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New Zealand's Next Top Model:
Intergrating tsunami inundation modelling
into land use planning.
WSA Saunders, G Prasetya, G S Leonard
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Integrating tsunami inundation modelling into land use planning

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ABSTRACT

This report provides guidance to land use planners and decision makers on how tsunami inundation modelling can be included into land use planning. After a brief overview of tsunami basics, Figure 6 presents a decision tree for including tsunami risk into land use planning, and forms the basis for this report. The purpose of this figure is to lead the decision maker through a process of tsunami modelling, risk assessment, review of data quality and inclusion into Land Information Memorandums (LIMs), emergency management, and land use planning.

Guidance on tsunami modelling levels for evacuation purposes is already available. To ensure consistency with this approach, the recommended modelling levels for land use planning are based on the same approach. Level 1 modelling is not recommended for land use planning purposes; Level 2 modelling is recommended for inclusion into LIMs and emergency management readiness; and Levels 3 and 4 are also recommended for land use planning purposes. Pre-event recovery planning for land use is also recommended for areas already developed.

Options are provided on how the Level 3 and 4 modelling can be incorporated into land use planning. We also discuss managing uncertainty, including one potential solution for mapping tsunami inundation zones that acknowledges scientific uncertainty. Three planning approaches are available, and can be used in combination: risk-based approach, precautionary approach, and participatory approach. An adaptive three-step risk-based approach is outlined, which involves determining severity of consequences; evaluating the likelihood of an event occurring relevant to the consequences; then the resource consent activity status is determined based on quantifying levels of risk. Resource consents become more restrictive as the consequences increase. Regulatory and non-regulatory options for including tsunami risk into land use planning are outlined.

KEYWORDS

Tsunami, inundation modelling, land use planning, risk-based approach, uncertainty, mapping, pre-event recovery.

1.0 INTRODUCTION

The objective of this report is to increase the use of tsunami inundation modelling in land use planning. The research is based on two key questions:

1. How can tsunami modelling be incorporated into land use planning?
2. What information do planners need from modellers to improve planning and policy for tsunami?

This report explores the difficulties in integrating physical science models into land use planning, with a focus on tsunami. Modelling for natural hazards is also not new, with flood modelling and associated mapping well established, and an increasing understanding and use of models and maps for extreme weather, ash fall, active fault stresses, liquefaction, landslides, and most recently tsunami inundation.

Historically flooding is the most common hazard that has been modelled and incorporated into land use planning. However, in assessing what lessons can be learned from flood modelling, it was found that there is no standard approach across New Zealand to incorporating flood modelling into land use planning. In many cases, it is not integrated into land use planning. Therefore flood modelling methodologies for incorporating flood zones into land use planning have not been included in this report.

1.1 Existing guidance

Existing guidance on land use planning for tsunami within New Zealand is limited. Currently the emphasis for managing tsunami hazards is on emergency management readiness and response. However, there is growing recognition of the potential effectiveness of risk reduction, especially when integrating modelling with land-use planning and urban design. To date there has been little progress in implementing such measures in New Zealand because of the infrequency of damaging tsunami in the recent past; the relatively low population density; difficulty in handling inherent model uncertainty; and a lack of understanding between planners and modellers. Few territorial and regional authorities in New Zealand have plan provisions that specifically address tsunami hazards, but the opportunity is provided at this time with plan reviews (Civil Defence Emergency Management (CDEM) Group plans, regional policy statements, district/city plans) being underway.

1.2 Limitations of this report

The report presents options for including tsunami modelling into land use planning only. However, the options provided are not exhaustive, and other methods (e.g. paleotsunami research and other planning tools) may also be appropriate.

1.3 Outline of report

This report begins by outlining what a tsunami is (Section 2), and New Zealand's exposure to tsunami. Section 3 provides an overview of the legislative roles and responsibilities for managing the tsunami hazard. Section 4 provides the framework for the remainder of the report: a decision tree for incorporating tsunami risk into land use planning, which includes four levels of tsunami modelling based on the Ministry of Civil Defence and Emergency

Management (MCDEM) tsunami evacuation zones, and is consistent with the Risk Management Standard (Standards Australia/New Zealand, 2009). Four modelling levels are outlined in Section 5, as well as uncertainties in modelling, and how to map uncertainty for tsunami (Section 6). Section 7 outlines three land use planning approaches to manage the tsunami risk (risk-based, precautionary, and participatory), and provides options for including tsunami in land use planning. Section 8 provides a methodology for a risk-based approach to tsunami, based on consequences. Appendix 1 outlines the methodology that was undertaken for this report; Appendix 2 lists the relevant provisions in the New Zealand Coastal Policy Statement; and Appendix 3 provides guidance on prioritising or weighting consequences.

2.0 TSUNAMI BASICS

The explanations in section 2.1 have been adapted from the MCDEM "Working from the same page" series (MCDEM, 2010, p3-6).

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;
- Underwater volcanic eruptions.

Tsunami waves differ from ordinary coastal waves (see Figure 1) in that the entire column of water, from the ocean floor to the surface, is affected. Tsunami waves contain considerable energy. This means tsunami waves travel much further, both in coastal surges and retreats, than ordinary coastal waves. Tsunami also create phenomena not characteristic of ordinary waves such as strong currents.

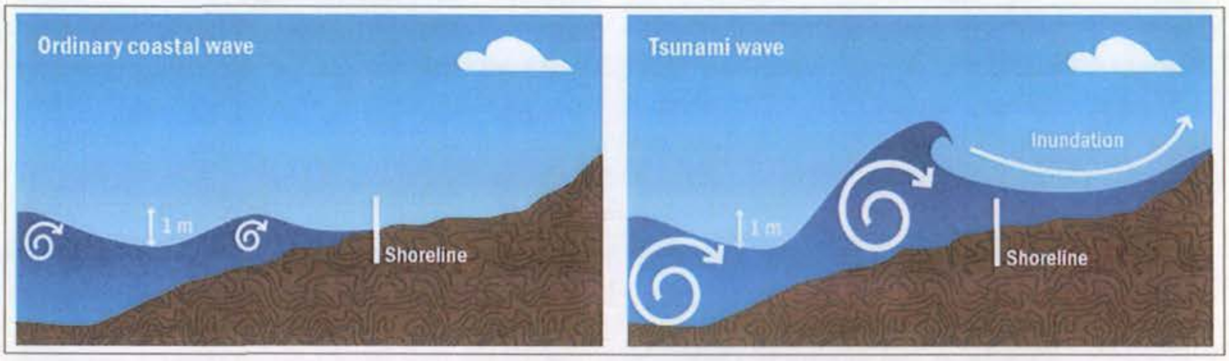


Figure 1 Wave energy in ordinary coastal waves is limited to the surface of the ocean. This energy rapidly dissipates as the wave breaks on the shoreline (left). Energy in tsunami waves however, affects the entire column of water from the ocean floor to the surface (right). This energy does not readily 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) increases to greater than one metre as the wave reaches the shoreline.

A tsunami can occur at any season of the year and at any time, day or night. On the open ocean tsunami waves are small and barely noticeable but when the waves enter shallow water they rise in height. Some tsunami can be very large and can rapidly and violently inundate coastlines, causing loss of life and property damage. Others can 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 so it is critical to know what to do as a precaution if you are in a vulnerable area.

Tsunami waves are described by their wave length, wave period, wave height, amplitude and their run-up (see Figure 2). Wave length is the distance between consecutive peaks. Wave period is the time between two consecutive peaks passing a point. 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 sea bottom configuration. Conversely, tsunami wave length 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.

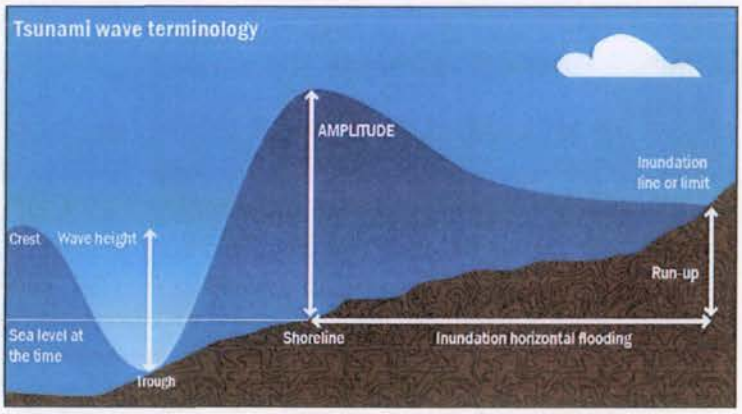


Figure 2 Tsunami terminology (MCDEM, 2010, p22).

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 3). The inundation distance and flux may be more important than the run-up. For example, for gently sloping topography, the run-up 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 less infrastructure is built on steep slopes.

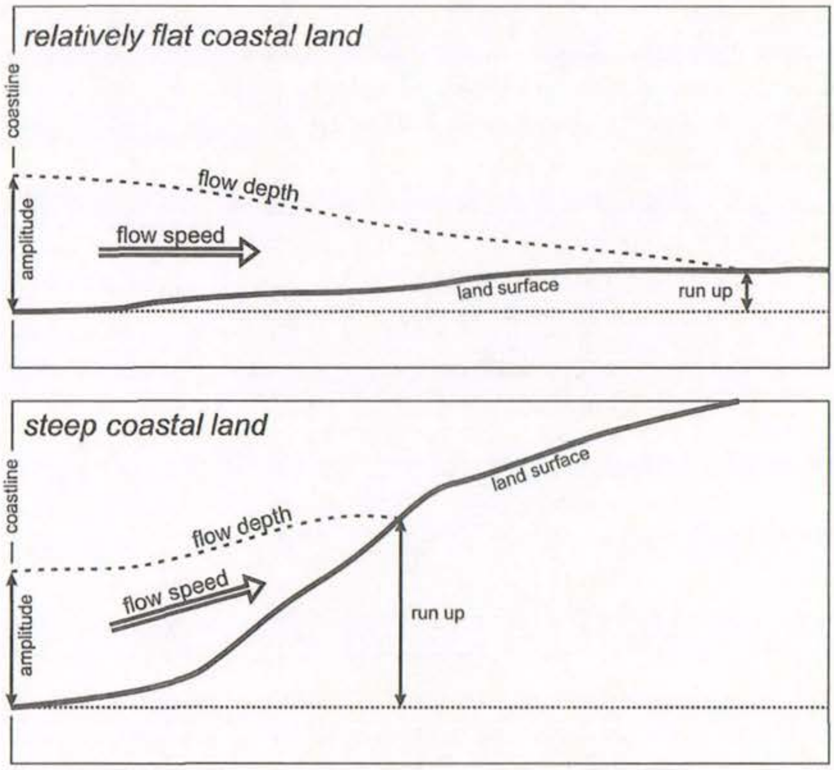


Figure 3 The same flow depth and speed (referred to together as 'flux') can give markedly different inundation distances and run-ups over flat compared to steep land.

