Integrating tsunami inundation modelling into risk-based land-use planning: an update of guidance

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GNS Science Miscellaneous Series 132

December 2019

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BIBLIOGRAPHIC REFERENCE

Beban J, Gunnell S, Saunders WSA. 2019. Integrated tsunami inundation modelling into risk-based land-use planning: an update of guidance. Lower Hutt (NZ): GNS Science. 47 p. (GNS Science miscellaneous series 132). doi:10.21420/6MGN-4T72

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ISSN 1177-2441 (print)
ISSN 1172-2886 (online)
ISBN 978-1-99-001007-1 (print)
ISBN 978-1-99-001008-8 (online)
http://dx.doi.org/10.21420/6MGN-4T72

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ABSTRACT

In 2011, GNS Science produced guidance aimed at land-use planners and decision makers on how tsunami inundation modelling can be incorporated into land-use planning to reduce the risk posed by this hazard (Saunders et al. 2011). However, land-use planning for tsunami hazard remains an underutilised tool in New Zealand, with most modelling completed to date only being sufficient to produce tsunami evacuation zone maps. In order to encourage and support the uptake of land-use planning methods to manage tsunami hazard risk, this updated guidance presents two examples of how a risk-based approach to address tsunami hazard has been developed at a regional and also district council level.

This updated guidance retains the format and content of the original document where appropriate. The basics of tsunami are again provided, along with identification of the key pieces of legislation governing natural hazard risk in New Zealand, and how they can contribute to managing tsunami risk. The opportunity is taken to update the guidance to reflect recent changes to legislation in New Zealand and emphasise the latest approaches to the risk assessment process.

Some of the key factors that need to be decided when considering tsunami inundation modelling are also discussed. The main message of this guidance is that the requirements of tsunami modelling need to be discussed and agreed with those undertaking the modelling before it is commissioned. This is to ensure that the scenarios modelled and the level of uncertainty in the results are suitable for the intended end-use, otherwise poor outcomes will arise. For example, tsunami inundation modelling to define evacuation zones in New Zealand is generally based upon the worst-case scenario (low probability but high potential consequences), as the purpose is to promote life safety. There is a high degree of conservatism in the results, as the modelling does not account for the full range of possible tsunami generating scenarios or tsunami wave behaviours. As such, this type of modelling should not be applied for land-use planning purposes to restrict private development rights. Guidance on tsunami modelling levels for evacuation purposes is available from the Ministry of Civil Defence and Emergency Management (MCDEM 2016), and this guidance continues to recommend that the modelling levels for land-use planning are based on the same approach. In general, Level 1 modelling is not recommended for use in New Zealand; Level 2 modelling is recommended primarily for emergency management readiness and inclusion into LIMs, with limited use for land-use planning; and Levels 3 and 4 are regarded as suitable for informing land-use planning decision-making.

To assist decision-makers with incorporating tsunami inundation modelling into land-use planning processes an updated decision tree is presented. Regulatory and non-regulatory options for including tsunami hazard risk into land-use planning are outlined, including avoiding new development or intensification in high risk areas, mitigating the risk with tsunami evacuation structures, and ensuring that development facilitates evacuations routes. A risk-based approach to managing tsunami risk should be taken, which is consistent with recent amendments to the Resource Management Act 1991 that require consideration of both the likelihood of a natural hazard event and the consequences to land and buildings when assessing if risk is significant when the subdivision of land is being proposed. A risk-based approach can be supported by precautionary approaches where uncertainty is high and must include the use of participatory approaches to ensure the outcomes reflect the expectations and risk tolerance of the affected community.

An adaptive risk-based approach based on the work of Saunders et al. (2013) is outlined, which involves determining severity of consequences of an event; evaluating the likelihood of an event occurring relevant to the consequences; then determining the resource consent activity status based on quantified levels of risk. Resource consent activity status becomes more restrictive as the potential consequences increase. Two case studies are presented demonstrating how this framework has been adapted for use in the Bay of Plenty Regional Policy Statement, where the use of an Annual Individual Fatality Risk (AIFR) metric has been introduced, and the draft Porirua District Plan that proposes to manage tsunami risk based on the sensitivity of activities.

KEYWORDS

Tsunami, inundation modelling, land-use planning, risk-based approach, uncertainty, Porirua District Plan, Bay of Plenty Regional Policy Statement.

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1.0 INTRODUCTION

1.1 Purpose and Scope of the Guidance

Despite the development of the 2011 guidance by Saunders et al., examples of land-use planning for tsunami within New Zealand local government remain limited. As found by Saunders et al. (2014), few territorial and regional authorities in New Zealand have plan provisions that specifically address tsunami hazard. Only one district plan was found to have an objective that included tsunami, just over 10% of district plans had policies related to tsunami, and only 7.2% of the plans reviewed (five district plans) included a rule for tsunami. The emphasis for managing tsunami hazards currently remains on emergency management readiness and response, with all regions of the country having undertaken tsunami evacuation zone mapping.

However, a shift towards planning for tsunami has been gradually occurring, with the Thames-Coromandel District Plan including tsunami specific objectives, policies and rules, consideration of planning measures to reduce tsunami risk at Te Tumu (a new growth area identified for Tauranga), and the inclusion of resource consent conditions to manage the increased tsunami risk created by the development of the America's Cup Village on Auckland City's harbour[1]. There is growing recognition of the potential effectiveness of risk reduction measures for tsunami, especially when integrating modelling with land-use planning and urban design.

Progress has been slow in implementing land-use planning measures in New Zealand, and this can possibly be attributed to the infrequency of damaging tsunami in the recent past, difficulty in handling inherent model uncertainty, and a lack of understanding between planners and modellers. Another reason may be that previous modelling by councils was not adequate to allow for modelling to be used at a scale that was defensible and robust enough for contested land-use planning processes. There have been significant advances in tsunami knowledge and probabilistic modelling in recent years, which provide councils with greater opportunity to use tsunami inundation modelling. This update seeks to improve the current situation by providing two case studies where a risk-based approach has been taken to managing the risk posed by tsunami, at both a regional council and territorial authority[2] level.

This update retains material from the original guidelines where relevant and revises those areas where changes or advances in understanding have occurred. An overview of tsunami basics is provided in Section 2.0 and the legislation under which tsunami hazard is managed in New Zealand is outlined in Section 3.0. Guidance on what tsunami modelling is appropriate for different applications and discussion on the types of uncertainty generally associated with tsunami hazard models is provided in Section 4.0. Section 5.0 looks specifically at current methods for incorporating tsunami hazard models into land-use planning, with case studies of the Bay of Plenty Regional Policy Statement (BOPRPS) and the recent draft Porirua District Plan provided in Section 6.0. Summarising comments are then provided in Section 7.0.

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[1] Panuku Development Auckland Limited v Auckland Council [2018] NZEnvC 179

[2] Territorial authorities are the second tier of local government in New Zealand and sit below regional councils. The term is used to refer to city and district councils, as well as unitary authorities that perform the functions of both a regional and city/district council.

1.2 Limitations of the Guidance

The guidance presents options for including tsunami modelling into land-use planning only. However, the options provided are not exhaustive, and other methods (e.g. paleo-tsunami research and other planning tools) may also be appropriate. This guidance is also representative of current knowledge and practice, and it is recognised that updating will be required with future advances in tsunami research and modelling.

2.0 TSUNAMI BASICS

The explanations in Section 2.0 have been adapted from Power (2013), which updates Berryman (2005) and the MCDEM "*Working from the same page*" series that was last updated in 2017 (MCDEM 2017).

2.1 What is a Tsunami?

A tsunami is a natural phenomenon consisting of a series of waves generated when a large volume of water in the sea, or in a lake, is rapidly displaced. Tsunami are known for their capacity to violently flood coastlines, causing devastating property damage, injuries, and loss of life. The principal sources of tsunami are:

- Large submarine or coastal earthquakes, in which there is significant displacement of the seafloor;
- Underwater landslides (which may be triggered by an earthquake or volcanic activity);
- Large coastal cliff or lakeside landslides; or
- Underwater volcanic eruptions.

Tsunami waves differ from ordinary coastal waves in that the entire column of water, from the ocean floor to the surface, is affected (Figure 2.1). Tsunami waves contain considerable energy which means they can travel much further than ordinary coastal waves. The amplitude of tsunami waves in deep water is normally less than one metre, and therefore they are often not noticed by ships or able to be seen by aircraft, although they can be detected in the open ocean by satellites with sea-surface elevation technology. However, as tsunami waves reach shallower waters, their speed decreases rapidly compared to that in the open ocean, and at the same time their height increases. A tsunami wave that is only half a metre high in the open ocean can transform into a 10m high wave, travelling at speeds of 10–40kmhr once it hits the shore.

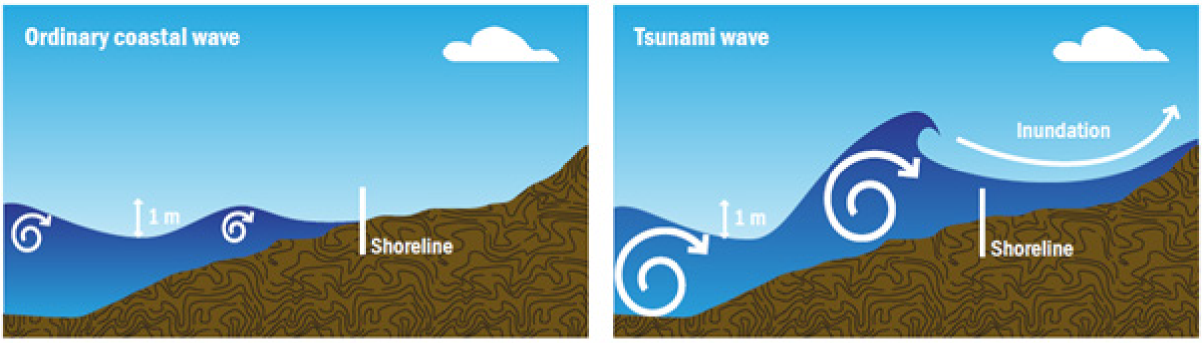

Figure 2.1 The difference between an ordinary coastal (wind) wave (left) and a tsunami wave (right). Wave energy in ordinary coastal waves is limited to the surface of the ocean. This energy rapidly dissipates as the wave breaks on the shoreline (left). Energy in tsunami waves however, affects the entire column of water from the ocean floor to the surface (right). This energy does not readily dissipate. Instead, water is pushed upwards over a large area giving it a long wavelength, and once it reaches a coastline it can travel much further inland than an ordinary coastal wave. A one metre tsunami cannot be likened to a one metre ordinary wave. One metre of wave height, the height between peak and trough, is shown; note how the amplitude (further defined in Figure 2.2) increases to greater than one metre as the wave reaches the shoreline.

While some tsunami can be very large and can rapidly and violently inundate coastlines, causing loss of life and property damage, others will be small but still dangerous to those near or in the coastal water. It is important to remember that not all earthquakes will generate a tsunami, and that earthquakes are not the only sign of an impending tsunami.

Tsunami waves are described by their wavelength, wave period, wave height, amplitude and their run-up (see Figure 2.2). Wavelength is the distance between consecutive peaks. This can vary for tsunami waves from several kilometres to over 400km, compared to a wavelength of around 100m for normal waves. Wave period is the time between two consecutive peaks passing a point, and can vary from several minutes to hours, rather than a few seconds for normal waves. Therefore, when tsunami waves reach the shore, they can inundate for several minutes, before retreating for as many minutes, before the arrival of the next wave. It is important to remember that the first wave may not be the largest in the wave sequence. Tsunami wave height is a measure of the vertical trough-to crest height of a tsunami wave. Tsunami wave height is not constant – it increases substantially as the waves approach the shore and it depends on the near shore bathymetry. Conversely, wavelength decreases as the wave approaches the shore. Once the wave reaches the shore the 'amplitude' is the height of the wave peak above the sea level at the time; and as the wave travels inland 'flow depth' is then used to describe the depth of water flowing over a specific point.

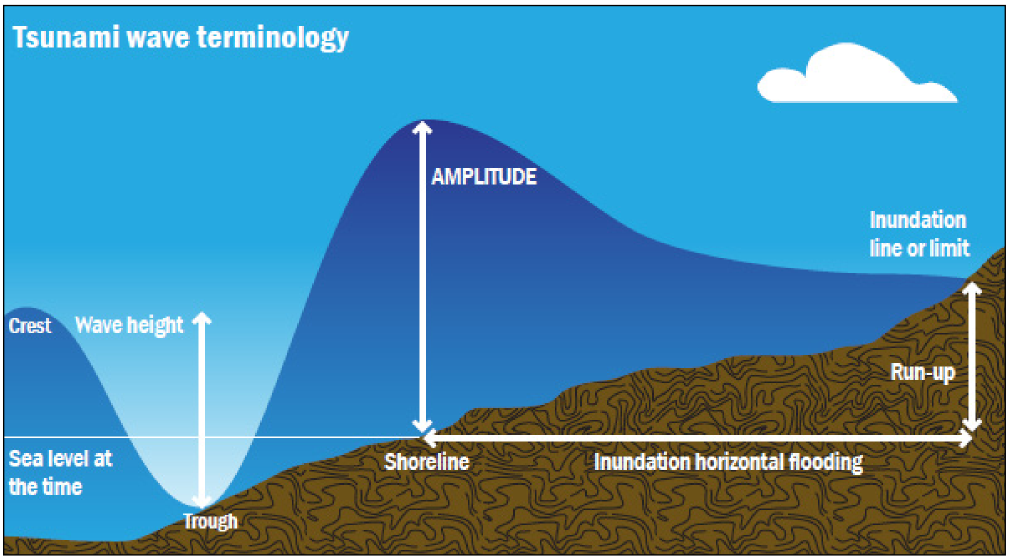

Figure 2.2 Tsunami terminology.

Tsunami run-up is the maximum vertical elevation (above either mean sea level or the sea level at the time of the tsunami) that the tsunami reaches at the inland limit of inundation. Run-up is dependent on the type and size of the tsunami, as well as coastal topography and land-use. Tsunami run-up is a more useful measure than tsunami wave height as it relates more closely to the onshore effects of a tsunami.

Run-up is not the only way to describe tsunami impact. Flow depth and speed, collectively referred to as 'flux', are the most important factors for engineering purposes such as for coastal protection or building design and construction (Figure 2.3).

The inundation distance and flux may be more important than the run-up. For example, for gently sloping topography, the run-up height may be minimal even though the tsunami impacts can be huge; for steep slopes, the run-up will be greater, but the impact is often less, as steep slopes are generally more difficult to develop with buildings and infrastructure.

