NZIER INSIGHT
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Tsunami risk
More needs to be done

New Zealand has just had a 'near miss' with a major off-shore earthquake event. Media covered how at 4.37 am on Friday 2 September a magnitude M7.1 earthquake struck 100kms off the coast of Te Araroa. Around 15 minutes later a sea level gauge registered a 30cm tsunami on the East Coast. Ironically earlier in the week the Civil Defence Emergency Management community had just undertaken Exercise Tangaroa, a simulation of a M 9.1 earthquake further offshore in the Kermadec Trench. So the team would have been in a high state of readiness.

The media were relatively restrained in their treatment of the confused sequence of events that followed. In brief – the magnitude of the earthquake did not meet the thresholds for a default tsunami warning, subsequently only an advisory about the earthquake was issued at 5:10 am. Later, at 5.55 am a tsunami warning for marine and beach areas was issued. The latter was nearly 1 hour 20 minute after the earthquake and 1 hour 5 minutes after the arrival of the first wave. Meanwhile the Pacific Tsunami Warning Center was providing contrary advice.[1]

This event has exposed two general misconceptions:

- that it is possible to issue timely warnings for local source events
- that the science of tsunamis is straight forward and a warning should have been issued straight away.

The simple fact is that self-evacuation is the single most important life-saving measure in the event of a local source tsunami, and the fact that communities around East Cape and Gisborne took exactly this action is applauded.

Learning is important if major risks are to be mitigated. The airline industry has demonstrated the value of reviews of 'near misses' as they provide a great opportunity to learn about what works and what doesn't. Debriefing reviews of the events of 2 September are underway by the organisations involved.[2]

There is a more general point that we need to learn from this event. While damaging tsunami are rare, their effects can be devastating to the communities in their path. Nearly 300,000 people perished in the Boxing Day tsunami, some as far away from the epicentre as India (10,000 deaths) and Africa (Somalia had 200 fatalities). More than 10 years later, many communities in Aceh, where the wave height reached 34 metres, have not recovered.

Tohuku in 2011 was another wake-up call because Japan has invested heavily in tsunami risk mitigation and there is widespread public understanding of tsunami and how to respond. The searing images of tsunami devastation are now more familiar from our television screens. Who can forget the sight of the giant wave pouring over the harbour wall in Fukushima, tossing cars about like Matchbox toys? But fortunately large tsunami always seem to happen somewhere else.

Not so, alas. New Zealand is precariously placed, sitting on the Pacific Ring of Fire, a belt of frequent volcanic eruptions and earthquakes around the edge of the Pacific tectonic plate. New Zealand lies at the intersection of the Pacific Plate and Indo-Australian Plate, which are slowly colliding, triggering earthquakes and volcanic

1 http://www.radionz.co.nz/podcasts/mediawatch.rss mwatch-sun-20160911-0907-mediawatch_for_11_september_2016-048.mp

2 Regardless of what the sequence of events were on 02 September, public education emphasises that when a local source tsunami occurs there will unlikely be time to issue an 'official' notification before the first waves arrive at the nearest coastlines. The official advice is therefore that people should heed the natural warning signs and take appropriate action (i.e. do not wait for official warnings). This advice is: If the earthquake makes it hard to stand up, or is a rolling earthquake that lasts a minute or more, or where changes in the sea are observed (rapidly going out, rapidly coming in or making noise) this should be taken as an immediate warning for coastal populations to take action to move inland or uphill to keep themselves and their families safe.

eruptions. Seismic activity brings with it the potential for a tsunami, and New Zealand is just as vulnerable to tsunami as Japan and Taiwan, South East Asia, the western coast of the Americas (from Alaska to Chile), or the islands of the Pacific.

So how big is New Zealand's tsunami risk, and is there anything we can do about it?

It's an 'ugly' problem

Tsunami is a classic 'ugly' public policy problem. Damaging tsunami are rare but when they occur the consequences can be devastating. New Zealand faces significant tsunami risk but New Zealanders have almost no direct experience of tsunami events so the risk and the responses required are not widely appreciated. While there is plenty of opportunity for experts to learn from other geo-hazards and other countries' tsunami experience, there is almost no opportunity for learning by doing for ordinary New Zealander. Although there is ample evidence of catastrophic tsunami that struck New Zealand hundreds of years ago,[3] tsunami like the Boxing Day event are uncommon. As a consequence, New Zealanders don't understand either the risk or the responses needed.

