Modelling of the tsunami risk to Papamoa, Wairakei and Te Tumu and implications for the SmartGrowth Strategy

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EXECUTIVE SUMMARY

The purpose of this report is to investigate the potential levels of inundation resulting from a tsunami generated from distant sources (South America), regional sources (Kermadec Trench) and local sources (various faults) for the suburbs of Papamoa, Wairakei and Te Tumu. Using this inundation data, the potential economic consequences and casualties resulting from these modelled events have been estimated and the resulting levels of risk for Papamoa, Wairakei and Te Tumu from the various scenarios have been discussed. This includes identifying whether the levels of risk from the various scenarios are acceptable, tolerable or intolerable, based on the thresholds identified within the Proposed Bay of Plenty Regional Policy Statement. Potential pre-event recovery measures have been identified that could be incorporated into the development of these suburbs to reduce the potential effects from a tsunami. Finally, potential changes to the SmartGrowth Strategy have been identified which will better recognise the risk from a tsunami for these suburbs and assist with reducing the resulting effects.

The tsunami modelling has shown that for distant and local sources, there is no significant inundation of the three suburbs. This is because the wave height which is generated from these distant and local sources is not sufficient to overtop the dune systems which are along the Papamoa – Te Tumu coastline.

For a regionally generated tsunami, the modelling estimates that for ruptures of up to magnitude 8.5 on the southern Kermadec Trench, or up to 8.8 on the northern portions of the trench, there is no significant inundation within Papamoa, Wairakei and Te Tumu. However, earthquakes resulting from the rupture of the whole Kermadec Trench or the continuous rupture of the central and southern portions of the trench the northern end of the Hikurangi Margin, are estimated to result in more significant inundation, particularly at Papamoa. The levels of inundation are less at Te Tumu than Papamoa from these larger events due to the presence of the dune systems along this section of the coastline. This has shown the important role that the dune systems along the Papamoa to Te Tumu Coastlines play and the need for these to be protected as part of any future development.

The calculated return periods for the regionally modelled scenarios were once every 610 years or less. The return period for the above scenarios is computed by dividing the amount of slip from an earthquake (m) with the annual convergence rate (m/year). These calculations are simplistic and do not take into account aseismic slip, and slip in earthquakes of other magnitudes. As such, the calculated return periods are strongly conservative and represent lower limits for the possible return times; the true return periods may be considerably longer.

The estimations of the building damage and deaths for these modelled events demonstrate that an earthquake of less than magnitude 8.5 on the southern Kermadec Trench, or less than magnitude 8.8 on the northern portions of the trench, is unlikely to result in a large number of fatalities for both the low density and high density development options for Papamoa, Wairakei and Te Tumu. The modelled events which involve the rupture of the whole Kermadec Trench or the continuous rupture of the central and southern portions of the trench the northern end of the Hikurangi Margin have significantly more deaths and building damage.

The annual probability of death did not rise proportionally to the increase in population when comparing a high density development to a low density development, particularly for Wairakei and Te Tumu. The reasons for this could include that the higher density developments have more housing located in areas which are less at risk from inundation and also have more multi storey buildings to assist with vertical evacuation.

Determining whether the risks associated with the proposal were tolerable, acceptable or intolerable followed the findings of the building damage assessment, with the multiple rupture events generally having either an intolerable number of deaths or intolerable building damage. Only one event was intolerable in terms of the annual probability of deaths and that was for Papamoa during the worst case scenario - and it is plausible that a more comprehensive derivation of the return periods would place the risk of such events in the tolerable category. This intolerability in the annual probability of deaths occurred for both the low and high density developments.

Based upon the pre-event recovery methodology for land use by Becker et al (2008) pre event recovery options are recommended which are specific to the to the study areas and would assist with reducing the consequences associated with a tsunami.

The SmartGrowth Strategy currently recognises natural hazards as an important factor to consider as the population of the Bay of Plenty increases. Opportunities exist to improve community resilience within the study area by amending the SmartGrowth Strategy in a manner which would encourage mitigation measures which can be adopted to reduce the effects from a tsunami. The key opportunities which exist include:

- Recognise the importance of low density development (i.e. parks and recreation spaces) in mitigating the risk from a natural hazard, in the SmartSpace chapter of the Sub-regional Growth Issues section of the strategy;
- Recognise the importance of natural features (dune systems) in mitigating the risk from a natural hazard in the Landscape chapter of the Sub-regional Growth Issues section of the strategy;
- Identify tsunami as a potential natural hazard which could result in land being classified as being severely constrained in Chapter 6.18 of the Sub-regional Growth Issues section of the strategy;
- Identify tsunami as a natural hazard in the growth issues and principles sections of the Open Coast chapter, which would also provide support to action 6;

- Recognise the importance of natural features (dune systems) in mitigating the risk from a natural hazard in the Landscapes Chapter of the SmartGrowth Strategy. There also needs to be an action developed which would assist with retaining landscapes which have a role in mitigating the effects from a natural hazard;
- Develop the precautionary approach further to include a risk based assessment. This would allow for appropriate land control approaches to be undertaken as the knowledge of risks increases;
- Address the conflict between allowing for the development of moderately constrained land through the use of engineering and structural measures, and principle 6 of the hazards chapter which seeks to avoid the use of protection works. This can be remedied by modifying principle 6 to allow for engineering works on Slightly and Moderately Constrained Land but not Severely Constrained areas;
- Incorporate pre-event recovery measures into the design of future residential development;
- Require the creation of future structure plans for new development, to also take into account the risk from natural hazards;
- Recognise the importance of parks, situated within low risk areas as potential evacuation points within the SmartSpace Chapter. The design of these parks could also take into account some of the pre-event recovery concepts (i.e. heating, water, shelter etc.).

The Tauranga Eastern Link has the potential to play a significant role in the evacuation of future Wairakei and Te Tumu residents from high risk tsunami areas. The extent to which this road will be effective in evacuating people will be largely determined by the size of the tsunami (which will determine the extent and depth of inundation) as well as its source (which will determine warning time). It is however recommended that, to increase the effectiveness of this road as an evacuation route, a detailed evacuation plan be created for the study area as it is developed and communicated to residents of these suburbs. This plan should clearly identify the evacuation routes that lead to designated areas of land, not situated within an inundation area. These areas of land would need to be easily accessible from the Tauranga Eastern Link and contain shelter, food, water, toilet facilities and cooking equipment for people. These areas would need to be identified and created in discussions with the Emergency Management Officer at the Bay of Plenty Regional Council.

1.0 INTRODUCTION

The Papamoa, Wairakei and Te Tumu suburbs have been identified within the SmartGrowth Strategy as being important areas to accommodate further population growth within the Bay of Plenty (Figure 1.1). These suburbs are all located on or in close proximity to the coastline and therefore are potentially at risk from a tsunami. Previous studies (Goff et al. 2006, Walters et al. 2006, De Lange et al. 2008, and Prasetya et al. 2008) have identified the subduction zone within the Kermadec Trench as the most significant source for a tsunami which would affect the Bay of Plenty.

The purpose of this report is to:

- Investigate the potential levels of inundation from a tsunami generated from distant sources (South America), regional sources (Kermadec Trench) and local sources (various faults).
- Model the potential economic consequences and casualties resulting from the various scenarios. The potential economic consequences and casualties modelled concentrate on the various scenarios of a tsunami being generated from the Kermadec Trench. This is because these scenarios include events where the tsunami does not inundate the three suburbs as well as events where the most significant inundation occurred.
- Discuss the levels of risk for Papamoa, Wairakei and Te Tumu from the various scenarios, including addressing whether the levels of risk are acceptable, tolerable or intolerable.
- Suggest pre-event recovery measures that could be incorporated into the development of these suburbs to reduce the potential effects from a tsunami.
- Suggest potential changes that could be made to the SmartGrowth Strategy to better recognise the risk that tsunami present to these suburbs and how this can be reduced.

The information in this report will assist with the future development of these suburbs and help with incorporating appropriate measures to reduce the potential risk of death and damage from tsunami.

Figure 1.1 Location of the study areas and relevant place names detailed within the report. (Source http://www.zoomin.co.nz/map/nz/tauranga/).

1.1 Scope and Limitations of this report

This report investigates the potential inundation levels for Papamoa, Wairakei and Te Tumu from distant, regional and local tsunami sources. In particular, one distant, six regional and three local scenarios have been modelled as has the resulting economic and social costs. These models are all based upon assumptions which include the use of averages. This report also assumes that the integrity of the existing dune systems is maintained and not eroded by a tsunami. As such, the levels of inundation which may result from an event and the resulting economic and social costs may be different, given the variability associated with a fault rupture and the final development form of the study areas.

1.2 Outline of report

This report begins by providing a brief overview of the suburbs subject to this study and the role of the SmartGrowth Strategy in managing development within these areas. The report will then outline the potential tsunami inundation generated from distant, regional and local sources for the study area (Section 2), Section 3 assesses the number of deaths, injuries and economic damage from these modelled scenarios for Papamoa, Wairakei and Te Tumu. These assessments have been undertaken for both low and high density developments within these study areas. Section 4 investigates the risk levels associated with these modelled events and their land use implications for the study area. The pre-event recovery options available to mitigate the effects from the tsunami are explored within Section 5 of the report. The opportunities for the SmartGrowth Strategy are discussed within Section 6. Section 7 then provides the overall recommendations and conclusions from the study. Appendix 1 identifies the methodology undertaken to calculate the levels of inundation from the modelled tsunami events and Appendix 2 identifies the levels of inundation resulting from several scenarios involving the rupture of the Kermadec Trench. The potential inundation resulting from the scenarios involving the rupture of local faults are identified in Appendix 3. Appendix 4 outlines the damage and casualty levels from the modelled scenarios for the three suburbs assuming a low density development. Appendix 5 outlines the damage and causality levels from the modelled scenarios for the three suburbs assuming a high density development. The annual probability of deaths and injuries for the modelled scenarios for the three suburbs are outlined in Appendix 6 (for both low and high density). Appendix 7 provides the suggested pre-event recovery planning considerations.

1.3 Overview of the Study Area and the SmartGrowth Strategy

This section of the report will provide a brief overview of the three suburbs subject to this study, as well as the relationship between the SmartGrowth Strategy and the development of these areas.

Papamoa, Wairakei and Te Tumu are located to the south east of Tauranga City (Figure 1.2). These three suburbs have been identified as key areas to accommodate future growth within the Bay of Plenty. Of these three suburbs, Papamoa is already largely developed and Wairakei and Te Tumu are identified future greenfield development sites.

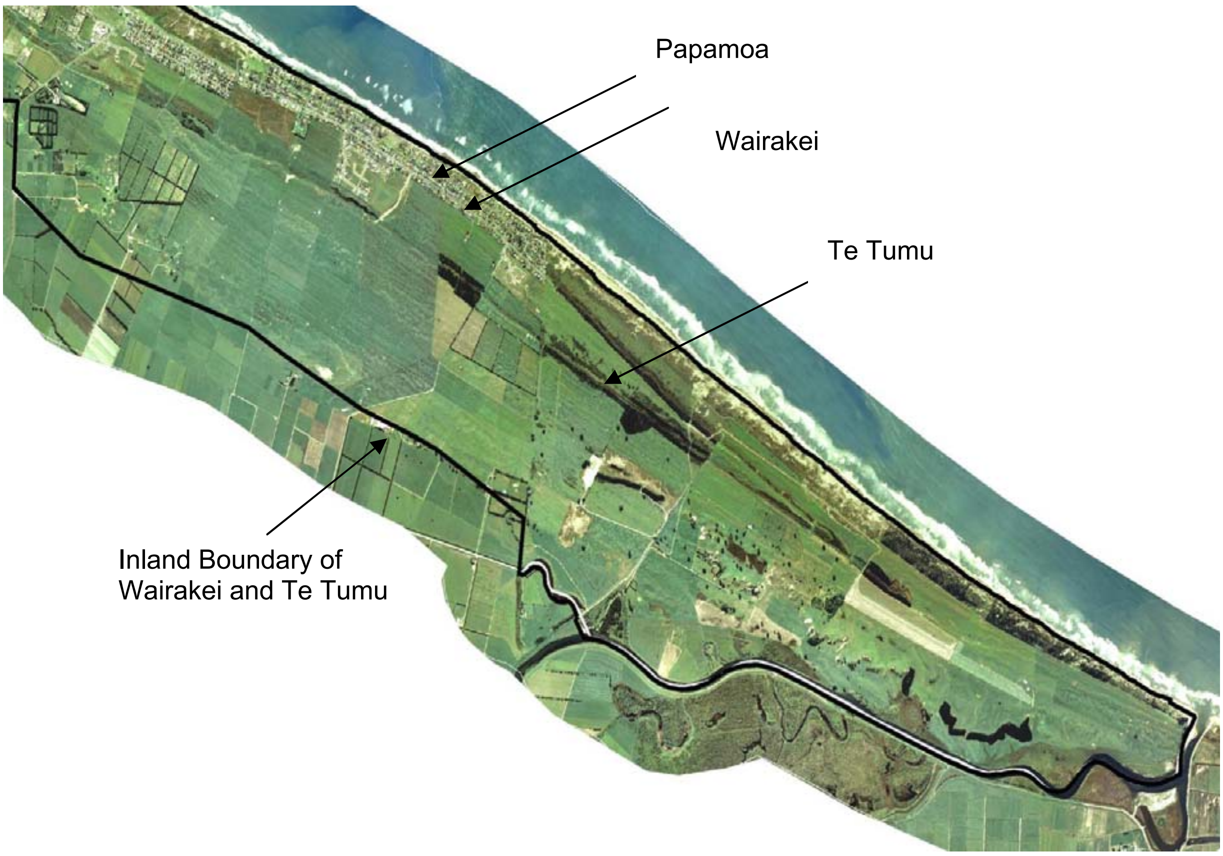

Figure 1.2 Location and extent of Papamoa, Wairakei and Te Tumu (Tauranga City Council 2004).

Papamoa is an existing coastal suburb which is largely residential in nature. The future development of this suburb is likely to comprise of intensifying the density of residential development which can be undertaken within its confines (SmartGrowth 2004).

As identified in Figure 1.2, Wairakei is inland from Papamoa. It is anticipated that Wairakei will accommodate a mix of residential, business and recreational activities when it is developed. Up to 12,500 people may live within the Wairakei Urban Growth Area, in a mix of single houses, townhouses and apartments (Tauranga City Council 2005). A plan change facilitating this development within Wairakei has recently become operative.

Te Tumu is located to the immediate south east of Papamoa and Wairakei and is located between the beach to the west and Kaituna River to the south and east. It is anticipated that Te Tumu will accommodate a mix of residential, business, commercial and recreational activities when it is developed. This includes a mix of low, medium and higher density residential development (Tauranga 2004). It is anticipated that development of Te Tumu would not commence until sometime after 2021 (SmartGrowth 2004).

The SmartGrowth Strategy is a programme aimed to manage growth in the Western Bay of Plenty. The programme is being led by Bay of Plenty Regional Council, Tauranga City Council, Western Bay of Plenty District Council, and Tangata Whenua who work with community groups and government agencies such as the NZ Transport Agency. This strategy was developed in response to community concerns about continued rapid population growth, and a lack of effective planning to manage this growth (SmartGrowth 2004). This strategy identifies potential growth areas for a variety of uses including residential, business and commercial activities. It also identifies the potential environmental, infrastructural, cultural, social and economic growth issues which are relevant for the future development of the Western Bay of Plenty.

2.0 TSUNAMI INUNDATION MODELLING

This chapter will examine the potential inundation resulting from tsunami which could occur at Papamoa, Wairakei and Te Tumu from distant, regional and local sources. This involves the modelling of tsunami from three local sources, five regional scenarios involving the Kermadec Trench and one distant source. In addition to this, modelling has been undertaken which varies the source slippage for 3 regional scenarios. This has been undertaken due to the large earthquake and tsunami from the March 2011 event in Japan. In particular, this Japanese event occurred on a subduction zone (similar to the Kermadec Trench) and the resulting slippage that occurred was greater than expected. For all of the scenarios modelled the levels of inundation are described and variations across the study areas are explained in Appendices 2 and 3.

2.1 Modelling Undertaken

The Ministry of Civil Defence and Emergency Management (MCDEM) recognises four levels of modelling in determining the degree of inundation from a tsunami:

Level 1 is the most basic of the models in which inundation is determined based on a maximum wave height projected inland from the coast to some cut-off elevation.

Level 2 uses a measure of rule-based wave height attenuation inland from the coast. This approach derives a more realistic output than a simple ‘bathtub’ model but is still a rough estimate which cannot account for physical variations in wave behaviour. The rule is applied to probabilistic coastal wave heights derived separately.

Level 3 is a computer-derived simulation model that theoretically allows for complexities that a simpler ‘rule’ cannot, such as varied surface roughness from different land uses, and water turning corners and travelling laterally to the coast on its inundation path. The model is applied to probabilistic coastal wave heights derived separately.

Level 4 is the most complete approach, based on an envelope around all inundations from multiple (likely to be many) well-tested computer models covering all credible scenarios and providing the most complex and accurate modelling (MCDEM 2009).

This project involves a partial level 3 modelling, as the calculations which have been undertaken are based on scenarios for which the shortest possible return periods were calculated; whereas a full Level 3 approach would require that the scenarios be determined from a probabilistic model of wave heights at the coast. The predicted inundation levels are calculated from a recognised tsunami modelling program and accurately incorporates the topography of the local environment based on a LIDAR (Light Detection And Ranging) survey.

All modelling was undertaken with a tsunami model (COMCOT) (Wang and Power 2011) using Mean High Water Spring (MHWS) conditions as the ambient water level as this assumes that the tsunami will arrive at high tide, which for a typical day, would represent the greatest potential risk from inundation.

The modelling which has been undertaken has assumed that the integrity of the dune systems are maintained throughout the tsunami event and are not eroded or compromised by the waves coming ashore. If the dune systems were eroded as a result of a tsunami, then the levels of inundation for the study area would likely to be greater than those modelled within this report.

Details of the computer models used, grid resolution and results for each scenario are contained in Appendix 1.

2.2 Tsunami Inundation from Distant Sources

The distant source scenario involves the modelling of the tsunami generated by a magnitude 9.1 earthquake off the coast of Peru. This scenario has been used as the energy from a tsunami generated along this area of coastline is more effectively directed towards New Zealand than what would occur if the tsunami was generated to the north along the Central and Northern Americas plate boundaries (Berryman et al., 2005) (Figure 2.1).

The fault parameters which were used are detailed in Table 2.1.

Table 2.1 Fault parameters for Peru scenario (Okal et al. 2006)

	Length	**Width**	**Dislocation**	**Strike**	**Dip**	**Rake**
Plane 1	600 km	150 km	15.0 m	305.0°	20.0°	90.0°
Plane 2	300 km	150 km	15.0 m	316.0°	20.0°	90.0°

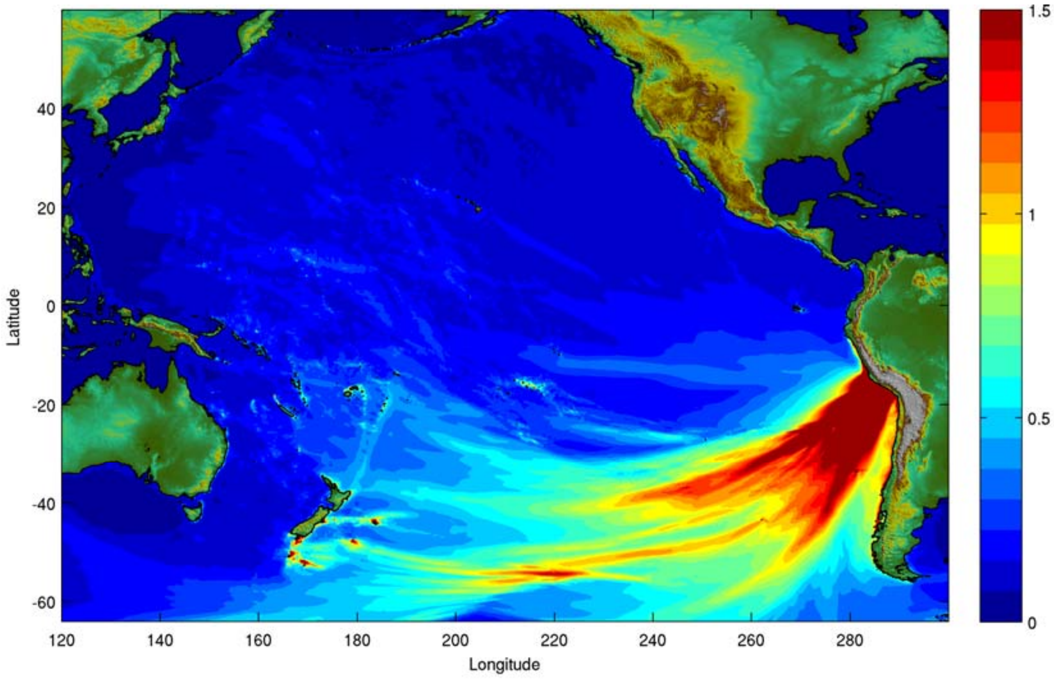

Figure 2.1 Maximum tsunami amplitude distribution for the Peru (M_w 9.1) fault rupture, showing the tsunami directivity towards New Zealand. Scale bar unit is in metres.

