of this research on modern risk assessment for the state are examined.

Introduction and Background

The Indian Ocean Tsunami of 2004 has prompted a worldwide, and particularly in Australia, surge of interest and research into the tsunami hazard. Most recent Australian research has focussed on cataloguing previous tsunami (Allport and Blong 1995; Dominey-Howes 2007), hazard definition and risk assessment (Rynn and Davidson 1999; Nielsen et al. 2006), development of warning systems (Allen and Greenslade 2008) and the emergency management of tsunami (Bird and Dominey-Howes 2006; Gissing et. al. 2008; Opper and Gissing 2005). Aside from research examining paleo-tsunami (Dominey-Howes et al. 2006; Glikson 2006; Bryant and Nott 2001; Young et al. 1997) little published work details the effects of tsunami on the Australian coastline in modern times. Whilst the number and magnitude of tsunami events affecting the eastern seaboard of Australia has been small, a study of one such event could assist tsunami researchers and emergency managers in model calibration, risk assessment and community education. Research into the 1960 tsunami in Hilo, Hawaii, identified numerous issues crucial to successful tsunami risk mitigation and demonstrated the usefulness of personal accounts in tsunami research (Johnston 2003; Dudley et al. in review). This research presents a case study of one such historical event.

This research was limited to the tsunami impact. Aspects relating to warning and the emergency management response were not researched though some aspects of the community response will be discussed.

The Tsunami Risk in New South Wales

All estuarine and other low lying coastal areas may be at risk of a tsunami. Local, regional and distant tsunami may impact NSW.

Due to the remoteness from tectonic plate boundaries local tsunami would most likely be generated by submarine landslides. Bathymetric surveys have found numerous slope failures along the margin of the continental shelf and areas with potential for future slope failure, some of which are adjacent to major coastal population centres. (Glenn et al. 2008).

Regional tsunami that could have a destructive impact on NSW may be generated on a number of subduction zones in the South West Pacific. These are the New Hebrides Trench, the Tonga-Kermadec Trench north of New Zealand, and the Puysegur Trench south of New Zealand (Working Group on Tsunami to the Prime Minister's Science, Engineering and Innovation Council 2005).

NSW is also exposed to numerous distant tsunami sources including South and Central America, Cascadia, the Aleutian Islands and Japan. Since European colonisation it is the Peru-Chile Trench that has generated the majority of the largest tsunami measured along the NSW coast.

New South Wales is a coastally oriented state with a large portion of the population using coastal areas for residence, employment or recreation. As an indication of the vulnerability to coastal hazards, including tsunami, within 1km of the coast and below about 10m above mean sea level, there are:

- A population of 328,800 (5.2% of the State's population). This population grows significantly during the summer holidays with many holidaymakers visiting the coastal fringe including up to 220,000 beachgoers during peak holiday periods.
- 160,700 dwellings.
- 225 caravan parks and camping grounds.
- 308 educational and child care facilities.
- 9 hospitals.
- 56 aged care facilities.

(New South Wales State Emergency Service 2005; Surf Life Saving NSW 2008)

The location of these elements combined with a low perceived risk of tsunami (Bird and Dominey-Howes 2006) leads to a very high vulnerability of coastal communities to this hazard.

Historical Evidence of Tsunami in New South Wales

Historical records and research into paleotsunami have identified 44 individual tsunami events that have been recorded in NSW between 105,000 years BP and June 2006 (Dominey-Howes 2007). The majority of tsunami that have occurred since European colonisation of NSW have been barely noticeable, recorded only on tide gauges. Four notable events have impacted NSW in this time period. The Chilean Earthquake Tsunami of 14th of August 1868 was recorded in Newcastle and Sydney where a number of boats broke from their moorings. In 1877 a tsunami with its source in North Chile caused some tidal fluctuations and minor disturbances in Sydney and Newcastle harbours. The tsunami caused by the eruption of Krakatau on the 27th of August 1883 was also observed in Sydney and Newcastle though no damage was reported. (Allport and Blong 1995).

The Tsunami of May 1960 was chosen for this research to assist emergency planners to better understand the potential effects of tsunami upon the NSW coastline. The 1960 tsunami is also the only tsunami within living memory of NSW residents which had significant impacts, making it the most suitable event to investigate because of the potential for acquiring additional data from personal observations.