2.2 New Zealand's tsunami exposure

New Zealand lies across the boundary between the Australian and Pacific tectonic plates (Figure 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 (Figure 4) may be one of the most important sources of tsunami that impact on New Zealand (Power, Reyners, & Wallace, 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.

Tsunami sources that impact on New Zealand can be divided into three categories (Berryman, 2005):

- Distant source — more than 3 hours travel time from New Zealand;
- Regional source — 1–3 hours travel time from New Zealand; and
- Local source — 0–60 minutes travel time to the nearest New Zealand coast (most sources are <30 minutes travel time).

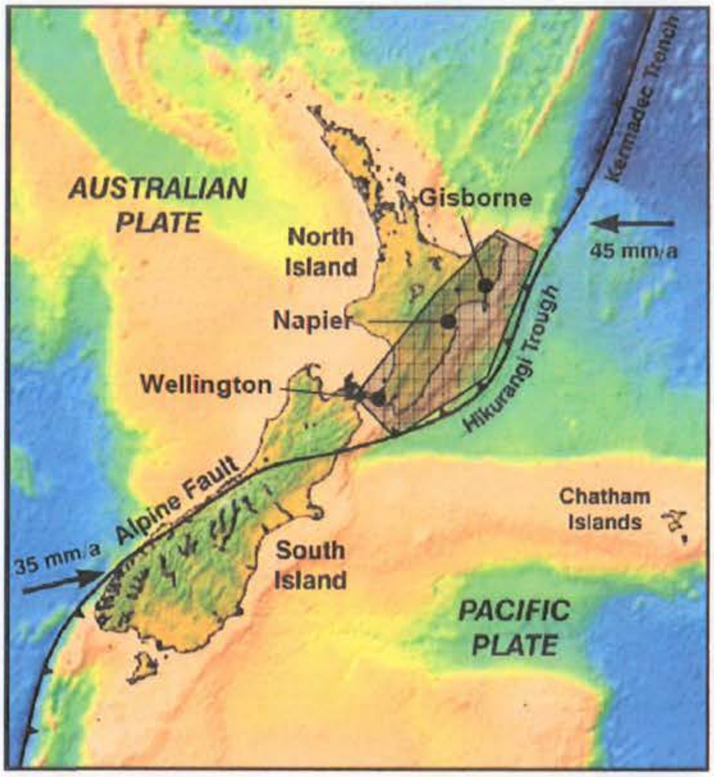


Figure 4 Location of the boundary between the Pacific and Australian tectonic plates. The plate interface along the Hikurangi Trough and Kermadec Trench is a possible source of tsunami. Numbers indicate the rate of movement on the plate boundary per annum; the hatched area represents/shows the surface projection of the boundary (Power et al., 2008, piii).

New Zealand has been affected by more than 40 tsunami in the last 165 years (Berryman, 2005) (see Figure 5). The eastern coast of New Zealand has the greatest exposure to tsunami (see Photos 1 and 2).

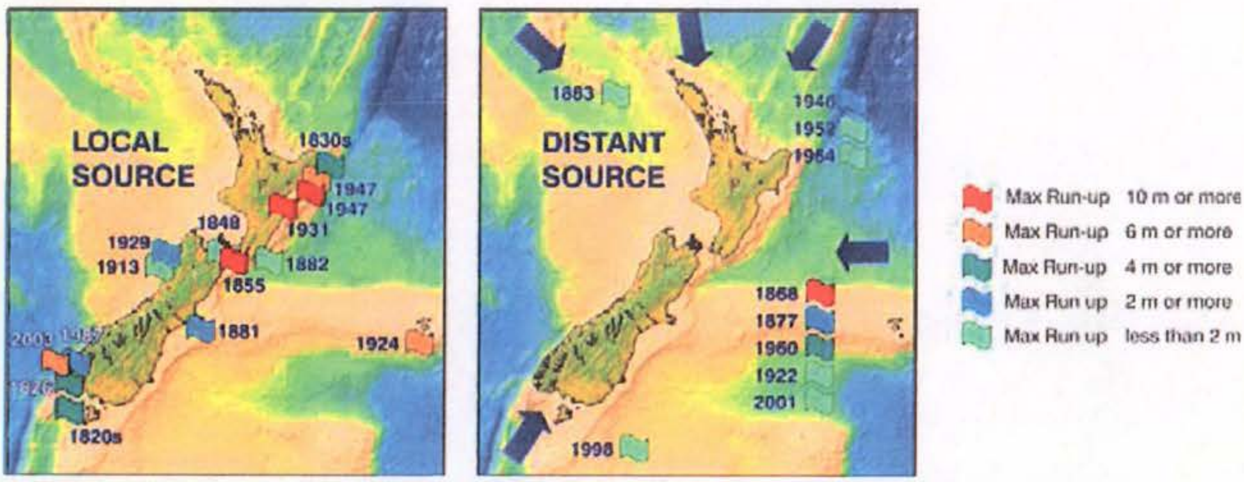


Figure 5 Largest tsunami recorded in New Zealand (Berryman, 2005, p9).

Photo 1 Damage to the foreshore at Wainui Beach, Gisborne, after a tsunami in 1947. This photo reinforces the importance of healthy dune systems in reducing the impacts on tsunami.

Source: Tairawhiti Museum, Gisborne.

Photo 2 Tsunami at Governor's Bay, Lyttelton Harbour, from the 2010 Chilean earthquake event.

Source: J. Gough.

The written historical record of tsunami in New Zealand only covers 165 years, which is 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 (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 (Berryman, 2005)

3.0 ROLES AND RESPONSIBILITIES FOR TSUNAMI RISK

3.1 An overview of natural hazard management

Land use planning should not be considered in isolation when considering hazard management. It is recommended that a combination of land use planning, design and construction, and emergency management options are considered as part of a holistic approach.

Five key pieces of legislation contribute to natural hazard management in New Zealand: the 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 (see Figure 6, which shows the relationships between these Acts).

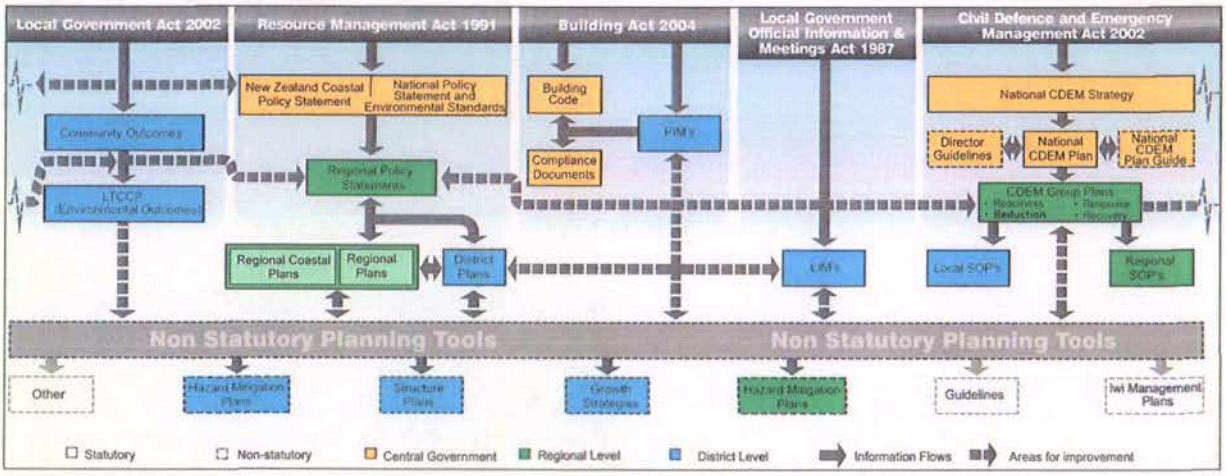


Figure 6 Legislative context for hazard management in New Zealand (Glavovic, Saunders, & Becker, 2010)

Figure 6 presents the five main statutes that govern natural hazards planning 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).

The statutes shown in Figure 6 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 (as shown by the dashed lines, there is room for better integration and improved linkages.)

The 2010 New Zealand Coastal Policy Statement (NZCPS, 2010) 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 states that "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, regional plans and district plans must give effect to the NZCPS, therefore Councils are now required to consider the effects of tsunami. Policy 24 refers to "areas at high risk", but this risk level is not defined. To assist in determining this level of risk, Section 8 of this report presents levels of risk, from acceptable through to intolerable. Section 7 provides guidance on options for including tsunami modelling into land use planning, and Appendix 2 summarises the relevant sections of the NZCPS and their linkages to this report.

Table 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.

Table 1 How statutes contribute to the management of tsunami risk (Saunders *in prep.*).

Statute	Implication for natural hazard management
Resource Management Act 1991	• Health and safety issue must be addressed. • Local authorities are required to avoid or mitigate the effects of natural hazards, not their occurrence (*Canterbury RC v Banks Peninsula DC, 1995).* • Proposed NZCPS includes specific coastal hazard (including tsunami) policies. • S106 (a consent authority may refuse subdivision consent in certain circumstances) does not allow for the consideration of all natural hazards as defined - only erosion, subsidence and slippage.
Building Act 2004	• The Building Code does not include tsunami, as it cannot economically mitigate the risk of tsunami for all buildings (some exclusions may apply in the future for critical facilities).
CDEM Act 2002	• 4R philosophy – risk reduction is assumed to be managed under the RMA (refer Saunders, Forsyth, Johnston, & Becker, 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, 2008ab; 2008ba).
Local Government Act 2002	• Financial planning for risk reduction activities. • Take into account the foreseeable needs of future generations.
Local Government Official Information & Meetings Act 1987	• Provides for natural hazard information to be included in LIMs.

Even though there is potential for good integration across statutes, there is no national guidance i.e. National Policy Statement or National Environmental Standards available for Councils.