For this scenario, the first wave arrives 16 hours 35 minutes after the fault ruptures. The maximum tsunami elevation along the coast from Mount Maunganui to Maketu Estuary ranges from 2.5m to 3.5m above the ambient water level (MHWS). No inundation occurs along the Papamoa and Te Tumu coastlines, as the waves generated do not overtop the existing dune systems. Inundation occurs at the Maketu Estuary and the low-lying areas behind the Maketu Estuary and Kaituna Rivers as illustrated in Figure 2.2.

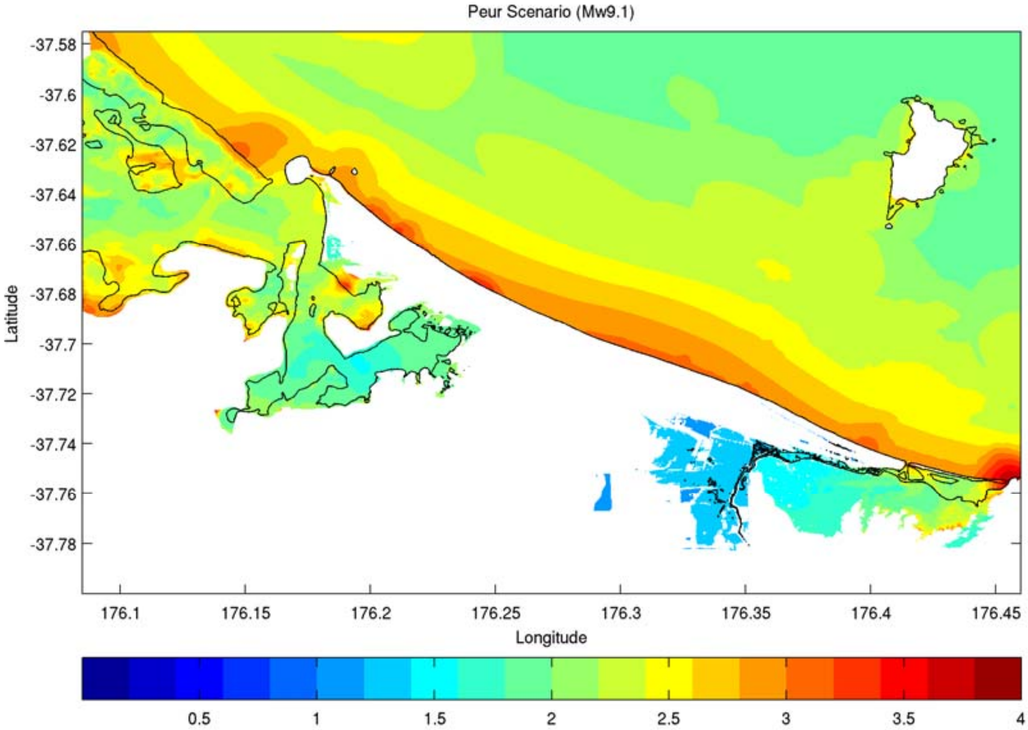

Figure 2.2 Maximum tsunami amplitude for the Peru (M_w 9.1) fault rupture scenario along the Bay of Plenty coastline. The maximum tsunami wave ranges from 2.5m to 3.5m above MHWS. The shaded colour represents the maximum tsunami height above MHWS. Scale bar is in metres

2.2.1 Tsunami Inundation from Regional Source - Kermadec Trench

Previous studies have been undertaken which have identified the Kermadec Trench as providing a significant tsunami risk to the Bay of Plenty Region (Power et al, 2011). For this study, four scenarios based on Power et al (2011) and one scenario that included the extension of the rupture into the Hikurangi Margin (Wallace et al. 2009) were used (Table 2.2). These scenarios were developed based on reviewed data. This data included larger historical earthquakes that have occurred along the Kermadec and Hikurangi Margin as well as geodetic modelling of the relative motions of the converging tectonic plates. Based on this assessment, the Kermadec Trench is divided into three segments, namely A, B, and C (Figure 2.3). These three segments are similar to the southern, central and northern end segments identified within previous works (Goff et al. 2006, De Lange et al. 2008). It should be noted that this segmentation represents an approximate division between portions of the Trench with different physical properties – in practice earthquake ruptures may cross between segments, and only partially rupture any one segment. Segmentation provides a convenient way to discuss different scenarios, but has very limited predictive power.

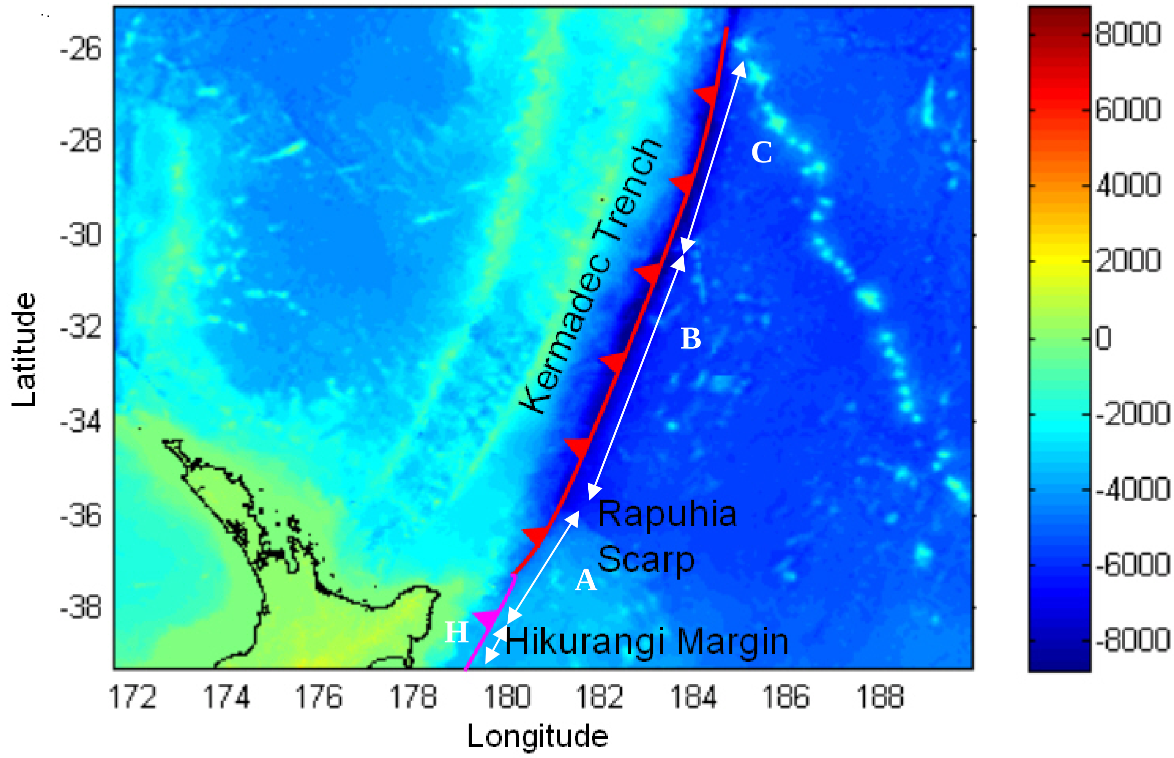

Figure 2.3 The segmentation of the Kermadec Trench based on Power et al. 2011 (Segments A, B, and C) and the extension to the Hikurangi Margin (Segment H) based on Wallace et al (2009). The scale bar units are in metres that show the depth of the ocean (for negative value) and the high of land (positive value).

The five regional scenarios which were modelled as part of this study and their relative fault parameters are detailed within Table 2.2. The warning time is estimated as the time interval between the main shock of an earthquake scenario and the time of the first wave starting to disturb the coastal front. For the modelled scenarios, the sign of first arrival is a drawback of the water front.

Table 2.2 The fault parameters for the modelled regional scenarios

Segment	Scenario	Length	Width	Slip	Magnitude	Warning Time (approx)
A	Southern	300 km	100 km	5.0 m	Mw 8.5	50 minutes
B	Central	600 km	100 km	10.0 m	Mw 8.9	70 minutes
C	Northern	500 km	100 km	8.0 m	Mw 8.8	100 minutes
A+B+C	Whole Kermadec	1400 km	100 km	22.0 m	Mw 9.4	50 minutes
H-K (A+B+H)	Kermadec – Hikurangi	537 km	97 km	20.0 m	Mw 9.1	50 minutes

The return period for the above scenarios is computed by dividing the amount of slip from an earthquake (m) with the annual convergence rate (m/year) (Table 2.3). These calculations are simplistic and do not take into account aseismic slip, and slip in earthquakes of other magnitudes. As such, the calculated returns periods in Table 2.3 are strongly conservative and represent lower limits for the possible return times; the true return periods may be considerably longer.

There is considerable uncertainty over the maximum magnitude of earthquake that the Kermadec Trench could experience. It is possible that earthquakes as large as those in the Whole Kermadec and Kermadec - Hikurangi scenarios do not occur, though the possibility of such events cannot be ruled out at present. It is important to bear this in mind when interpreting the results.

Table 2.3 The computed return periods for the modelled events

Scenario	Slip (m) Scenario		Convergence Rate (mm/year)	Return Period (rounded to the nearest 10th year) Scenario		Magnitude Scenario	
	(i)	(ii)		(i)	(ii)	(i)	(ii)
Southern	5.0	30.0	49.5	100	610	8.5	9.0
Central	10.0	30.0	55.5	180	540	8.9	9.2
Northern	8.0	22.0	62.7	130	350	8.8	9.1
Whole Kermadec	22.0	30.0	55.9	390	540	9.4	9.45
Kermadec - Hikurangi	20.0	-	55.9	360	-	9.1	-

Appendix 2 contains the full results from the modelling of the above scenarios. The results show that the tsunami generated in the rupture scenarios along the Kermadec is not large enough to inundate the study area. These results also demonstrate that among the Southern, Central and Northern Scenarios, the Southern Kermadec Scenario produced the largest tsunami in the studied area and the Northern Kermadec Scenario produced the smallest.

The Whole Kermadec and the Kermadec - Hikurangi scenarios produced greater levels of inundation than the Southern Central and Northern scenarios. The scenario involving the rupture of the whole Kermadec Trench produced a tsunami elevation which was between 5m and 10m above MHWS. This scenario resulted in significant inundation occurring at Papamoa. In contrast, no significant inundation occurs between Te Tumu and the Kaituna River Mouth as the 12m high sand dunes prevent overtopping by the tsunami (which has a maximum elevation of 5.0m to 8.0m above MHWS in this area)

The Kermadec – Hikurangi Scenario was considered to be the worst case scenario for the suburbs. This scenario generated a tsunami between 5.5m and 15m above MHWS. This scenario resulted in significant inundation occurring at Papamoa. This inundation continues towards the north western portion of Te Tumu, which has lower sand dunes than the remainder of the coastline to the south east. Most of Te Tumu is not inundated by the tsunami as the sand dunes along this part of the coastline are high enough to prevent overtopping.

Figures 2.4 – 2.6 demonstrate the different levels of inundation as described above. Figure 2.4 shows there is no inundation in the study area from the Southern Kermadec Scenario, whereas Figures 2.5 and 2.6 identify the level of inundation resulting from the Whole Kermadec and the Kermadec – Hikurangi (worst case) scenarios respectively.

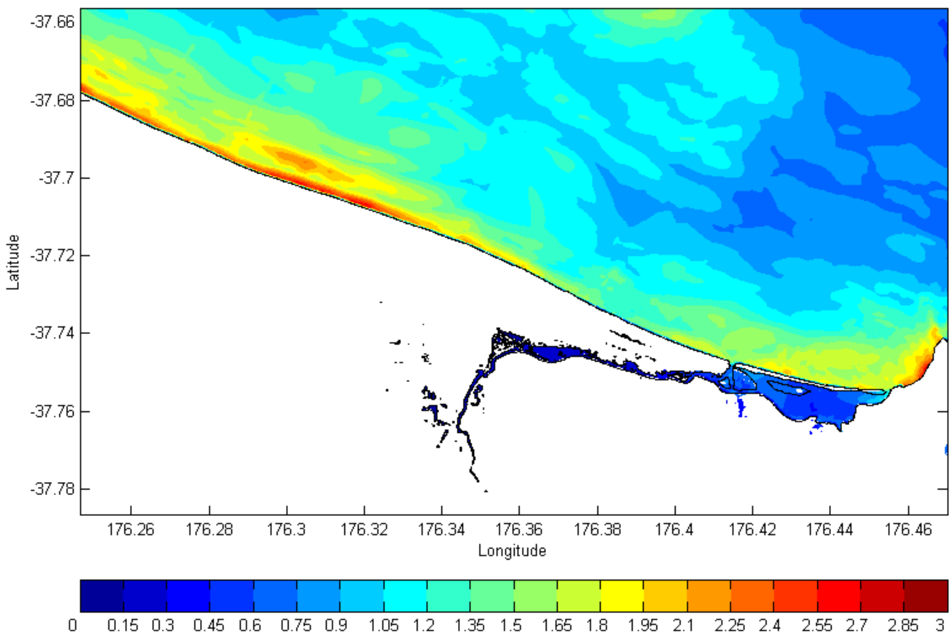

Figure 2.4 The maximum tsunami elevation above MHWS for the Southern Kermadec Scenario for the Papamoa and Te Tumu coastline. This modelling shows that there is no significant inundation except to the area around the Maketu Estuary. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

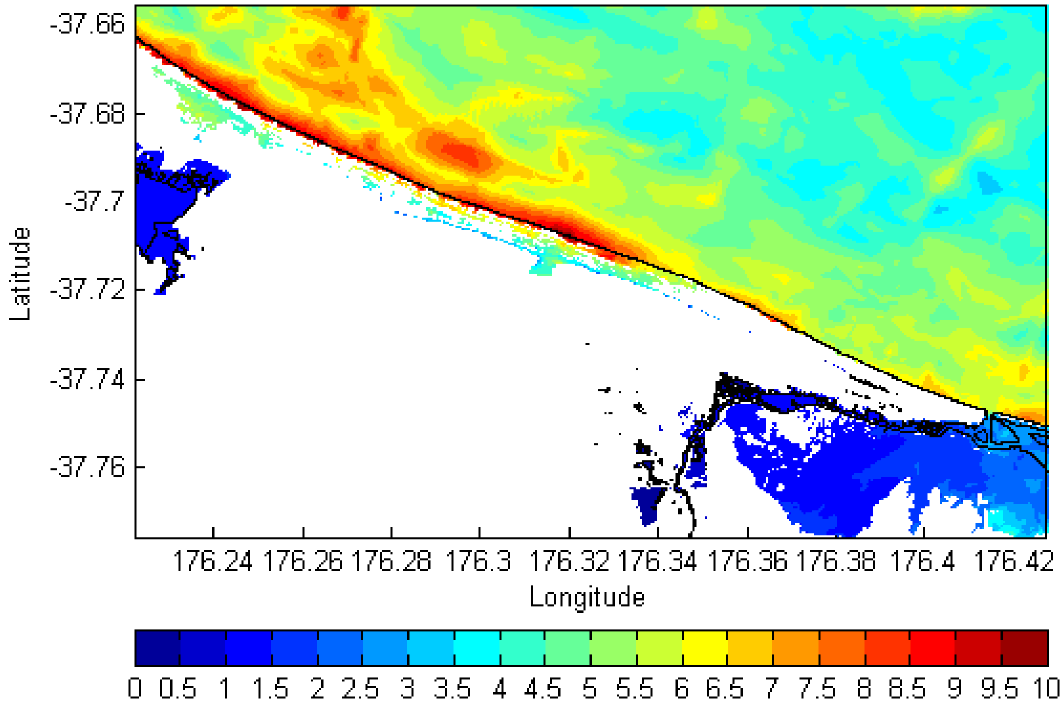

Figure 2.5 The maximum tsunami elevation above MHWS along the Papamoa and Te Tumu coastlines from the whole Kermadec scenario. No inundation occurs along the Te Tumu coastline as the sand dunes are high enough to prevent overtopping by the tsunami. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

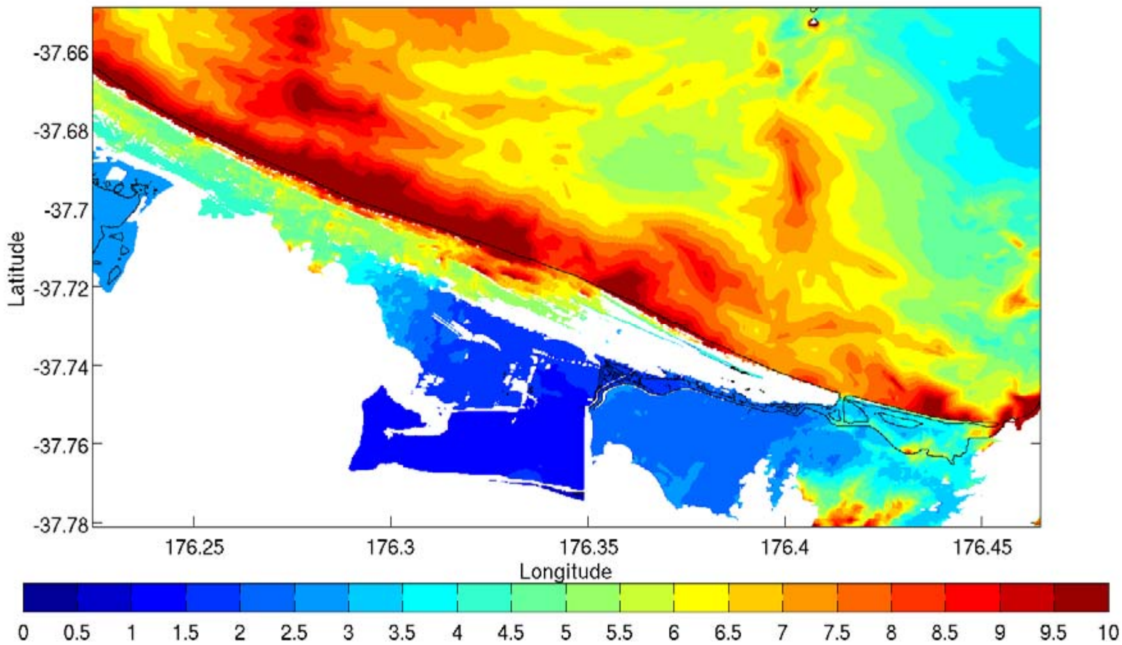

Figure 2.6 Detailed inundation pattern along Papamoa coast near Mt Maunganui which shows extensive inundation occurring between Papamoa and Te Tumu from the Kermadec - Hikurangi Scenario. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

2.3 Tsunami Inundation based on variations to the Kermadec Scenarios

The earthquake slip associated with the 2004 Indian Ocean and 2011 Japan tsunamis was greater than what was originally thought would occur on these subduction zones. This means that the degree of slip rupture on a subduction zone may be greater than what was originally thought based on the existing knowledge of the rheology and kinematics of the subducted plate. As such, modelling has been undertaken which shows the resulting tsunami if a 30m slip resulted from an earthquake on the southern and central portions of the Kermadec Trench as well as an event which involved the continuous rupture of the whole Kermadec Trench. No modelling for a variation to the Northern Kermadec Scenario was undertaken as a tsunami generated from the fault rupturing in this area has the least effect on the study area.

The modelling which increases the slip from an earthquake to 30m has been provided to show the effect that increasing the slip has on the generation of a tsunami. The data within this report however has been based on the previous models, which are considered to be more credible events which could result from the rupturing of the Kermadec Trench. It should be noted however that the level of inundation associated with increasing the slip to 30m is comparable to the level of inundation associated with the worst case scenario.

2.3.1 Variations of the Kermadec Scenarios

For this study the parameters within Table 2.4 have been used when determining the likely tsunami which would result if the amount of slip was 30m.

Table 2.4 The fault parameters for the three variations modelled assuming a 30m slip on the Kermadec Trench.

Scenarios	Earthquake Magnitude	Fault Length (km)	Depth (km)	Slip Angle (°)	Strike Angle (°)	Slip (m)
Southern	Mw 9.0	300	4-6km	90	202.9 – 212.4	30
Central	Mw 9.2	600	6.7-8km	90	197.5 – 205	30
Whole Kermadec	Mw 9.45	1400	4-8km	90	191.7 – 212.4	A + B = 30m, C=22m

For all three of the modelling events which increased the amount of slip to 30m, there was inundation of the suburbs (see Appendix 2 for the full results for the modelling which was undertaken for the slip variation scenarios). The variations which resulted in the greatest level of inundation were the scenarios involving the variations to the Southern and Whole Kermadec Trench scenarios. The levels of inundation for these two scenarios were similar (Figures 2.7 - 2.10). These two scenarios generated a tsunami which had a maximum elevation of 8m – 15m above the ambient water height, resulting in significant inundation of Papamoa and the north western area of Te Tumu. This inundation occurs as the tsunami height is greater than the dune systems which are located along this area of the coastline.

However, the central and south eastern areas of Te Tumu are not inundated as the dune systems along this area of the coastline are approximately 12m and therefore have a greater height than the modelled tsunami. However, most of the low-lying areas along the Maketu Estuary and Kaituna River plain are inundated by the tsunami.