The Chilean Tsunami of 23rd May 1960

The tsunami was caused by a 9.5Mw earthquake which occurred at 1911 UTC on the 22nd May (0511 on the 23rd of May AEST) off the coast of southern Chile. This was the largest earthquake that has been instrumentally recorded and was preceded by 4 earthquakes of magnitude 7Mw or greater and followed by many aftershocks. Over 1000km of fault line was ruptured by this series of earthquakes. These earthquakes occurred along the Peru-Chile Trench an active subduction zone with significant historical seismicity. Extensive damage was caused in southern Chile with estimates of casualties due to the earthquake and tsunami ranging from 470 to 5700 people. The Chilean government estimated that over 2,000,000 people were left homeless, 58,622 homes were completely destroyed and that at least US$500 million of damage was caused (1960 values), areas of shoreline were permanently altered by subsidence and the Puvehue volcano erupted 47 hours after the main shock (NOAA/NGDC 2006).

The tsunami caused by this earthquake was noted on shorelines throughout the Pacific basin. Damage was particularly severe in the Hawaiian Islands where, despite the operation of an official warning system, there were 61 deaths and US$23 million in damage (1960 values). The worst hit area was Hilo, which had been previously devastated by the 1946 Alaskan tsunami. It was struck by a 35 foot (10.7m) bore (NOAA/NGDC 2006; Johnston 2003; Dudley and Lee, 1998; Cox and Mink 1963). Japan was struck by waves up to 6m high which caused 199 deaths and US$50 million in damage (NOAA/NGDC 2006).The tsunami was also noted in the Samoa and Cook Islands and in French Polynesia, where wave run-ups of up to 3.4m were reported on Tahiti (Keys 1963; Vitousek 1963).

In New Zealand wave run-ups of up to 4.5m occurred and there was damage to many boats and harbour facilities, some land inundation and losses of livestock (de Lange and Healy 1986). In addition to the impacts in New South Wales the tsunami was also noted in other Australian locations including Cairns, Townsville, Mackay, Urangan, Brisbane and Coolangatta in Queensland, Wilsons Promontory in Victoria, Hobart in Tasmania, Port Macdonnell in South Australia and Freemantle in Western Australia. (Allport and Blong 1995) The location of the earthquake, observed run-ups and the study area are shown in Figure 1.