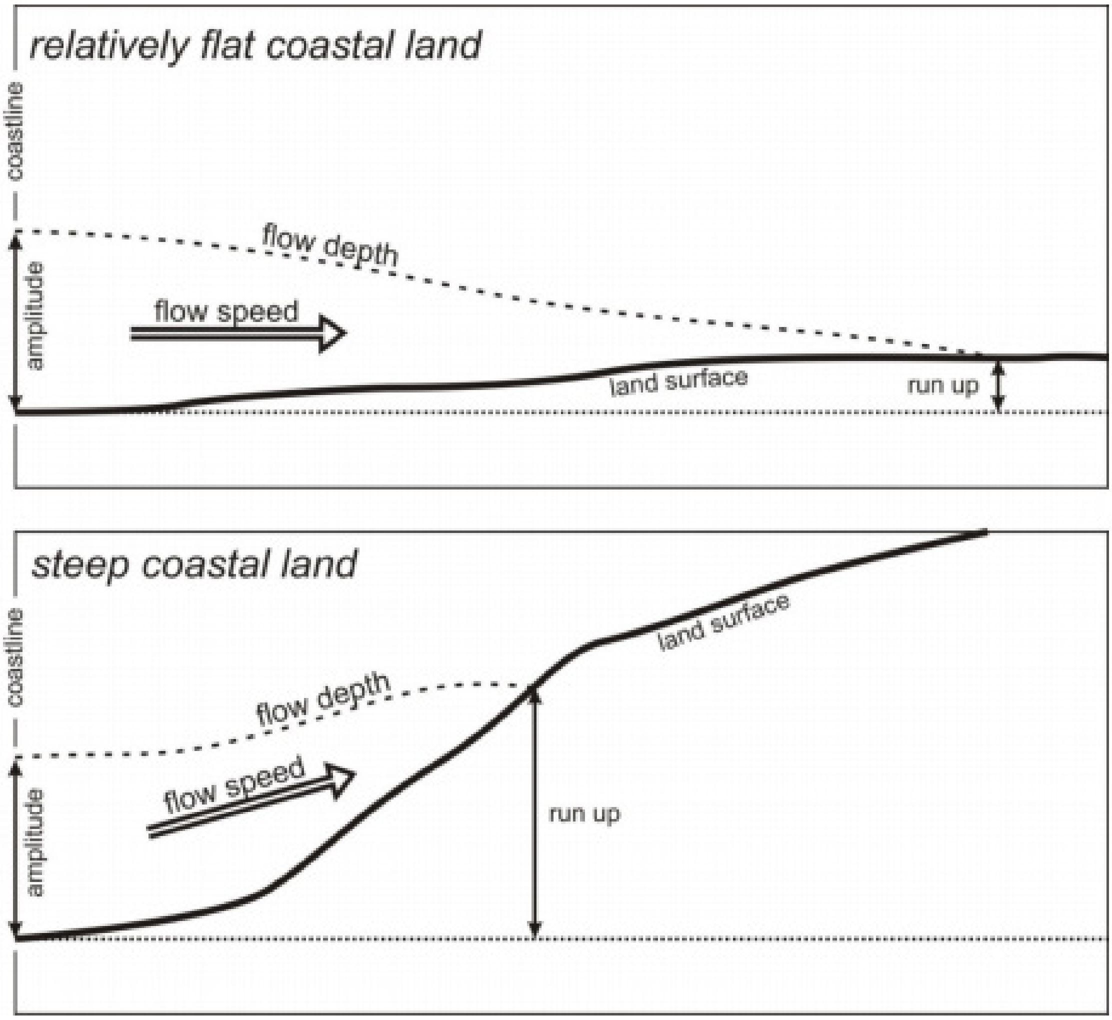

Figure 2.3 The influence of topography on inundation distance. The same flow depth and speed (referred to together as 'flux') can give markedly different inundation distances and run-ups over flat compared to steep land.

Sea level rise may also influence inundation distance in the future; for example, as sea levels rise in the future, erosion of a dune system may increase, leading to inundation further inland than at present.

2.2 Tsunami Damage

Casualties and damage resulting from tsunami are generally due to the following factors:

- Fast moving water torrents (both inundating and receding) and travelling bores[3] which can have a significant impact upon buildings, infrastructure and people and cause substantial erosion of the coast and sea-floor. The receding tsunami flow is often the main cause of drowning, as people are swept out to sea.
- The impact of debris carried by the inundating and receding tsunami flows on people and structures.

[3] Tsunamis often form bores in harbours, man-made waterways, and in coastal rivers and streams, which are a non-breaking stepped increase in water level caused by the funnelling of the tsunami wave. They can travel several kilometres up a watercourse and can damage wharves and bridges and flooding of adjacent flat land (Power 2013).

- Fire and contamination, which can occur when fuel installations are floated or ruptured by debris. Contamination can also be caused by broken or flooded sewerage pipes, or other sources of harmful chemicals.
- Inundation and saltwater-contamination by the ponding of potentially large volumes of seawater can cause longer term damage to buildings and productive farmland.

The potential effects of tsunami can be categorised as tangible and intangible, with tangible effects further grouped into direct and indirect effects. Direct effects are the most visible consequences from the immediate impact, such as structural damage and loss of life. Indirect effects emerge later, and while a consequence of the event, are not due to the direct impact, such as disruption of economic and social activities. Instead of direct and indirect effects, the terms damages and losses are sometimes used, for example in the Post Disaster Needs Analysis (PDNA) which is conducted after a disaster event.

Table 2.1 provides a summary of the types of direct impacts that can be caused by tsunami waves, while Table 2.2 considers indirect and intangible effects.

Table 2.1 Potential direct impacts of tsunami (Power 2013).

	People & animals	**Built environment**	**Natural environment**
Inundation	Drowning	Damage by inundation/water contact	Disturbance of marine habitats (coral reefs, seagrass beds, lagoons, mangroves, intertidal flats)
		Failure of mechanical equipment, electrical and communication systems and equipment	Loss of protected areas
		Structural damage due to hydrostatic forces (e.g. pressure on outside walls)	Disturbance of terrestrial habitats (forests, wetlands, riverine areas, beaches, dunes, surface and groundwater, soils)
		Damage to buoyancy (flotation or uplift forces)	Damage to farmland and yield
		Saturation causing slope instability (e.g. stop banks)	
Currents	Washed off feet	Structures washed away due to hydrodynamic forces (pushing forces and drag)	Loss of coastline/beach, dunes, seagrass beds etc. due to erosion
	Impact with structures	Walls, fences, road surfaces, railways, ports/harbours, power, telecom poles, gas, oil or water pipelines damaged or destroyed	Breaking and overturning of trees

	People & animals	Built environment	Natural environment
		Scouring of building or bridge foundations, power poles, coastal or river defences, railways and road embankments	Fish and shellfish thrown ashore, with consequent contamination
		Scattering and subsidence of concrete blocks	Destruction and loss of rafts, fishes and shells in aquaculture
		Ship, boat and wharf damage	Harbour change in water depth (erosion and accumulation)
		Damage to farms buried by sands	Disturbance, soil erosion and siltation
Debris	Injured or killed by debris	Structural damage by debris impact	Hazardous waste
		Rails and roads buried by sediment and debris	Build-up of marine debris
Contamination / Fire	Injury/illness due to contact with contaminated water	Oil spills from vehicles, ships, heaters, storage tanks	Salinisation
		Contamination due to sewage	Contamination of near-shore environment
		Fire from gas of electricity leaks	Eutrophication
		Damage from sediment deposition	
		Fire from waterborne flammable materials	

Table 2.2 Summary of main indirect and intangible impacts of tsunami (Power 2013).

Indirect			
Social	**Infrastructure**	**Economic**	**Intangible**
Increased costs for medical treatment and care	Disruption of networks (roads, lifelines, etc.)	Disruption to flows of goods and services	Inconvenience of disruption of services
Disruption of households (e.g. extra travel costs, temporary accommodation, etc.)	Loss or reduction of earnings and income	Costs of relocation	Health effects
		Additional costs in public sector (e.g. extra staff, training, etc.)	

Indirect			
Social	**Infrastructure**	**Economic**	**Intangible**
Increased debts	Loss of production and services		Loss of memorabilia
Increased poverty	Clean-up costs	Disruption of businesses	Loss of confidence
Costs of relocation	Increased operating and distribution costs	Loss or reduction of earnings and income	Loss of contracts
Additional heating costs	Costs of demolition and debris removal	Loss of production and services	Stress, trauma, depression
Loss of jobs/livelihood	Increase in water and sanitation operating costs	Costs of emergency response and relief	Loss of environmental assets
Loss or reduction of earning and income	Increase communications service during recovery phase	Clean-up costs	Loss of heritage/cultural assets
Increased prices for food, energy, and other products		Decrease in tourism	Loss of tourist attractions
Decreased land prices		Losses in yields (crop and livestock)	Decrease in air and water quality
Disruption of provision of basic public services (education, health, cultural etc.)		Revenue losses to central, regional and local governments (from reduced tax base)	Degradation of landscape quality, loss of biodiversity and soil erosion
Increased operating costs		Costs of higher unemployment	Reduced quality of life, and inequities in the distribution of impacts and disaster relief
		Fewer businesses (due to bankruptcies etc.)	Lack of food and drinking water
		Costs of responding to new situation (e.g. tourism campaign)	Reduced investor confidence
		Costs of demolition and debris removal	Social conflicts
		Downstream effects of relocation and restructuring on economy and workforce (decline of GDP, decrease in exports, inflation)	

2.3 New Zealand's Tsunami Exposure

New Zealand lies across the boundary between the Australian and Pacific tectonic plates (Figure 2.4). To the east of the North Island, the Pacific plate is being thrust beneath the Australian plate in a process known as subduction, and the reverse occurs off the southwest part of the South Island. The Hikurangi plate interface may be one of the most important sources of tsunami that impact on New Zealand (Power et al. 2008). Large tsunami, such as those that struck the Indian Ocean in 2004 and Japan in 2011 are most frequently caused by earthquakes on plate boundaries where subduction takes place.

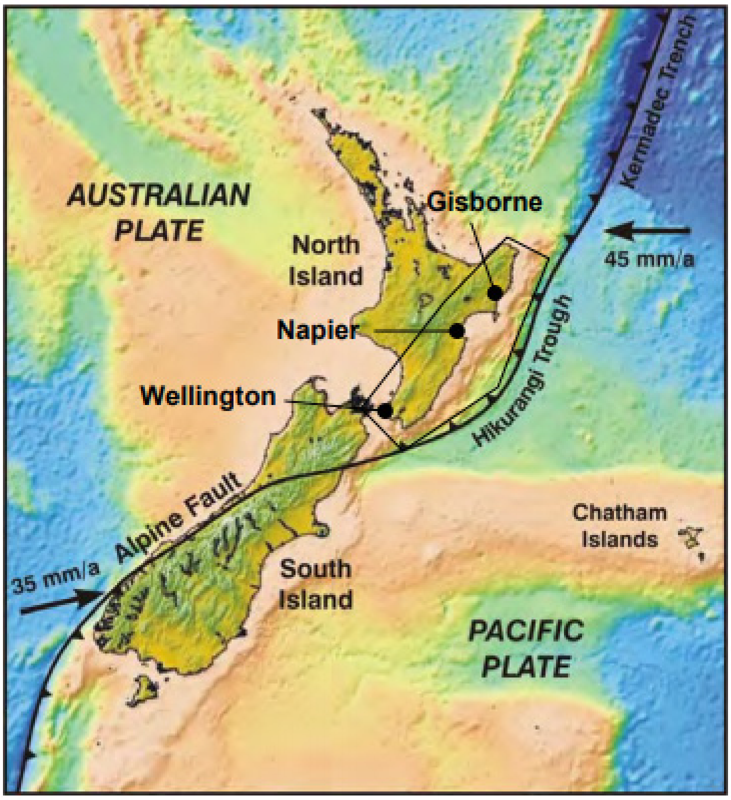

Figure 2.4 Location of the boundary between the Pacific and Australian tectonic plates. The plate interface along the Hikurangi Trough and Kermadec Trench is a possible source of tsunami. Numbers indicate the rate of movement on the plate boundary per annum; the enclosed area represents/shows the surface projection of the boundary (Power et al. 2008).

Tsunami sources that impact on New Zealand can be divided into three categories (Berryman 2005), shown in Table 2.3 below:

Table 2.3 Tsunami sources and expected travel times.

Source	Travel time
Distant source	More than 3 hours travel time from New Zealand
Regional source	1–3 hours travel time from New Zealand
Local source	0–60 minutes travel time to the nearest New Zealand coast (most sources are <30 minutes travel time)

Distant sources include tsunami generated from earthquakes on the South American margin along Chile and Peru, Alaska-Aleurian margin, Kamchatka-Kuril-Japan margin, south Pacific subduction zones of the Solomon Islands and the Tonga-Kermadec trench. Regional source tsunami will most likely be generated from the Puysegur trench, southwest of New Zealand, and the Tonga-Kermadec trench, northeast of New Zealand . Local sources are the Hikurangi subduction zone and the Fiordland-Puysegur subduction zone (Power 2013).

New Zealand has been affected by at least 80 tsunami during the period 1835–2011 (Downes et al. unpub data in Power 2013) (Figure 2.5). The eastern coast of New Zealand has the greatest exposure to tsunami due to the proximity to areas of high local seismicity. However, every part of the New Zealand coastline is subject to some degree of tsunami hazard (Power 2013). Despite this high level of exposure, New Zealand has limited direct experience of tsunami, and therefore managing the risk is generally not prioritised (NZIER 2015).

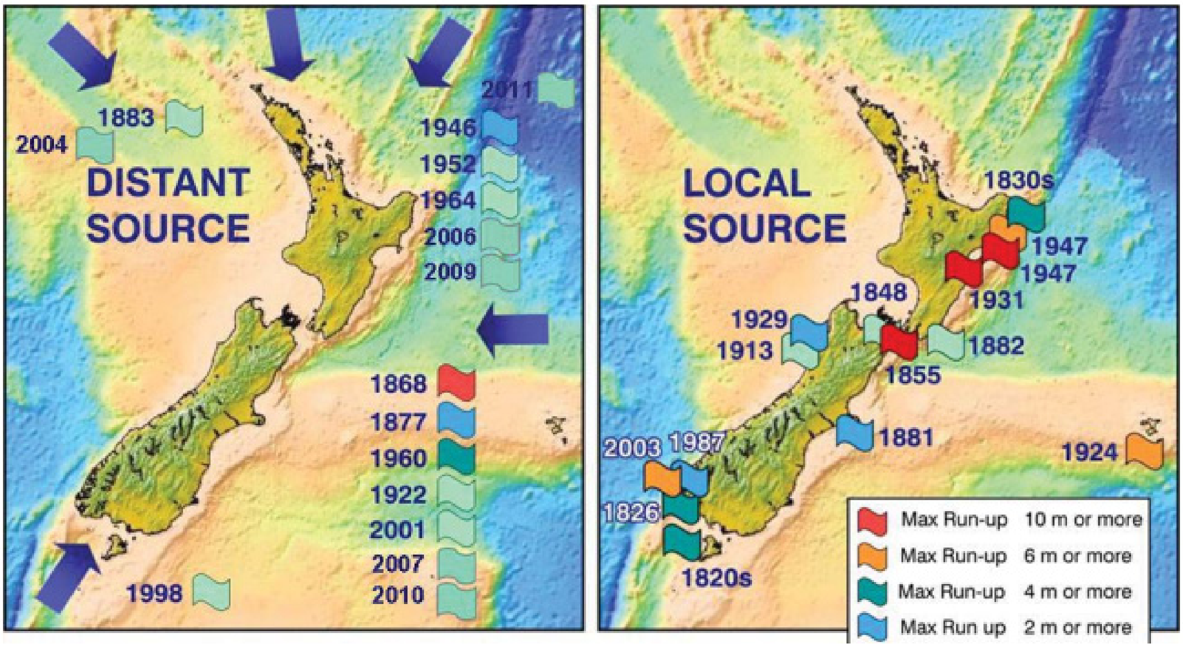

Figure 2.5 Run-up height from distant and local-source tsunami in the New Zealand historic record, 1820s to 2013 (Fraser 2014 updated from Berryman 2005).

The written historical record of tsunami in New Zealand covers too short a timeframe to reflect the full range of possible tsunami events that New Zealand might experience. Many large earthquakes have recurrence intervals of hundreds of years for the smaller events (e.g. M8.5) to several thousand years for the largest earthquakes (e.g. M9.5). Also, historical record of small tsunami, or tsunami in the early years of our history, in sparsely populated or remote places (such as Fiordland) is almost certainly incomplete (Berryman 2005).

In 2005, a national review of New Zealand's hazard and risk from tsunami was undertaken (Berryman 2005). That report examined all the likely sources of tsunami that could affect New Zealand, with an evaluation of their potential to generate tsunami, the likely waves produced, and their impact on the principal urban centres around the New Zealand coastline. The information contained in the 2005 report has since been updated, with *Review of Tsunami Hazard in New Zealand (2013 update)* (Power 2013) and *Review of Tsunami Risk facing New Zealand: A 2015 Update* (Horspool et al. 2015) now providing the current state of knowledge in terms of the tsunami risk faced by New Zealand. The 2013 report considers all likely sources of tsunami that could impact upon New Zealand and the likely size of the tsunami generated as it hits the coastline, using a revised probabilistic hazard model (Figure 2.6). As seen in

Figure 2.6, it provides hazard estimates for the entire coastline of New Zealand, expanding upon the 2005 report which only provided estimates for the main city centres.