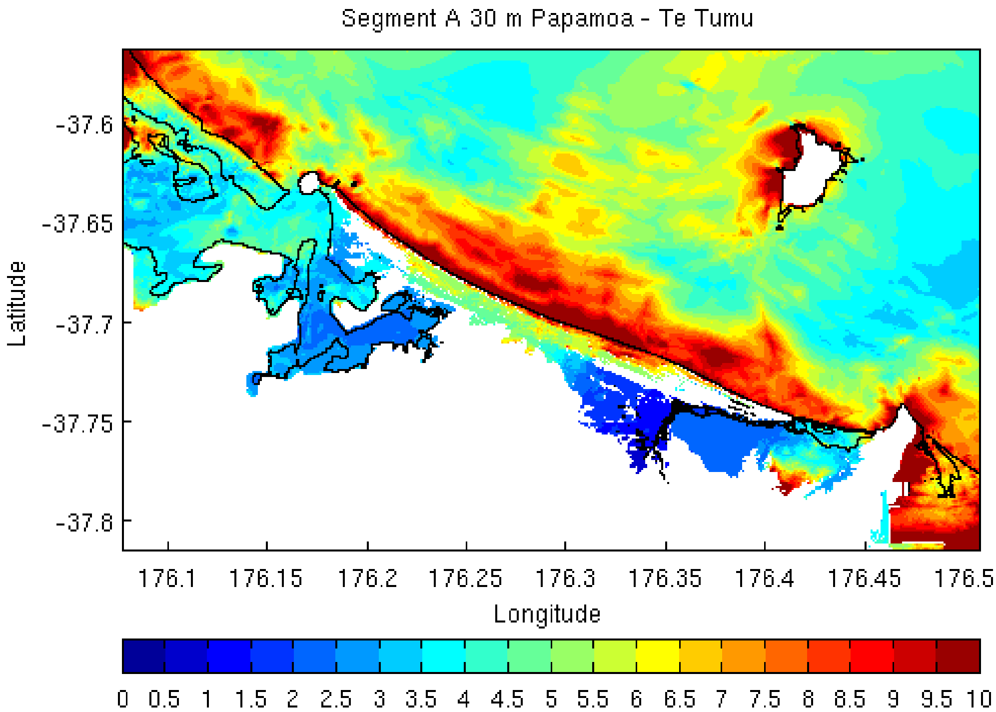

Figure 2.7 For the variation of the Southern Kermadec Scenario, the sub-regional model shows the maximum tsunami elevation varies between 8.0m and 15.0m above MHWS between the Maketu Estuary and Matakana Island. Significant inundation occurs at Papamoa and the north western half of the Te Tumu coastline. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

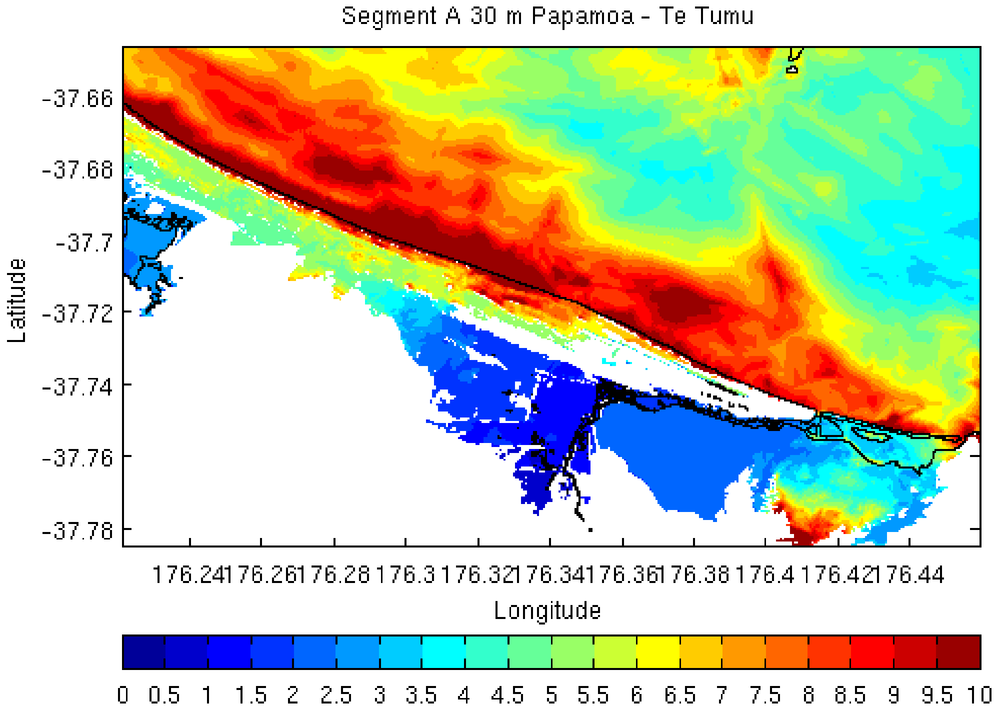

Figure 2.8 For the variation of the Southern Kermadec Scenario the detailed inundation modelling shows the extent of inundation inland along the Papamoa and Te Tumu coastline. The ~12m high sand dunes along the coastline of Te Tumu towards the Kaituna River Mouth prevent the tsunami inundating this part of the region. Most of the low-lying areas along the Maketu Estuary and Kaituna River Plain are inundated by the tsunami. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

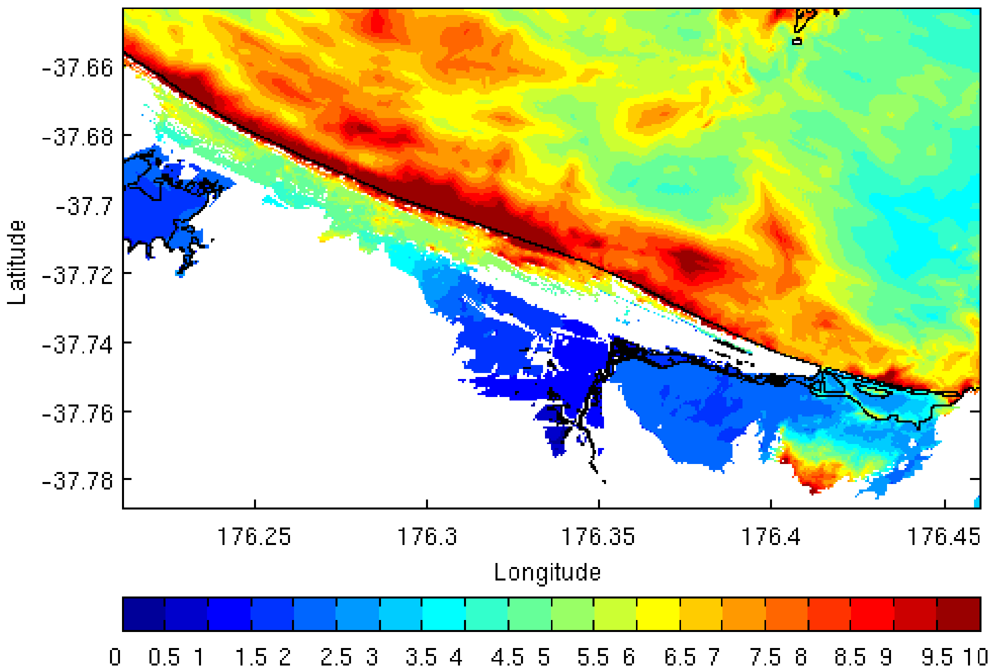

Figure 2.9 For the variation of the Whole Kermadec Scenario the detailed inundation modelling identifies the extent of inundation inland along the Papamoa and Te Tumu coastlines. The sand dunes between Te Tumu and the Kaituna River Mouth prevent the tsunami from inundating this part of the coastline. Most of the low-lying areas along the Maketu Estuary and Kaituna River Plain are inundated by the tsunami. Scale bar unit is in metres.

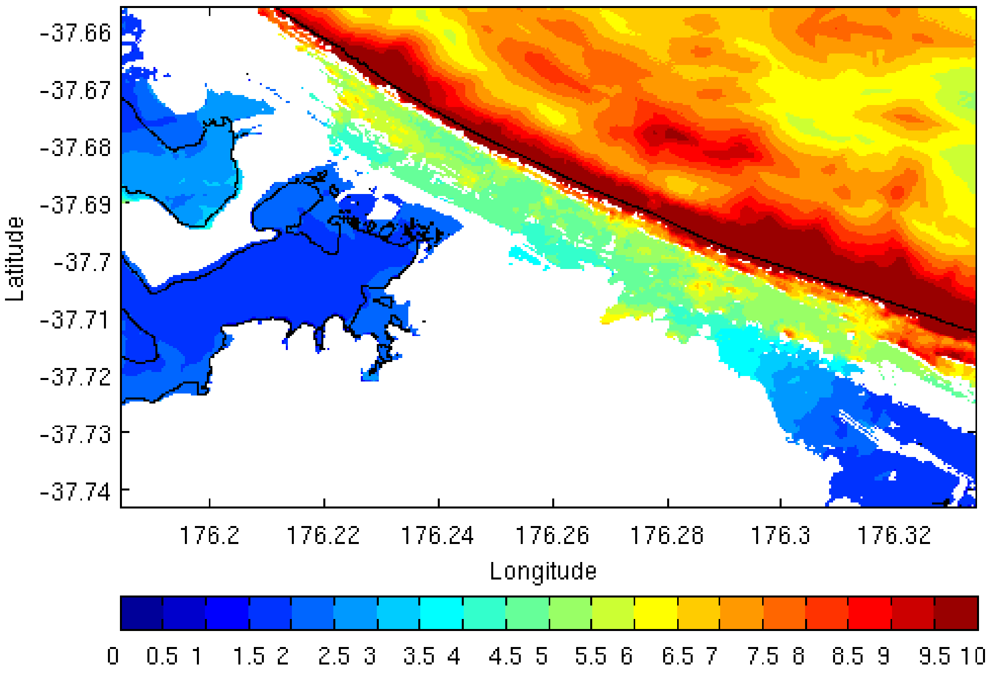

Figure 2.10 For the variation of the Whole Kermadec Scenario, the inundation extends inland at Papamoa indicating that the tsunami has overtopped the sand dunes along the beach. The tsunami overland flows propagate further down to the low-lying areas towards Te Tumu. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

The variation of the Central Kermadec Scenario produced less inundation in the study areas than what was associated with the variations of the Southern and Whole Kermadec Trench scenarios as described above. The variation of the Central Kermadec Scenario generated a tsunami which had a maximum elevation of 3.0m – 8.0m above MHWS, resulting in localised inundation of Papamoa. However, Te Tumu is not inundated as the dune systems along its coastline are approximately 12m and therefore have a greater height than the modelled tsunami. The low-lying area behind the Maketu Estuary is inundated to a moderate depth by the tsunami (Figure 2.11).

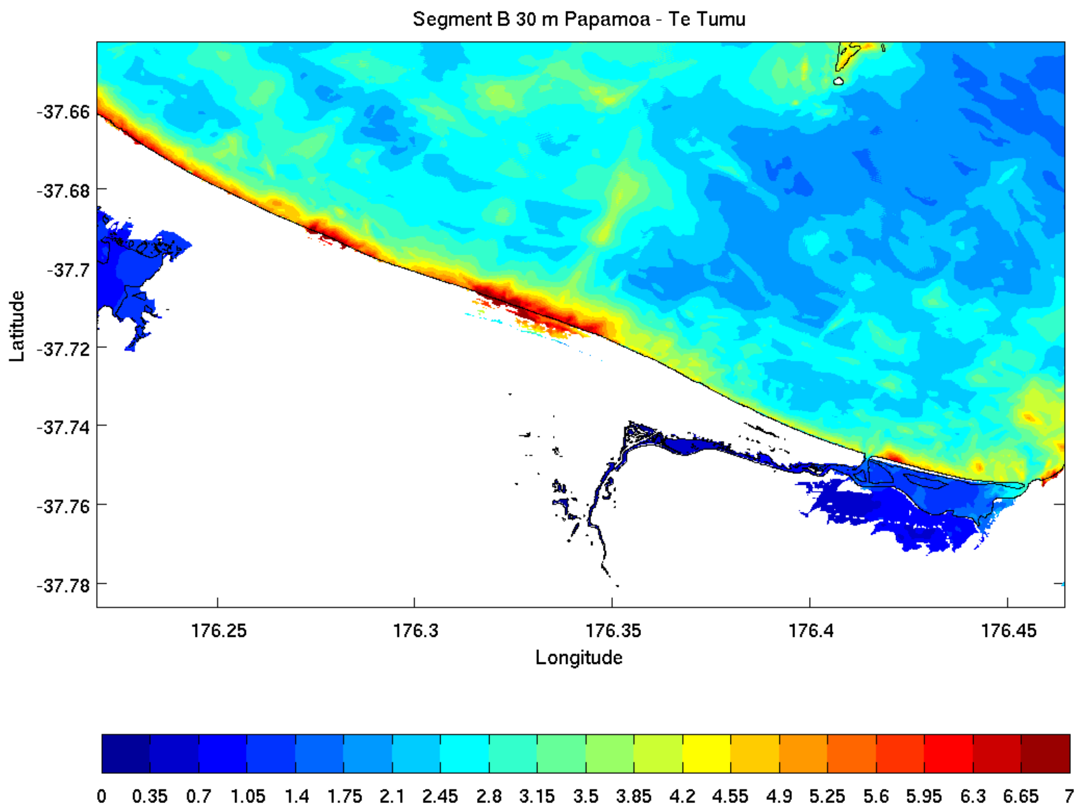

Figure 2.11 For the variation of the Central Kermadec Scenario, the detailed inundation modelling identifies localised inundation occurring along the Papamoa and Te Tumu coastlines. The tsunami from this event scenario is not capable of overtopping most of the sand dunes at Te Tumu. Localised inundation occurs at the low-lying area behind the Maketu Estuary. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

2.4 Tsunami Inundation from Local Sources

The faults as described by Lamarche and Barnes (2005) had been used by Walters et al. (2006) to assess the impact from a tsunami generated from local sources within the Bay of Plenty Region. These local faults are as follows:

- A composite Astrolabe Fault (AST-C1);
- The Volkner Fault (VOLC-C1); and
- The White Island Fault (WIF-C1)

These faultlines are located offshore from the study area (Figure 2.12). Normal faulting in this area rarely exceeds 2m vertical displacement from a single event, but the larger boundary faults may be capable of greater seabed displacements (Walter et al. 2006). Lamarche and Barnes (2005) indicated that a typical return period for these faults varies from a few hundred to thousands of years.

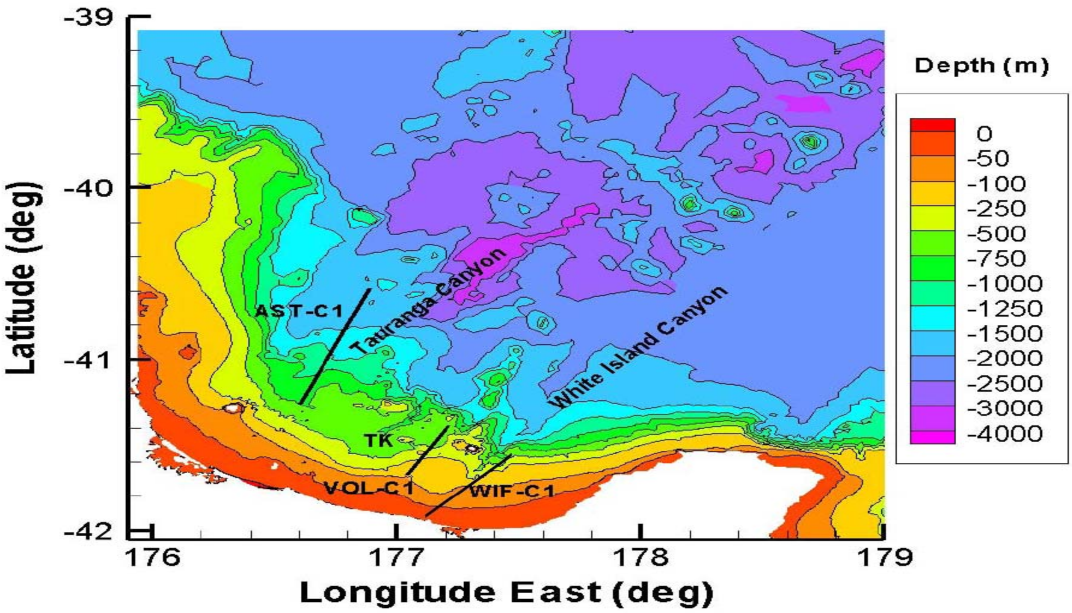

Figure 2.12 Fault delineation based on Lamarche and Barnes (2005) for the offshore environment of the Bay of Plenty (Walter et al. 2006). These have been used to assess the potential tsunami impact to the Papamoa – Te Tumu suburbs.

2.4.1 Local Source Scenarios

For this study the parameters within Table 2.5 have been used when determining the likely tsunami which would result from these faultlines rupturing. These parameters are based in the findings within Lamarche and Barnes (2005).

Table 2.5 The fault parameters for the three local faultlines

Faultline	Earthquake Magnitude	Fault Length (km)	Depth (km)	Slip Angle (°)	Strike Angle (°)	Slip (m)
Astrolabe	Mw 7.1	76	12	90	17.65	2.35
Volkner	Mw 6.79	34.6	8	90	25.46	1.39
White Island	Mw 7.01	50.6	8	90	36.76	2.03

For the three modelled local events, the resulting tsunami does not inundate any of the suburbs (see Appendix 3 for the full results for the modelling which was undertaken for the local sources). This is demonstrated by the modelling for the Astrolabe Fault Scenario which produced the largest tsunami for the three local source scenarios. The modelling for the Astrolabe Fault Scenario shows that the resulting tsunami elevations for the Bay of Plenty between the Maketu Estuary and Matakana Island range from 0.5m to 1.0m above MHWS. The highest maximum tsunami elevation of ~ 1.0m occurs near the entrance to the Maketu Estuary (Figures 2.13 - 2.15).

No significant inundation occurs in the study area for the tsunamis generated from the rupturing of the local faultlines due to the height and protection of the existing dune systems along the Papamoa coastline.

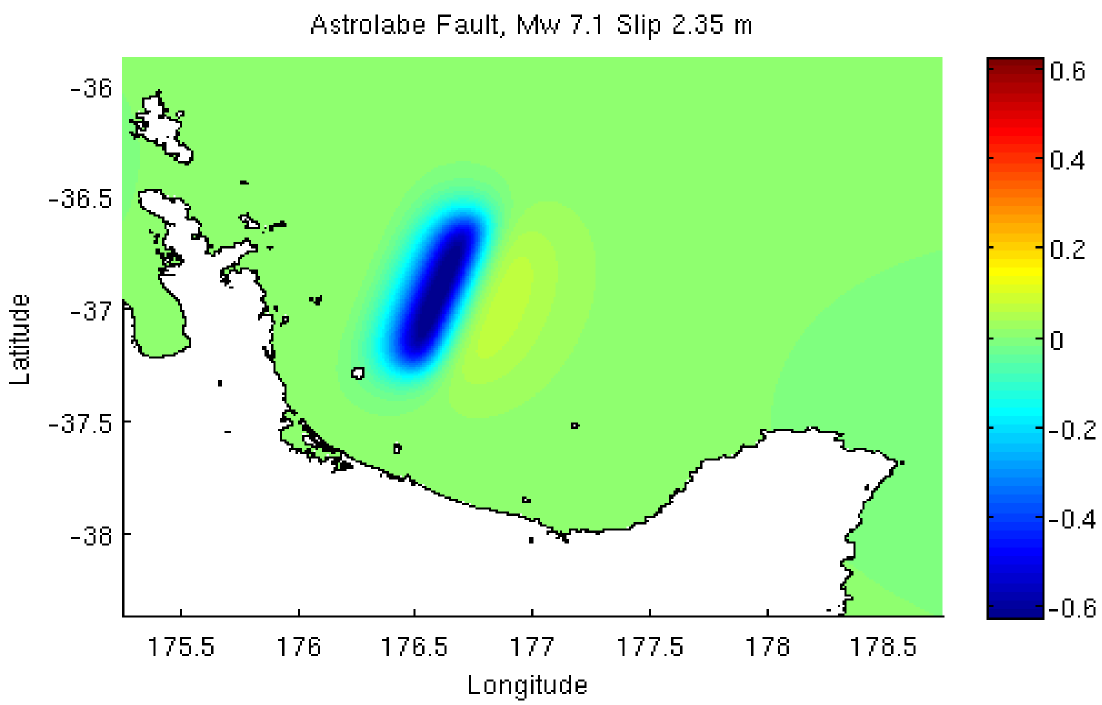

Figure 2.13 The initial sea surface displacements for the Astrolabe Fault scenario. Scale bar unit is in metres.