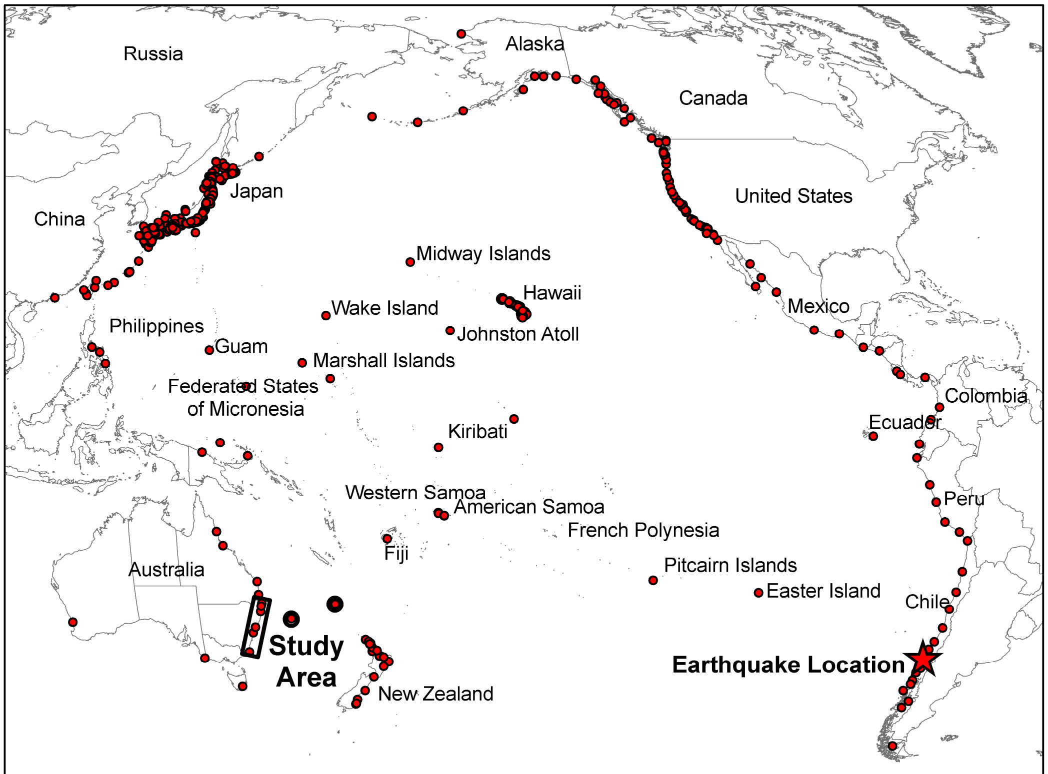

Figure 1: The Pacific Tsunami of May 22nd 1960, Runup Locations. (NOAA/NGDC, 2006)

Methodology

An extensive search was conducted for material and oral histories which contained mention of the tsunami. A search of newspapers in coastal New South Wales held by the NSW State Library was conducted for the issues including and immediately following the 24th of May 1960. Material from the NSW State Archives was also searched. Historical societies, museums and local studies libraries in coastal areas were contacted. The State Emergency Service also issued a media release seeking accounts of the tsunami from the public. Articles were published in 5 newspapers, in Manly, and on the South Coast, and there were numerous radio interviews asking for people to provide accounts or records of the event.

Other organisations contacted include the Royal Australian Navy, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Marine and Atmospheric Research, Bureau of Meteorology National Tidal Centre, NSW Department of Primary Industries – Aquaculture, NSW Farmers Association Oyster Committee, National Archives, Australian Hydrographic Service and Manly Hydraulics Laboratory.

Descriptions of the tsunami and its effects were recorded, ascribed to a location and assigned an accuracy and confidence score. The observations were analysed to extract information on the characteristics of the tsunami and any damage that was caused. The amplitude of the tsunami was estimated based on the types of observation given. For observations reported as a crest to trough height or an observed rise or fall the amplitude was taken to be half of the observed value. For observations of a wave, bore or where the tsunami height was reported as the peak to the predicted tide stage, the amplitude was taken to be the same as the observed value.

Observations that came from visual estimation were assigned low accuracy. Observations with a reported methodology which would allow some form of validation were assigned a medium accuracy. Where the observation was measured using a methodology that is generally accepted as providing accurate measurements of tsunami amplitude it was assigned high accuracy.

An observation of damage or impacts that could not be directly attributed to tsunami behaviour was assigned very low confidence. A single isolated observation that came from a personal account was assigned low confidence. An observation that was quoted in the media at the time was assigned medium confidence. Where there were multiple independent observations of the same location, or where the observation was recorded by some type of equipment it was assigned high confidence.

An attempt was also made to locate tide gauge records, in order to resolve discrepancies between various published databases (NOAA/NGDC 2006; Dominey-Howes 2007) and obtain other information regarding the onset, period and maximum wave amplitude of the tsunami at various locations. It was determined that the following tide recorders were in operation in NSW at the time (Hamon 1963):

Gauge Name	**Owner/Operator**
Lord Howe Island	Department of Civil Aviation
Richmond River Entrance, Ballina, NSW	Public Works Department (PWD)
Clarence River Entrance	PWD
Coffs Harbour	PWD
Newcastle	PWD
Camp Cove, Port Jackson, Sydney	Maritime Services Board (MSB)
Fort Denison, Port Jackson, Sydney	MSB
Port Kembla	PWD
Eden	CSIRO/Harbour Master

Table 1: NSW Tide Recorders

All the tide gauges were of the float type. A float sits in a stilling well and is attached to a pen stylus which records on a drum. The rotation speed, scale and size of the float and well can vary. If the tsunami magnitude is less than the range of the gauge and the period is greater than 5-15 minutes then the tide recording can be considered an accurate record of the tsunami (Berkman and Symons 1964). This was the case for all the tide gauges examined. Thus they can be considered to accurately represent the tsunami oscillations in their respective locations.

