Hawke's Bay Tsunami Risk Management Report

Tsunami Threats and Vertical Evacuation Structures in Hawke's Bay.

Graham Palmer

Table of Contents

Originally produced as a management report assignment for Massey University's geography department as part of the 'Applied Field Geomorphology' course (145.304) – October 20, 2019.

(MBIE structural guidelines update added April 2022).

Executive Summary

Since the history of human settlement began in Hawke's Bay, numerous villages, towns and cities have become established along its coast. These population centers were established to take advantage of the many benefits which the sea has to offer. However, we have since discovered that this coastal proximity comes with potentially deadly hidden dangers. Recent geomorphological studies have revealed a long history of earthquakes, coastal subsidence and tsunami which have struck the Hawke's Bay region over the past seven thousand years. Knowledge of these past events now reveals the level of exposure that residents, workers and visitors have to potentially life-threatening tsunami from various sources.

Public education regarding these hazards and their natural warning signs (*a vital tool for self-evacuation*) is ongoing. However, there are known earthquake faults in Hawke Bay and offshore at the Hikurangi subduction margin, which are capable of triggering tsunami that would reach the coast in well under an hour. In this scenario, many residents' attempts to flee the coastal plains to high ground or move a safe distance inland would be futile in the time available. The potential death toll from such an event could be staggering. Fortunately, international experience and studies have shown that many lives can be saved by providing alternatives to traditional evacuation methods.

Lessons can be learnt from Japan, a nation that is well accustomed to seismic threats and the tsunami which they can bring. Their strategy of creating vertical evacuation structures (VES) in tsunami hazard areas, is credited with saving countless lives during the Japan earthquake and tsunami of 2011. Despite the estimated 18,000 + death toll, most people were able to find suitable refuge in purpose-built structures, greatly reducing the potential casualties. It will be proposed that in New Zealand, central government should assist local councils in the adoption of similar strategies in preparation for inevitable events that will one day strike our widely distributed coastal communities.

Introduction

A tsunami is not like a normal storm wave. Rather than taking seconds to pass by, tsunami can take several minutes. Storm waves can travel at speeds of a few meters per second, whereas tsunami can travel at 500kmph in deep water. The wavelength of a storm wave is usually measured in meters from front to back, while tsunami can be measured in kilometers from front to back. Because the waves slow down as they enter shallow water, the back of a tsunami will begin to catch up with the front, causing water to pile up to potentially dangerous and damaging heights. A tsunami is not just water; as they come ashore, they begin to entrain debris which act as battering rams, significantly increasing their destructive potential. When crossing flat ground, they can penetrate several kilometers inland, until their energy is spent, or until they are blocked by topography (Power, 2013). Tsunami waves may continue to cause strong coastal currents for many hours or days following the initial event.

Tsunami can be generated by three main triggers:

1. The most common trigger is when an underwater earthquake causes a sudden rise or fall in sea floor. This sudden movement of land displaces a large body of water which then travels out in all directions away from the source. Such quakes can also produce landslides (either under or into water), triggering further tsunami.
2. Underwater volcanic eruptions can generate tsunami that usually only affect smaller areas, but can occasionally have wide ranging impacts.
3. The rarest sources of tsunami are large bolides (meteorites), but these are the least likely to be observed in a given lifetime and will not be addressed further here.

The potential threat to lives and property has recently been highlighted by events around the globe. The 2006 Boxing Day Indonesia earthquake and tsunami plus the 2011 Japan earthquake and tsunami claimed an estimated 250,000 lives between them (CNN, Wikipedia). This has caused considerable urgency in understanding and attempting to manage the same potential risks here in New Zealand.

The tectonic setting of coastal Hawke's Bay is located on a fore-arc basin, a structure formed near the leading edge of the Australian tectonic plate. Offshore to the east, there are numerous active faults, including the Lachlan fault and the Hikurangi subduction zone, where the Pacific tectonic plate is diving westwards underneath the Australian tectonic plate. Powerful earthquakes originating on these faults are capable of producing large tsunami that would affect all of coastal Hawke's Bay (Wallace et al, 2014).

