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Review of New Zealand's preparedness tsunami hazard, comparison to risk and recommendations for treatment

Confidential

Compiled by Terry Webb

Client Report
2005/162
December

Review of New Zealand's preparedness for tsunami hazard, comparison to risk and recommendations for treatment

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Prepared for

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EXECUTIVE SUMMARY

Following the disastrous tsunami in the Indian Ocean on December 26 2004, the New Zealand Government resolved to consider the risk of such events in New Zealand and requested that the Ministry of Civil Defence and Emergency Management develop a national picture of the risk of tsunami for New Zealand, the consequences, and New Zealand's preparedness to deal with these eventualities. Two reports were commissioned, the first, known as the Science Report (Berryman, 2005) summarises the current state of knowledge of tsunami and uses that knowledge to assess the level of risk at a national and regional level in terms of casualties and buildings affected.

This, the second report, known as the Preparedness Report, reviews the current arrangements for tsunami warnings in New Zealand at national and regional level, and compares these with the levels of risk derived from the Science Report. This report also recommends measures for improving national and regional management of tsunami risk.

The results of the Science Report show relatively high levels of risk at national level and in some regions compared to others hazards. This will come as a significant surprise to many people and shows that tsunami risk has not been paid sufficient attention in the past.

Our review of current national arrangements for tsunami preparedness included: a description of the Pacific Tsunami Warning System; national arrangements for distributing messages (the National Warning System, the National Duty Officer, and the role of Scientific Advisors). The status of the seismic monitoring system (GeoNet) and the sea-level monitoring system were also reviewed. The review of all of these arrangements was in the context of distant-, regional-, and local-source tsunami. The other components of a fully effective warning system (supporting research; planning; cooperation, discussion, and communication; education; exercising; and evaluation) were also briefly discussed.

The nature and effectiveness of tsunami warning systems varies according to the lead time available to effect an evacuation. For distant-source tsunami, the relatively long time that is available to implement an appropriate response means that the risk can be reduced or eliminated with an effective warning system.

For regional-source tsunami and for distant locations in a local-source tsunami there is barely sufficient time to issue a simple warning given current arrangements. This is a recognised deficiency, so it is acknowledged that no formal system currently exists for regional-source events. Effective evacuation is thus dependent on pre-planning and public education as there will be no time for an organised evacuation.

Local-source early warning systems pose a much greater scientific and operational challenge than those developed for regional or distant-source tsunami. The most advanced local-source early warning system is that in Japan, which can deliver warnings within 3 minutes of an earthquake. Given that the early warning system is just part of what is required to achieve an effective warning system (and thus risk reduction) there is no guarantee that it alone will remove a large proportion of people from harm's way, in spite of all the investment that has been made. It would be difficult to justify a similar investment in New Zealand given the much lower population density. Given the difficulty of implementing effective local-source warnings, educating the public to recognise natural tsunami warning signs is the principal preparedness measure for local-source tsunami.

Given the significant proportion of risk related to local-source tsunami, decreasing the risk of multiple fatalities will not be easy using just a warning system approach. A mix of approaches involving warning systems, engineering and 'soft' mitigation, and land-use planning will be required.

We have compared the adequacy of national arrangements with national risk. In terms of risk measures, the most useful for comparative purposes was the likelihood of multiple fatalities in a single event compared to other natural hazards events. Given that fatalities in historical natural hazard events have numbered in the low hundreds and 500–1,000 fatalities are expected, at most, in a large Wellington Fault earthquake, the figure of over 5,000 for a similar (1 in 500 year) likelihood tsunami event is very high. Given the large uncertainties in casualty estimates across all natural hazards we cannot be sure that tsunami are significantly worse, but they are certainly of a similar order to earthquakes, volcanoes, and (possibly) sudden-onset floods (debris flows).

The 5,000 fatality estimate for tsunami is based on zero warning system effectiveness — we did not attempt to make a quantitative estimate of warning system effectiveness because it would have been too subjective to be meaningful. Instead, we have presented two scenarios of warning system effectiveness. The first is based on 95% evacuation for distant-source tsunami where warning times are long and 10% evacuation for local-source tsunami for which there is no formal warning system, self-evacuation being the most effective option. The second scenario uses figures of 99% and 20% respectively. Using these scenarios, national fatalities with a 500-year likelihood are still at least commensurate with other natural hazards. Given that substantial amounts are invested in both warning systems and mitigation for these other natural hazards, on the grounds of the acceptability of multiple fatalities to Government, a similar investment in tsunami mitigation would appear to be an inescapable conclusion.

Given the level of risk, we have identified issues with national arrangements, in particular with the provision of scientific advice and with the information content of messages broadcast to Civil Defence Emergency Management (CDEM) Groups, who will have to make evacuation decisions. In particular, wave heights are difficult to predict and likely areas of inundation are even more uncertain. In the long term, modelling will be accurate enough to give more precise tsunami impact forecasts. In the short term, however, to enable appropriate CDEM Group response and planning we need to develop operational systems and develop tsunami warning message content that takes account of present high uncertainties. To address this we make the following recommendations:

Recommendation 4.1: That the GeoNet system be used to integrate sea-level data with real-time seismic monitoring in order to generate alert information for regional- and local-source tsunami and that the GeoNet Duty Team be trained and given tools (Recommendation 4.2) to provide the scientific advice required by MCDEM and CDEM Groups for interpretation of tsunami alert information, including that from PTWC for distant-source tsunami. This training will need to be in tsunami generation, propagation, and impact and provided by a range of New Zealand experts in the disciplines of seismology, numerical water modelling, and historical impact.

Recommendation 4.2: A system is developed to predict impacts from distant-, regional- and local-source tsunami:

a) As a first step, the methodology developed in the Science Report needs to be turned into an operational tool, in particular, a wider range of earthquake sources needs to be catered for and wave heights at more coastal locations need to be calculated.
b) A second step is to incorporate, in consultation with local authorities, better impact information to inform response decisions such as evacuation. Once developed, the system should be implemented within GeoNet and its outputs made available for dissemination to CDEM Groups when a PTWC warning/watch bulletin is issued or a large earthquake is detected by GeoNet.
c) The methodology needs to be regularly updated in the light of new knowledge so that best estimates of likely impact can always be provided. In time, it is expected that this system will evolve to embrace outputs from NOAA's real-time forecasting model.

We use the term 'effective tsunami warning system' in this report to refer to all of the components required to detect a tsunami and effectively remove people from harm's way, and including all of the linkages and steps in between. This goes beyond the early warning system itself and additionally includes: supporting research; planning; cooperation, discussion, and communication; education; exercising; and evaluation. We have identified shortcomings in these wider effective warning system elements and so make two additional recommendations at national level:

Recommendation 4.3: Components of an effective warning system beyond early warnings require support at national level. We recommend resource material (content for education material, signage methodology, evacuation planning tools, etc.) and consistency guidelines;

national education strategy; exercising; research in support of improved warning; and evaluation.

Recommendation 4.4: A great lack of knowledge of tsunami process and risk has been identified. In order to better determine our risk exposure to inform mitigation decisions as well as enable better wave height and impact prediction in future events (Recommendation 4.2), there needs to be a significant new investment at a national level in tsunami research.

In our review of region-level arrangements for tsunami preparedness there was an extensive study of CDEM Group Plans as well as structured telephone interviews with each region. We were looking, in particular, for the presence of all the elements of an effective warning system. Many plans were incomplete in this regard, especially for tsunami-specific arrangements, which we regard as necessary except for a few components such as the arrangements for the receipt of warnings. It is preferable that regions separate relevant local-, regional-, and distant-source arrangements to achieve effective warnings. This has not been done by many regions yet.

In our comparison of regional preparedness with regional risk we looked at both multiple fatalities and the risk to individuals living on the coast (in main New Zealand coastal cities). Given the high level of national risk, it is not surprising that the risk at many main centres is high compared to other natural hazards, although there is significant variation around the country. Gisborne, Napier, Wellington, Lower Hutt, Christchurch and Dunedin can have over 500 fatalities in a 1 in 2500 year likelihood event, assuming zero warning system effectiveness. Christchurch and Dunedin can reduce multiple fatalities greatly through effective warnings of distant- and regional-source tsunami. While the other centres listed above can all reduce the level of multiple fatalities with effective distant-source warning systems, they are left with significant residual risk from local sources, which will require mitigation through a range of measures. Foremost in this will be public education to improve response to local events through self evacuation.

Individual risk measures have the advantage that they can be compared against what is regarded as tolerable (or not), based on international benchmarks. If we include the effect of our scenario warning systems, no individual risk at any city is clearly intolerable, but six cities have a level of individual risk that would be regarded as intolerable if it was imposed or the individual was not informed as to what the risk was.

Another factor looked at in our city-by-city analysis was the distribution of likely warning time based on the distance to the most hazardous sources to that city. There is, again, wide variability. This analysis will enable regions to look at what balance to strike between technical early warning system effectiveness and public education (on natural early warnings to facilitate self-evacuation).

Finally, we have looked at wider mitigation options beyond warning systems and evacuation, and have grouped these in a consistent way with the three approaches consistently used in coastal hazard and climate change guidelines for local government in New Zealand, namely:

- *Protection (or defence)* — physical interventions such as the building of seawalls, rock revetments, beach and fore-dune nourishment with external sand or gravel, or building up vulnerable coastal roads or causeways;
- *Adaptation (or accommodation)* — dune and coastal vegetation restoration, plant or enhance coastal forests, re-create coastal/estuarine wetlands or marshes, raise and deepen foundations of dwellings, better tie-downs to foundation, open-up ground floors of engineered buildings;
- *Landuse planning* — range of land-use controls, plans and policies that will be different for new subdivisions (coastal green-field developments) or existing developments (e.g. managed retreat including engineering lifelines where possible, establishing coastal hazard zones).

As a result of the regional-level review and comparisons we have arrived at the following recommendations:

Recommendation 7.1. CDEM Groups participate in identifying where national guidelines would be beneficial, and in developing and implementing national guidelines where appropriate for regional effective warning system components (Figs. 1.1 & 6.4), via a national working group. This working group should include representation by (but not restricted to) MCDEM, CDEM Groups, scientific organisations, and key individual scientists.

Recommendation 7.2. CDEM Groups complete regional preparedness across all of the topics examined under regional-level written arrangements, as reviewed from Group plans and documents beyond Group plans, so that all the components of an effective warning system (Figs. 1.1 & 6.4) are in place, as appropriate for the level of risk in each region. Decide whether generic or tsunami-specific arrangements are appropriate for each. Actions should be in line with the national working group developed guidelines recommended above, where appropriate, and should consider the timeframes and likely availability and content of warning messages. Specific actions for regions to undertake include:

a. Decide whether there is a need for improvements to the warning message receipt and dissemination protocols in the various warning situation scenarios, and consider options for public notification methods discussed here and in Appendix 9, as well as any additional options that are identified by the national working group. Implement the most suitable options.

b. Implement all planning components of an effective early warning system including: sub-group-level planning; decision preplanning; evacuation zone and route mapping; evacuation decision-making; roles of key response agencies; arrangements for giving the 'all-clear'; and tsunami warning SOP's for all three source-type (local, regional, and distant) warning scenarios.

c. Develop pre-planned and exercised communication between central government agencies, local emergency management agency staff, scientists, media, and community representatives. Renewal of contacts must be regular and permanently sustained. Specific written arrangements with dissemination media (especially radio, but also Rural Fire, Surf Lifesaving etc.) are essential (MoUs) and should distinguish distant, regional and local sources.

d. Develop regional public education (across all available/feasible media), staff training, maps and signage. It must contain details for public-response to natural warnings of local-source tsunami.

e. Develop and conduct on a regular ongoing basis regional exercising of tsunami warning effectiveness, including how these may tie in with national exercises.

Recommendation 7.3. CDEM Groups

a. Incorporate new developments in effective warning system components and design into ongoing improvements of regional tsunami preparedness.

b. Quantitatively evaluate the effectiveness of planning, public education, training strategies, simulation exercising and hardware reliability testing, feeding the results fed back as effective warning system improvements.

Recommendation 7.4. CDEM Groups consider the implementation of land-use planning tools and other layered mitigation options and regulations to reduce vulnerability to tsunami hazards at a regional level.

We hope this provides at least a nationally consistent basis for taking the next steps towards a safer New Zealand.

1.0 INTRODUCTION

Following the disastrous tsunami in the Indian Ocean on December 26 2004, the New Zealand Government resolved to consider the risk of such events in New Zealand. The Director of the Ministry of Civil Defence and Emergency Management was required to develop a national picture of the risk of tsunami for New Zealand, the consequences, and New Zealand's preparedness to deal with these eventualities.

The Institute of Geological & Nuclear Sciences (GNS) was commissioned by the Ministry of Civil Defence and Emergency Management (MCDEM) to provide two reports, the first, known as the Science Report (Berryman, 2005) summarises the current state of knowledge of tsunami and uses that knowledge to assess the level of risk at a national and regional level in terms of casualties and buildings affected.

A second report, known as the Preparedness Report (this report), reviews the current arrangements for tsunami warnings in New Zealand at national and regional level, and compares this with the levels of risk derived from the Science Report. This report also recommends measures for improving national and regional management of tsunami risk.

The scope of work and methodologies used were reviewed and advised by a Steering Group comprising representatives from MCDEM, Department of the Prime Minister & Cabinet (DPMC), and the Ministry of Research Science & Technology (MoRST). The Terms of Reference to meet the scope of work and tasks derived from it are included in Appendix 1. These tasks have been used to define the structure of this report, which is summarised in Section 1.2.

The National Civil Defence Emergency Management (CDEM) Strategy is part of the CDEM framework established by the CDEM Act. It establishes the concept of comprehensive risk management, through the '4 Rs' of risk Reduction, Readiness, Response, and Recovery. Within that context this report is largely focussed on warning systems, which fall into the Readiness category. The report does also address, in a general way, available mitigation options, which are classified as a Reduction activity. Finally, a warning system can be used to predict impacts and issue an all-clear, both of use in the initial Response phase of activity.

1.1 Contributors

Many people have contributed to this report. In particular we need to note the following contributions:

Rob Bell	Input on sea-level measurements, mitigation options and policy & planning.
Kelvin Berryman	Linkage to Science Report work and overall review.
David Coetzee	Extensive written and verbal input on national arrangements.
Hugh Cowan	Input on aspects of the early warning system and the GeoNet contribution.
Willem de Lange	Input over the Scientific Advisor role.
Gaye Downes	Extensive written and verbal input on most aspects of the report.
Kevin Fenaughty	Input on GeoNet procedures.
Jane Forsyth	Turning text into understandable English.
Ken Gledhill	Input on GeoNet procedures.
David Johnston	Input on many parts of the project and especially the pubic education aspects.
Graham Leonard	Extensive written and verbal input on many aspects of the report, especially relating to regional level.
Lisa Pearse	Input on the current status of regional arrangements; the information requirements at CDEM Group level; and the needs at national level.
Doug Ramsay	Input on mitigation options and policy & planning.
Wendy Saunders	Extensive written and verbal input on the current status of regional level, especially with respect to CDEM Group Plans.
Warwick Smith	A guiding hand in both national and regional level risk analysis.
Tony Taig	Provision of advice on risk measures and comparisons.

Project Management and Report Preparation

Hannah Brackley, Sue Hatfield, Penny Murray, Daryl Barton, Carolyn Hume and Philip Carthew all made valuable contributions, often under tight time pressure.

1.2 Structure of this report

In the remainder of this introductory chapter we discuss the component parts required for an effective warning system. We then provide some background material on tsunami affecting New Zealand in terms of distant-, regional- and local-source events. We finish by discussing relevant legislation. In Chapter 2 we review current arrangements for tsunami warnings at a national level. This includes identifying and documenting the relevant agencies and their roles and responsibilities in current arrangements. In Chapter 3 we assess the "fit for purpose" of current national warning system arrangements with respect to the national assessment of risk (Science Report). We then recommend, in Chapter 4, possible solutions to shortcomings identified in Chapter 3. We then move to regional level and identify and document the agencies, their roles and their responsibilities in current arrangements for tsunami warning (Chapter 5). Then in Chapter 6, following the approach at national level, we assess the "fit for purpose" of current regional warning system arrangements with respect to the regional assessment of risk from the Science Report. In Chapter 7 we recommend procedures for better risk management at regional level relating to shortcomings identified in Chapter 6. Chapter 8 reviews the state of tsunami education and assesses the role of education in increasing tsunami preparedness. The summary and conclusions presented in Chapter 9 complete the main body of the report, which is followed by a number of appendices containing more detailed material.

1.3 Effective tsunami warning systems

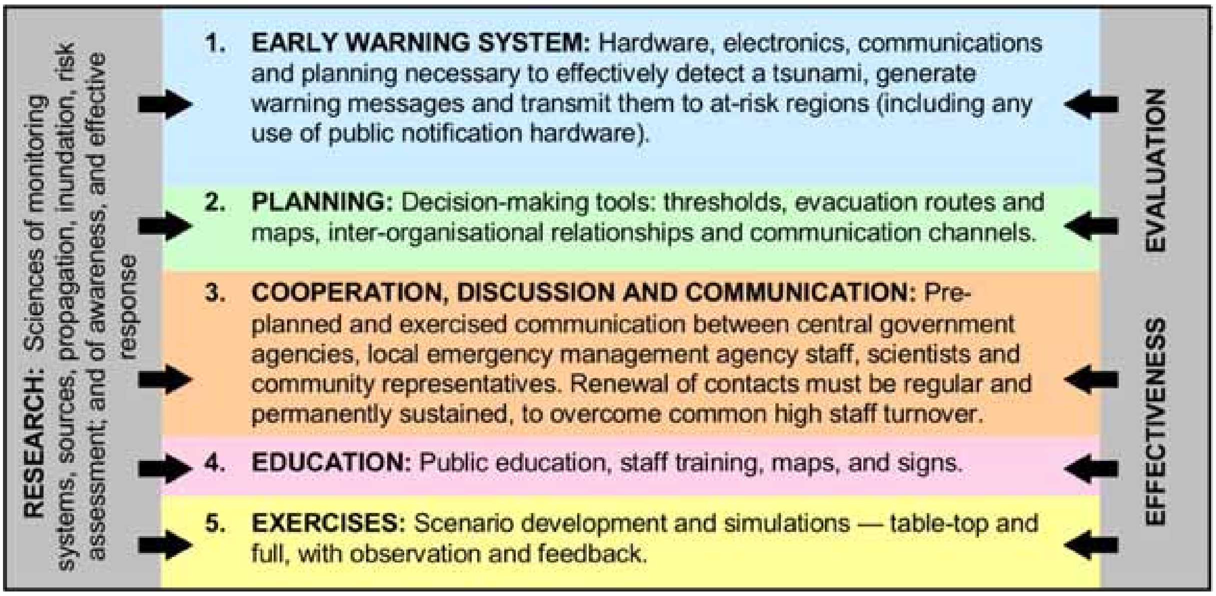

Figure 1.1 Components of an effective tsunami warning system as used in this report and explained further in Johnston *et al.*, 2005. See Fig. 2.1 for the structure of the early warning part of the system in New Zealand.

It is impossible to state with certainty exactly what is required for a tsunami warning system to be fully effective. This is because there is no single 'best practice' internationally that has been seen to effectively remove most people from harm's way consistently. By drawing together a) evidence from observations of public response to past events internationally, b) empirical studies, and c) common sense best practice, recommendations for developing appropriate and effective response to tsunami warnings have been grouped into the components shown in Fig. 1.1 (and discussed and justified in detail by Johnston *et al.*, 2005). These components are consistent with, and expand in detail on, the United Nations International Strategy for Disaster Reduction (UN-ISDR) Platform for the Promotion of Early Warnings (PPEW) components of an 'effective early warning system' (PPEW, 2005): 'prior knowledge of the risks faced by communities', 'technical monitoring and warning service for these risks', 'dissemination of understandable warnings to those at risk', and 'knowledge and preparedness to act'. This model is also consistent with the concept of 'people-centred early warning systems' as promoted by the International Early Warning Programme (IEWP, 2005).

1.4 Background information on tsunami affecting New Zealand

As outlined in the Science Report, 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 inundate coastlines, causing devastating property damage, injuries, and loss of life. The principal sources of tsunami are:

- large submarine or coastal earthquakes (in which significant uplift or subsidence of the seafloor or coast occurs);
- underwater landslides (often triggered by an earthquake);
- large landslides from coastal (or lakeside) cliffs;
- large underwater volcanic eruptions; and
- meteor impact in the ocean (very rare).

For Emergency Management purposes it is useful to distinguish between distant-, regional-, and local-source tsunami because the source location affects the available warning time as well as some of the tsunami characteristics. Using this classification, sources of tsunami that can affect New Zealand are summarised briefly here and discussed in detail in the Science Report.

1.4.1 Distant sources

Distant sources are defined here as having more than 3 hours of tsunami travel time to the nearest New Zealand coastline. The only significant distant sources affecting New Zealand, excluding very rare events, are large plate interface earthquakes at subduction zones around the Pacific Rim. The New Zealand risk is dominated by South American sources although other sources do on occasions pose a risk that will require warnings to be issued. Large distant-source tsunami will affect many parts of the New Zealand coast with much along-coast variability. The largest events will cause significant sea level variations for at least 12 to 72 hours after the first arriving waves. The first few waves to arrive may not be the largest, large waves may be interspersed with small waves, and small waves may be a problem when arriving at high tide, all of which can be a significant issue for public safety, for rescue operations and for calling "all clear".

As all the major sources are at least 10 hours travel time from New Zealand, there is, in theory, adequate time to evaluate the potential of the tsunami and provide timely warnings to CDEM Groups and to the public. However, with the current state of knowledge it will be difficult to predict accurate wave heights in advance, so false alarms or warning system failures may result.

1.4.2 Regional Sources

Regional sources are defined here as having 1–3 hours of travel time to the nearest New Zealand coastline. The only significant sources affecting New Zealand, excluding very rare events, are earthquakes occurring in tectonically active regions to the north of New Zealand from Vanuatu to Samoa, Fiji and Tonga (from about 33ºN). Earthquake-generated tsunami are strongest in the direction perpendicular to the fault or plate boundary. This means that many regional sources, such as the Tonga Trench, are a greater threat to other nations than to New Zealand. However, a tsunami from the southern New Hebrides arc (i.e. the subduction zone southeast of Vanuatu) is directed towards New Zealand, and poses a significant threat, recognised for the first time in the Science Report. Warning times for regional sources are short compared to the time needed to organise evacuation, presenting a challenge to our emergency management arrangements.

No large regional events have been experienced in historical times, but it is expected that such sources will produce sea level variations for 12 to 48 hours and will impact several hundred kilometres of coastline, again with significant along-coast variability.

1.4.3 Local Sources

Local sources are defined here as having less than 1 hour of travel time to the nearest New Zealand coastline, but many have less than 30 minutes and some travel times are as short as 10 minutes. There are a number of local sources that can affect New Zealand with reasonable frequency. Predominant are large, plate interface earthquakes along the Kermedec, Hikurangi and Puysegur subduction zones. Of these, Hikurangi subduction zone earthquakes present the greatest threat. Other offshore earthquakes on crustal faults are also significant on a smaller scale. For any of these earthquake sources, the size of the subsequent tsunami may be increased by submarine landslides triggered by the earthquake shaking. In addition, large coastal-cliff landslides (e.g., triggered by a large on-shore earthquake such as on the Alpine Fault) can generate local tsunami. While it is possible to develop a warning system for local-source earthquakes (such as that in Japan, which delivers informed warnings within 3–5 minutes), implementation would take considerable development of infrastructure and scientific knowledge (a database of 1000s of scenario events). Hence, a system would be very expensive to implement compared to that needed for warnings for distant- or regional-source tsunami and the short response time makes it more difficult to ensure an effective outcome. In such cases, self-evacuation (preferably by pre-designated evacuation routes) in response to natural warning signs (strong shaking, and/or sudden sea level changes and roaring from the sea) is recognised as an effective, and in many countries the primary, option.

A problem with the reliance on natural warning signs in New Zealand is the occurrence of 'slow' tsunami earthquakes. Their characteristics include their location in subduction zones, their capacity to produce greater than expected tsunami for their magnitude, and the fact that they do not produce the strong shaking expected for an earthquake of that size. At least two of this type of earthquake have occurred in the last 100 years (both in 1947), but their long-term frequency is largely unknown.

A small local-source tsunami would produce short-duration (2–3 hours or less) sea level variations, but a potentially high local impact in which the run-up diminishes rapidly further along the coastline. A larger local-source tsunami may produce high run-up[1] (10 m or more), and affect sea levels for a longer period (possibly up to 12 hours), with impact over at least a regional scale, decreasing with distance. For example, fault rupture in a very large plate interface earthquake on the east coast of the North Island may extend for 200–300 km and the resulting tsunami may affect the same or larger length of the nearby coast with large run-ups. Such an event could cause significant to severely damaging waves along the whole east coast of the North and South Islands, and in the Chatham Islands.

1.5 Legislation

As part of this report, there is a requirement to document the roles and responsibilities of key response agencies at national and regional level. These include MCDEM, CDEM groups, Police, Fire Service, Health and Welfare services (including Ministry of Health, District Health Boards, Ambulance, Ministry of Social Development and National Welfare Recovery Coordination Group), EQC, and inter-agency groups. Appendix 2 outlines these roles and responsibilities as required under various pieces of legislation.

In summary, tsunami preparedness is incorporated into the following legislation:

- Civil Defence Emergency Management Act 2002, which provides for planning and preparing for emergencies via the National CDEM Plan and Group Plans, and outlines the legislative roles and responsibilities for key agencies;
- Resource Management Act 1991, for managing landuse activities such as the location of a building and its effects on the environment via regional and district plans;
- Building Act 2004, which manages the construction of buildings and the effects that building may have in accelerating, worsening, or result in damage from natural hazards; and
- Local Government Act 2002, which encourages local authorities to focus on promoting the social, economic, environmental and cultural well-being of their communities, consistent with the principles of sustainable development.

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[1] TSUNAMI RUN-UP (m), a measure much used in tsunami-hazard assessment, is the maximum vertical height the waves reach above the current sea level at the time of impact.

2.0 REVIEW OF CURRENT ARRANGEMENTS FOR EFFECTIVE WARNINGS AT NATIONAL LEVEL

In this section we describe how the current tsunami warning system works for the Pacific Ocean and at national level. We also document and review the roles and responsibilities of principal agencies in current arrangements, namely the Ministry of Civil Defence and Emergency Management (MCDEM), the Pacific Tsunami Warning Center (PTWC), and monitoring agencies in New Zealand (GNS and NIWA).

The sections below are structured according to the components of an effective warning system that we discussed in Section 1.3 (Fig. 1.1), namely: the early warning system itself as it operates in New Zealand (see Fig. 2.1); supporting research; planning; cooperation, discussion, and communication; education; exercising; and evaluation.

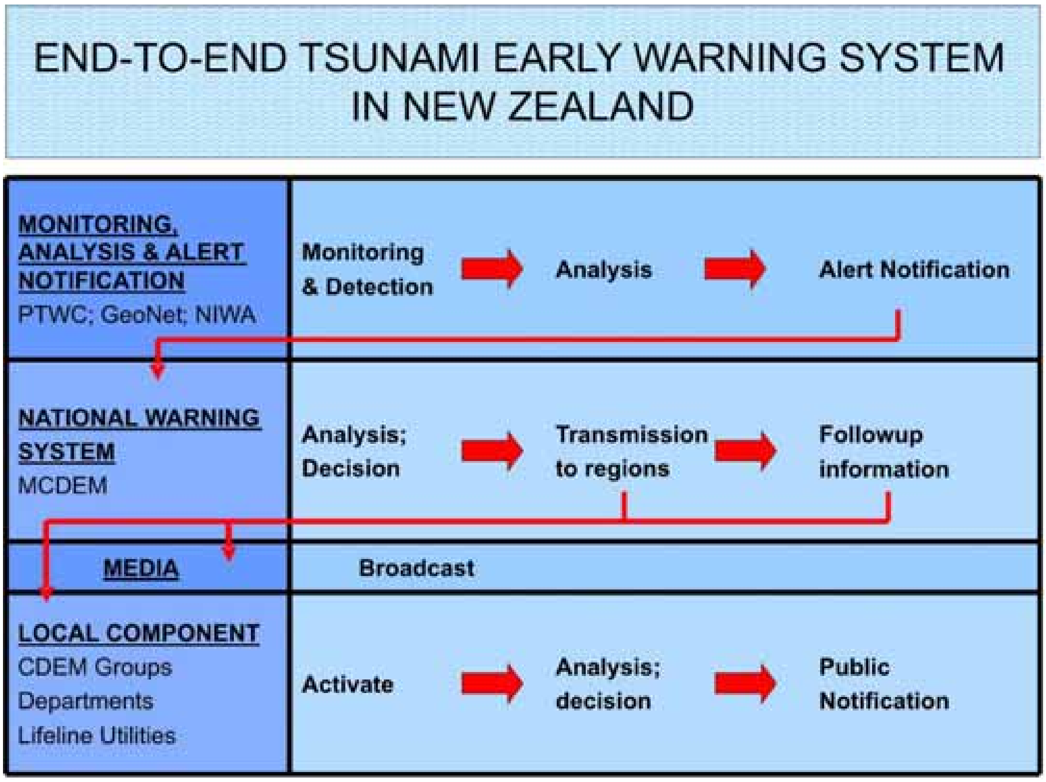


Figure 2.1 End-to-End Tsunami Early Warning System in New Zealand

2.1 Early warning systems

At present the principal early warning system is for distant-source tsunami, for which we rely on the Pacific Tsunami Warning Centre (PTWC) in Hawaii for warning information. We have thus separated the detailed early warning system discussion into distant, regional, and local parts, with the regional and local discussion covering just the differences from the distant-source system.

2.1.1 Distant-source tsunami

A tsunami generated in 1960 by a magnitude 9.5 earthquake off the coast of Chile was the most recent event large enough to cause significant damage in New Zealand. It also disrupted coastal activities for several days. New Zealand joined the Pacific Tsunami Warning System a few years after 1960, and the first national tsunami warning arrangements were set up at this time.

2.1.1.1 The Pacific Tsunami Warning Center

Established in 1949, the Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, operates what is generally referred to as the Pacific Tsunami Warning System. PTWC provides warnings for Pacific-wide tsunami to most countries in the Pacific Basin as well as to Hawaii and all other US interests in the Pacific outside of Alaska and the US West Coast (who are covered by the West Coast Alaska Tsunami Warning Centre). PTWC is also the warning center for Hawaii's local and regional tsunami.