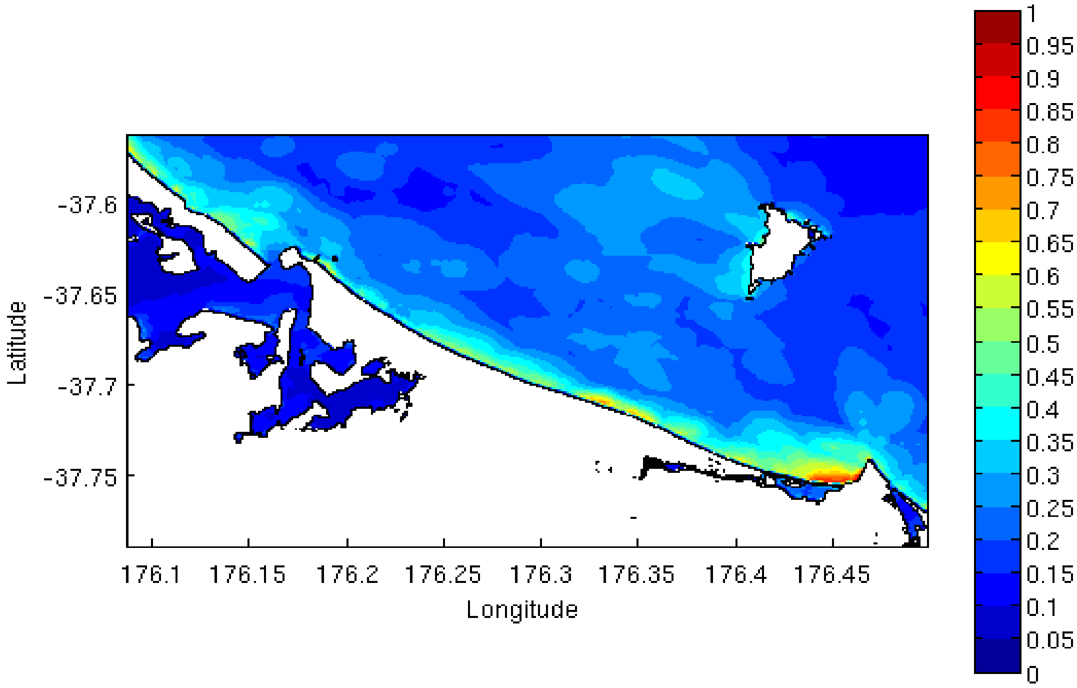

Figure 2.14 For the Astrolabe Fault Scenario, the maximum tsunami elevation varies from 0.5m – 1.0m above MHWS along the east coast of the Bay of Plenty. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

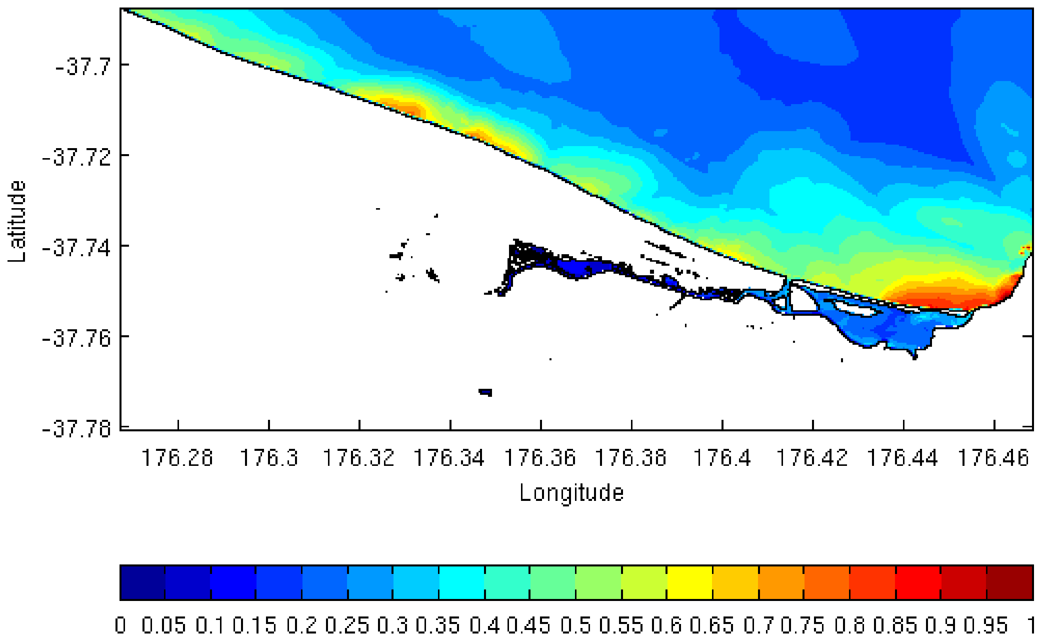

Figure 2.15 For the Astrolabe Fault Scenario, the maximum tsunami elevation varies from 0.2m – 0.6m above MHWS along the Papamoa – Te Tumu coastline. At the entrance to the Maketu Estuary the inundation may be up to 1.0m deep. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

2.5 Conclusions

- Inundation modelling of the Southern (Mw = 8.5), Central (Mw = 8.9) and Northern (Mw = 8.8) Kermadec scenarios based on Power et al. (2011) identifies that no inundation would occur in the study areas due to the presence of the existing dune systems. However, for the continuous rupture of the Whole Kermadec Trench (the whole Kermadec scenario, Mw = 9.4) or the Kermadec - Hikurangi scenario (Mw9.1), identify that inundation occurs within the study areas. The most significant inundation associated with these events occurs at Papamoa, where the dune systems are low and more degraded than at Te Tumu.
- The tsunami resulting from a the fault rupture involving the southern extent of the Kermadec Trench which has the greatest effect on the degree of inundation experienced by the study area. The warning time associated with this tsunami is approximately 50 minutes.
- The Central and Northern Kermadec scenarios do not generate large tsunamis for the study area as the resulting wave is not directed into the East Coast of the North Island.
- Variations the three Kermadec scenarios in Power et al. (2011) were also modelled by applying the slip of 30m identified in the recent 11 March 2011 Mw 9.0 Tohoku Earthquake in Japan:
    - Variation of the Southern Kermadec Scenario (Slip = 30m, Mw = 9.0): extensive inundation in the study areas;
    - Variation of the Central Kermadec Scenario (Slip = 30m, Mw = 9.2): localised inundation at Papamoa;
    - Variation of the Whole Kermadec Trench Scenario (Slip = 30m, Mw = 9.0): extensive inundation in the study areas, similar to the variation of the Southern Scenario.
- The Kermadec-Hikurangi scenario (slip = 20.0m, Mw = 9.1), involving a fault rupture extending from the Kermadec Trench into the northern portion of the Hikurangi Margin, is assumed as the worst case scenario that the data within this report has been based upon. It is however worth noting that the inundation that occurs in the worst case scenario is similar to those of the variation of the Southern Kermadec Scenario and the variation of the whole Kermadec scenario.
- For the purposes of this study, the inundation scenarios that use a slip of 30m have been provided as information only. All recommendations and calculations within this report have been based on the scenarios that do not take into account the 30m slip which has been modelled based on the Japanese event. However, it is noted that the inundation which results from increasing the slip to 30m is comparable to the inundation which arises from the worst case scenario with less slip.
- The model results show that the sand dunes provide an effective and important barrier to a tsunami. The preservation or conservation of these sand dunes along the beach front is critical, and any activities that deteriorate the dune systems should be avoided. If the dune systems are degraded due to climate change, storm waves or other extreme events, actions need to be carried out to re-condition the sand dune systems back to their original state to provide a natural protective function (Prasetya, 2007).

2.6 Limitations of the current work

No erosion of the dunes or sedimentation has been considered or taken into account during the modelling processes. Therefore, no morphology changes to beaches and sand dunes which may occur due to strong currents and breaking waves have been incorporated into this model. In the event that erosion of the dune systems were to occur, then the levels of inundation resulting from a tsunami would be greater than the modelling within this report.

Most of the scenarios used in this report assume earthquake rupture with uniform slip. However, in real events, the slip varies on a variety of spatial scales. The pattern of slip distribution may strongly affect the resulting tsunami in the near-field (close to the source) more so than far from the source (Geist, 1998). The uniform slip distribution used here may represent an approximation of an ‘average’ event compared to real earthquakes of the same magnitude which may have larger slip in some areas and less slip in others.

3.0 BUILDINGS, POPULATIONS, DAMAGE AND CASUALTIES

Using a detailed assets model for the study area, building damage and casualty figures for the modelled tsunami scenarios has been undertaken. The models investigate the potential numbers of deaths and injuries, and economic damage, from several scenarios as a function of water depth. Modelling was undertaken for both low and high density developments within the area, with the number of deaths and injuries being worst case situations in which it is assumed that no evacuations have occurred.

Figure 3.1 is a concept plan for the proposed new suburbs of Wairakei and Te Tumu. Note that the existing suburb of Papamoa (white background) is of necessity included in the modelling because the eastern part of it lies between Wairakei and the sea. (See also Figure 1.1). The plan shows proposed locations for housing of various densities, institutions (e.g. schools) and employment (industry and major shopping centres).

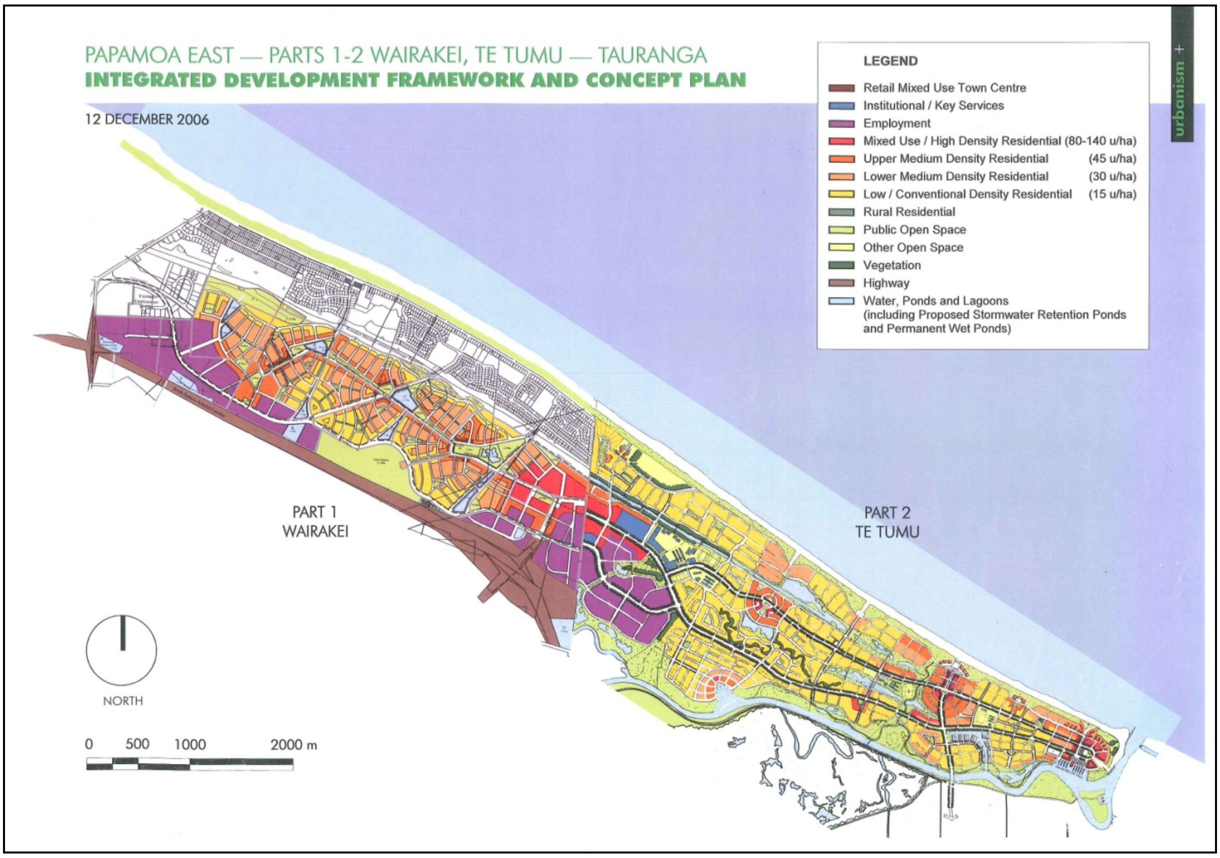

Figure 3.1 Conceptual design of the proposed new suburbs of Wairakei and Te Tumu.

3.1 Base Information for Building and Population Models

Four major items were needed in the assets and occupancy models, namely:

1. Buildings (locations, construction types, sizes, values, numbers of storeys, and uses)
2. Open spaces (locations, and type e.g. beaches, parks, gardens and footpaths)
3. Numbers of occupants for each building or open space during the night
4. Numbers of occupants for each building or open space for a typical work day

Basic requirements on total populations and building types and densities were provided by Environment Bay of Plenty, as follows:

(a) Building types and densities:

- Low-density housing (target: 12-20 dwellings per hectare)
- Medium-density housing (target: 30-50 dwellings per hectare)
- High-density mixed use (target: 60+ dwellings units per hectare)

There were also population-based needs for retirement villages, schools, commercial and industrial property, and medical facilities. After a period of trial and error the following were adopted as the basic accommodation types to meet the above needs:

- Low-density housing (15 houses per hectare)
- Medium-density housing (30 living units per hectare)
- Retirement village (30 living units per hectare)
- High-density mixed use (60 living units plus 30 commercial/office units per hectare)

The above were small buildings, i.e. 100 to 500 m^2. There were also many large buildings, with floor areas in the range 1000 – 20,000 m^2, for uses such as industrial, large retail, education and rest home/health (see Sections 3.3 and 3.4 below for details).

(b) Total population targets:

- Low-density development: Wairakei 6000, Te Tumu 20,000
- Medium-development: Wairakei 8500, Te Tumu 28,000
- High-density development: Wairakei 8500, Te Tumu 34,000

(c) Population Structure: a projection taken from Statistics New Zealand was suggested as the age distribution of the populations of both Wairakei and Te Tumu (Table 3.1).

Table 3.1 Assumed population structure (year 2031 projection for Tauranga)

Age Band	Percent
0-4 (years)	6.0
5-9	6.1
10-14	6.1
15-19	6.0
20-24	5.7
25-29	5.7
30-34	6.0
35-39	6.2
40-44	6.3
45-49	5.9
50-54	5.4
55-59	5.5
60-64	5.8
65-69	5.8
70-74	5.4
75-79	4.6
80-84	3.6
85+	3.8
Total	100

3.2 Assumptions

Other assumptions that were made in order to give a realistic family structure to the population were as listed in Tables 3.2 to 3.4. The percentages were based on judgement, trial and error, and Statistics New Zealand information on living arrangements for older people.

Table 3.2 Assumed percentages of families having various numbers of children, according to the ages of the parents. People younger than 20, or older than 65, were assumed to have no children living with them.

Parents Age Band (years)	Children per Family					
	0	1	2	3	4	5
20-29	40 %	50	10	0	0	0
30-54	35	35	20	7	2	1
55-65	40	50	10	0	0	0

Table 3.3 Percentages of older people in various types of accommodation.

Age Band	Own Home	Retirement Village Unit	Rest Home	Hospital
65-69	94.1 %	5.0	0.8	0.1
70-74	88.1	10.0	1.8	0.1
75-79	75.9	20.0	3.9	0.2
80+	52.2	30.0	17.1	0.7

Table 3.4 Percentages of older people living in 1, 2 or 3-person households.

Age Band	Persons per Household		
	1	2	3
65-69	25 %	70	5
70-74	28	68	4
75-79	37	59	4
80+	53	42	5

Then, based partly on the above and partly on judgement, the percentages of dwellings having various numbers of occupants were derived for day and night scenarios and for retirement and other types of household (Table 3.5).

Table 3.5 Percentages of dwellings having various numbers of occupants (a) for retirement villages, and (b) all other cases, for night-time and daytime scenarios.

Number of Occupants	All Others	All Others	Retirement	Retirement
	Day	Night	Day	Night
0	49.9 %	0 %	0 %	0 %
1	30.0	15.9	61.6	61.6
2	15.0	40.2	36.5	36.5
3	4.6	29.4	1.9	1.9
4	0.5	10.7	0	0
5	0	2.8	0	0
6	0	0.7	0	0
7	0	0.3	0	0

Assumptions, judgements and statistical data related to work day occupancies are given in Tables 3.6 to 3.9.

Table 3.6 Percentages of people in various locations during a normal work day.

Age Band	Home	Playcentre	Kindergarten or Care	Primary	Intermediate Secondary	Tertiary	Work
0-4	30 %	20	50	0	0	0	0
5-9	0	0	0	100	0	0	0
10-14	0	0	0	0	100	0	0
15-19	0	0	0	0	50	20	30
20-24	0	0	0	0	0	30	70
25-64	20	0	0	0	0	0	80
65-69	70	0	0	0	0	0	30
70-74	90	0	0	0	0	0	10
75+	100	0	0	0	0	0	0

Table 3.7 Percentages of people indoors at their location during a normal work day.

Age Band	Home	Playcentre	Kindergarten or Care	Primary	Intermediate Secondary	Tertiary	Work
0-4	70 %	80	80	0	0	0	0
5-9	0	0	0	80	0	0	0
10-14	0	0	0	0	80	0	0
15-19	0	0	0	0	80	80	85
20-24	0	0	0	0	0	80	85
25-74	70	0	0	0	0	0	85
75-79	50	0	0	0	0	0	0
80-84	80	0	0	0	0	0	0
85+	100	0	0	0	0	0	0

Table 3.8 Percentages of people remaining in Wairakei and Te Tumu for a normal working day. The remainder were assumed to commute to Tauranga and Mt Maunganui.

Age Band	Percentage
0-4	100
5-9	100
10-14	100
15-19	80
20-24	80
25-74	80
75-79	100
80-84	100
85+	100

Table 3.9 Percentages and numbers of people in various occupations in Wairakei and Te Tumu, estimated using Statistics New Zealand data for Tauranga.

Statistics Industry Classification	Percent of Total Population	Number, Low-Density Model	Number, High-Density Model	General Location Type
Agriculture, Forestry and Fishing	1.3	272	445	Industry Zone
Mining	0	7	11	Industry Zone
Manufacturing	4.9	1,012	1,655	Industry Zone
Electricity, Gas, Water and Waste Services	0.2	37	60	Outdoor
Construction	5.1	1,063	1,738	Industry Zone
Wholesale Trade	2.2	463	756	Industry Zone
Retail Trade	5.7	1,190	1,944	Shops / Offices
Accommodation and Food Services	2.4	506	828	Shops / Offices
Transport, Postal and Warehousing	2.3	473	772	Industry Zone
Information Media and Telecommunications	0.5	104	170	Shops / Offices
Financial and Insurance Services	1.2	252	412	Shops / Offices
Rental, Hiring and Real Estate Services	1.6	332	542	Shops / Offices
Professional, Scientific and Technical Services	3.3	681	1,113	Shops / Offices
Administrative and Support Services	1.4	291	476	Shops / Offices
Public Administration and Safety	1.2	260	424	Shops / Offices
Education and Training (NB: Not Students)	2.9	611	999	Schools
Health Care and Social Assistance	4.5	943	1,541	Hospital / Offices
Arts and Recreation Services	0.6	126	206	Shops / Offices
Other Services	2.1	430	703	Shops / Offices
Not Elsewhere Included	2.4	494	807	Industry Zone
Total Workers remaining in Wairakei & Te Tumu		9,545	15,602	
Commute to Tauranga & elsewhere		2,386	3,901	
Total Workers		11,931	19,503	

3.3 Small Buildings

Layout of the new suburbs was done within Excel spreadsheets using purpose-written macros. Four basic types of small buildings were used, i.e. single-storey houses, 2-storey twin units, 3-storey high-density mixed-use units, and single-storey retirement village twin units. All were arranged in twin rows of buildings between side roads that were approximately perpendicular to the coast. Basic details of the layouts follow.

- Single-storey house: Section size 20 m x 25 m, house footprint 200 m^2, height 1 storey, side road width 16 m (giving 15 houses per hectare – low-density residential housing).
- Twin unit: Section size 20 m x 25 m, building footprint 200 m^2, height 2 storeys, side road width 16 m (giving 15 buildings per hectare, i.e. 30 living units – medium-density residential).
- Mixed use units: Section size 10 m x 30 m, building footprint 150 m^2, height 3 storeys (level 1 commercial use, levels 2 and 3 residential apartments), side road width 20 m (giving 25 buildings per hectare, i.e. 50 living units and 25 commercial units per hectare – high-density mixed use). The arrangement was a 10 m x 15 m (footprint) building at the

front of the section, a yard/parking area of 10 m x 12 m behind, plus half-share of a 6 m wide access way.

- Retirement village: Section size 20 m x 25 m, building footprint 300 m^2 (two living units, 150 m^2 each), height 1 storey, side road width 16 m (giving 15 buildings per hectare, i.e. 30 living units – medium-density residential).
- The section and house sizes and the road widths were taken from sizes and widths observed in the existing suburb of Papamoa.

The resulting numbers of buildings and living units that were needed to house the required numbers of people, for low-density and high-density cases, were as follows:

Table 3.10 Numbers of buildings and living units required for low- and high-density scenarios.

Location	**Wairakei Low-Density**		**Wairakei High-Density**	
Living Type	Buildings	Living Units	Buildings	Living Units
Houses	1144	1144	0	0
Twin-Units	408	816	2168	4336
Mixed-Use	152	304	152	304
Retirement Units	88	176	216	432
Location	**Te Tumu Low-Density**		**Te Tumu High-Density**	
Living Type	Buildings	Living Units	Buildings	Living Units
Houses	3804	3804	160	160
Twin-Units	1364	2728	4608	9216
Mixed-Use	528	1056	962	1924
Retirement Units	280	560	392	784

3.4 Large Buildings

Large buildings were treated on a case-by-case basis, with buildings in each main use category ("General Location Type" in Table 3.9) being sized to house the required numbers of people according to the building occupancy densities given in Table 3.11.

Table 3.11 Building occupancy rates for various broad-use categories.