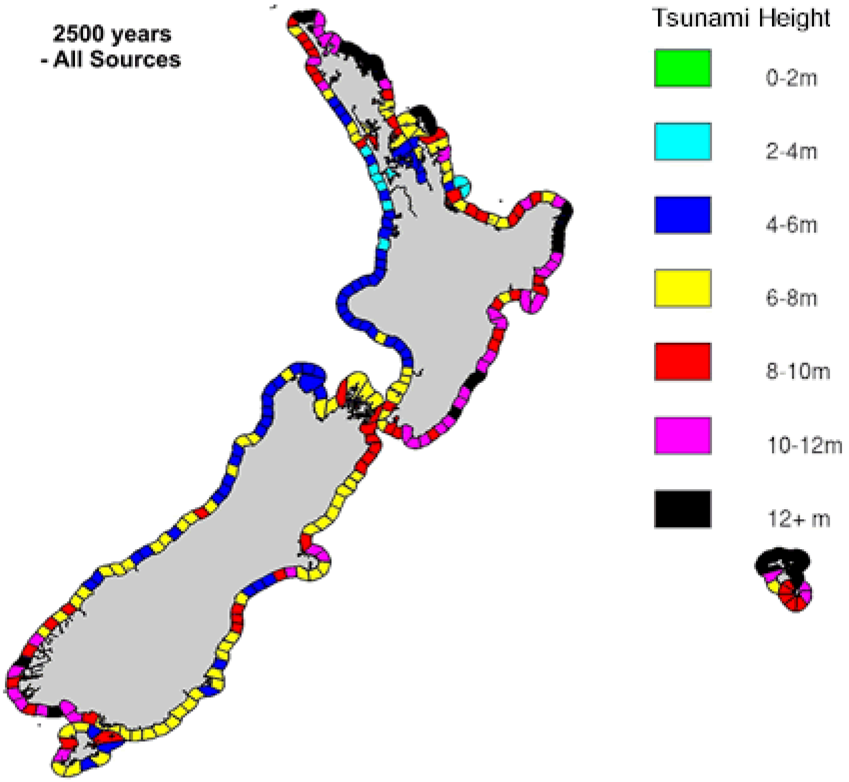

Figure 2.6 The expected maximum tsunami heights in metres at the 2500-year return period, and 50th percentile of confidence, for 20km sections of the New Zealand coastline (Power 2013).

While the reassessment found that tsunami hazard had not greatly increased from that detailed in the 2005 report, it did find that the hazard had increased in those areas most susceptible to tsunami generated by local subduction zones, namely the east-facing coasts of the North Island and the southwest corner of the South Island (Power 2013). The 2013 report did not update the risk estimates of the 2005 report, and this was consequently completed by Horspool et al. (2015), to supplement a report prepared by the New Zealand Institute of Economic Research (NZIER) for the Earthquake Commission (NZIER 2015). Horspool et al. (2015) updated the modelled losses for four high-risk cities, being Wellington, Napier, Tauranga and Auckland, for a range of tsunami scenarios, including a M9.0 Hikurangi subduction zone tsunami and a M 8.9 Kermadec subduction zone tsunami. The results clearly demonstrate that the management of tsunami risk needs to be prioritised by land-use planners to reduce the potential impacts of a large magnitude subduction zone tsunami at New Zealand's coastline, such as that experienced by Japan in 2011.

3.0 ROLES AND RESPONSIBILITIES FOR TSUNAMI RISK

3.1 An Overview of Natural Hazard Management

Five key pieces of legislation contribute to natural hazard management in New Zealand: Resource Management Act 1991 (RMA), Building Act 2004, Civil Defence Emergency Management Act 2002 (CDEM Act), Local Government Act 2002 (LGA), and the Local Government Official Information and Meetings Act 1987 (LGOIMA). Figure 3.1 shows the five main statutes that govern natural hazards planning and how they operate at different levels of government, namely central (orange), regional (green) and district/city (blue) levels. The hierarchy of plans established under each law provide various statutory and non-statutory tools for natural hazards planning (see solid and dashed boxes). The solid arrows show established relationships in the hierarchy of provisions. The dashed arrows highlight relationships between existing provisions that can be improved. These relationships may be one- or two-way. These legislative provisions and the array of tools they provide constitute a robust 'toolkit' for natural hazards planning. However, many of these tools are not well known or used to their full potential to reduce hazard risk and build community resilience (Glavovic et al. 2010).

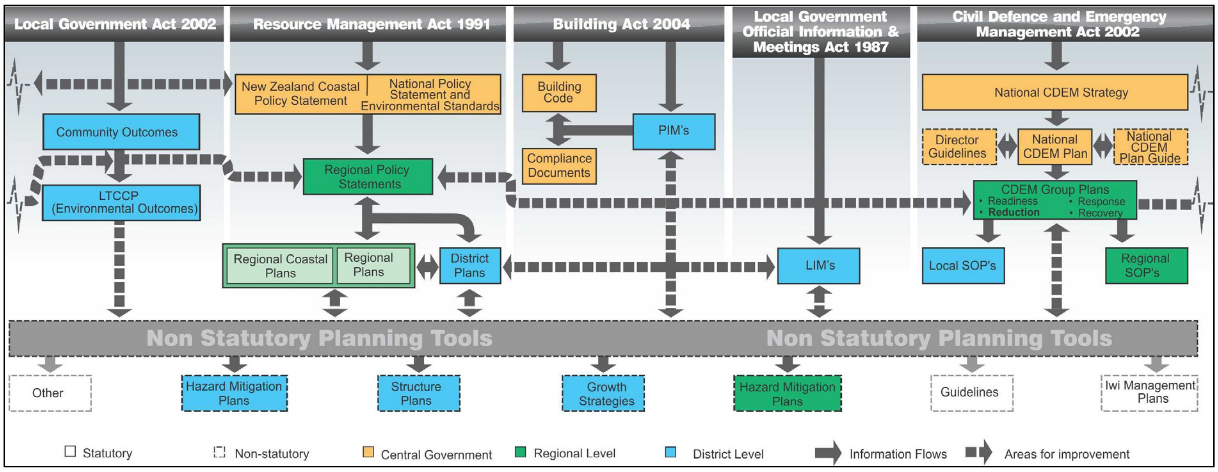

Figure 3.1 Legislative context for hazard management in New Zealand (Glavovic et al. 2010).

The statutes shown in Figure 3.1 have a common purpose of sustainable management or development, and share the common well-beings of social, economic, environmental, cultural, and health and safety. It is therefore desirable that they be applied in an integrated way. To date this has been achieved more in theory than in practice, and as shown by the dashed lines, there is room for better integration and improved linkages.

Table 3.1 provides a summary of how these statutes contribute to the management of the tsunami risk in New Zealand. It can be seen from the table that the reduction of risk lies primarily with the RMA, whereas emergency management (readiness, response, recovery) lies with the CDEM Act. Even though there is potential for good integration across statutes, there is currently no national guidance in the form of a National Policy Statement or National Environmental Standard available for councils.

Table 3.1 How statutes contribute to the management of tsunami risk (adapted from Saunders et al. 2013).

Statute	Implication for natural hazard management
Resource Management Act 1991	• The management of significant risks from natural hazards (which is defined to include tsunami) is a matter of national importance (s6(h)). • Section 106 allows a consent authority to refuse to grant a subdivision consent if there is a significant risk from natural hazards. Section 106(1A) requires an assessment of risk to include consideration of the likelihood of an event and the material damage to land and structures, inferring a risk-based approach. • The sustainable management purpose of the Act includes enabling people and communities to provide for their health and safety (s5), which makes planning for tsunami an RMA issue. • The New Zealand Coastal Policy Statement (NZCPS) includes specific coastal hazard (including tsunami) policies that require the identification of areas potentially affected, and consideration of the potential effects and how to avoid or mitigate them.
Building Act 2004	• The Building Code does not specifically include tsunami, as it cannot economically mitigate the risk of tsunami for all buildings (some exclusions may apply in the future for critical facilities). • However, the structural provisions require that all physical conditions likely to affect the stability of buildings be accounted for, and therefore includes tsunami. • Provides for natural hazard information to be included on a Project Information Memoranda (PIM)
CDEM Act 2002	• Risk reduction is assumed to be managed under the RMA (refer to Saunders et al. 2007). • Encourage and enable communities to achieve acceptable levels of risk. • Readiness and response driven i.e. guidance for tsunami evacuation planning, mapping, and signage (MCDEM 2016).
Local Government Act 2002	• Financial planning for risk reduction activities. • To meet the current and future needs of communities. • Section 11A – *"…a local authority must have particular regard to the contribution that the following core services make to its communities:* • *(d) The avoidance or mitigation of natural hazards.*"
Local Government Official Information & Meetings Act 1987	• Provides for natural hazard information to be included in Land Information Memoranda (LIM) reports. • If the natural hazard is identified within a District Plan, this information is not required to be provided in a LIM (s44A(2)(a)(ii)).

3.1.1 Resource Management Act 1991

In terms of land-use planning, the RMA provides the strongest opportunity for managing tsunami risk. It is the principal environmental statute in New Zealand, the purpose of which is to promote the sustainable management of natural and physical resources, by:

> *…managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while:*
>
> *a. sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *b. safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *c. avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

Natural hazards are defined as "any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment."

Amendments to the RMA in 2017 elevated the management of significant natural hazard risk to a matter of national importance. This means that every RMA decision requires consideration of section 6(h) including, but not limited to:

- Objective and policy formation for Regional Policy Statements;
- Objective, policy and rule formation for Regional and District Plans;
- Resource consent applications and processing; and
- Subdivision applications and processing.

This insertion of section 6(h) means that natural hazards that have a low likelihood, but high potential consequences, and therefore present a significant risk, such as tsunami, need to be considered within land-use planning decisions. Further strengthening the emphasis on risk, a resource consent for subdivision may be refused where it is considered that there is a significant risk from natural hazards (section 106(1)(a)). Determination of whether the risk is significant requires an assessment of both the likelihood and material damage of a particular event to land and structures (section 106(1A)).

Consequently, the risk from natural hazards needs to be considered when managing use and development under the RMA to enable and provide for the social, economic and cultural well-being of people and communities, as well as their health and safety.

To achieve the purpose of the RMA in the coastal environment, the NZCPS provides the policies and objectives to guide local authorities in the management of the coastal environment. Policy 27 of the NZCPS identifies that it is the responsibility of local government to develop strategies to manage exposure to risk along the coast, and specifically includes tsunami in Policies 24 (Identification of coastal hazards) and 25 (Subdivision, use and development in areas of coastal hazard risk). In particular, Policy 25 directs:

In areas potentially affected by coastal hazard over at least the next 100 years:

a. *avoid increasing the risk of social, environmental and economic harm from coastal hazards;*

b. *avoid redevelopment, or change in land-use, that would increase the risk of adverse effects from coastal hazards;*

…

f. *consider the potential effects of tsunami and how to avoid or mitigate them.*

Regional Policy Statements (RPSs), regional plans and district plans must give effect to the NZCPS. Therefore, Councils are required to consider the potential consequences of tsunami, as well as the effect of sea level rise on tsunami risk. Policy 24 refers to "areas at high risk", but this risk level is not defined. Section 5.0 provides guidance on options for including tsunami modelling into land-use planning and risk-based approaches for determining levels of risk.

3.1.2 Land Information Memoranda

While land-use planning under the RMA plays an important role in managing the risks from tsunami, it should not be viewed in isolation when considering how to best approach hazard and risk management. It is recommended that a combination of land-use planning, engineering design and construction, and emergency management options are considered as part of a holistic approach, as supported by the legislative arrangements presented in Table 3.1.

Another important tool is provided by the LGOIMA, under which territorial authorities can issue a Land Information Memoranda (LIM) on request. The LIM provides information the council holds on a parcel of land, including natural hazards. LIMs provide the applicant with the opportunity to become aware of any hazard that may affect their property and enable them to assess their willingness to accept or tolerate that risk. If hazard information is included within a district plan, it is not required to be included in a LIM. However, if a LIM does not include information that the council holds (i.e. not included in the district plan), the council can be liable. It is recommended that information on tsunami from inundation modelling Levels 2–4 are included within a LIM. This could consist of tsunami evacuation maps and information on what the evacuation zones mean. Saunders and Mathieson (2016) also highlight the need for regional consistency in how tsunami information is provided in LIMs, as they found that while LIMs prepared for properties in Lower Hutt included relevant tsunami information, those sampled from Wellington City Council did not.

3.2 Building Act 2002

The Building Act currently has limited application for addressing the risk from tsunami. Section 31 does allow for the preparation of a Project Information Memoranda (PIM) by a territorial authority which will identify any special feature of the land, including susceptibility to natural hazards. In relation to tsunami hazard, this will generally consist of providing tsunami evacuation zone maps, as this is often the highest level of information held by council on tsunami risk.

However, in recent years the importance of evacuation structures to mitigate the risk from tsunami has become increasingly recognised. In 2018, the Ministry for Civil Defence and Emergency Management (MCDEM) published guidelines to help Civil Defence and Emergency Management Groups with assessing whether vertical evacuation structures are a possible option for their region (MCDEM 2018). Phase 2 of this work will be guidance by the

Ministry of Business, Innovation and Employment (MBIE) on the design and performance standards for the construction of purpose-built structures and the retrofitting of existing buildings for use as tsunami evacuation structures. The guidance is due for release in the next few months, and depending on the final findings and recommendations, it is likely that the role of the Building Act in managing the risk from tsunami will increase.

3.3 Other Influencing Legislation

Other pieces of legislation may influence aspects of the siting of specific facilities in coastal locations, and risk management strategies adopted with respect to tsunami hazards. For example, in 2007 the New Zealand Environment Court (W082/2007) decided to uphold appeals relating to the effects of a Marine Education Centre proposed for an exposed coastal site, susceptible to tsunami risk, south of Wellington city (Garside et al. 2009). This resulted in a significant ruling that applicants seeking resource consents for the establishment and operation of public facilities in areas susceptible to natural hazards should not overlook evacuation planning in their application, as outlined in the Health and Safety in Employment Act 1992 (Garside et al. 2009).

Other examples include the Education Act 1989, that places requirements on school boards to provide safe physical and emotional environments for their students (therefore tsunami risk needs to be considered when siting schools in low-lying coastal areas); and the Hauraki Gulf Marine Park Act 2000, where s7 (recognition of national significance of the Hauraki Gulf) and s8 (management of the Hauraki Gulf) have the force of a National Policy Statement. The associated Forum in its strategic issues document has identified coastal hazards as a matter to be considered.

4.0 TSUNAMI MODELLING

There are three key factors that tsunami modelling needs to consider:

1. That the level of model uncertainty and risk acceptability suit the intended use of the maps produced;
2. The range of tsunami scenarios that are modelled to generate mapped zones for planning, including source, magnitude and probability; and
3. What modelling approach is to be used.

It is the combination of these two factors that will determine the quantity and quality of input data required, and how the results can be used (AIDR 2018).

4.1 Decide Modelling Parameters

Before commissioning tsunami inundation modelling, discussions need to be held between planners and those undertaking the modelling to agree the:

1. Intended use of the inundation maps produced;
2. Level of risk that is acceptable or tolerable; and
3. Degree of uncertainty in the resulting inundation maps.

This will help ensure that a practical tsunami inundation map is produced that this suitable for its intended use. If agreement is not reached on these factors before modelling is commenced, modelling is rarely fit for purpose, leading to poor outcomes. This is also the case if existing modelling is used for another purpose than what it was developed for, for example using tsunami evacuation maps to inform land-use planning policy.

4.1.1 Intended Use

Clarifying the intended use of the tsunami inundation maps is vital to ensuring that the resultant maps are fit for purpose. As discussed further below in Section 4.3, tsunami modelling can be conducted at a range of developmental levels. Lower levels of tsunami modelling have a higher degree of uncertainty

4.1.2 Risk Tolerance

Deciding which probability of occurrence for a natural hazard event that should be used often represents a value judgement that can be difficult to deal with in the political arena. Tsunami can prove particularly challenging, as damaging tsunami have a low likelihood, but as demonstrated internationally by the devastating 2004 Indian Ocean tsunami, the Samoa tsunami in 2009, and the 2011 Tōhoku tsunami, they can have devastating and far reaching consequences.

For tsunami, a 1 in 2500-year event is considered to represent the worst-case scenario for New Zealand (Leonard et al. 2008), which would potentially have similar impacts to the 2011 Tōhoku tsunami. For comparison, a tsunami the size of the Tōhoku tsunami was previously estimated to have a recurrence interval of every 800 to 1100 years for Japan (Minoura et al. 2001), which has been revised to approximately every 700 years in its aftermath (Satake 2015). When deciding what level of risk is acceptable, councils and their communities will have to balance the likelihood or probability of a tsunami event against the potential consequences. For example, while modelling the worst-case scenario is an accepted standard for defining tsunami evacuation zones in New Zealand, depending on the risk tolerance of a local authority and community, an event with a 2500-year return period may be deemed too unlikely to support the restriction of private property rights.