The warning system requires the participation of many seismic, sea-level, communication, and dissemination facilities operated by most of the nations in and around the Pacific Ocean. For example, the New Zealand GeoNet project supports the operation of US-owned seismographs in Wellington, Scott Base, Raoul Island, and Rarotonga. Administratively, participating nations are organized under the International Oceanographic Commission (IOC) as the International Coordination Group (ICG) for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS). New Zealand formally became a participant/member state in 1965. Biennial meetings of ICG/PTWS, attended by representatives from each member country (not all attend), are high level formal business meetings, at which progress is reviewed and activities coordinated resulting in improvements of the service.

The operational objectives of the PTWC are to: detect and locate major earthquakes in the Pacific region; determine whether they have generated tsunami; and provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunami, especially to human life and welfare.

To achieve these objectives, PTWC continuously monitors the seismic activity and sea-level at sites throughout the Pacific Basin operated by member nations. It has a small dedicated team of seismologists/tsunami specialists who live permanently on site, the duty person being able to be at a desk at the centre within 2-3 minutes and to issue the first earthquake information within 10–20 minutes. PTWC has well-established, frequently reviewed standard operating procedures (SOP's) and information (including historical and some pre-computed models) for evaluating the potential of a large earthquake to produce a tsunami.

After an earthquake has been located and its magnitude determined, a decision is made concerning further action. If the earthquake is within or near the Pacific Ocean basin and its magnitude is 6.5 or greater, but less than or equal to 7.5 (≤ 7.0 in the Aleutian Islands), a **Tsunami Information Bulletin** is issued**.** The bulletin will contain one of three possible evaluations:

- A Pacific-wide tsunami was not generated based on earthquake and historical tsunami data. This will be the only bulletin issued. No Pacific-wide tsunami warning is in effect;
- An investigation is underway to determine whether a Pacific-wide tsunami has been generated. Additional bulletins will be issued hourly or sooner as information becomes available. No Pacific-wide tsunami warning is in effect; or
- No destructive Pacific-wide tsunami threat exists. However, some areas may experience small sea level changes. This will be the final bulletin issued unless additional information becomes available. No Pacific-wide tsunami warning is in effect.

If the earthquake has a magnitude greater than 7.5 (>7.0 in the Aleutian Islands), a **Regional Tsunami Warning/Watch Bulletin** is issued, alerting agencies to the possibility that a tsunami may have been generated and providing data that can be relayed to the public so that necessary preliminary precautions can be taken. The initial assessment for this bulletin is based only on seismic information and so it advises that a tsunami investigation is underway. The area placed in Tsunami Warning status will encompass a 3-hour tsunami travel-time. Those areas within a 3–6 hour tsunami travel-time will be placed in a Watch status.

PTWC will then check water level data from automatic sea level gauges located near the earthquake epicentre for evidence of a tsunami. A Tsunami Warning/Watch will be followed hourly by additional bulletins until it is either upgraded to a Pacific-wide Tsunami Warning or is cancelled. If sea level data show that a tsunami has been generated that poses a threat to the population in part, or all, of the Pacific, the Tsunami Warning/Watch Bulletin is extended until there is no longer the threat of a destructive tsunami or it is upgraded to a warning for the whole Pacific (see below). The dissemination agencies implement predetermined plans to evacuate people from endangered areas. If the sea level data indicate that either a negligible tsunami or no tsunami has been generated, PTWC issues a cancellation of its previously disseminated Tsunami Warning/Watch. PTWC will extend the Tsunami Warning/Watch status until certain that no danger exists to further areas after which time PTWC will issue a cancellation.

A **Pacific-wide Tsunami Warning Bulletin** is issued on a Pacific-wide basis after confirmation has been received that a tsunami capable of causing destruction beyond the local area has been generated and poses a threat to the coastal population for the entire Pacific Basin. Each hour updated information will be sent until the Pacific-wide Tsunami Warning is cancelled. Generally, there is sufficient time and sufficient sea level information for PTWC Bulletins to confirm a significant Pacific-wide distant-source tsunami many hours prior to its arrival in New Zealand.

At present, the PTWC Tsunami Warning/Watch Bulletins contain earthquake magnitude and location information, expected first arrival time at a limited number of locations around the Pacific (including New Zealand), as well as sea-level data as it becomes available. They contain no forecasts of wave heights. It is the responsibility of each nation's response system to evaluate the likely impact in their area, and to implement appropriate response plans (such as the National and Group CDEM Plans in New Zealand).

One limitation that needs to be recognised is that for very large earthquakes over magnitude 8.5, such as the 2004 Sumatra magnitude 9.3 earthquake, the first estimates of magnitude that PTWC can obtain using their monitoring systems may underestimate the true magnitude. Evaluating the true magnitude is delayed because of the need for particular seismic waves to arrive at seismographs. This limitation is relevant to New Zealand as distant earthquakes generally need to be over magnitude 8.5 to generate tsunami that are significant here.

PTWC sends Tsunami Bulletins via the World Meteorological Organization's Global Telecommunications System, by email, and by phone. Messages are sent to MCDEM, MetService, and Airways Corporation to ensure receipt.

PTWC bulletins are also disseminated via a Tsunami Bulletin Board to all subscribers to the Board, which include scientists and other interested parties. While this system generally performs well, it is not a part of the warning system and is thus not designed to be robust and so cannot be relied upon to disseminate messages in a timely manner.

2.1.1.2 National Arrangements

2.1.1.2.1 National Warning System

The National Warning System provides a framework for the dissemination of National Warning Messages by MCDEM that can apply to any type of threat to selective or inclusive audiences. The system and procedures for the passing of National Warning Messages is administered by MCDEM as a deliverable of Vote: Emergency Management. There are well-documented agreed procedures and protocols for disseminating and acknowledging receipt of messages, and the system is tested regularly (see Appendix 3).

National Warning Messages can be issued at the direction of the National Controller or the Director of MCDEM when a warning of danger to the public or property is necessary, or when requested by another warning agency. A National Warning Message is issued to the CDEM Sector (local authorities, emergency services and certain others), who in turn respond in accordance with their own arrangements to disseminate or act further upon the particular information (see Fig. 2.2 for the National Warning System flowchart). National Warning Messages can be extended to radio and television for public broadcast. Clear guidelines are given to media organisations on the priority and the broadcast frequency required for particular warnings.

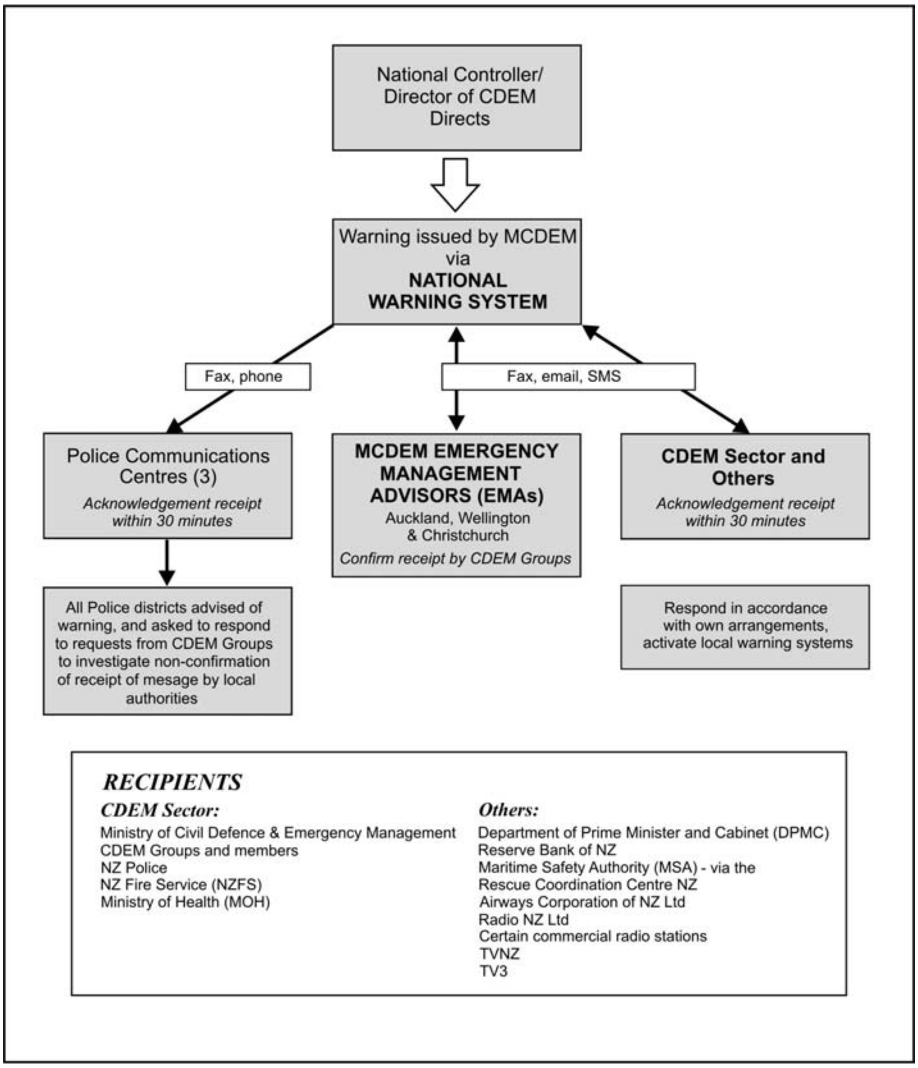


Figure 2.2 Flowchart of the operational procedures of the National Warning System.

MCDEM is currently in the process of developing a new memorandum of understanding with Radio NZ and the Radio Broadcasters Association, representing commercial broadcasters, following which the same will be done for television. Broadening the dissemination of national warning messages to some government agencies and lifeline utilities is currently limited by the lack of arrangements within those agencies to receive and respond to such messages at all hours and not by MCDEM's ability to disseminate them.

The National Warning System does not include or prescribe the actions required in response to national warning messages. It depends, however, on the responsibility of national and local government bodies to maintain systems to receive, disseminate, and respond to warning information generated through the National Warning System.

With the development of the new National CDEM Plan came the opportunity and need to review the National Warning System in New Zealand. This review was conducted by MCDEM through a comprehensive consultation process within the CDEM sector and specific attention was given to tsunami warnings. While some areas for improvement were identified, the review confirmed the processes and procedures for distant-, regional-, and local-source tsunami. These are documented in Appendix 3. A flow-chart of warning system operational procedures that specifically relate to distant-source tsunami is shown in Fig. 2.3.

2.1.1.2.2 Role of National Duty Officer

To fulfil its responsibility under the National Warning System, MCDEM maintains a 24-hour National Duty Officer capability whose primary role is to receive and act upon alert notifications received from monitoring agencies. For distant-source tsunami, the monitoring agency is PTWC and thus MCDEM is the designated national agency for receiving official PTWC messages. There is a well-established formal arrangement with PTWC to receive messages via robust communications systems that PTWC test at regular intervals.

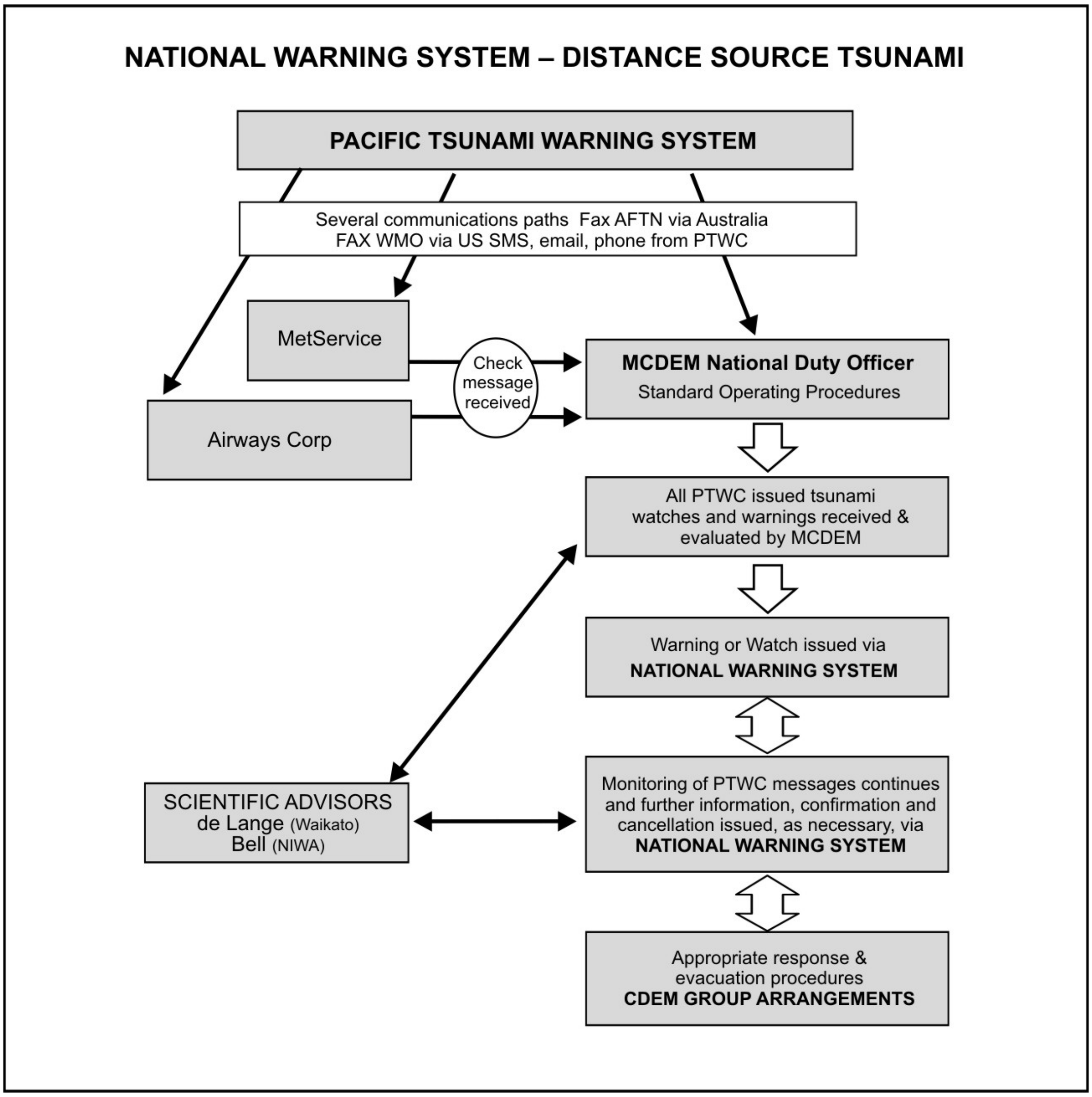


Figure 2.3 Flowchart of the operational procedures of National Warning System for distant-source tsunami.

The National Duty Officer capability is central to an effective early warning system and is therefore designed around a documented communications system and guided by set SOP's. These contain the guidelines on what actions are to be taken by the MCDEM National Duty Officer when dealing with information related to CDEM-related incidents or emergencies and potential emergencies. They contain a number of sections related to generic functions and responsibilities, as well as establish procedures for dealing with information related to adverse weather, earthquake, tsunami, volcanic eruption and civil defence emergencies and note the arrangements related to the National Duty Officer roster and call plans.

Those functions that relate specifically to tsunami warnings, including guidelines on the minimum earthquake magnitude and location thresholds that need to be met to initiate contact with MCDEM scientific advisors, are given in Appendix 4. These guidelines contain no information on what impact might be expected from any event, what wave heights constitute a hazard, or when to call "all clear", and so the Duty Officer is dependent on advice from the PTWC and Scientific Advisors.

The SOP's also contain a pro-forma tsunami warning message (Appendix 5). MCDEM suggests that the format of this message should serve as a guide only and may not represent the contents of the message that will in fact be disseminated. This is due to the uncertainty of exactly what data will be available at the time of issuing a warning. Hence, should an event occur for which extra data might be available, there will be little time to consider the best and most concise way to convey that information.

2.1.1.2.3 Role of Scientific Advisors

The role of the scientific advisors is a key part of the National Warning System in relation to tsunami. The scientific advisors are responsible for interpreting the watch/warning bulletins issued by PTWC and hence evaluating the potential tsunami impact. Currently, scientific advisors do not receive PTWC messages and may only become aware of an event when contacted by the National Duty Officer. When the scientific advisor role was first set up, the interpretation was traditionally based on historical data and a tsunami travel time chart developed by Alex Gilmour (Gilmour, 1964; 1967). Over time, guidelines were developed by the advisors, and have continued to develop, to assist with assessing the scale of response. These guidelines are based on location and magnitude of the associated seismic event, and are included in Appendix 6. They contain no information on how to estimate expected wave heights.

Requests for scientific advice have often resulted in a wait and see approach. In a few cases in the last ten years or so, it has been necessary to proceed further. The advice then involved estimates of the maximum wave heights and suggestions of response strategies. The last such event was the Balleny Islands Tsunami of 25 March 1998. The advice given by the scientific advisor was that the maximum likely tsunami height was <15 cm and that, as the tsunami would be arriving at night during rough wave conditions, the best response was to notify the port authorities at Bluff, as well as the Police and local authorities. The tsunami was <15 cm in height and not noticed by observers. Unfortunately, the PTWC arrival times were used as the basis for issuing the information to Southland, and the tsunami arrived earlier than predicted.

One of the difficulties with the scientific advisor role in recent years has been the changes in the way Public Good Science is funded, and the move from DSIR to CRIs. This, and the retirement of several scientists, has led to changes in scientific advisor team. Dr Willem de Lange (University of Waikato) and Dr Rob Bell (NIWA) are at present listed as MCDEM scientific advisors in National Duty Officer SOP's. The current arrangements with MCDEM's scientific advisors for tsunami is loosely structured, and MCDEM recognises that the role needs reviewing, and that SOP's and expectations of the role need to be agreed upon and formalised. Given the few scientists working on tsunami in New Zealand and even fewer working in areas that are relevant to warning response, it cannot be expected that there are other people who could fulfil the role at short notice without having had a mandate to pre-plan.

2.1.1.3 Sea level recorder network

Currently, the New Zealand network of sea-level gauges consists of 20 mainly open-coast gauges operated by NIWA alone or by other agencies including regional/territorial councils and port companies. Of the eight NIWA sea-level gauges, five (all on the east coast) are equipped with "tsunami ring buffers" that provide 1-minute sampling and up to 3-days data storage. Several port companies and the gauge at Jackson Bay operated by the National Tidal Centre (Adelaide) are also equipped with similar buffers or at least sample at 1-minute intervals. Overall, the sea-level gauges in New Zealand are not necessarily located geographically for optimal tsunami detection purposes and few have a near real-time capability. However, they do provide valuable information for understanding tsunami impact after an event, for calibrating numerical models, and on occasions for confirming a tsunami during office hours or at a few hours notice.

The Port Company/Regional Council gauges range from relatively open-sea situations to those in long harbours. The latter are likely to be of limited value for tsunami monitoring purposes, as they are subject to localised effects.

LINZ is the agency responsible for national tidal information and receives data from port sea-level gauges for determining tidal datum levels, tidal predictions and also to archive records. A consultant (Mulgor Consulting Ltd.) maintains an online system that links to several port company sea-level gauges and processes those data to provide services for port companies, including long-wave analysis, which also covers wave periods in the tsunami band.

Currently, confirmatory sea-level information from the NIWA open-coast sea-level network and from port company/regional council gauges, is provided informally to MCDEM on a best-endeavours basis. Rob Bell, NIWA's coordinator and advisor on the sea-level network, has advised MCDEM on several events in the last few years. Fortunately, these have either occurred in office hours e.g., the magnitude 8.1 earthquake north of Macquarie Island on 24 December, 2004 (that only resulted in a small 0.2 m tsunami wave in Foveaux Strait), or the events resulted in no major consequences even though outside normal office hours e.g., the magnitude 7.2 Fiordland earthquake on 21 August 2003 and the 26 December 2004 Sumatra mega-tsunami, which was tracked by NIWA staff the following day. During the Macquarie tsunami event, MCDEM, Environment Southland, and PTWC were provided with hourly updates and plots, using 1-minute data from the tsunami ring-buffer on the Dog Island sea-level gauge in Foveaux Strait until the threat subsided and the all-clear was given by MCDEM.

These informal systems currently relied on to provide scientific support and tsunami detection to MCDEM have largely been developed on the initiative of scientists e.g., the development and operation of an open-coast sea-level network by NIWA with multiple uses, and building inter-personnel relationships across the emergency-management sector. However, no formal service agreements exist to underpin these informal arrangements. This raises issues about responsibility, liability, timeliness, operational procedures, availability of trained personnel, and just as important, what the expectations are of how each party will respond and what is to be delivered or exchanged and to what specification. Planned enhancements to the sea-level system are discussed in Section 4.2.3.

2.1.2 Regional-source tsunami

2.1.2.1 National arrangements

As for distant-source tsunami and in Appendix 3, MCDEM relies to a large extent on PTWC Bulletins for warning of large earthquakes that are 1–3 hours tsunami travel time from New Zealand (i.e., regional-source events). Procedures are essentially the same as for distant-source tsunami (Fig. 2.4), but the limited time available means that there may not be sufficient time for the process to work. For this reason the arrangements are not regarded as being a formal warning system (Appendix 3). In addition, there are few, or no, sea-level gauges between New Zealand and its regional sources and hence little time, or no means, for PTWC to confirm a significant tsunami prior to its arrival here.

The best possible time frames for the respective steps in the current tsunami warning procedures to be completed are given in Table 2.1. This scenario assumes that all communications and IT connectivity are functional and available, that the event occurs during daylight hours, the Scientific Advisor is immediately available and he has all the information needed at hand, and that the warning message is simple. In a more realistic scenario, more time will be needed in each section, but principally in those sections that are greyed. It is possible that another hour or more in total may be needed. It is also possible that subsequent messages from PTWC (for example, increase in magnitude of the earthquake) may require a new message and the need to revise response plans at CDEM level.

Table 2.1 Estimates of the best possible time frames needed to complete steps in the current tsunami warning system. Note that under a new MOU with specified radio stations (noted in Section 2.1.1.2.1) radio broadcasts can be possible within 15 minutes of receipt of an MCDEM message.

Process		Best possible (minutes)
MCDEM	PTWC message received (time since earthquake)	10
	Interaction National Duty Officer & National Controller	5
	Interaction National Duty Officer/National Controller & Scientific advisors	10
	Compile message	10
	Send message	5
Total for this part of the process		**40**
CDEM Groups	MCDEM message received and receipt confirmed	30
	Local assessment & warning/response activation	30
Total including CDEM response		**100 minutes**

Table 2.1 indicates that for regional-source tsunami and for distant locations in a local-source tsunami (Fig. 2.5), there is barely sufficient time to issue a simple warning, but its effectiveness is dependent on pre-planning and public education as there will be no time for an organised evacuation. Even with the best possible circumstances there is insufficient time for warning the nearest coast in local-source tsunami (see Fig. 2.5b).

The greyed areas indicate the part of the warning process where response times can be reduced most in the future with comprehensive pre-planning.

2.1.2.2 GeoNet

GeoNet was principally designed to monitor geological hazards close to New Zealand and is thus described in more detail under local-source tsunami (Section 2.1.3.2). Hence GeoNet currently has poor capacity to accurately determine the location and magnitude of potential regional-source tsunamigenic earthquakes, that is, those in tectonically active regions to the north and south of New Zealand (New Hebrides arc, Tonga Trench, Kermadec and Macquarie Ridge areas). This is because of lack of regional seismic data and the algorithms to determine magnitudes above 7.0 quickly and accurately. Large earthquakes north of 30ºS and south of 50ºS are not routinely located. Similar limitations also apply to GeoNet's ability to monitor volcanic unrest or to detect landslide events along the Kermadec Ridge. Discussions on the establishment of a South-West Pacific Tsunami Warning System have been ongoing for several years, particularly since the ICG/ITSU conference in Wellington in 2003. It is expected that the result will be at least the free exchange of seismic and sea-level data between PTWC (including that from Pacific Island Countries), Australia, and New Zealand, which will greatly enhance GeoNet's regional coverage.

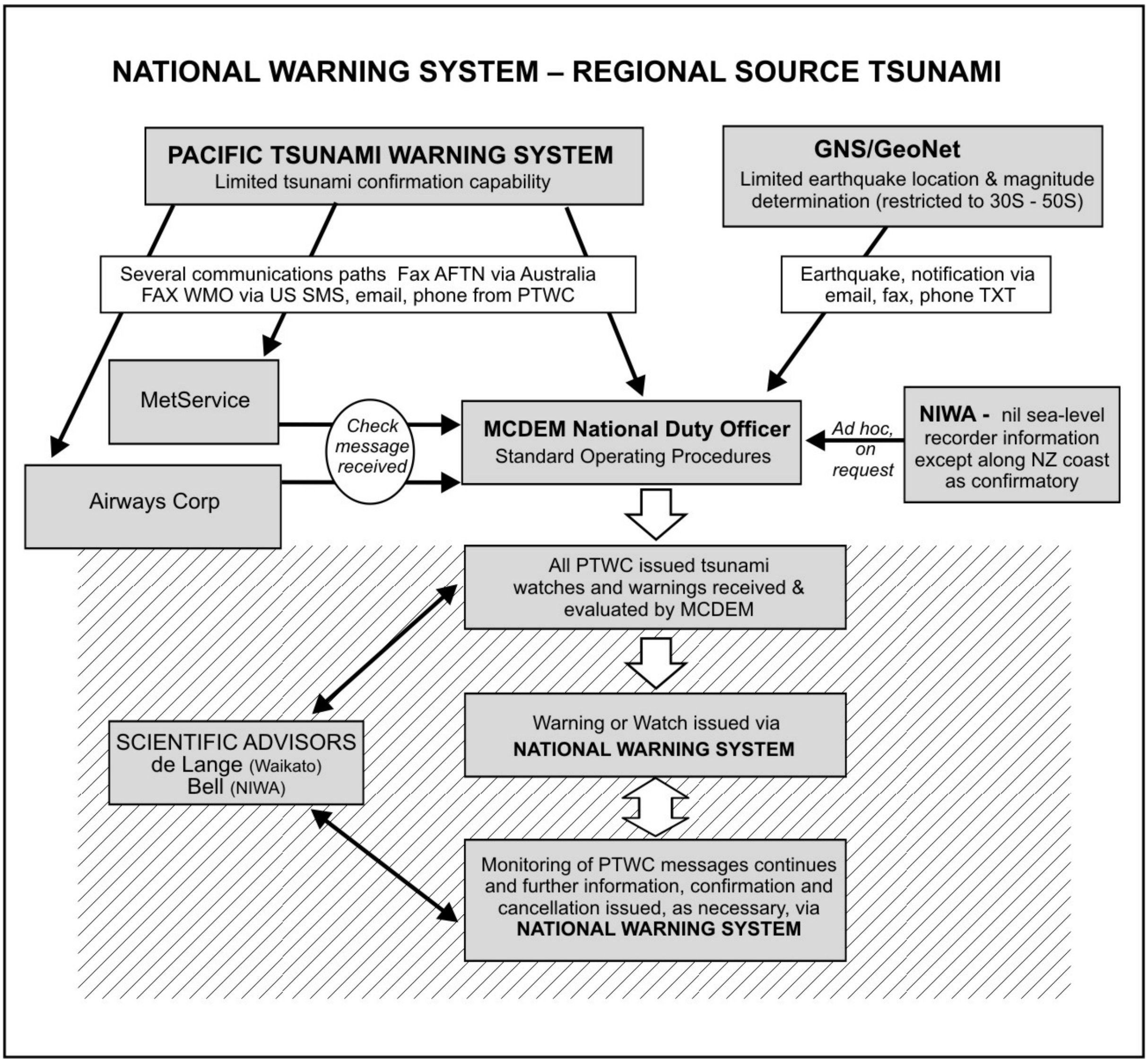


Figure 2.4 Flowchart of the operational procedures of National Warning System for regional-source tsunami. Note that the hatched area indicates that these procedures may not be possible in the time available.

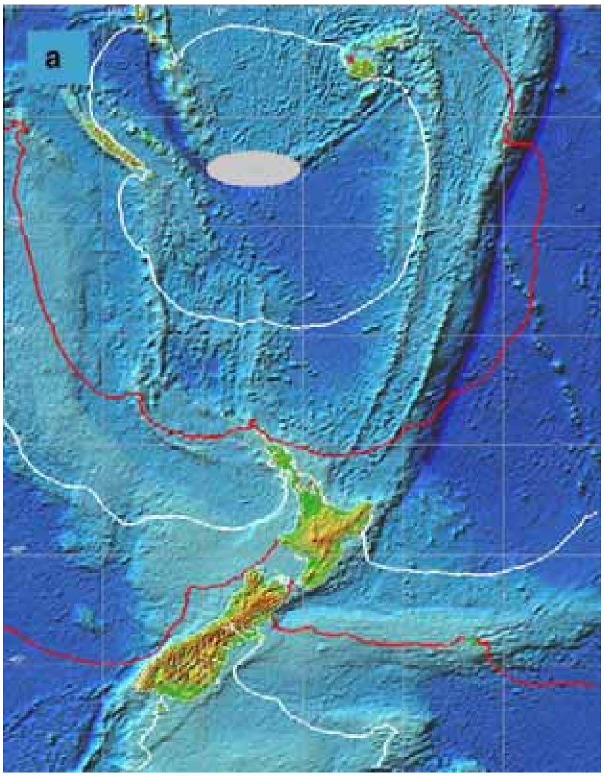


Figure 2.5a Travel times for the tsunami from a large earthquake on the subduction zone southeast of Vanuatu. The colour of the line changes every hour of travel time, indicating a tsunami from this source would arrive in Northland about 2 hours after initiation.