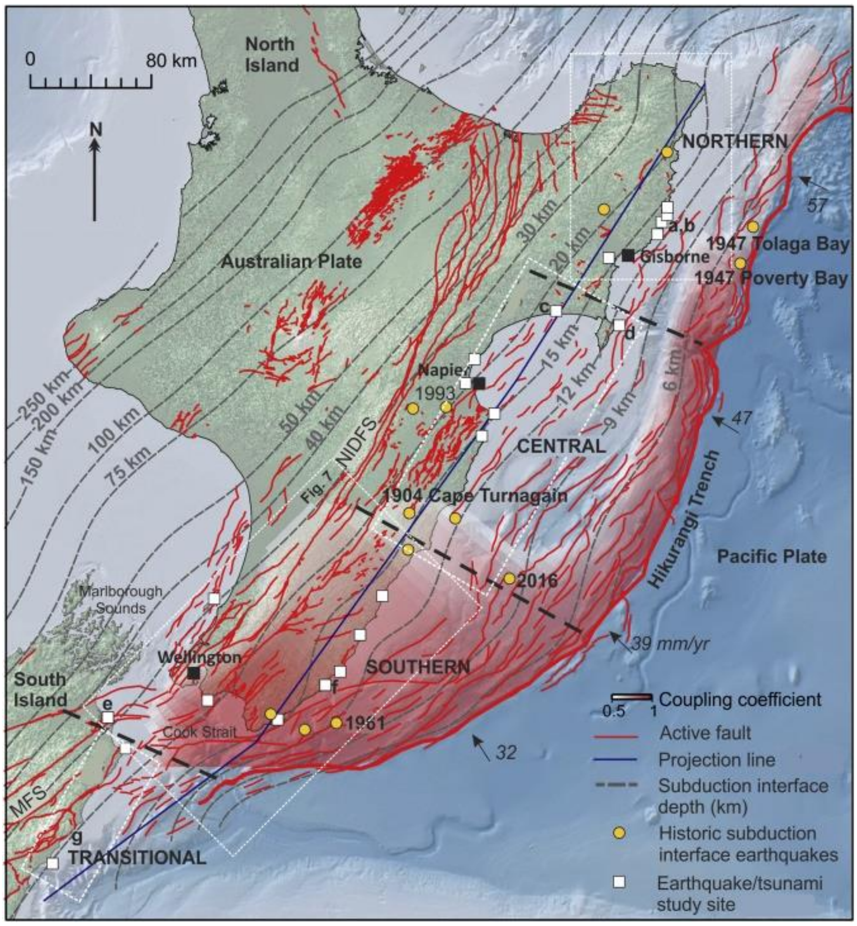

Figure 1. Tectonic setting of the east coast.

Hawke's Bays coast, as with all of coastal New Zealand, is at risk of tsunami inundation from various sources and distances. Distant sources potentially include South America and Alaska. Earthquakes offshore from South America have triggered some of the biggest tsunami to affect New Zealand in the history of human settlement (Power et al, 2007). Closer to home, the geologically active Tonga-Kermadec region poses a threat for intermediate source tsunami. However, the greatest threat to human life comes in the form of a local source tsunami, generated by a nearby offshore earthquake.

Case Studies

One of the first steps in understanding the potential risks posed by tsunami in the region, is to assess the frequency and scale of these events in the past. Cochran et al (2005), made one such study into the geomorphic record of Holocene deposits on the coastal plain between Wairoa and Mahia Peninsula, northern Hawke's Bay. Their investigation found 11 sets of sand layers. Three of these are believed to be the result of alluvial processes, while the rest are marine in origin. The nature of these marine deposits indicates that they were laid down as high energy flows, either from tsunami, or storm surges (Cochran et al, 2005).

Two of these deposits from c. 6300 and c. 4800 year BP respectively are believed to be tsunami related, due to evidence of associated subsidence events. The c. 6300 year inundation also strongly coincides with already known evidence for a tsunami at a site 10 km further west along the coast (Chagué-Goff et al, 2002). The remaining deposits require further investigation to verify their source (Cochran et al, 2005).