Councils will also have to decide how to incorporate the impact of sea level rise on tsunami effects, and an example of how this has been done is provided in Section 6.2.

4.1.3 Uncertainty in Tsunami Modelling

It is important to be aware of uncertainties in tsunami modelling, to ensure that the limitations and assumptions of the modelling are well understood, taken into consideration, and the modelling data and quality are retained.

Uncertainties in inundation modelling include the quality of the information about:

- Water interaction with ground roughness (including buildings and land-use types);
- Quality of digital elevation model (map contours vs. LiDAR);
- Quality of bathymetry;
- Real shape of ocean displacement (e.g. fault offset or bulge); and
- Reflections and refractions of waves across the ocean.

Uncertainties from the modelling software can be reduced through validation of the modelling software using benchmark cases or common validation standards. For example, the 2013 updated tsunami hazard model for New Zealand better represents the scientific uncertainty that is present in the understanding of earthquake source parameters, by incorporating the results of 300 tsunami simulations (Horspool et al. 2015).

For earthquake-generated tsunami there are several sources of uncertainty. One source is uncertainty over the magnitude of future earthquakes, as this determines the average level of slip on the rupture surface (commonly referred to as the 'fault plane'). Another is in relation to how the slip is distributed across the rupture surface. In actual events, the slip on the fault plane varies on a variety of spatial scales. In practice, for most tsunami modelling the slip is assumed to be uniform, which is acceptable for far field (distant) events, but not for near field (local) ones. The New Zealand Probabilistic Tsunami Hazard Model (NZPTHM) developed after the event of the 2011 Tōhoku Japan tsunami, which was caused by a very non-uniform slip, is the first attempt to account for the effects of this type of slip (Power 2013). A further cause of model uncertainty is due to limitations in how well the geometry of the rupture surface is known, and whether neighbouring or splay faults (additional fault(s) that 'splay' off of the main fault plane) may be activated (Geist 1998). As all modelling includes uncertainties, it is essential that the assumptions are noted as they affect the model results cumulatively.

There are also various types of uncertainty in decision making that may play a role in the process of deciding whether to incorporate tsunami modelling into land-use planning. For example, political uncertainty may arise as the decision maker struggles with the political acceptability of options (van Asselt 2000). To overcome this, decision makers need to be provided with an opportunity to learn and understand the importance of the tsunami modelling, and the role it can play in reducing future risks to communities. Regardless of the type or degree of uncertainty, the message should not change – that a tsunami is expected, it will impact communities, and we need to plan now for the event.

4.1.4 Scale of Mapping

Typically, tsunami modellers present their inundation maps with a scale based on grid spacing (e.g. 20m) while planners generally work with a ratio scale (e.g. 1:20,000). There are two primary issues that control the modelling outputs:

1. Having a scale that is fine enough so that the inundation maps are not pixelated when viewing; and
2. Computing restrictions, in particular:
    a. The amount of data in the modelling;
    b. The computational complexity; and
    c. The run time of the model (which can take from hours to weeks for an individual model, and a probabilistic study may require running tens to hundreds of models).

A process of "line smoothing" is often required when raw map data is ambiguous, i.e. when no clear pattern of tsunami inundation/risk emerges from the modelling.

4.2 Modelling of Scenarios

Tsunami inundation hazard is generally modelled using either deterministic (scenario-based) or probabilistic models. Whichever of these two approaches is used the modelling should be conducted to the agreed level of risk tolerance as discussed above in Section 4.1.2.

Deterministic methods model only a selected number of tsunami scenarios, for example the maximum credible event (or worst-case scenario) or a triggering event at a number of different return periods. While computationally less intensive than probabilistic methods, the results are generally conservative and do not provide a comprehensive assessment of potential tsunami inundation hazard (AIDR 2018). Conversely probabilistic methods look to model all credible tsunami scenarios and consider the contribution from a number of different potential triggers at a range of likelihoods. It can also account for factors such as sea level rise. However, probabilistic modelling is currently time and cost intensive, and needs to be supported by good quality data, meaning that it is yet to be fully utilised in New Zealand to support local government decision-making.

4.3 Developmental Levels for Modelling

Four developmental levels are recognised for establishing tsunami evacuation zone boundaries (MCDEM 2016). To ensure consistency between tsunami evacuation mapping techniques and land-use planning requirements, it is recommended the same framework for describing modelling is employed. This section provides an abridged discussion of the development levels as provided in the CDEM Director's Guideline for Tsunami Evacuation Zones (MCDEM 2016). The reader must refer to MCDEM (2016) for the complete and specific description of each of these levels when applying them to tsunami modelling.

Level 1 uses a simple 'bathtub' model where inundation is determined based on maximum wave amplitudes, projected inland from the coast to a topographic barrier or arbitrary cut-off point in low-lying areas (Figure 4.1).

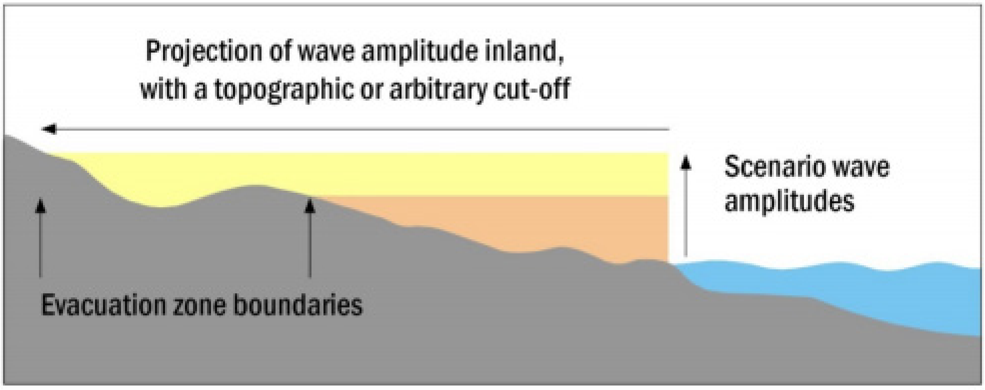

Figure 4.1 Level 1 cross section showing how evacuation zone boundaries can be mapped using a projection of wave heights inland, based on a simple 'bathtub' model.

This approach is the simplest method of mapping evacuation zones and does not account for the complexities of actual tsunami inundation (AIDR 2018). While this method has low input requirements, it also has a corresponding low a low level of accuracy (AIDR 2018) and is not recommended for use in New Zealand for tsunami evacuation mapping or land-use planning purposes (MCDEM 2016).

Level 2 uses a measure of rule-based attenuation of the potential run-up height that depends on the distance inland from the coast (Figure 4.2). It is an empirical approach. A GIS (Geographic Information System) based approach can be utilised for applying the attenuation rule which calculates the indicative evacuation zone based on maximum potential tsunami run-up. This approach derives a more realistic output than a simple 'bathtub' model but is still a rough estimation which does not account for physical variations in wave behaviour. In the form that it is applied in New Zealand, it is generally conservative (i.e. erring towards overestimation of inundation extent). This conservatism helps the zones to cover a broad range of potential scenarios and must be combined with local knowledge to support the process.

Level 2 is the recommended approach if LiDAR-grade (i.e. better than 1m vertical accuracy) elevation data, and a similar grade bathymetry data (e.g. from a port-specific navigational chart), are not available; in part because of the conservative nature of the approach, and in part because hydrodynamic models (used in Levels 3 and 4) are more error sensitive when run over low accuracy data.

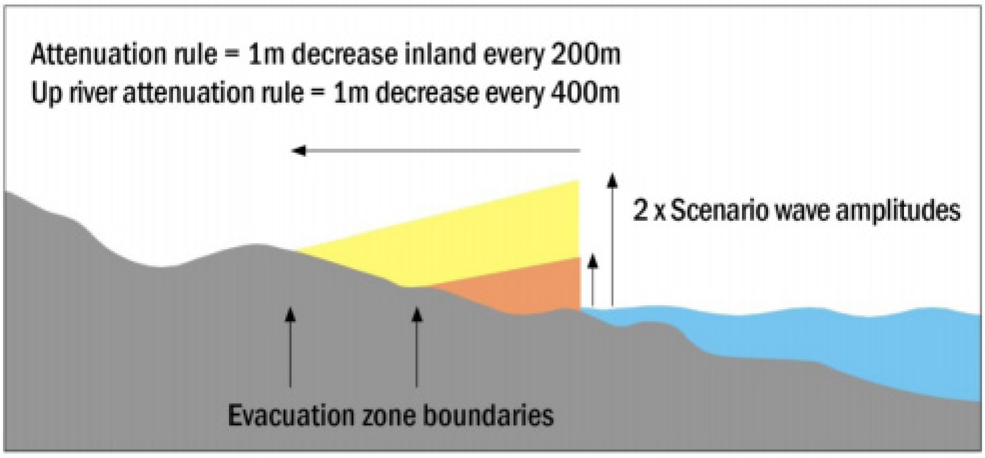

Figure 4.2 Level 2 cross section at the coast showing how evacuation zone boundaries are determined using an attenuation rule, in which elevation decreases from a maximum wave height at the coast and is projected inland according to a slope angle calibrated against real and modelled tsunami.

In New Zealand, the Level 2 approach is used to define tsunami evacuation zones, as the level of conservatism is appropriate, as it will promote life safety. The Red Zone delineates the area that will be impacted by a tsunami in the range of 0.2 to 1.0 metre amplitude and is generally only defined if there is adequate elevation data available. Otherwise it should be considered to cover the beach and foreshore area, which is generally expected to be approximately 2m above the high tide contour level. The Orange Zone is defined by the probabilistic wave height with a 500-year return period, and the Yellow Zone is defined by the probabilistic wave height with a 2500-year return period, which is considered to represent the maximum credible event (Leonard et al. 2008). In New Zealand the 84^{th} percentile wave height has been chosen to be used from the probabilistic model to provide a margin of safety to reflect the degree of uncertainty in the model and source datasets (Horspool et al. 2015). This is then doubled to define the evacuation zone, as run-up can be up to two times the arriving wave amplitude due to wave-focussing by the shoreline and onshore topographic features (Leonard et al. 2008; Fraser & Power 2013). Wave height is then attenuated as it moves inland based on whether the wave is flowing over land, within a harbour or within a river channel, and is overlain with local topography in a Digital Elevation Model (DEM) to determine maximum potential inundation (Fraser & Power 2013).

Leonard et al. (2008) and Fraser and Power (2013) provide more detail on the development of the Level 2 approach and how it has been implemented in New Zealand to date. Level 2 is the minimum standard recommended for establishing evacuation zone boundaries, however it is considered an interim approach, and evacuation zone boundaries should be refined by higher level modelling as science and data improves, and funding becomes available (Leonard et al. 2008; MCDEM 2016).

Level 2 modelling has limited land-use planning potential at the territorial authority level, however it may be used to identify areas where a tsunami hazard exists and used to formulate objectives and policies around what outcomes are sought with respect to this hazard. Whilst objectives and policies would ideally be supported by a rule framework, Level 2 modelling is too conservative to warrant the restriction of private property rights. However, by including objectives and policies for tsunami in the District Plan until such time that adequate modelling is completed, it ensures that section 6(h) and 106 assessments are not undertaken in a vacuum of policy direction and provides the initial step to further consideration of tsunami risk.

Level 3 uses a physics-based computer simulation of the process by which water inundates across land, which theoretically allows for complexities that a simpler ‘rule’ cannot, such as changes in the direction of water flow under the influence of the shape of the land and variations in surface roughness from different land-uses. Such modelling is expensive, and the quality of outputs is dependent on the science behind the model and the quality of the elevation or bathymetry data used. The wave hitting the coast may be either:

1. Based on an incoming wave of particular amplitude (this is the less-preferred Level 3 approach), or
2. Based on multiple scenarios ‘de-aggregated’ from an appropriate probabilistic model and modelled from source (this is the preferred Level 3 approach).

Level 3 modelling provides more refined results and therefore is the minimum recommended for land-use planning purposes, particularly where the restriction of private property rights may result.

Level 4 is the most comprehensive approach, based on drawing an envelope around all inundations from many well-tested computer models run from source through to inundation.

The number of models must be enough to cover the full range of scenarios that can be expected from all sources. It results in improved modelling of all tsunami, but particularly those that are generated by other mechanisms than earthquakes, such as landslides, and volcanic eruptions (AIDR 2018). Development to this level of sophistication requires a comprehensive scientific understanding of all possible tsunami sources (distant, regional and local), and wave propagation and inundation behaviours, across a range of magnitudes, and has not been applied in New Zealand to date.

Levels 3 and 4 use precise physics-based computer models but will only produce accurate zones if the underlying shallow bathymetry and elevation datasets are also precise and accurate. Thus LiDAR (Light Detection And Ranging) data for topography, and multibeam survey for near-shore bathymetry, are considered minimum prerequisites for Levels 3 and 4.

Since the original 2011 guidelines were published, the New Zealand Probabilistic Tsunami Hazard Model (NZPTHM) has been updated to incorporate more tsunami sources based on findings from recent studies and to better represent scientific uncertainty in the knowledge of earthquake source parameters (Horspool et al. 2015). It will continue to be updated over time. As the understanding of local tsunami hazard and risk improves, local authorities and CDEM Groups should be able to advance the level of technical sophistication used in defining tsunami hazard and evacuation zones. For example, Level 3 and 4 methods for modelling the Orange Zone are in development (MCDEM 2016). Until higher stage assessments can be undertaken, a precautionary approach is recommended in defining the placement of evacuation zone boundaries.

As highlighted in Section 4.1, the decision on what level of modelling is required needs to be made by decision makers in conjunction with the tsunami modellers to ensure that the results are fit for the intended purpose. For example, modelling to inform evacuation planning whether at Level 2 or 3 will generally be based on 'worst case' scenarios to promote life safety (see: Mueller et al. 2015), while modelling to inform land-use planning will be based on a wider range of more likely range of scenarios (see: Power et al. 2015). Due to the currently prohibitive time and cost requirements of Level 4 modelling, Level 3 modelling is currently the most practical and robust for land-use planning purposes.

Table 4.1 provides a summary of each model developmental level, the methodology applied, data requirements and what local government applications the results potentially have.

Table 4.1 Summary of the four model developmental levels for determining tsunami hazard.

	Level 1[4]	Level 2	Level 3	Level 4
Inundation modelling methodology	Bathtub	Rule-based attenuation	2D inundation models (e.g. nonlinear shallow water equations)	Advanced hydrodynamic methods
Elevation data requirements	Best available	As for Level 1	High resolution LiDAR and bathymetric data for inundation zones and nearshore areas	As for Level 3
Suitable applications (in addition to previous level)	Initial identification of areas that need further assessment	CDEM emergency and evacuation planning (minimum recommended level), community response plans, evacuation mapping, information and warning signage and the implementation of educational programs (like the Wellington Region blue lines programme).	Detailed land-use planning under the RMA. This modelling would allow for the development of objectives, policies and rules pertaining to development in the tsunami hazard areas (minimum recommended level).	Preferred level for all land-use planning purposes, however not yet implemented in NZ.
	High level analysis under the LGA to determine risks to future growth areas	Public awareness and education including signage, evacuation route identification and painting of evacuation lines on the ground.	Preferred level for CDEM emergency and evacuation planning.	
		Recovery planning under the LGA & CDEMA.	Strategies and Growth Plans under the LGA.	
		Limited land-use planning purposes under the RMA. Can be used to develop objectives and policies (but not rules) to guide section 6(h) and 106 assessments, as well as implementation of the NZCPS.		
		LIMs & PIMs (for education and general information purposes)		

[4] This level is not generally recommended for use in New Zealand.

5.0 INCORPORATING TSUNAMI MODELLING INTO LAND-USE PLANNING

As previously discussed, section 6(h) of the RMA requires the management of significant natural hazard risk and Policy 25 of the NZCPS requires that councils plan for coastal hazards (including tsunami) out to at least a 1:100-year event. Given these provisions, there is strong national direction to consider tsunami hazards within land-use planning.

The NZPTHM (Power 2013) provides a useful reference when determining the potential severity of the hazard for several return period scenarios along the New Zealand coastline. Councils can use this information to provide an indication of the severity of the tsunami hazard that their region faces, and whether a land-use planning response is required to address the natural hazard to meet their requirements under the RMA.