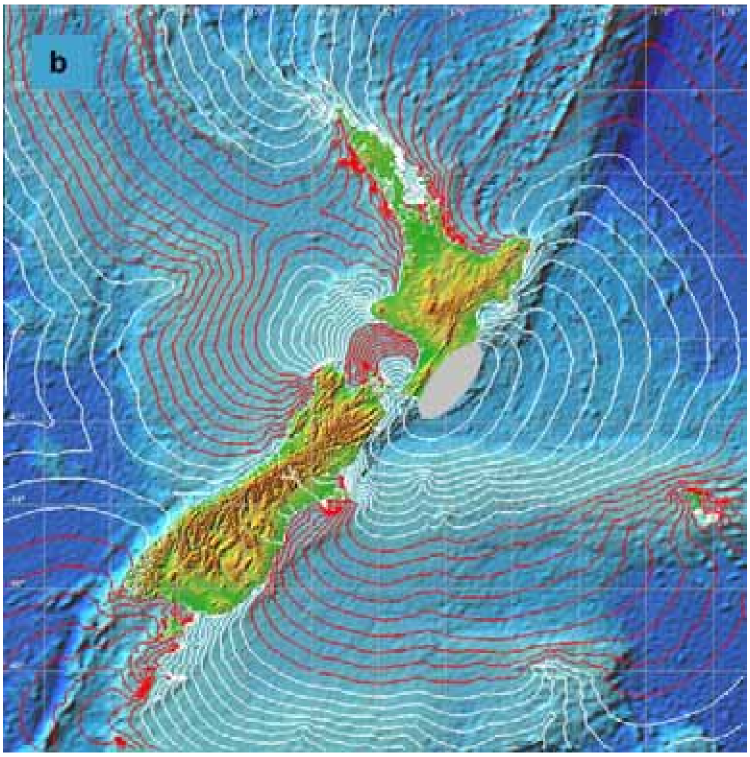


Figure 2.5b Travel times for the tsunami from a large earthquake on the subduction zone off the east coast of southern North Island. The colour of the line changes every hour of travel time as above, but there is a line for each 5 minutes of travel time. In this event, the tsunami arrives at Canterbury and East Cape about an hour after initiation.

2.1.3 Local-source tsunami

2.1.3.1 National arrangements

For earthquakes within New Zealand's continental margins (i.e., local-source events) MCDEM receives messages from PTWC and GeoNet. Although not specified in PTWC's operational procedures (PTWC presentation, Tsunami Workshop, Suva, Fiji, September 2005), the issuing of the first information bulletin usually occurs within 10–20 minutes of a large earthquake, too late for bulletins to be issued prior to the arrival of the tsunami, given that the tsunami travel time will be less than 60 minutes. Current PTWC and GeoNet notifications to MCDEM thus provide little or no time for developing appropriate warnings for the coast nearest the source of the tsunami, and perhaps only a little more time for appropriate warnings for more distant coasts (in the event of a very large tsunami caused by a plate interface earthquake). Because along-coast warnings may still be useful, MCDEM may issue them through the National Warning System. Given the difficulty of implementing effective local-source warnings, the MCDEM National Warning System Procedures (Appendix 3) note that educating the public to recognise natural tsunami warning signs is the principal preparedness measure for local-source tsunami.

2.1.3.2 GeoNet

The New Zealand GeoNet project is a national geological hazards real-time monitoring and data collection system, designed for rapid event response and to provide data for research into earthquake, volcano, landslide and tsunami hazards. GeoNet is primarily funded by the Earthquake Commission and is being built and operated by the Institute of Geological and Nuclear Sciences (GNS) on a non-profit basis, with all data being made freely available.

2.1.3.2.1 Earthquake-generated tsunami

The GeoNet system incorporates dual data centres with duty officers on a 20 minute 24x7 response time for analysing significant earthquakes. Earthquakes are located using a nationwide network of seismograph stations, which transmit their data to the Data Management Centres (DMC) for analysis by automated processes. If the automated processes detect an earthquake, the Duty Officer is notified and confirms the automatic location. If the earthquake is real and significant, the earthquake information is released.

The 24x7 GNS Duty Officers apply the following guideline to recognise potential local-source tsunamigenic earthquakes: a shallow event (12 km or less), magnitude 5.5 or above, off the New Zealand coast. This magnitude is, at present, considered to be the minimum threshold magnitude for an earthquake of the right type to generate a tsunami[2]. Other than

[2] Normally, an earthquake of this magnitude is insufficient to cause enough sea-floor deformation to cause a major tsunami. However, New Zealand has experienced a special type of earthquake called a "slow tsunami earthquake" (or just 'tsunami earthquake"). One defining characteristic of these earthquakes is the greater than

applying this guideline, GeoNet does not have any means at present to further analyse the tsunamigenic capacity of the earthquake. When such an earthquake occurs, the GeoNet Duty Officers have a SOP to inform MCDEM as soon as possible by email, fax, and TXT. The (new) National CDEM Plan will confirm and formalise this process.

Planned enhancements to GeoNet's sensors, real-time analysis and communications capability that are necessary to implement a more comprehensive tsunami alert system based on the identification and characterisation of large earthquakes off the New Zealand coast are discussed in Section 4.2.1.

2.1.3.2.2 Landslide-generated tsunami

GeoNet's local earthquake detection system might also detect large submarine and coastal landslides that occur spontaneously, that is, not in association with earthquakes. However, as seismograph records of landslides are usually very different from those of earthquakes, they may not trigger an alert to the Duty Seismologist. Even if an alert was triggered and the landslide was able to be located, there is no simple way to relate seismic signals to critical landslide parameters, such as speed and volume, to determine their tsunamigenic potential, although in time this is likely to become possible.

2.1.3.2.3 Volcano-generated tsunami

Monitoring New Zealand's on-land and near-shore volcanoes is part of the GeoNet project. Prior to significant eruption events there will probably be precursory seismic activity over months, weeks and days. Should a volcano show signs of activity that might eventuate in a large eruption and hence generate a tsunami, a contingency plan and a period of heightened public and organisational awareness of the need to evacuate might be able to be established. There is no contingency planning for this at present, however, and, as with landslides, there are no means to relate seismic signals to relevant parameters such as eruption volume which influence tsunamigenic potential.

expected tsunami for their magnitudes calculated using local seismograph records (that is, local or Richter magnitude, M_L). Surface wave (M_S), and moment magnitudes (M_W), determined using overseas seismograph records, are much higher. This type of earthquake is not well understood internationally, with various mechanisms for tsunami generation being proposed. These earthquakes also present the problem that they may not produce strong shaking on land.

2.2 Effective warning systems

2.2.1 National-scale tsunami hazards research directly related to warning systems

Several universities (University of Waikato, University of Canterbury, Auckland University, Lincoln University), as well as GNS and NIWA, have tsunami research programmes. Some relate to the science of tsunami, while others relate to the social science of developing tsunami awareness and preparedness in communities. While all of the science of tsunami research (i.e. historical database, paleotsunami, submarine landslide recognition and processes, and numerical modelling) contributes to the development of a national picture of tsunami hazard, only GNS and/or NIWA programmes are directly related to understanding, informing and improving warning system processes (that is, the whole effective warning system), and providing in a coordinated way the scenario event data and generalised hazard and risk models needed at national level to appropriately respond in a warning situation. These programmes have very limited funding amounting to a few FTE, restricted by the needs of other hazards research programmes. Outside these programmes, the research is also limited by available funding and tends to be focussed on very specific problems rather than being a part of a coordinated programme.

Research is supplemented by funding from territorial authorities but their funding is usually too limited to include more than a little of the numerical modelling that is needed to develop a full picture of the hazard in their area. For example, only one or two worst case scenarios might be developed for those regions that can afford the relatively high cost, but this does not provide the comprehensive picture that they need individually and the nation needs to respond in a coordinated and nationally consistent manner.

The Science Report further describes the extent of current knowledge and understanding of tsunami processes, and its limitations.

2.2.2 National-scale warning system effectiveness evaluation

As noted in Section 2.2.6 below, MCDEM tests the National Warning System on a regular basis and, as part of the test, a report on the effectiveness of the test is disseminated to all participants. The report notes message delivery failures (due to wrong numbers/addresses), receipt of message confirmation times, failures to confirm receipt of messages, and any other issues that pertain to the system that aroused attention as a result of the test. These tests, however, do not include communication of warnings to the public, although local authorities may use them to test warning systems.

The National coastal survey (see Section 8.2 for details) provides a snapshot of how well people understand and might respond to tsunami warning messages, and hence how effective public response would be. This is discussed further in Sections 4 and 7 of this report.

2.2.3 National-level effective warning system planning

At present, there appear to be few national guidelines and decision-making tools (such as minimum tsunami height response thresholds, earthquake thresholds, evacuation routes and map planning, educational material) to help CDEM Groups and other agencies to develop effective warning systems that are consistent and coherent across Group boundaries. This is further discussed in Chapter 7.

2.2.4 National-level co-operation, discussion and communication

This component of an effective warning system involves pre-planned and exercised communication between central government agencies, local emergency management agency staff, scientists and community representatives. Below we list the initiatives that have taken place over the past three years.

2.2.4.1 TSUNZ2002, February 2002

TSUNZ2002, an EQC-sponsored two day workshop in February 2002 organised by Gaye Downes (GNS), James Goff (GeoEnviromental Consultants) and Roy Walters (NIWA), brought together New Zealand-based tsunami researchers, consultants and MCDEM to discuss tsunami hazards in New Zealand. International tsunami scientist, Professor Lori Dengler (Humboldt University, California), was a keynote speaker and guest at this event. Dengler acted as international reviewer of the Science Report.

2.2.4.2 Tsunami Action Group (TAG)

After TSUNZ2002, MCDEM organised a one-day workshop involving key people from TSUNZ2002 and CDEM Group representatives to discuss tsunami early warning systems in New Zealand, and the scientific research that underpins the system. At that time a Tsunami Action Group (TAG) was established to bridge the gap between science and emergency management and to provide emergency management with advice on tsunami hazards relevant to the long-term planning of early warning systems. The last meeting was in November 2002.

2.2.4.3 Natural Hazards Workshop, Tauranga, August 2004

The first scenario-development workshop for the distant-source tsunami component of the National Warning System was conducted on the 11th of August 2004, in Tauranga. Some recommendations for improvements to the National Warning System procedures component of New Zealand's distant-source early warning system were developed from this workshop.

2.2.5 National-level public education, staff training, maps and signage

MCDEM maintain a website designed to provide the public with information of how to act in a tsunami warning and have some brochures available. Several other nationally available websites, such as those maintained by Regional Councils and EQC, also have tsunami-specific information. Generally, these websites differ in content and the instructions on what to do after a strong-shaking earthquake are not always clear or nationally consistent.

MCDEM have developed the National Public Education Strategy [MCDEM, 2003 #17], which sets out the strategic framework for public education for the CDEM sector in New Zealand for the 2003-2008 period. This document was developed in consultation with the sector and contains a number of strategies and short-, medium- and long-term goals within each. These are further discussed in Section 8.4.4.

2.2.6 National-level exercising

As part of the PTWC system, test messages are issued at unannounced times on a monthly basis to determine writer-to-reader delays in disseminating tsunami information, to test the operation of the warning system by the evaluation of two-way communications with interactive personnel response, and to keep communication operating personnel familiar with the procedures for handling message traffic pertaining to the PTWC.

MCDEM also tests the National Warning System four times per year — two tests are conducted inside normal working hours and two tests outside working hours. Each test is followed up by a report that is disseminated to all participants. Testing is conducted in accordance with the National Warning System SOP's and are based on:

- Testing the respective means of communication;
- Testing confirmation-of-receipt-of-message times; and
- Testing and updating address lists.

Exercising with regard to CDEM response is traditionally conducted on an ad-hoc basis in terms of frequency, content and format as determined by the respective response agencies. CDEM Group Plans include provisions for exercising.

MCDEM is however currently leading a project aimed at the development of a national exercise programme (NEP) for CDEM. MCDEM obtained agreement from the CDEM Groups and national engineering lifelines for the requirement of such a national exercise programme, and an NEP charter to determine the programme has subsequently been developed. An outcome is the formation of a representative NEP governance group that will draw a 10-year schedule for the national exercise programme by the end of 2005. The NEP establishes a framework by which the capability of Government, its departments, CDEM Groups and CDEM Group member organisations to respond to emergencies individually and collectively will be exercised and tested on a regular and programmed basis. The NEP is acknowledged in the new National CDEM Plan although participation is voluntary.

The ICG/PTWS at its 20th session in October 2005 recommended that an end-to-end tsunami exercise be carried out for the entire Pacific Ocean in 2006. The exercise should simulate each member country being put into a warning situation that requires decision-making and the subsequent issuing of a warning. The exercise is to include all steps prior to public notification. MCDEM is represented on the task team assigned with the formulation and implementation of the exercise. The ICG/PTWS intends this exercise to be the first in a regular schedule of Pacific-wide tsunami exercises.

3.0 COMPARISON OF NATIONAL ARRANGEMENTS FOR TSUNAMI WARNINGS WITH IDENTIFIED RISK

In this Chapter we address the requirement in the Terms of Reference to assess the ‘fit for purpose’ of New Zealand’s national warning arrangements, given the level of risk identified in the Science Report. The methodology in the New Zealand Risk Management Standard (NZS 4360) enables us to make a qualitative ranking of risks according to severity and likelihood. For this report we have adopted a more advanced approach whereby risk, be it in terms of casualties (deaths and injuries) or dollar loss, is quantified. The quantitative approach enables comparisons of risk to be made with other inherently risky activities.

In undertaking comparisons at national level, casualties can be looked at in terms of the risk to groups of people, when multiple fatalities may occur, or in terms of risk to a single person alone (individual risk). Both approaches are valid, depending on the context. Firstly, multiple fatalities are important in terms of a national picture of risk — is the national risk, measured in terms of the likelihood of multiple deaths, acceptable to Government? Secondly, it is worth discussing individual risk at a national level, because national arrangements are critical to regional warning system effectiveness (which, in turn, directly controls individual risk). We discuss these two aspects of risk in turn.

3.1 Multiple fatalities

While much work has been done internationally and in New Zealand on what levels of individual risk are acceptable, the acceptability to governments of multiple deaths is far less clear. The issue has been addressed where the risk is imposed on people in the interests of the ‘greater good’ such as in the nuclear industry or in the construction of large dams for electricity generation. In the case of tsunami, as for other natural hazards, the risks are more in an ‘Act of God’ category, although are closely related to where we choose to live. In general, New Zealanders have had little opportunity to be well-informed in terms of the associated risks of a coastal habitation.

Other significant causes of multiple deaths are pandemics, wars, and terrorism. The latter two are in a somewhat different category to natural hazards and so comparisons are unlikely to be useful. Pandemics are more pervasive than natural hazard events, but may provide useful comparisons, especially with the current work in preparing for a possible avian influenza pandemic. For now, the most relevant comparisons are with other natural hazards.

Historically, flooding deaths are low, but this is achieved through relatively reliable severe weather forecasting, catchment monitoring, and planning and procedures for effective evacuation. Relatively recent experience and frequent occurrence of the hazard enable the public to be better prepared to respond appropriately. Regional Councils presumably consider this level of planning effort to be justified.

While historically fatalities have been low, there is a risk of multiple fatalities where warning times are short, for example at the Waiho River or in areas exposed to debris flows ('flash floods').

Volcanic eruptions causing casualties in New Zealand are infrequent and there is no quantitative picture of national risk. In historical times, the most deadly eruption was that of Mt Tarawera in 1886, which killed an estimated 153 people. Much larger eruptions, such as that in Lake Taupo in 181 A.D., would devastate a large area of the central North Island if they occurred today. Until the advent of the GeoNet project, volcano monitoring has been run at very minimal levels in this country, but in future we would expect some warning of such eruptions, which would enable evacuation. In the absence of any quantitative risk analysis, however, we cannot judge what degree of attention this hazard should receive compared to others.

New Zealand's worst earthquake in terms of fatalities was the magnitude 7.8 Hawke's Bay earthquake, which occurred in 1931 (256 deaths). This event led to a change in construction standards and since then there has been an on-going investment in research to regularly improve building standards so that we can continue to improve the mitigation of this hazard. We are able to estimate the likely deaths due to future earthquakes in New Zealand, although no uncertainty analysis has yet been undertaken at national level. This comparison was shown in the Science Report and is also plotted as the dashed black curve in Fig. 3.1. At a likelihood of 1 in 2,500 years, the expected casualties in a single event are expected to be in the range 500–1,000.

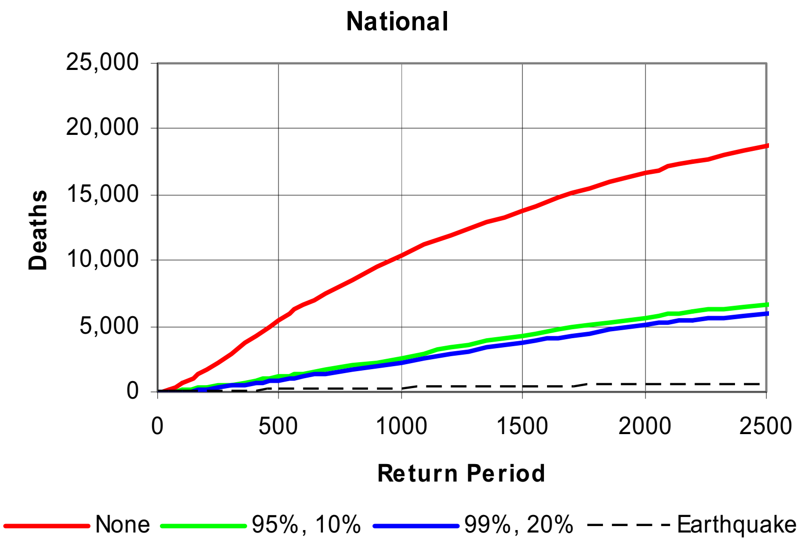


Figure 3.1 New Zealand national total deaths in a single tsunami event compared to the return period of that event. The curves represent: (a) no warning effectiveness (red solid), (b) 95 % removal of people from harm's way in a distant warning and 10 % in a local warning (green) and (c) 99 % removal of people from harm's way in a distant warning and 20 % in a local warning (blue). Estimated earthquake death rates are shown for comparison (black dashed).

In summary then, the likely losses from floods, volcanoes, and earthquakes with a likelihood of 1 in 2,500 years are less than 1,000 in a single event, although no systematic analysis has been undertaken for volcanoes and sudden-onset flood events may have high impacts in some locations. Significant investment in warning systems has been made for floods for many years and commensurate activity is now underway for volcano monitoring as part of the GeoNet project. There is also much effort expended in both flood and earthquake mitigation, particularly through engineering measures. Estimated dollar losses would have been a part of mitigation decisions, not just loss of life, as these are becoming more important for these hazards. Warning systems, however, tend to protect life (including livestock) much more than property, especially when the lead time is short.

Fig. 3.1 shows the median estimates for total national deaths from single tsunami events as a function of return period. The red curve assumes no warning system; compared to earthquakes, risk at the median level is very high. A limitation of this analysis is that the figures for multiple fatalities are really indicative of a night-time situation when people are in their homes. Likely fatalities during the day are expected to be lower as many people will be working in CBD areas, many of which are less exposed than areas of coastal housing. Nor do the multiple risk figures take account of holiday periods when people are away from their homes. At these times there will also be heightened risk at popular beachfront holiday locations, again not accounted for in the relatively simple models that were required for this project. These factors, however, in no way alter the fact that the risk of multiple tsunami fatalities is high compared to other natural hazards.

We have not attempted to assess the effectiveness of the national warning arrangements in a quantitative way, such as in terms of the percentage of people evacuated, because any estimate would be highly subjective. For example, in New Zealand we achieve close to 100% evacuation for flood events, while recent experience in one of the world's best prepared communities for tsunami (the Pacific Northwest) showed many shortcomings. Given such disparities and the need for huge assumptions, quantitative estimates would be meaningless. The only way of reliably quantifying the result of a change in the warning system effectiveness would be to monitor the response to real or simulated tsunami events before and after the change. Such monitored simulations are recommended at national and regional levels in Sections 4.4 and 8.5.4 respectively.

As an alternative to quantifying the effectiveness of current arrangements we have chosen scenarios that will serve to illustrate the benefits of effective early warnings. Distant-source tsunami warnings are expected to be much more effective than those for local sources, so numbers as high as those achieved for floods should be possible if all the elements of a fully effective warning system (Section 1.3) are implemented. These, or other, scenarios can be used as targets, with the targets set to get the risk of fatalities down to acceptable levels.

When the effect of an early warning system is factored in at national level (Fig. 3.1), the number of fatalities is still well above those for other natural hazard events for the scenarios we have considered. Given that substantial amounts are invested in both warning systems and mitigation for the other natural hazards, on the grounds of the acceptability of multiple fatalities to Government, a similar investment in tsunami mitigation would appear to be an inescapable conclusion.

Given the significant proportion of risk related to local-source tsunami, decreasing the risk of multiple fatalities will not be easy using just a warning system approach. As has already been pointed out in the wake of the 2004 Boxing Day tsunami (e.g. Bell *et al.*, 2005), a mix of approaches involving warning systems, engineering and 'soft' mitigation, and land-use planning will be required.

3.2 Individual risk

At a local level, the concept of individual risk is very useful when we wish to make comparisons with other everyday risks. There has been much work internationally on what levels of individual risk are acceptable and the work of Taig in a New Zealand context was referred to in the Science Report (Berryman, 2005; Table 9.2).

Using the concept of individual risk on a national scale, however, is not straightforward. This is mainly because individual risk is highly variable, depending on location. An average figure would be quite misleading because many people are at no risk from tsunami, diluting the figures for those most at risk. This is in contrast, for example, to road accident risk, which is widely distributed among those using the roads and indeed, the whole population.

As mentioned above, however, national arrangements are integral to an effective early warning system at regional level, so the national arrangements need to be effective to reduce individual risk to an acceptable level.

Fig. 3.2 shows the median individual risk for major coastal centres in New Zealand as a function of height above sea level for those people living at the foreshore (a worst-case example). With no effective warning system, no localities show intolerable levels of risk ($>10^{-3}$) for people living at 2 m elevation above mean sea level. All risk levels are reduced at 4 m elevation. Several centres, however, have levels that would be regarded as intolerable (10^{-4}–10^{-3}) if the risk was imposed. For natural hazards we would argue that the equivalent to an imposed risk is living with a risk about which you are not well-informed, as is largely the case for tsunami (see CDEM Group plan hazard rankings for tsunami in Chapter 5).

The individual risk figures that we have discussed so far were median estimates. When the risk issues relate to life safety (as opposed to dollar loss), 84th percentile estimates are usually used. This naturally drives very conservative design when uncertainties are high, reinforcing the need for on-going research to reduce the level of uncertainty and hence get away from overly conservative design. The equivalent 84th percentile individual risk levels are shown in Fig. 3.2. With these estimates Gisborne falls into the intolerable risk category when there is no effective warning system.

For the individual risk analysis we have halved the computed risk value so that the figures quoted are more representative of an average situation, rather than night-time when people are in their homes or day-time when they are at work. The individual risk figures take no account of holiday periods when people are away from their homes. At these times there will be heightened risk at popular beachfront holiday locations, again not accounted for in the relatively simple models that were required for this project.

In the same way as for multiple fatalities, we can introduce the effectiveness of warning systems using scenarios. These are also shown in Fig. 3.2. The warning system effect tends to separate the localities into lower and higher bands, depending on the balance between distant and local sources. The scenario warning system effectiveness reduces the residual risk in Gisborne to below the intolerable level, but six centres still have risks in the10^{-4}–10^{-3} range (intolerable if imposed or uninformed). Ideally, there should be a strategy for reducing the risk in Gisborne, Napier, and the Wellington Region to below 10^{-4}.

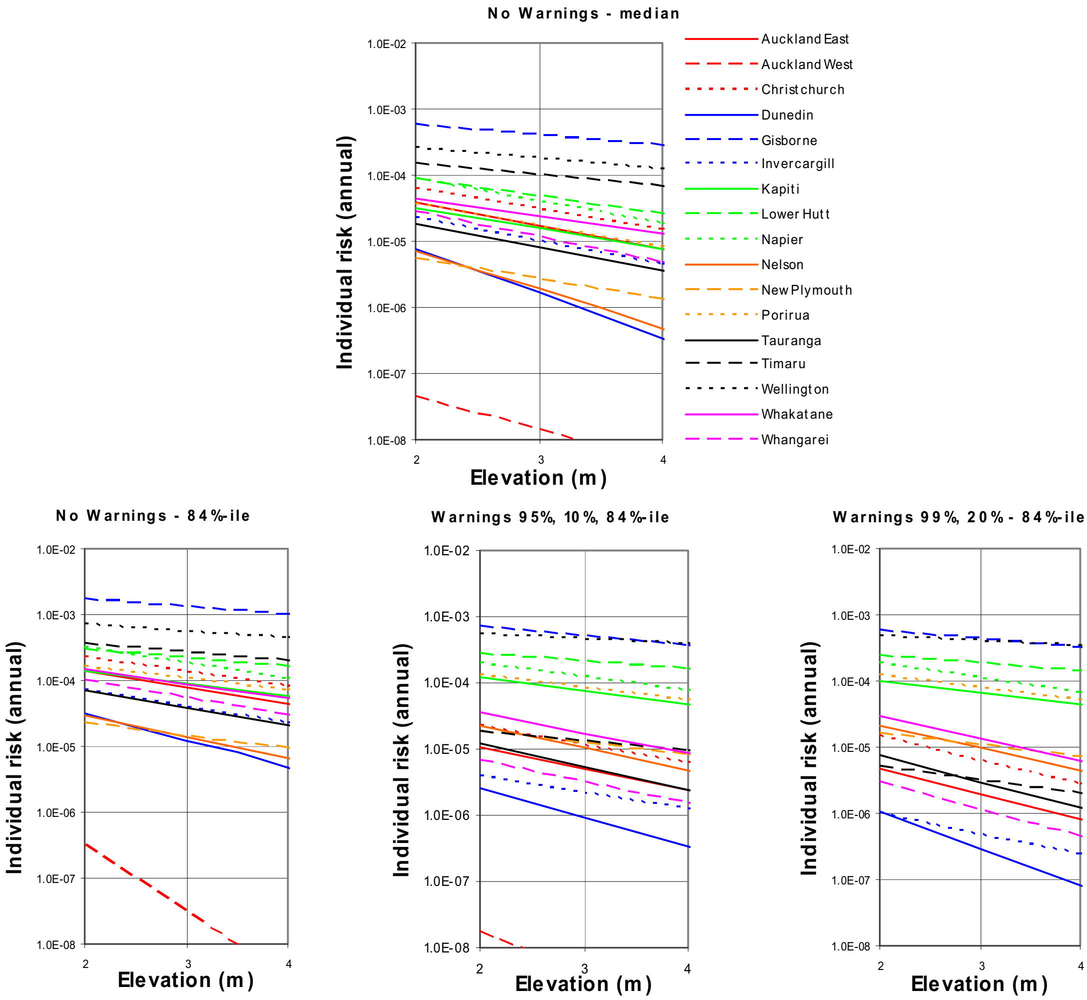


Figure 3.2 Individual annual probability of loss of life at a given height above sea level for each location analysed. The top graph shows the median estimates, under a situation of no warning. The lower three graphs show the 84th percentile figures for three situations: no warning, warnings 95% effective for tsunamis from distant sources and 10% effective for local sources, and warnings 99% and 20% effective.

As for multiple fatalities, the individual risk figures emphasise the importance of having an effective early warning system and thus reinforce the need for the national level arrangements to be effective. Beyond that there is a need to further reduce individual risk from local-source tsunami.

3.3 Effectiveness of national tsunami warning arrangements

3.3.1 Early Warning System: monitoring, analysis & notification

3.3.1.1 Distant-source tsunami

The National Warning System is judged to be effective in terms of being able to receive PTWC bulletins and to pass them on the CDEM Groups. There are minor issues with respect to the accessibility of National Duty Officers caused by the use of an answering service, but these are being attended to.

There are significant issues with the analysis of the PTWC messages, the formulation of warning messages to CDEM Groups, and their expectations of what will be in those messages.

The first key issue is with the provision of scientific advice to MCDEM. Current arrangements are very informal given that this is an operational system on which thousands of lives may depend. The informal nature of current arrangements is largely due to CRIs not being funded to provide a formal service in this regard, while some institutions that are relied upon for advice (notably NIWA and the University of Waikato) are also not operationally structured for that purpose.

The second key issue, which is related to the first, is with the warning message information that is required at CDEM Group level to make a decision as to whether to evacuate, and what areas to evacuate. With current knowledge, wave heights are difficult to predict and likely areas of inundation are even more uncertain and are beyond the scope of CDEM Groups to determine. The prediction of wave heights is a problem internationally and will improve in time through further research and the development of numerical models. Given the difficulty in predicting wave heights, it is likely that evacuation to higher than necessary levels will occur, causing a greater than necessary disruption as well as straining the capacity to evacuate. Extreme over-prediction of wave heights, effectively resulting in false alarms, will also reduce the effectiveness of future warnings.

Another issue is that there are no procedures, principally sea-level monitoring and analysis on a national scale, to determine when the "all clear" should be declared.

3.3.1.2 Regional-source tsunami

A shortcoming for regional-source tsunami warning is the lack of real-time sea-level data (and even envisaged capability) to detect and monitor the tsunami before it reaches our coasts and to monitor its impact as it progresses along the country, as well as the means to interpret what information the recorded wave heights are giving on likely impact at places yet to be reached.

As mentioned in Section 2.1.2.2, GeoNet currently has poor capacity to accurately determine the location and magnitude of potential regional-source tsunamigenic earthquakes because of lack of regional seismic data and appropriate systems to handle such data. It is expected that in future the free exchange of seismic and sea-level data between PTWC, Australia, and New Zealand will greatly enhance GeoNet's regional coverage. Improvements to tsunami systems within GeoNet are already planned as part of the full funding of GeoNet.

In addition to the shortcomings identified above for distant-source tsunami warnings, regional-source warnings, by definition, involve tight timeframes which may be too short for the current National Warning System arrangements to be effective. This is a recognised deficiency, so it is acknowledged that no formal system exists for regional-source events.

3.3.1.3 Local-source tsunami

It is acknowledged that there are no formal arrangements for local-source tsunami, with public education being the principal preparedness measure (see below). Again there is a need for real-time sea-level data to detect and monitor the impact of a local-source tsunami at the nearest coast and for analysis tools so that appropriate warnings can be given to places that are further away from the tsunami source region.

There is also a need for GeoNet to be able to alert people quickly to the fact that a large, potentially tsunamigenic earthquake has occurred. While effective local warnings are not currently available and are likely to take considerable time to develop, improved early information will be of use in some situations.

Finally, the Early Warning System represents only part of any solution. The risk levels discussed above clearly point to the requirement for a fully effective tsunami mitigation system. If this is to be achieved, the extra elements of research; planning; cooperation, discussion and communication; education; exercises; and evaluation need to be present. These are discussed briefly in Section 3.3.2.

3.3.2 Effective warning system components beyond early warning

Although not reviewed in as much detail as for regional arrangements, national-level preparedness in terms of effective warning system components beyond the early warning system appears very low compared to the national-level risk. These components, reviewed in Section 2.2 fall under the headings of (from Fig. 1.1):

- Warning response planning
- Cooperation, discussion and communication
- Education, staff training, maps and signage
- Exercises
- Underpinning tsunami hazards research
- Warning system effectiveness evaluation

Chapter 4 details national-level recommendations for improvements to these arrangements. These recommendations are focused on providing national resources (content for education materials, signage methodology, evacuation planning guidelines, etc.) and consistency for detailed arrangement development within regions (Chapter 7).