Because they happen infrequently, tsunami are not top of mind. When the Christchurch earthquakes struck in 2010 and 2011, memories of earlier events such as the Edgecumbe earthquake in 1987 were still reasonably fresh in people's minds. Some survivors of the Napier earthquake of 1931 were still alive. Post Christchurch, earthquakes register in people's assessment of their own personal safety as a possibility they need to prepare for. Many of us have emergency kits at home and have made plans with the family about what to do if the Big One should happen.

But when tsunami warnings have been issued in the past, people have gone down to the shore to have a look. No one is alive who remembers the tsunami that swept into Wellington Harbour after the Wairarapa earthquake in 1855, across the Rongotai isthmus, where Wellington Airport and the suburbs of Kilbirnie and Rongotai are now. The first waves arrived in Wellington minutes after the earthquake. In Lambton Quay the waves were 2-2.5m high. They sloshed back and forth in the harbour and Cook Strait for 12 hours. Some 500 kms of coastline were affected, from Otaki in the north to the Clarence River in the south.

Most of us live close to the coast – beachfront property is booming. But anyone living near the coast is vulnerable to tsunami depending upon the terrain. The lead times vary depending on where the tsunami was generated. Relief operations may not be able to start for many hours because wave activity may continue for up to 24 hours after the event. The consequences are complex to understand and model, since they are the product of the interaction between physical processes, the built environment, and many individual decision-makers making life and death decisions – for the first time.

Worse, there is limited direct evidence of the effectiveness of individual mitigation options. Tsunami is an orphan risk. That makes tsunami hazard an 'ugly' problem for policy makers to resolve.

All bets are off

GNS Science has recently re-assessed New Zealand's tsunami hazard in the light of the three big ones: the Indian Ocean in 2004, Samoa in 2009, and Japan in 2011. They were all produced by earthquakes substantially larger than scientists had thought likely, and 'contradicted previous geophysical assumptions about the maximum magnitudes of earthquakes that could be created on tectonic plate boundaries'.[4] Moreover, the movement between the tectonic plates in the earthquake that triggered the Japanese tsunami was highly variable. In some places the tectonic plates moved by as much as 50 metres, but elsewhere by only 5-10 metres. The amount of movement affects how much the seabed moves, which determines how big the tsunami will be.

There is now greater uncertainty about the maximum potential size of earthquakes on plate boundaries around the Pacific. Scientists consider that some parts of New Zealand are much more vulnerable to tsunami triggered

[3] McFadgen, B. G. Hostile Shores: Catastrophic Events in Prehistoric New Zealand and Their Impact on Māori Coastal Communities. Auckland, N.Z.: Auckland University Press 2007.

[4] W.L. Power (compiler), Review of tsunami hazard in New Zealand, GNS Science Consultancy Report 2013/131, Wellington, 2013, p. ix. www.gns.cri.nz/content/download/9921/53211/.../Tsunami%20Report%202013.pdf

by local or regional events than they previously thought. Specifically, the hazard has increased for the east-facing coasts of the North Island and the southwest corner of the South Island.

Big waves

A tsunami is a series of waves created when a large volume of water is rapidly displaced. Tsunami are caused by large submarine or coastal earthquakes, when the seabed is lifted up or subsides significantly; by underwater landslides (which may be triggered by earthquakes or volcanoes); by large landslides from sea cliffs; by volcanic eruptions; or by meteor strikes.

No part of the New Zealand coast is safe. Distant sources such as South America and the West Coast of the USA can create tsunami that will affect New Zealand. Waves from the tsunami caused by the 1960 Chile M9.4 earthquake were still able to reach 4m above normal sea level in parts of New Zealand (having reached 25m near the source in Chile and 10m in parts of Hawaii). The M7.1 Gisborne earthquake of 1947, for instance, created a tsunami with an 11m maximum run-up that affected the coast north of Gisborne.

Tsunami risk is a function of three factors: the nature and extent of the tsunami hazard; the characteristics of the coastline; and how exposed and vulnerable the people and built environment are.[5]

There are three tsunami scenarios to consider: local, regional, and distant.