Hayward et al (2006), described six possible subduction interface earthquakes affecting Hawke’s Bay over the previous 7,000 years. They studied core samples taken from Ahurirri lagoon, Napier, utilising foraminifera and diatoms as markers. Most of these events were associated with land subsidence which totalled 8.5 meters during the period investigated. The historic magnitude 7.8 1931 earthquake resulted in 1.5 meters of uplift at the chosen coring location.

Wallace et al (2014), attempted to quantify the earthquake and tsunami inundation potential from the Hikurangi subduction zone. They found that earthquake magnitudes of 8.0 or larger are possible from the subduction interface. When comparing this thrust zone to that of the Japan Trench, it appears that a massive 9.0 earthquake similar to the 2011 Tōhoku-Oki earthquake may be possible east of Hawke’s Bay, should the full length of the fault fail. They found that tsunami could be expected to begin affecting the coast in between 20 minutes to 1 hour following a major offshore earthquake, depending on the epicentre location.

Utilising many survivors accounts from the Eastern Japan tsunami, Fraser et al (2012), and Suppasri et al (2016), emphasised the importance of providing alternatives to fleeing inland, or to high ground to avoid tsunami threats from local sources. They used the lessons learned from the great east Japan Tsunami of 2011 as the basis of their study. There, countless lives were saved by the availability and use of steel reinforced concrete structures. Vertical evacuation structures (VES) are designed to provide a safe refuge within a tsunami-inundation zone by offering sufficient elevation above the maximum water level. Safe elevation may be provided by artificially raised open ground, by towers designed specifically for evacuation or by buildings in daily use that can be used for evacuation when required (Fraser et al, 2012).

Figure 2. Papamoa VES. Example of an earth mound vertical evacuation structure, centrally located at Gordon Spratt Park, Papamoa. It has terraced sides that can be used as seating to watch sports games during day to day use and has ramped paths for mobility access. The structure is 10 meters above sea level and capable of harbouring up to 3,600 people. It was built as part one in a series of three such structures at a total cost of $2.9 million (SunLive Media, December 3, 2015). Photo by the author.

Tsunami with run-up heights of a metre or more have occurred about once every 10 years on average somewhere around New Zealand. These are from a mix of distant and local sources. Statistically, smaller tsunamis occur more frequently than large (Power, 2013). In order to estimate the impacts of a variety of possible events, Fraser et al (2014), modelled a series of inundation maps for the Napier area under a range of rupture scenarios. The most likely scenario for local source tsunami is rupture of one or more small to moderate size faults within the area of Hawke Bay. One such potential rupture point is the Lachlan Fault, just east of Mahia Peninsula. Strain estimates are believed to make magnitude 7.7 Earthquakes possible from there, leading to a tsunami of up to 6 meters flow depth at the coast of Napier (Fraser et al, 2014).

A less common, but far more devastating scenario is that of a rupture on the subduction interface, producing a megathrust earthquake of between magnitude 8-9 and tsunami of potentially 8+ meters run-up (Fraser et al, 2014).