4.0 RECOMMENDATIONS FOR IMPROVING THE NATIONAL MANAGEMENT OF TSUNAMI RISK

In the previous chapter we identified shortcomings in the national arrangements for effective tsunami warnings. Here we discuss planned enhancements to both national and international early warning systems and also make further recommendations about what is required. To facilitate the discussion we look at early warning systems for distant-, regional-, and local-source tsunami in turn, as the requirements vary according to the warning time available. We then look at the wider issues relating to the other elements needed to achieve an effective warning system (as far as we have determined, from international examples, Section 1.3).

To achieve the maximum mitigation of tsunami risk a balanced range of defences are needed (sometimes referred to as layered defence), not just effective warning systems. These other defences include protection, adaptation, and land-use planning. While mitigation options will involve national strategies, they will also involve local solutions, so we defer discussion of them until Chapter 7. The recommendations contained within this chapter are thus limited to those addressing an effective warning system.

4.1 Distant-source early warning systems

As mentioned in the preceding chapter, in the event of a distant-source tsunami warning alert from PTWC there is a significant issue about the information that is required at CDEM Group level to make a decision as to whether to evacuate and to what areas to evacuate. With current knowledge, wave heights are difficult to predict and likely areas of inundation are even more uncertain. For this reason, PTWC Bulletins predict wave arrival times and then only give information on wave heights already observed (they purposefully do not predict wave heights).

4.1.1 Currently-planned enhancements to PTWC information

At present, the Pacific Tsunami Warning Centre uses data from seismic monitoring and coastal tide gauges to develop tsunami warning messages based on historical comparisons, empirical models and pre-calculated scenarios, where available. However, research is currently underway to develop a near-real time system that can incorporate information from a network of deep water buoys, known as DART buoys (Gonzalez et al, 1998), and use these to refine, in real-time, predictions from a database of tsunami models (Titov, 2001).

In the event of an earthquake, a model is selected from the database which best matches the known information on the source, and the results from this model can then be used to predict the likely impact at locations not yet reached. Detailed information on earthquakes is needed for accurate tsunami wave height prediction (for example on the extent and location of fault rupture and the amount and distribution of vertical deformation). This takes time to infer, as often only basic and approximate information is available in the first hours, and some information may not be available for days or months. These limitations can be overcome by refining the tsunami model in real time according to information from sensors that measure the tsunami directly in the form of water level readings from either deep-water buoys, or tide-gauges on coasts already reached (in future satellite measurement may be added to this list). Information from deep-water buoys is considerably more useful than that from coastal tide-gauges as the signal from coastal tide-gauges is confounded by the effects of the local bathymetry (i.e. seafloor topography) on the tsunami.

At present, the network of seven DART buoys, operated by Pacific Marine and Environmental Laboratory (PMEL, part of National Oceanic & Atmospheric Administration, USA), is strongly concentrated in the northeast Pacific (Fig. 4.1). Only two buoys currently operate south of the equator, and both of these are in the eastern half of the Pacific. Considerable expansion of the network is planned (32 new buoys by mid-2007), including some sites in the South Pacific that may benefit New Zealand.

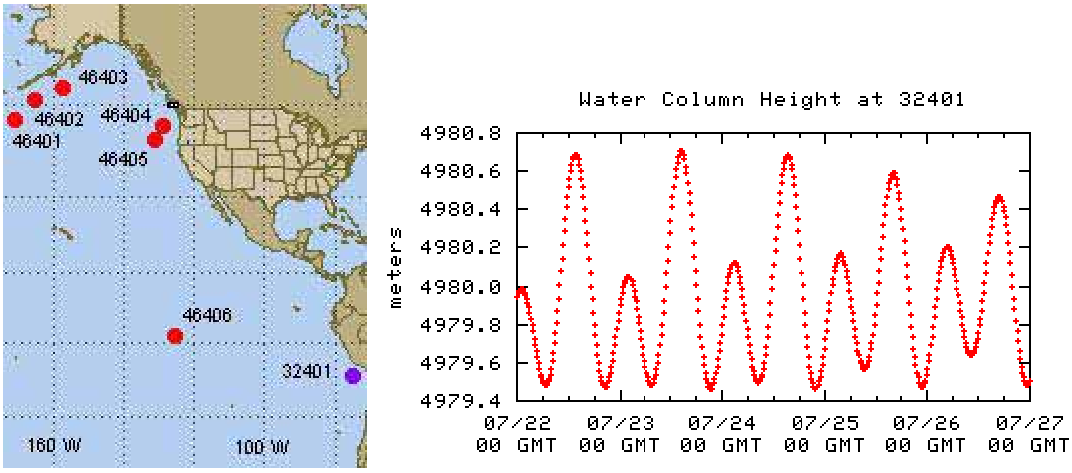


Figure 4.1 Locations of DART buoys operating on 27 July 2005, and time-series data from buoy 32401 located off the coast of Peru showing a strong tidal signal (Source: National Data Buoy website).

New Zealand benefits enormously from being part of the Pacific Tsunami Warning System. By contributing to the development and operation of the emerging real-time system we can ensure that the distant sources most likely to impact here are well prepared for. Currently, GNS is actively collaborating with PMEL so that the system can be applied locally. GNS is also contributing to the characterisation of New Zealand and South American earthquake sources, which will be used in the pre-computed PMEL models.

Bathymetry data is a key input to real-time forecasting models. Good quality is important especially in shallow water, and good topography data is important for inundation models. A central database of bathymetry and topography data for tsunami modelling is essential.

The emerging real-time PTWC warning system provides broad scale information on approaching tsunami (the SIFT model, Fig. 4.2). More accurate, and detailed, information on the likely impact of incoming tsunami can be deduced from this by developing Standing Inundation Models (SIMs). SIMs is an extension to the basic forecasting model and provides which provides higher-resolution forecasts for specific locations. These can only be computed in real-time for a limited number of key locations, which might be locations most at risk.

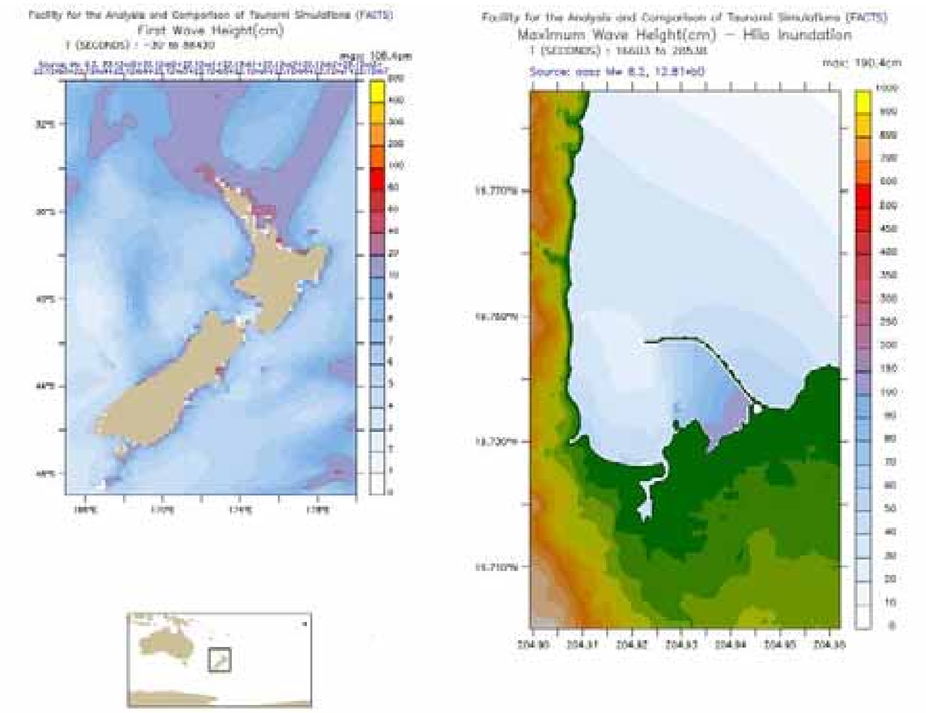


Figure 4.2 Example output from the SIFT tsunami model for a hypothetical Aleutian source tsunami (left). Example output from a SIM inundation model for Hilo, Hawaii (right). (Source: NOAA website).

The real-time warnings from PTWC will be available for those locations for which detailed bathymetry at specified locations is in their system, and hence, GNS's current collaboration and the development of a internet node through which calculations can be made means New Zealand can participate. The internet node is an important part of the system and is the only one outside the U.S. However, it should be noted that the real-time system may not be in operation for several years, and it does not obviate the necessity of developing a database of pre-computed scenarios in New Zealand as these are necessary to pre-plan response, in both the areas that would be covered by real-time forecasts and in those areas where real-time forecasts will not be possible.

PTWC is also increasing the amount of seismic and sea-level data that it receives as more seismographs are brought into a real-time environment around the Pacific. This serves to reduce the time it takes PTWC to locate an earthquake and determine its magnitude. New Zealand is in a good position to contribute additional seismic and sea-level data to PTWC once planned upgrades to appropriate networks are implemented (see below).

4.2 Regional-source early warning systems

As mentioned in the previous chapter, regional-source early warnings, by definition, involve tight timeframes that may be too short for the current National Warning System arrangements to be effective. A further shortcoming is the lack of real-time sea-level data to detect and monitor the tsunami before it reaches our coasts and to monitor its impact as it progresses along the country, as well as the means to interpret what information the recorded wave heights are giving on likely impact at places yet to be reached .

4.2.1 Currently-planned enhancements to GeoNet

At present, GeoNet is four years into a 10-year upgrade plan, the work-plan for which was decided in 2001 under more limited funding than was originally envisaged when the concept GeoNet was first proposed. The Earthquake Commission has recently increased funding to support the completion of GeoNet's development, and a new work plan was established in mid-2005.

When complete and fully implemented, GeoNet will be equipped with the sensors, real-time analysis and communications capability that are necessary to operate a more comprehensive tsunami alert system based on the identification and characterisation (i.e., type of earthquake mechanism) of large earthquakes off the New Zealand coast than is available now. GeoNet alone, however, will be insufficient to improve regional early warnings. This improvement can only be achieved through international exchange of seismic and sea-level data, particularly with PTWC (some Pacific Island stations) and Australia. Discussions about the sharing of seismic data have been underway for 1-2 years now and more recently the exchange of sea-level data has also been on the agenda of several teleconferences. Once appropriate real-time data exchange has been achieved, GeoNet could make a major contribution to the detection of local and regional tsunami-generating earthquakes, and will provide data for the Pacific-wide tsunami detection system.

4.2.2 Currently-planned enhancements by Australia

The Australian Government has agreed to spend A$69M over 4 years on a tsunami early warning system to protect Australia from both Indian Ocean and SW Pacific source tsunami. This project will include, if Pacific Island states are in agreement, the enhancement of seismic and sea-level monitoring throughout the SW Pacific within a 90 minute tsunami travel time of

Australia. These enhancements will greatly benefit New Zealand in terms of regional early warnings as the upgraded monitoring networks will cover the main SW Pacific tsunami source zones. No study has yet been undertaken of what further extension of the network would be required to give commensurate protection to New Zealand from regional sources.

4.2.3 Currently-planned enhancements to New Zealand sea level gauges

Following the December 26 2004 tsunami in the Indian Ocean the Government directed Land Information New Zealand (LINZ) to identify, in consultation with the Ministry of Research, Science and Technology (MORST), improvements that can be made to New Zealand's system of sea level gauges to improve its ability to detect and monitor tsunami and thereby decrease our level of risk.

LINZ are coordinating the development of the project in discussion with representatives from all sectors likely to be involved and, in addition, are continuing active discussions with Australian counterparts in the Bureau of Meteorology and GeoScience Australia to ensure projects on each side of the Tasman track along similar lines with at least the capacity to exchange compatible data-streams from each other's seismic and sea-level stations and associated warning bulletins. Discussions have also been held with other SW Pacific countries at National Disaster Management Officer level and with PTWC.

Several essential components for an improved system have been identified. The principal component is the tsunami-enabling of some existing sea-level gauges and the installation of new gauges, all with true real-time telemetry to a data centre. The required extent of the upgraded network has not yet been finalised as it needs to be informed by the Science Report in terms of the most high-risk sources. Other components of the upgraded sea-level system relate to real-time data reception, processing, and archiving — equivalent to what is done now for seismic and continuous GPS data at the GeoNet data centres.

The integration of sea level and seismic observations for rapid analysis and response is a logical step that would complement existing international arrangements for real-time sharing of seismic data and reflect comparable international best practices (e.g. the Pacific Tsunami Warning Centre and Alaska-West Coast Tsunami Warning Centre). As noted previously, funding for the GeoNet 24x7 duty team and dual data centres already exists. The integration and rapid analysis of sea level observations with seismic monitoring and the additional training required for interpretation could be absorbed within the GeoNet Project budget. Additional resources are required to implement the sea-level network upgrade, including communications (already agreed by Government) and for the work suggested under Recommendation 4.2.

Recommendation 4.1: That the GeoNet system be used to integrate sea-level data with real-time seismic monitoring in order to generate alert information for regional- and local-source tsunami and that the GeoNet Duty Team be trained and given tools (Recommendation 4.2) to provide the scientific advice required by MCDEM and CDEM Groups for interpretation of tsunami alert information, including that from PTWC for distant-source tsunami. This training will need to be in tsunami generation, propagation, and impact and provided by a range of New Zealand experts in the disciplines of seismology, numerical water modelling, and historical impact.

4.2.4 Model-database development

The development of a comprehensive database of pre-computed models is the desirable best practice system. However, it has not been achieved widely because of the large amount of work needed and difficulty in incorporating all the variability in tsunami behaviour. Japan is notable for the early warning system it has developed to provide warnings for local, regional and distant sources. Their warning messages are based on ~100 pre-computed models of distant-source tsunami, and on ~100,000 pre-computed models of local-source tsunami. Japan is fortunate in having a long historical record with which to identify their most hazardous sources and to calibrate and verify their numerical models.

The improved instrumentation and numerical modelling will eventually greatly improve the accuracy of wave height estimates being issued by PTWC. However, until such time as it is developed, it is possible to use the methodology developed to estimate wave heights for the risk calculation (Science Report) to develop scenarios within acceptable levels of uncertainty. The risk calculation has been informed with paleo-tsunami and historical tsunami information as well as by some numerical modelling. Because of warning time limitations, the relevant scenarios need to be calculated in advance and kept up-to-date by incorporating new knowledge.

Recommendation 4.2: A system is developed to predict impacts from distant-, regional- and local-source tsunami:

a) As a first step, the methodology developed in the Science Report needs to be turned into an operational tool, in particular, a wider range of earthquake sources needs to be catered for and wave heights at more coastal locations need to be calculated.
b) A second step is to incorporate, in consultation with local authorities, better impact information to inform response decisions such as evacuation. Once developed, the system should be implemented within GeoNet and its outputs made available for dissemination to CDEM Groups when a PTWC warning/watch bulletin is issued or a large earthquake is detected by GeoNet.
c) The methodology needs to be regularly updated in the light of new knowledge so that best estimates of likely impact can always be provided. In time, it is expected that this system will evolve to embrace outputs from NOAA's real-time forecasting model.

4.3 Local-source early warning systems

Local-source early warning systems pose a much greater scientific challenge than those developed for regional or distant-source tsunami. The most advanced local-source early warning system is that in Japan, which can deliver warnings within 3 minutes of an earthquake. Given that the early warning system is just part of what is required to achieve an effective warning system (and thus risk reduction), there is no guarantee that it alone will remove a large proportion of people from harm's way, in spite of all the investment that has been made. It would be difficult to justify a similar investment in New Zealand given the much lower population density.

When fully implemented as originally planned, GeoNet will make a major contribution to the detection of local and regional tsunami-causing earthquakes and our ability to generate local-source early warnings will improve as new knowledge of tsunami develops. There is thus the potential, in time, to implement effective local warnings, but the other components of an effective warning system will also be needed to transform timely early warnings into effective warnings and community response.

Two approaches are more important in the short-term,
(1) improved nationally-coordinated education, and improved resources and consistency-guidelines for regions to implement effectiveness measures for response to natural early warnings (including education, signage, evacuation mapping, exercises, and the planning, research and effectiveness monitoring associated with these) so that there is some degree of self-evacuation, and
(2) implementing early warnings for locations further (one to three hours travel time) from the earthquake, where hardware-based early warnings can be issued in time to enable evacuation (which will probably still need to be self evacuation — i.e. there will not be time for Police and other organisations to proactively evacuate people, as they could be expected to in a distant-source (> 3 hours travel time) early warning).

The situation where a local source produces a tsunami that takes more than an hour of travel time to reach some parts of New Zealand, is little different, in terms of early warning dynamics, to how a regional-source tsunami is addressed, and is thus covered under Recommendation 4.2.

4.4 Components of an effective warning system beyond early warnings

The components of an effective warning system beyond early warnings are: planning; discussion and communications; public education, signage, maps; and exercises (Section 1.3). The majority of these elements are best applied at a regional level, and so relevant recommendations are detailed within Chapter 7. For all of the regional recommendations given in that chapter, national-level resources and consistency-guidelines need to be provided; they have been requested by most regions in the interviews detailed in Section 5.3.

As well as providing resources and consistency for regions, the following components of an effective tsunami warning system should be directly addressed at a national level:

- Public education — implementation and/or improvement of the tsunami component of the national public education strategy (discussed further in Section 8.4.4). This includes effectiveness monitoring of public awareness.
- Exercising — Exercising the end-to-end early warning system for New Zealand. Regions may decide to exercise the remaining components of an effective warning system in conjunction with this (i.e., through to evacuation and the 'all-clear').

Recommendation 4.3: Components of an effective warning system beyond early warnings require support at national level. We recommend resource material (content for education material, signage methodology, evacuation planning tools, etc.) and consistency guidelines; national education strategy; exercising; research in support of improved warning; and evaluation.

4.4.1 Research needs

Research needs at a national level can be put into two categories: physical science and social science. The physical science needs were spelt out in the Science Report (Berryman, 2005; Chapter 11) along with some preliminary priorities. This research will, in time, improve our understanding of tsunami processes and our ability to estimate risk. At the same time, such research will improve real-time wave height and impact predictions after future large earthquakes. A national approach to this research is preferred for a number of reasons. Regions have limited resources for commissioning research on the scale required (particularly smaller regions); there are economies of scale because distant, regional or large local sources affect more than a single region; a national approach brings consistency to the methodology, enabling better comparisons as well as further efficiency gains.

Recommendation 4.4: A great lack of knowledge of tsunami process and risk has been identified. In order to better determine our risk exposure to inform mitigation decisions as well as enable better wave height and impact prediction in future events (Recommendation 4.2), there needs to be a significant new investment at a national level in tsunami research.

The social science research needs relate more directly to the components of an effective warning system and are spelt out in more detail in Chapter 7.

4.5 Summary

The results of the Science Report show relatively high levels of risk at national level and in some regions compared to others hazards. This will come as a significant surprise to many people. It is important that the community responds to this in a positive way, rather than feeling overwhelmed by what needs to be done. A positive factor is that recent changes to emergency management in New Zealand provide a good basis for fixing this problem. Our risk comparisons show that an effective warning system needs to be implemented. To do this requires a balanced approach at national and regional level, along with the associated research needed to better understand the risk to inform decisions further into the future and to ensure that the warning system is as effective as reasonably practical.

This is in contrast to previous territorial authority-commissioned event and impact research, which has been focused on the tsunami hazard to that region alone and has often been based on a limited dataset.

5.0 REVIEW OF CURRENT ARRANGEMENTS FOR WARNINGS AT REGIONAL LEVEL

Under the CDEM Act 2002, local authorities must form CDEM Groups within each region. Subsequently 16 CDEM Groups have been formed throughout New Zealand. The CDEM Groups are consortia of local authorities working in partnership with emergency services, major utilities and others to support coordinated planning for, and response to, emergencies. Among others, CDEM Groups must identify, assess and manage relevant hazards and risks, and respond to and manage the adverse effects of emergencies in their areas. Their powers include, among others, provision, maintenance, control and operation of (local) warning systems. Every CDEM Group must prepare and approve a CDEM Group plan. These plans must state the hazards and risks to be managed by the Group, and the civil defence emergency management necessary to manage those hazards and risks.

In this section we identify current arrangements for tsunami warning at regional level. These include CDEM Group plans, supporting regional and district planning, involvement of Police, local authorities, and fire services. In addition, inter-agency communication protocols and relationships (formal and informal) are documented. Appendix 2 documents CDEM Group roles and their responsibilities from a legislative perspective.

Three methods have been used: a self-reported review of tsunami-process and risk research done by Groups/regions (Section 5.1); a review of CDEM Group Planned arrangements (Section 5.2); and a survey-based review of arrangements beyond, and in support of, these Plans (Section 5.3).

5.1 Summary of tsunami research commissioned by regions

A letter was sent out to Groups in advance of the warning arrangements interviews (Sections 5.3 and 5.4), requesting details of any process, hazard and risk research conducted. A summary of the research that has been conducted at a regional level is presented in Appendix 7.

5.2 Review of effective tsunami warning system arrangements within CDEM Group Plans

5.2.1 Tsunami risk scores in CDEM Group Plans

The attached matrix (Table 5.1) outlines how the tsunami risk has been ranked compared to other hazards in each of the CDEM Group Plans. As noted in MCDEM (2002), two steps are required to clarify risks and manage them:

Table 5.1 Summary of regional tsunami risk rankings given in CDEM Group Plans. Note that regional tsunami sources are not differentiated in Group Plans, in part due to this terminology being new and in part due to regional sources only recently being recognised as being potentially significant.

CDEM Group Plan	Distant Source				Local Source				No. in Rank	Comments
	NZS 4360	SM(U)G	Other	Rank	NZS 4360	SM(U)G	Other	Rank		
Northland	High	7.7	High Priority	6th	High	7.7	High Priority	7th	23	SMUG Priorities
Auckland		7.0	Moderate Priority	15th		6.0	Lower Priority	20th	28	SMUG Priorities
Waikato			High	6th			Very High	1st	26	For the Thames Valley area. Does not state what method of analysis was used
Bay of Plenty			Higher Priority	4th			Higher Priority	4th	21	NZS & SMG used, but no details provided. *
Gisborne		8.5		3rd		8.5		2nd	27	
Hawke's Bay			Priority 3	29th			Priority 1	7th	38	Does not state what method of analysis was used.
Taranaki									10	NZS & SMUG used, however tsunami not listed in the top 10 hazards, details not included
Manawatu-Wanganui				4th				4th	12	Does not have enough information to undertake an objective prioritisation across and risk assessment. *
Wellington			Medium Risk	13th			High Risk	6th	24	SMUG analysis undertaken, but no details provided
Marlborough	Low	7.2		3rd	Low	7.2		3rd	23	*
Nelson Tasman	Moderate	7.9	High Priority	5th	Moderate	7.9	High Priority	5th	16	*
West Coast	High/ Moderate	0.0		18th	High/ Moderate	0.0		18th	25	*
Canterbury		9.0		8th		9.0		8th	36	*
Otago	Extreme			9th	High			23rd	41	Hazards listed alphabetically within each risk level
Southland			Low Risk	20th			Low Risk	20th	32	NZS & SMUG used, details not included. *
Chatham Islands	High	12.0		8th	Extreme	15.0		1st	20	

NZS 4360 = Level of Risk as per the AS/NZ 4360:2004 Risk Management Standard (or previous versions)

* Does not differentiate between local- and distant-source

The AS/NZS4360:2004 Risk Management Standard to establish the context, and identify, analyse, evaluate and treat the risks; and the SMUG (seriousness, manageability, urgency, growth) model, to prioritise risk. Some plans have amended this model to 'SMG', which excludes the 'urgency' component.

There are some inconsistencies between the methods that have been used to rank the risks of various hazards in the plans. Otago used only the AS/NZS 4360 standard, while others the SMUG methodology (Auckland, Gisborne, Wellington, Canterbury). Some have used a combination of the AS/NZS 4360 and SMUG methodologies (Northland, Bay of Plenty, Marlborough, Nelson Tasman, West Coast, Southland, Chatham Islands); and others have used other analysis methods, of which the details are not included (Waikato, Hawke's Bay).

There are also inconsistencies between distant- and local-source tsunami information within the plans. Bay of Plenty, Manawatu-Wanganui, Marlborough, Nelson Tasman, West Coast, Canterbury and Southland Group Plans do not differentiate between local and distant sources within their risk analysis. This contrasts with the description of hazards within the plans, in which detail is provided on local and distant sources for tsunami.

Hazards have been ranked within each plan, and this is shown on the matrix for distant and local sources. A separate column shows the total number of hazards ranked. From the matrix, it can be seen that two plans, Waikato and the Chatham Islands, have ranked the risk from a local tsunami hazard first. For the Waikato plan, this is specifically for a local-source tsunami for the Thames Valley region. The Gisborne Plan ranks a local-source tsunami as second, and a distant-source tsunami third. Although there is little information available in the Manawatu-Wanganui region, the distant- and local-source tsunami risk was ranked fourth.

The West Coast rated a tsunami (without differentiating between distant and local sources) as a high/moderate risk using the AS/NZS 4360 standard, but it scored 0.0 in the SMUG analysis. Tsunami was ranked 18th overall in the plan.

5.2.2 CDEM Group Plan-documented effective tsunami warning system arrangements review

A review of the CDEM Group Plans in relation to tsunami was undertaken, and resulted in the attached matrix (Table 5.2) being produced. This matrix outlines what information on tsunami is included within each CDEM Group Plan around the country, including the Chatham Islands (16 in total). The contents were scored on whether they included details about specific topics; if they were mentioned topics in passing with no detail; if they were not included at all; or if the information was annexed or in a separate supporting document.

Table 5.2 CDEM Group Plans' effective tsunami warning system arrangements

REGIONAL AND LOCAL LEVEL WARNINGS FOR TSUNAMI - CDEM GROUP PLAN CONTENTS

CDEM Group Plan	Address Local & Distant Sources	MCDEM responsible for issuing warnings	Who is regionally responsible	How warnings disseminated regionally	How warnings disseminated locally	SOP's	Public Warning Tests	Monitoring of Warning Systems	CDEM Staff Training	CIMS	Public Education	Pre-event mitigation/ reduction	Other regional ment	
													Police	Fire
Northland	✓	✓ A	✓ A	✓ A	X	✓ A	●	X	✓	●	●	●	●	●
Auckland	✓	✓	●	A	A	A	X	X	✓	●	A	●	✓	✓
Waikato	●	✓	✓	✓	●	A	●	X	✓	●	● A	●	●	●
Bay of Plenty	✓	● A	● A	● A	● A	● A	X	X	✓	●	●	X	✓	✓
Gisborne	✓	✓ A	✓ A	✓ A	✓ A	✓ A	●	X	●	●	●	●	●	●
Hawke's Bay	✓ A	✓ A	✓ A	✓ A	✓ A	✓ A	● A	X	●	●	●	●	✓	✓
Taranaki	X	● A	A	● A	A	A	X	X	● A	✓	● A	●	✓	✓
Manawatu-Wanganui	●	X	X	X	X	●	X	●	✓	●	●	●	●	●
Wellington	✓	✓	✓	●	●	A	X	X	● A	● A	● A	●	✓	✓
Marlborough	✓	✓	●	●	●	A	●	X	●	●	●	●	✓	✓
Nelson Tasman	✓	✓ A	A	A	A	A	●	●	● A	●	●	●	●	●
West Coast	✓ A	✓	✓	✓ A	✓ A	✓ A	X	X	●	●	●	X	●	●
Canterbury	✓	✓	● A	● A	●	X	X	X	●	●	●	●	●	●
Otago	●	✓	● A	A	A	● A	A	X	●	●	● A	A	✓	✓
Southland	✓ A	✓ A	✓ A	✓ A	●	✓ A	X	●	●	●	●	●	✓	✓
Chatham Islands	✓	✓ A	A	A	A	A	●	X	●	●	●	●	✓	✓

Included with details ✓
Mentioned in passing, no details ●
Not included or yet to be completed X
* Draft CDEM Plan
Annexed/Supporting Documentation A

The Canterbury Plan also includes district CDEM plans which further detail local warning systems, SOPs, training and education policies.

It is noted in MCDEM (2002) that not all of the detail necessary in operational planning should be kept in the main body of Group Plans. Many aspects can be annexed, or form part of subordinate or partner agency plans, with references made to them in the body of the Group Plan where necessary. These can include standard operating procedures (SOP's), contact lists, resource lists, etc.

Many supporting documents are referred to, but do not form part of the formal plan. The common documents referred to in the Group Plans include strategies/SOPs for evacuation; warning systems; public information and education; and specific contingency plans, including those for tsunami. An 'A' is given on the matrix where documents have been referred to but are not contained within the Group Plan.

Some CDEM Group Plans included district CDEM plans (such as the Canterbury and Auckland Group Plans), which provide further detail on local procedures for warnings, response, and evacuation. These have not been reviewed.

5.2.2.1 Limitations of review

The following limitations are acknowledged in reviewing in the CDEM Group Plans;

- The review is subjective, but has been partly checked by survey questions (Section 5.3) to improve consistency.
- Supporting documents are beyond the scope of this review. These may contain information relevant to the categories on the matrix and the survey of regional representatives aim to cover the content of these (Section 5.3).
- Some CDEM Group plans have sub-plans that have not been reviewed. For example, the Canterbury plan includes sub-plans for each of the districts within its jurisdiction.
- Where strategies/SOP's are noted as 'to be completed' within plans, and are yet to be produced (such as public education strategies, staff training strategies, warning SOP's), these have not been incorporated (and are given an 'x' in the table), as they have not been approved.

5.2.2.2 Components reviewed and key results

Addresses Local & Distant Sources
This category outlines whether the plans differentiate between local- and distant-source tsunami. Taranaki is the only plan that categorises both local- and distant-source into the one 'tsunami' definition. Waikato, Manawatu-Wanganui, and Otago mention the two sources without details of them, while the remainder do provide explanations of the two sources and their timeliness.

MCDEM responsible for issuing warnings
Whether plans state that the Ministry of Civil Defence & Emergency Management is responsible for issuing the initial warnings of an expected tsunami. The Manawatu-Wanganui plan does not provide any detail of warnings from MCDEM, or how they will be distributed. Eight plans have annexed their warning information (Northland, Bay of Plenty, Gisborne, Hawke's Bay, Taranaki, Nelson Tasman, Southland and the Chatham Islands).

Who is regionally responsible?
The Plan outlines who is regionally responsible for disseminating warnings and information. Ten plans have annexed their warning information, being those in the previous question plus Canterbury and Otago. The Manawatu-Wanganui plan provides no details.