Results

Overall the search for historical information generated 38 personal accounts of which 6 were written and the remainder were given orally and 1 second hand account from the Royal Australian Navy. Reports from 18 newspapers were also located. The tide sheets from the Camp Cove and Fort Denison recorders were copied from State Archives and a reproduction of a tide recording from CSIRO Cronulla was also located. A report containing an analysis and reproduction of the tide recordings from Norfolk

Island, Lord Howe Island, Ballina, Iluka, Coffs Harbour, Newcastle, Fort Denison, Camp Cove and Eden was also sourced. (Berkman and Symons 1964)

These observations and reports were assigned to 70 individual sites and were analysed to determine the tsunami amplitude, period, time of observation, peak speed of the current, number of waves observed, type of observation, type of damage (if any), the dollar figure (2007 values) assigned to any damage and the sources of the information. The locations of observations, observed amplitude and observation confidence are shown in figures 2 and 3.

Discussion

Data Collection

In most cases the reports for each location were either from a single personal account, given nearly 50 years after the event, or a newspaper report. Both of these are prone to inaccuracies, overestimation and omission of important details. Although efforts were made at the time to collect recordings from tide gauges (Berkman and Symons 1964) there were no systematic approaches to collect other information on the tsunami. This has limited the coverage and accuracy of this research. In addition, original records from only two of the ten tide recorders in operation at the time could be sourced. The records from the others have likely not been appropriately archived. Future post-tsunami data collection efforts need to concentrate on collecting, archiving and preserving records of physical measurements of the tsunami as well as systematically gathering and validating observations of tsunami behaviour and reports of damage even when the tsunami impact has not been severe.

Tsunami Behaviour

The tsunami occurred on a weekday morning when it was low to half tide. Most observations were from harbours, bays, rivers and other partially enclosed waterways with only 4 being from open coastline or offshore. Whilst numerical modelling demonstrates that tsunami amplitudes are magnified in partially enclosed waters (Baldock 2008), it is also likely that people were concentrated around these areas therefore leading to a bias towards these types of observations. A breakdown of the types of tsunami behaviour observed at the locations follows:

Type of Observation	Number of Locations behaviour observed
Water Level Change	52
Damage	25
Strong Currents	14
Wave/Bore	9
Roaring Water	4
Land Inundation	2

Table 2: Observed Tsunami Phenomena

The most common type of observation was an unexpected change in the water level at the location. The event earned the description in the common press of the day “tidal wave” as is it manifested itself as an irregularity of the tides at most locations. After the observations of damage the next most common observation was that of strong currents. Personal accounts and newspaper reports gave estimates, based on visual observation of the water movement and its effects on boats, of the speed of the current that ranged from 6-30 knots (3-15m/s), depending on location. The largest reported current, 30 knots (15m/s) came from Iron Cove near Balmain and The Spit in Middle Harbour, Sydney. (Sydney Morning Herald 25/05/1960, Beashel 2008) There were some of reports of boats being able to make little headway against these currents despite operating at full power.

Period

Personal accounts and newspaper reports gave estimates of period, based on the observed interval between two wave peaks or between the peak and subsequent trough. Depending upon location, the period of the waves ranged from 8 to 120 minutes. All but 6 observations recorded periods between 15 and 30 minutes. Given that most observations of the period were made many hours after the tsunami arrived, they are more likely to represent that of the local basin or harbour rather than the true period of the tsunami. Where an initial period of the tsunami could be determined from tide records it is given below:

Tide Recorder Location	Initial Wave Period
Norfolk Island	60
Lord Howe Island	22
Eden	32
Newcastle	30
Iluka	12
Ballina	38

Table 3: Initial Tsunami Period (Berkman and Symons 1964)

Interference waves and reflections can complicate the determination of the true period of a tsunami wave. Therefore, because of the distance from the tsunami source the observation point, it is difficult to determine the true tsunami period (Berkman and Symons 1964).

Wave Amplitude

In 61 of the 70 locations a change in water level, wave or bore was reported. In 44 locations some indication as to the magnitude of the wave height or water level change was given. The amplitude of the tsunami (mean water level to peak height) was determined from these observations. The observations ranged from 0.08-4.3m with the largest amplitude of 0.85m recorded by a tide gauge at Eden. (Berkman and Symons 1964) The largest observed amplitude was from a sailing instructor who reported riding over a 4.3m wave offshore of Balmoral Beach in Sydney Harbour. (Fitzgerald 2008) There is lower confidence in the higher observations as they came from unverified personal accounts. The range of observed amplitudes is shown below.