3.2 Land Information Memorandum (LIM)

Under the Local Government Official Information and Meetings Act 1987, territorial authorities can issue LIMs 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 which the Council may hold (i.e. not included in the district plan), the Council can be liable.

As per Figure 7, it is recommended that information on tsunami from inundation modelling Levels 2-4 are included within a LIM. This could include tsunami evacuation maps and information on what the evacuation zones mean.

3.3 Other influencing legislation

A number of 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, Johnston, Saunders, & Leonard, 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 ss 7 (recognition of national significance of the Hauraki Gulf) and 8 (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 A DECISION TREE FOR INCORPORATING TSUNAMI RISK INTO LAND USE PLANNING

Figure 7 presents a decision tree for including tsunami risk into land use planning, and forms the basis for this report. The purpose of this figure is to lead the decision maker through a process of modelling, risk assessment, review of data quality and inclusion into LIMs, emergency management, and land use planning.

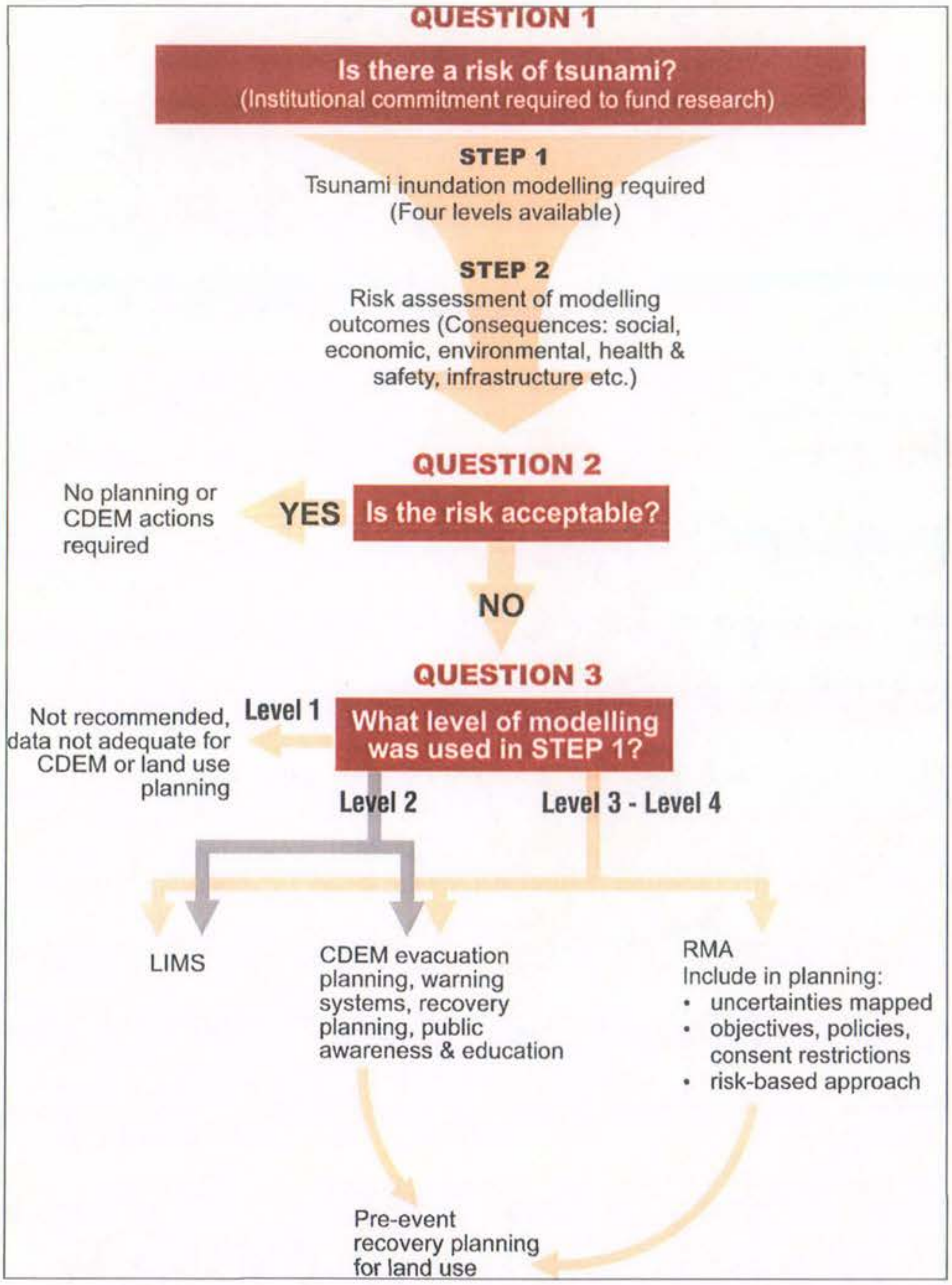


Figure 7 Decision tree for including tsunami risk in land use planning.

This framework is consistent with the Risk Management Standard (Standards Australia/New Zealand, 2009), in that has the potential to become an integral part of the planning and decision making process; explicitly addresses uncertainty; is systematic and structured; is based on best available information; is tailored to land use planning; takes into account human and cultural factors via consequences (refer Section 8); and provides the opportunity to facilitate improvement and enhancement of existing planning processes. It also requires the institutional mandate and commitment to begin the process. The focus of this report is on risk treatment via CDEM and land use planning options. While not shown in Figure 7, the final step in this framework should be monitoring and reviewing for effectiveness.

5.0 TSUNAMI MODELLING DEVELOPMENTAL LEVELS

To ensure consistency between evacuation mapping techniques and land use planning requirements, it is recommended the same framework for describing modelling is used. The following explanation is modified from the MCDEM publication "Tsunami Evacuation Zones" (MCDEM, 2008b, p9-10). It provides background information on different levels of modelling quality, as included in Figure 7.

Evacuation zone boundaries can be determined using a variety of hazard models. Zones ideally need to represent an envelope around all possible inundations from all known tsunami sources, taking into account all the ways each of those sources may generate a tsunami. The high degree of uncertainty in tsunami source models, and the very time consuming and resource intensive nature of modelling, make this comprehensive approach to tsunami risk assessment unlikely in the short term. The recommended approach to developing tsunami evacuation zones is to map now using existing knowledge, and progressively refine the accuracy of boundaries as the science improves over time and funding becomes available.

Four developmental levels (1-4) are recognised for establishing tsunami evacuation zone boundaries. Levels 3 and 4 use precise 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 multi-beam survey for near-shore bathymetry, are considered a minimum prerequisite for levels 3 and 4.

Level 1 is a simple 'bathtub' model in which inundation is determined based on a maximum wave height (Figure 8), projected inland from the coast to some cut-off elevation. This approach provides the crudest and simplest method of mapping evacuation zones.

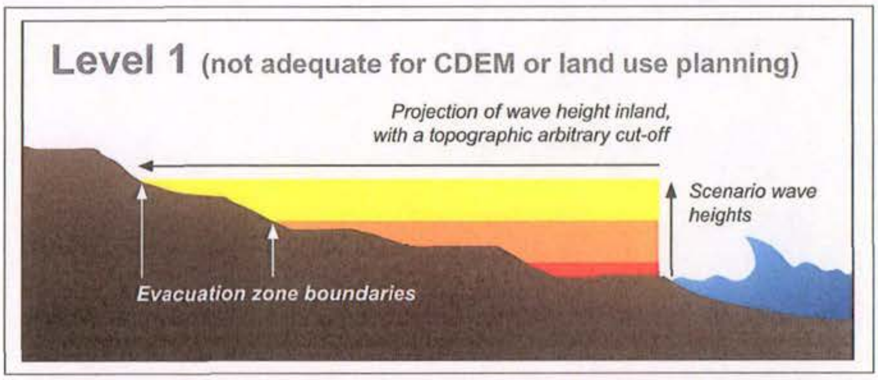


Figure 8 Cross section showing how evacuation zone boundaries can be mapped using a projection of wave heights inland, based on a simple 'bathtub' model.

Level 2 uses a measure of rule-based wave height attenuation inland from the coast (Figure 9). A GIS (Geographic Information System) can be utilised for applying the attenuation rule. This approach derives a more realistic output than a simple 'bathtub' model but is still a rough estimate which cannot account for physical variations in wave behaviour. The rule is applied to probabilistic wave heights derived separately, and the yellow zone should be tied to the credible worst case height from the probabilistic work. This rule does not account for all scenarios and improvements are expected to come with time. Rules developed for evacuation mapping may take a precautionary approach that is more likely to overstate the area at risk than understate it. Local knowledge must also be applied to support the process.

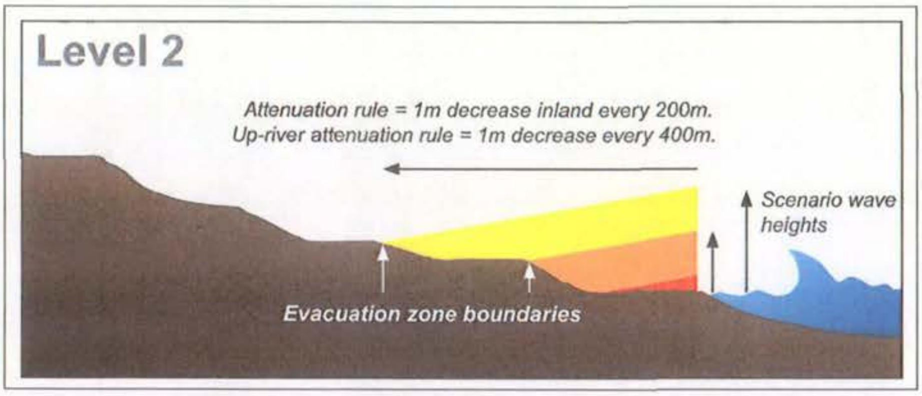


Figure 9 Cross section at the coast showing how evacuation zone boundaries are determined using an attenuation rule, in which elevation decreases from a maximum wave height at the coast and is projected inland according to a slope angle calibrated against real and modelled tsunami.

Level 3 is a computer-derived simulation model that theoretically allows for complexities that a simpler 'rule' cannot, such as varied surface roughness from different land uses, and water turning corners and travelling laterally to the coast on its inundation path. The model is applied to probabilistic wave heights derived separately, and the yellow zone should be tied to the credible worst case height from the probabilistic work. Such modelling is expensive and the quality of outputs is dependent on the science behind the probabilistic hazard model.