How are warnings disseminated regionally?
The Plan states how these warnings will be distributed to the public at a regional level. Six plans provide details on how warnings are distributed, with further details provided in annexes for 12 plans. The Manawatu-Wanganui plan does not provide any details. In contrast, the West Coast plan lists the names and contact numbers for the local authority contacts, however there are no details as to what happens then.

How are warnings disseminated locally?
How the warnings will be issued at a local/district level. Only three plans provide details on this process (Hawke's Bay, Gisborne, West Coast). Nine plans have annexed their procedures. Two plans (Northland, Manawatu-Wanganui) do not mention how local warnings will be issued, however Northland's may be included in their supporting documentation.

Standard Operating Procedures (SOP's)
Whether SOP's are mentioned or annexed. Applicable SOP's include those for warning systems, response and evacuation. Fourteen plans have SOP's as supporting documentation. Canterbury does not include SOP's, however they may be included in their district emergency management plans.

Public Warning Tests
Whether or not public warning systems are tested regularly. Warning tests were only mentioned in passing in seven plans, with no details in the plans on how these tests would be conducted. One plan (Hawke's Bay) includes an annex on warning tests. Four plans make reference to testing public warning systems, but do not include detail about how these tests will operate.

Monitoring of warning systems
Whether or not the warning systems are monitored after testing for their effectiveness. No plans provided details on how warning systems would be monitored, reviewed, and improved if necessary, and only two made reference to it in passing. This could technically be reviewed under the overall monitoring of the Plan as required under the Act.

CDEM Staff Training

Are staff trained in CDEM? Are there details on the format of this training? All plans mention staff training, with four plans providing details on training staff with specific responsibilities, and general training. An 'all hazards' approach to training is given in the plans.

CIMS

As noted in DGL 2/02, response arrangements included in CDEM Plans should also include the relationship between incident control and wider CDEM coordination. The Coordinated Incident Management System (CIMS) provides the model for command, control, and coordination of emergency response. It sets up a means of coordinating the efforts of agencies as they work towards the common goal of stabilising an incident. Integrated with readiness, the response to an event should be pre-determined with each agency knowing their role, i.e. for evacuation and warnings.

Having the CIM's framework in place as part of readiness to considered to be an important part of preparedness for any event. All plans mentioned CIMS, with the Taranaki plan the only one to provide details.

Public education

Most reference to public education was at an 'all hazards' approach, and no details were given as to what subject was to be promoted, who the intended audience was, when it would happen, or in what format. Five plans (Auckland, Waikato, Taranaki, Wellington and Otago) did have public education supporting documents.

Reduction/Pre-event mitigation

Two plans did not include pre-event mitigation/reduction measures, while the other plans mentioned reduction in passing. This was only in a very general sense and with no specific details of what these mitigation measures could be. It was mostly managed through an 'all hazards' approach. One plan (Otago) may include details in supporting documentation.

Other regional/local agencies mentioned

The CDEM Act lists a number of agencies that must be involved in CDEM Group arrangements (Section 20 of the Act). This category highlights whether these and other agencies are mentioned, and if details are provided on what their roles are, contact information, and which are the lead agencies.

All plans mention other agencies, but some only to the degree as required under the Act, with no further detail of their actual roles and responsibilities. Nine plans outline other agencies roles and responsibilities in detail.

Inter-agency communications
This category summarised the formal communication paths between the numerous agencies, such as specific committees and their membership.

All plans (excluding Taranaki) included the required linkages as specified in the CDEM Act, in particular in regard to the Coordinating Executive Groups (CEGs). Some plans also included other linkages such as those to engineering lifelines, CDEM Organisation Forums, and the Combined Emergency Services Coordinating Committee.

Evacuation
Being ready to evacuate is an integral part responding to warnings. This category reviewed evacuation procedures; whether they were mentioned with details, such as who was in involved and what their roles were, or whether it was just referred to with no details. Most plans included details of evacuation procedures, with two plans having further information in annexes (Bay of Plenty and Gisborne). Two plans did not mention evacuation details – Manawatu-Wanganui and Nelson Tasman.

Media Management
This category examined whether the Plans included a media management plan or strategy for managing the media prior to and post-event. Three plans did include media management: Gisborne, Canterbury and Southland. Three plans did not have media management in place (Manawatu-Wanganui, Nelson Tasman, Marlborough), and three plans only mentioned them in passing. Seven plans annexed their media management plans.

It should be noted, however, that many Groups intend to complete a media management plan in their future work plans.

5.3 CDEM Group member arrangements beyond the Group Plan

Arrangements specifically for, and affecting, tsunami are also held at Group and sub-Group level, which are not directly referred to in the Group plan texts as summarised in Section 5.2. In order to capture these arrangements, structured interviews with representatives from all 16 CDEM Groups were conducted in person (3) and over the telephone (13). They were taped and transcribed to record all details reported. Questions and a summary of the results are in Table 5.3. Discussion of the key components that varied amongst, and were common across, the Groups is given in the following sections.

Table 5.3 Arrangements for tsunami response beyond Group Plan, including plan-supporting documents (see Section 5.3.3 for the definitions used)

	Early Warning System: Regional Components									***Planning***										***Communications***			***Education etc.***				
CDEM Group Plan	**Who in Group receives warning**	**Where warning comes from**	**Proportion of time can receive warning**	**How warning is received**	**What is done with warning**	**Who is contacted once warning received**	**Tsunami warning hardware**	**Tsunami warning hardware testing**	**Arrangements for getting info to public**	**Sub-group-level plans**	**Sub-group-level plans were last reviewed**	**Tsunami warning decision preplanning**	**Inundation or evacuation mapping**	**Evacuation decider/ manager**	**Role of police**	**Role of Fire Service**	**Role of other key organisations**	**Arrangements for giving "all-clear"**	**Tsunami warning SOP's**	**Communications with other regions**	**Media/ communications plans**	**Arrangements with radio station(s)**	**Tsunami warning public education**	**Tsunami training**	**Awareness/ monitoring research**	**Tsunami-related signs exist**	***Tsunami warning simulations***
Northland	wg	wg	wg	wg	wg	wg	-	-	wg	**wt**	-	-	-	wg	wg	wg	p	p	-	-	wg	og	-	-	*	-	Wg
Auckland	wg	wg	wg	wg	**wt**	**wt**	-	-	og	-	-	**wt**	**wt**	og	p	-	wg	-	**wt**	wg	wg	og	wg	wg	*	-	Wg
Waikato – to meet	wg	wg	wg	wg	wg	wg	wg	wg	wg	**wt**	2005	-	-	wg	wg	wg	wg	-	**wt**	og	wg	wg	ot	wg	*	-	Wg
Bay of Plenty	wg	wg	wg	wg	wg	wg	-	-	wg	**wt**	2004	**wdl**	-	wg	wg	wg	wg	-	-	wg	wg	wg	-	-	*	-	Wg
Gisborne	wg	wg	wg	**wd**	**wdl**	**wdl**	**wd**	og	**wd**	**wdl**	2004	**wdl**	**wd**	**wd**	**wd**	**wd**	**wd**	-	**wdl**	-	og	od	old	**wl**	* +	-	Od
Hawke's Bay	**wt**	wg	wg	**wd**	**wt**	**wt**	wg	wg	**wt**	-	-	wg	-	**wt**	**wdl**	**wdl**	**wdl**	ot	**wt**	-	wg	wg	**wt**	wg	wg *	-	Wg
Taranaki	**wd**	**wd**	og	wg	wg	wg	og	-	wg	-	-	-	-	wg	pg	wg	wg	pg	**wt**	-	wg	wg	wg	-	* +	-	Wg
Manawatu-Wanganui	wg	wg	wg	wg	wg	wg	wg	wg	wg	**wt**	2005	-	-	wg	wg	wg	wg	-	-	-	wg	og	wg	-	*	Y	Wg
Wellington	**wdl**	**wdl**	wg	og	**wdl**	**wdl**	wg	wg	wg	**wdl**	2005	ot	**wdl**	wg	wg	wg	wg	og	**wdl**	wg	wg	ot	**wt**	-	* +	Y	Wg
Marlborough	wg	wg	wg	wg	og	og	og	og	ot	wg	In rev	-	**wt**	og	og	og	p	-	-	wg	wg	og	wg	-	-	-	Wg
Nelson / Tasman	wg	wg	wg	wg	wg	wg	og	-	p	-	-	-	-	wg	og	og	-	-	-	-	wg	og	wg	-	-	-	Og
West Coast	og	og	wg	wg	p	og	p	-	wg	-	-	-	-	wg	og	p	wg	-	-	wg	wg	wg	wg	wg	-	-	Wg
Canterbury	wg	wg	wg	wg	**wd**	wg	wg	wg	wg	**wd**	2005	-	**wt**	**wt**	**wt**	ot	wg	-	**wd**	wg	wg	og	wg	-	* +	-	Wg
Otago †	wg	**wt**	**wt**	**wt**	**wt**	**wt**	wg	wg	wg	**wdg**	2005	**wt**	**wt**	wg	wg	wg	wg	og	**wd**	-	wg	**wt**	**wt**	**wt**	*	-	Wg
Southland	wg	wg	wg	wg	**wt**	og	og	og	**wt**	wg	2005	**wt**	-	wg	wg	p	p	pg	**wt**	-	wg	wg	og	-	*	-	Wg
Chathams	**wt**	**wt**	wg	**wt**	**wt**	**wt**	wg	og	wg	N/A	N/A	**wt**	**wt**	**wt**	wg	wg	wg	wg	**wt**	-	og	og	wg	**wt**	-	-	Wg

5.3.1 Limitations of the survey

The survey was conducted at a regional level, and endeavoured to capture arrangements at a territorial authority level where these were different to the regional arrangements. The scope of the report did not include full surveying of all territorial authorities, so some specific arrangements may have been omitted. Within the scope of this report it was not feasible for the authors to review all supporting documents (numbering at least in the hundreds). Therefore surveying those at regional level with knowledge of the supporting documents was conducted. As such there will always be some variation in the understanding of the meaning of a question by the person being interviewed, especially when many of these questioned arrangements are potentially complex and varied within themselves. Therefore, two regions with a similar arrangement on paper, or in reality, may have been recorded as having different types or levels of arrangement as a result of the survey.

5.3.2 Arrangements surveyed

5.3.2.1 Early warning system: regional components

Who in Group receives warning
Pre-arranged name or position of the person(s) within the CDEM Group that is/are responsible for receiving a tsunami warning (official warnings are only 'received' for distant-source at present)

Where warning comes from
Pre-arranged source for tsunami warnings

Proportion of time can receive warning
Arrangement for the proportion of the time the CDEM Group can receive a tsunami warning.

How warning is received
Arrangement listing by which methods/equipment a tsunami warning is received.

What is done with warning
Arrangement(s) for actions on, and/or dissemination of, a warning that has been received by the CDEM Group.

Who is contacted once warning received
Pre-arranged name or position of the person(s) within and beyond the CDEM Group that is/are contacted once the Group has received a tsunami warning.

Tsunami warning hardware
Arrangements detailing what public notification hardware exists and can be used for tsunami warnings within the CDEM Group's region.

Tsunami warning hardware testing
Arrangements dictating how and when tsunami public notification hardware is tested for reliability.

Arrangements for getting info to public
Arrangements for using public notification hardware, and any other mechanisms, to get tsunami warning/evacuation information to the public.

5.3.2.2 Planning: tsunami warning arrangements

Sub-group-level plans
Whether the region has multiple CDEM plans below the Group plan, most commonly these take the form of regional/city CDEM plans.

Sub-group-level plans were last reviewed
When sub-group-level plans were last reviewed.

Tsunami warning decision preplanning
Preplanning for decisions that will have to be made in the event of a tsunami warning. These might include flow-diagrams for decision making, source or wave thresholds that trigger evacuation, zones evacuated at specific thresholds, time periods for uncertainties that will still trigger actions.

Inundation or evacuation mapping
Maps of: potential inundation areas, these may simply be zones below specific elevations above sea level; evacuation zones using a more complex criteria; evacuation routes; tsunami-at-risk facilities. Also an education tool.

Evacuation decider/ manager
Who (organisation or individual) who decides whether an evacuation should take place. This may vary depending on circumstances.

Role of police
Arrangement detailing the role of the Police in a tsunami warning/evacuation.

Role of Fire Service
Arrangement detailing the role of Fire Service in a tsunami warning/evacuation.

Role of other key organisations
Arrangement(s) detailing the role of any other key organisations in a tsunami warning/evacuation.

Arrangements for giving "all-clear"
Protocols and criteria for disseminating a warning-cancellation or –cessation message.

Tsunami warning SOP's
Standard Operating Procedures for operation in a tsunami warning. Generic SOP's that can be applied to tsunami are not noted here, because the relevance to tsunami varies highly between the different types of generic SoP (e.g. welfare SoP vs. emergency operations centre SoP). While some regions reported the existence of tsunami-specific SOP's, the quality and number of these have not been reviewed.

5.3.2.3 Communications, relationships

Arrangements for communications with other regions
Arrangements for communication with other regions, or organisations, during a tsunami warning. No regions noted specific arrangements for fostering and/or maintaining inter-personal relationships.

Media/ communications plans
Arrangements for communication with the media and public, both for outgoing messages and handling incoming inquiries.

Arrangements with radio station(s)
Arrangements for broadcast of tsunami warning/evacuation information via radio stations.

5.3.2.4 Education, staff training, maps and signage

Tsunami warning public education
Arrangements for public education of tsunami hazards, risk and/or components of an effective tsunami warning system.

Tsunami training
Arrangements for training CDEM Group and/or other personnel in relation to tsunami warnings.

Inundation or evacuation mapping
Arrangements for the preparation and possibly use of maps of: potential inundation areas, (in many cases these were simply be zones below specific elevations above sea level); evacuation zones using a more complex criteria; evacuation routes; and/or tsunami-at-risk facilities.
Note that maps are also a planning and public education tool in their own right.

Awareness/ monitoring research
Arrangements for effectiveness-monitoring of any or all components of an 'effective tsunami warning system.' For public education this would include public awareness monitoring; for simulation exercises (which test a range of components of an effective system) this would include observer reporting.

Tsunami-related signs exist
Arrangements for the existence, and possibly maintenance, of tsunami hazard, warning system, and/or evacuation signage.

5.3.2.5 Simulation exercises

Arrangements for tsunami warning simulation exercises.

5.3.3 Codes used in arrangements matrix (Table 5.3)

(w)ritten, or (**o**)ral, or (**p**)erception	W, O, P
(d)istant and/or (**l**)ocal, or general-(**t**)sunami, or (**g**)eneric	D, L, T, G

For example:

'wg' indicates a generic written arrangement that could be applied to tsunami

'**ot**' indicates a general-tsunami oral arrangement (no distinction of local- vs. distant-source)

'**wdl**' indicates written distinct arrangements for distant and local tsunamis.

'-' indicates no arrangement given

'*'indicates participated in the 2003 Coastal Survey (includes tsunami public awareness) (see Section 8.2)

'+' indicates additional public awareness research has been conducted, but is not planned on a regular ongoing fashion.

Bold contain general-tsunami, distant and/or local details

Under 'tsunami-related signs exist' 'Y' indicates that signs do exist somewhere in that Group's region, 'N' indicates that they do not.

'†' The Otago CDEM Group Territorial Authorities (TAs) maintain their own separate plans. Those documented here are of Dunedin City; Dunedin is contracted to provide planning direction for the group, but it is unclear as to whether or not the other Otago TAs have implemented these specific arrangements following Dunedin, as they did not reply to enquiries.

5.4 Summary of regional arrangements for effective tsunami warning systems

This section summarises the combined results of the three reviews conducted and presented in Sections 5.1–5.3.

5.4.1 Research

Groups without comprehensive effective warning arrangements consistently made it clear in interviews that they want to understand their risk better, before implementing such arrangements.

Variable types and scope of tsunami hazard research have been conducted at a regional level (Appendix 7).

Some regions requested national assistance in determining risk, and guidance on what early warning message(s) to expect and how to prepare for them.

Public awareness and simulation monitoring has been conducted by only some regions, sporadically over time.

A standardised regional public awareness survey was conducted in 2003 across many of the CDEM Group regions. The results are presented and discussed in the context of public education in Chapter 8. This is the only public awareness monitoring for tsunami that has been conducted by most regions.

5.4.2 Early warning system: regional components

Regions consistently have a written arrangement for generic warnings coming from MCDEM, to documented person(s) or named position(s), 24 hour 7 days a week, via a documented set of channels (hardware is described). Only some regions note specific tsunami warning receipt procedures.

Warning receipt and notification hardware, documentation of its usage, and any testing varies across the country.

Once an early warning has been received the list and order of those contacted varies between regions.

The existence of public notification hardware (e.g. sirens), documentation of its usage, and/or whether any testing of the hardware is done, varies between regions.

5.4.3 Planning: tsunami warning arrangements

Sub-group-level planning (e.g. district level) exists on only some regions.

Preplanning for decisions does not yet exist in most regions. They expect to decide on actions once an early warning has been received, including identifying criteria or thresholds to be used to decide on evacuation.

There are no full written tsunami-specific arrangements for the 'all clear' documented at a regional level. This is important to rescue, and controlling evacuation.

Evacuation zones have not been drawn in most regions.

In a declared emergency the CDEM Group was stated by almost all regions as responsible for deciding on evacuation, with variability between the CDEM Group and Police being responsible for managing that evacuation. All agreed that the Police are able to decide on and manage evacuations if an emergency is not declared, but that would be an unlikely scenario.

Police also have statutory roles, especially in maintaining law and order and transportation routes.

The roles of Fire Service and other agencies are mostly perceptions or oral agreements.

Some regions have SOP's for tsunami hazards.

5.4.4 Co-operation, discussion and communication

Only some regions have generic communication links with other councils, and/or external agencies (other than CDEMG members).

All regions have arrangements with Radio stations that vary from 'memorandums of understanding' to oral agreements.

Media communications and enquiry plans exist or are being developed in all regions, but sit as documents with varying detail, and most are generic.

5.4.5 Education, staff training, maps and signage

Public education methods and content vary across regions. Content is mostly all-hazard with tsunami covered in 'hazard descriptions' sections of some material. Only a few regions have specific tsunami public education initiatives.

There is almost no training in place for tsunami-specific procedures.

Some regions mention tsunami as part of generic hazard training.

Signs are only present in Tararua (Manawatu-Wanganui region) and Masterton district. Additional regions have discussed signage within the CDEM Group, with some of these having put the proposal to council. Council support has so far been variable within those regions/districts.

The CDEM Groups surveyed consistently stated that the want national direction on signage**.**

5.4.6 Exercises

Regional simulations (a requirement for all regions) are generally annual, documented as such in the plan, and role through a range of hazards. All are multi-organisational, and some have evaluation from external agencies with this feeding this back into planning.

6.0 COMPARISON OF CURRENT ARRANGEMENTS FOR WARNINGS TO TSUNAMI RISK AT REGIONAL LEVEL

In this chapter we compare the regional arrangements for tsunami preparedness with the levels of risk identified in the Science Report (Berryman, 2005) region-by-region. To do this we look at both multiple fatalities and individual risk. Multiple fatalities have already been discussed from a national perspective in Section 3.1. They are also an important consideration at local level in terms of the impact on a given community, although our analysis is limited to numbers of fatalities rather than percentage of populations affected.

6.1 Summary of regional risk

Fig. 6.1 shows risk in terms of fatalities in a single event for each centre as a function of likelihood, expressed as return period. This figure immediately shows the regions with the highest risk of multiple fatalities and, as expected in view of the picture of national risk, the risk is very high compared to other natural hazards. It must be stressed, however, that these data do not include the positive effect that current warning systems may have.

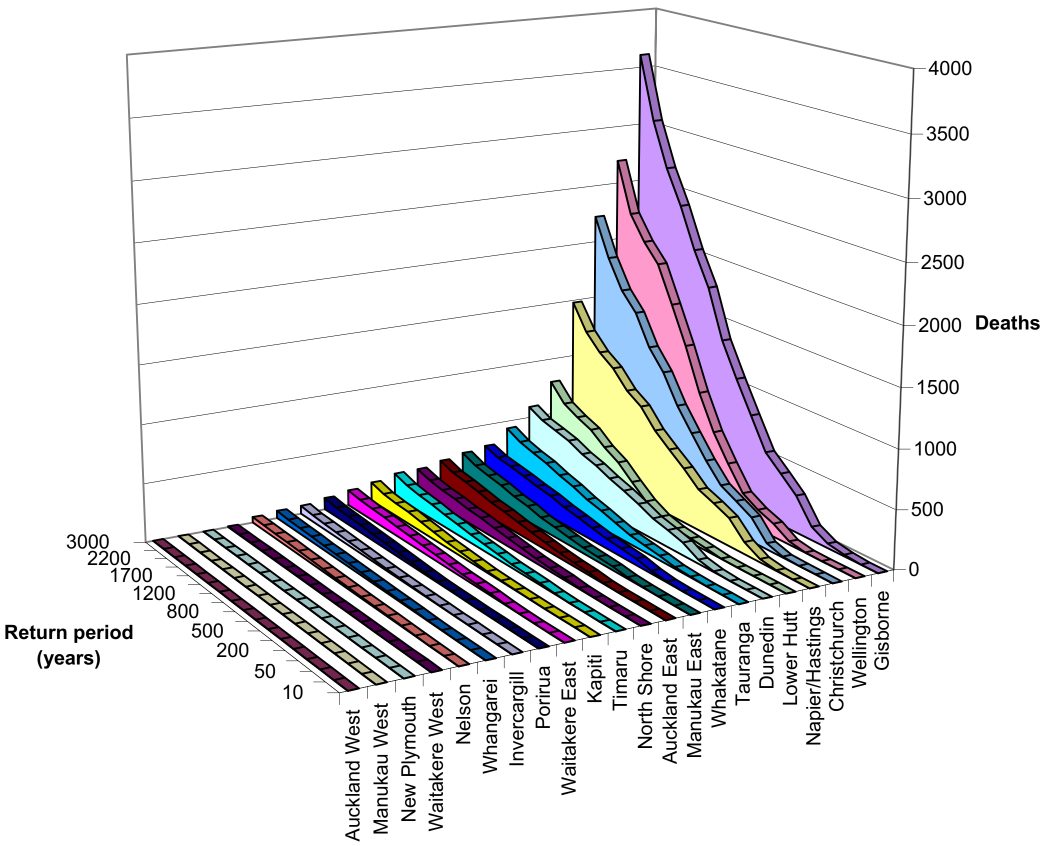


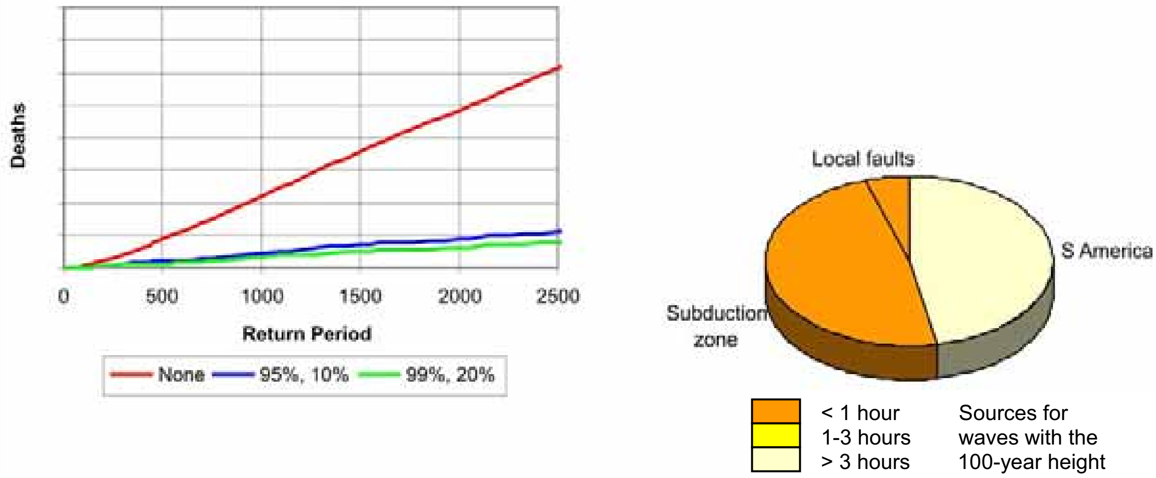
Figure 6.1 Tsunami fatalities in a single tsunami event for New Zealand cities compared to the return period of that event (likelihood), with no warning system effectiveness.

A further limitation of this analysis, already mentioned in Chapter 3, is that the figures for multiple fatalities are really indicative of a night-time situation when people are in their homes. Likely fatalities during the day are expected to be lower as many people will be working in CBD areas, many of which are less exposed than areas of coastal housing. For individual risk, however, we have halved the computed risk value so that the figures quoted are more representative of an average situation. Neither multiple nor individual risk figures take account of holiday periods when people are away from their homes. At these times there will also be heightened risk at popular beachfront holiday locations, again not accounted for in the relatively simple models that were required for this project.

In Appendix 8 we briefly present and discuss the level of multiple fatalities for each centre studied and, for each region, comment on warning system arrangements in terms of the need for distant-, regional- or local-source warnings to achieve good risk mitigation. Fig. 6.2 shows a sample region, with the graph showing the reduction in median expected deaths due to two estimates of the effectiveness of a warning system. The table lists the median and 84th percentile estimates of annualised personal risk at 2m and 4m above mean sea level for those living at the foreshore (i.e. worst-case). The colour coding in the table identifies Taig's risk ranges, as described in the accompanying Science Report (Berryman, 2005; Table 9.2). The relationship between multiple fatalities and individual risk varies between regions because the multiple fatality calculation takes account of topography, while individual risk is for an assumed elevation at the foreshore.

The pie chart shows the sources and colour-coded travel times to each particular location for waves at the 100-year height. For the graph and table the term "distant" refers to the New Hebrides and more remote sources, and the term "local" to all closer sources. The pie chart colour-codes the sources within approximately 1 hour travel time of the particular location, the ones between 1 and 3 hours, and more distant sources.

In light of the regional-level analysis, Gisborne, Napier, Wellington, Lower Hutt, Christchurch and Dunedin can have over 500 fatalities in a 1 in 2500 year likelihood event, assuming zero warning system effectiveness. Christchurch and Dunedin can reduce multiple fatalities greatly through effective warnings of distant- and regional-source tsunami. While the other centres listed above can all reduce the level of multiple fatalities with effective distant-source warning systems, they are left with significant residual risk from local sources, which will require mitigation through a range of measures. Foremost in this will be public education to improve response to local events through self evacuation.



	Elevation:	2m	4m
None	84%	1.0×10^{-3}	7.0×10^{-4}
	50%	5.0×10^{-4}	2.0×10^{-4}
effective 95% distant, 10% local	84%	5.0×10^{-4}	2.0×10^{-4}
	50%	1.0×10^{-4}	5.0×10^{-5}
effective 99% distant, 20% local	84%	3.0×10^{-4}	2.0×10^{-4}
	50%	1.0×10^{-4}	5.0×10^{-5}

Figure 6.2 A sample of data presented for each regional centre in Appendix 8 showing deaths as a function of likelihood with and without effective warnings, a table of individual risk, and a pie chart showing source contributions colour coded by travel time.

As mentioned in Section 3.2, individual risk is a useful measure at local level because of the availability of other comparative risk data. In Appendix 8 we briefly comment on the levels of individual risk, both with and without effective early warnings at the levels specified.

In light of the regional-level risk analysis, Gisborne is the only centre where current individual risk is clearly intolerable. Even with our scenario warning system effectiveness, individual risk in Gisborne is intolerable if people are not informed. The significant local-source risk again means public education about local-source events will be an important component of risk reduction.

Napier/Hastings, Kapiti, Porirua, Lower Hutt and Wellington are all centres where individual risk, with or without effective warnings, are at intolerable levels if people are not informed. Of these centres, few people are exposed in Kapiti and Porirua but, as mentioned above, significant multiple fatalities can occur in the other centres.

6.2 Distant-source vs. local-source warnings

In the region-by region analysis (Appendix 8) we discuss the required balance of distant-, regional-, and local-source warning systems. A way of portraying this at the national level is shown in Fig. 6.3, whereby one can derive the likely annual death rate based on assessment of the effectiveness of distant-source versus local-source early warning systems. The purpose of Fig. 6.3 is mainly illustrative, the aim being to stress the importance of having both components operating effectively to achieve a high level of risk reduction in regions where both distant and local sources are important.

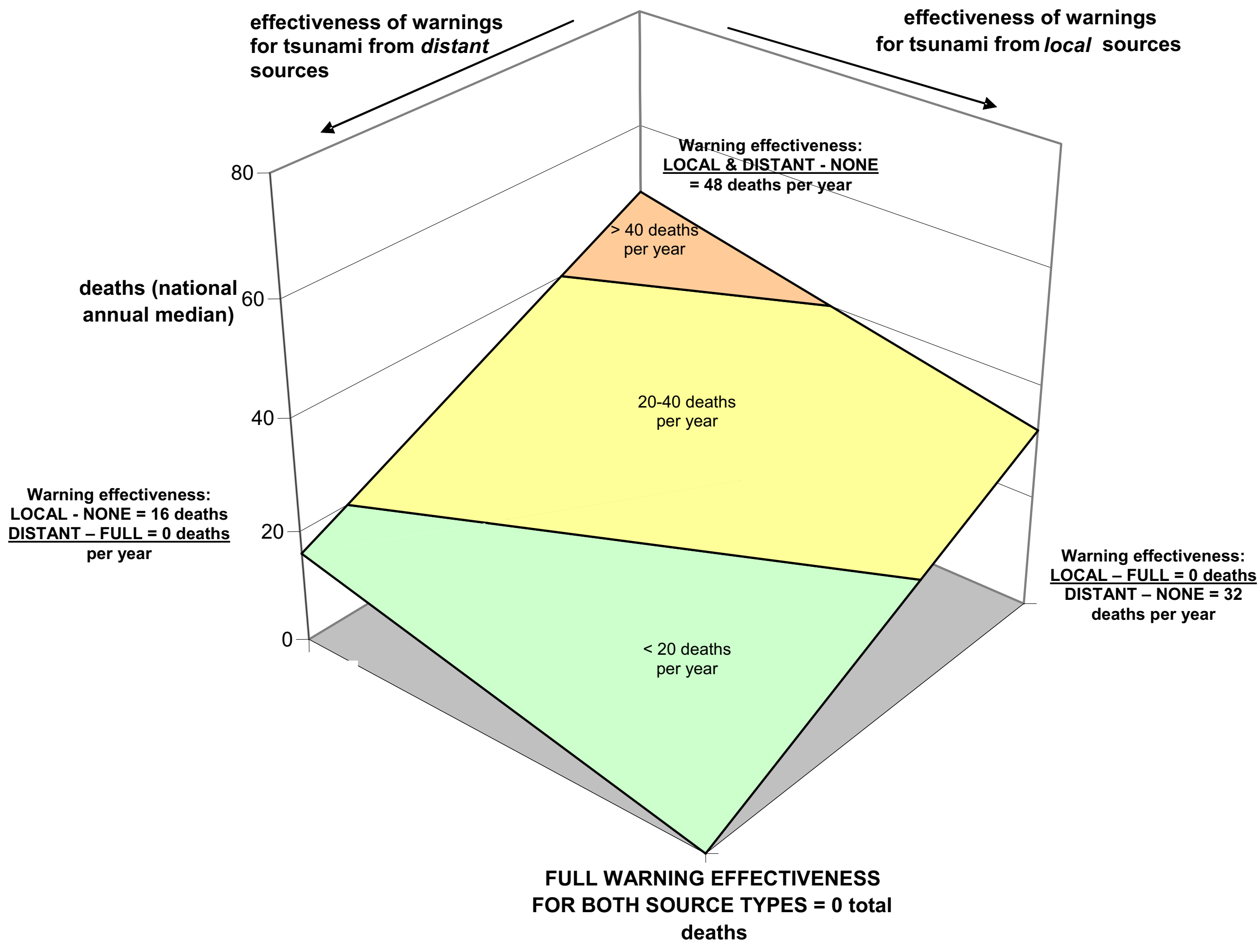


Figure 6.3 Likely annual death rate based on an assessment of the effectiveness of distant-source versus local-source early warning systems.