Observed Amplitude	Number of observations
0-0.3m	14
0.31-0.6m	13
0.61-0.9m	9
0.91-1.2m	5
1.21-1.5m	1
1.5m+	2

Table 4: Tsunami Amplitude

It should be noted that the maximum amplitude, in particular for those records observed by tide recorders, did not occur until many hours after the tsunami was first detected. The table below details, for tide gauges, the time after the tsunami was first detected that the oscillations of maximum amplitude occurred.

Tide Recorder Location	Time between first observation and Maximum Amplitude (hours:minutes)
Norfolk Island	5:18
Lord Howe Island	8:38
Eden	5:35
Newcastle	10:35
Coffs Harbour	6:15
Iluka	6:27
Ballina	14:10

Table 5: Delay till Maximum Amplitude (Berkman and Symons 1964)

Similar time delays were observed on tidal records at many locations throughout the Pacific (Berkman and Symons 1964). In most cases along the NSW coast the largest amplitudes and damage occurred between 0600 and 1200 on the 24th whereas the tidal records indicate that the tsunami first arrived at approximately 2200 on the 23rd. This reinforces the knowledge that the first wave of a tsunami is not necessarily the largest.

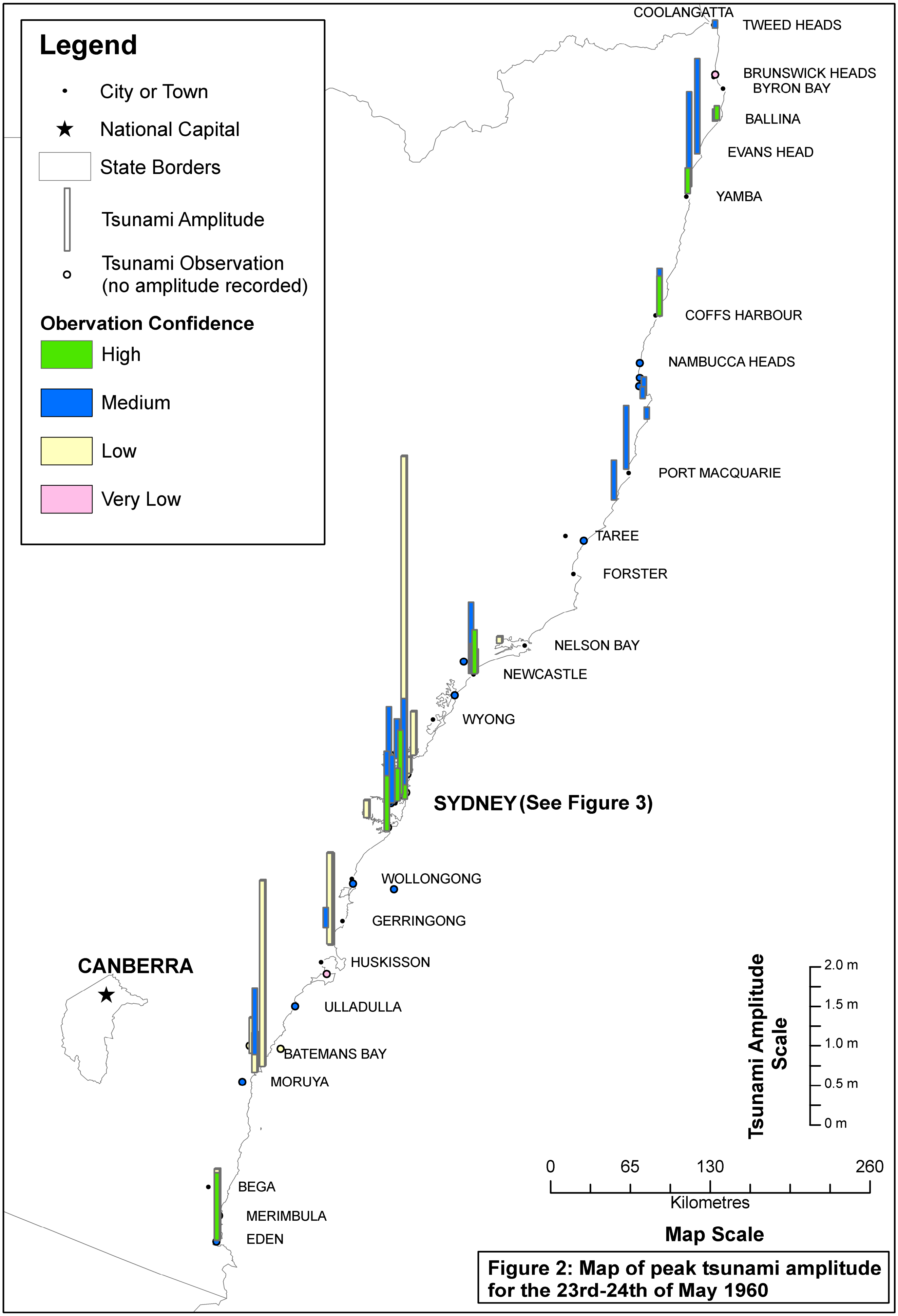

Figure 2: Map of peak tsunami amplitude for the 23rd-24th of May 1960

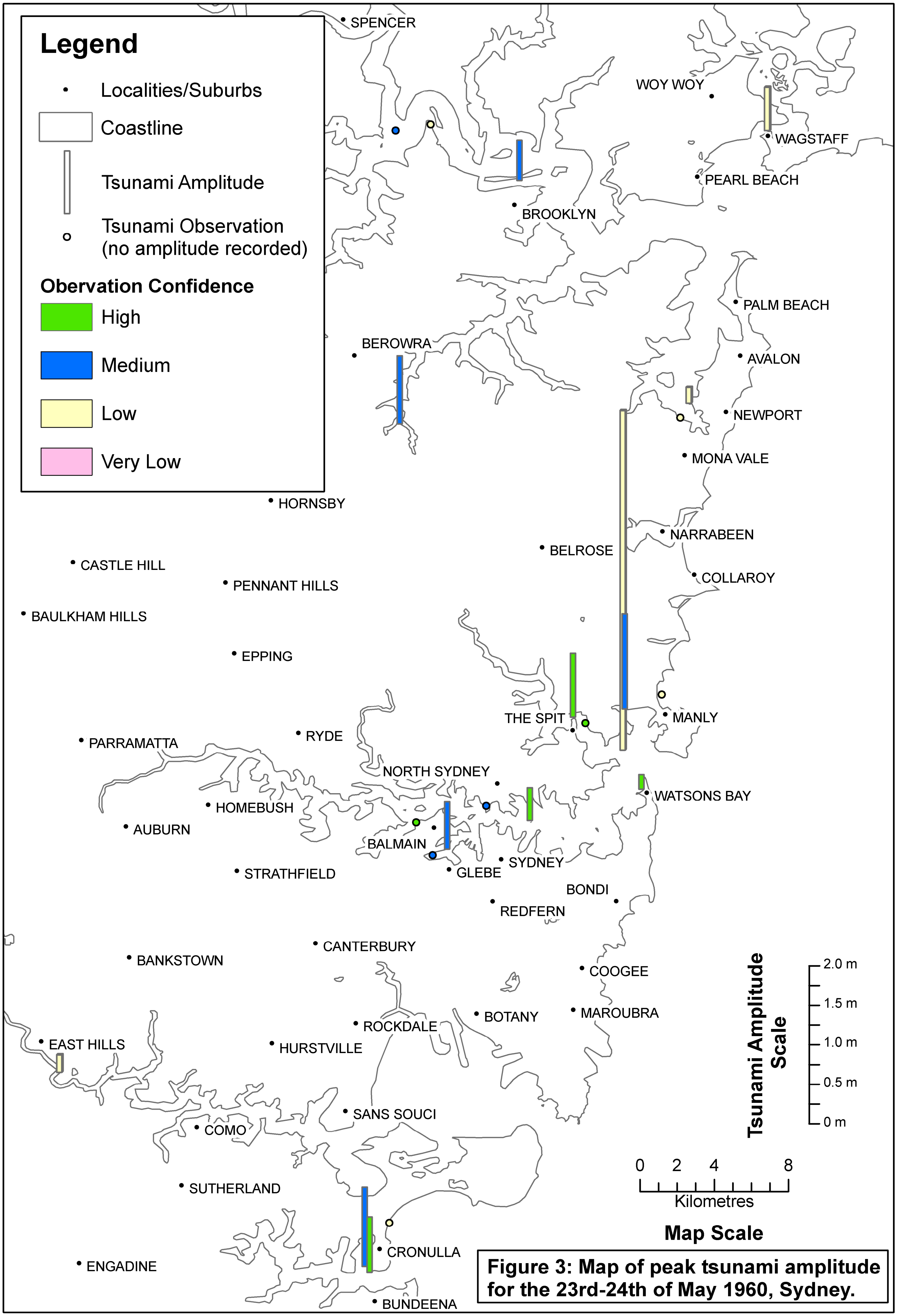

Figure 3: Map of peak tsunami amplitude for the 23rd-24th of May 1960, Sydney.