- Tsunami from **local** sources such as a local earthquake will strike the nearest shore in less than 60 minutes. They could happen anywhere around New Zealand but the risk is highest on the eastern coast of the North Island.
- **Regional** sources generate waves that take 1-3 hours to arrive. The coastal areas most at risk from regional source tsunami are both coasts of the northern half of the North Island and the southern half of the South Island.
- **Distant** sources are defined as taking more than three hours to arrive. The most frequent sources are large earthquakes – greater than magnitude 8 – most of which occur around the edge of the Pacific Ocean. The east-facing coasts of both islands are most at risk.

What's the damage?

We worked with GNS to look at the size of the risk to New Zealand in order to understand how it compares with other disasters, and to identify the options for mitigating the risks to tolerable levels. GNS Science has modelled the tsunami risk, assuming that the event takes place at night, when most people are home, with limited evacuation. The risk combines the exposure to local regional and distant sources. This would be a worst case scenario. The results are shown in Table 1.

Table 1 The risk from a composite 1/500-year tsunami event with limited evacuation

Potential exposure (fatalities and injuries rounded to nearest 000)	Fatalities	Injuries	Property loss
84th percentile	33,000	27,000	$45 bn
50th percentile	17,000	15,000	$28 bn
16th percentile	4,000	4,000	$9 bn

Source: Horspool et al (GNS Science 2013)

By way of comparison, the Christchurch earthquake of 22 February 2011 caused 185 fatalities and injured several thousand people, with insured property loss from the earthquake series totalling $30 bn. New Zealand's war fatalities total 30,000 in all conflicts.

[5] Op. cit., p. 7.

We then used expert judgement to establish plausible evacuation rates that could reduce the exposure to risk illustrated in Table 1. Table 2 shows the 'size of the prize'. It suggested the potential to reduce fatalities by 6,530 or around one third of New Zealand's exposure to a 1/500 year event (median value).[6] For local tsunami, improving self-evacuation rates has the most potential, whilst for regional tsunami, developing an official warning capability within 1-3 hours offers the most promise. In terms of reducing fatalities, the analysis suggests it would be cost-effective for New Zealand to invest an extra $50 million per annum in tsunami mitigation.

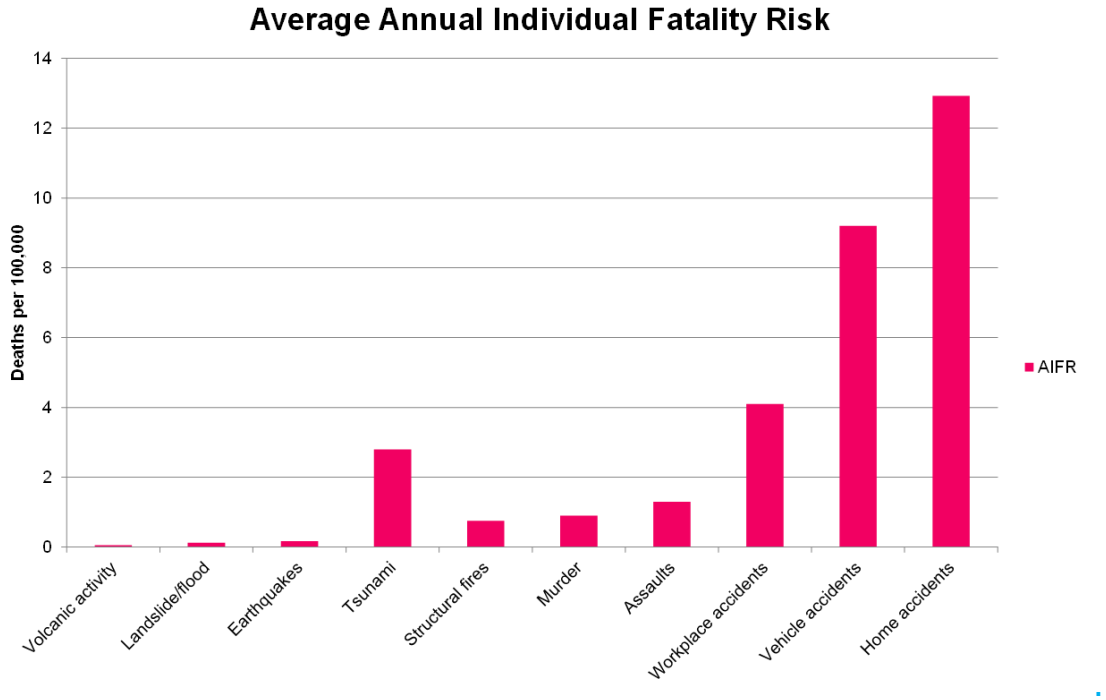
Table 2 The potential impact on fatalities from investment in mitigation