Main Use Category	Daytime Occupancy Rate (m^2 per person)	Night-time Occupancy Rate (m^2 per person)
Industrial	108	3000
Retail (Shops / Offices)	25	1500
Educational	10.75	1500
Hospital	45	50

3.4.1 Industrial

About 100 Ha of land at the western end of the Wairakei block is designated as "Employment" (Figure 3.1). In the model it was all assigned to Industrial use, and populated with buildings broadly modelled on existing industrial buildings in the suburb of Omanu. For the low-density case there were 20 buildings at 10,000 m^2 each and 52 at 4000 m^2 each, giving a total floor area of 408,000 m^2 (i.e. 41 Ha). For the high-density case there were 20 buildings at 16,000 m^2 each and 52 at 6700 m^2 each, giving a total floor area of 668,400 m^2 (i.e. 67 Ha).

3.4.2 Retail

There was about 150 Ha of land designated as either "Employment", “Institutional / Key Services” or “Retail Mixed Use Town Centre” between the Wairakei and Te Tumu blocks (Figure 3.1). This was assigned to large retail buildings including a mall, tertiary education, and resthomes including basic health facilities. The retail buildings and mall were broadly modelled on existing buildings located on Domain Road in Papamoa.

For the low-density case there were 11 retail buildings, viz. a mall at 11,000 m^2, 2 shops at 3000 m^2 each, 4 shops at 2000 m^2 each, and 4 shops at 850 m^2 each, (28,400 m^2 total,). For the high-density case the buildings were all approximately 65% larger (47,000 m^2 total).

3.4.3 Educational

Five types of educational facility were provided: tertiary, pre-school, primary school, intermediate school and high school. Locations and sizes of buildings for the low-density case were as follows: tertiary – two buildings of 4360 m^2 each located together near the eastern end of the Wairakei block, secondary – ten buildings of 2100 m^2 each located together near the western end of the Te Tumu block, and intermediate – eight buildings of 790 m^2 each located together near the western end of the Te Tumu block. Four combined primary school and pre-school complexes were created, one near the eastern end of the Wairakei block and three spaced within the Te Tumu block. Each comprised five buildings of about 900 m^2 for primary use plus 5 buildings of about 600 m^2 for per-school use. All were single-storey buildings. The tertiary buildings were assumed to be of reinforced concrete construction, and all of the others of timber construction.

For the high density case the tertiary buildings were assumed to be two-storey, and all of the remaining buildings were increased in size by about 60% to accommodate the higher numbers of pupils.

3.4.4 Resthome / Health

A single resthome facility was sited near the western end of the Te Tumu block to meet the needs of both Wairakei and Te Tumu. It also included basic hospital facilities. For the low-density model it consisted of three single-storey buildings of about 7000 m^2 each, to house 413 resthome occupants, 18 hospital patients and 43 staff. For the high-density model the building size was increased to 11,600 m^2 each, to house 657 resthome occupants, 30 hospital patients and 70 staff.

3.5 Open Spaces

At any time of the day some people are indoors at their places of work, some are indoors at home, and some are outdoors. For the purposes of our model "work" means "not at home", and so includes students, shoppers, hospital patients etc. Two scenarios were used for the modelling, day-time and night-time, with the percentages of people in various places being as listed in Table 3.12. The percentages were taken from a model developed for New Zealand (Cousins 2010, Spence et al 1998). Three types of open space were used, viz. near-building (e.g. footpaths, house sections, carparks), general (e.g. parks, wasteland, farmland) and beaches.

Table 3.12 Locations of people for day-time and night-time scenarios.

Time of day	Indoors at Work	Indoors at Home	Outdoors
Workday (11 a.m.)	58 %	22 %	20 %
Night-time (2 a.m.)	4 %	95 %	1 %

3.6 Allocation of People to Buildings and Spaces

The sequence of processing was as follows:

Step 1: Families were created as described in Section 3.2, particularly Tables 3.2 to 3.4, and allocated to dwellings on a random basis using the probabilities from Table 3.5.

Step 2: Non-residential buildings were occupied using the occupancy rates of Table 3.11. A small degree of randomness was included in the process.

Step 3: Shoppers were allocated to the large retail buildings in numbers equal to the numbers of workers in the buildings. They were randomly taken from dwellings. Shoppers are not specifically added to the occupants of the small shops/offices of the mixed-use type buildings, the assumption being that people would come and go from these so that the total numbers of occupants at any time of the day would not be very different from the number initially allocated.

Step 4: Occupants of buildings were randomly selected and moved outdoors to near-building open space in the proportions required.

Step 5: Some of the outdoors people were randomly selected and moved to beaches and other open space. The target numbers were 100 on beaches and 10 in other open space for the low-density model, and 200 and 20 respectively for the high-density model.

The results of this process are summarised in Tables 3.13 to 3.16. The low density targets for night-time population, i.e. 6000 for Wairakei and 20,000 for Te Tumu, were achieved without difficulty. However the high density target for Te Tumu, 34,000, was not able to be achieved using reasonable housing densities, and so 3,800 people were transferred the Wairakei area in order to meet the combined target for both areas. For convenience Tables 3.13 and 3.15 include the Building Values. They are derived in Section 3.7 below.

Table 3.13 Model population and building value by suburb – Low-Density Model

Suburb	Daytime Population	Night-time Population	Building Replacement Value ($m)
Papamoa	8,500	16,700	2,500
Wairakei	10,100	6,100	1,700
Te Tumu	13,700	20,100	3,600
Totals	32,300	42,900	7,800

Table 3.14 Model population by location type – Low-Density Model

Location	Daytime Population	Night-time Population
Indoors	25,900	42,500
Outdoors	6,400	420
Beach	100	6
Totals	32,400	42,926

Table 3.15 Model population and building value by suburb – High-Density Model

Suburb	Daytime Population	Night-time Population	Building Replacement Value ($m)
Papamoa	8,800	16,700	2,500
Wairakei	16,600	12,400	3,400
Te Tumu	22,700	30,200	5,800
Totals	48,100	59,300	11,700

Table 3.16 Model population by location type – High-Density Model

Location	Daytime Population	Night-time Population
Indoors	38,400	58,700
Outdoors	9,520	590
Beach	180	10
Totals	48,100	59,300

3.7 Construction Types and Values

Small buildings were randomly allocated building types according to the percentages of Table 3.17, which were based on surveys of buildings in Hawke’s Bay. The large buildings were allocated construction types as follows: retail – tilt-up construction (reinforced concrete panel walls, portal frame, and light iron roof); industrial – a variety of wall types, but with portal frames and light iron roofs; resthome/health – concrete frame buildings, educational – light timber construction for single-storey buildings, concrete frame construction for 2-storey buildings.

Table 3.17 Percentages of construction types allocated to small buildings

Age	Construction Type	Residential, Retirement	Mixed Use
pre-1940	Light Timber	92	NA
	Brick Masonry (URM)	4	
	RC Shear Wall	2	
	Concrete Masonry	2	
1940-on	Light Timber	96	25
	RC Shear Wall	2	25
	Concrete Masonry	2	25
	RC Frame	0	25

The following floor heights were assumed: residential and retirement dwellings – 0.3m, educational buildings – 0.5m, all others – 0.1m. Construction cost rates ($2011/m^2, scaled from $2007 construction cost rates for New Zealand (Rawlinsons 2007)) are listed in Table 3.18.

Table 3.18 Construction cost rates

Use Category	Construction Cost ($/m^2)
Residential 1-storey	1800
Residential 2-storey	2355
Retirement	1800
Mixed use	2355
Industrial	1380
Large Retail	2138
Resthome / Health	3330
Educational	2310

3.8 Damage Rates for Buildings

Models for estimating building damage as a function of tsunami water depth have been developed from a combination of damage data from historical tsunamis, information taken from the New Zealand building code for houses, and judgement (Cousins *et al* 2007a, 2007b, 2009, Reese *et al* 2007 and Standards New Zealand 2000). Judgement was required because the historical data were of uncertain reliability and often incomplete, and also because the building code could only be used set lower limits to the lateral strengths of the types of building covered in it. The models used in the current project are shown in Figures 3.2 and 3.3. Basically, swiftly flowing water of 2m depth is expected to collapse a timber single-storied house, 2.8m for a timber 2-storey house, 4m for a concrete single storey house and so on.

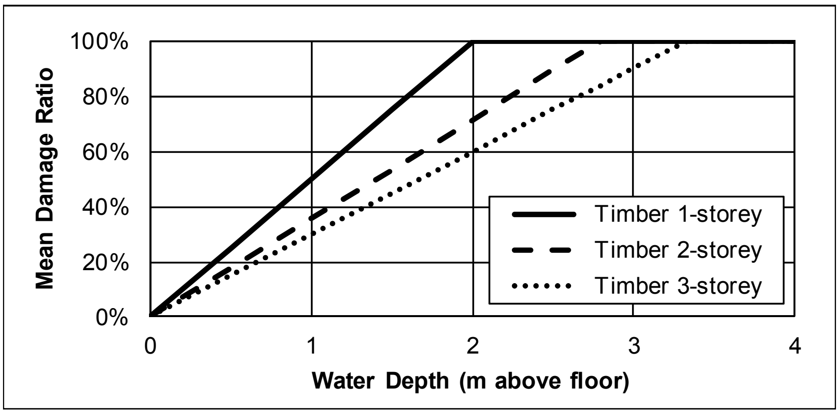

Figure 3.2 Tsunami fragility functions for timber buildings.

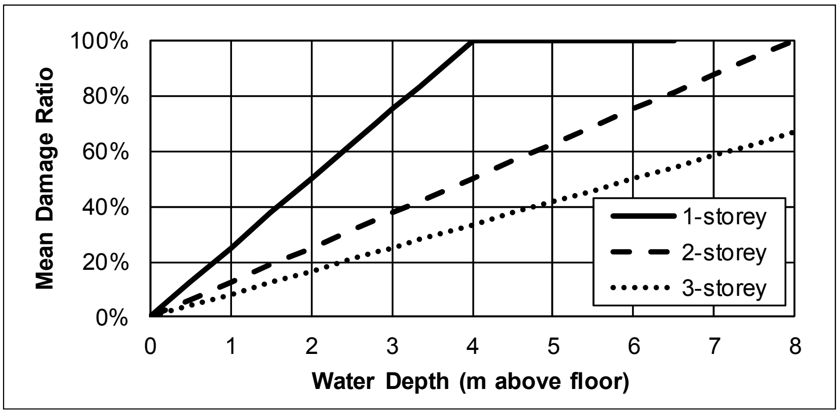

Figure 3.3 Tsunami fragility functions for concrete buildings.

3.9 Casualty Rates

Based on data from historical tsunamis, we have developed very simple models for rates of death and injury to people overwhelmed by tsunami (Berryman 2005, Cousins *et al* 2007a, 2007b, Reese *et al* 2007, Saunders 2006). The models are:

Death rate (% of people exposed) = 4 x water depth (m)

Injury rate (% of survivors) = 4 x water depth (m)

The models are illustrated in Figures 3.4 to 3.6, noting that in all three plots the casualty rates are expressed as percentages of the total population exposed. The match with the data is as good as can be expected. Note also that all buildings reaching a damage ratio of 1 are assumed to collapse, and a worst-case situation of zero self-evacuation is also assumed. These figures show, for example, that when there is a water depth of 5m, a death rate of approximately 20% of the number of people exposed is expected.

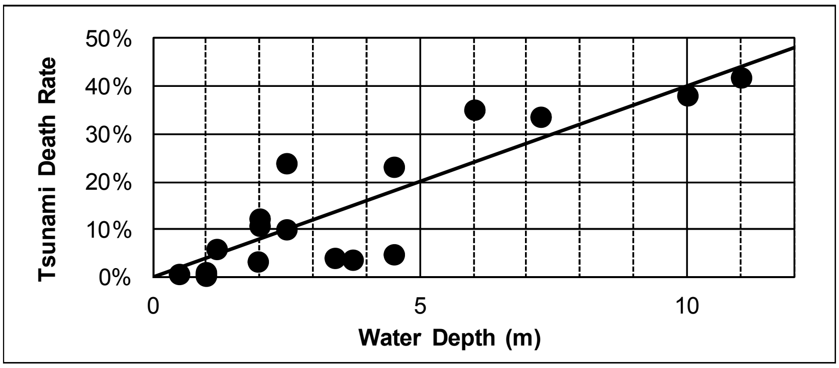

Figure 3.4 Rates of death observed in tsunamis, data (points) and model (solid line).

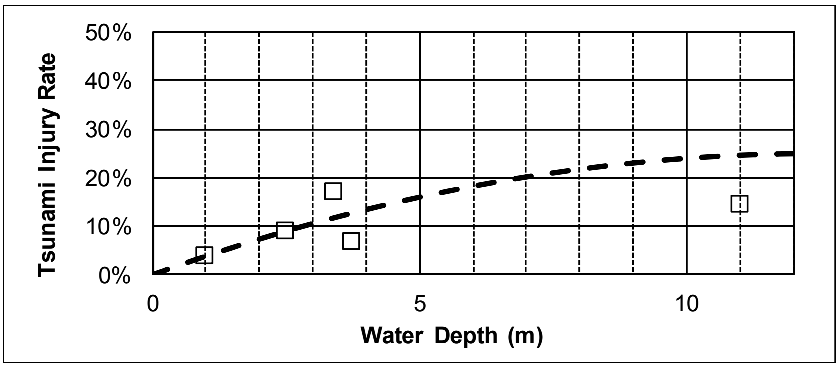

Figure 3.5 Rates of injury observed in tsunamis, data (points) and model (dashed line)

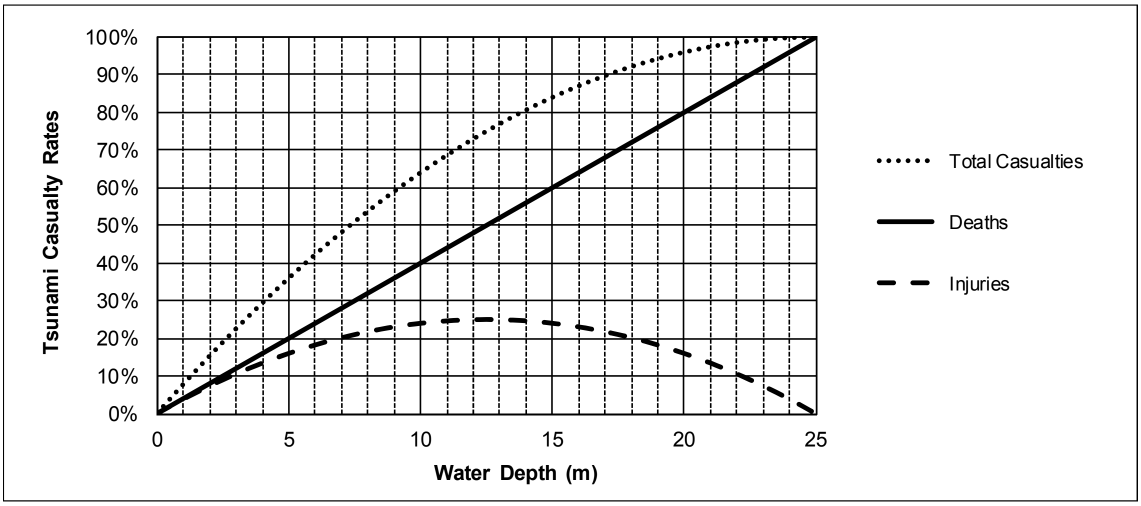

Figure 3.6 Modelled rates of death and injury from tsunami – extrapolated

3.10 Casualty and Loss Estimates

There were four basic steps in the loss modelling, (a) the tsunami modelling as described above was used to estimate water depths for every building and person location in the assets model, (b) the damage and casualty rates were calculated using the functions illustrated in

Figures 3.2 to 3.6, (c) the damage rates were multiplied by the building values to give the direct damage costs, and (d) the casualty rates were combined with a random number to determine whether a particular person was killed or injured. This was done for all six tsunami scenarios, for both the low- and high density population models, for day and night situations (i.e. a total of 24 simulations).

The damage and death rates which have been calculated do not take into account the scenarios modelled based on the Japanese event as the possibility for these to be assessed rose too late to be included within the report. However, the levels of inundation of these events are comparative to the worst case scenario and therefore the damage and death rates would be similar.

Detailed tables of casualties and losses are given in Appendices 4 and 5 (for the low-density and high-density models respectively), followed by tables of annual probabilities of death or injury in Appendix 6. Summary tables for "best" and "worst" case scenarios are presented here. The best-case scenario is rupture of just the southern portion of the Kermadec Trench and the worst case is the combined rupture of the Kermadec and Hikurangi Trenches (Appendix 2).

For the best case (least damaging) of the scenarios, the numbers of deaths are small in all three suburbs (Tables 3.19 and 3.20). Note that high accuracy cannot be claimed for the results – a figure of "3" for example should be interpreted as "probably between 1 and 10". The numbers of injuries are similar to the numbers of deaths.

Table 3.19 Southern Kermadec Scenario – casualties and losses by suburb, low-density model.

Suburb	Daytime Deaths (number)	Daytime Death Rates (%)	Night-time Deaths (number)	Night-time Death Rates (%)	Building Damage ($million)	Building Damage (%)
Papamoa	3	0.04	0	0	0	0
Wairakei	2	0.02	1	0.02	0	0
Te Tumu	4	0.03	4	0.02	9	0.25
Totals	9	-	5	-	9	-

Table 3.20 Southern Kermadec Scenario– casualties by location, low-density model

Location	Daytime Deaths (number)	Daytime Death Rates (%)	Night-time Deaths (number)	Night-time Death Rates (%)
Indoors	1	0.004	4	0.009
Outdoors	0	0	1	0.2
Beach	8	8	1	17

For the worst case scenario, the numbers of deaths are high, and the damage costs are very high (Tables 3.21 and 3.22). Also, as is made clear by the overall death and cost rates, there are clear differences between the three suburbs, with Te Tumu being the least dangerous and Papamoa being the most dangerous. The daytime–night-time variations in numbers reflect the workday migrations of people. Papamoa and Te Tumu experience net losses of people during the daytime, whereas Wairakei, which is home to many industrial, commercial, health/resthome, and post-primary educational buildings, experiences a net gain. There is little difference between the indoors and outdoors death rates, while the much higher beach rates results from the high water depths (10-12m) on the beaches.

Table 3.21 Worst Case Scenario – casualties and losses by suburb, high-density model.

Suburb	Daytime Deaths (number)	Daytime Death Rates (%)	Night-time Deaths (number)	Night-time Death Rates (%)	Building Damage ($m)	Building Damage (%)
Papamoa	680	8	1260	8	1800	71
Wairakei	470	3	400	3	1200	36
Te Tumu	310	1.4	570	1.9	1000	18
Totals	1460	-	2230	-	4000	-

Table 3.22 Worst Case Scenario – casualties and losses by location, high-density model.

Location	Daytime Deaths (number)	Daytime Death Rates (%)	Night-time Deaths (number)	Night-time Death Rates (%)
Indoors	1090	3	2200	4
Outdoors	290	3	30	5
Beach	80	43	3	33

Annual probabilities of death or injury for individuals were obtained by dividing the numbers of deaths or injuries by the populations exposed (Tables 3.13 to 3.16) and then by the computed return period for the scenario (Table 2.3). Full discussion and interpretation of the results are provided in Section 4 below, with just a few illustrative results being shown here (Tables 3.23 to 3.26). Both low- and high density results are given for the "best" and "worst" case scenarios, primarily to illustrate that the differences between the low- and high-density results are largely insignificant. For convenience, numbers smaller than 1×10^{-6} are highlighted in green and numbers larger than 1×10^{-4} in red.

Table 3.23 Southern Kermadec Scenario – low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	3×10^{-6}	6×10^{-6}	0	0
Wairakei	2×10^{-6}	0	2×10^{-6}	0
Te Tumu	3×10^{-6}	7×10^{-7}	2×10^{-6}	5×10^{-6}

Table 3.24 Southern Kermadec Scenario – high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	8×10^{-6}	1×10^{-5}	6×10^{-7}	0
Wairakei	6×10^{-7}	2×10^{-6}	8×10^{-7}	0
Te Tumu	2×10^{-6}	3×10^{-6}	1×10^{-6}	2×10^{-6}

Table 3.25 Worst Case Scenario – low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Wairakei	9×10^{-5}	8×10^{-5}	1×10^{-4}	1×10^{-4}
Te Tumu	5×10^{-5}	5×10^{-5}	6×10^{-5}	6×10^{-5}

Table 3.26 Worst Case Scenario – high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Wairakei	8×10^{-5}	8×10^{-5}	9×10^{-5}	8×10^{-5}
Te Tumu	4×10^{-5}	3×10^{-5}	5×10^{-5}	4×10^{-5}

3.11 Variability and Limitations in the Modelling

This study is essentially trying to forecast the future, and when dealing with tsunami this cannot be done with precision. We are dependent on imperfect knowledge of past events and of future conditions. We rely heavily on the apparent robustness of taking averages of effects on substantial numbers of assets, and on models of natural phenomena, some of which are at an early stage of development, and which will be subject to modification as new information and interpretations become available.

Reliable data on casualty rates are scarce and the variability is large. The data for death rates are adequately modelled as a linear function of water depth (Figure 3.6) and, if treated as lognormally distributed, show a level of variability about the median which is similar to that seen in data on earthquake damage and casualties.

Available data on injury rates were simply not sufficient to define a reliable relationship between injury rate and water depth. While our model is an adequate match to the few data that were available, it is largely speculative.