The tsunami did not necessarily dissipate in amplitude as it propagated up these systems. At Bobbin Head, where some moorings were broken, the tsunami amplitude was larger than that observed at other locations on the Hawkesbury River and Broken Bay. At Iron Cove strong currents and damage were reported.

It is likely that the effects penetrated even further inland as tsunami can create standing waves in rivers with the point of maximum amplitude being midway between the river mouth and the most upstream point of tsunami penetration (Abe 1986).

Land Inundation

Inundation of land areas was only reported at Batemans Bay. Water was observed to come over the seawall behind the house of the postmaster. This had previously been observed when there was a high tide and rough seas. Water also washed over a road on the southern side of the bay. The road has since been raised. The tsunami also washed along a street on the northern side of the bay which is very low set and had previously been affected by coastal erosion. As the height of the tsunami at Batemans Bay was similar to that reported in other locations, particularly on the South Coast, this indicates that there are parts of the town that are more vulnerable to coastal inundation hazards than other parts of the coast which experienced similar tsunami amplitudes but no reports of land inundation.

Damage

Most of the damage caused by the tsunami was due to the strong currents created in rivers, bays and channels, not by tsunami run-up. This demonstrates that a tsunami does not need to exceed the high water mark to cause damage and disruption to marine infrastructure. The breakdown of damage is as follows:

Damage	Number of Locations
Moorings	7
Fishing Equipment	4
Oysters	3
Boat Sunk	2
Boat Grounded	2
Cargo	2
Injury to person	2
Scouring	3
Construction Equipment	2
Wharves	2
Swimming Pool	2
Vehicle	1
Maritime	1

Infrastructure	
Breakwater	1

Table 6: Damage Caused by Tsunami

It is difficult to ascribe an actual dollar figure to the damage caused by the tsunami. In only three instances was the cost associated with the damage reported. The largest reported cost was thousands of pounds associated with Oyster losses at Batemans Bay. Accounting for inflation, in 2008 dollars, this is larger than $25,000. In comparison the other two figures, for a capsized fishing boat and public swimming pool, summed to $21,600. Given these figures it is possible to estimate a minimum reported cost of $50,000 in 2008 dollars for damage caused by the tsunami. However, as most reports of damage did not give a dollar value, and because to the limitations of the survey methodology, it is likely that the actual figure is much higher particularly if oyster losses at other locations were counted. In addition, due to the individual price change in certain goods, these dollar values are not reflective of modern losses that could be experienced were a tsunami to cause damage of a similar type and extent.

Boating

The most common report of damage was of broken moorings. Both fishing and recreational boats were reported to have broken their moorings. The largest number of broken moorings in one location was approximately 30 at The Spit in Middle Harbour, Sydney. In addition there were two reports of vessels sinking. One 24ft fishing boat was sunk in Throsby Inlet, Newcastle and a punt loaded with timber was sunk near Glebe in Sydney Harbour. There were two reports of vessels being grounded and numerous reports of some level of disruption to marine activities. It was remarked in some newspaper reports that had the largest tsunami oscillations occurred at high tide there would have been more significant damage to boating. It is difficult to assess the current vulnerability of the boating sector to tsunami but it is likely to be high, particularly for recreational boating. As an indication there are 217,074 registered recreational watercraft and 9485 commercial vessels operating in NSW and there are 20,368 commercial and private moorings in NSW. (NSW Maritime 2008) Further work is required in this area to determine the exposure and vulnerability of this sector to the tsunami hazard.

Aquaculture

Damage was reported to have occurred to oyster leases in the Hawkesbury River and the Clyde River at Batemans Bay. The largest reported damage cost was to the oyster industry at Batemans Bay.