It is important is recognise that the current legislation does not require all-natural hazard risk to be managed, just the risk that is significant – therefore an assessment of risk is required. While there is currently little clarity on what constitutes a significant natural hazard risk, councils can use other documentation to assist with making this determination for themselves, including:

- Civil Defence Emergency Management (CDEM) Group Plans, which rank hazards based upon their risk;
- MCDEM Director's Guidelines for CDEM Group Planning which includes guidance on the risk assessment process;
- Regional Policy Statements, which may define what constitutes a high, medium and low hazard;
- National Policy Statements, such as the New Zealand Coastal Policy Statement which is directive around the need to plan for coastal hazards for at least the next 100 years;
- Research on tsunami risk which may have been undertaken by other local or regional councils, or civil defence emergency management teams.

For a number of councils, tsunami will likely constitute a natural hazard that does require a land-use planning response due to its consequences. It is important that if councils take a land-use planning response to tsunami hazards, then the hazard is modelled and mapped in a manner that is robust and appropriate for land-use planning. This is discussed in more detail in relation to the case study presented in Section 6.2.

5.1 Options for Land-Use Planning

While there is limited guidance available for planning options for tsunami, in 2001 the National Tsunami Hazard Mitigation Program in the U.S. outlined seven planning principles (National Tsunami Hazard Mitigation Program 2001). These are given below and shown in Figure 5.1:

- Know your community's tsunami risk: hazard, vulnerability and exposure;
- Avoid new development in tsunami run-up areas to minimize future tsunami losses;
- Locate and configure new development that occurs in tsunami run-up areas to minimise future tsunami losses;
- Design and construct new buildings to minimise tsunami damage;
- Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects;

- Take special precautions in locating and designing infrastructure and critical facilities to minimise tsunami damage (not shown in Figure 5.1); and
- Plan for evacuation.

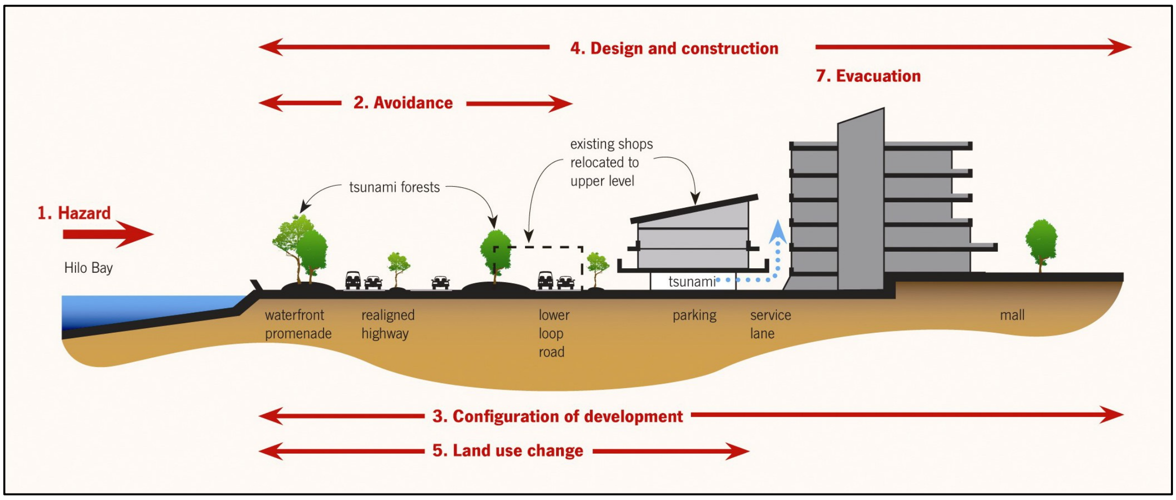

Figure 5.1 Seven principles for planning and designing for tsunami hazards in Hilo, Hawaii (adapted from National Tsunami Hazard Mitigation Program 2001).

Taking into account the above principles, the following regulatory and non-regulatory approaches provide options for incorporating tsunami risk into land-use planning.

5.1.1 Regulatory Approaches

Regulatory approaches for managing risk from tsunami include:

- Understand your tsunami hazard and risk (e.g. identification of at-risk areas), and include tsunami as a coastal hazard if appropriate;
- Consistent risk reduction objectives and policies between CDEM Group Plans, RPSs, and regional and district plans, for example:
    - Avoid new development in high-risk areas e.g. via setbacks or preventing development from occurring. This may be impractical at some locations;
    - If development is to be allowed, require vertical evacuation solutions in new greenfield developments where the distance to evacuation zones is too great (e.g. Te Tumu development in Papamoa);
    - Avoid locating critical facilities (e.g. public utilities, medical facilities, facilities with post-disaster functions, emergency services, large dams, hazardous facilities) within the tsunami hazard zone;
    - Mitigation i.e. community response plans, integration with emergency management preparedness and building design (e.g. for vertical evacuation). This may not address life safety concerns for local-source events;
    - Limit infill development and intensification of coastal areas to that which appropriately mitigates risk so as not to increase the risk to people and property;
    - Ensure that new roading and footpath networks support effective evacuation (e.g. avoid cul-de-sacs in new developments, or where unavoidable ensure there is a connecting walkway that facilitates evacuation).

- Planners, emergency management officers and transportation planners/engineers work together to ensure the integrity of tsunami evacuation routes are retained i.e. future proofed via high road of importance ranking;
- Ensure tsunami inundation modelling at Levels 2–4 are included in LIMs and PIMs, with an explanation of what the different modelling levels and zones mean as well as actions required;
- Take a risk-based approach to the formation of District Plan objectives, policies and rules (see Section 5.3) i.e. more restrictive consent activity status with increasing risk;
- Either encourage low-density development to reduce the number of people and amount of property at risk; or encourage high-density development, with medium- to high-rise buildings to allow for vertical evacuation (also reduces number of people at risk and limits impacts on buildings). These may appear contradictory, however either strategy can reduce the number of people at risk;
- Where relevant, require an assessment of tsunami risk within the Assessment of Environment Effects (AEE) as part of any resource consent application;
- As a condition of consent, require the consent holder to prepare an evacuation plan/community response plan, which must be approved by Council, with an annual audited evacuation exercise (refer to Environment Court case Kahikatea Estate ENV-2006-AKL-001021 where this approach has been used for flooding).
  - NOTE: if the risk requires a community response/evacuation plan in order to be mitigated, consideration must be given to whether the proposal is meeting the sustainable management purpose of the RMA.
- Combine hazard zones e.g. coastal erosion setbacks, tsunami inundation plus allowance for climate change (sea level rise, increased erosion etc.);
- Incorporate design standards for buildings in tsunami inundation zones, particularly for those that could be used for vertical evacuation (this is an area of continuing research, see Fraser 2014 and Leonard et al. 2011).

Vertical evacuation options to mitigate tsunami inundation risk are currently being considered by the Ministry of Civil Defence and Emergency Management (MCDEM) and the Ministry for Business, Innovation and Employment (MBIE). In 2018 MCDEM published a guideline for Civil Defence Emergency Management Groups in New Zealand on how to assess the need for tsunami vertical evacuation options, and how to plan for them (MCDEM 2018). While the preference is for people to evacuate from inundation zones, it is recognised by the guidelines that timely evacuation is not possible for all localities in New Zealand, particularly for locally sourced tsunami. However, tsunami vertical evacuation should be a last resort option where the risk to life from tsunami cannot be reduced to an acceptable level by other mitigation measures. Guidance from MBIE on design considerations for tsunami vertical evacuation structures is due to be released in the coming months.

NZIER (2015) assessed the options available in terms of impact versus cost and found that regulatory approaches that restricted the location of institutions and infrastructure, and placed conditions on building consents were low cost, high impact solutions. While avoiding development in areas prone to tsunami inundation is desirable, it is recognised that it is likely to be politically unfavourable. In such instances the focus should be on ensuring that no sensitive activities or critical facilities, such as day care centres or hospitals, are located within such areas (NZIER 2015).

5.1.2 Non-Regulatory Approaches

Non-regulatory approaches for tsunami hazard areas include, but are not limited to, the following options (in no particular order):

- Restore or enhance natural defences, such as dune systems, mangroves, wetlands, and coastal vegetation;
- With participation from the community, develop a strategy for relocating at-risk land-uses;
- Pre-plan for land-use recovery (e.g. change) post-tsunami event (see: Becker et al. 2008);
- Ensure tsunami hazard zones are incorporated into any structure plans, master plans, development plans, etc., with evacuation routes future-proofed and accessible;
- Communicate risk to owners and visitors via information boards. An example of these information boards is provided in Figure 5.2; and
- Early warning systems.

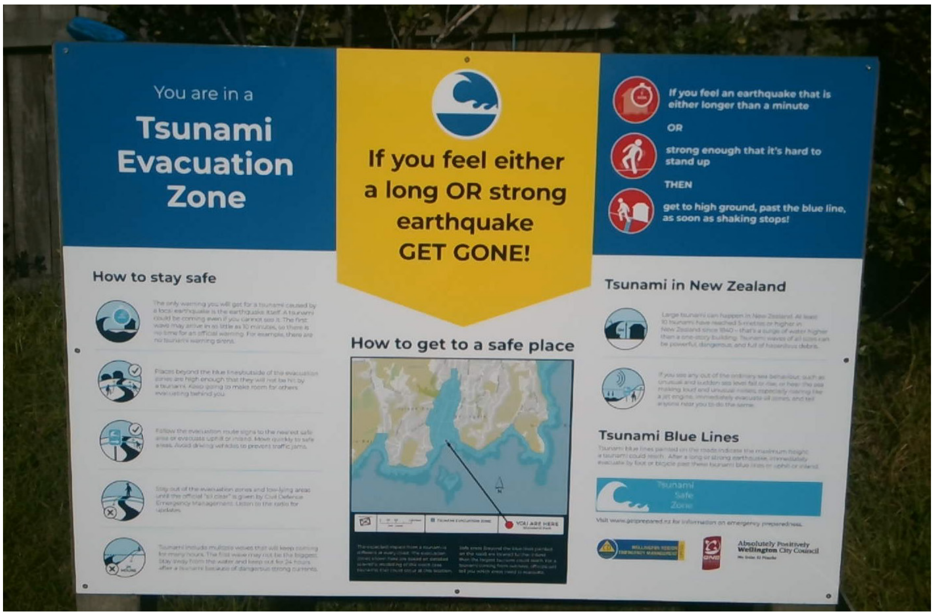

Figure 5.2 Example of a tsunami evacuation information board (Photo: D Neely).

5.2 Planning Approaches for Tsunami Risk

Klinke and Renn (2002) promote three approaches to managing risk:

- Risk-based approaches, identifying numerical thresholds (i.e. quantitative safety goals, exposure limits, standards, etc). To be effective, the likelihood (i.e. probability of occurrence) and consequences (i.e. extent of damage) should be relatively well known, and uncertainty low;
- Reduction activities derived from the application of the precautionary principle (e.g. 'As Low As Reasonably Practical' (ALARP)). In this approach, greater levels of uncertainty exist because of lack of knowledge; and
- Standards derived from participatory processes, including roundtables, deliberative rule making, mediation, and community response planning processes.

These three approaches can be used in isolation, or as a combination. While recent amendments to the RMA now infer a risk-based approach be taken when planning for natural hazard risk, precautionary and participatory approaches will be useful in the interim where hazard information is incomplete or has a high level of uncertainty. Table 5.1 summarises which approach should be used depending on the information available.

Table 5.1 Choice of approaches for managing risk.

Information available	Recommended approach	Examples within land-use planning
Probability of occurrence and extent of damage are relatively well known; uncertainty is low, i.e. high certainty tsunami zone	Risk-based	Risk-based approach to policy and resource consents
Greater levels of uncertainty, lack of knowledge, i.e. uncertain tsunami zone	Precautionary	ALARP, emergency management (i.e. warnings, evacuation), use of s73 of the Building Act (limits liability)
Mix of above	Participatory	Consultation, public participation in developing policy, conflict resolution

5.2.1 Risk-Based Approaches

Risk-based approaches involve considering both the likelihood and the consequences of a hazard event. Tsunami hazard modelling to developmental Level 3 or 4 is required to inform risk-based planning approaches to avoid, mitigate or reduce tsunami risk. In New Zealand, modelled inundation levels at the 16th, 50th and 84th percentile of certainty are often provided to end users, to allow them the discretion to decide what level of uncertainty is acceptable for a given purpose.

Saunders et al. (2013) provide guidance on a risk-based approach that is based on five steps, being:

1. Know your hazard;
2. Determine the severity of the consequences;
3. Evaluate the likelihood of an event;
4. Take a risk-based approach; and
5. Monitor and evaluate.

These steps are interlinked, as shown in Figure 5.3.

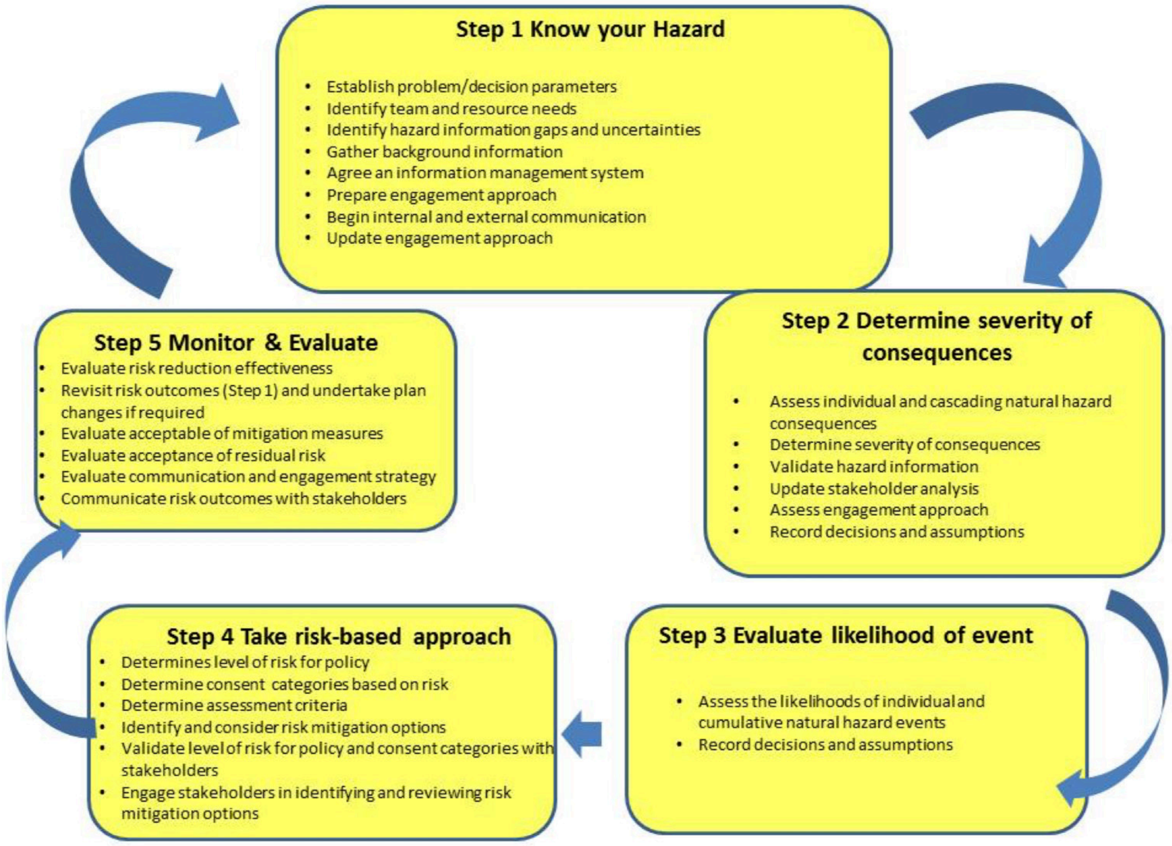

Figure 5.3 Five-step risk-based planning approach.