Level 4 is the most complete approach, based on an envelope around all inundations from multiple (likely to be many) well-tested computer models covering all credible scenarios. Development to this level of sophistication will require a comprehensive scientific understanding of all possible tsunami sources (distant, regional and local), and wave propagation and inundation behaviours, across a range of magnitudes.

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. Until higher stage assessments can be undertaken, a precautionary approach is recommended in defining the placement of evacuation zone boundaries.

While the recommended minimum development standard for defining tsunami evacuation zone boundaries is a model consistent with developmental Level 2 (rule-based approximation), we consider this not accurate enough for land use planning purposes, and only recommend Level 2 for inclusion in LIMs, evacuation planning and other emergency management requirements. As shown in Figure 7, for land use planning purposes it is recommended either Levels 3 or 4 are required.

5.1 Timeframes for modelling and land use planning

There is no consistent all-hazard probability of occurrence used as a basis for planning for natural hazards events in New Zealand. While some hazards have similar return periods, their likelihood, consequences, forecasting and warning capabilities may be different (Table 2). For example, high rainfall events can be forecast, flood warnings can be given, and evacuation of communities at risk is possible – unlike the situation for earthquakes (Saunders, 2010). Likelihood and consequences are based on guidance provided by Standards New Zealand (Standards New Zealand, 2004b).

Table 2 Comparative land use planning timeframes for selected natural hazards in New Zealand (adapted from Saunders, 2010).

	Planning timeframe (years)	Aimed at avoiding	Warnings available	Mappable	Affected by climate change	Likeli-hood	Scale of impact
Flood	20 - 100+	Loss of life and property, inundation and perhaps structural damage	Yes	Yes	Yes	Almost certain	Minor/ Moderate
Coastal erosion	100	Inundation, loss of property, and structural damage	Yes	Yes	Yes	Likely	Minor
Active faults / earthquake	</= 20,000	Loss of life and property, structural damage	No	Yes	No	Possible	Moderate /Severe
Tsunami (local and distal)	</+ 2,500	Loss of life and property, structural damage	Yes (distal only, natural warning for local source)	Yes	Trigger is not, but dune/ ecosystem health is	Possible	Moderate /Severe
Landslide	</+ 2,500	Loss of life and property, structural damage	No/in some situations	Yes	Yes	Possible	Minor/ Moderate

Deciding which probability of occurrence should be used often represents a value judgement that may be difficult to deal with in the political arena. At one end of the scale are hazards that produce modest levels of damage on a relatively frequent basis, generally with a recurrence interval of less than 20 years; at the other end are catastrophic events that occur less frequently, perhaps once every 500 years or less, but produce devastating levels of damage and consequences (Deyle, French, Olshansky, & Paterson, 1998). These high-consequence, low-likelihood events are the most important (and difficult) public hazards to manage (Slovic, Fischhoff, & Lichtenstein, 2000), as has been acknowledged in New Zealand. In the Environment Court case Save the Bay v Canterbury Regional Council (C6/2001), the Court recommended a greater recognition of catastrophic natural events, stating that 90% of damage to the environment caused by natural hazards occurs in 10% or fewer of events. The Court suggested that "authorities should recognise this inverse relationship in the preparation and wording of their plans". However, a devastating earthquake or landslide (such as Hawkes Bay 1931, Abbotsford 1979 or Christchurch 2011), does tend to focus public and political attention on the consequences of large but infrequent events. Such events can catalyse and enable upgrading of building codes, hazard awareness and planning practice.

6.0 UNCERTAINTY

There are two main types of uncertainty that can affect the inclusion of tsunami in land use planning: (1) uncertainties in the tsunami inundation modelling; and (2) uncertainties in the decision making process. This section will outline the first type, and present a method for including modelling uncertainty into land use planning.

6.1 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 (see following sub-section on mapping uncertainty), and the modelling data and quality are retained.

Uncertainty is encountered at various steps of the modelling process. There are four types of modelling uncertainties as outlined below and in Figure 10 (van Asselt, 2000):

1. Technical: from the quality or appropriateness of the input data used to describe the system, from aggregation (temporal and spatial) and simplification, as well as from lack of parameters from data and approximations;
2. Methodological: due to uncertainty in equations and model structures;
3. Epistemological: uncertainty in levels of confidence and model validity; and
4. Model operation uncertainties: due to hidden flaws in technical equipment, and/or accumulation of uncertainties propagated through the model.

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.

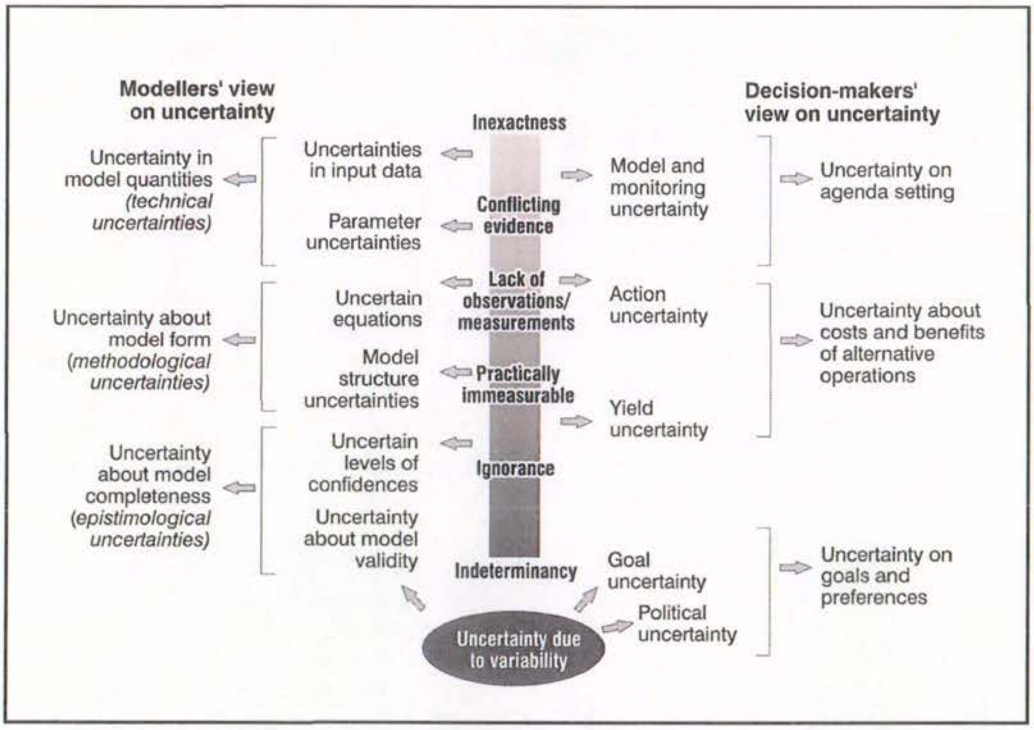


Figure 10 Uncertainties in modelling (van Asselt, 2000, p91).

For earthquake-caused 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 real 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. 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.

Various types of uncertainty in decision making 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.

6.2 Mapping uncertainty for land use planning

For other natural hazards i.e. active faults and landslides, uncertainty is already included in planning maps. Examples of mapping uncertainty include using a 'well defined', 'constrained' and 'distributed' mapping of active faults (Kerr et al., 2003, see Figure 11); and landslide 'core' and 'fringe' areas (Saunders & Glassey, 2007, see Figure 12).

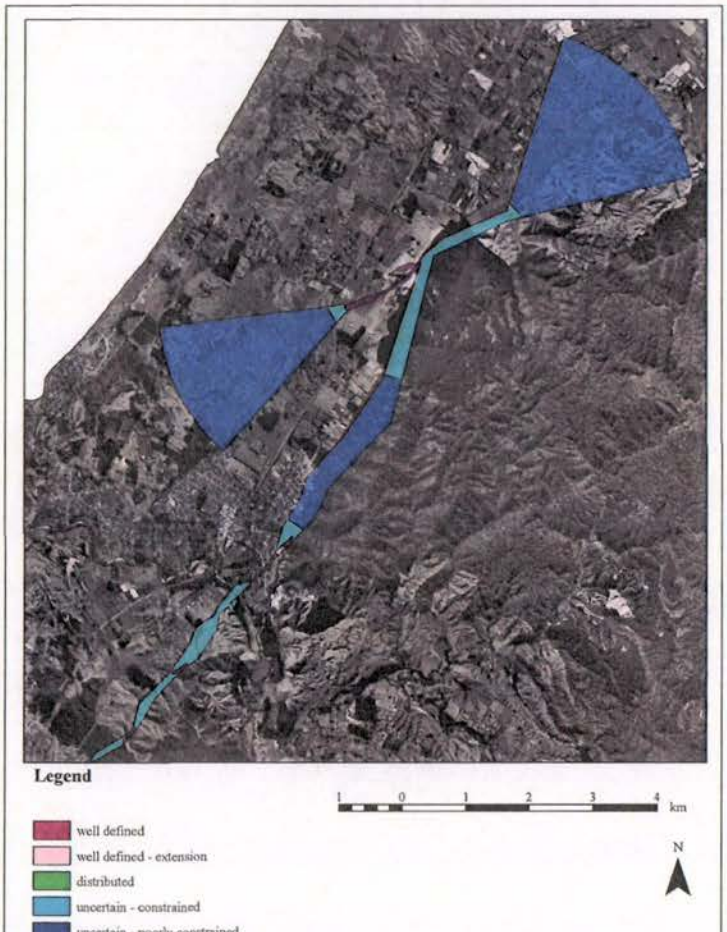


Figure 11 Example of uncertainty cones in active fault mapping, with colours depicting type of fault and level of uncertainties (Kerr et al., 2003).

