

Assessing Tsunami Risk in New Zealand

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Summary

Following the disastrous tsunami in the Indian Ocean in December 2004, there was much concern in New Zealand about the level of tsunami risk here. Most people were vaguely aware that tsunamis can happen, even that they have affected New Zealand coasts in the past, but few recognised that they can cause such huge losses as became evident in the days following Christmas 2004. Through the Ministry of Civil Defence and Emergency Management, GNS Science was engaged to consider how to evaluate tsunami risk to coastal communities in New Zealand, and to New Zealand as a whole. This was not a research project, in which study of earthquake sources and tsunami damage might be done, but rather an effort to amass the existing data on all aspects of tsunami generation, propagation and damage, and to use these data to prepare an assessment of the risk to New Zealand. Two reports, one on the assessment of risk and a second on preparedness aspects, were prepared. They represent the first attempt, anywhere in the world, to assess tsunami risk in such a comprehensive way. As such they have been welcomed by the scientific community, by insurance interests and by other organisations involved in risk management.

1. Introduction

Risk assessment for tsunami must of necessity involve all aspects of tsunami generation, propagation across oceans, runup at coastlines, inundation of built-up areas, and effects on assets and people. Because we do not know exactly the details of any given tsunami, let alone when it will occur, we must construct detailed models that describe each aspect, and combine them in such a way as to enable us to calculate, at the end of the exercise, the probable damages, and to know how likely they are. It is also very important to recognise the uncertainty at each step of the modelling, so that the final results can reflect this. It was expected from the outset that uncertainty ranges would be quite wide, because of the lack of knowledge about details of the tsunami generation, propagation and inundation process.

2. Earthquake sources

Tsunamis from anywhere in the Pacific can affect New Zealand. Local earthquakes located offshore are obviously important, as in 1855 on the Wellington coast and 1947 to the north of Gisborne. But earthquakes in South America, such as in 1868 and 1960, have also inundated the New Zealand coastline, and a complete assessment of risk must take these into account. Seismological information about how often large earthquakes occur in each significant source region can be obtained from historical earthquake catalogues, and with modern studies we can determine the likely magnitudes of these earthquakes. For many earthquake faults off the New Zealand coast, there have been no historical earthquakes on which to base such modelling, but geological data on the age and activity of the faults can be brought to bear to aid the modelling. Figure 1 shows the earthquake sources considered in the MCDEM report. Not shown are many local faults which were also included in the analysis.

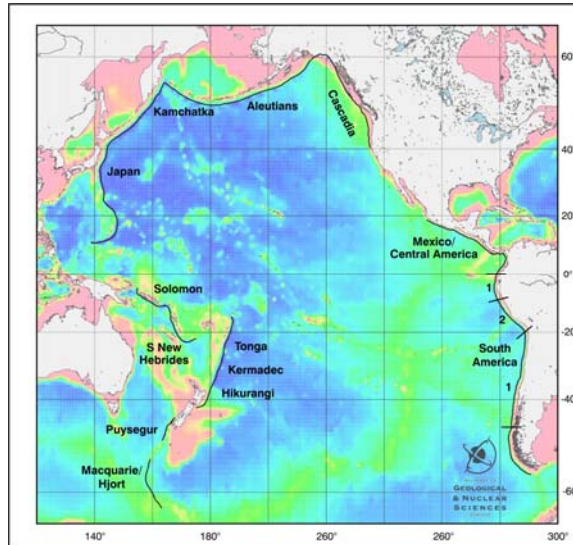


Figure 1. Earthquake sources considered

3. Tsunami height

The wave height generated depends on how much uplift or subsidence takes place on the ocean floor. In the 2004 Indian Ocean tsunami, for instance, a section of ocean floor about 1200 km long was uplifted 10 metres. No wonder there was a large wave! In risk assessment we use the magnitude of the earthquake to predict the amount of disruption of the ocean floor, and hence the initial wave height. Earthquake source modelling provides some clues here.