4.0 LAND USE PLANNING - IMPLICATIONS OF RISK

This chapter will examine high density and low density development scenarios for Papamoa, Wairakei and Te Tumu and the levels of risk to these from the modelled tsunami events. The levels of risk for each of the development densities for each suburb were determined to be acceptable, tolerable or intolerable, based on the methodology developed by Saunders (2011). The thresholds for determining whether the identified risks are acceptable or otherwise, was based on a combination of the annual probabilities of death/ number of deaths detailed within the Proposed Bay of Plenty Regional Policy Statement and the economic damage thresholds by Saunders (2011).

4.1 Determining risk

Figures 4.1 and 4.2 identify the methodology used in this chapter to determine whether the risks to the proposed development scenarios from the modelled tsunami events are acceptable, tolerable or intolerable.

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

Figure 4.1 Methodology for determining the acceptability or otherwise of the consequences from a natural hazard (Saunders et al. 2011).

Saunders (2011) recognises that natural hazards are unlikely to affect a community evenly, with some areas suffering greater effect than others. This can lead to a disparity in the consequences a community suffers, and make it difficult to determine the level of risk appropriate for an event. For example, a community may suffer no loss of life or serious injuries from a tsunami, so therefore the health and safety risk is acceptable or tolerable. This same event however could destroy 60% of the housing stock, so the economic and social costs would probably be intolerable. There are two approaches which can be undertaken to address this disparity.

Saunders (2011) suggests that a ranking of consequences could be undertaken, where the most severe consequence is taken as representing the severity of an event. The second approach is one that the Ministry for Civil Defence and Emergency Management (MCDEM) has created, the “SMG” model for determining hazard priorities (MCDEM, 2009). Under the SMG model, S = seriousness, M = manageability and G = Growth. Under the seriousness ranking MCDEM (2009 p17) recommends the social environment (which includes health and safety), has the highest weighting at 50%, with the others (built, economic and natural environments) weighted as follows:

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

Communities are able to readjust these weightings to reflect their particular community values and priorities.

This chapter adopts the first approach, whereby the severity of the event is taken as the most severe of the consequence. This approach is considered to provide the most cautious outcome to the level of risk which can be expected to be experienced by these communities for each of the development options.

4.2 Proposed Bay of Plenty Regional Policy Statement

The Proposed Bay of Plenty Regional Policy Statement has adopted a risk-based approach to determine whether the effects from a natural hazard on a development are acceptable, tolerable or intolerable. This policy statement defines the levels of risk that are acceptable, tolerable or intolerable to the health and safety of the regions communities. These levels of risk have been used in this study when considering the density scenarios for Papamoa, Wairakei and Te Tumu. Figure 4.2 is an adapted version of the methodology identified in Figure 4.1 which incorporates the acceptable, tolerable and intolerable risk levels as identified within the Proposed Bay of Plenty Regional Policy Statement.

Scale of impact	Tolerability	Description of consequences: Health & safety	Description of consequences: Economic	Severity of Consequence
Major	Intolerable	Risk of death exceeds $1x10^{-4}$ or if the frequency of an event which causes 50 deaths is greater than 1 in 5000	Severe - more than 50 % of assets	VI
Severe			Major - between 10-50 % of assets	V
Moderate	Tolerable	Risk of death is between $1x10^{-4}$ and $1x10^{-6}$	Moderate - between 1 - 10 % of assets	IV
Minor			Minor - between 0.1- 1 % of assets	III
			Minor - between 0.01- 0.1 % of assets	II
Negligible	Acceptable	Risk of death is less than $1x10^{-6}$	Small - less than 0.01% of assets	I

Figure 4.2 Methodology for determining the acceptability or otherwise of the consequences from a natural hazard which incorporates the Proposed Bay of Plenty Regional Policy Statement Health and Safety limits.

The Proposed Bay of Plenty Regional Policy Statement only sets risk thresholds in relation to death, not economic or environmental damage or the level of injuries to the local population. On this basis, the economic figures identified by Saunders (2011) have been used. Furthermore, no analysis has been undertaken on whether the annual risk of injuries as detailed in Appendix 6 are acceptable, tolerable or intolerable for the study area.

The economic figures which have been used may not necessarily reflect the desired level of risk which the communities within the Bay of Plenty are willing to accept. Ideally, consultation should be undertaken with the local communities within the Bay of Plenty so that the risk which relates to economic damage can be formulated to reflect the desires of the local population. These levels may be different to those used within this assessment and could lead to differing conclusions about whether the risks associated with the proposal are acceptable, tolerable or intolerable.

4.3 Density scenarios for Papamoa, Wairakei and Te Tumu

This section presents the number of deaths and annual probability of death to an individual within Papamoa, Wairakei or Te Tumu from the modelled tsunami events. When determining the annual probability of risk the following calculation has been used:

Annual probability of death = (Number of deaths or injuries / the population exposed) / annual return period for the event.

This calculation has been undertaken at a suburb level and looks at the potential risks to each individual area. The calculation uses the populations at risk as a factor as this assists with normalising the results across the three suburbs and allows for meaningful comparisons (especially given the differing population sizes across these three suburbs).

The value and percentage of building damage for each of the modelled events for low and high density developments will also be presented.

The annual probability of death, the number of deaths and the percentage of building damage are then compared to the thresholds detailed within Figure 4.2. The acceptability and tolerability for each of the modelled events for Papamoa, Wairakei and Te Tumu are then discussed.

For all of the modelled scenarios, the calculated return periods (Table 2.3) are less than 5000 years (though it is important to note the highly conservative nature of the return period calculations in Section 2, and the uncertainty regarding the maximum magnitude earthquakes that the Kermadec Trench can support). As such, based upon the risk levels which are within the Proposed Regional Policy Statement, any scenario which results in the death of more than 50 people will be considered to be intolerable.

For each of the modelled events, the annual probability of death, the number of deaths and the percentage of building damage for low and high density developments in Papamoa, Wairakei and Te Tumu are discussed. No modelling was undertaken for a moderate density development. This is because there is not a large amount of difference between the levels of risk calculated for the lower and higher density developments. Where variations in the risk levels between these different density scenarios occurred, there was generally no change in whether the overall consequences to the development would be acceptable, tolerable or intolerable.

Additionally, no assessment of the potential social impacts and environmental effects resulting from the modelled tsunami events was undertaken as this level of information was beyond the scope of this project.

It should also be recognised that the death rates and numbers calculated assume that no evacuation of the suburb has occurred before the tsunami occurred.

4.4 Low Density Development

The low density development model is based on the study areas having the populations detailed within Table 4.1 below. This table also represents the building replacement values for each of the suburbs. These populations are based on a housing density of approximately 12 -20 dwellings per hectare.

Table 4.1 The daytime and night time populations and building replacement values for a low density development within the three suburbs, as derived by the methodology described in section 3.8.

Suburb	Daytime Population	Night-time Population	Building Replacement Value ($m)
Papamoa	8,500	16,700	2,550
Wairakei	10,100	6,100	1,670
Te Tumu	13,700	20,100	3,560
Totals	32,300	42,900	7,780

4.4.1 Papamoa

Table 4.2 identifies the annual probability and number of deaths for a low density development within Papamoa and the resulting building damage from the modelled tsunami events.

Table 4.2 The annual probability of death, number of deaths and building damage to a low density development within Papamoa for the modelled tsunami events. Shaded figures show the intolerable levels of risk as per the Proposed Regional Policy Statement.

Earthquake Scenario	Number of Deaths (day)	Annual risk of Death (day)	Number of Deaths (night)	Annual risk of Death (night)	Building Damage $m (% damaged)
Southern Kermadec	3	3×10^{-6}	0	0	0
Central Kermadec	4	3×10^{-6}	0	0	0
Northern Kermadec	4	4×10^{-6}	0	0	0
Whole Kermadec	70	2×10^{-5}	170	3×10^{-5}	290 (11%)
Worst Case Kermadec - Hikurangi Scenario	620	2×10^{-4}	1260	2×10^{-4}	1820 (71%)

Based on Figure 4.2, Table 4.2 shows that the annual probability of death and the number of deaths for the Northern, Central or Southern scenarios can be considered tolerable for a low density development within Papamoa.

The number of deaths associated with the whole Kermadec Trench or the worst case scenario exceeds the 50 person threshold within the Proposed Bay of Plenty Regional Policy Statement, and therefore can be considered intolerable. Only the worst case scenario exceeds the threshold for the annual risk of death as in the proposed policy statement. The return periods calculated in Section 2 are highly conservative – it is plausible that a more comprehensive derivation of the return periods would place the risk of the ‘worst case scenario’ events in the tolerable category.

For events involving the Northern, Central or Southern scenarios, the amount of building damage can be considered to be acceptable. However, in events involving the whole Kermadec Trench or the worst case scenario, the level of building damage exceeds the 10% threshold and therefore can be considered to be intolerable.

4.4.2 Wairakei

Table 4.3 identifies the annual probability and number of deaths for a low density development within Wairakei and the resulting building damage from the modelled tsunami events.

Table 4.3 The annual probability of death, number deaths and building damage to a low density development within Wairakei for the modelled tsunami events. Shaded figures show the intolerable levels of risk as per the Proposed Regional Policy Statement.

Earthquake Scenario	Number of Deaths (day)	Annual risk of Death (day)	Number of Deaths (night)	Annual risk of Death (night)	Building Damage $m (% damaged)
Southern Kermadec	2	2×10^{-6}	1	2×10^{-6}	0
Central Kermadec	2	1×10^{-6}	0	0	0
Northern Kermadec	0	0	0	0	0
Whole Kermadec	10	2×10^{-6}	1	0	0
Worst Case Kermadec - Hikurangi Scenario	320	9×10^{-5}	290	1×10^{-4}	640 (38%)

Table 4.3 shows both the annual probability of death and the number of deaths for the majority of events are acceptable or tolerable. The exception is the worst case scenario where, both the annual risk of death (night time) and the number of deaths (day or night) are intolerable. It is plausible that a more comprehensive derivation of the return periods would place the risk of the 'worst case scenario' events in the tolerable category.

For the majority of the events, the level of building damage modelled can be considered either acceptable or tolerable. The exception is the worst case scenario where the modelled damage of approximately 38% of the building stock can be considered intolerable as it exceeds the 10% threshold.

4.4.3 Te Tumu

Table 4.4 identifies the annual probabilities of death and number of deaths for a low density development within Te Tumu and the resulting building damage from the modelled tsunami events.

Table 4.4 The annual probability of death, number of deaths and building damage to a low density development within Te Tumu for the modelled tsunami events. Shaded figures show the intolerable levels of risk as per the Proposed Regional Policy Statement.

Earthquake Scenario	Number of Deaths (day)	Annual risk of Death (day)	Number of Deaths (night)	Annual risk of Death (night)	Building Damage $m (% damaged)
Southern Kermadec	4	3×10^{-6}	4	2×10^{-6}	9 (0.25%)
Central Kermadec	4	2×10^{-6}	2	6×10^{-7}	8 (0.2%)
Northern Kermadec	4	2×10^{-6}	1	4×10^{-7}	4 (0.1%)
Whole Kermadec	20	4×10^{-6}	50	6×10^{-6}	90 (3%)
Worst Case Kermadec - Hikurangi Scenario	260	5×10^{-5}	450	6×10^{-5}	720 (20%)

Table 4.4 shows that the annual probability of death and the number of deaths are acceptable or tolerable for the majority of events. The exception to this is the worst case scenario. While the annual risk of death occurring can be considered to be tolerable for this scenario, the number of deaths exceed the 50 person threshold of the Proposed Bay of Plenty Regional Policy Statement. As such, the potential risk resulting from this scenario in terms of the number of resulting deaths can be considered to be intolerable.

For the majority of the events, the level of building damage modelled can be considered either acceptable or tolerable. The exception is the worst case event where the modelled damage of 20% of the building stock can be considered intolerable.

The annual probability of death and the level of building damage for Te Tumu are generally less during a worst case scenario than the other suburbs. This is largely due to the protection that the existing dune system along the beach face of Te Tumu provides to this area of coastline. This dune system is an extremely important natural feature, which significantly reduces the level of inundation experienced by this suburb.

4.5 High Density Development

The high density development is based on the study areas having the populations which are detailed within Table 4.5. This table also represents the building replacement values for each of the suburbs. This population density represents a housing density of approximately 60 dwellings per hectare.

Table 4.5 The daytime and night time populations and building replacement values for a high density development within the three suburbs, as derived by the methodology described in section 3.8.

Suburb	Daytime Population	Night-time Population	Building Replacement Value ($m)
Papamoa	8,800	16,700	2,500
Wairakei	16,600	12,400	3,400
Te Tumu	22,700	30,200	5,800
Totals	48,100	59,300	11,700

4.5.1 Papamoa

Table 4.6 identifies the annual probabilities of death and number of deaths for a high density development within Papamoa and the resulting building damage from the modelled tsunami events.

Table 4.6 The annual probability of death, number of deaths and building damage to a high density development within Papamoa for the modelled tsunami events. Shaded figures show the intolerable levels of risk as per the Proposed Regional Policy Statement.

Earthquake Scenario	Number of Deaths (day)	Annual risk of Death (day)	Number of Deaths (night)	Annual risk of Death (night)	Building Damage $m (% damaged)
Southern Kermadec	7	8×10^{-6}	1	6×10^{-7}	0
Central Kermadec	11	7×10^{-6}	1	3×10^{-7}	0
Northern Kermadec	5	4×10^{-6}	0	0	0
Whole Kermadec	100	3×10^{-5}	200	3×10^{-5}	290 (12%)
Worst Case Kermadec - Hikurangi Scenario	670	2×10^{-4}	1260	2×10^{-4}	1800 (71%)

Table 4.6 demonstrates that both the annual probability of death and the number of deaths for the Northern, Central or Southern scenarios can be considered to be tolerable for a high density development within Papamoa.

The number of deaths associated with a tsunami resulting from the whole Kermadec or worst case scenarios exceeds the 50 person threshold within the Proposed Bay of Plenty Regional Policy Statement and therefore can be considered to be intolerable. Only the worst case scenario exceeds the threshold for the annual risk of death as in the policy statement. It is plausible that a more comprehensive derivation of the return periods would place the risk of the 'worst case scenario' in the tolerable category.

Papamoa is the only suburb where the annual probability of death in a high density development is either the same or greater than the low density development. This is likely to occur for several reasons including:

i) The sand dunes located along the Papamoa beachface are generally lower and more degraded than the dune system at Te Tumu and therefore are more easily overtopped by a tsunami.

ii) Papamoa has already been extensively developed and the land available to accommodate the higher density development is at a similar risk of inundation from a tsunami as the low density housing option. As such, the number of deaths increases proportionally to the additional population which would reside within this community.

Papamoa generally experiences greater inundation from a tsunami than both Wairakei and Te Tumu. The reasons for this are as follows:

i) Wairakei is generally located inland from Papamoa and is therefore further from the beach front and is less likely to be affected by tsunami inundation;

ii) The sand dunes located along the Papamoa beachface are generally lower and more degraded than the dune system at Te Tumu and therefore are more easily overtopped by a tsunami;

iii) Papamoa has already been extensively developed and the land available to accommodate the higher density development is at a similar risk of inundation from a tsunami as the low density housing option. As such, the number of deaths increases proportionately to the additional population which would reside within this community.

For the Northern, Central or Southern scenarios, the amount of building damage can be considered acceptable. However, in the whole Kermadec and worst case scenarios, the level of building damage exceeds the 10% threshold and therefore can be considered to be intolerable.

4.5.2 Wairakei

Table 4.7 identifies the annual probabilities of death and number of deaths for a high density development within Wairakei and the resulting building damage from the modelled tsunami events.

Table 4.7 The annual probability of death, number of deaths and building damage to a high density development within Wairakei for the modelled tsunami events. Shaded figures show the intolerable levels of risk as per the Proposed Regional Policy Statement.

Earthquake Scenario	Number of Deaths (day)	Annual risk of Death (day)	Number of Deaths (night)	Annual risk of Death (night)	Building Damage $m (% damaged)
Southern Kermadec	1	6×10^{-7}	1	8×10^{-7}	0
Central Kermadec	4	1×10^{-6}	0	0	0
Northern Kermadec	2	9×10^{-7}	0	0	0
Whole Kermadec	10	1×10^{-6}	1	2×10^{-7}	0
Worst Case Kermadec - Hikurangi Scenario	510	$8 \text{ X } 10^{-5}$	400	$9 \text{ X } 10^{-5}$	1200 (36%)

Table 4.7 demonstrates that the annual probability of death and the number of deaths for the majority of events are acceptable. The exception is the worst case scenario. For this event, the annual risk is tolerable but, the number of deaths exceeds the 50 person threshold of the Proposed Bay of Plenty Regional Policy Statement. As such, the potential risk for this scenario in terms of the number of resulting deaths is intolerable.

There are several instances where the annual probability of death from the events modelled is lower for high density than for lower density developments in Wairakei. However, this does not mean that less people die in a higher density development than in a low density development. In fact, for all of the modelled events the number of deaths increases with a higher density development. However, as a higher density development has a greater population base, the annual risk of a death or injury to an individual person is less, as there are more people that could be affected.

For the majority of the events, the level of building damage modelled is either acceptable or tolerable. The exception is the worst case event, where the modelled damage is approximately 36% of the building stock and therefore is intolerable. Where building damage does occur, the value of the damage is greater than a low density development, but the percentage of buildings generally affected do not change. One reason for this includes that there are more buildings within a higher density development than a low density scenario, so a tsunami has to affect a greater number of structures to a community to result in an increase in the percentage of buildings affected. Alternatively, more buildings are likely to be constructed within areas that are less at risk from damage from a tsunami, thereby offsetting the additional structures which would be damaged within the at risk zones.

4.5.3 Te Tumu

Table 4.8 identifies the annual probability and number of deaths for a high density development within Te Tumu and the resulting building damage from the modelled tsunami events.

Table 4.8 The annual probability of death, number of deaths and building damage to a high density development within Te Tumu for the modelled tsunami events. Shaded figures show the intolerable levels of risk as per the Proposed Regional Policy Statement.

Earthquake Scenario	Number of Deaths (day)	Annual risk of Death (day)	Number of Deaths (night)	Annual risk of Death (night)	Building Damage $m (% damaged)
Southern Kermadec	5	2×10^{-6}	3	1×10^{-6}	11 (0.2%)
Central Kermadec	8	2×10^{-6}	5	9×10^{-7}	11 (0.2%)
Northern Kermadec	7	2×10^{-6}	2	5×10^{-7}	5 (0.09%)
Whole Kermadec	30	3×10^{-6}	30	3×10^{-6}	120 (2%)
Worst Case Kermadec - Hikurangi Scenario	270	$4 \text{ X } 10^{-5}$	570	$5 \text{ X } 10^{-5}$	1000 (18%)

Table 4.8 shows the annual probability of death and the number of deaths is acceptable or tolerable for the majority of events. The exception is the worst case scenario. For this event, while the annual risk of an event occurring is tolerable, the number of deaths exceed the 50 person threshold of the Proposed Bay of Plenty Regional Policy Statement. As such, the potential risk for this scenario in terms of the number of resulting deaths is intolerable.

As with Wairakei, there are several models where the annual probability of death is lower for the population in a high density development than a low density development. Again, this does not mean that less people die in a higher density development than a low density development. For the majority of the events modelled, the number of deaths increases with a higher density development. However, as a higher density development has a greater population base, the annual risk of a death or injury to an individual person is less, as there are more people that could be affected.

The number of deaths for both low and high density developments within Te Tumu is not substantially different. However, it is recognised that a higher density development generally has a greater number of deaths than a low density development. Given that a higher density development within Te Tumu has 9000 more people during the day and an additional 10,100 people at night than a low density scenario, the additional numbers of deaths are not proportionate to the additional population. The reasons why this may occur include:

- The additional housing for a higher density population is located in areas that are less at risk from inundation from a tsunami;
- A higher density development includes more two storey dwellings than a low density

scenario, which is mainly single storey housing. A two storey dwelling provides a vertical evacuation option to its occupants, which allow them to escape above the flow of the tsunami.

For the majority of the events, the level of building damage modelled is either acceptable or tolerable. The exception is the worst case event where the modelled damage is approximately 18% of the building stock and therefore is intolerable. Where building damage does occur, the value of the damage is greater than a low density development, but the percentage of buildings affected generally does not change. One of the reasons for this is that there are more buildings within a higher density development than a low density scenario, so a tsunami has to affect a greater number of structures in a community to result in an increase in the percentage of buildings affected. Alternatively, more buildings are likely to be constructed within areas that are less at risk from damage from a tsunami, thereby offsetting the additional structures which would be damaged within the at risk zones.

4.6 Conclusions

Based on the annual probability of death, number of deaths and the potential building damage for the modelled tsunami events, the following conclusions can be made:

- Papamoa generally has a tolerable level of deaths for the Southern, Central and Northern scenarios. However, the whole Kermadec Trench and worst case scenarios result in the number of deaths exceeding the 50 people limit stipulated within the Proposed Bay of Plenty Regional Policy Statement. The annual risk of death for both the low and high density developments is only exceeded in the worst case scenario. It is plausible that a more comprehensive derivation of the return periods would place the risk of the ‘worst case scenario’ in the tolerable category.
- For all events modelled, Papamoa generally has a greater number of deaths than Te Tumu and Wairakei for both the low and high density development scenarios. Papamoa is also the only suburb where the annual probability of deaths and injuries in a high density scenario is the same or greater than a low density development (however the overall tolerability level between the two development scenarios for the different modelled events does not change).
- In Papamoa, for the Southern, Central and Northern scenarios, the amount of building damage is considered to be acceptable. In the whole Kermadec Trench and worst case scenarios, the level of building damage can be considered to be intolerable.
- The figures used to determine whether the damage to buildings are tolerable or otherwise have been based on the levels stipulated in Saunders (2011) and may not represent the level of risk which the local communities are willing to accept.
- The potential annual probability of death for the low and high density development scenarios for Wairakei is either acceptable or tolerable for the majority of the modelled events. The exception is for a low development scenario at night time in Wairakei, where the number of deaths exceeds the annual probability level as stipulated within the Proposed Regional Policy Statement. It is plausible that a more comprehensive derivation of the return periods would place the risk in the tolerable category.
- The number of deaths which occur for Wairakei and Te Tumu as a result of scenarios involving the failure of the whole Kermadec Trench (high density only) and the worst

case scenario (for both development options) exceeds the 50 death limit stipulated within the Proposed Bay of Plenty Regional Policy Statement.