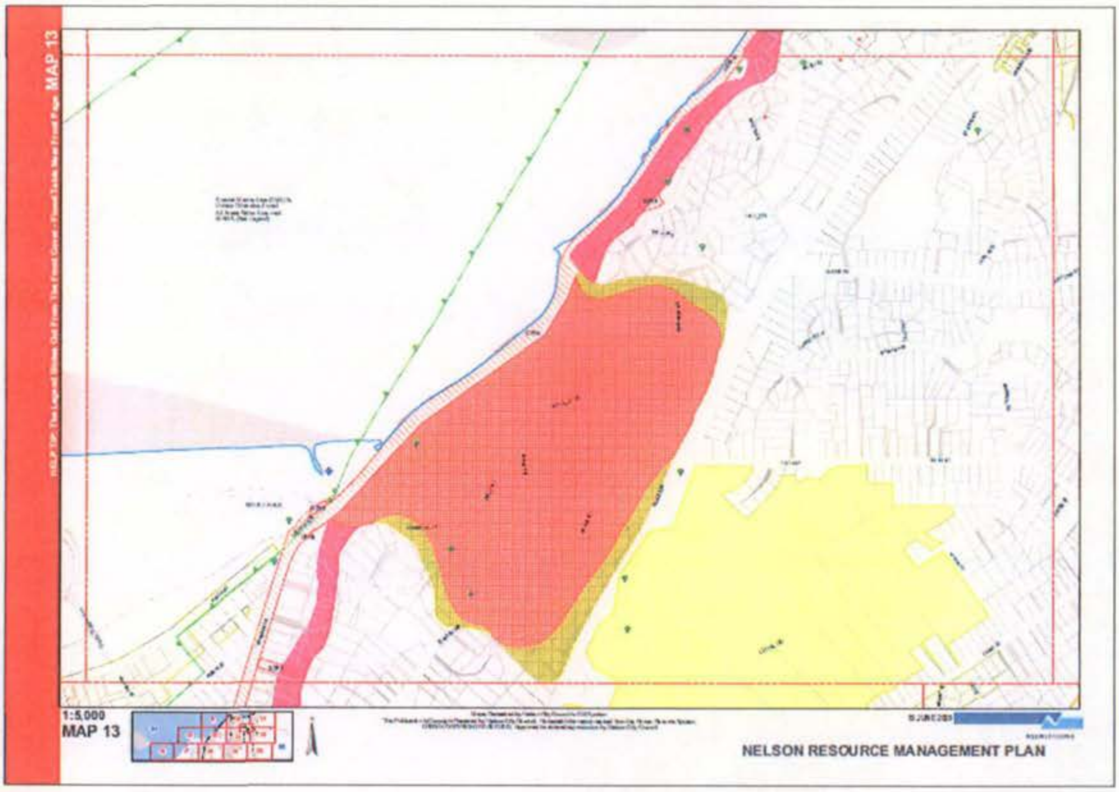


Figure 12 The Tahunanui Slope Risk Area, commonly known as the Tahunanui Slump, is defined on the Planning Maps (above) within the Nelson Resource Management Plan. It consists of a core area where the hazard is known (red), surrounded by a fringe area where the edge of the active slump has not been able to be accurately defined (green) (Nelson City Council). Rules stipulate that new residential units within the core are non-complying; within the fringe area they are discretionary (Rule REr.77.3).

For tsunami, a similar approach could be taken, as shown in Figures 13 and 14. Figure 13 presents a cross section of modelled probabilistic tsunami wave heights at the coast, and associated levels of (un)certainties. The middle hashed zone is bounded by the lower and upper levels of a chosen level of confidence. Figure 14 presents a birds-eye view of the zones shown in Figure 13.

Confidence levels are expressed as percentages. On a graph or a map they define a confidence interval either side of an average value. In Figures 13 and 14 this average value lies in the middle of the hashed 'Uncertain tsunami inundation' zone.

The confidence interval is the size of the hashed 'uncertain tsunami zone'. For 99% confidence, 1% of the time the true value will lie outside of the interval, while at 95% confidence, 5% of the time the true value will lie outside. Choosing a higher confidence (e.g. 99% instead of 95%) will make the hashed zone larger; the lower limit will become closer to the coast and the upper limit will be further inland.

The confidence interval used depends on how certain one needs to be that the following two situations will not occur:

(a) a section of the 'high certainty of tsunami inundation' zone is actually not at risk from tsunami; or

(b) a section of the 'high certainty of no inundation' zone is actually at risk from tsunami.

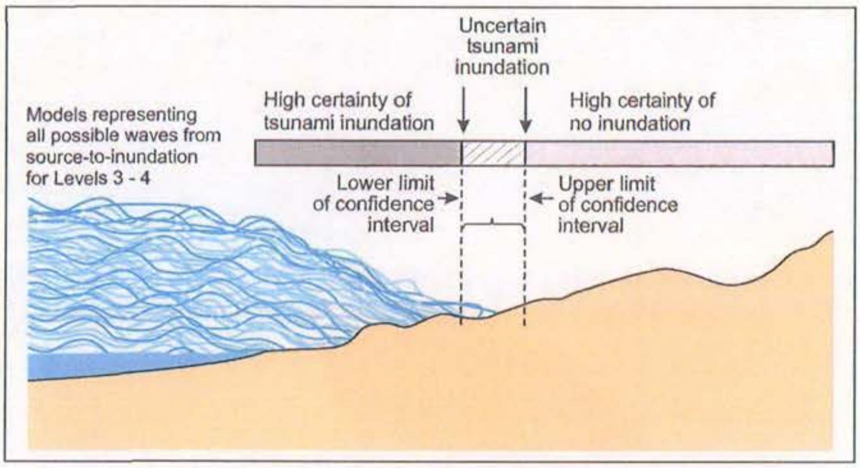


Figure 13 Cross section of modelled probabilistic tsunami wave heights at the coast, and associated levels of (un)certainties (to a chosen level of confidence – i.e. a confidence interval).

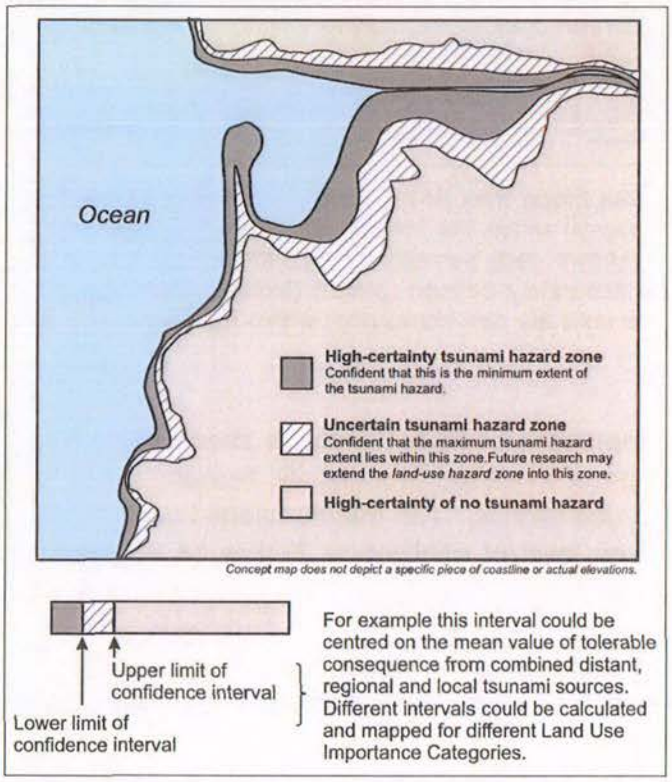


Figure 14 Map view of the tsunami inundation shown in Figure 11.

At the present time few studies of tsunami hazard are sufficiently comprehensive to allow quantitative estimation of uncertainty, though it is hoped that such studies will become more common.

6.2.1 Scale of mapping

Typically tsunami modellers present their inundation maps with a scale based on grid spacing (e.g. 20m), while planners require 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, especially: the amount of data in the modelling; the computational complexity; and 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 risk/inundation emerges from the modelling.

When undertaking tsunami inundation modelling, planners should take the opportunity to discuss their scale needs with the tsunami modeller to ensure a practical inundation map is produced that suits both the planners and modellers.

7.0 PLANNING APPROACHES TO TSUNAMI RISK

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

1. 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;
2. 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
3. Standards derived from a 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.

When deciding which approach is most appropriate to use, policy makers need to evaluate what information they have, how complete it is, and what the level of uncertainty is. Table 3 summarises which approach should be used depending on the information available.

Table 3 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 resource consents (refer Kerr et al., 2003; Saunders & Glassey, 2007)
Greater levels of uncertainty, lack of knowledge, i.e. uncertain tsunami zone	Precautionary	ALARP, emergency management (i.e. warnings, evacuation), use of s72 of the Building Act (limits liability)
Mix of above	Participatory	Consultation, public participation in developing policy, conflict resolution

As the risk based approach requires the most information and lowest uncertainty, guidance is provided in Section 8 on how this information can be used within a land use planning context.

7.1 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 15:

1. Know your community's tsunami risk: hazard, vulnerability and exposure;
2. Avoid new development in tsunami run-up areas to minimize future tsunami losses;
3. Locate and configure new development that occurs in tsunami run-up areas to minimise future tsunami losses;
4. Design and construct new buildings to minimise tsunami damage;
5. Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects;
6. Take special precautions in locating and designing infrastructure and critical facilities to minimise tsunami damage (not shown in Figure 15); and
7. Plan for evacuation.

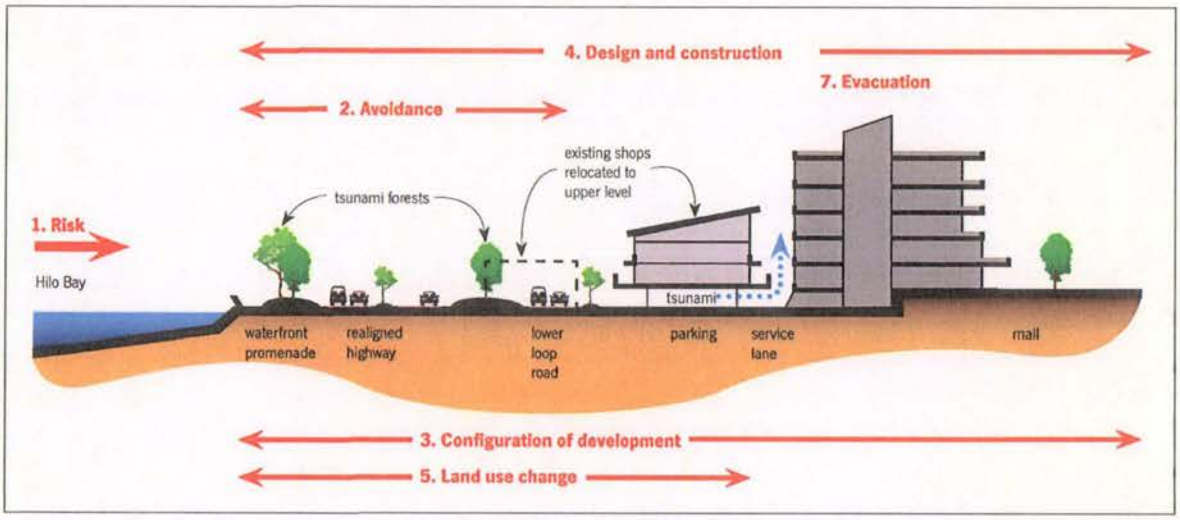


Figure 15 Seven principles for planning and designing for tsunami hazards in Hilo, Hawaii (adapted from National Tsunami Hazard Mitigation Program, 2001, p27).