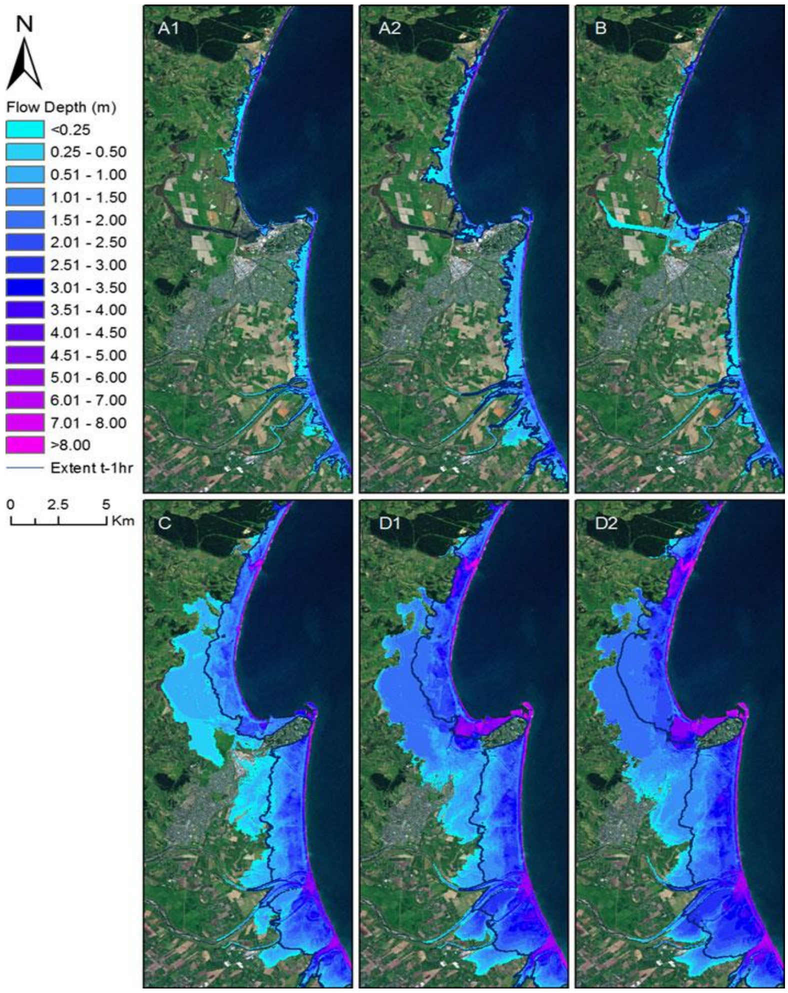

Figure 3. Maximum flow depth and inundation extent 1 h after rupture in and around Napier Territorial Authority due to simulated scenarios. Legend and scale are identical for each map. A1, A2: Lachlan Fault rupture using simple fault geometry with 9.0 m slip (MW 7.7) at MSL and MHW, respectively; B Rupture of the plate interface offshore Hawke's Bay (MW 8.4) at MSL; C Rupture of southern and central Hikurangi subduction margin (MW 8.8) at MSL; D1, D2 Rupture of the whole Hikurangi subduction margin (MW 9.0) at MSL and MHW, respectively (Source: Frazer et al, 2014).