6.3 Effectiveness of the tsunami warning system at regional level

Fig. 6.4 summarises regional-level preparedness as determined from group plans, documents beyond group plans, and structured interviews. The figure shows that there is a lack of even generic arrangements for many components of an effective warning system. There is a general lack of tsunami-specific arrangements which we regard as necessary except for a few components such as the arrangements for the receipt of warnings. It is preferable that regions separate relevant local-, regional-, and distant-source arrangements to achieve effective warnings. This has not been done by many regions yet.

Furthermore, the existence of tsunami-specific planning does not necessarily indicate that that planning is appropriate in terms of effective warning response, or relative to the risk. The planning needs to be based around the correct assumption of risk, especially in terms of evacuation zones.

In Appendix 8 we briefly discuss the status of these arrangements as part of the region-by-region risk discussion.

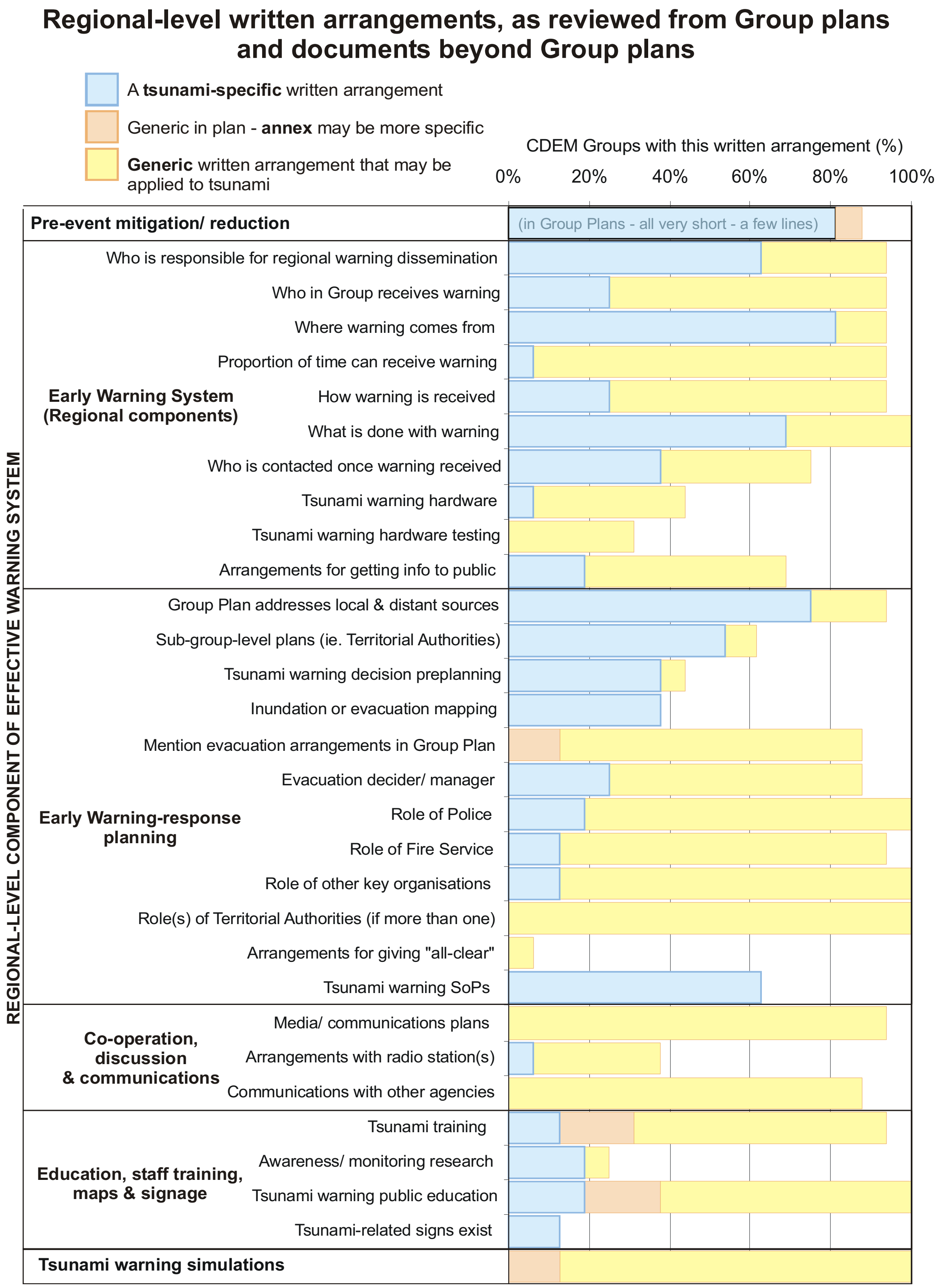


Figure 6.4 Regional-level preparedness as determined from CDEM Group Plans, documents beyond Group Plans, and structured interviews.

7.0 RECOMMENDATIONS FOR PROCEDURES FOR BETTER TSUNAMI RISK MANAGEMENT AT REGIONAL LEVEL

In the previous section we identified that many regions have intolerable and unacceptable levels of risk at regional level as well as at individual level. We also identified that many regions do not have arrangements to the preparedness level required for all the components of an effective tsunami warning system (Fig. 6.4). This section recommends actions and guidelines to address the shortcomings in preparedness compared to risk.

In **theory**, all tsunami risk can be mitigated through land-use planning. A range of landuse planning tools are available (detailed in Section 7.7), and are commonly used in some areas of the world to reduce tsunami risk (Eisner, 2005). However, due to a public desire to use coastal areas and the relatively long return period of damaging tsunami, regulations and land-use planning are in reality unlikely to provide effective mitigation for the entire risk. An effective warning system and other mitigation options, such as protection and adaptation, are required to addresses the residual risk through a layered defence. We discuss these other options in Section 7.3.

To facilitate the warning system discussion we look briefly at early warning systems for distant-, regional- and local-source tsunami in turn, as the requirements vary with the warning time available. However, many of the components of an effective system beyond early warnings are common to all tsunami regardless of source. The sections below follow the five components of effective warning systems (as far as we have determined, from international examples, to be effective, Section 1.3): (1) Early Warning Systems (Section 7.1); (2) Planning (Section 7.2.1); (3) Co-operation, discussion and communications (Section 7.2.2); (4) Education, staff training, maps and signage (Section 7.2.3), explored in detail in Section 8; and (5) Exercises (Section 7.2.4). These components must be underpinned by quantitative research and effectiveness evaluation, with research recommendations given in Section 7.6.

7.1 Early Warning System components

7.1.1 Distant sources

Section 6 indicates that many regions have a significant level of risk from distant-source tsunami. The relatively long time that is available to implement an appropriate response means that the risk can be reduced or eliminated with an effective warning system. As indicated in Chapters 3 and 4, there are currently significant issues in the National Warning System procedures with regard to shortcomings in the content of the warning messages. They do not currently provide CDEM Groups with the information they expect and require in a distant-source warning situation. This limits Groups' ability to respond appropriately to a warning message and also to plan for response.

Currently, the majority of CDEM Groups expect to evaluate tsunami alert and warning information with expert advice as it is received, making decisions around evacuation, and even deciding what areas should be evacuated in most cases, at the time. Table 2.1 indicates that in the best possible scenario CDEM Groups will receive their first message within an hour of the potential tsunami-generating earthquake. As most sources are more than 10 hours travel time from New Zealand, it could be perceived that this allows sufficient time to develop a response. However, Section 2.1.1.1 indicates that there are many factors, such as new information from PTWC (earthquake magnitude upgrade, sea-level data) as well as the time of day that the tsunami will impact, which together could reduce the available response time by possibly several hours.

Recommendations 4.1–4.4 address the issues that CDEM Groups need to be better informed in a warning situation. They also address in part the issue that CDEM Groups require national support to better understand hazards and risks, and national guidelines on many aspects to help implementation of the other components that comprise an effective warning system and without which the early warnings will not be as effective as they should be.

Recommendation 7.1. CDEM Groups participate in identifying where national guidelines would be beneficial, and in developing and implementing national guidelines where appropriate for regional effective warning system components (Figs. 1.1 & 6.4), via a national working group. This working group include representation by (but not restricted to) MCDEM, CDEM Groups, scientific organisations, and key individual scientists.

While national guidelines will be of assistance in improving arrangements for many of the components of an effective warning system, which are recognised as inadequate in Section 6 and further discussed in subsequent sections of this chapter, many aspects that can be improved by CDEM Groups without waiting for national guidelines, for example, improved warning message receipt and dissemination protocols (see Section 7.1.3 onwards).

7.1.2 Regional sources

Chapter 6 and its associated appendix indicate that few regions have a significant level of risk from regional-source tsunami (such as Kermadec, S. New Hebrides). However, smaller population areas not included in the risk analysis, such as those in Northland exposed to S. New Hebrides arc events, could experience large tsunami (Berryman, 2005).

The short time that is available to implement an appropriate response at national level for regional events (see Fig. 2.5) means that the national arrangements for regional-source tsunami are not regarded as a formal warning system. However, on occasions MCDEM may issue warnings. Further, implementation of Recommendation 4.1 will mean that a national warning system for regional-source events will be put in place in the future, and CDEM

Groups will need to develop the means to appropriately respond and get information out to the public in a very short time frame. Whereas in the distant-source tsunami situation there is time to organise an evacuation of people to whatever level is required, the timeframe in regional-source tsunami means that people will need to know to self-evacuate to pre-designated and known areas with only minimal direction. This places many more demands on CDEM Group pre-planning.

7.1.3 Local sources

Section 6 indicates there are many regions have locations that have a significant and sometimes intolerable risk from local-source tsunami. The short time frame between the initiation of locally-generated tsunami waves and their arrival in coastal locations means that it is difficult to mitigate the risk with a national warning system. As discussed in Section 4.3, there is currently no formal national warning system in place for local-source tsunami for those locations nearest the source, and to implement one in the future requires considerable infrastructure development and expenditure. As indicated in Chapter 1, local-source tsunami (e.g. Hikurangi subduction zone earthquakes) also have the capacity to be significant at locations distant from the source. In this case, regional-source tsunami arrangements are applicable.

Mitigating the risk of a local-source tsunami at locations nearest the source requires an urgent and immediate response by people knowledgeable of the appropriate actions in response to natural warning signs (e.g. to move to higher ground, to higher stories in high rise buildings, or inland) to protect human safety. As was illustrated in a number of locations around the Indian Ocean on Boxing Day 2004, knowledge of natural warning signs can save lives.

Natural warning signs of tsunamis broadly include:

- earthquake shaking
- sea-level fluctuations
- various sounds that have been described as thunder, thunder-bolt, locomotives and helicopters

Given the potential significance of natural warning signs of tsunamis to alert the public and motivate appropriate action, it is vital that the level of public awareness of these signs is developed and maintained and people must be able to recognize when they are in a safe place versus an unsafe place (see Recommendation 7.2).

The constraints placed on effective removal of people from harm's way at locations nearest the source of a local-source tsunami and at locations distant from the source need to be recognised when developing CDEM Groups plans.

7.1.4 Message receipt protocols

The CDEM Warning System document requires that Group have 24x7 ability to receive and respond to warning messages including tsunami. Almost all groups have these in writing; most are generic, covering all hazards. It is uncertain as to whether generic arrangements are adequate for tsunami, and recognise the time frames for the various tsunami warning situations. Groups also need to have all of the communications channels in place to disseminate warning messages to response agencies and to the public (see discussion of effective public notification systems in Section 7.1.5 and of effective warning messages in Section 7.2.1.3).

7.1.5 Effective public notification systems

In this section and in following sections, many aspects of an effective warning system are discussed in relation to the review of regional preparedness described in Section 5. Effective public notification system form part of early warning systems.

Within New Zealand there is a wide variety of current and planned approaches It is frequently asked "What is the best system"? (Regional Councils, pers comm., 2005). There are a wide range of public notification systems available, most commonly including sirens and media announcements (Appendix 9). International research shows that the most-appropriate system will vary between communities and should be tailored around the specific nature of the location, society, and hazard (OEM&ODGAMI, 2001; Mileti, 2004; Sorensen, 2000). The audience will vary in terms of demography. The activities they are conducting when a notification is given will also be variable and may vary for the same person at different times. For example the notification needed for tourists in a motel will be different from that of a permanent resident on the street, or even in that same motel.

For the public notification system to be assured as reliable in the event there must be redundancy, permanently ongoing testing and maintenance, battery back up (OEM&ODGAMI, 2001; Darienzo et al, 2005; Gruntfest & Huber, 1989).

Cost has been found to be a major limiting factor in the scope and nature of systems implemented in the Pacific Northwest, USA [(OEM&ODGAMI), 2001 #8]. Effective systems require clear, concise and consistent signals and messages, with redundancy. Patchy response to the June, 2005 tsunami alert in the Pacific Northwest has been attributed to conflicting information and variable transmission vs. failure of signals [Biever & Hecht, 2005 #22].

Recommendation 7.2a. Decide whether there is a need for improvements to the warning message receipt and dissemination protocols in the various warning situation scenarios, and consider options for public notification methods discussed here and in Appendix 9, as well as any additional options that are identified by the national working group. Implement the most suitable options.

Recommendation 7.2a is the first of five recommendations to come under the umbrella of the broader recommendation to complete regional preparedness across all of the topics shown down the left column of Fig. 6.4 “Regional-level written arrangements, as reviewed from Group plans and documents beyond Group plans”, so that all the components of an effective warning system are in place. Decide whether generic or tsunami-specific arrangements are appropriate for each. Actions should be in line with national working group developed guidelines recommended above, where appropriate, and should consider the time frames and likely availability and content of warning messages.

Each recommendation under 7.2 relates to one of the five components of effective warning system and to the underpinning research and effectiveness evaluation (for example, 7.2a relates to Early Warning Systems). Recommendations 7.2b–g are given in the following pages at the end of the discussion to which they relate.

7.2 Other components of an effective warning system

7.2.1 Effective warning system planning

This section discusses key aspects of planning for effective response to tsunami early warnings, and then makes a recommendation for improvement.

7.2.1.1 Planning warning response thresholds

As noted in Section 7.1.1, the majority of CDEM Groups currently expect to make many decisions upon receipt of the warning message. It can be seen from historic evacuations that there is inadequate time during a warning event to develop a decision-making framework. A clear understanding of the information that will (and especially likely will not) be included in early warnings, and the uncertainty likely attached to this, is essential. Thresholds based around expected warning content, certainty and timing must be pre-determined. Evacuation zones, routes and destinations must also be pre-determined, as well as all of the logistical support planning needed to disseminate the evacuation order and complete the evacuation safely.

This must also contain clear written provision for giving a warning and evacuation cancellation, and/or an ‘all-clear’, with the thresholds and full planning for completing this.

7.2.1.2 Evacuation zone mapping and evacuation planning

Evacuation is deemed necessary by authorities when a perceived risk to human life or property reaches unacceptable levels. Research has highlighted the need for people living within high-risk areas to be made aware during preparedness campaigns of the likely need to evacuate in the event of a tsunami warning so that they are willing to move away if advised.

Defining such high risk areas in advance is essential for an effective evacuation. However, this step has only been undertaken in a few coastal areas in New Zealand for tsunami risk and is clearly one of the most pressing needs. The principal function of evacuation is to ensure that people move from a place of relative danger to a place of relative safety via a route that is itself free from significant danger. The destination as well as the route must be considered in the plan, as well as other options such as vertical evacuation. There needs to be careful coordination of the timing and conduct of an evacuation and this must be done in association with agencies who are assessing risk and ordering the evacuation, as well as those responsible for receiving evacuees or meeting evacuees at agreed upon locales.

If the evacuation of a hazardous zone is to proceed in an orderly manner, it is essential that people know where to go, and what route to take. Unless the risk to life is immediate and obvious, people may be reluctant to leave their homes or other places, including schools. Assurance must be given that the evacuated area will be monitored and remain off limits to unauthorized people and information that untoward behaviour (e.g., break-ins) in evacuated areas is not common (Tierney et al., 2001) must be provided.

In most communities, experience of large scale evacuations is minimal, and the logistical and social problems associated with such an action are substantial. Evacuation planning is an essential part of emergency management planning.

Evacuations usually involve four types of movement: 1) self-evacuation where people move out in their own vehicles or with friends/relatives; 2) movement of people who do not own or have access to private vehicles; 3) movement of people from institutions (e.g., jails, hospitals); 4) movement of people with special needs who require specialized vehicles. Emergency planning must make provisions for all types. Evacuation planning must:

- Designate the lead agency who will issue the evacuation order;
- Designate the agencies who will play supporting and receiving roles;
- Outline the roles and responsibilities of all the agencies involved;
- Identify the potentially dangerous zones to which or through which the population should not be evacuated;
- Identify the preferred evacuation routes and ways to keep them open under inundation conditions;
- Identify assembly points for persons who require transport for evacuation and public information pertaining to these;
- Consider the means of transport, traffic control, assistance and direction;
- Identify potential shelters and accommodation in refuge zones;
- Consider research findings and incorporate them.

Sheltering in place/vertical evacuation

In some locations evacuation may not the best option. Instead the appropriate response may be to vertically evacuate if adequately high refuge points are available.

7.2.1.3 Planning effective tsunami warning system messages

The issue of planning effective tsunami warning system messages is not specifically addressed in Fig. 6.4, but would be part of Tsunami Warning Decision Pre-planning, for which many Groups have no tsunami-specific arrangements. Research into the effectiveness of warnings system messages has been undertaken for several decades (Mileti & Sorensen 1990, Sorensen, 2000). Through this sustained social science research effort much is known about what makes warnings effective. Public response to tsunami warnings is most dependent upon the information provided by authorities during the event (Mileti 2004). The Partnership for Public Warnings (2003) concludes that an effective warning system messages should:

(1) be focused on people at risk;
(2) be ubiquitous;
(3) be capable of reaching people irrespective of what they are doing;
(4) be easy to access and use;
(5) not create added risk;
(6) be reliable;
(7) provide appropriate lead time so people can have a chance to protect themselves and
(8) generate authenticated messages.

Research has also highlighted the critical importance of the message itself (Mileti & Sorensen 1990, Mileti & O'Brien 1992). For warning messages to be effective they need to be clear and understandable; accurate; frequent; credible; specific to the situation of the recipient (and user) and give specific advice on what the effect will be and what to do to reduce the risk from the impending hazard event (Aguirre 2004, Mileti & Sorensen 1990, Sorensen, 2000). Even with a well designed and implemented system, delivering sound warning messages a number of factors may conspire to reduce its ultimate effectiveness (Aguirre 2004).

Human response to warnings has been found to relate to factors such as: age, ethnicity, gender, social status, previous experience of hazards and/or past warnings, proximity to the hazard, physical cues in the environment and responses of others receiving the same warning (Sorensen, 2000). The recipients of warnings may be from a number of user groups and have a range of needs, roles and responsibilities and thus respond in different ways (Aguirre 2004).

Groups with responsibilities to initiate measures to protect the public may include the emergency services, emergency management agencies, mass media, and industry users (e.g. tourism operators). The issue of whether or not to issue a tsunami warning is always a difficult decision. To develop capacity to respond effectively and make appropriate decisions by those with warning roles and responsibilities it is essential consideration is given to training, exercises and drills.

The at-risk public, who are often targeted recipients of warnings delivered by the fore mentioned groups, are not themselves a homogenous group. Differing subpopulations with our society (e.g. young, older, the poor, new immigrates, tourists, those in institutions etc) have differing levels of vulnerability and have been shown to respond in different ways to warnings (Aguirre 2004; Drabek 1994, 1996; Paton et al.1999).

Although research has consistently shown information provide during an event is the key to an effective response pre-event education is also important. There has been limited research into the role pre-event public education has in improving warning response (Sorensen, 2000) but the evidence supports that well design public education initiatives will increase response. The warnings and emergency public information during an event Mileti (2004) suggests that public education should at least address:

- Who will issue the warning message(s)
- What the warning message(s) could say
- How the warning message(s) will be issued
- What communication media will be used and how to access them

It is also important to include in each message:

- What should be done in response to that warning message

Recommendation 7.2b. Implement all planning components (Fig. 6.4) of an effective early warning system including: sub-group-level planning; decision preplanning; evacuation zone and route mapping; evacuation decision-making; roles of key response agencies; arrangements for giving the 'all-clear'; and tsunami warning SOP's for all three source-type (local, regional, and distant) warning scenarios.

7.2.2 Cooperation, discussion and communication

Fig. 6.4 shows that few CDEM Group plans have tsunami-specific arrangements for this component of an effective warning system. For effective response to early warning messages it is necessary to: (a) develop relationships for fast and trusted communication in a warning situation; (b) test communication channels (hardware and suitability of planning); and (c) overcome common high staff turnover (Galley et al, 2004).

Recommendation 7.2c. Develop pre-planned and exercised communication between central government agencies, local emergency management agency staff, scientists, media, and community representatives. Renewal of contacts must be regular and permanently sustained. Specific written arrangements with dissemination media (especially radio, but also Rural Fire, Surf Lifesaving etc.) are essential (MoUs) and should distinguish distant, regional and local sources.

7.2.3 Public education, staff training, maps and signage

Fig. 6.4 shows that few CDEM Group plans have tsunami-specific arrangements for this component of an effective warning system. Pre-event public education (detailed in Section 8) and event-imminent warning messages (Section 7.2.1.3) should not be confused (Mileti, 2004).

Public education through media releases, brochures/posters, meetings, internet resources etc. are critical to understanding of warning system details and the range of suitable responses (Mileti, 2004).

Training for emergency management, response and managerial staff must be regular and permanently sustained to overcome ongoing staff turnover. The actions of staff are a key determinant on the effective response of the public to an early warning system (Leonard et al, 2004).

Maps and signage are effective for both public education and effective response to a warning. University of Canterbury research is underway looking at New Zealand signage content. Signage has been shown to be critical in increasing public awareness of hazards and warning systems, and maximising effectiveness of early warnings (Dengler, 2005). Signs showing hazard zones, evacuation routes and safe zones (including key tsunami facts) should all be used. Permanently scheduled checking for replacement/maintenance is also necessary. Agreed and widely distributed evacuation maps are also a requirement for public awareness and effective warning response (Crawford, 2005).

Recommendation 7.2d. Develop regional public education (across all available/feasible media), staff training, maps and signage. Discussion to aid this process is given in Section 8. It must contain details for public-response to natural warnings of local-source tsunami.

7.2.4 Simulation drills and exercises

Fig. 6.4 shows that no CDEM Group plans have tsunami-specific arrangements for this component of an effective warning system. Simulation exercises are essential to maximise effective response to a warning system (Leonard et al, 2004; Galley et al, 2004). These test hardware, pre-planning and staff training, and involve practising the warning, decision-making and evacuation process in either a desk-top or full (sirens/loudspeakers activated, personnel deployed, people moved) way. To optimise their effectiveness they should be repeated, vary between desk-top and 'full', and preferably at least annual.

However, the frequency is a balance between positive maintained readiness and awareness, and any negative social disruption (see 'pros and cons' in Appendix 9).

Recent research in Hawaii (Gregg et al. in press) found that familiarity with the routine siren tests and test frequency has not greatly influenced levels of understanding of the meaning of the siren. Awareness of the siren tests and frequency was high, but understanding of the meaning of the siren was uniformly low. Furthermore, given the low level of relationship between awareness of tests and knowledge of appropriate actions when sirens are sounded (i.e., tune to a radio or television), the time frame for generating distal warnings may be inadequate, and leave only a few hours for facilitating appropriate behaviour in citizens.

Recommendation 7.2e. Develop and conduct on a regular ongoing basis regional exercising of tsunami warning effectiveness, including how these may tie in with national exercises.

7.2.5 Scientific research

The need for increased investment in scientific research at a national level is addressed in Recommendation 4.4. From a warnings systems perspective, effective tsunami warning systems must be underpinned by:

(a) Event research (for example the source and nature of tsunamis that effect a specific area);
(b) Impact research (for example hazard maps, asset catalogues, tsunami type and depth vs. loss relationships);
(c) Evacuation zone maps, evacuation planning, warning response thresholds; and
(d) Evaluation and improvement of warning effectiveness (this includes observing simulation drills, researching public awareness and evaluation the effectiveness of education initiatives).

This research must be done in a measured way and periodically updated in a permanently ongoing fashion, i.e. sustainable (Johnston *et al*., 2005; Gregg *et al*., (submitted); Crawford, 2005).

7.2.5.1 Tsunami process, hazard and risk research

Appendix 7 provides a summary to date of tsunami event research conducted at regional level. It can be seen from that summary that there is substantial variability in the amount and direction of event research conducted by each region, with no one region commissioning research comprehensive enough to fully understand the tsunami risk to their region.

7.2.5.2 Effective warning system methods research

As stated in Section 1.1 there is no single international best-practice for consistently effective tsunami warning systems. Social science research into making warnings maximally effective is ongoing. Some current key findings are noted above under sections of 7.2, and in Section 8.

Recommendation 7.3a. Incorporate new developments in effective warning system components and design into ongoing improvements of regional tsunami preparedness.

7.2.6 Effectiveness evaluation: public awareness of tsunami, simulation exercises

Without an understanding of the state of awareness and preparedness it is impossible to gauge what is and is not working in New Zealand's effective tsunami warning strategy, and there is, therefore, no way of informing improvements.

Effectiveness of difference information delivery methods needs to be evaluated within the context of each community. For example oblique image-draped hazard maps were found to be most readable in the island of Monserrat (Haynes *et al.*, 2004), whereas more traditional plan-view hazard maps were found to be the most understandable at Tongariro National Park, New Zealand (Coomer & Leonard in prep.).

Simulation exercises are an essential component of public education and staff training (Section 7.5). For these to be of longer-term benefit they must be externally observed in a quantifiable way. There must also be written procedures for discussion and incorporation of improvements from the observations into revised planning. In addition to full simulation exercises, more frequent hardware tests are needed to deal with equipment fatigue and failure and variability of audibility, due to environmental end equipment variation.

Recommendation 7.3b. Quantitatively evaluate the effectiveness of planning, public education, training strategies, simulation exercising and hardware reliability testing, feeding the results fed back as effective warning system improvements.

7.3 Wider mitigation options

Wider tsunami risk mitigation options are those aside from effective warnings systems, so relate to three main approaches (or combinations):

- *Protection (or defence)* — physical interventions such as the building of seawalls, rock revetments, beach and fore-dune nourishment with external sand or gravel, or building up vulnerable coastal roads or causeways;

- *Adaptation (or accommodation)* — dune and coastal vegetation restoration, plant or enhance coastal forests, re-create coastal/estuarine wetlands or marshes, raise and deepen foundations of dwellings, better tie-downs to foundation, open-up ground floors of engineered buildings;
- *Landuse planning* — range of land-use controls, plans and policies that will be different for new subdivisions (coastal green-field developments) or existing developments (e.g. managed retreat including engineering lifelines where possible, establishing coastal hazard zones).

These three approaches are consistently used in coastal hazard and climate change guidelines for local government in New Zealand and for that reason are adopted here. Under the RMA and NZCPS, the Landuse Planning and Adaptation approaches are preferred over Protection.

The document 'Designing for Tsunamis' by the U.S. National Tsunami Hazard Mitigation Program (2001) sets out seven principles for planning and designing for tsunami hazards, of which five relate to wider mitigation measures and are covered by the three approaches listed above. The other two principles relate to knowing the risk and planning for evacuation and are covered off in this and the Science Report.

A more extensive review of planning options for managing tsunami and other coastal hazards in the New Zealand context can be found in Bell *et al*. (2001) and Ministry for the Environment (2004).

7.3.1 Protection

Japan is the leading user of engineered protection measures such as high seawalls to reduce tsunami risks. Even so, they are increasingly becoming controversial, even on Okushiri Island where 4% of the population (198 people) were killed by a large tsunami in 1993. Anecdotal accounts of their controversial nature in Okushiri say that it is due to their imposing nature which cuts off sea views, and lowered awareness of and preparedness for tsunami risks due to the feeling of greater security. Other negative issues associated with their installation in Japan are reduced public access to the coast and reports of overtopping and failure of some walls.

Evidence from the building of river stopbanks is that they eventually increase risk because they enable people to build on former floodplains. That stopbanks will ultimately breach in a rare flood event is a given, because they are designed for an acceptable level of flood recurrence interval (balancing out economic burden and environmental impacts), beyond which the stopbanks will overtop. The losses in such events are then much larger than they would have been without protection (and the related intensification of settlement that followed). The parallel effect for tsunami may be somewhat different in that seawalls will cut down the volume of initial inundation in over-topping events, but may well exacerbate the momentum of the inundating torrent. Observations in Thailand of the behaviour of conventional seawalls during the Boxing Day tsunami graphically demonstrated the poor performance and failure from undermining of these structures during the out-rush after the first wave (Bell et al., 2005). Consequently, to design for large impulses on **both** sides of any tsunami seawall requires major engineering construction techniques as exemplifies by Japanese engineers. The main lesson is that any proposal to build seawalls needs to take account of engineering, environmental and societal issues.