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

7.1.1 Regulatory approaches

Regulatory approaches for the high certainty and uncertain tsunami zones include, but are not limited to, the following options (in no particular order). See also Figure 15:

- Know your tsunami 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 district/city plans;
  - Avoid new development in at-risk areas e.g. via setbacks. May be impractical at some locations;
  - Avoid locating critical facilities (e.g. public utilities, medical facilities, facilities with post-disaster functions, emergency services, large dams, hazardous facilities) within

tsunami hazard zone;
  - Mitigation i.e. community response plans, integration with emergency management preparedness and building design (e.g. for vertical evacuation). May not address life safety concerns for local-source events;
  - Limit infill development so as not to increase the risk to people and property.
- 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, with an explanation of what the different zones mean and actions required;
- Take a risk-based approach to policy and consents (see following section) i.e. more restrictive consent activity status with increasing risk;
- Either encourage low-density development to reduce the number of people and 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 this strategy may also reduce the number of people at risk;
- Include the assessment of tsunami risk within the Assessment of Environment Effects (AEE);
- As condition of consent require an evacuation plan/community response plan to be drafted and accepted by Council, with an annual audited evacuation exercise (refer to Environment Court case Kaihikatea Estate ENV-2006-AKL-001021 where this approach has been used for flooding). NOTE: if the risk requires a community response/evacuation plan, is the proposal sustainable?
- Combine hazard zones e.g. coastal erosion setbacks, tsunami inundation plus allowance for climate change (sea level rise, increased erosion etc);
- Include specifics of local tsunami response plans into long term planning documents. For example, ensuring that identified tsunami evacuation routes are future-proofed within plans;
- Incorporate design standards for buildings in tsunami inundation zones, particular for those that could be used for vertical evacuation (future research area).

7.1.2 Non-regulatory approaches

Non-regulatory approaches for the high certainty and uncertain tsunami zones 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, Saunders, Hopkins, Wright, & Kerr, 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.

8.0 TAKING A RISK-BASED APPROACH TO LAND USE PLANNING

As per Figure 7, a risk-based approach can be taken to planning for all natural hazards – in this case, tsunami. An adaptive three-step approach is recommended for this approach, which can also be combined with the precautionary and participatory approaches. The three steps are listed below:

1. Determine severity of consequences;
2. Evaluate the likelihood of an event occurring that produces the consequences; and
3. Using a risk-based approach, determine the activity status of land use (i.e. activity status of resource consents) according to steps (1) and (2).

Each step is briefly outlined below. A full explanation of each step is available on request (Saunders *in prep.*).

8.1 Step 1: Determine severity of consequences

The first step of the process is to ascertain what the land use is. This can be assisted by consulting district/city plans. For example, plan zones may include the following: coastal, rural, housing, town centre, industrial, conservation, open space, recreation, etc. These zones and policy areas can provide a guide for the types of land use permitted in a particular area. This approach also ensures consistency with the terms used within the district plan context. Inspections on the ground should then confirm the actual land uses.

Once the land use has been confirmed, the consequences of an event on that land use need to be determined. Figure 16 provides a matrix consisting of three key parts: scale of impact, consequences, and severity of consequence.

<table>
<tr><th rowspan="2">Scale of impact</th><th colspan="4">Description of consequences</th><th rowspan="2">Severity of Consequence</th></tr>
<tr><th>Health & safety</th><th>Social</th><th>Economic</th><th>Environmental</th></tr>
<tr><td>Major</td><td>Multiple fatalities, or significant irreversible effects to >50 persons.</td><td>On-going serious social issues. Significant damage to structures and items of cultural significance</td><td>Severe i.e. over $10 million -or- more than 50 % of assets</td><td>Severe, long-term environmental impairment of ecosystem functions</td><td>VI</td></tr>
<tr><td>Severe</td><td>Single fatalities and / or severe permanent disability (>30%) to one or more people.</td><td>On-going serious social issues. Significant damage to structures and items of cultural significance</td><td>Major i.e. between $1 million and $10 million -or- 10-50 % assets</td><td>Very serious, long-term environmental impairment of ecosystem functions</td><td>V</td></tr>
<tr><td>Moderate</td><td>Moderate irreversible disability or impairment (<30%) to one or more persons.</td><td>On-going social issues, permanent damage to buildings and items of cultural significance</td><td>Moderate i.e. between $100,000 and $1million -or- 10 % of assets</td><td>Moderate, short term effects by not affecting ecosystem functions</td><td>IV</td></tr>
<tr><td rowspan="2">Minor</td><td rowspan="2">Reversible injury possibly requiring hospitalisation.</td><td>On-going social issues, temporary damage to buildings and items of cultural significance</td><td>Minor i.e. between $10,000 and $100,000 -or- 1 % of assets</td><td rowspan="2">Minor effects on physical environment</td><td>III</td></tr>
<tr><td>Medium-term social issues, minor damage to dwellings</td><td>Minor i.e. between $10,000 and $100,000 -or- 0.1% of assets</td><td>II</td></tr>
<tr><td>Negligible</td><td>Minor first aid or no medical treatment required.</td><td>Negligible short -term social impacts on local population, mostly repairable</td><td>Small i.e. less than $10,000 -or- 0.01% of assets</td><td>Insignificant effects on physical environment</td><td>I</td></tr>
</table>

Figure 16 Scale of impact and consequences.

Individual and multiple life safety can also be used in the 'health and safety' consequence column, however this attribute does contain the likelihood within it (rather than being the next step). If life safety risk were included, it could be as follows for an individual:

Intolerable	above ~ 10^{-2} / year
Generally tolerable with consent	~ 10^{-3} to 10^{-4} / year
Tolerable	~ 10^{-5} to 10^{-6} / year
Acceptable	~ 10^{-6} to 10^{-7} / year

Using this approach, an intolerable event has a 1 in 100 chance of occurring in any one year; while the acceptable level of risk has a 1 in 10 million chance of occurring in any one year.

The description of consequences should be completed by the Council with participation from the community, to reflect the local hazardscape and social, economic and environmental contexts. The consequences in Figure 16 are presented as an example of what can be achieved – other categories and subcategories could be added. For example, a separate category could be added for the built environment, with subcategories of residential, commercial/industrial, public buildings and assets, rural, and lifeline utilities. For any particular tsunami event, the consequences may not be equal, e.g. casualties may be high, but with lower environmental consequences. In such cases, either the highest level of consequence can be used in Figure 16, or they can be weighted (see Appendix 3). The matrix has been derived from a combination of guidance from Standards New Zealand (Standards New Zealand, 2004b), Berryman (2005), and regulatory requirements (i.e. social, economic and environmental well-beings).

8.2 Step 2: Evaluate the likelihood of an event

Once the consequences have been determined, only then should the likelihood of an event occurring which results in those consequences shown in Step 1 be evaluated. By focusing on consequences first, the current approach of putting people and property in harm's way based on small timeframes, should be overcome. Table 4 provides a likelihood scale which can be used as a guide.

Table 4 Likelihood scale (adapted from Standards New Zealand, 2004b)

Level	Descriptor	Description	Indicative Frequency (expected to occur)	AEP*
7	Almost certain	The event will occur on an annual basis	Once a year or more frequently	1
6	Likely	The event has occurred several times or more in your career	Once every three years	0.3
5	Possible	The event might occur once in your career	Once every ten years	0.1
4	Unlikely	The event does occur somewhere from time to time	Once every thirty years	0.03
3	Rare	Heard of something like this occurring elsewhere	Once every 100 years	0.01
2	Very rare	Have never heard of this happening	One in 1000 years	0.001
1	Almost incredible	Theoretically possible but not expected to occur	One in 10,000 years	0.0001

* AEP – annual exceedance probability

Once the consequences (Step 1) and likelihood (Step 2) have been determined, then the options for land use planning can be assessed. The methodology of this final stage of the process is outlined in the following section.

8.3 Step 3: Take a risk-based approach

In order to take a risk-based approach, the consequences and likelihood need to be quantified to provide a level of risk. To achieve this, a matrix can be used incorporating the relevant risk level, expressed as a function of consequences x likelihood (Figure 17). Consequences are relabelled from roman numerals into Arabic numerals to allow for the calculation. The risk then ranges from 1 (extremely low) to 42 (extremely high).

	Consequences					
Likelihood	**1**	**2**	**3**	**4**	**5**	**6**
7	7	14	21	28	35	42
6	6	12	18	24	30	36
5	5	10	15	20	25	30
4	4	8	12	16	20	24
3	3	6	9	12	15	18
2	2	4	6	8	10	12
1	1	2	3	4	5	6

Figure 17 Quantifying consequences and likelihood

The risk levels then need to be determined. Figure 18 shows how the risk levels were determined from Figure 17. In practice participation and associated debate would be required within Council and with the community to decide these levels of risk.

Risk	Level of risk
1-6	Acceptable
7-16	Tolerable
17-26	Tolerable with consent
27-42	Intolerable

Figure 18 Qualifying levels of risk from Figure 16

Once levels of risk have been determined, the matrix is then colour coded (Figure 19), based on the levels of risk shown in Figure 17. The use of colours allows a faster assessment of the levels of risk involved. The colours of green (acceptable), yellow (tolerable), orange (tolerable with consent) and red (intolerable) are considered standard colours for this approach (Standards New Zealand, 2004b).

