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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