In terms of dune and vegetation restoration, observations in Thailand and Sri Lanka after the Boxing Day tsunami suggest that healthy coastal dunes and greenbelts such as mangroves and coastal vegetation can significantly reduce the momentum where inundation depths do not exceed a few metres (Bell, *et al.*, 2005; Liu *et al.*, 2005). While working with nature's natural defences will be more acceptable to coastal communities, but the same issues relating to living with a false sense of security and higher losses in rare events may remain.

7.3.2 Adaptation

The New Zealand investigation team to Thailand in 2005 concluded that no changes to New Zealand building codes were considered relevant for mitigating vulnerability to tsunami (Bell *et al*., 2005), but they did recommend that land-use planning and emergency management requirements for low-lying areas should be reviewed, especially for essential facilities. In our view, stopping the development of desirable coastal locations will be extremely difficult, especially if the individual risk is within acceptable levels. However, incorporation of wider set-backs or coastal buffer strips into new developments along with coast-care projects will mitigate small to moderate tsunami. There remains though considerable areas of **existing** coastal development that is already subject to "coastal squeeze" from ongoing coastal erosion and sea-flooding hazards, now set in the backdrop of sea-level rise and associated climate change impacts. For some of these areas, managed retreat may be the only sustainable long-term solution to reducing the risk of coastal hazards including smaller tsunami events.

In terms of building design changes, some modifications could be investigated such as foundations and openness of ground floors of multi-storey buildings. In Thailand and Sri Lanka, ground failure/scouring often caused permanent damage to residential dwellings — a process that is inherent to a large degree building on unconsolidated sand or gravel. Pile foundations performed better, but then such foundations perform poorly for resisting lateral movement during earthquakes. In reaching their conclusions, the Thailand investigation team recognised that for large infrequent tsunami events, the prime focus must be on saving lives rather than modifying building design.

We have discussed wider mitigation options as part of the Terms of Reference for this report. Mitigation options will inevitably involve national strategies as well as local solutions.

7.3.3 Land-use planning tools

As discussed at the start of this section, land-use planning can provide a valuable set of tools to reduce vulnerability to tsunami hazards. This is most easily implemented in undeveloped areas and local government should give due consideration to avoidance and mitigation of tsunami hazards in planning for coastal locations. Fig. 7.1 shows the planning framework for hazards under the Resource Management Act. This can be used to reduce tsunami risk.

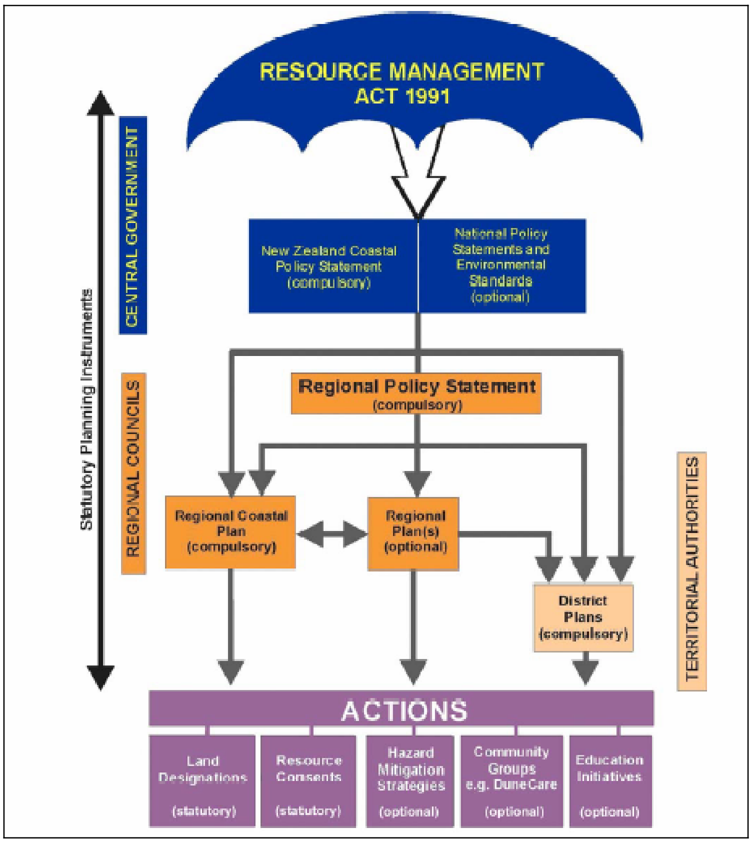


Figure 7.1 Hazard planning framework in New Zealand under the umbrella of the Resource Management Act 1991 (Bell *et al*., 2001; adapted from Environment Waikato, 1999).

7.3.3.1 Regional Plans

Regional Plans provide a tool for managing and reducing tsunami risk. The following points outline how the tsunami risk could be incorporated into Regional Plans:

- Where appropriate, identify the avoidance and mitigation of adverse effects of tsunami as a regionally significant issue.
- Define policies to address integrated management of effects of all relevant natural hazards in the region.

- Assess and define tsunami risk areas.
- Define policies to state how tsunami hazard will be addressed and by whom, including:-
  - The respective roles of regional and territorial authorities in a region for integrated management of tsunami hazards; and
  - A preferred management approach for avoidance or mitigation of adverse effects of tsunami hazards in relation to :-
    - Existing developed areas; and
    - New developments.
- Review effectiveness of policies and their implementation;
- Regularly review assessment of tsunami risk areas to factor in new data and information (e.g. 5–10 yearly).

7.3.3.2 District plans

At the district level, District Plans are the planning tool for managing and reducing tsunami risk. The following points outline how the tsunami risk could be incorporated into District Plans:

- Define policies to implement territorial authorities' roles provided for in regional plans.
- Define policies to implement a preferred management approach for avoidance or mitigation of effects of tsunami hazards in relation to both existing and new developments.
- Assess and define tsunami risk areas.
- Where appropriate, identify those tsunami risk areas on district planning maps.
- Review existing district plan provisions (rules in particular) to incorporate tsunami hazard information (e.g. reassess flood hazard areas, coastal erosion, and sea level rise; allow signage for emergency information purposes; etc).
- Develop appropriate methods (regulatory and non-regulatory) to implement preferred management approach (e.g. rules for subdivision, guidelines for new buildings, financial contributions for tsunami hazard mitigation works/services, etc.).
- Ensure location and design of key infrastructure and critical facilities in relation to tsunami risk areas are taken into account in planning decisions.
- Require resource consent applicants to provide information on tsunami-resistant designs or other mitigation measures for new developments within tsunami risk areas.

7.3.3.3 Long Term Council Community, Strategic, Community and Annual Plans (LTCCP)

Under the Local Government Act 2002, local authorities are required to identify community outcomes for the immediate to long-term future of their district or region every six years. The outcomes form the basis on which local authorities will develop their Long Term Council Community Plans (LTCCPs).

The community outcomes and LTCCP are intended to inform other planning functions undertaken by the local authority. Environmental outcomes from the LTCCP may inform and may be incorporated into policy statements and plans under the Resource Management Act 1991.

LTCCP's can incorporate tsunami risk reduction measures by the following points:

- Assess and identify the need for areas that should be open space or passive use (e.g. because of tsunami risk) and have a purchase programme for such land.
- Discourage the location and design of critical community facilities and infrastructure in areas at risk from tsunami when undertaking a new development.
- Consider redevelopment and resiting of community resources and infrastructure when due for renewal or replacement.
- Consult communities on desired outcomes for tsunami mitigation and preparedness strategies.

7.3.3.4 Assessment of Environmental Effects (AEE) and Development Plans (public or private sector)

An AEE is required for landuse consent applications, and must consider the effects and mitigation measures of an activity on natural hazards. The following provides how AEE's and development plans can incorporate the tsunami risk into hazard mitigation options:

- For resource consent requirements, ensure that comprehensive development plans and/or AEE's consider tsunami risk for all coastal developments.
- If development is permitted, locate and design structures (especially high occupancy buildings) to mitigate the effects of a tsunami.
- Consider additional mitigation measures for construction and design in tsunami risk areas (e.g. maintenance and enhancement of natural sand dunes; minimum floor heights and establishment of land-based evacuation routes).

7.3.3.5 Public Information

As well as regional and district plans and policies, the tsunami hazard can also be available to landowners via Land Information Memorandum (LIMs) and Project Information Memorandum (PIMs). Tsunami hazard information is also accessible to the public via hazard registers which are regularly maintained and updated by Councils, and web-based sources.

Recommendation 7.4. Consider the implementation of land-use planning tools and other layered mitigation options and regulations to reduce vulnerability to tsunami hazards at a regional level.

8.0 RECOMMENDATIONS FOR PUBLIC EDUCATION AS PART OF TSUNAMI PREPAREDNESS

This section reviews the state of tsunami education and assesses the role of education in increasing tsunami preparedness.

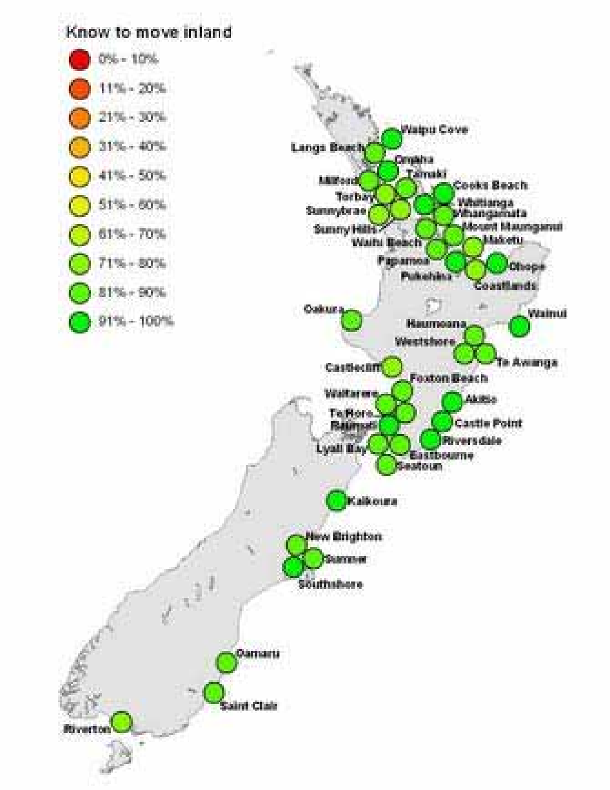
8.1 Introduction

New Zealand is exposed to a wide range of potentially devastating impacts from a range of natural hazards. Although New Zealanders have been subject to significant tsunami in the past (e.g., 1855, 1868 and 1960), we have had a calm period over the past 45 years. The fact that few New Zealanders have experienced disastrous tsunami is a good thing, in terms of their survival. The downside, however, is the resulting complacency and limited understanding of tsunami risk. However, it is clear that the 2004 Boxing Day tsunami in the Indian Ocean has significantly increased public awareness of tsunami risk in New Zealand. Our level of experience at individual, community and national levels in dealing with significant tsunami needs to be better understood if we are to develop effective risk management measures. The benefits of a better understanding of tsunami risk are found in increased support for risk reduction activities, increased readiness and response capability and an understanding of how to recover from events in an efficient manner. In building these capabilities we will reduce our economic exposure to future tsunami (and other natural hazards).

8.2 Summary of levels of awareness

From January to June 2003 a large-scale national survey of coastal residents and visitors in 41 coastal communities was undertaken to determine perceptions of, and preparedness for, coastal hazards (mainly tsunami and coastal erosion) (Johnston et al. 2003a; Johnston et al. 2003b). The aim was to build up a picture of the social dynamics at work in coastal communities and identify the key factors that link awareness with preparedness. Several key variables were measured derived from theoretically robust and empirically tested process model for preparedness (Paton 2000, 2003, Paton et al. 2001, 2003).

(a)



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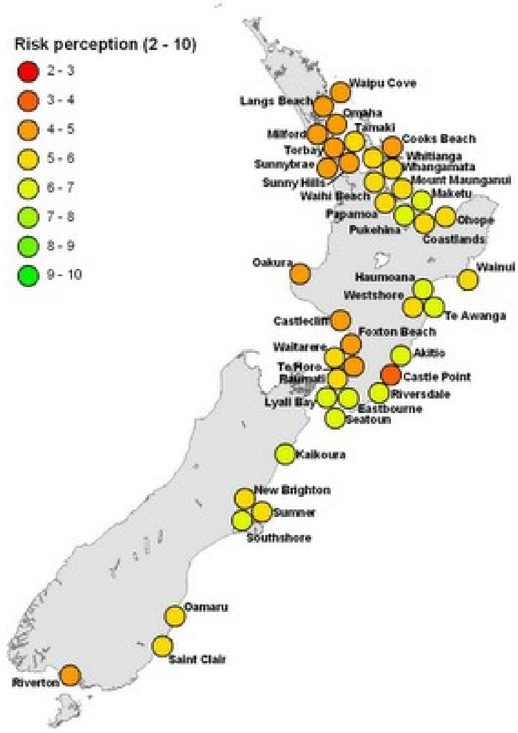

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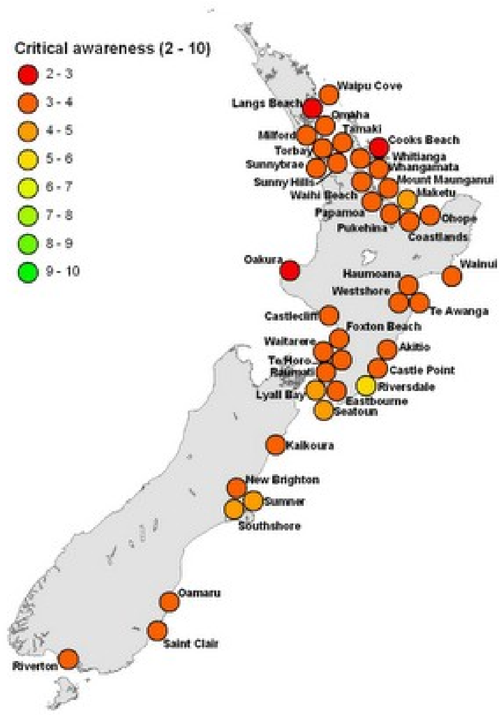

Figure 8.1 Levels of awareness of (a) correct actions to take in a tsunami (move inland), (b) risk perception, and (c) critical awareness, across New Zealand from the 2003 National Coastal Survey.

8.2.1 Tsunami knowledge

Awareness of the timing of the last tsunami to affect New Zealand was very low in most communities, with only a couple of exceptions. Only in Wainui, Whitianga and South Shore (Christchurch) were more than half of the respondents aware of tsunami affecting their areas within the last 100 years. In most cases "don't know" was the most common response. The average for "don't know" across all communities was 64%. Personal experience of tsunami and/or experience of damage and losses from tsunami were almost nil, with only few people reporting either.

Table 8.1 Means for the preparedness process variable from the 2003 National Coastal Survey.

Variable	Scale Min. – Max.	Highest mean	Lowest mean	National mean
Risk perception (Fig. 8.1)	2-10	6.8 Lyall Bay	4.0 Castlepoint	5.4
Critical awareness (Fig. 8.1)	2-10	5.2 Riversdale	2.8 Langs Beach	3.7
Outcome expectancy	2-10	8.1 Maketu	5.6 Castlecliff	6.3
Self efficacy	2-10	8.7 Castlepoint	7.4 Oamaru	7.9
Intention/information search	3-9	5.2 Maketu	3.6 Torbay	4.1
Responsibility	1-5	4.1 Riversdale	2.9 Torbay	3.8

8.2.2 Critical awareness and risk perception

The extent to which people discuss and think about hazards (termed critical awareness) has been shown to be an important precursor of readiness, along with risk perception (Paton et al. 2001). Critical awareness presented at low levels nationally (mean = 3.7, Table 8.1; Fig. 8.1).

A number of questions explored risk perceptions for tsunami. When asked to name the top hazard that could affect their communities in the future, only a minority of residents rated tsunami. However when asked about the timing of the next tsunami, around a third of groups had a majority believing tsunami were likely to affect their communities within their lifetime. Less than a quarter of respondents in any community believed a tsunami was likely within the next ten years. The national average was 11%. On the risk perception scale, national levels were low to moderate (mean 5.4, Table 8.1; Fig.8.1).

8.2.3 Outcome expectancy and self-efficacy

Belief that hazard effects can be mitigated by individual efforts (termed outcome expectancy) were recorded at moderate levels nationally (mean = 6.3, Table 8.1). Judgement regarding their capabilities to mitigate hazard effects (termed self-efficacy) also presented at moderate levels (mean = 7.9; Table 8.1).

8.2.4 Tsunami warning system

Knowledge of the New Zealand public tsunami warning system was assessed by asking people what made up the system. There was generally low awareness in the majority of locations, with over two thirds of people not knowing what made up the system. Of those who knew, radio and TV announcements were the most commonly cited, followed by sirens. A significant number of people in various locations reported loud speaker announcements and door to door visits from authorities.

When asked who is responsible for issuing warnings, the responses followed a similar pattern nationally. The order was local Civil Defence (63% on average), followed by police/fire (34% on average) and then Local Council (20%). Interestingly around 17% of respondents on average thought that NIWA and/or GNS were responsible - roughly equal to the figures for Regional Councils.

8.2.5 Response actions

Despite the low awareness of warning systems, there was a high awareness of the correct action to take (Fig. 8.1). When asked what actions people would take in the event of a tsunami warning, an average of 87% nationally said they would move inland. This was followed by an average of 62% saying they would listen to the radio and around half saying they would stay away. Few people cited 'don't know' as an option.

There were low levels of knowledge nationally about the response times people would have following a warning and following a strong earthquake. The most common response to the question regarding the amount of time people will have to move to safety after hearing the tsunami warning or feeling a strong earthquake was 'don't know'.

8.2.6 Intention/information searching

The intention to seek information is a consistent predictor of undertaking preparedness actions (Paton et al. 2003). Around a third of people had reported receiving or seeing tsunami information nationally, with less than 11% having asked for information. Fewer than 11% expressed any intention to seek tsunami information (mean of 4.1 in the intention/search scale, Table 8.1).

8.2.7 Overcoming barriers to preparedness

Tsunami are uncontrollable events; however, the effects of tsunami can be partly controlled in the sense that they are mitigated by preparedness. Some preparedness takes the form of building regulations and other legislation, but regulations need to be complemented by citizens' own preparation. Yet despite the risk, only a few citizens and businesses take the trouble to prepare for natural hazards. It is therefore useful to clarify psychological and social factors that contribute to a failure to prepare for tsunami and show how best we can overcome these obstacles.

8.2.8 Risk perception

Expert estimates of risk are based on objective analyses of the likelihood of hazard activity and its consequences within a specific area. It is common to find considerable disparity between these expert assessments and the manner in which they are interpreted and acted on by the public and other groups (including some councils) (Adams, 1995; Paton et al., 2005). This discrepancy sometimes remains even when people are presented with scientific information. People's understanding of risk and response to risk are determined not only by scientific information or direct physical consequences, but also by the interaction of psychological, social, cultural, institutional and political processes (Burns et al., 1993; Sjöberg, 2000). Factors affecting risk perception are usually not independent and vary between different hazards.

Beliefs about risk and risk reduction behaviour are also influenced by attributional processes (explanations about the cause of events) and intentional processes. Processes relevant here are "unrealistic optimism" and "normalisation bias" (Paton, Smith, & Johnston, 2001). Unrealistic optimism, sometimes referred to as the "illusion of invulnerability" is seen where people underestimate the risk to themselves and overestimate the risk to others (Weinstein & Klein, 1996). Thus, while people may acknowledge objective risk in their community, they are more likely to attribute its negative implications to others rather than themselves. This bias leads people to take risky options, and applies with judgments about tsunami and earthquakes, in that citizens think they are better prepared than others, which leads them to think that they will be safe (Helweg-Larsen, 1999; Spittal et al., 2005). This bias is difficult to change, but it can be affected by showing people lists of precautions that have been carried out by other people (Weinstein & Klein, 1996).

The normalisation bias results when people extrapolate a capability to deal with major hazards from a minor (objective) but rarely occurring hazard experience. Like the optimistic bias, this process results in people underestimating risk (relative to scientific and planning estimates) and acting in ways that, from an objective perspective, are counter-intuitive and counterproductive.

Denial of risk is a related bias that inhibits positive actions. Furthermore, denial is greatest among people who are most at risk, partly because denial serves to reduce anxiety. Denial can be reduced by people seeing that they have some control over a hazard.

The communication of risk information can have a distorting effect, particularly where risks with minor bio-physical consequences elicit extreme concern or significant risks are underestimated by communities and organisations. This phenomenon has been termed "the social amplification of risk" (Kasperson et al. 1988). Accusations of "irresponsible media", "organisational incompetence" and "public hysteria" are common (Rip, 1988). The problem arises when sources such as the media overemphasise adverse or catastrophic aspects of a problem and fail to provide a balanced view. It can also arise in situations where there is a lack of trust in information sources, particularly when these sources dismiss the concerns, needs and interests of the community.

An additional bias is a tendency to overestimate the capacity of hazard mitigation strategies to eliminate a threat through the operation of an interpretive bias known as risk compensation (Adams, 1995). This phenomenon has also been known as the levee syndrome. This construct describes how people maintain a balance between the perceived level of safety proffered by their environment and the level of risk manifest in their actions and attitudes. Thus, a perceived increase in extrinsic safety (e.g., hazard monitoring, structural mitigation) can decrease perceived risk (as perceived by an individual or group), reducing the perceived need for action. This becomes problematic because planners, in the process of engineering structural mitigation or disseminating information on their response role, assume that people's risk estimates, and thus their behaviour, remains constant. This assumption is unfounded. The dissemination of information on structural mitigation has been found to lead to a reduction in levels of household and personal preparedness and a transfer of responsibility for safety to civic authorities (Paton et al., 2000).

8.2.9 Changing outcome expectancy and fatalism

People differ in their outcome expectancy about the value of preparedness actions. A key factor affecting outcome expectancy is fatalism, the attitude that "nothing that I do will make any difference, so there is no point in trying." In regard to tsunami, fatalism is the attitude that tsunami are so powerful that there is no use preparing. This is common in discussions about locally generated tsunami where the public are told that no warnings are possible. Some people believe that when the 'big one' comes, it will be so powerful that their best efforts will be laid to waste. This fatalism often reflects a failure to distinguish between the uncontrollable force of tsunami and the relative controllability of some effects by effective evacuations or better land-use planning.

News reports of natural disasters, such as earthquakes, usually take the opposite tack, and focus on widespread damage rather than buildings that stood firm or people who survived. News reports immediately after an earthquake focus on the greatest damage; by contrast, later reports such as anniversary reports are more analytical and focus on the characteristics of the buildings that collapsed and lessons that can be learned. People who read these more analytical reports about the Kobe, Japan, earthquake were less fatalistic about the damage than people who read the immediate news reports about the same earthquake (Cowan, McClure, & Wilson, 2001). Thus the information that citizens are exposed to can alter their fatalism and understanding.

Reporting of the Boxing Day Indian Ocean tsunami contained many positive stories of non-fatalistic behaviour that constituted effective natural early warning responses. This was encouraging, and such publicising of it will change some people's fatalistic view of tsunami to a more correct perception that appropriate actions can mitigate tsunami hazard.

8.2.10 Motivation

Changing risk perceptions alone will not necessarily bring about behavioural change or increased action to address a particular risk. Social-cognitive processes mediate between perceived risk and risk reduction actions. People may not be motivated to prepare if they do not accept their risk status or perceive hazards as salient. Irrespective of the level of risk, action is constrained if people see hazard effects as insurmountable (low outcome expectancy), see themselves as lacking the competence to act (low self efficacy), or are not disposed to action (low action coping). Risk perception may not guide actions if people lack resources for implementation (low response efficacy), transfer responsibility for their safety to others (low perceived responsibility), distrust information sources, or stress uncertainty regarding the likely timing of hazard occurrence (Paton, 2003).

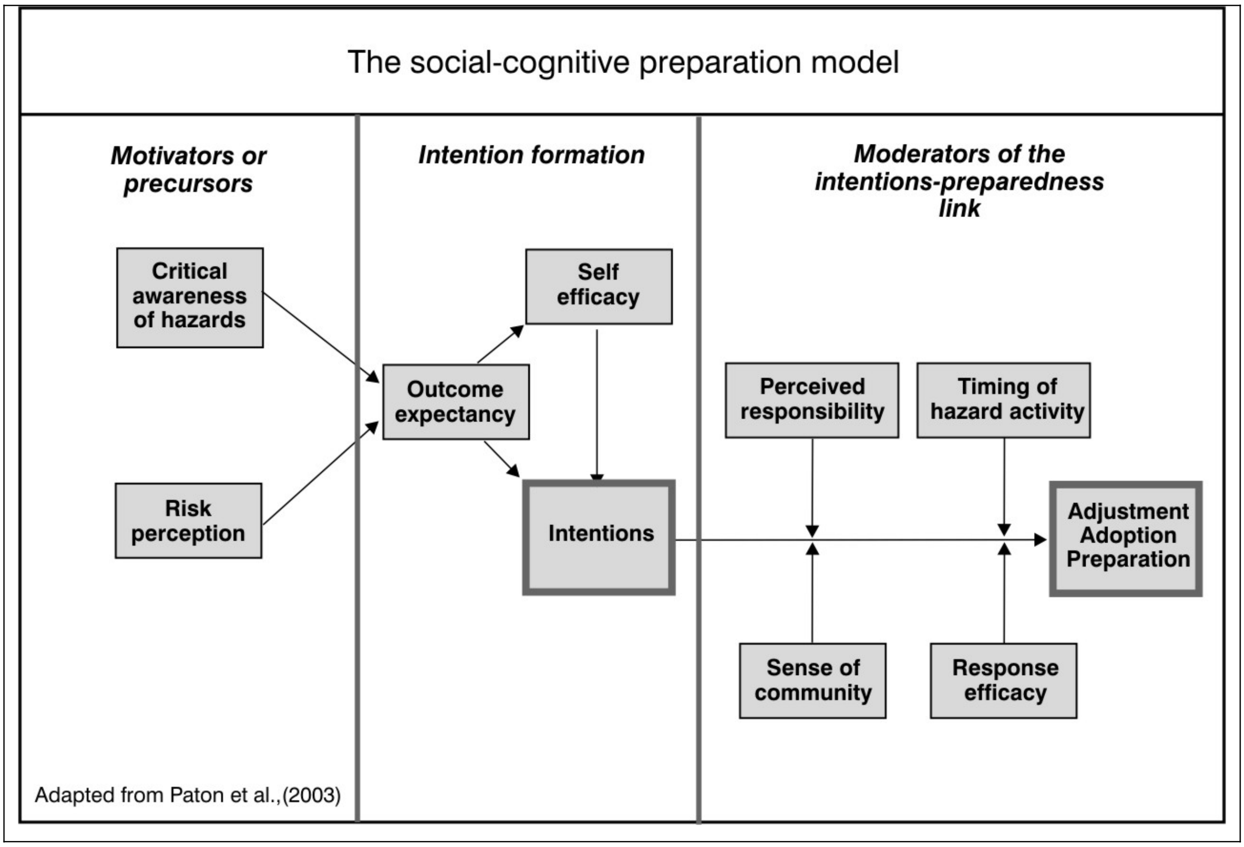

Figure 8.2 The social-cognitive process model for preparedness

Some people take no action no matter what information they receive, but the realisation that preparedness may make a difference to tsunami outcomes is one prerequisite for voluntary action, and with prudent people it is likely to enhance action.

An explanation for low preparedness has previously been discussed using a process model of preparedness (Paton, 2003; Paton, Smith & Johnston, 2003) that comprised three distinct, but related, stages (Figure 8.2). Acknowledging the distinction between these stages is important. They comprise different variables and require different intervention strategies to achieve change.

In the social-cognitive preparation model (Figure 8.2), the relationship between precursors and intentions is mediated by outcome expectancy and self efficacy. Low to moderate levels of outcome expectancy (belief that hazard effects can be mitigated by individual efforts) were recorded in the 2003 New Zealand survey and these act to reduce preparedness. Low-moderate levels of self-efficacy (judgement regarding their capabilities to mitigate hazard effects) will also constrain preparedness. Low to moderate levels of these variables is consistent with the finding of low to moderate levels of preparedness intentions. Only 11% of the sample indicated a definite intention to actively prepare.

8.2.11 Moving from intention to preparation

The model describes how preparedness can be limited or enhanced by several factors. Moderate to high levels of personal responsibility, resource availability (resource efficacy) and sense of community lessen the likelihood of their acting to moderate preparedness. A final control is the time frame within which people anticipate the occurrence of the next tsunami (Paton, 2003). Those who anticipated this occurring within the next 12 months were likely to convert their intentions into actual preparedness. In the 2003 National Survey, less than 1% of the sample thought that a tsunami was likely within the next year and 11% in the next ten years (Johnston et al. 2003). The fact that most people do not believe a tsunami could occur in the near future is likely to significantly limit the movement from intention to preparedness.

8.3 Recommendations: Education and engagement to motivate preparedness and effective warnings

Research clearly shows that getting people to prepare for tsunami and other natural hazards cannot be achieved through public education alone (Finnis, 2004). To facilitate motivation, public education and empowerment strategies (Paton, 2000) that emphasize the salience of hazard issues for community members are required. Improved preparedness and warning responses can also be gained from enhancing community members' beliefs in the feasibility of mitigating hazard and warning response through personal actions (e.g., counter beliefs that hazards have totally catastrophic effects) and enhancing beliefs in personal competency to implement these activities. Changing these factors requires a mix of public education, social policy, training, and empowerment strategies. The third stage, converting intentions into actual behaviour, could be enhanced by focusing on encouraging acceptance of a 'sooner rather than later' message. It is also important to understand the belief and attitudes that underpin the above responses. A combination of (1) public education, (2) community empowerment and (3) psychological intervention is required to develop an effective warning response capacity and to get people to participate in preparedness activities. It is also a process which takes time; it is not possible to deliver all three components at once and immediately expect change.