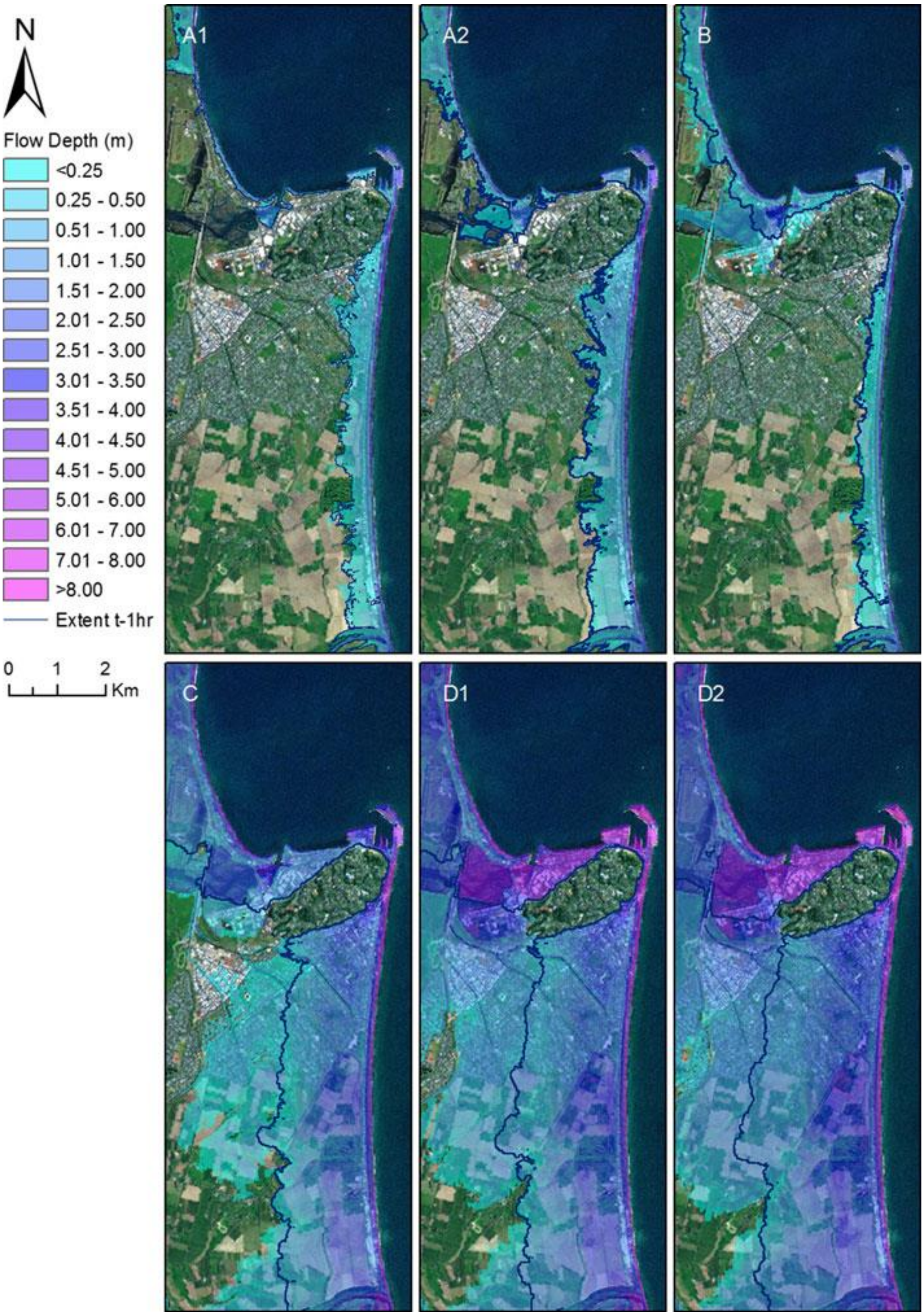

Figure 4. Maximum flow depth and inundation extent 1 h after rupture in Napier city due to simulated scenarios. Legend and scale are identical for each map. A1, A2 Lachlan Fault rupture using simple fault geometry with 9.0 m slip (MW 7.7) at MSL and MHW, respectively; B Rupture of the plate interface offshore Hawke's Bay (MW 8.4) at MSL; C Rupture of southern and central Hikurangi subduction margin (MW 8.8) at MSL; D1, D2 Rupture of the whole Hikurangi subduction margin (MW 9.0) at MSL and MHW, Respectively (Source: Frazer et al, 2014).

Discussion

These case studies highlight the potential risks for earthquake and tsunami inundation along the Hawke's Bay coast. Current management methods are largely based around public education of the potential tsunami threat. These efforts have centred around two key strategies: Education regarding coloured tsunami hazard zones, and public education regarding self-evacuation triggered by natural warning signs.

Tsunami Hazard Zones have been established based on inundation maps modelled by Frazer et al (2014). The three zones represent the level of threat at which each area should be evacuated. These signs have been positioned in prominent locations throughout the at-risk areas.