When determining the consequences of a hazard event, the effects on buildings, infrastructure and utilities need to be considered, in addition to the number of fatalities and injuries. The risk-based approach presented in Saunders et al. (2013) uses absolute numbers to determine the consequences to human life, however recent practice has seen a shift towards the use of life loss metrics, such as annual individual fatality risk (AIFR). This expresses the probability of a fatality for an individual at a specific site in any given year and has been used to express the level of risk posed to individuals from tsunami for the main cities in New Zealand (Horspool et al. 2015), as well as for specific sites (Power et al. 2015). Individual and multiple life safety can also be used in the 'health and safety' consequence column of Saunders et al. (2013), however this attribute does contain the likelihood within it (rather than being the next step). If life safety risk were included, Table 5.2 provides guidance on commonly accepted levels of life risk for an individual (see: Taig et al. 2012), however in practice levels of risk acceptability should be determined with public and specialist input (see: Kilvington & Saunders 2015).

Table 5.2 Guidelines for acceptable levels of personal risk (adapted from Horspool et al. 2015).

Risk Level (Tolerability)	**Risk Level (AIFR)**	**Significance**
Low (acceptable)	10^{-6} to 10^{-7} per year or lower	Unlikely to be nationally significant unless there are some very special features at risk.
Low (tolerable)	~10^{-5} to 10^{-6} per year	Many New Zealanders probably already face natural risks at home and at work of this scale. Might want to avoid new consents to add to the numbers where possible. Government needs to note that if it helps one group of people at these sorts of risk level "on safety grounds" then it might face large numbers of equally valid claims for help in the future.
Medium (tolerable with consent)	~ 10^{-4} to 10^{-5} per year	Some New Zealanders probably already face natural hazard risks at home/work of this scale. Definitely avoid new consents to add to the numbers. Government helping out at these sorts of levels on safety grounds might open up further claims.
High (intolerable/ tolerable with consent)	~10^{-3} to 10^{-4} per year	Getting up to the sort of levels regarded as intolerable for non-beneficiaries in regulatory regimes focused on man-made hazards. Government should not be comfortable if risks at this level are being imposed on people without their consent, or with people being induced to accept risks at this level.
Very High (intolerable)	~10^{-2} to 10^{-3} per year	Widely regarded as intolerable even for beneficiaries of an activity with a degree of control over the risk (e.g. employees in hazardous industries). There need to be special reasons to tolerate any kind of individual risks at this scale from pretty much any cause.
	Above ~10^{-2} per year	Intolerable for almost any accidental cause in any developed country. Even if the risk is entirely for the benefit of the exposed person (e.g. a patient seeking a risky treatment for a serious medical condition) special care is warranted to ensure the recipient really understands and accepts the risk.

The use of a risk metric such as AIFR enables the risk from a specific natural hazard event to be placed in the context of other risks to life routinely faced on a daily basis (Gunnell 2019a; Taig et al. 2012). For example, when the risk from tsunami is compared with other sources of risk in New Zealand, tsunami risk is several orders of magnitude greater than for other geo-hazards and is comparable to more frequently occurring risks, such as vehicle and workplace accidents. Yet spending on tsunami mitigation is 1% of that spent on avoiding these types of accidents (NZIER 2015). Having this understanding allows more informed decisions to be made on mitigation options.

Two case studies are presented in Section 6.0 to demonstrate different ways of adapting the risk-based approach of Saunders et al. (2013) at both a regional and territorial authority level of local government.

6.0 CASE STUDIES

There are many ways of approaching risk-based planning and two contrasting risk-based planning approaches are outlined in this section: a consequence-based approach taken by the Bay of Plenty Regional Council for addressing tsunami in their Regional Policy Statement (RPS), and an activity-based approach proposed by Porirua City Council, which uses the sensitivity of activities as a basis for their planning framework.

6.1 Bay of Plenty Regional Policy Statement

Prior to the amendments to the RMA in 2017 that introduced the management of significant risk of natural hazards as a matter of national importance, the Bay of Plenty Regional Council (BOPRC) chose to adopt a risk-based approach in their RPS to manage the natural hazards faced in their region. Their approach uses the framework developed by Saunders et al. (2013) as a foundation, but excludes economic considerations from the consequence table, and includes an annual individual fatality rate (AIFR) metric to assess consequences to life for both the general population and the population in care[5]. The RPS also takes the step of specifying the likelihoods that are to be modelled for each hazard, in order to determine the event that poses the maximum risk (Table 6.1).

There are four steps required for the primary analysis:

Step 1: Selecting the Starting Likelihood for Risk Assessment

For this step, a table is provided that specifies the likelihood that is to be modelled for the initial analysis each identified hazard, based on an Annual Exceedance Probability (AEP)[6] (Column A of Figure 6.1). Not all hazards have the same likelihood for the initial analysis; however volcanic hazards, liquefaction, tsunami and earthquake induced landslides are all to be assessed initially for a 0.1% AEP event, which equates to a 1 in 1000-year event.

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[5] Population in care is defined in the RPS as "the population within the hazard assessment area that is in:

(a) Hospital; and
(b) Aged care facilities; and
(c) Schools; and
(d) Early education and infant day care facilities.

[6] AEP (Annual Exceedance Probability) is the probability that a natural hazard event of a certain size will occur, or will be exceeded, in a time period of one year. For example, an inundation level with a 2% AEP means that there is a 2% chance in any one year of that level being equalled or exceeded (Bay of Plenty Regional Policy Statement 2016a).

Hazard	Column A: Likelihood for initial analysis AEP (%)	Column B: Likelihood for secondary analysis	
		AEP (%) - More likely	AEP (%) - Less likely
Volcanic hazards (including geothermal)	0.1	0.2	0.005
Earthquake (liquefaction)	0.1	0.2	0.033
Earthquakes (fault rupture)	0.017	0.2	0.005
Tsunami	0.1	0.2	0.04
Coastal erosion	1	2	0.2
Landslip (rainfall related)	1	2	0.2
Landslip (seismic related)	0.1	0.2	0.033
Flooding (including coastal inundation)	1	2	0.2

Figure 6.1 Likelihood table in the BOPRC RPS (Bay of Plenty Regional Council 2016b, p21).

Step 2: Determining Potential Consequences

Secondly, the potential consequences of the event scenario modelled in Step 1 need to be determined. Consequences can be determined either quantitatively or qualitatively. Guidance is provided on each method, with the consequence table within the RPS providing the framework for assessing the level of consequences (Figure 6.2).

Step 3: Assign a Consequence Level

Based on Step 2 a consequence level of insignificant, minor, moderate, major or catastrophic should be assigned by applying the table shown in Figure 6.2. It is possible that the hazard scenario analysed will have different levels of consequence across each of the five types of consequences identified. In this situation, the applicable consequence level will be the one that corresponds to the row in the consequence table that represents the highest measured or estimated consequence.

Consequence level	Built			Lifelines utilities	Health & safety
	Social/cultural	Buildings	Critical buildings		
Catastrophic	≥25% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	≥50% of buildings within hazard assessment area have functionality compromised.	≥25% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for > 1 month (affecting ≥ 20% of the town/city population) OR out for > 6 months (affecting < 20% of the town/city population).	>101 dead and/or >1001 injured
Major	11–24% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	21–49% of buildings within hazard assessment area have functionality compromised.	11–24% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 week – 1 month (affecting ≥ 20% of the town/city population) OR out for 6 weeks to 6 months (affecting < 20% of the town/city population).	11–100 dead and/or 101–1000 injured
Moderate	6–10% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	11–20% of buildings within hazard assessment area have functionality compromised.	6–10% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 day to 1 week (affecting ≥ 20% of the town/city population) OR out for 1 week to 6 weeks (affecting < 20% of the town/city population).	2–10 dead and/or 11–100 injured
Minor	1–5% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	2–10% of buildings within hazard assessment area have functionality compromised.	1–5% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 2 hours to 1 day (affecting ≥ 20% of the town/city population) OR out for 1 day to 1 week (affecting < 20% of the town/city population).	≤1 dead and/or 1–10 injured
Insignificant	No buildings of social/cultural significance within hazard assessment area have functionality compromised.	<1% of buildings within hazard assessment area have functionality compromised.	No damage within hazard assessment area, fully functional.	A lifeline utility service is out for up to 2 hours (affecting ≥ 20% of the town/city population) OR out for up to 1 day (affecting < 20% of the town/city population).	No dead No injured

Figure 6.2 BOPRC RPS consequence table (Bay of Plenty Regional Council 2016a, p377).

Step 4: Determine the Level of Risk

The final step in the initial analysis is to determine the level of risk posed using the Risk Screening Matrix provided in Figure 6.3, based on the likelihood specified in Column A of Figure 6.1, and the consequence level assigned in Step 3.

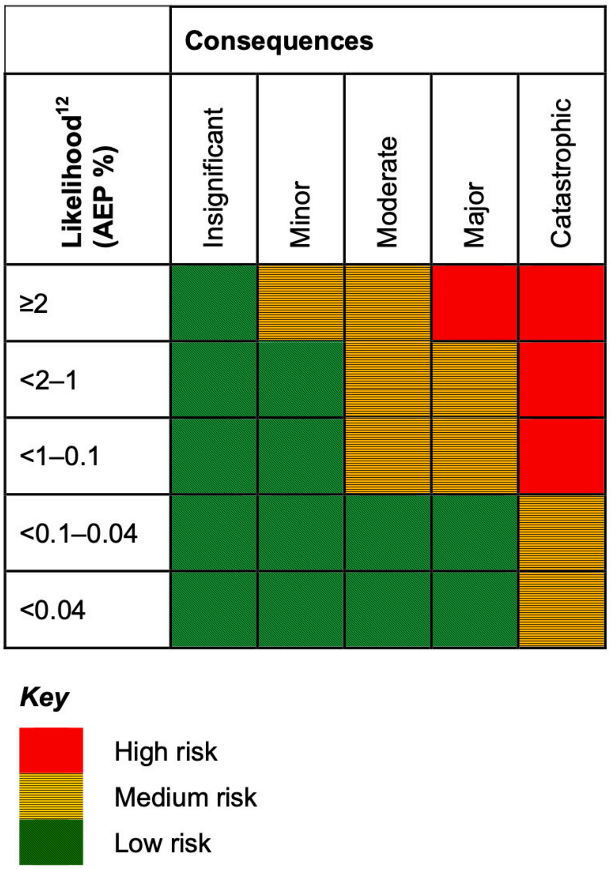

Figure 6.3 Risk Screening Matrix (Bay of Plenty Regional Council 2016a, p374).

While Steps 1–4 will categorise, the risk associated with a natural hazard event of a certain likelihood, this initial analysis will not identify what event likelihood represents the maximum risk. It is noted that the maximum risk will not necessarily be the event with the greatest potential consequence, as due to these events being less likely they are afforded a lower risk level in the Risk Screening Matrix (Figure 6.3). As such, if the primary analysis determines the risk to be low or medium, secondary analysis is required. This involves applying the likelihoods of Column B from the table provided in Figure 6.1. Further steps are provided for this secondary level of analysis, which includes the calculation of AIFR.

The BOPRC approach provides a consistent approach to managing natural hazard risk across the region, and across all types of natural hazards. Guidance has been provided to assist councils and applicants in applying the risk-based approach[7], however there are some challenges to implementing the risk-based approach of the BOPRPS, particularly in terms of the time and cost involved in gathering the detailed data required to adequately inform the

[7] https://cdn.boprc.govt.nz/media/579449/natural-hazard-risk-assessment-user-guide-web_final.pdf

assessment (Gunnell 2019b). While it is recognised that this should alleviate over time with improvements in modelling and data, the example of the Porirua District Plan review discussed below provides an alternative risk-based approach that is based upon the sensitivity of activities, rather than the modelling of different event scenarios.

6.2 Porirua Tsunami Modelling

As detailed in Gusman et al. (2019), Level 3 tsunami inundation modelling has been undertaken for Porirua City to inform the natural hazards provisions being developed under the current review of their District Plan. The probabilistic tsunami hazard assessment methodology used was based on that presented in Power (2013), which updated the tsunami hazard for the entire coastline of New Zealand but included some refinements to the calculation (see: Gusman et al. 2019).

Six tsunami scenarios were created and run for four return periods (100, 500, 1000 and 2500 years), a total of 24 scenarios. The scenarios accounted for:

1. Distant earthquakes on subduction interfaces (Peru, Central Chile, Kurile-Kamchatka, Solomon Islands);
2. Local or regional earthquakes on subduction interfaces (Hikurangi and Puysegur Trench);
3. Local earthquakes on crustal faults (Mascarin, Wairarapa, Jordon-Kekerangu-Needles, Palliser-Kaiwhata).

All tsunami were assumed to occur at high tide (specifically Mean High Water Springs). This assumption was made to ensure that the maximum inundation was being captured by the modelling as, because a tsunami consists of a sequence of waves that may occur over many hours, there is no certainty about what stage of the tidal cycle the largest wave might hit.

The inundation flows from the different de-aggregated scenarios were combined using the ‘weighted median’ approach developed by Power et al. (2015), to produce an overall estimate of tsunami flow depths at the four different return periods (Figures 6.4 to 6.7).

In addition, Sea Level Rise (SLR) of 1.0 metre was assumed, to be consistent with that incorporated into existing flood hazard modelling for Porirua. In order to understand the sensitivity of the modelling results to SLR, the scenarios were also modelled at two additional levels of assumed SLR, being 0.65m and 1.99m. To demonstrate the effects, Figures 6.8 to 6.10 show the 500-year tsunami hazard maps at each of these three SLR levels. The results show that SLR will increase the frequency of tsunami inundation. For example, the depth of tsunami inundation of the Porirua Central Business District (CBD) in the 500-year event with 1.99m of SLR (Figure 6.10) is similar to the depth of tsunami inundation in the 2500-year event with 1.0m of SLR (Figure 6.11). Generally speaking, this suggests that the extra metre of SLR makes the flooding of the CBD five times as likely.

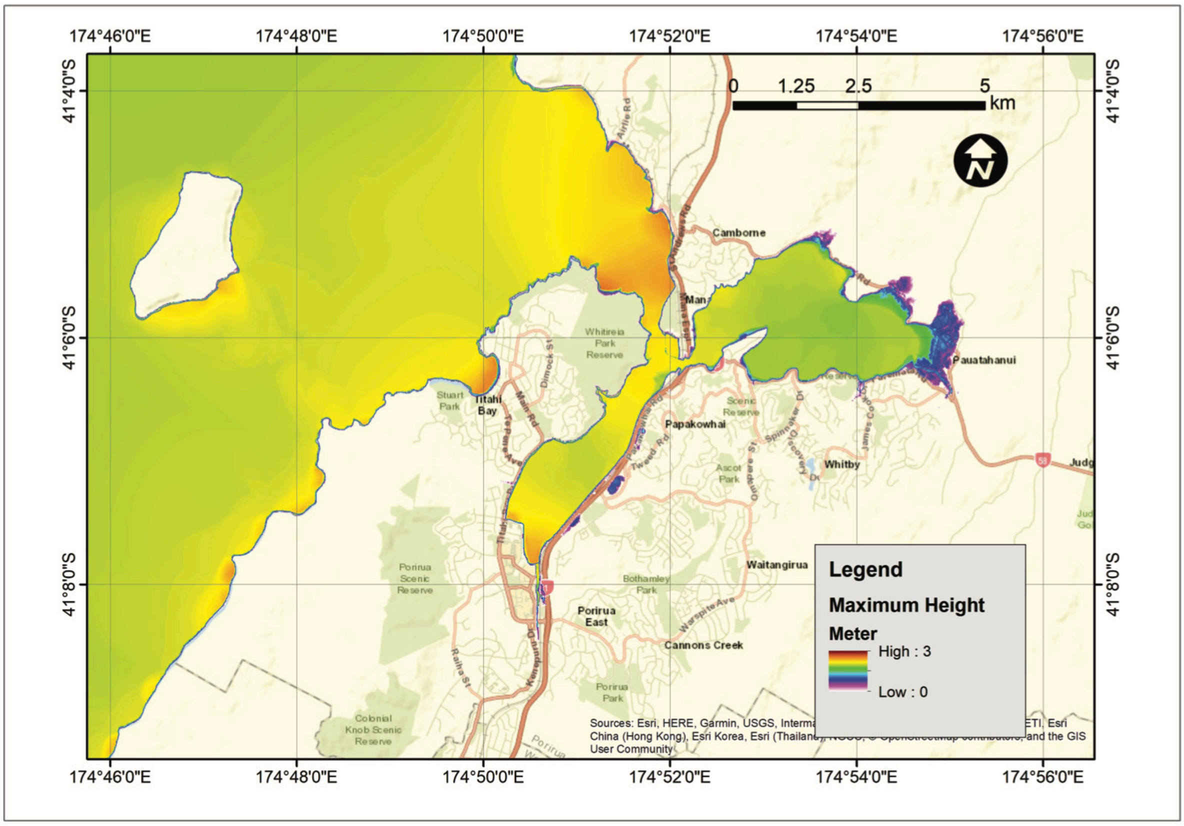

Figure 6.4 Simulated combined (weighted median) tsunami inundation from the 100-year return period scenarios, assuming 1.0m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations (Gusman et al. 2019).