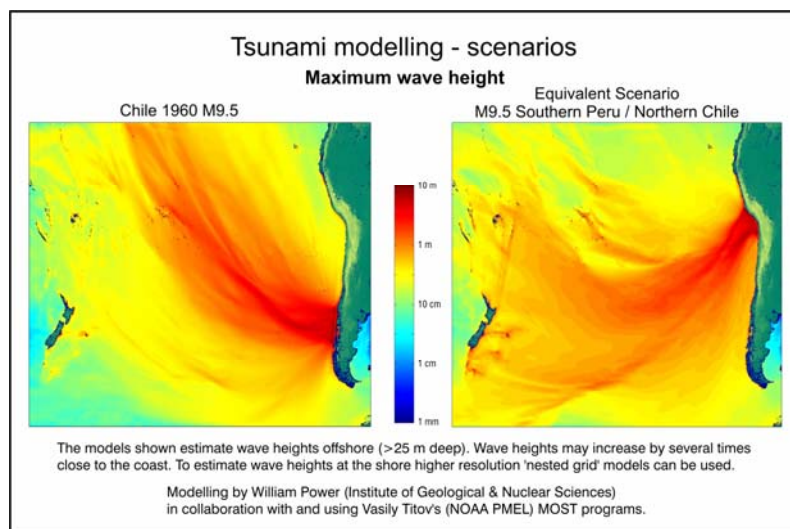


Figure 2. Two modelling scenarios, for tsunamis generated by earthquakes in South America

4. Tsunami propagation

Tsunamis travel very fast across the deep ocean (up to 600 km/hr). The speed depends on water depth, so they slow down when they reach the coast. The arrival time of the first wave can be predicted quite precisely, although this may not be the largest. More difficult to assess, however, is the height of the wave when it arrives at the coast, and for this we

use very detailed computer modelling, which involves knowing the water depth everywhere along the path. Figure 2 shows two examples of modelling of tsunamis from South America.

5. Inundation

As the water shallows when the wave approached the coast, the velocity decreases so that the back of the wave catches up with the front. The result is a large increase in wave height, and this is what caused the wave heights of tens of metres along the Sumatra coast in 2004. But the way in which this wave runs up on land is extremely complicated, affected not only by the height of the land and shape of the beach but also by the obstacles to the water, such as buildings, trees, dunes, etc. So this aspect of modelling also fraught with much uncertainty. The aim is to estimate the depth and speed of water everywhere in the inundation zone, but it is very difficult to do this precisely. In the MCDEM study GNS used three different inundation models, combining their results to show the resultant uncertainty in loss estimates.

6. Assets

What assets will be affected by the inundation? A comprehensive loss assessment needs a detailed register of assets. For building loss, this involves not only the number and location of buildings, but also their resilience to damage. Light frame buildings are likely to be carried away by tsunamis of more than a metre or two, but sturdier buildings will remain, perhaps with walls punched out by the water. Assessment of deaths and injuries will require knowledge of the number of people in vulnerable locations, and will also depend critically on whether or not there is an effective warning. For an tsunami that was generated in South America there is likely to be 12 to 14 hours' warning, enough to evacuate almost everybody from vulnerable locations, but for locally generated tsunamis, which strike perhaps only a few minutes after the earthquake, this will not be possible. Studies of likely deaths and injuries should properly distinguish between day and night situations, whether it is holiday season or not, and whether or not a warning system can be expected to be effective.

7. Results: individual locations

The 2005 study assessed the risk for 22 different localities, presenting estimates of likely wave heights, costs to buildings, deaths and injuries as these vary with probability of occurrence. The term "Return Period", which is used in the graphs below, needs to be understood. If an event recurs about once every 200 years, say, it has an annual probability of occurrence of 1 in 200 and we say it has a mean return period of 200 years. This does not mean that occurrences are regular, 200 years apart. Rather it refers to the chance that such an event will occur this year: 1 in 200, in this case. It is a long term average measure, useful for comparing different events and other occurrences. Thus Figure 1 below expresses the wave height (above mean sea level) on the eastern coast of Auckland City, for return periods out to 2500 years. Thus there is a 1 in 2500 chance that there will be wave of 5.5 metres or more on that coast, this year or any year. There is a 1 in 500 chance that it will be greater than 3.6 metres. Note also the broken lines, which indicate the uncertainty in the modelling. The 3.6 metres estimate for the 500 years, could be as great as 5 metres, or as small as 2.7 metres. This uncertainty represents the lack of knowledge about precise parameters for earthquake occurrence,

tsunami generation and propagation. These broken lines represent the 16th and 84th percentiles in the data.