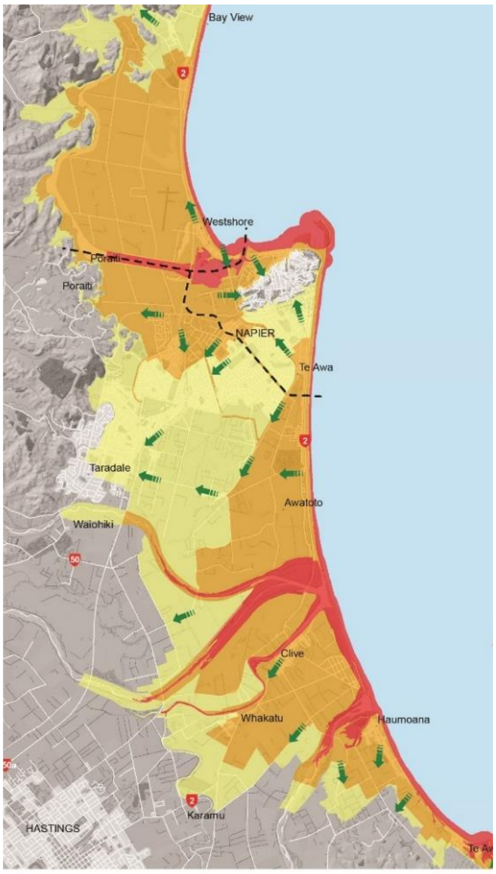

Figure 5. Tsunami Hazard Zones. The red zone should be evacuated under any level of tsunami threat. The orange zone should be evacuated under threat of a distant source tsunami and where there is time for official warnings. The Yellow zone, and all others, should be evacuated following a long or strong earthquake.

Figure 6. Self-evacuation Education. Public education campaigns are largely based on self-evacuation following natural warning signs, such as a long or strong earthquake.

Figure 7. (November 17, 2019) An example of social media (Facebook) advertising for the "Shake Out" and "Tsunami Hikoi" events run on a regular basis to help raise public awareness by East Coast LAB, operating in conjunction with civil defence, scientists, emergency managers, experts and stakeholders across the East Coast.

In the event of a distant source tsunami, public warning systems will be activated. These systems include a series of sirens positioned in high risk areas and communication via media. Warnings to the public would be triggered as a result of the Pacific Tsunami Warning system – a network of ocean buoys that constantly monitor for any sudden or non-normal changes in sea level. While distant source tsunamis are almost as likely as local source, the key differences are the time available for an evacuation, and the likely severity of inundation.

Many distant source tsunamis are unlikely to exceed three meters at the coast. The time required to safely evacuate the hazard zone vs the tsunami travel time means that most distant source tsunami would have a far smaller likelihood to claim a significant number of lives.

In the case of a mid-distance tsunami generated from the Tonga-Kermadec region (either seismic or volcanic source), some locals may feel an earthquake as a gentle, rolling motion that would last a minute or more. It is probable that many people would not perceive this as a natural tsunami warning. However, any tsunami generated could potentially begin to impact NZ's coast in around one hour following the original event. Currently, the Pacific Tsunami Warning System could take that length of time to receive the required data and issue any warning, leaving little, if any time to effect evacuations in the upper half of the North Island. This leaves a dangerous gap in tsunami monitoring, which aims to be filled by the deployment of DART (*Deep-ocean Assessment and Reporting of Tsunamis*) buoys north of NZ over the next two-three years (GNS Website, 2019).

Local source events will afford very little warning For HB residents. Fraser et al (2012), and Suppasri et al (2016), highlighted several compounding issues that can delay safe evacuation in the event of a locally generated threat. In Japan, the shock of a violent earthquake was found to impact the time it took to begin evacuation in many cases. Decision paralysis, liquefaction, damaged, blocked or congested roads. All these mean that pedestrian evacuation would be the most likely scenario for many residents of Napier. Further complicating this, coastal HB has a history of coseismic uplift/subsidence associated with major seismic events.

In the 1931 magnitude 7.8 earthquake, the areas north of Haumoana were lifted by up to two meters relative to sea level. However, the majority of geologically recent earthquake events in the region are known to have resulted in at least some subsidence (Hayward et al, 2006). This fact further complicates hazard planning by potentially depressing some areas relative to sea level and any subsequent tsunami.

Much of the residential area of Napier has been constructed on the former estuary that once occupied the land between Napier and the western hills of Park Island. This area of land was drained following the 1931 uplift, and today, thousands of homes are positioned on the young, unconsolidated sediments of the former estuary. The area is low-lying and generally has a fairly high water table, making it a very high risk for liquefaction during severe earthquake shaking. This liquefaction poses a potential obstacle for residents attempting to evacuate to safe ground in the event of a local source tsunami. It is possible that many roads would be unpassable, either from liquefaction, or as the result of uneven settling of the land. As such, it is very likely that without nearby VES, the only viable mode of escape would either be on bike or foot (Fraser et al, 2012).