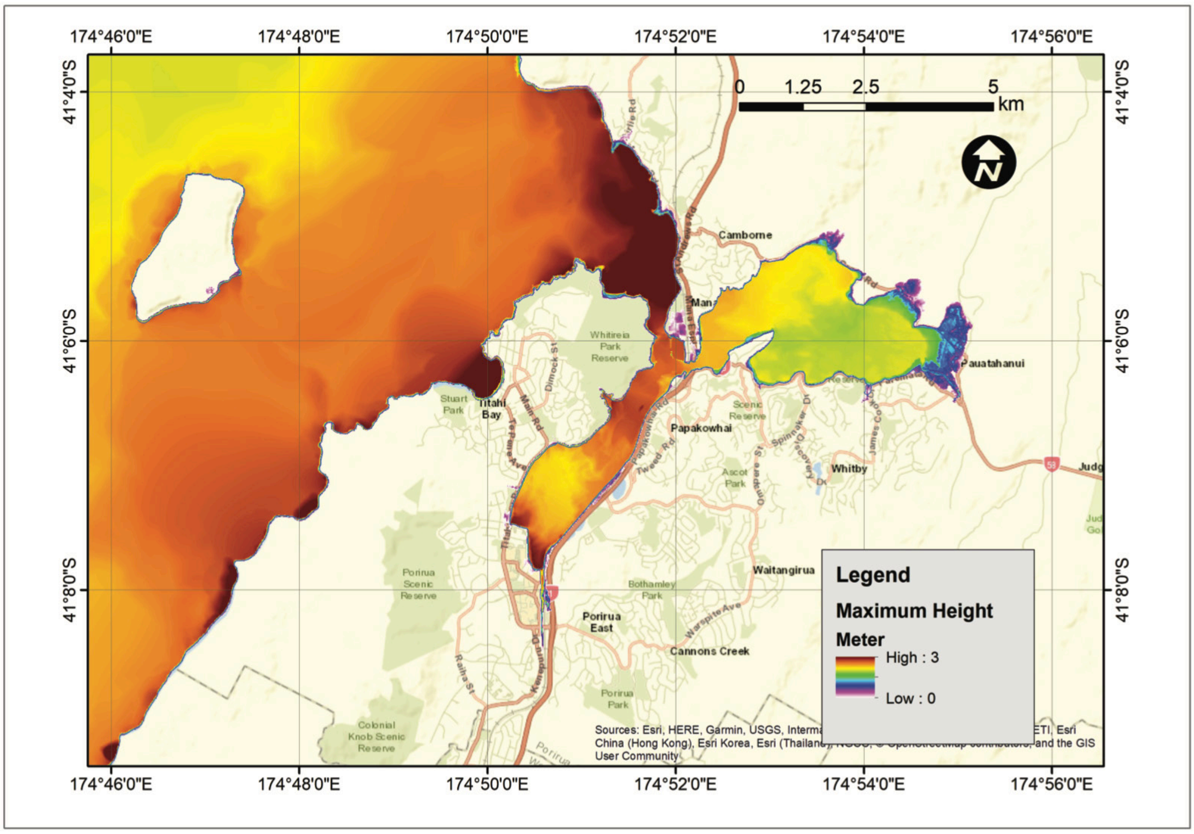

Figure 6.5 Simulated combined (weighted median) and adjusted tsunami inundation from the 500-year return period scenarios, assuming 1.0m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations (Gusman et al. 2019).

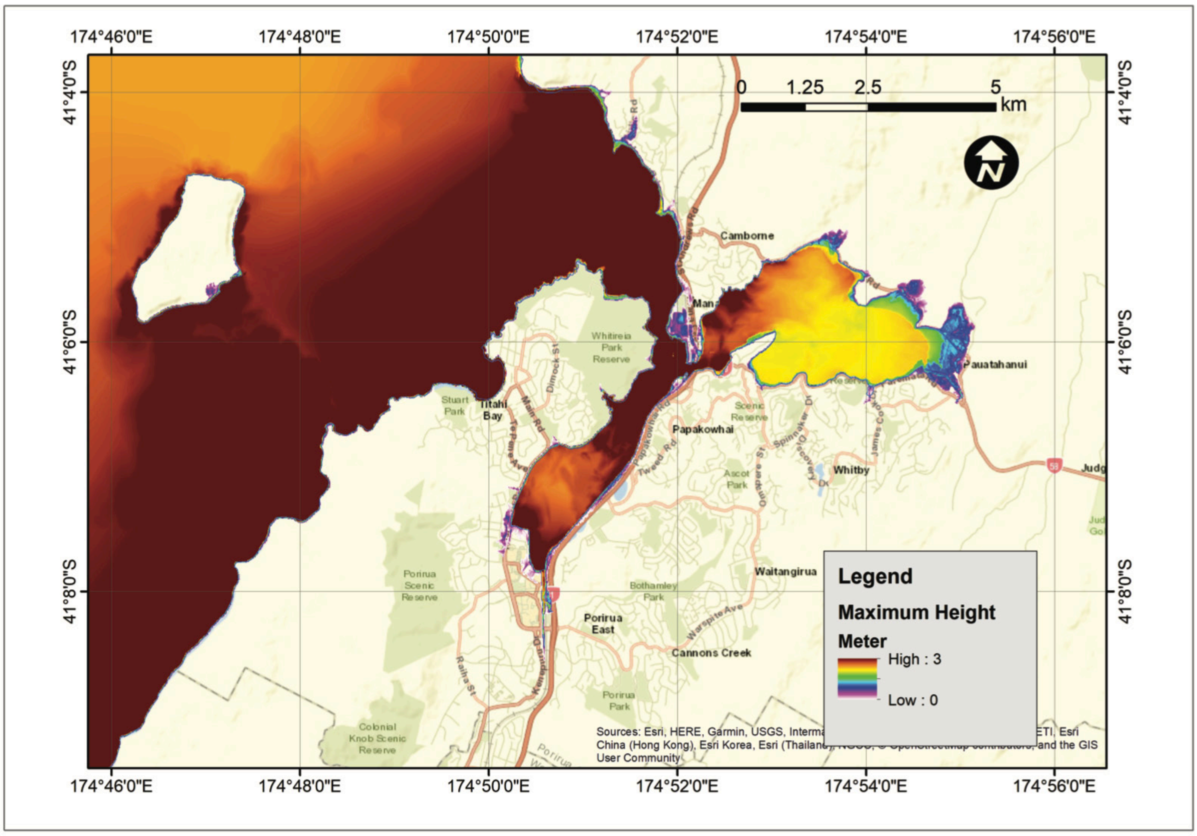

Figure 6.6 Simulated combined (weighted median) and adjusted tsunami inundation from the 1000-year return period scenarios, assuming 1.0m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations (Gusman et al. 2019).

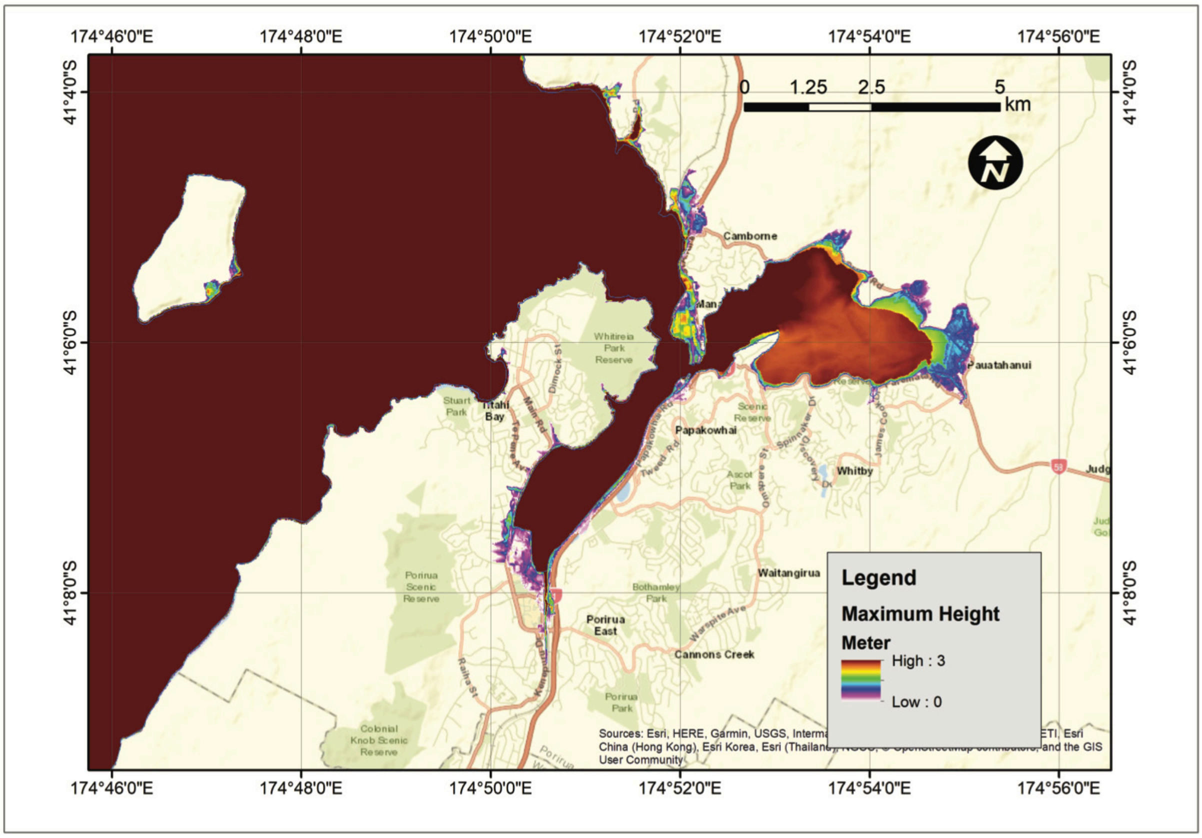

Figure 6.7 Simulated combined (weighted median) and adjusted tsunami inundation from the 2500-year return period scenarios, assuming 1.0m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations (Gusman et al. 2019).

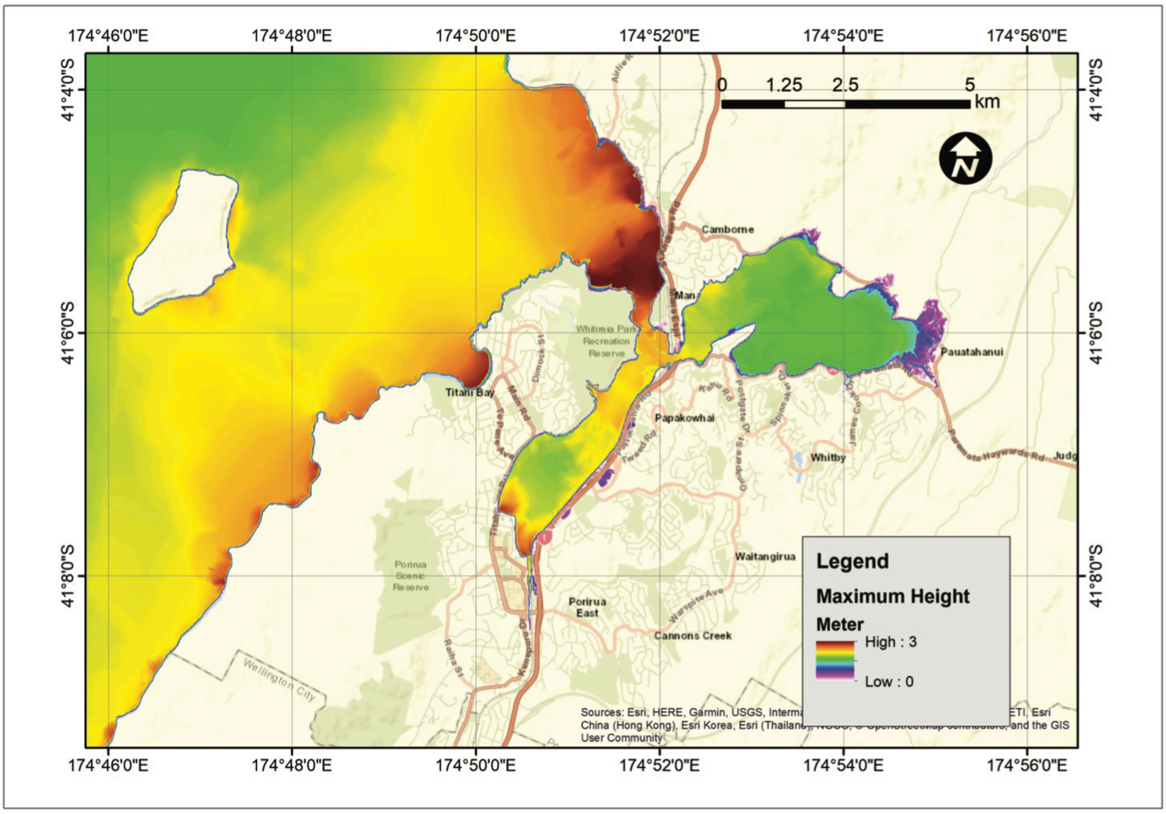

Figure 6.8 Simulated combined (weighted median) tsunami inundation from the 500-year return period scenarios assuming 0.65m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations (Gusman et al. 2019).

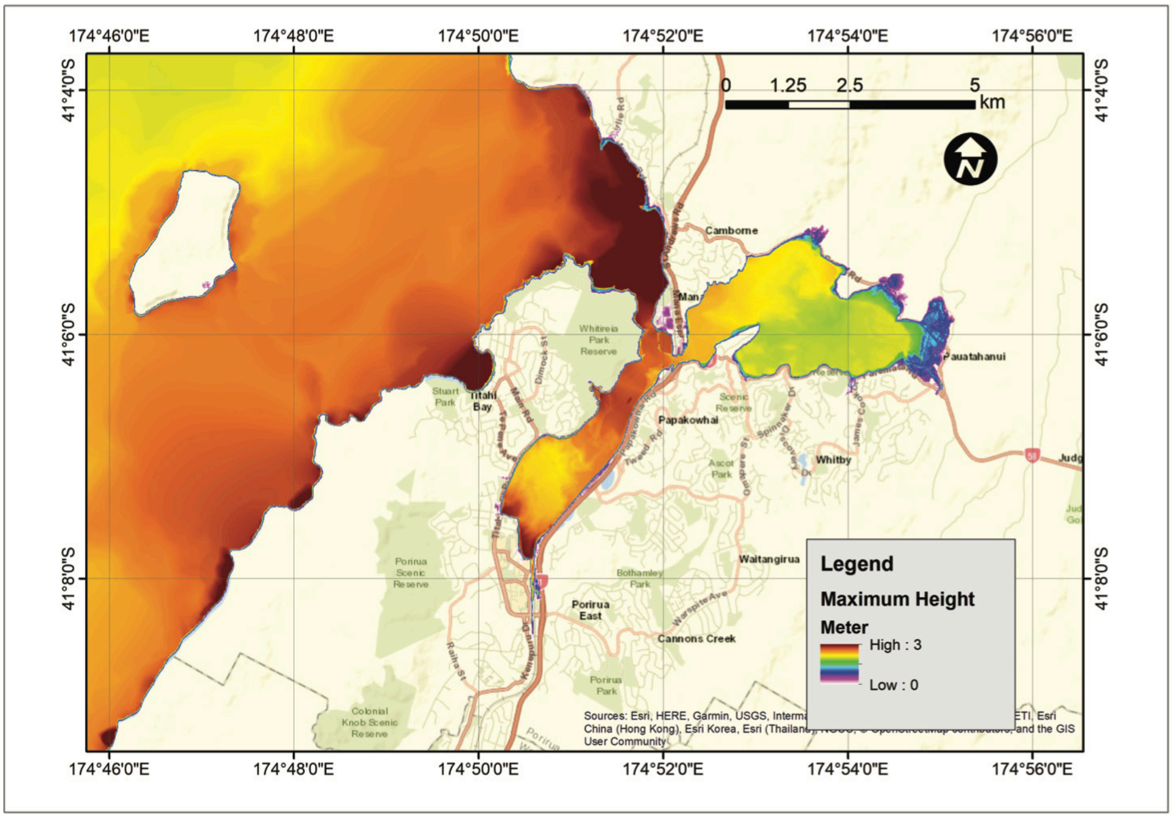

Figure 6.9 Simulated combined (weighted median) tsunami inundation from the 500-year return period scenarios assuming 1.0m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations. This figure is identical to Figure 6.5 and is reproduced here for convenience (Gusman et al. 2019).