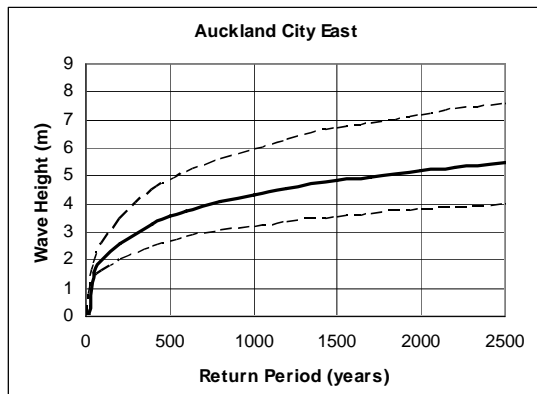


Figure 3. Wave heights at Auckland East, for return periods from 0 to 2500 years.

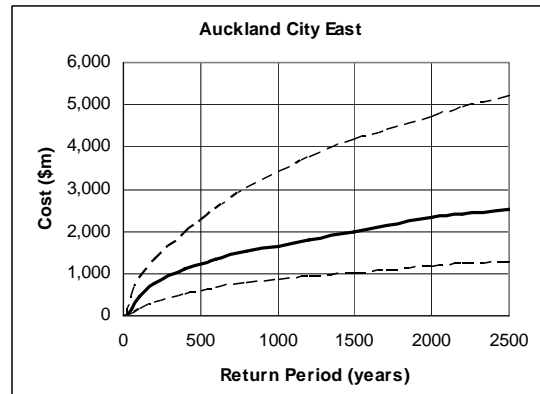


Figure 4. Cost of damage to buildings

Figure 4 to 6 show the estimated costs of damage to buildings, deaths and injuries resulting from waves inundating the eastern shores of Auckland City. It is clear that there is risk from tsunami in both the Waitemata and Manukau harbours, so they were treated separately in the analysis. It turned out that the risk on the western side (Manukau harbour) is much less than on the eastern side (Waitemata harbour) because of the exposure on the east to many more earthquake sources). As with the estimates of wave height, the uncertainty bounds are quite wide.

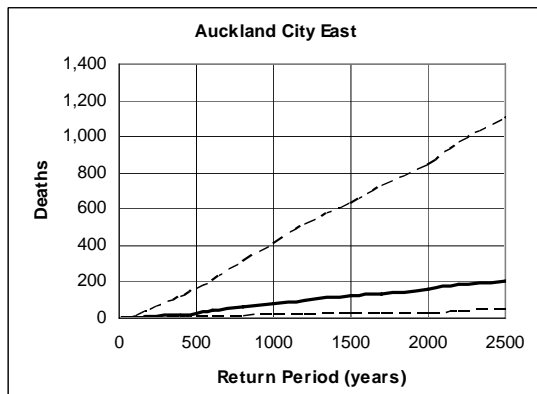


Figure 5. Likely deaths at Auckland East

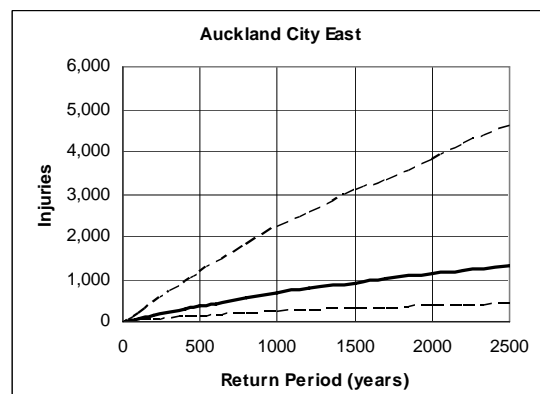


Figure 6. Likely injuries at Auckland East

8. Results: national totals

In addition to assessing the risk to individual localities, it is also important to examine the widespread effects of a tsunami, in that many localities could be affected on the same occasion. This would most likely result from a Pacific-wide tsunami, such as from South America, which could inundate many localities on New Zealand's east coast. Figure 7 shows the total cost of damage to buildings, nationwide, in individual tsunami events, and Figure 8 shows the related deaths. That these are much greater than the expected loss in earthquakes (especially the deaths estimate) is demonstrated in Figures 9 and 10.