Tsunami ranging in size from six to ten meters in height could reach as far inland as five kilometers on the coastal plains, affecting up to 20,000 residents living in the three identified tsunami hazard zones (Frazer et al, 2014). This potential extent of inland inundation means that large portions of the red and orange zones of Napier are probably not within walking distance/time of safe ground. The same scenario is likely to be true of a number of communities along the rest of the Hawke's Bay coast. This raises the question of how to reduce the length/time of evacuation routes, particularly in more densely populated suburbs.

Currently, the Ministry of Business, Innovation and Employment (MBIE) are developing guidance and standards for vertical evacuation structures (VES) in residential, commercial and industrial tsunami hazard zones (Ministry of Civil Defence & Emergency Management, 2018). It may be possible that some existing structures will already meet the code (Suppasri et al, 2016).

Conclusions

The continuation of current public tsunami education is vitally important in reducing the potential death toll from any future event. However, education alone cannot be expected to help all people to evacuate in time. Should a large tsunami be triggered by a local earthquake, many residents within the red and orange zones are currently faced with more than a 30-minute walk to safe ground. International experience show this timeframe is simply inadequate for many.

In the hypothetical case of a tsunami generated from a magnitude 7.7 earthquake on the Lachlan Fault, the first waves could arrive at the coast within 15-20 minutes of severe shaking. Many roads are impassable and most people are in some degree of shock. In this scenario, it quickly becomes obvious that very high loss of life would occur. A worst-case scenario, local source tsunami could potentially cost thousands of lives along the Hawke's Bay coast.

When viewed from the standpoint of a risk assessment matrix, the risk of such an event occurring in any one year is relatively small. However, the level of exposure to this hazard is potentially severe. If we continue on with a lack of alternative evacuation methods being available, it is simply a matter of time before good fortune runs out and a large scale tragedy unfolds.

Recommendations

It is my recommendation that public awareness education continues in a similar manner to present. This is proving to be effective and can be quickly adapted as required with new information and advice as it becomes available.

I also urge that, once available to view, the new standards set by MBIE for VES should be adopted into long-term planning for implementation by respective councils, with guidance and financial support from central government.*

The placement of suitable structures close to residential populations would allow for a much shorter evacuation route for many residents, ultimately having the potential to save thousands of lives. These structures will take different forms, but the best designs will be multi-use infrastructure created as a public/private partnership as highlighted by Fraser et al (2012), and Suppasri et al (2016).

All such structures must be designed to withstand the maximum credible event in a given location based on modelled seismic loading and impacts from multiple tsunami surges. Their capacity and number will be designed to cater for the populations present in the community where they are built. They will be tall enough to give shelter from the largest projected wave heights, allowing for century scale sea level rise, and up to 1.5-meter coseismic subsidence.

**NOTE: MBIE has since published the first edition of "Tsunami Loads and Effects on Vertical Evacuation structures – Technical Information" in May 2020. This document is available for download here:* *https://www.building.govt.nz/building-code-compliance/specific-buildings/designing-vertical-evacuation-structures-for-tsunami-loads/*

Examples of such possible designs include, but are not limited to:

- Existing reserves in residential areas could be modified into earth mounds. These will continue to play a role as green spaces, while offering sanctuary in an emergency.
- New subdivision consents for any potentially susceptible areas should be legislated to include an approved VES design.
- In business or industrial areas, multistory parking buildings make excellent candidates for this role, generating income while providing a useful service and serving as vertical evacuation structures when required.

The knowledge of how to save many lives from tsunami is readily available. What is now required is the resources, time and willpower to convert that knowledge into practical action and preparedness.

References

C. Chagué-Goff, S. Dawson, J.R. Goff, J. Zachariasen, K.R. Berryman, D.L. Garnett, H.M. Waldron, D.C. Mildenhall, A tsunami (ca. 6300 years BP) and other Holocene environmental changes, northern Hawke's Bay, New Zealand, Sedimentary Geology, Volume 150, Issues 1–2, 2002, Pages 89-102, ISSN 0037-0738, https://doi.org/10.1016/S0037-0738(01)00269-X.