- The potential annual probability of death for the low and high density development scenarios for Te Tumu is either acceptable or tolerable for all events. However, the number of deaths which occur as a result of the Whole Kermadec and the worst case scenarios for both development options exceeds the 50 death limit stipulated within the Proposed Bay of Plenty Regional Policy Statement.
- While in many cases the annual probability of death for a high density development within Te Tumu or Wairakei is lower for a low density scenario, this does not mean less deaths or injuries. Rather, the population base is greater for a high density development thereby, reducing the annual probability of death to any single individual within these communities.
- The potential building damage to Te Tumu and Wairakei is generally intolerable during the modelled worst case scenario.
- There is uncertainty regarding the largest earthquakes that could occur on the Kermadec Trench. It may be the case that earthquakes as large as those in the Whole Kermadec or the 'worst case scenarios', do not occur; but the possibility cannot presently be ruled out.

5.0 PRE-EVENT RECOVERY PLANNING (FOR LAND USE)

Once a risk such as a tsunami has been identified, it is prudent to think through the impacts of a potential tsunami event, what response might need to occur and how the recovery process could work. Such prior thinking is termed 'pre-event recovery planning' and the details of such a concept are outlined in a report by Becker et al. (2008). The report primarily addresses pre-event recovery planning in a land-use context, but also notes other response and recovery issues. Thinking through all the potential impacts of an event and accounting for these beforehand will reduce any initial risk, and makes the recovery process more efficient.

This section outlines the concept of pre-event recovery planning and suggests a few pre-event recovery measures that could be considered for the development of Papamoa, Wairakei and Te Tumu.

5.1 Pre-event recovery planning methodology

A methodology for pre-event land-use recovery planning has been developed based on the Australian/New Zealand Risk Management Standard 4360:2004[1]. The methodology is presented in the form of a flow chart, allowing users to follow a comprehensive set of steps in completing the process of planning for land-use recovery. There are five main steps in the process:

- Establishing the context for land-use recovery and identifying risks
- Identifying gaps
- Analysing risks and developing options for land-use recovery

[1] Now superseded by the AS/NZS ISO 31000:2009, which is similar in nature to the previous 4360:2004

- Evaluating risks and prioritising options for land-use recovery
- Treating risks (implementation).

Figure 5.1 presents the flow chart that can be used for the consideration of pre-event recovery planning. The suggestions in the flow chart are prompts only, and are not an exhaustive list of information sources, options or considerations. They are presented to encourage the user to think about the land-use recovery process within their local context.

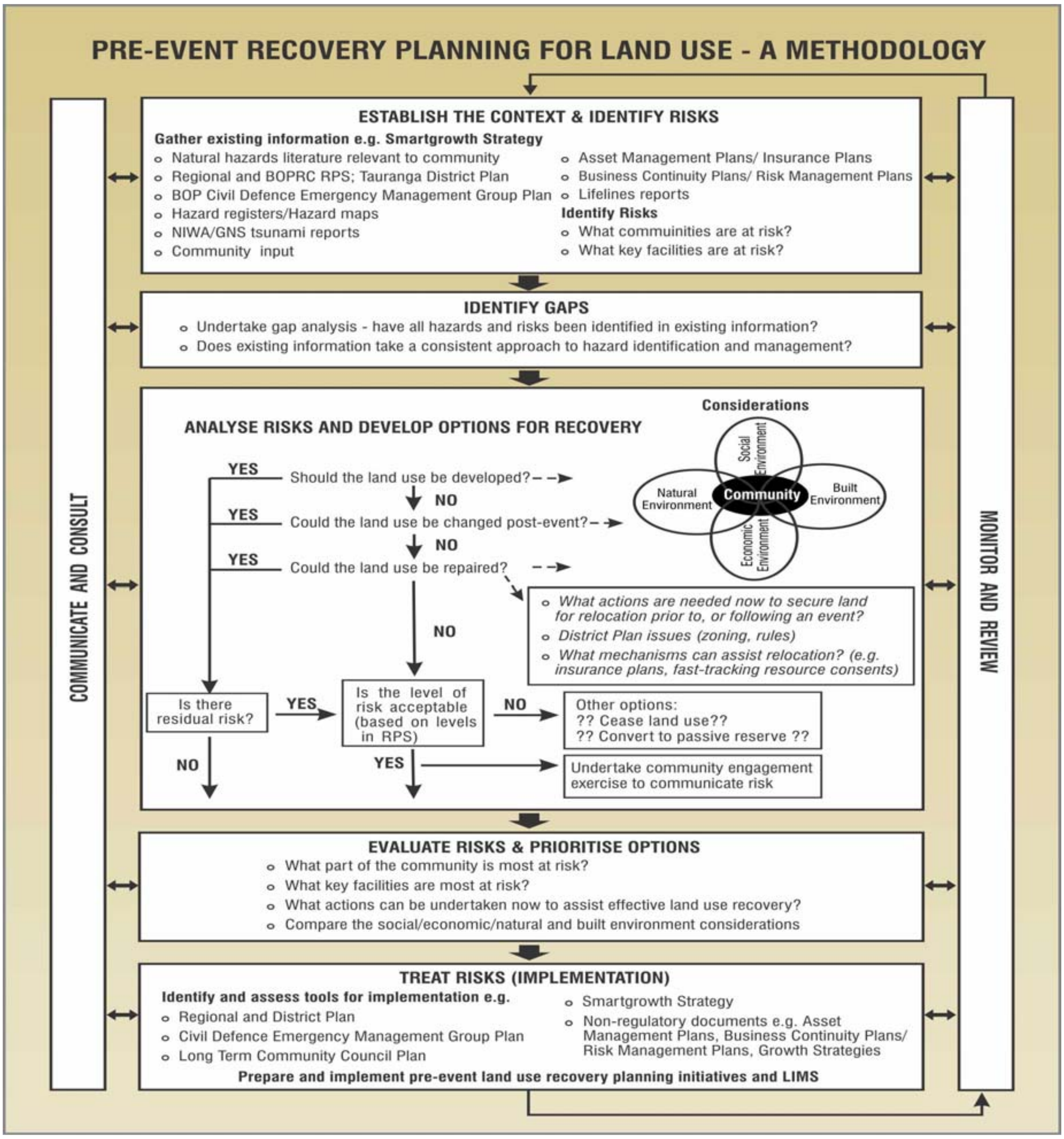

Figure 5.1 Flowchart for the consideration of pre-event recovery measures involving land use.

5.2 Pre-event recovery measures relevant to Papamoa, Wairakei and Te Tumu

There are a number of pre-event recovery measures that could be considered for the future development of Papamoa, Wairakei and Te Tumu. These include zoning tools, design controls for subdivisions and other aspects such as mitigation structures, appropriate infrastructure development, acquiring property in hazardous zones and completing a pre-event recovery plan. Appendix 7 outlines a full list of pre-event recovery options based on work undertaken in the report by Becker et al. (2008).

5.2.1 Evacuation Plan

The Western Bay of Plenty Regional Council has prepared a draft evacuation plan, which includes the evacuation of Papamoa. There is the ability to use the tsunami modelling data within this report to update and refine this plan to ensure that it accurately reflects the risk which this suburb faces.

The evacuation plan should also be updated as Wairakei and Te Tumu are developed. This plan would need to show the evacuation routes for these two suburbs and identify what measures would need to be incorporated to ensure that these routes operate as efficiently as possible. This plan should also clearly identified designated safe areas which would be able to provide shelter, food and medical care to evacuees.

5.2.2 Zoning Tools

Zoning can be used to prevent or minimise new development in hazardous areas. In order to determine whether specific zoning is required, it is first necessary to assess the risk. Maps and information on the probability of a tsunami event can assist with this process. It may be appropriate to zone the area as a “tsunami hazard zone” and in this area restrict the type of activities that can take place, with methods such as rules or assessment performance criteria. Specific rules or assessment/performance criteria might include: hazard setbacks; minimum floor heights; controlling the location of buildings, requiring specific construction design; and reduced building densities.

The current concept plan allows for a setback from the coast similar to that already in place as previous developments within the local area (Papamoa). This setback is essentially an area of public open/reserve space, with the intention of protecting the dunes. The setback does not entirely remove the risk of tsunami, and some of the proposed residential areas are situated in the primary evacuation zone. A wider setback from the beach frontage could be considered, and this at risk area could be utilised as low intensity recreation grounds. Additionally protection of a dune structure is extremely important for reducing the risk from tsunami, as well as for coastal erosion, storm surge and general ecological and amenity reasons. Thought should be given to ensuring that the zoning in the area recognises the importance of the dune system for protection from tsunami and explicitly states this (e.g. in the District Plan).

In areas at risk from hazards, it can be pertinent to ensure that population densities are kept at a low level rather than a high one. This may include reducing the number of residential units in an area, or ensuring that there are no places or activities where people come to gather (e.g. stadium, schools, etc.) located in the area. The current concept plan for the development of Wairakei and Te Tumu seeks to have a mix of predominantly low/conventional and medium density development in the areas most at-risk from tsunami (i.e. closest to the beach). There are also a few pockets of high density development close to the sea, and some areas where large numbers of the population may congregate and be at risk (e.g. shopping centre, school). There is potential to consider how a tsunami event may affect such higher density areas and what could be done to mitigate the risk, whether it be moving the high density areas to a better location or providing a way of managing the residual risk (e.g. vertical evacuation; evacuation inland).

5.2.3 Subdivision control and design

Requirements may be placed on an approved development, such as, only allowing particular design features, in order to mitigate the risk to hazards. Requirements may pertain to aspects such as lot sizes, infrastructure type, building platform level, road layout and lot access (e.g. for easy evacuation).

Keeping larger lot sizes in areas at risk from tsunami would keep development density low and thus reduce the vulnerable population living in tsunami-affected areas.

At present examples of typical buildings have been presented for the concept design, but these buildings have not been considered specifically with regard to tsunami. Rather, they are typical structures based on good practice in relation to the Building Code. It may be possible to consider whether particular tsunami-resistant designs and/or placement of structures (e.g. side-on to the beach rather than front-on) should be recommended over others in the areas known to be in a “tsunami hazard zone”. Alternatively, where two storey dwellings are proposed, consideration could be given to having garage / low use areas on the ground floor with the main living areas of the building on the second floor. This approach would assist with the vertical evacuation of residents of the dwelling and reduce the effects from a tsunami.

In the instance of tsunami, subdivision and road layout can be vital to assisting with evacuation. In general roads should lead to safe places (e.g. inland, to high ground, or to some other accessible evacuation point), be accessible (e.g. be wide enough, ensure public access) and aid timely evacuation. Where there are no roads, there should be some other alternative form of evacuation (e.g. a pathway or access way that people can use instead). The routes and safe places should be marked with signage so people know how and where to evacuate to. Roads and pathways should be designed so that they cannot be cut off (e.g. by flooding), and people isolated. The current concept plan for Wairakei and Te Tumu has a mixture of roads running alongside and away-from the beach. A number of canals, holding ponds and rivers affect the location of transport routes away from beach, creating potential difficulties with directly evacuating away from the coast and/or river. Consideration could be given in the subdivision design to ensure there are a number of key designated routes people could use to evacuate to a safe place, whether that be inland, to high ground or vertically up a building.

5.2.4 Additional design controls

As well as design controls for subdivisions, design controls may also be placed on other aspects such as mitigation structures. For example, other countries attempt to use barriers or walls as tsunami protection, and design controls could be used to specify how such mitigation structures should be built. It is however noted that the New Zealand Coastal Policy

Statement would not generally support this approach to mitigating the effects from a tsunami as the use of mitigating structures is not generally supported by this policy (New Zealand Coastal Policy Statement 2010)

5.2.5 Appropriate infrastructure development

Infrastructure should be planned for in a way that ensures that the development and replacement of infrastructure in an area subject to tsunami is appropriate. Any new key infrastructural facilities should not be located in hazardous zones. Interdependencies should also be considered. Performance requirements can be set for stormwater and wastewater infrastructure and discharges. Depending on the infrastructure in question, standards and requirements for development could be set at regional, district or organisational levels (e.g. through regional policy statement, regional or district plans, hazard mitigation plans, stormwater management plans, etc.). Provision should also be made to ensure that appropriate funding is allocated both for the continued improvement and development of infrastructure, and for recovery operations after an event. There should be a link between hazard-related infrastructure policies and the overall long term development and growth strategies for infrastructure.

5.2.6 Acquisition of property in hazardous zones

In areas that are already developed, properties identified as being in hazardous zones can be acquired and retired. In New Zealand this has happened in a number of instances and through a variety of mechanisms. In some cases the local council has bought properties off people and turned them into reserves, in others the government has done so, and other acquisition have resulted from partnership agreements between individuals and authorities. As the development of Wairakei and Te Tumu is still a concept only, this option does not apply. However, based on new hazard information, if properties in Papamoa (or the eastern coastline) are deemed at high risk, this could be an option for reducing risk for those properties. If that is a desire, mechanisms for achieving this should be identified (e.g. setting aside budget or financial contributions)

5.2.7 Assessment of Environmental Effects (AEE)

AEEs are required to accompany resource consent applications for activities. It should be ensured that specific hazards, such as tsunamis, are addressed as part of any AEE in potential tsunami affected areas, and that where necessary, solutions to avoid, mitigate or remedy the hazard are proposed. Information obtained from AEEs should link back to other sources of hazard information within a local authority (e.g. hazard register) to ensure knowledge about potential hazards is collated and maintained. (Note: Because AEEs are usually completed by developers or consultants, they may not necessarily contain comprehensive knowledge about a hazard, but can at least act as a ‘flag’.)

5.2.8 Consents

Provision should be made for consenting procedures during the response and recovery process. Consents for emergency activities may be needed in the response and initial recovery phase (e.g. debris disposal), as well as consents for particular activities over the longer recovery period. The ‘normal’ consent process may be constrained by the numbers of consents coming in, the time available to process these consents and the nature of the consents. The consenting process may be eased by identifying the types of consents likely to be needed following an event, creating appropriate documentation, applying for certain consents in advance and developing a more streamlined process (either as part of 'business as usual' or specifically for use during the event).

5.2.9 Easements

When creating new easements, it is necessary to think about what might be needed with respect to recovery (e.g. does the easement cover the correct/right amount of area to ensure access for recovery operations?). It may also be pertinent to consider what additional easements might be needed during the recovery process. For example, a large tsunami may damage a pipeline. When putting the pipeline back after the tsunami it may be better to put it in a different location, for which an easement may be required. (NOTE: Easements are legal agreements, and can be difficult to alter once an agreement has been made).

5.2.10 Pre-event recovery plan

One of the options that could be considered in allowing the development of Wairakei and Te Tumu to go ahead is the completion of a specific recovery plan for an area. Recovery plans for events around the world have proved useful, particularly in helping define roles and responsibilities after the event, leading to a smoother recovery process. In considering a recovery plan the following questions might be asked:

- What kind of hazards is the area subject to? (including tsunami)
- What kind of impacts might those events have?
- What do we need to plan for in terms of recovery?

A recovery plan may include the following aspects related to land-use planning:

- Consideration of how re-planning of a stricken area might occur after an event e.g. Will residential areas go in the same place or be in a similar form? Will services go in the same place or be in a similar form? Provisions should be made to ensure this planning can take place (e.g. in the regional or district plan).
- During recovery and rebuilding, require compliance with existing standards and best practice ('build back better').
- Consider and account for demands created on the consenting process.
- Consider allocating areas for particular activities (e.g. debris disposal, emergency accommodation) and make provision for these in relevant documents (e.g. though zoning in the district plan, ensuring that Bylaws allow the activity, etc.).
- Think about the use of a 'development moratorium' after a disaster, whereby non-urgent major planning decisions are halted for a period of time after an event until thought can be given to future rebuilding and redevelopment in a considered way.
- Consider in advance what will be done with historic buildings or structures if an event was to occur, and make provisions for dealing with them.
- Identify and allocate sites for emergency operations.
- Outline priorities for infrastructure repair.
- Consider evacuation needs, including allocation of evacuation routes and temporary waiting locations, exercises and training of staff and the populations for evacuation, as well as whether temporary and/or permanent relocation of people is required.

- Engage with the community before an event to help prepare them for how to respond if a tsunami was to occur (e.g. household preparedness, evacuation response, adaptation and recovery post-event).
- Make provision for engagement with the community about how they might want an area to look after an event. This engagement should take place both prior to and after an event. Early engagement with the community will make them more comfortable in taking part in reduction and recovery processes.
- Establish inter-agency working groups of skilled people to address specific recovery issues for the economic environment, social environment, rural environment, built environment etc.
- Ensure there will be coordination of recovery issues both before and after an event (e.g. CDEM, land-use planning, lifelines, insurance, health and safety, etc.).
- Ensure that recovery after an event has a funding source, or that there is a process set up that covers this. Link with appropriate funding sources (e.g. LTCCP, asset plans) to ensure that any planning after an event can take place as per recovery plans.
- Identify any tools (e.g. GPS, GIS, aerial photography) that can be used for hazard/risk assessment before an event, and impact assessment post-event. Incorporate any relevant procedures needed to make use of these tools after an event in the CDEM plan or other relevant local government plans.
- Ensure the recovery plan is updated as needed, especially as new information comes to hand about the hazards, lessons are learned from events/exercises, or if new development takes place.

Alternatively if a specific pre-event recovery plan is not desired, it is possible to consider incorporating many of these recovery aspects into other documents such as district or regional plans, civil defence emergency management plans, financial plans or other non-statutory plans.

6.0 SMARTGROWTH STRATEGY REVIEW

The population of the Bay of Plenty is expected to increase significantly between now and 2051. The SmartGrowth Strategy sets the framework for the response that the western Bay of Plenty sub region (being comprised of Tauranga City Council, Western Bay of Plenty District Council and Bay of Plenty Regional Council) will undertake to provide for and manage this future growth. This strategy recognises that there are a variety of social, ecological, cultural and infrastructure issues associated with an increasing future population which need to be addressed. The SmartGrowth Strategy also identifies what implementation options are available to address the issues associated with this future population growth.

This chapter evaluates the SmartGrowth Strategy and explores the options available to incorporate the identified tsunami hazard and risk into this document. Firstly, the tsunami risk and hazard is evaluated in context of the sub regional growth issues identified in the plan. This is followed by an evaluation of the identified implementation methods, and where appropriate, suggestions to better identify and address the tsunami risk and hazard are provided.

It should be recognised that the chapter concentrates on the implications of a tsunami on the SmartGrowth Strategy, and other natural hazards have not been considered.

6.1 Sub-regional growth issues

The sub regional growth component of the SmartGrowth Strategy identifies a variety of social, ecological, cultural and infrastructure issues associated with an increasing population within the western Bay of Plenty sub-region. What is less recognised, are the potential natural hazard risks associated with future development, including the risk from a tsunami.

Chapter 6.12 of the SmartGrowth Strategy identifies the importance of high value open space in addition to providing arts and leisure opportunities within future developments.

Parks and recreational areas generally have a low density of development and often small concentrations of people within their confines. As such, parks and recreational areas are recognised as being a good land-use for areas at risk from a natural hazard (including a tsunami).

While the ecological benefits of parks are identified within Chapter 6.12 of the SmartGrowth Strategy, the potential natural hazard mitigation value has not been recognised. Given the importance of the unmodified dune system along the Te Tumu section of the coastline in mitigating the potential risk from a tsunami, this hazard mitigation benefit could be recognised within this chapter. The recognition of the provision of reserve land in high risk areas (including the coastline) would align with the Environment Bay of Plenty Regional Parks Policy, which seeks to obtain regional parks within the coastal environment.

The important role of parks and recreational areas not located in high risk hazard zones as possible evacuation points could be incorporated into the SmartGrowth Strategy. Certain features could be incorporated into these areas to assist with the recovery from an event. For example in Seabrook, Washington State, firepits have been provided in local parks. In the event of an emergency, these fire pits can provide warmth, light and ability for people to cook food.

Landscapes are recognised within Chapter 6.13 of the SmartGrowth Strategy, particularly for their contribution to visual amenity values of an area. There is also the opportunity in this chapter to recognise the role of natural landscapes in mitigating the risk from a natural hazard. This is particularly so in greenfield development areas where a large proportion of the future population expansion of the western Bay of Plenty sub-region is proposed to be located. These greenfield development areas contain landscapes with a high degree of natural integrity and therefore have the potential to also play a significant role in mitigating the effects associated with a natural hazard. This can be seen at Te Tumu where the dune system plays an extremely important role in mitigating the risk from a tsunami, as the dunes are sufficient in size not to be overtopped by the majority of the modelled events.