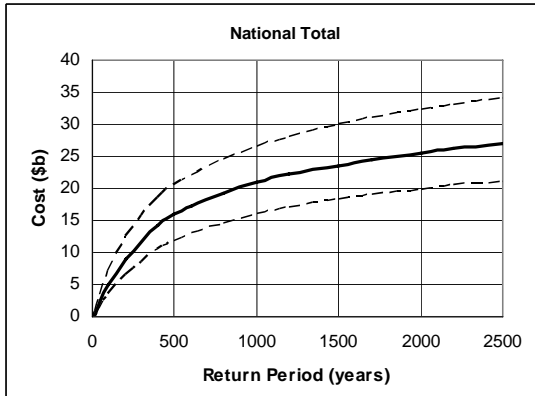


Figure 7. Cost of building damage, nationwide

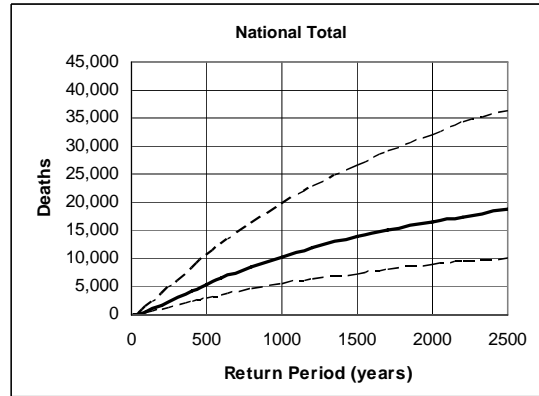


Figure 8. Total deaths per event, nationwide

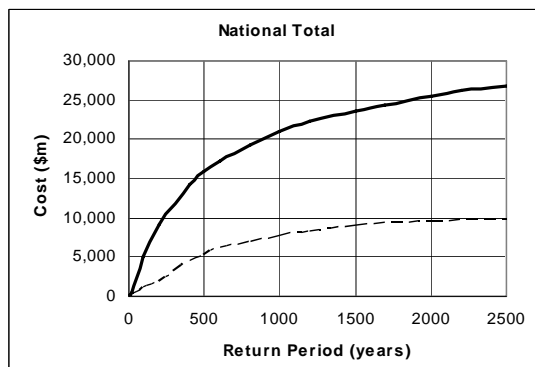


Figure 9 Comparison of likely losses from tsunami (solid line) and earthquake (broken line)

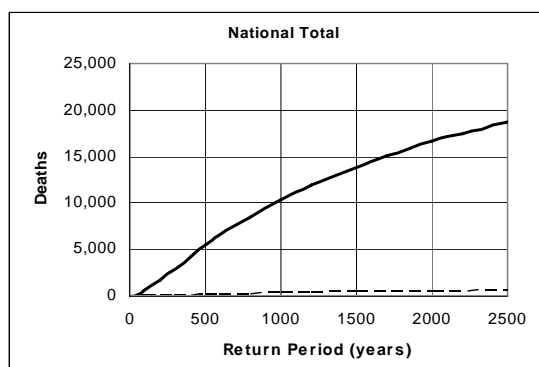


Figure 10. Comparison of likely deaths from tsunami (solid line) and earthquake (broken line)

9. Where do the waves mostly come from?

In a process known as deaggregation, we can determine the predominant sources of the most damaging waves. The analysis gives the result that for some localities, such as Christchurch, the predominant source of damaging waves is South America. The reason is not hard to determine: there are very few local sources of tsunamis off the East Coast of the South Island. But for Wellington, while it is still exposed to tsunamis from South America, the predominant source is the Hikurangi subduction zone off the East Coast of the North Island. The consequences for Civil Defence are very significant: a warning system in Christchurch could be expected to be very effective, because there is likely to be a warning of 12 hours or more before the tsunami arrives. Wellington is not so fortunate, because a warning of an hour or less is not adequate for any effective evacuation exercise. Localities like Gisborne and Napier are exposed to tsunamis from both local and distant sources, so the possibility of an effective warning is intermediate between the Wellington and Christchurch situations.

10. Where to from here?

Much remains to be done, in terms of research that will help refine the modelling. Seismological knowledge of the various earthquake source regions is increasing all the time, and models of their behaviour are being developed. It is expected, therefore, that we will be much better informed about these sources in the future, in terms of the likely magnitudes of earthquakes and their frequency of occurrence. The process of generation

of tsunamis from earthquakes is not well described either, and understanding of this can be expected to improve. Many computer codes are being developed to model the propagation across oceans and their inundation of coastal land. Lastly, the effects on buildings and people will be better understood when more data come to hand of actual losses. An example of new information with regard to both inundation and damage comes from the tsunami in Java in July 2006. GNS and NIWA staff travelled to Java to examine the aftermath of the tsunami, took detailed measurements of inundation and obtained information about damage and casualty counts.

It can confidently be expected that future studies, using this new information, will provide more robust assessments of tsunami risk in New Zealand.

Website from which the two reports can be downloaded:
emergency.management@dia.govt.nz