	Consequences					
Likelihood	**1**	**2**	**3**	**4**	**5**	**6**
7	7	14	21	28	35	42
6	6	12	18	24	30	36
5	5	10	15	20	25	30
4	4	8	12	16	20	24
3	3	6	9	12	15	18
2	2	4	6	8	10	12
1	1	2	3	4	5	6

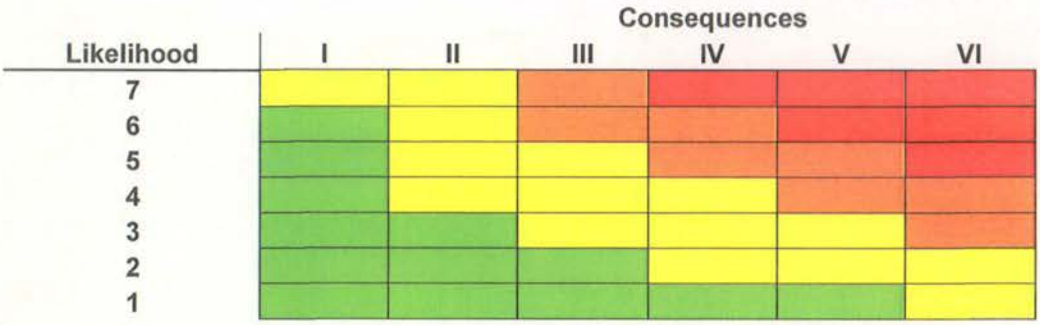
Figure 19 Colour coding the matrix based on level of risk

The final stage of the process is to relabel the consequence values 1 – 6 into roman numerals, to ensure no confusion between the likelihood scale and consequence scale. The final stage of the process uses the colours, based on the levels of risk, to determine the consent status (i.e. treatment) of the activity (Figure 20).

Level of risk	Consent status
Acceptable	Permitted
Tolerable	Controlled
Tolerable with consent	Discretionary, restricted discretionary
Intolerable	Non complying, prohibited

Figure 20 Level of risk and associated consent status

Figure 21 provides the final framework where risk equates to consent status applied.



Likelihood

7	Almost certain
6	Likely
5	Possible
4	Unlikely
3	Rare
2	Vary rare
1	Almost incredible

Consent status

- Permitted
- Controlled
- Discretionary
- Non complying, prohibited

Figure 21 The risk-based planning framework

Non-complying and prohibited are merged together, but it is acknowledged that the former allows for development, while the later avoids development. For the purposes of this example, the two are merged to allow for high consequence activities to take place in high risk areas, which may not be able to be avoided. For example, a port has to be located on the coast, but its location may also be susceptible to tsunami. For similar reasons as stated above, discretionary and restricted discretionary have been combined. Consent categories become more restrictive as the risk increases.

Figure 21 is only a guide to what can be achieved – community engagement and participation are required to determine the levels of risk and consequences. Consent categories and the evaluation of levels of risk in Figure 19 may change depending on the context and community appetite for risk. Other options may also be available to reduce losses, which are acceptable or tolerable for communities. For example, sharing the risk of potential losses via insurance, or accepting/tolerating the risks involved.

9.0 PRE-EVENT RECOVERY PLANNING FOR LAND USE

A tool shown in Figure 7 is pre-event recovery planning for land use. This concept focuses on how land or land use may be affected by a natural hazard event (in this case, tsunami), and how it could be recovered or used after an event (Becker et al., 2008). Pre-event recovery planning involves planners and emergency management officers thinking through issues that may arise, such as whether a land use should be relocated after an event. A methodology for pre-event land-use recovery planning was developed in 2006 and updated in 2008 (Becker et al., 2008), based on the Australian/New Zealand Risk Management Standard 4360:2004 (now superseded by SNZ 31000:2009). The objective of the Standard is to:

"provide guidance to enable public, private or community enterprises, groups and individuals to achieve:

- a more confident and rigorous basis for decision-making and planning;
- better identification of opportunities and threats;
- gaining value from uncertainty and variability;
- pro-active rather than re-active management;
- more effective allocation and use of resources;
- improved incident management and reduction in loss and cost of risk, including commercial insurance premiums;
- improved stakeholder confidence and trust;
- improved compliance with relevant legislation; and
- better corporate governance" (Standards New Zealand, 2004a).

The Standard has been used as the conceptual basis for this methodology, as it provides a generic and flexible model that allows for the incorporation of risk management into all aspects of local authority governance structures in a logical and systematic manner. Further, given that there are many aspects to consider for pre-event recovery planning, the Standard lends itself to the level of analysis needed for land-use recovery planning.

A framework has been constructed to assist resource management planners in undertaking pre-event recovery land-use planning. This is presented in the form of a flow chart (Figure 22) with a comprehensive set of steps toward completing the process. The suggestions shown in Figure 22 are prompts only, and are not an exhaustive list of information sources, options or considerations. They are presented to encourage the reader to think about the land-use recovery process within their local context.

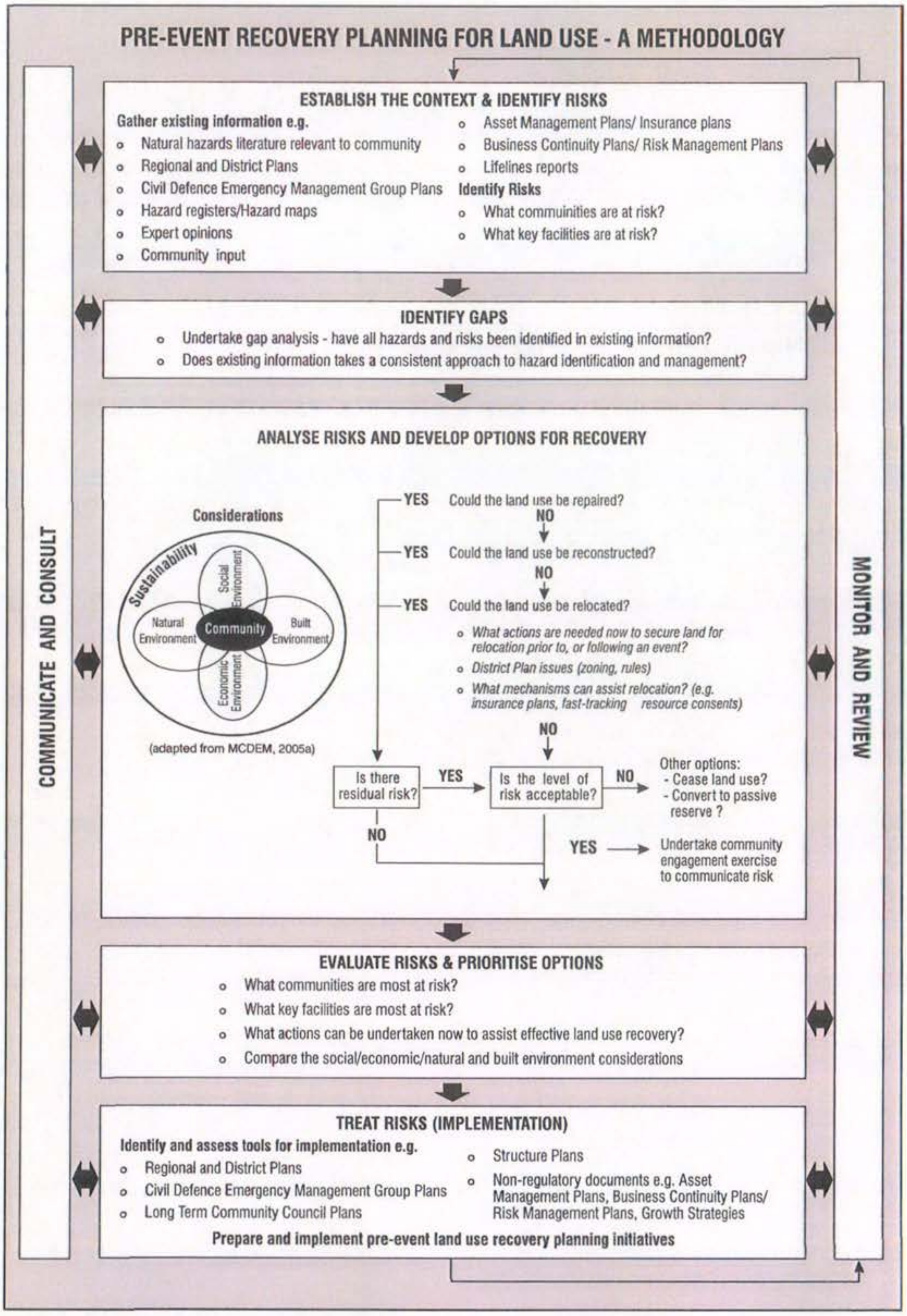


Figure 22 Pre-event recovery framework (Becker et al., 2008, p9).

Pre-event recovery planning is predominantly used in contexts where development has already occurred, but this approach provides a strategy for reducing future risks.

10.0 FUTURE RESEARCH

The information contained in this report will benefit from future research in the tsunami area. Research already underway includes an update of the national tsunami report completed in 2005 (Berryman, 2005), further investigations of the risk-based approach (Saunders *in prep.*), and scoping of building requirements for tsunami evacuation (GNS Science and others).

11.0 LINKS FOR FURTHER INFORMATION

For further information on the concepts discussed in this report, the following links may be of assistance:

- Ministry of Civil Defence and Emergency Management http://www.civildefence.govt.nz/
- Quality Planning www.qualityplanning.org.nz
- Review of tsunami hazard and risk in New Zealand (Berryman report) http://www.civildefence.govt.nz/memwebsite.nsf/srch/BB3393D739D0E858CC2570DC0000C614?OpenDocument
- New Zealand Coastal Policy Statement http://www.doc.govt.nz/publications/conservation/marine-and-coastal/new-zealand-coastal-policy-statement/new-zealand-coastal-policy-statement-2010/
- Community tsunami response plans (example from Northland) http://www.massey.ac.nz/~trauma/issues/2010-1/mitchell.htm
- Designing for tsunami: seven principles for planning and designing for tsunami hazards http://nthmp-history.pmel.noaa.gov/Designing_for_Tsunamis.pdf
- Tsunami Preparedness information guide for disaster planners http://www.ioc-tsunami.org/images/stories/documents/manualandguides49_e.pdf
- Pre-event recovery planning for land use use in New Zealand www.gns.cri.nz/content/download/4747/26126/file/Download.pdf

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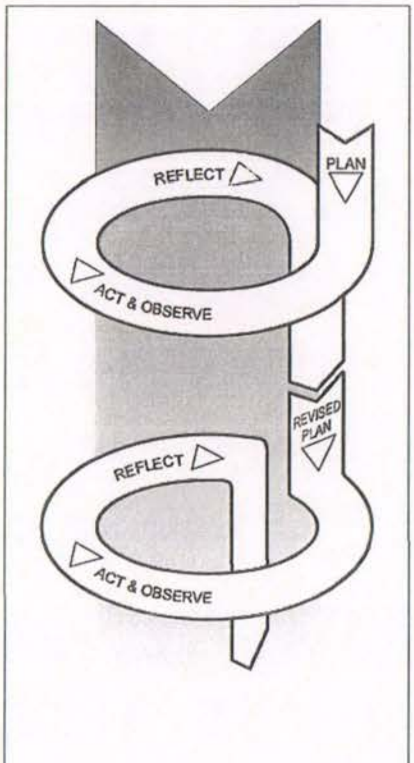
APPENDICES

APPENDIX 1 METHODOLOGY

In order to achieve the objectives of the research, a number of qualitative social science research methodologies were employed, including participatory action research, case studies and workshops.