8.3.1 Barriers and Predictors

A first step in the process is to understand the barriers that prevent people from preparing and responding appropriately to warnings. Key barriers are:

- risk perception – "A tsunami won't affect *this* area for another 100 years"
- optimistic bias – "A tsunami will never affect *me*"
- response efficacy – "There are more important things than tsunamis to think about"
- outcome expectancy – "*No* amount of preparedness will help"

- normalisation bias – "Tsunamis have affected New Zealand in the past and *didn't* impact on us"
- external locus of control – "Tsunamis are an *act of God*"
- transfer of responsibility – "*Civil Defence* will be there to help me"

It is also important to understand the variables that can predict preparedness, some of which are also 'barriers':

These predictors are:

- risk perception – "A tsunami affects *this* area every 100 years"
- outcome expectancy – "A certain amount of preparedness will help"
- self-efficacy – "I can do something to prepare for a tsunami"
- problem-focused coping – "*I* am reducing the risk of a tsunami affecting *me*"
- critical awareness – "A tsunami could affect *this location* tomorrow"
- anxiety – "I am concerned that a tsunami will affect my property" (positive anxiety is a motivator; negative anxiety (extreme) is a barrier)
- response efficacy – "There are more important things than tsunamis to think about"
- sense of community – "*I* feel at home in *my* community"

8.3.2 Improving preparedness

In the first stage of a public education campaign, risk perception, critical awareness and anxiety are the variables that need to be addressed as they are the factors that initially motivate people to prepare. The intention-formation variables (outcome expectancy, self-efficacy and problem-focused coping) then need to be focused upon in the second stage of the campaign. After targeting these variables, people should have good intentions to prepare, but can still be hindered by the moderating variables such as perceived timing of the next hazard event, sense of community and response efficacy, so these variables are to be addressed in the third stage of the campaign. Table 8.2 shows the stage of the process/campaign, associated variables and the basic strategy that should be applied to each variable.

Table 8.2 Stage of the education and engagement process/campaign, associated variables and basic strategy that should be applied to each variable (Finnis, 2004)

Stage of Process	Variable	Basic Strategy
Precursor	Risk perception	Communication Empowerment
	Critical Awareness	Communication
	Anxiety	Psychological intervention
Intention Formation	Outcome expectancy	Communication Empowerment
	Self-efficacy	Empowerment
	Problem-focused Coping	Empowerment
Moderator	Timing of hazard activity	Communication
	Sense of community	Empowerment
	Response Efficacy	Empowerment

It must be kept in mind that communities are not static populations, and although initially a community must move through these stages of awareness and participation, a return to each of these strategies in a repetitive cycle must be planned and perpetually ongoing to allow for transient populations and ageing.

8.3.3 Improving effectiveness of warning response

As mentioned in Section 7.4, the five key components of warning system public education that are critical for effective response to that warning are (modified by Mileti, 2004):

- Who will issue the warnings
- What the warning could say
- How the warning will be issued
- What communication media will be used and how to access them
- What should be done in response to the warning (evacuation routes, and hazard/evacuation maps)

8.3.4 Developing integrated tsunami education and engagement strategies for New Zealand

National education strategy

The National Public Education Strategy (MCDEM, 2003) sets out the strategic framework for public education for the CDEM sector in New Zealand for the 2003-2008 period. This document was developed in consultation with the sector and contains a number of strategies and short-, medium- and long-term goals within each (summarised in Table 8.3).

Table 8.3 National Public Education Strategy principles (MCDEM, 2003)

Strategic Principle 1: Committed partnerships:
1.1 Develop Sector Partnerships
1.2 Obtain External Funding and Sponsorship
1.3 Identify Hazards And Their Consequences For At-Risk Groups
Strategic Principle 2: Support For The Sector
2.1 Plan And Deliver National Public Education Programmes
2.2 Promotion, Development And Use Of Key Messages
2.3 Focus On Children As Agents Of Change
2.4 Promote Organisational Preparedness
2.5 Maximise The Impact Of National And International Emergency Events
2.6 Support Initiatives To Raise Awareness Of The 4 R's And New Zealand Risk Management Approach
Strategic principle 3: research and evaluation
3.1 Utilise Current Market Research Principles To Benchmark, Evaluate And Improve Programmes

As detailed in the document, the purpose of the strategy is to provide a high-level overview of the direction for public education in emergency management for the next five years. It outlines:

- the vision and goals of the national public education working group
- issues faced by those tasked with delivering public education
- strategic principles and proposed strategies to address these issues
- indicative tasks for short, medium and long term

The strategy defines programmes that are best coordinated and delivered at a national level by the Ministry working with the national public education working group, and supports strategies for programmes delivered by CDEM Groups, regional and territorial local authorities.

CDEM Group plans (Section 4) outline a range of public education initiatives that vary from group to group, and these plans, or supporting documents to them variably give details of specific education methods, audiences and content. According to the legislation, it is for Groups to decide what education initiatives will occur within their jurisdiction, supported by national policy (such as the above strategy) and resources. CDEM Groups noted a desire for national direction on consistency and content in some areas, especially signage and hazard/evacuation mapping.

Monitoring of public awareness to assess education and engagement effectiveness

Before implementing public education for tsunamis, the audience needs to be understood. The audience's current level of awareness and preparedness needs to be investigated (see Section 8.2 for key results of a New Zealand study in 2003), along with defining at-risk groups and determining the beliefs, needs and preferences of particular groups. This will provide baseline data to monitor the effectiveness of the campaign and enable a more targeted approach.

Delivering education

There is room for a mixture of national and Group-level initiatives. Although Groups are legislatively required to deliver education, recent national-level resourcing increases are available to develop nationally consistent resources and possibly aid in their delivery, in partnership with Groups. This is consistent with the National Public Education Strategy outlined above.

Research has found that public education should include the following actions (Finnis, 2004; Mileti et al, 2004):

- Target at-risk groups
- Use preferred media types
- Use many media types
- Use many credible sources
- Information should be provided frequently
- Develop consistent national signage
- Develop hazard and/or evacuation maps
- Booklets with specific information and instructional pictures
- Provide different sources for information searching
- Don't expect miracles, have a performance target
- Monitor audiences and programme effectiveness

Community engagement

The empowerment component of a campaign is achieved through community development programmes conducted in a consultative environment; for example, community meetings and focus groups. Recommendations for these are:

- Target at-risk groups or groups with community influence e.g. schools
- Identify group needs
- Programmes should be carried out one at a time
- Programmes should have a specific objective
- Ongoing programme evaluation

An ideal vehicle to accomplish some of this consultation exists in New Zealand within the District Plan, Long-Term Community Consultation Plan and Community Outcomes local government processes. CDEM Group plan development and revision also have statutory requirements (see Section 2) for consultation.

Psychological intervention

Activities can be designed to prepare the community psychologically to cope with tsunami, thus reducing anxiety and improving self efficacy. These can be incorporated in both public education and community empowerment initiatives and include written and verbal information on how to recognise and cope with psychological factors such as problem-focused coping, anxiety and stress.

8.4 Capacity building within key sector groups

There are key groups within the community that need special consideration or may have leadership roles in a warning.

8.4.1 School education

Education of natural hazards within schools is an effective method of improving awareness at home and in preparing schools themselves. Any school education must be developed in line with local syllabus, and be tailored to the location of each school, to make it most relevant and thus improving interest and information retention.

8.4.2 Education of tourists

Effective education about hazards specifically aimed at tourists is difficult to achieve due to the transient nature of tourists and language barriers. If tourists were able to gain a clear understanding of the potential hazards, the warning systems, and how to respond to these, there would be less reliance on other parties (such as tourism personnel) to assist. However, reaching tourists with this type of information is unlikely to be successful so other strategies, such as focussing on tourism firms and personnel, need to be considered.

Research from Drabek (1994, 1996) highlights a number of key issues that the tourism sector needs to address. The perception from tourism personnel has been that if tourists are told that an area is disaster-prone it would deter people from visiting the area, and result in a downturn in business. In contrast, interviews held with visitors (Drabek, 1996) at there is an expectation for improved disaster preparedness from managers, and that failure in an event of a disaster would be remembered as a negative experience that could cause the loss of future revenue and lives. From this we can deduce that it is better not to spend too much effort telling tourists about potential natural hazards, but to make sure that tourism firms and personnel are educated and trained in how to respond to warnings.

8.4.3 Staff training

Engaging and educating staff in the service sector are critical factors to improve response to warning systems. Recent research in New Zealand, at Ruapehu ski areas, has found that staff training is critical to achieve the correct public response to warnings (i.e. a relatively high proportion of skiers moving out of harm's way) (Leonard et al, 2004). The most significant lessons learned by tourism personnel who had been involved in a natural disaster are (Drabek, 1994; Drabek, 1996:

- Plan appropriate protective actions
- Resist threat denial
- Debunk the panic myth (a myth that the public panic when warned of disaster)
- Have one person in charge
- Improve employee and customer communication
- Plan to provide customer sheltering
- Anticipate the needs of special populations
- Provide records protection
- Recognise family priorities
- Structure media relationships (This is a major issue, as media commonly exaggerate and misinform. This can have adverse impacts on current and future tourism business).

A number of public and volunteer agencies have key roles in a tsunami situation. Their training needs will be similar to those discussed above for service staff, but will also include extra responsibilities which should be written as plans as follows.

8.4.4 Government agencies

As well as having staff in need of training (above), CDEM group member organisations, especially the Police, New Zealand Fire Service, and local government have a potential role in educating the wider population and participating in public notification of warning messages. These roles should be discussed and developed in a regular and ongoing way with the wider Group and be documented in detailed planning. There are other government agencies who may also have a role and this should be discussed with them, including Maritime New Zealand, for example.

8.4.5 Non-government and volunteer agency potential roles

There are a myriad of organisations with potential roles in pre-event education and dissemination of warning messages. These include, for example, surf lifesaving, rural fire, port companies, the Royal New Zealand Coastguard, etc. Any incorporation of these agencies would need consultation to determine capacity, expectations and detailed planning. Involved agencies should be included in exercises.

Surf lifesaving clubs

New Zealand's extensive foreshore and beach areas are vulnerable to tsunami and experience high use for most of the year. By their nature, surf lifesaving clubs could play a significant role in evacuations from beaches. In many locations they have the policies, procedures, alert systems and training in place for beach closures. Tsunami-specific training could significantly enhance the capacity of surf lifesaving club members to respond to warnings (including 'natural warnings', Section 7.3).

Rural fire

CDEM Groups identify that in almost all areas the New Zealand Fire Service and Rural Fire have a key role in generic emergency management and evacuations. Rural fire authority volunteers are community members, often in remote and sparsely settled areas. They usually have extensive spatial knowledge of the area and contacts within the community, and are ideal extensions of warning alert systems in areas where dedicated warning hardware is limited. These arrangements are mostly informal oral agreements or perceptions at present, and should be formalised in written MoUs and plans, and enhanced by additional training.

8.5 Delivery methods

The full range of public education delivery methods that are available and financially feasible should be used. These are likely to include, but are not restricted to, media publicity/coverage, public talks, staff training, maps (evacuation zones and routes especially, with a mixed use of 3D/perspective and plan-view), signage and printed matter including brochures and posters.

The focus should be on covering a range of methods that access the most at-risk people possible. This can be evaluated and modified to achieve maximal effectiveness through surveys of public awareness and observation of simulation exercises.

9.0 CONCLUSIONS

In this report we have examined national and regional arrangements for effective tsunami warnings and preparedness. In assessing these arrangements against the level of risk, the Science Report has provided a sound basis for comparison, given the limitations of current knowledge. The results of the Science Report show relatively high levels of risk at national level and in some regions compared to others hazards, even with warning systems. This will come as a surprise to many people and shows that tsunami risk has not been paid sufficient attention in the past.

The nature and effectiveness of tsunami warning systems varies according to the lead time available to effect an evacuation. For distant-source tsunami, the relatively long time that is available to implement an appropriate response means that the risk can be reduced or eliminated with an effective warning system. For regional-source tsunami (and for distant locations in a local-source tsunami) there is barely sufficient time to issue a simple warning given current arrangements. This is a recognised deficiency, so it is acknowledged that no formal system currently exists for regional-source events. Effective evacuation is thus dependent on pre-planning and public education as there will be no time for an organised evacuation. Local-source early warning systems pose a much greater scientific and operational challenge than those developed for regional or distant-source tsunami, so again educating the public to recognise natural tsunami warning signs is the principal preparedness measure.

Given the significant proportion of risk related to local-source tsunami, decreasing the risk of multiple fatalities will not be easy using just a warning system approach. A mix of approaches involving warning systems, engineering and 'soft' mitigation, and land-use planning will be required.

We have compared the adequacy of national arrangements with national risk. In terms of risk measures, the most useful for comparative purposes was the likelihood of multiple fatalities in a single event compared to other natural hazards events. Given that fatalities in historical natural hazard events have numbered in the low hundreds and 500–1,000 fatalities are expected, at most, in a large Wellington Fault earthquake, the figure of over 5,000 for a similar (1 in 500 year) likelihood tsunami event is very high. Given the large uncertainties in casualty estimates across all natural hazards we cannot be sure that tsunami are significantly worse, but they are certainly of a similar order to earthquakes, volcanoes, and (possibly) sudden-onset floods (debris flows).

The 5,000 fatality estimate for tsunami is based on zero warning system effectiveness — we did not attempt to make a quantitative estimate of warning system effectiveness because it would have been too subjective to be meaningful. Instead, we have presented two scenarios of warning system effectiveness. The first is based on 95% evacuation for distant-source tsunami where warning times are long and 10% evacuation for local-source tsunami for which there is no formal warning system, self-evacuation being the most effective option. The second scenario uses figures of 99% and 20% respectively. Using these scenarios, national fatalities with a 500-year likelihood are still at least commensurate with other natural hazards. Given that substantial amounts are invested in both warning systems and mitigation for these other natural hazards, on the grounds of the acceptability of multiple fatalities to Government, a similar investment in tsunami mitigation would appear to be an inescapable conclusion.

Given the level of risk, we have identified issues with national arrangements, in particular with the provision of scientific advice and with the information content of messages broadcast to Civil Defence Emergency Management (CDEM) Groups, who will have to make evacuation decisions. In particular, wave heights are difficult to predict and likely areas of inundation are even more uncertain. In the long term, modelling will be accurate enough to give more precise tsunami impact forecasts. In the short term, however, to enable appropriate CDEM Group response and planning we need to develop operational systems and develop tsunami warning message content that takes account of present high uncertainties. To address this we have made the following recommendations:

Recommendation 4.1: That the GeoNet system be used to integrate sea-level data with real-time seismic monitoring in order to generate alert information for regional- and local-source tsunami and that the GeoNet Duty Team be trained and given tools (Recommendation 4.2) to provide the scientific advice required by MCDEM and CDEM Groups for interpretation of tsunami alert information, including that from PTWC for distant-source tsunami. This training will need to be in tsunami generation, propagation, and impact and provided by a range of New Zealand experts in the disciplines of seismology, numerical water modelling, and historical impact.

Recommendation 4.2: A system is developed to predict impacts from distant-, regional- and local-source tsunami:

a) As a first step, the methodology developed in the Science Report needs to be turned into an operational tool, in particular, a wider range of earthquake sources needs to be catered for and wave heights at more coastal locations need to be calculated.
b) A second step is to incorporate, in consultation with local authorities, better impact information to inform response decisions such as evacuation. Once developed, the system should be implemented within GeoNet and its outputs made available for dissemination to CDEM Groups when a PTWC warning/watch bulletin is issued or a large earthquake is detected by GeoNet.
c) The methodology needs to be regularly updated in the light of new knowledge so that best estimates of likely impact can always be provided. In time, it is expected that this system will evolve to embrace outputs from NOAA's real-time forecasting model.

We have also identified shortcomings in the wider effective warning system elements (Fig. 1.1) and so have made two additional recommendations at national level:

Recommendation 4.3: Components of an effective warning system beyond early warnings require support at national level. We recommend resource material (content for education material, signage methodology, evacuation planning tools, etc.) and consistency guidelines; national education strategy; exercising; research in support of improved warning; and evaluation.

Recommendation 4.4: A great lack of knowledge of tsunami process and risk has been identified. In order to better determine our risk exposure to inform mitigation decisions as well as enable better wave height and impact prediction in future events (Recommendation 4.2), there needs to be a significant new investment at a national level in tsunami research.

In our review of region-level arrangements for tsunami preparedness there was an extensive study of CDEM Group plans as well as structured telephone interviews with each region. We were looking, in particular, for the presence of all the elements of an effective warning system. Many plans were incomplete in this regard, especially for tsunami-specific arrangements, which we regard as necessary except for a few components such as the arrangements for the receipt of warnings. It is preferable that regions separate relevant local-, regional-, and distant-source arrangements to achieve effective warnings. This has not been done by many regions yet.

Given the high level of national risk, it is not surprising that the risk at many main centres is high compared to other natural hazards, although there is significant variation around the country. Gisborne, Napier, Wellington, Lower Hutt, Christchurch and Dunedin can have over 500 fatalities in a 1 in 2500 year likelihood event, assuming zero warning system effectiveness. Christchurch and Dunedin can reduce multiple fatalities greatly through effective warnings of distant- and regional-source tsunami. While the other centres listed above can all reduce the level of multiple fatalities with effective distant-source warning systems, they are left with significant residual risk from local sources, which will require mitigation through a range of measures. Foremost in this will be public education to improve response to local events through self evacuation.

Individual risk measures have the advantage that they can be compared against what is regarded as tolerable (or not), based on international benchmarks. If we include the effect of our scenario warning systems, no individual risk at any city is clearly intolerable, but six cities have a level of individual risk that would be regarded as intolerable if it was imposed or the individual was not informed as to what the risk was.

Another factor looked at in our city-by-city analysis was the distribution of likely warning time based on the distance to the most hazardous sources to that city. There is, again, wide variability. This analysis will enable regions to look at what balance to strike between technical early warning system effectiveness and public education (on natural early warnings to facilitate self-evacuation).

Finally, we have looked at wider mitigation options beyond warnings systems and evacuation, and have grouped these in a consistent way with the three approaches consistently used in coastal hazard and climate change guidelines for local government in New Zealand, namely:

- *Protection (or defence)* — physical interventions such as the building of seawalls, rock revetments, beach and fore-dune nourishment with external sand or gravel, or building up vulnerable coastal roads or causeways;
- *Adaptation (or accommodation)* — dune and coastal vegetation restoration, plant or enhance coastal forests, re-create coastal/estuarine wetlands or marshes, raise and deepen foundations of dwellings, better tie-downs to foundation, open-up ground floors of engineered buildings;
- *Landuse planning* — range of land-use controls, plans and policies that will be different for new subdivisions (coastal green-field developments) or existing developments (e.g. managed retreat including engineering lifelines where possible, establishing coastal hazard zones).

As a result of the regional-level review and comparisons we have arrived at the following recommendations:

Recommendation 7.1. CDEM Groups participate in identifying where national guidelines would be beneficial, and in developing and implementing national guidelines where appropriate for regional effective warning system components (Figs. 1.1 & 6.4), via a national working group. This working group include representation by (but not restricted to) MCDEM, CDEM Groups, scientific organisations, and key individual scientists.

Recommendation 7.2**.** CDEM Groups complete regional preparedness across all of the topics examined under regional-level written arrangements, as reviewed from Group plans and documents beyond Group plans, so that all the components of an effective warning system (Figs. 1.1 & 6.4) are in place, as appropriate for the level of risk in each region. Decide whether generic or tsunami-specific arrangements are appropriate for each. Actions should be in line with the national working group developed guidelines recommended above, where appropriate, and should consider the timeframes and likely availability and content of warning messages. Specific actions for regions to undertake include:

a. Decide whether there is a need for improvements to the warning message receipt and dissemination protocols in the various warning situation scenarios, and consider options for public notification methods discussed here and in Appendix 9, as well as any additional options that are identified by the national working group. Implement the most suitable options.

b. Implement all planning components of an effective early warning system including: sub-group-level planning; decision preplanning; evacuation zone and route mapping; evacuation decision-making; roles of key response agencies; arrangements for giving the 'all-clear'; and tsunami warning SOP's for all three source-type (local, regional, and distant) warning scenarios.

c. Develop pre-planned and exercised communication between central government agencies, local emergency management agency staff, scientists, media, and community representatives. Renewal of contacts must be regular and permanently sustained. Specific written arrangements with dissemination media (especially radio, but also Rural Fire, Surf Lifesaving etc.) are essential (MoUs) and should distinguish distant, regional and local sources.

d. Develop regional public education (across all available/feasible media), staff training, maps and signage. It must contain details for public-response to natural warnings of local-source tsunami.

e. Develop and conduct on a regular ongoing basis regional exercising of tsunami warning effectiveness, including how these may tie in with national exercises.

Recommendation 7.3. CDEM Groups

a. Incorporate new developments in effective warning system components and design into ongoing improvements of regional tsunami preparedness.

b. Quantitatively evaluate the effectiveness of planning, public education, training strategies, simulation exercising and hardware reliability testing, feeding the results fed back as effective warning system improvements.

Recommendation 7.4. CDEM Groups consider the implementation of land-use planning tools and other layered mitigation options and regulations to reduce vulnerability to tsunami hazards at a regional level.

We hope this provides at least a nationally consistent basis for taking the next steps towards a safer New Zealand.

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11.0 REFERENCES

Adams, J. 1995 Risk. London, UCL press.

Aguirre, B. 2004. Homeland security warnings: lessons learned and unlearned. International Journal of Mass Emergencies and Disasters: 22(2): 103-115.

Bell, R.; Cowan, H.; Dalziell, E.; Evans, N.; O'Leary, M.; Rush, B.; Yule, L. (2005). Survey of impacts on the Andaman Coast, southern Thailand following the great Sumatra–Andaman earthquake and tsunami of December 26, 2004. Invited paper, Bulletin of the New Zealand Society for Earthquake Engineering 38(3): 123–148.

Berryman, K. (Compiler), 2005. Review of Tsunami Hazard and Risk in New Zealand, Institute of Geological and Nuclear Sciences client report CR2005-104, Lower Hutt.

Biever, C. & Hecht, J., 2005. Alarm bells ringing over US response to tsunami scare, New Scientist, pp. 8-9.

Burns, W.J., Slovic, P., Kasperson, R.E., Kasperson, J.X., Renn, O., Emani, S. 1993. Incorporating structural models into research on social amplification of risk; implications for theory construction and decision making. Risk Analysis, 13, 611-623.

Coomer, M.A., Leonard G. (in prep). Tongariro crossing hazard awareness survey: public perceptions of volcanic danger. *Institute of Geological & Nuclear Sciences Science Report*.

Cowan, J., McClure J., Wilson, M., 2002. What a difference a year makes: how immediate and anniversary media reports influence judgments about earthquakes. Asian Journal of Social Psychology *5,* 169-185.

Crawford, G., 2005. TsunamiReady communities: no overnight solution, Natural Hazards Observer, pp. 5-6.

Darienzo, M., Aya, A.L., Crawford, G.L., Gibbs, D., Whitmore, P.M., Wilde, T. and Yanagi, B.S., 2005. Local tsunami warning in the pacific coastal United States. Natural Hazards, 35(1): 111-119.

Dengler, L., 2005. The role of education in the National Tsunami Hazard Mitigation Program. Natural Hazards, 35(1): 141-153.

Drabek, T.E., 1994. Disaster Evacuation and the Tourist Industry, University of Colorado, Institute of Behavioral Science, Program on Environment and Behavior, Boulder.

Drabek, T.E., 1996. Disaster Evacuation Behavior: Tourists and other Transients, University of Colorado, institute of Behavioral Science, Program on Environment and Behavior, Boulder.

Eisner, R.K., 2005. Planning for tsunami: Reducing future losses through mitigation. Natural Hazards, 35(1): 155-162.

Finnis, K., 2004. Creating a Resilient New Zealand: Can public education and community development campaigns create prepared communities? An examination of preparedness motivation strategies, Ministry of Civil Defence and Emergency Management, Wellington

Galley, I., Leonard, G., Johnston, D., Balm, R. and Paton, D., 2004. The Ruapehu lahar emergency response plan development process: An analysis. The Australasian Journal of Disaster and Trauma Studies, 2004(1): 1-33.

Gilmour, A.E., 1964. Tsunami travel times to New Zealand. 1:37,090,000. Wellington: New Zealand Oceanographic Institute.

Gilmour, A.E., 1967. Tsunami travel times to New Zealand. New Zealand Journal of Marine and Freshwater Research, 1, 139-142.

González, F.I., Milburn, H.M., Bernard E.N. and Newman, J.C., *Deep-ocean Assessment and Reporting of Tsunamis (DART): Brief Overview and Status Report,* In proceedings of the International Workshop on Tsunami Disaster Mitigation, 19-22 January 1998, Tokyo, Japan (1998). http://www.ndbc.noaa.gov/Dart/brief.shtml

González, F.I., Mofjeld, H.O., Titov, V.V., Venturato, A.J., Simmons, R.S., Hansen, R., Combellick, R., Eisner, R.K., Hoirup, D.F., Yanagi, B.S., Yong, S., Darienzo, M., Priest, G.R., Crawford, G.L. and Walsh, T.J., 2005. Progress in NTHMP Hazard Assessment. Natural Hazards, 35(1): 89-110.

Gregg, C.E. and al, e., (submitted). Understanding of a siren-based hazard warning system for the natural warning signs of tsunamis in Hawai'i.

Gruntfest, E.C. and Huber, C., 1989. Status Report on Flood Warning Systems in the United States. Environmental Management, 13: 279-286.

Haynes, K., Barclay, J., Lake, I. and Pidgeon, N., 2004. An evaluation of volcanic hazard maps as a communication tool. Proceedings, IAVCEI General Assembly, 2004, Pucon Chile. s05a_pth_079.

Helweg-Larsen, M. (1999). (The lack of) optimistic bias in response to the Northridge earthquake: The role of personal experience. Basic and Applied Social Psychology, 21 1119-129

Johnston, D., Bell, R., Stewart, C., Hickman, M., Thompson, J., Kerr, J., Glassey, P., 2003. The 2003 national coastal survey: assessing community understanding and participation in coastal management in New Zealand. *Proceedings of the Coasts & Ports Australasian Conference*, 9-12 September 2003, Auckland, New Zealand.

Johnston, D., Leonard, G., Bell, R., Stewart, C., Hickman, M., Thomson, J., Kerr, J., Glassey, P. 2003. Tabulated Results of the 2003 National Coastal Community Survey. *Institute of Geological & Nuclear Sciences Science Report* 2003/35, 118p.

Johnston, D., Paton, D., Crawford, G.L., Ronan, K., Bürgelt, P. and Houghton, B., 2005. Measuring tsunami preparedness in Coastal Washington, United States. Natural Hazards, 35(1): 173-184.

Johnston, D.M., 1997. Physical and social impacts of past and future volcanic eruptions in New Zealand. PhD Thesis, Massey University, Palmerston North, 410 pp.

Jonientz-Trisler, C., Simmons, R.S., Petty, E., Yanagi, B.S., Crawford, G.L., Darienzo, M., Eisner, R.K. and Priest, G.R., 2005. Planning for Tsunami-Resilient Communities. Natural Hazards, 35(1): 121-139.

Kasperson, R.E., Renn, O., Slovic, P., Brown, H.S., Emel, J., Goble, R., Kasperson, J.X., Ratick, S. 1988. The social amplification of risk: a conceptual framework. <u>Risk Analysis, 8</u>, 177-187.

Leonard, G., Johnston, D., Paton, D. and Kelman, I., 2004. Mitigating the lahar risk at Whakapapa Ski Area, Mt Ruapehu: Public perceptions and the effectiveness of the new warning system, Institute of Geological and Nuclear Sciences science report, Lower Hutt.

Liu, P.L.F., Lynett, P., Fernando, H., Jaffe, B.E., Fritz, H., Higman,B., Morton, R., Goff, J., and Synolakis, C. (2005). Observations by the International Tsunami Survey Team in Sri Lanka. Science 308, 1595.

MCDEM, 2002. Working Together: Developing a CDEM Group Plan Director's Guidelines for CDEM Groups (DGL 2/02). Ministry of Civil Defence & Emergency Management, Wellington.

MCDEM, 2003. Working together for prepared communities: National public education strategy 2003-2008, Ministry of Civil Defence and Emergency Management (MCDEM), Wellington.

Mileti, D.S., 2004. Communicating emergency public information., Notes from Training Course, revision 2.

Mileti, D., Nathe, S., Gori, P., Greene, M. and Lemersal, E., 2004. Public Hazards Communication and Education: The State of the Art, Natural Hazards Center Natural Hazards Informer issue 2, Boulder.

Mileti, D.S., O'Brien, P. 1992. Warnings and disasters: normalizing communicated risk. Social Problems 39: 40-57.

Mileti, D.S., Sorensen, J.H., 1990. Communication of emergency public warnings, Oak Ridge National Laboratory, Oak Ridge. 144pp.

OEM & ODGAMI, 2001. Tsunami Warning Systems and Procedures guidance for local officials., Oregon Department of Geology and Mineral Industries ODGAMI Special Paper 35.

Paton, D. (2000) Emergency Planning: Integrating community development, community resilience and hazard mitigation. *Journal of the American Society of Professional Emergency Managers* 7: 109-118.

Paton, D., (2003) Disaster Preparedness: A social-cognitive perspective. *Disaster Prevention and Management* 12: 210-216.

Paton, D., Johnston, D., Gough, J., Dowrick, D., Manville, V., Daly, M., Batistich, T., Baddon, L. 1999. Auckland Volcanic Risk Project: Stage 2. *Auckland Regional Council, Technical Publication Number* 126.

Paton, D., Millar, M., and Johnston, D. (2001) Community Resilience to Volcanic Hazard Consequences. *Natural Hazards* 24: 157-169.

Paton, D., Johnston, D., Houghton, B., Becker, J. & Crumbie, G. (2003) Tsunami Preparedness in Coastal Washington State. *Journal of the American Society of Professional Emergency Managers* 10: 97-108

Paton, D., Smith, L.M., & Johnston, D. (2005) When good intentions turn bad: Promoting natural hazard preparedness. Australian Journal of Emergency Management,20, 25-30.

Rip, A. 1988. Should social amplification of risk be counteracted? Risk Analysis, 8, 193-197.

Sjöberg, L., 2000. Factors in risk perception. Risk Analysis, 20, 1-11.

Sorensen, J., 2000. Hazard warning systems: review of 20 years of progress. Natural Hazards Review(May): 119-125.

Spittal, M. J., McClure, J., Siegert, R. J. Walkey, F. H. (2005). Optimistic bias in relation to preparedness for earthquakes. Australasian Journal of Disaster and Trauma Studies, 2005-01, 1-10.

Tierney, K.J., Lindell, M.K., Perry, R.W. 2001. Facing the unexpected: disaster preparedness and response in the United States. Joseph Henry Press, Washington D.C.

Titov, V.V., Gonzalez, F.I., Mofjeld, H.O. and J.C. Newman, *Project SIFT (Short-term Inundation Forecasting for Tsunamis),* ITS 2001 Proceedings, Session 7, Number 7-2, p 715 (2001).

Weinstein, N. D., & Klein, W. M. (1996). Unrealistic optimism: Present and future. Journal of Social & Clinical Psychology, 15, 1-8.

12.0 APPENDICES