U. A. Cochran , K. R. Berryman , D. C. Mildenhall , B. W. Hayward , K. Southall & C. J. Hollis (2005) Towards a record of Holocene tsunami and storms for northern Hawke's Bay, New Zealand, New Zealand Journal of Geology and Geophysics, 48:3, 507-515, DOI: 10.1080/00288306.2005.9515129

Fraser, S.A., Power, W.L., Wang, X. et al. Nat Hazards (2014) 70: 415. https://doi.org/10.1007/s11069-013-0820-x.

Fraser, Stuart & Leonard, Graham & Murakami, Hitomi & Matsuo, Ichiro. (2012). Tsunami Vertical Evacuation Buildings – Lessons for International Preparedness Following the 2011 Great East Japan Tsunami. Journal of Disaster Research. 7. 446-457.

Hayward BW, Grenfell HR, Sabaa AT et al (2006) Micropaleontological evidence of large earthquakes in the past 7200 years in southern Hawke’s Bay, New Zealand. Quat Sci Rev 25(11–12):1186–1207

Mueller, C., Power, W., Fraser, S., and Wang, X. (2015), Effects of rupture complexity on local tsunami inundation: Implications for probabilistic tsunami hazard assessment by example, *J. Geophys. Res. Solid Earth*, 120, 488– 502, doi:10.1002/2014JB011301.

Power, W. L. (compiler). 2013. Review of Tsunami Hazard in New Zealand (2013 Update), *GNS Science Consultancy Report* 2013/131. 222 p.

Power W., Downes G., Stirling M. (2007) Estimation of Tsunami Hazard in New Zealand due to South American Earthquakes. In: Satake K., Okal E.A., Borrero J.C. (eds) Tsunami and Its Hazards in the Indian and Pacific Oceans. Pageoph Topical Volumes. Birkhäuser Basel.

Anawat Suppasri, Panon Latcharote, Jeremy D. Bricker, Natt Leelawat, Akihiro Hayashi, Kei Yamashita, Fumiyasu Makinoshima, Volker Roeber & Fumihiko Imamura (2016) Improvement of Tsunami Countermeasures Based on Lessons from The 2011 Great East Japan Earthquake and Tsunami — Situation After Five Years, Coastal Engineering Journal, 58:4, 1640011-1-1640011-30, DOI: 10.1142/S0578563416400118.

Jenni Tipler, Sarah-Jayne McCurrach, Ministry of Business, Innovation and Employment, Ministry of Civil Defence and Emergency Management, Wellington, New Zealand, https://www.atcouncil.org/docman/atc-15-16-presentations/219-2-6-tipler/file

Jenni Tipler, Sarah-Jayne McCurrach, Ministry of Business, Innovation and Employment, Ministry of Civil Defence and Emergency Management, Wellington, New Zealand, https://www.atcouncil.org/docman/atc-15-16-papers/170-p2-06-tipler/file

WALLACE, L., COCHRAN, U., POWER, W., & CLARK, K. (2014). Earthquake and Tsunami Potential of the Hikurangi Subduction Thrust, New Zealand: Insights from Paleoseismology, GPS, and Tsunami Modeling. *Oceanography, 27*(2), 104-117. Retrieved from http://www.jstor.org/stable/24862161.

Other Sources

Boxing Day Tsunami - https://www.britannica.com/event/Indian-Ocean-tsunami-of-2004

Historic tsunami in NZ - https://en.wikipedia.org/wiki/List_of_tsunamis_affecting_New_Zealand

East Japan Tsunami - https://edition.cnn.com/2013/07/17/world/asia/japan-earthquake---tsunami-fast-facts/index.html

GNS Tsunami Monitoring - https://www.gns.cri.nz/Home/Our-Science/Natural-Hazards-and-Risks/Tsunami/Tsunami-Monitoring

Designing VES for tsunami loads - https://www.building.govt.nz/building-code-compliance/specific-buildings/designing-vertical-evacuation-structures-for-tsunami-loads/

Papamoa VES - https://www.sunlive.co.nz/news/114518-tsunami-shelter-costs-rise.html