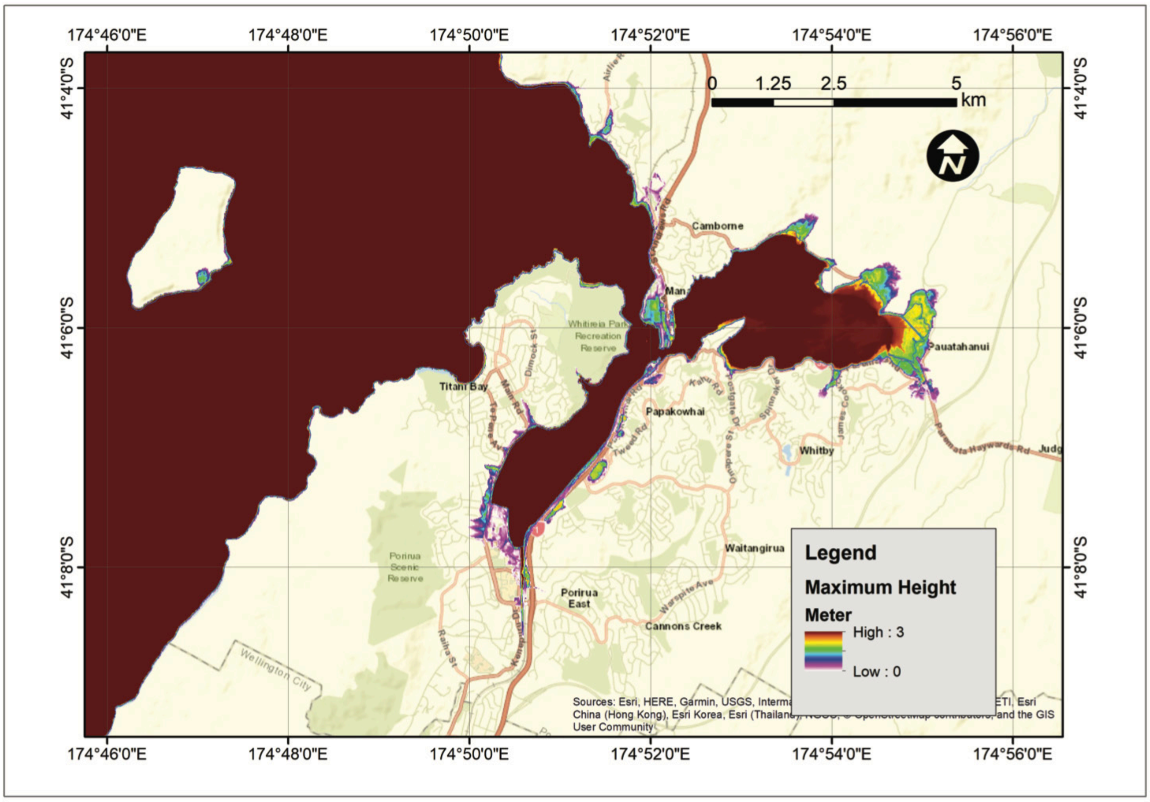

Figure 6.10 Simulated combined (weighted median) tsunami inundation from the 500-year return period scenarios assuming 1.99m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations (Gusman et al. 2019).

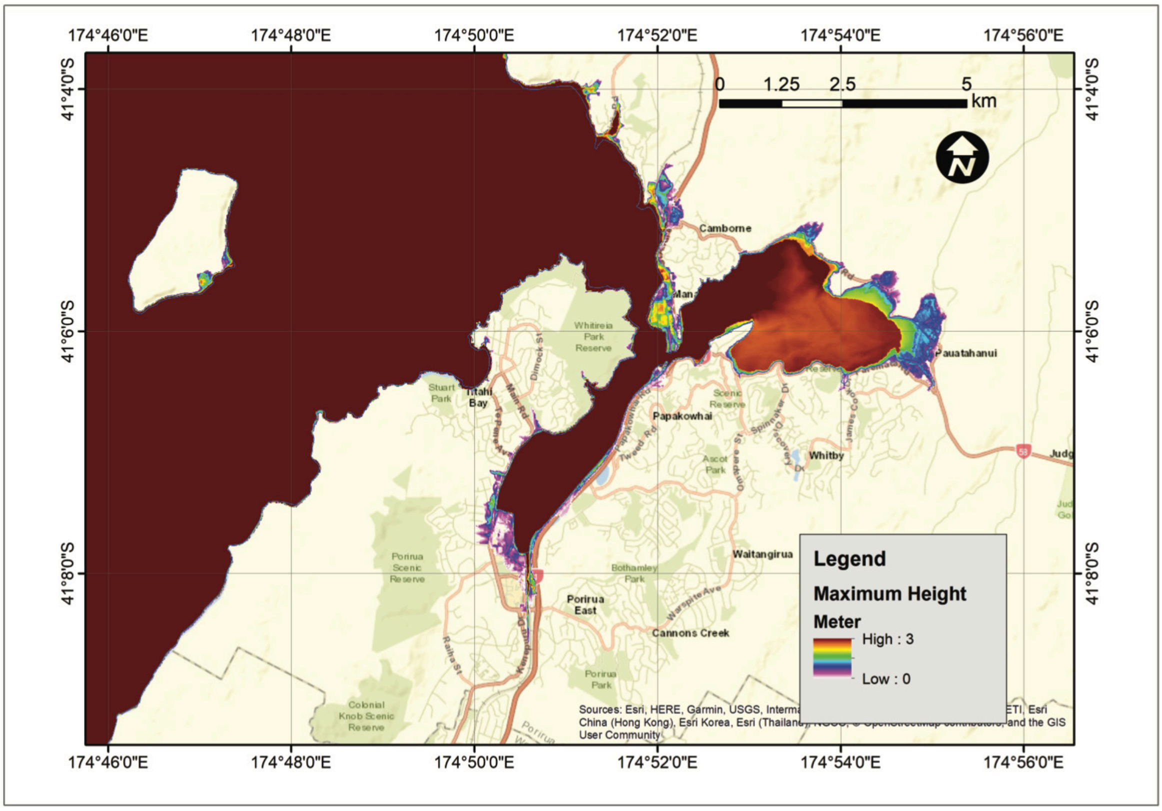

Figure 6.11 Simulated combined (weighted median) tsunami inundation from the 2500-year return period scenarios assuming 1.0m of SLR. Onshore the colour scale shows maximum flow depths, offshore the colour scale shows maximum water elevations. This figure is identical to Figure 6.7 and is reproduced here for convenience (Gusman et al. 2019).

There are a number of limitations of the modelling, which must be considered when applying the results. Those in addition to that noted in Power (2013, p.169) are:

- The modelling is based on an ‘equivalent roughness’ approach (Wang et al. 2017) which does not explicitly account for the effects of individual buildings and other structures on tsunami inundation flows;
- The degree of subsidence in Porirua due to a Hikurangi subduction earthquake may have been overestimated by the inundation models, as the location of maximum subsidence is determined by the position of the down-dip limit of rupture, which is not well known; and
- The degree of uplift in Porirua due to a Wairarapa Fault earthquake may be different, as in this study Wairarapa Fault earthquakes were accompanied by movement on the Wharekauhau Thrust, which may or may not occur.

6.2.1 Draft Porirua District Plan

In September 2019 Porirua City Council released a draft of a full review of its District Plan for consultation. As part of this review, the Council proposed a risk-based approach to the management of a number of natural hazards, including tsunami. As with the BOPRPS example, this risk-based approach used Saunders et al. (2013) as a basis, but modified aspects of the consequence approach to simplify the resulting objective, policies and rule framework. This policy approach was supported by Level 3 tsunami inundation modelling, as detailed above in Section 6.2.

The proposed approach took two steps. The first step was to identify activities based on their sensitivity to natural hazards with respect to the potential risk to life and building damage. This step used the Building Importance Category under the Building Code as a starting point to determine whether an activity was a:

- Hazard Sensitive Activity;
- Potentially Hazard Sensitive Activity; or
- Less Hazard Sensitive Activity.

A planning lens was then applied to the categorisation of buildings to ensure that they aligned with the non-statutory guidance that applies to natural hazards and to ensure that no perverse outcomes may be achieved in terms of risk to life and property. This assessment resulted in activities such as residential units being considered as Hazard Sensitive Activities. The proposed categorisation of activities in terms of their sensitivity is provided Table 6.1.

Table 6.1 Proposed hazard sensitivity classification of land-use activities.

Hazard provisions sensitivity classification	**Land-use Activities**
Hazard Sensitive Activities	• Childcare Centres • Community Facilities • Educational Facilities • Emergency Service Facilities • Hazardous Facilities • Hospital Activities • Medical and Health Service Activities • Residential Units and Minor Residential Units • Retirement Village Premises • Service Stations • Subdivision that creates a building platform within an identified hazard area for the purpose of accommodating an identified hazard sensitive activity • Visitor Accommodation
Potentially Hazard Sensitive Activities	• Buildings associated with primary production (excluding Residential Units, Minor Residential Units, Residential Activities or buildings identified as Less Hazard Sensitive Activities) • Commercial Activities • Industrial Activities • Retail Activities • Rural Industrial Activities • Buildings associated with Sport and Recreation Activities • Subdivision that creates a building platform within an identified hazard area for the purposes of accommodating an identified potentially hazard sensitive activity
Less Hazard Sensitive Activities	• Accessory buildings used for non-habitable purposes • Buildings associated with primary production (excluding Residential Units, Minor Residential Units, Residential Activities or buildings associated with more than the initial processing of products) • Buildings as defined under Leisure Activities • Buildings associated with marina operations (above MHWS) • Recreational activities • Subdivision that creates a building platform within an identified hazard area for the purposes of accommodating an identified less hazard sensitive activity

Any activity not identified in the above table that is proposed in a natural hazard overlay shall be assessed as a potentially hazard sensitive activity.

The sensitivity table also accounts for change in activities in existing buildings. This is a change in approach from how existing planning is undertaken for natural hazards, where consent is normally triggered for new buildings, but not for a change of activity in existing buildings. The sensitivity table allows for the consideration in the change in risk as a result of differing activities establishing themselves within a tsunami hazard area.

The second step was to rank the hazard return periods around whether they represented a low, medium or high hazard. As discussed previously, the following four return periods were mapped for tsunami hazard:

- 1:100-year scenario;
- 1:500-year scenario;
- 1:1000-year scenario; and
- 1:2500-year scenario.

The NZCPS was used as guidance for determining what constitutes a high hazard. Under Policy 25, councils are required to plan for coastal hazards out to at least 100 years. On this basis, the 1:100-year scenario was considered to be high hazard. This ranking also aligned with other hazards, where storm inundation and coastal erosion under the existing sea level conditions are considered to also be high hazard areas.

The 1:500 and 1:1000-year scenarios were considered to represent medium to low hazard areas respectively. The 1:500-year likelihood event is afforded a moderate hazard ranking as the recurrence interval of 1:500 is widely employed for risk mitigation assessments and aligns with the Building Code's ultimate limit state earthquake design standards (AS/NZS 1170) (NZIER 2015; Power et al. 2016).

Unlike the BOPRPS methodology for tsunami risk, which seeks to determine the maximum credible event and therefore requires consideration of a 1:2500-year scenario, in the development of the proposed Porirua District Plan framework the decision was made that a 1:2500-year return period was too extreme to warrant a land-use planning response. It is the return period that is used for Civil Defence and Emergency Management tsunami evacuation mapping in New Zealand (including Porirua) to represent the maximum credible event (Leonard et al. 2008) and it was considered that the risk was best addressed through other legislative mechanisms such as CDEM Act (e.g. response plans, warnings) and the LGOIMA (i.e. LIMs).

The District Plan then combines the sensitivity of the activity with the hazard ranking, with an increasingly restrictive activity status as the sensitivity of the activity and the potential severity of the hazard increases.

The proposed objectives, policies and rules seek to ensure the following outcomes are achieved:

- Avoid development for Hazard Sensitive Activities in the High Hazard Area (Non-Complying Activity);
- Discourage development for Hazard Sensitive Activities in the Medium Hazard Area and Potentially Hazard Sensitive Activities in the High Hazard Area unless appropriate mitigation measures are incorporated into the proposal (Discretionary Activity);
- Generally, allow, subject to mitigation measures, Hazard Sensitive Activities in the Low Hazard Area and Potentially Hazard Sensitive Activities in the Medium Hazard Area (Restricted Discretionary Activity);
- Permit Less Hazard Sensitive Activities in all Hazard Areas (Low, Medium and High) and allow Potentially Hazard Sensitive Activities in the Low Hazard Area (via a Controlled Activity status).

Small scale additions to buildings for Hazard Sensitive Activities and Potentially Hazard Sensitive Activities are provided for in all Hazard Areas, subject to mitigation measures to reduce the potential damage, and provided the risk to life and properties is low and will not be increased by the proposal.

The activity status that aligns with the above outcomes for tsunami hazard are detailed in Table 6.2.

Table 6.2 Activity status for different sensitivity activities across the hazard zones.

Hazard Ranking	**High**	**Medium**	**Low**
Hazard Sensitive Activity			
Potentially Hazard Sensitive Activity			
Less Hazard Sensitive Activity			

Key:

Colour	**Activity Status**
	Non-Complying
	Discretionary
	Restricted Discretionary
	Controlled
	Permitted

While the draft provisions are still to be tested by the Schedule 1 RMA process that applies to District Plan reviews and have yet to be implemented in practice it provides an example of an alternative risk-based approach to that adopted by the BOPRPS.

7.0 SUMMARY

While every region in New Zealand has undertaken tsunami evacuation mapping, land-use planning for tsunami hazard remains an area that is not generally addressed by local authorities in New Zealand. Yet there is a legislative requirement under the RMA to manage the risk posed by tsunami.

There are a number of regulatory and non-regulatory pathways identified to incorporate tsunami inundation modelling into land-use planning, including avoiding new or intensification of development in high risk areas, providing for tsunami evacuation structures and evacuation routes, as well as restoring and protecting natural defence systems, such as dunes and wetlands.

A risk-based approach is supported for managing tsunami risk in local government plans, which involves consideration of both the likelihood of a tsunami event and the potential consequences to life, buildings and infrastructure. A risk-based approach needs to include public consultation, particularly in terms of determining the threshold for what level of risk is acceptable to the community. Two case studies are presented of where a risk-based approach is being applied within local government to address tsunami inundation risk. The BOPRPS provides an example of where a prescriptive framework is provided for natural hazard risk assessments at a regional level. It specifies the return periods at which tsunami risk is to be assessed, as well as requiring quantification of the risk to life, through use of an AIFR metric. In the Porirua District Plan review case study, Level 3 tsunami modelling has been used to support a risk-based approach where the likelihood of tsunami events is used to define areas of low, medium and high tsunami hazard, while consequence is based on the sensitivity of activities. Objectives, policies and rules have developed to manage the tsunami risk posed in each hazard area.

As tsunami research continues to improve, including recent updates to the probabilistic tsunami inundation model for the entire coastline of New Zealand and improvements in elevation and bathymetry data held by councils, it is anticipated that more local authorities will choose to incorporate tsunami hazard into regional and district plans and policies over time.

It is vital that before commencing tsunami inundation modelling, that there is a clear understanding between planners and tsunami modellers about the intended use of the results, to ensure that the modelling is fit for purpose, and desired outcomes can be achieved. This will include consideration of risk tolerability, the differing levels of uncertainty in the results, what type of modelling is suitable.

8.0 ACKNOWLEDGEMENTS

The funding provided by EQC (Earthquake Commission) and Porirua City Council for this project is gratefully acknowledged. Thanks are also given to Graham Leonard and Scott Kelly of GNS Science for their review and useful comments on the guidance.

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