Tsunami warning	Less than 1 hour	1-3 hours	More than 3 hours	Total
Lives lost (worst case)	5,500	3,700	8,100	17,271
Estimated evacuation rate	25%	25%	95%	
Plausible target evacuation rate	96%	90%	98%	
Avoided fatalities	3,900	2,400	240	6,530
Annualised value of lives saved (@$3.88m)	$300 m	$18 m	$2 m	$51 m

Source: Gill, D., Webb T. and Clough P. (2015)

So how does tsunami risk compare with the risk of other kinds of accidental death? Figure 1 compares the average individual tsunami fatality risk with earthquake, murder, vehicle accidents, and other causes of death.

Figure 1 Comparison of tsunami risk with other risks?



Source: Gill, D., Webb T. and Clough P. (2015)

[6] Gill, D., Webb T. and Clough P. (2015). Tsunami risk facing New Zealand: NZIER report to the Earthquake Commission. http://nzier.org.nz/publication/tsunami-risk-facing-new-zealand

Bang for the buck

How much are we spending on tsunami at present? Not very much, as Table 3 reveals. Annual public spending is around $2.55 million p.a. It seems disproportionately low when expressed per unit of risk. For instance, if we spent the same amount on tsunami as we do on workplace accidents (per unit of risk), we'd spend $60 million a year. If we spent as much as we do on vehicle accidents our annual spend on tsunami would be $260 million.

Table 3 Comparison of spending and risk

Event	Government spending $ m in 2008/9	AIFR/100,000	$ m spending per unit of risk
Assaults	$122	1.3	$93.85
Workplace accidents	$85	4.1	$20.73
Vehicle accidents	$854	9.2	$92.83
Tsunami	$2.55	2.8	$0.910

Source: Ministry of Health Mortality Statistics and NZIER estimates

So what are the options for mitigating tsunami risks to a tolerable level? There is a range of options, some that need to be undertaken in advance, and others that would improve our management of the event at the time. We found the best approach was not to focus solely on changing behaviour to promote greater self-evacuation or relying solely on engineering or structural solutions. Rather, the best strategy would be a mixture of the two approaches.

Plenty of low hanging fruit

We identified some quick wins which had a relatively high impact at reasonably low cost. To illustrate, two low-hanging fruit options include hardening critical infrastructure, such as ensuring 24-hour standby facility for selected parts of the cellular network, and providing designated evacuation buildings. In the aftermath of the Tohuku earthquake around 5,000 people took refuge in evacuation buildings and were able to be rescued.

We also identified some '**long march' options** requiring sustained effort over several years. The 'long march' options are diverse and include:

- An effective public alerting system to allow during event communications and messaging
- A 24/7 professionally staffed Tsunami Warning Centre to speed up the issuing of warnings
- Enhanced education on self-evacuation focused on tsunami drills in schools in coastal areas
- Completion of inundation mapping so all of New Zealand is covered
- Evacuation plans, including maps and signage; and devising family and organisation plans in the event of a warning
- Land use planning, such as restrictions on where institutions like schools or rest homes can be located.

What is important is that New Zealand takes the opportunity provided by the recent 'near miss' to learn from what worked and what didn't, understand the extent of tsunami risk and put in place the remedial actions required. NZIER's analysis shows that there are some 'quick wins' like designated evacuation buildings which can mitigate risk at limited cost and some longer term options that can reduce risk over time at low cost. The development of a 21st century public alerting system, backed by a professional staffed Tsunami Warning Centre, will mean New Zealand has the sort of infrastructure required to better mitigate tsunami risk.

In conclusion it is worth noting that this discussion has been about the cost effectiveness of options in reducing fatalities and injuries from local and regional tsunami. In fact, there are fewer options to mitigate property loss. As we saw with the Christchurch earthquakes and their aftermath, strengthening critical infrastructure and better management and response to an event can help with business continuity and reduce the economic losses.

But the first, essential step is to recognise the risk. It's an 'ugly' problem, but there's a lot that can be done if we face it squarely.

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