The research was based within Participatory Action Research (Types II and III from (Cameron, 2007), which is characterised by researching *for* (Type II) and *with* (Type III) institutions. Thus, the research undertaken is on behalf of institutions, and aims to produce insights and recommendations for institutions to respond to; and representatives from institutions participate as co-researchers. This approach also has the benefit of building institutional commitment to act on findings. The research is a mix of Types II and III PAR – while this research is primarily *for* local government planners at a national level, it is or will be undertaken *with* local government practitioners. Action research provides a research cycle of questioning, planning, acting and observing, reflecting, questioning etc which will form the basis of each phase of the research (see Figure A1).



Within the action research design, a case study approach was employed. This allowed multiple research methods and data collection from multiple sources using a variety of techniques, for example workshops and documents. Case studies have the benefit of keeping attention focused on contexts, never extracting variables from the conditions in which they arise. The case study approach is very suitable for aiding professional practice (Shipman, 1997), in this context the profession of land use planning. As the research questions in this study are 'how' and 'what' questions, case studies are relevant strategies to be employed (Yin, 2003). For the purposes of this research, case studies were undertaken in three areas – Gisborne (governed by the unitary Gisborne District Council) and Thames Coromandel (governed by Thames-Coromandel District Council and Environment Waikato); and Bay of Plenty (led by Bay of Plenty Regional Council). In these case study areas recent tsunami inundation modelling had been undertaken for the respective Councils, and the Councils supported the project and were willing to collaborate.

Figure A1 Spiral of participatory action research (Kemmis & Wilkinson, 1998)

Two workshops were held in each region (six in total) order to discuss planners' wants/needs with the modellers; and to discuss and work through an outcome that is acceptable to both planners and modellers. Workshops were undertaken with specific planning and CDEM staff from each case study council to assess what their needs are from modelled tsunami inundation. Questions were pre-circulated to allow for respondents to consider their answers. The first workshop was recorded and transcribed with permission from the interviewees, following ethical procedures from Massey University. The second workshop involved both planners and a tsunami modeller, which allowed the modeller to elaborate on the practical aspects of tsunami inundation modelling; the uncertainties of source characterisation and the probabilistic modelling of the event; the importance of recognising different inundation processes for hazards mitigation and risk reduction measures; and drafting future development scenarios.

The draft report was circulated amongst participating Councils for their feedback.

Using the methodologies outlined above, the research was undertaken in six phases:

1. Review how flood modelling is currently incorporated into land use planning;
2. Workshops with key planning and CDEM staff at GDC, TCDC, EW and BOPRC to understand information needs, requirements, and outputs from tsunami modelling;
3. Workshop planners' wants/needs with tsunami modellers at GNS Science, and draft a model which can meet those requirements
4. Workshop results with planners and GNS Science modellers.
5. Recommend a toolbox of options to assist with the transfer of modelling knowledge into land use planning (e.g. suggest how information can be included within DP, RPS, CDEMG plans)
6. Summarise research into a GNS Science Miscellaneous Report for submission to the EQC; and into a 'popular' article for Planning Quarterly.

The project was evaluated by peer review and judged to be low risk by the Massey University Human Ethics Committee. Further details of the ethical procedures can be obtained via contact with the primary author.

APPENDIX 2 RELEVANT PROVISIONS IN THE NEW ZEALAND COASTAL POLICY STATEMENT

The following table provides a summary of relevant provisions in the NZCPS for managing tsunami. Regional policy statements, regional plans and district plans must give effect to the NZCPS.

Objective / Policy	Relevance
Objective 5 To ensure that coastal hazard risks taking account of climate change, are managed by: • locating new development away from areas prone to such risks; • considering responses, including managed retreat, for existing development in this situation; and • protecting or restoring natural defences to coastal hazards.	Climate change does potentially have an impact on tsunami inundation. If dune systems are eroding and retreating inland, in some instances the tsunami inundation zone may travel further inland.
Policy 7 Strategic planning (2) Identify in regional policy statements, and plans, coastal processes, resources or values that are under threat or at significant risk from adverse cumulative effects. Include provisions in plans to manage these effects. Where practicable, in plans, set thresholds (including zones, standards or targets), or specify acceptable limits to change, to assist in determining when activities causing adverse cumulative effects are to be avoided.	Cumulative effects can equate to societal risk. Acceptable levels of risk (i.e. thresholds) are presented in Section 8. Tsunami inundation areas can be zoned, as outlined in Section 6.2.
Policy 24 Identification of coastal hazards (1) Identify areas in the coastal environment that are potentially affected by coastal hazards (including tsunami), giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, are to be assessed having regard to: (a) physical drivers and processes that cause coastal change including sea level rise; (b) short term and long term natural dynamic fluctuations of erosion and accretion; (c) geomorphological character; (d) the potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent; (e) cumulative effects of sea level rise, storm surge and wave height under storm conditions; (f) influences that humans have had or are having on the coast; (g) the extent and permanence of built development; and (h) the effects of climate change on: (i) matters (a) to (g) above; (ii) storm frequency, intensity and surges; and (iii) coastal sediment dynamics; taking into account national guidance and the best available information on the likely effects of climate change on the region or district.	Tsunami is a coastal hazard whose risk needs to be identified. *At least* a 100 year timeframe needs to be considered. This is a minimum only, and needs to be expanded for tsunami (refer Section 5.1).

Objective / Policy	Relevance
Policy 25 Subdivision, use and development in areas of coastal hazard risk In areas potentially affected by coastal hazards 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; (c) encourage redevelopment, or change in land use, where that would reduce the risk of adverse effects from coastal hazards, including managed retreat by relocation or removal of existing structures or their abandonment in extreme circumstances, and designing for relocatability or recoverability from hazard events; (d) encourage the location of infrastructure away from areas of hazard risk where practicable; (e) discourage hard protection structures and promote the use of alternatives to them, including natural defences; and (f) consider the potential effects of tsunami and how to avoid or mitigate them.	*At least* a 100 year timeframe needs to be considered. This is a minimum only, and needs to be expanded for tsunami (refer Section 5.1). Specifically includes tsunami. This report assists in providing guidance on land use planning for risk reduction.
Policy 26 Natural defences against coastal hazards (1) Provide where appropriate for the protection, restoration or enhancement of natural defences that protect coastal land uses, or sites of significant biodiversity, cultural or historic heritage or geological value, from coastal hazards. (2) Recognise that such natural defences include beaches, estuaries, wetlands, intertidal areas, coastal vegetation, dunes and barrier islands.	Recognised in Section 7.1.1. "Tsunami forests", healthy dune systems and coastal vegetation are all accepted tsunami mitigation measures.
Policy 27 Strategies for protecting significant existing development from coastal hazard risk (1) In areas of significant existing development likely to be affected by coastal hazards, the range of options for reducing coastal hazard risk that should be assessed includes: (a) promoting and identifying long-term sustainable risk reduction approaches including the relocation or removal of existing development or structures at risk; (b) identifying the consequences of potential strategic options relative to the option of 'do-nothing'; (c) recognising that hard protection structures may be the only practical means to protect existing infrastructure of national or regional importance, to sustain the potential of built physical resources to meet the reasonably foreseeable needs of future generations; (d) recognising and considering the environmental and social costs of permitting hard protection structures to protect private property; and (e) identifying and planning for transition mechanisms and timeframes for moving to more sustainable approaches; (2) In evaluating options under (1): (a) focus on approaches to risk management that reduce the need for hard protection structures and similar engineering interventions; (b) take into account the nature of the coastal hazard risk and how it might change over at least a 100 year timeframe, including the expected effects of climate change; and (c) evaluate the likely costs and benefits of any proposed coastal hazard risk reduction options.	Addressed in Section 7. Health and safety, social, economic, and environmental consequences are address in Section 8. Hard protection structures for tsunami are not recommended in New Zealand, due to their environmental and social impacts along the coastline.

Objective / Policy	Relevance
(3) Where hard protection structures are considered to be necessary, ensure that the form and location of any structures are designed to minimise adverse affects on the coastal environment. (4) Hard protection structures, where considered necessary to protect private assets, should not be located on public land if there is no significant public or environmental benefit in doing so.	

APPENDIX 3 PRIORITISING CONSEQUENCES

For a natural hazard event that impacts on a community, more than likely the effects across the four types of consequence (Health & safety, Social, Economic, Environmental) will not be equal. To assist in reconciling these differences between consequences and to allow a summary 'severity of consequences' label to be given, two options are available for ranking consequences: (1) 'first past the post', where the most severe consequence provides the severity of consequence across all consequences; and (2) using the 'SMG' model by MCDEM for determining hazard priorities (MCDEM, 2009).

Under the SMG model, S = seriousness, M = manageability, and G = growth. For this risk-based framework, the focus is on the 'seriousness' ranking. MCDEM (2009, p17) recommend that the social (which includes health and safety), built, economic and natural environments are weighted as follows:

- Social – 50% of the total value, due to the high priority of protection of human life and safety, and community readiness, response, and recovery in CDEM;
- Built – 25% of the total value, due to the importance of protecting lifelines and other critical infrastructure in relation to social concerns;
- Economic – 15% of the total value, reflecting a secondary priority, and that the built environment will normally account for most of the economic damage; and
- Natural – 10% of the total value, reflecting the relatively low level of concern with the environment in the CDEM sector.

This approach takes into account that some types of consequence will have larger impacts on society than others. Again, it would be up to the Council, stakeholders and communities to decide which approach is most appropriate for their context, e.g. the percentages could be adapted to the local context. Once a severity of consequence label has been assessed, the land use then requires consideration.

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