Oyster farmers, in addition to the rest of the NSW aquaculture industry of which oysters make up 70% (NSW Farmers Association 2007), are one of the most vulnerable maritime industries because of their inability to relocate assets in response to a tsunami warning. Damage can occur from the action of waves and currents, as was reported in the Hawkesbury, or from silt stirred up by the tsunami, as reported in Batemans Bay.

The Clyde River Oyster farming industry, where most of the damage was reported in 1960, today accounts for 11% of the state's oyster production, or about $3.9 million. The total oyster industry in New South Wales is worth more than $37 million each year

(Wiseman 2007). Further research is required to determine the actual exposure of this industry to the tsunami hazard.

Injuries

Whilst there was no official record of any death or injury due to the tsunami there were a number of anecdotal reports of injuries and "near misses" directly attributable to the tsunami.

One report of injury came from Clontarf, near The Spit in Middle Harbour, Sydney, where a young girl fell over the edge of the beach as it was being scoured away. She was rescued by two young bystanders (The Northern Star 25/05/1960).

Another report of injury came from a young boy who was with friends on North Cronulla Beach. They noted the wave coming ashore and he was helping his friends scramble up the seawall when he was slammed into it by the force of the wave. (Perry 2008)

The two "near miss" reports were both from fishermen. Two rock fishermen at Malua Bay, near Batemans Bay, had seawater rapidly rise to around waist level but managed to escape when the water subsequently receded (Mackey, 2007). At Woody Head, near Iluka, a group of seven fishermen who were loading their catch onto a truck had to run up the beach to escape the tsunami wave (The Northern Star 25/05/1960).

Community Behaviour

At most locations the response of the community was not well recorded. Reports focussed primarily on observations and damage. In most cases, people did not report receiving any warning, thus the community behaviour is likely to be based solely on the natural signs of the tsunami that they experienced. There were no reports of people fleeing the coastline en masse although there were a few isolated instances of small numbers of people fleeing when the hazard was immediate and apparent, as at Woody Head, North Cronulla Beach, and Malua Bay. There were a few other isolated instances of people recognising that there was a threat and deciding to leave the area around the water or advise others to do so. In most instances where there was damage to moorings or some other disruption to boats, newspapers reported that local residents and workers took action to protect property and recover drifting boats rather than fleeing. For example at the Spit, owners and employees of the marinas rushed to the water to secure boats and retrieve those that had broken their moorings. The actions that people took in this event cannot be generalised to modern times as the level of public knowledge and awareness of tsunami is likely to be greatly different due to recent events and public education campaigns.

The tsunami did lead to a rudimentary tsunami warning system being established for Australia, with warnings received by the Department of the Navy from the Honolulu Magnetic Observatory before being transmitted by the Bureau of Meteorology to Civil Defence, and ports and harbour authorities. A second large earthquake in Chile led to a warning being issued on the 26th of May 1960. The NSW Civil Defence Organisation was placed on alert and there were some small evacuations noted in the Newcastle area (Newcastle Morning Herald 27/5/1960; NSW Civil Defence Organisation 1961).

Conclusion

This study has demonstrated that a distantly generated tsunami can impact New South Wales, damaging property and creating a risk to life. The importance of maintaining a good historical record has been highlighted as few official records could be obtained. The lack of a systematic post-event data collection for the tsunami event creates difficulty in speculating how a similar tsunami may impact NSW today. With regards to the emergency management of tsunami, two key features of this event should be noted. The waves of maximum amplitude occurred many hours after the tsunami first arrived. Should this reoccur in future events some people may return to evacuated areas and waterways after the initial arrival of the tsunami only to be caught out by the largest waves many hours later. Emergency managers need to stress this aspect of tsunami in public education programs and evacuation messages and ensure arrangements are in place to shelter people for the 10 or more hours it may take for the largest wave amplitudes to arrive. The tsunami penetrated significant distances inland up coastal rivers to areas that some in the community may consider safe. It is important that low lying areas along coastal waterways are included in emergency planning, and specifically targeted with public education and warning messages to ensure that people in these areas are aware of the tsunami hazard. With today's increased coastal vulnerability, appropriate emergency risk management should be applied to further investigate and manage the tsunami hazard in New South Wales.

Further work is required to analyse the threat to aquaculture and recreational boating. This research also highlights the need for extensive post-event data collection after any future tsunami which has impacted New South Wales.

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