Chapter 6.18 recognised that severely constrained land is an issue for future expansion. Within this chapter, the specific natural hazards of flooding, slope stability and erosion are identified as potential matters that may result in land being severely constrained. There is however no recognition of the potential tsunami risk and whether in some instances, this hazard in itself, may result in an area of land being identified as being severely constrained.

6.2 Evaluation of implementation methods

The implementation methods of the SmartGrowth Strategy are grouped under a series of identified issues broadly corresponding with the Vision and Outcomes Statement. The implementation methods address the following points:

Growth Issues – These are a summary of the issues identified through the research and consultation which was undertaken for the SmartGrowth Plan.

Principles – These are the specific principles to guide the actions.

Actions – These are the specific tasks that need to be carried out to implement the strategy.

(SmartGrowth 2007)

The following section of this chapter reviews the identified growth issues, principles and actions in the SmartGrowth Strategy in the context of mitigating the risk from a tsunami. Where appropriate, it discusses where there may be opportunities available within the implementation methods of the SmartGrowth Strategy to recognise the risk and available mitigation measures to offset the potential effects from a tsunami.

6.2.1 Open coast

The open coast is recognised in the SmartGrowth Strategy in Chapter 7.12 as a high demand area for future residents. As such, over time, the pressure to develop the land which bounds the open coast will increase. One of the identified growth issues for the open coast is the potential effect that climate change and rising sea levels will have on coastal erosion and flooding.

This is also a relevant consideration regarding the potential effect that a tsunami may have on the coastline, as rising sea levels have the potential to result in an increased level of erosion of the existing dune systems. If these dunes are eroded, the protection that they could provide to a community may diminish, thereby increasing the risk that the community faces from a tsunami over time. It is therefore important that the long term implications of sea level rise on existing natural features are understood and where possible mitigated, especially where these may play a role in protecting a community from a natural hazard.

While the impact that climate change and rising sea levels will have on coastal erosion and flooding is acknowledged within Chapter 7.12, there is no recognition of the potential risks from a tsunami to both current and future developments. The risk from a tsunami should be recognised within this chapter of the SmartGrowth Strategy as the open coast of the Bay of Plenty is susceptible to tsunami from local, regional and distance sources. This risk in turn may make some areas of the open coastline unsuitable for an intensification in development or for future greenfield expansion.

The principle section of the open coast chapter recognises the potential risk from human hazards and the need to actively manage these. However, this chapter does not recognise the potential risk from natural hazards, such as a tsunami. The risks associated with a tsunami (and other coastal hazards) should be identified within the principles section of the Open Coasts Chapter, to ensure that it achieves the required recognition and attention.

Action 6 of the open coasts chapter recognises the need to avoid placing developments within areas which are susceptible, or likely to be susceptible to coastal hazards. This action is clear in its intention to mitigate the future effects from coastal hazards. However it should be supported in the growth issues and principle sections of this chapter with the identification of the risk from a coastal hazard, as identified in the paragraph above.

6.2.2 Landscape

As previously identified, the SmartGrowth Strategy recognises the importance of the visual amenity values that landscapes can have on the local environment, and the need to protect these. This is reinforced in the Landscape Chapter (Chapter 7.1.8) of the SmartGrowth Strategy, where the visual amenity and cultural values of the landscape are recognised within both the growth issues and principles sections.

However, this chapter of the SmartGrowth Strategy also does not recognise the importance of natural landscape features play in mitigating the risks from a natural hazards. While these features may not have a high visual amenity value, they may have a significant role in mitigating natural hazards. This has been demonstrated in the tsunami modelling undertaken for this study, where the 11m high dune system on the seaward side of Te Tumu plays an important role in reducing the effects from a tsunami on this potential future development. As such, any future development within Te Tumu should include the protection of these dune systems as a mitigation measure to reduce the risk to the future community from a tsunami.

Chapter 7.1.8 of the SmartGrowth Strategy could also encourage the restoration of existing landscape features which could reduce the effects of a natural hazard. This has been demonstrated in the modelling where Papamoa is generally the most affected area by a tsunami. This is due to the degraded nature of the sand dunes along the beach front, which can be more easily overtopped by a tsunami than at Te Tumu, where the dune systems are higher and healthier. If the dunes along the Papamoa coastline were restored, then they could potentially reduce the impacts of a tsunami on this area.

Given the protecting role of landscapes is not currently recognised in Chapter 7.1.8, there are no corresponding actions identified which mitigate the effects of a natural hazard. If consideration was given to protecting natural features which assist in mitigating the effects from a natural hazard, then an action would also be required to be added to this chapter of the SmartGrowth Strategy. This action would need to identify the role that the landscape provided in mitigating the potential effects from a natural hazard (including a tsunami). This approach would be well supported by existing national, regional and local policies. There would however be the requirement for appropriate research to be undertaken at the Greenfield development stage to identify and recognise the mitigating role which certain landscape features may have. These could then be protected at the time of subdivision.

6.2.3 Hazards

Chapter 7.1.9 recognises tsunami as a potential natural hazard which can affect human life, property and eco-systems. This chapter promotes a precautionary approach to be undertaken to hazard management given the significant consequences to human life and property. This chapter also recognises that natural systems can provide protection against hazards and the need for these to be identified and protected.

It is however suggested that in addition to a precautionary approach being undertaken to hazard management, a risk-based approach to development is also incorporated into the SmartGrowth Strategy. This approach will ensure that as the knowledge of risks from a natural hazard increases, then appropriate measures to offset these risks can be incorporated into future developments. This approach may also allow for development within areas which were originally considered to be at risk from a natural hazard but as a result of improved knowledge or modelling are now at reduced risk.

Chapter 7.1.9 recognises that the effects from a natural hazard can be reduced through community education and preparedness. It should however be recognised that community education and preparedness should be secondary approaches, with the primary approach being avoiding developments within areas which are at a high risk from a natural hazard (including tsunami).

There appears to be some conflict within Chapter 7.1.9 of the SmartGrowth Strategy which needs to be addressed. Within the growth issues section of the chapter, three categories are identified for the assessment of urban suitability. These categories are as follows:

Slightly constrained: *Urban subdivision design, development practices and the completed urbanised environment would be at most slightly affected. Sound conventional design and practice would easily overcome the constraint (if any), and there would be no long-term effects.*

Moderately constrained*: Urban subdivision design, development practices and the completed urbanised environment would be substantially affected. Special design and practice are needed to achieve sustainable management of the constraint(s). This usually means the intervention of specialists in ground and structural engineering and special planning approval processes.*

Severely constrained*: Urban subdivision design, development practices and the completed urbanised environment would be so affected by the constraint(s) that sustainable developments are unlikely. Land that conforms to urban land-use capability classes D or E (Jessen 1987) is considered severely constrained.*

Following on from the growth issues are the three principles identified below:

i) Areas that are severely constrained by hazard effects are avoided;

ii) Areas that are slightly or moderately constrained by hazard effects are subject to mitigation; and

iii) The use of hazard protection works is avoided for any new development.

The conflict arises as principle 2 recognises that it may be appropriate to develop within moderately constrained areas. Moderately constrained areas, however, by definition require special design and practice. This conflicts with principle 7 which seeks to avoid the use of hazard protection works in areas of new development. It may be more appropriate that principle 7 is modified to allow for hazard protection works to be undertaken as part of a development where the site is either identified as being slightly or moderately constrained. However, the use of hazard protection works should not extend to areas that are severely constrained as this would result in a conflict with the seventh growth issue of this chapter (which recognises hazard protection works can increase vulnerability when design standards are exceeded) as well as well as principle 1.

6.2.4 Residential Development

The residential development chapter (Chapter 7.2.3) of the SmartGrowth Strategy concentrates on how future housing will look and feel as the region expands. This chapter does not mention whether the housing form and location could be partially determined by the risk from a natural hazard. Some of the concepts of the pre-event recovery chapter could be incorporated into this part of the SmartGrowth Strategy for example, encouraging lower density development within areas at risk from a natural hazard. Risk could also be managed through the provision of vertical evacuation paths, having designated evacuation points in low risk areas and having a roading network that supports evacuation inland and won't be compromised by flooding.

The SmartGrowth Strategy has also identified the importance of the creation of structure plans for the development of future greenfield subdivisions. These structure plans would need to take into account urban design matters and natural and cultural issues such as ecological, landscape and cultural sites and areas. There is currently no provision for the risk of a natural hazard to be taken into account when formulating these plans. It is therefore recommended that the development of these structure plans take into account the potential risk from natural hazards and identify the way these effects will be mitigated. This could be addressed within the structure plans in a variety of ways; including having no development within severely constrained areas, retaining and preserving natural features that reduce the effects from a hazard, and incorporating pre-event recovery matters into the design of the structure plan.

6.2.5 SmartSpace – Chapter 7.2.9

The SmartSpace Chapter concentrates on how the leisure, recreational, open space and ecological needs of future communities can be met through the provision of parks, recreational space etc. While natural hazards are not identified within this chapter, there is the opportunity for pre event recovery principles to be recognised when determining the location of parks and recreational space. In particular, parks and recreation spaces could be evacuation points, if they are located in an area with a low hazard risk. Furthermore, parks and recreational spaces can also be utilised for emergency shelter, as recently demonstrated with Hagley Park after the 22 February 2011 Christchurch earthquake.

It has been previously identified that recreational grounds should be located within areas with a high natural hazard risk, due to their associated low density of development. This assertion remains, but it is also recognised that the recreational needs of a community are not going to be entirely met by providing parks in high risk areas. Recreational grounds and parks developed in areas that are not at high risk, should be considered for their potential role after a natural hazard event, for example as evacuation points (safe location).

6.3 Tauranga Eastern Link

The implications of the tsunami risk on the proposed Tauranga Eastern Link have also been considered. The tsunami mapping of the Papamoa and Te Tumu areas have demonstrated that, in a worst case scenario, some inundation of the Tauranga Eastern Link could be expected. This inundation would be approximately 1.5m deep and would largely occur around the Kaituna River. In a smaller tsunami event, there would possibly be minor inundation of the Tauranga Eastern Link around the Kaituna River, but the extent of this inundation would be considerably less and would be about 0.5m deep.

The design of the roading network is an important pre-event recovery measure which can assist with managing the risk from a natural hazard. In particular, a well-designed roading network should lead people to safe places (e.g. inland, to high ground, or to some other accessible evacuation point), be accessible (e.g. be wide enough, ensure public access) and aid timely evacuation. Roads that provide an evacuation route should be clearly identified and should be designed so that they cannot be cut off, thereby leaving people isolated. Ideally, these roads would lead to designated evacuation points (or safe locations). Within these safe locations would be facilities available to people including shelter, toilets, water, food and cooking facilities.

The Tauranga Eastern Link would be an important evacuation route, as it would have four lanes and heads inland to the south of Te Tumu. The connectivity onto this aerial route appears to be reasonable, with access achievable at the northern end of Papamoa as well as a proposed future intersection where the Te Tumu development would be located. The effectiveness of the Tauranga Eastern Link as an evacuation route however will largely depend on the warning time associated with a worst case scenario tsunami. If the tsunami generated came from the Southern Scenario source area, the warning time would be approximately 50 minutes, with longer if the source was more distant. A warning time of 50 minutes does not provide a large amount of time to evacuate future residents of these suburbs. As such, it is important that a detailed evacuation plan is developed which details how people could evacuate, including promoting primary walking routes. This would potentially give residents the opportunity to evacuate to a safe locations prior to the Tauranga Eastern Link being inundated (especially if the source of the tsunami did not originate from the Southern Scenario source area).

To maximise the effectiveness of the Tauranga Eastern Link as an evacuation route, areas land located in a part of the region considered to be safe from the inundation of a tsunami, should be identified as gathering point for people. These areas of land would need to be easily accessible from the Eastern Link and contain shelter, food, water, toilet facilities and cooking equipment for people. This area would need to be identified and created in discussions with the Emergency Management Office at the Bay of Plenty Regional Council.

6.4 Conclusions

The SmartGrowth Strategy currently recognises natural hazards as an important fact to consider as the population of the Bay of Plenty increases. However, this strategy could better recognise the risk of natural hazards, particularly tsunami on future development. In particularly the following changes were recommended to the SmartGrowth Strategy:

- Recognise the importance of low density development (i.e. parks and recreation spaces) in mitigating the risk from a natural hazard, in the SmartSpace Chapter of the Sub-regional Growth Issues section of the strategy;

- Recognise the importance of natural features (dune systems) in mitigating the risk from a natural hazard in the landscape chapter of the Sub-regional Growth Issues section of the strategy;
- Identify tsunami as a potential natural hazard which could result in land being classified as being severely constrained in Chapter 6.18 of the Sub-regional Growth Issues section of the strategy;
- Identify tsunami as a natural hazard in the growth issues and principles sections of the open coast chapter, which would also provide support to action 6;
- Recognise the importance of natural features (dune systems) with mitigating the risk from a natural hazard in the Landscapes Chapter of the SmartGrowth Strategy. There also needs to be an action developed which would assist with retaining landscapes which have a role in mitigating the effects from a natural hazard;
- Develop the precautionary approach further to include a risk based assessment. This would allow for appropriate land control approaches to be undertaken as the knowledge of risks increase;
- Address the conflict between allowing for the development of moderately constrained land through the use of engineering and structural measures and principle 6 of the hazards chapter which seeks to avoid the use of protections works. This can be remedied by modifying principle 6 to allow for engineering works on Slightly and Moderately Constrained Land but not Severely Constrained areas;
- Incorporate pre-event recovery measures into the design of future residential development;
- Require the creation of future structure plans for new development, to also take into account the risk from natural hazards;
- Recognise the importance of parks, situated within low risk areas as potential evacuation points within the SmartSpace Chapter. The design of these parks could also take into account some of the pre-event recovery concepts (i.e. heating, water shelter etc.).

The Tauranga Eastern Link has the potential to play a significant role in the evacuation of future Wairakei Te Tumu residents from high risk tsunami areas. The extent to which this road will be effective in evacuating people will be largely determined by the size of the tsunami (which will determine the extent and depth of inundation) as well as its source (which will determine warning time). It is however recommended that, to increase the effectiveness of this road as an evacuation route, a detail evacuation plan should be created for the study area as it is developed and communicated to residents of these suburbs. This plan should clearly identify the evacuation routes and lead to designated areas of land, not situated within an inundation area. These areas of land would need to be easily accessible from the Tauranga Eastern Link and contain shelter, food, water, toilet facilities and cooking equipment for people. These areas would need to be identified and created in discussions with the Emergency Management Officer at the Bay of Plenty Regional Council.

7.0 RECOMMENDATIONS

Based on the findings of this report, a variety of recommendations can be made to ensure that the risk and effects of tsunami on the Papamoa, Te Tumu and Wairakei suburbs can be reduced:

- The existing sand dunes along the Te Tumu coastline (and to a lesser extent Papamoa) provide an effective and important barrier to a tsunami. The preservation or conservation of these sand dunes along the beach front is critical, and any activities that deteriorate the dune systems should be avoided. If the dune systems are degraded due to storm waves or other extreme events, actions need to be carried out to re-condition the sand dune systems back to their original state to provide a natural protective function.
- If possible, the dune systems along the Papamoa should be restored and conserved to improve their role in mitigating the effects from a tsunami.
- Consultation should be undertaken with the local community to determine the acceptable, tolerable and intolerable levels of injury and building damage resulting from a tsunami. This information can then be used to further determine whether the levels of risk resulting from the modelled tsunami events are acceptable, tolerable or intolerable.
- A variety of pre-event recovery measures should be adopted into the design of these suburbs to lessen the effects from a tsunami. These measures include providing evacuation paths (including vertical evacuation routes), having high risk areas vested as reserve land and developing pre-event recovery plans.
- Changes to the SmartGrowth Plan should be made in line with the recommendations of Chapter 6.4. These changes will result in better recognition of the tsunami risk on the study area as well as suggesting potential mitigation measures to reduce the effects from such an event.
- A detailed evacuation plan should be formulated for the suburbs as they are developed which identifies the evacuation routes (including primarily pedestrian routes) for people to use. This plan should be communicated to the local residents and the evacuation routes clearly identified. These routes should lead to multiple safe areas.
- To increase the effectiveness of the Tauranga Eastern Link as an evacuation route, designated area(s) of land, which is not situated within an inundation area, should be identified to accommodate people escaping such an event. These areas of land would need to be easily accessible (including by foot) from the Tauranga Eastern Link and contain shelter, food, water, toilet facilities and cooking equipment for people.

8.0 ACKNOWLEDGEMENTS

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9.0 REFERENCES

Becker, J., Saunders, W. S. A., Hopkins, L., Wright, K., & Kerr, J. (2008). *Pre-event recovery planning for land use in New Zealand: an updated methodology*. Lower Hutt: GNS Science.

Berryman, K.R. (compiler), 2005. “Review of tsunami hazard and risk in New Zealand”. Client Report 2005/144, Institute of Geological & Nuclear Sciences, Lower Hutt.

Bonnardot, M.A., Regnier, M., Ruellan, R., Christova, C., and Tric, E. (2006). Seismicity and State of Stress within the Overriding plate of the Tonga-Kermadec Subduction Zone. Tectonics. Vol. 26. TC5017. Pages 1-15. doi: 10.1029/2006TC002044.

Cousins, W.J. 2010. “Wellington area earthquake casualty estimation – 2010 update”. Client Report 2010/60 Institute of Geological & Nuclear Sciences, Lower Hutt.

Cousins, W.J., Power, W.L., Palmer, N.G., Reese, S., Tejakusuma, I. & Nugrahadi, S. 2007. “Damage and casualties in the South Java tsunami of 17th July 2006”. Proceedings, Annual Conference of the NZSEE, 30 March – 1 April 2007, Palmerston North. Paper No. 32.

Cousins, W.J., Power, W.L., Destegul, U.Z. and King, A.B. 2007. “Combined Earthquake and Tsunami Losses for major earthquakes affecting the Wellington Region”. GNS Science Consultancy Report 2007/280.

Cousins, W.J., Power, W.L., Destegul, U.Z., King, A.B., Trevethick, R., Blong, R., Weir, B. & Miliauskas, B. 2009. “Earthquake and tsunami losses from major earthquakes affecting the Wellington Region”. Conference of the New Zealand Society for Earthquake Engineering, April 3-5, 2009, Christchurch. Paper No. 24.

De Lange, W.P., Prasetya, G., Spiers, K.C., Moon, V.G. (2008). Utilising Paleotsunami Data for Hazard Assessment: Numerical Modelling to Identify Credible sources in Wallendorf, L., Ewing, L., Jones, C., and Jaffe, B. (eds). Solutions to Coastal Disaster 2008 – Tsunamis. American Society of Coastal Engineering. Pages 248-253.

Finnis, K., 2004. *Creating a Resilient New Zealand*. Wellington: Ministry of Civil Defence and Emergency Management. Available at: www.civildefence.govt.nz.

Geist, E.L.(1998). Local tsunamis and earthquake source parameters.Adv.Geophys.Vol.39. Pages. 117-209.

Goff, J., Pearce, S., Nichol, S.L., Chague-Goff, C., Horrocks, M., Strotz, L. (2010). Multi-proxy record of regionally source tsunamis, New Zealand. Geomorphology. Vol.118. Pages 369-382.

Goff, J., Walters, R., and Callaghan, F. (2006). Tsunami Source Study. Environment Waikato Technical Report 2006/49. ISSN: 1172-4005.

Lamarche, G. and Barnes, P. (2005). Fault Characterisation and Earthquake Source Identification in the Offshore bay of Plenty. NIWA Client Report: WLG2005-51. 57 pp. 36 Figs.

McCaffrey, R. (2008). Global Frequency of Magnitude 9 Earthquakes, The Geological Society of America. Vol.36 .No.3. Pages 263-266

McCaffrey, R. (2007), The Next Great Earthquake, *Science* 23 March 2007 315: 1675-1676.

McClure, J., Walkey, F., & Allen, M. (1999). When Earthquake Damage is seen as Preventable: Attributions, locus of Control and Attitudes to Risk. Applied Psychology: An International Review, 48, 239-256.

MCDEM. (2008). *Tsunami evacuation zones: Director's guideline for Civil Defence Emergency Management Groups [DGL08/08]*. Wellington: Ministry of Civil Defence and Emergency Management.

MCDEM. (2009). CDEM Group Plan Review - Director's guidelines for Civil Defence Emergency Management (CDEM) Groups [DGL 09/09]. Wellington: Ministry of Civil Defence & Emergency Management.

Quality Planning Website 2008. Guidance notes for Emergency Works Provisions of the RMA 1991. Accessed July 2008. http://www.qp.org.nz/

Pachecho, J.F., Sykes, L., and Scholz, C. (1993). Nature of Seismic Coupling Along Simple Plate Boundaries of the Subduction Type. Journal of Geophysical Research. Vol. 98. No.B8. Pages 14,133-14,159.

Prasetya, G., De Lange, W.P., and Healy, T.R. (2008). Hydrodynamic Modelling of Tsunami Overwash of Whitianga Township and Harbour. Coastal Marine Group. The University of Waikato. Technical Report for Environment Waikato. 95 pages.

Prasetya, G. (2006).The role of Coastal Forest and Trees in Combating Coastal erosion, In Proceeding of Regional technical Workshop on Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forest and trees, 28-31 August 2006, Le Meridien, Khao lak, Thailand.

Power, W., Wallace, L.M., Wang, X., Reyners, M. (2011). Tsunami Hazards Posed to New Zealand by the Kermadec and Southern New Hebrides Subduction Margins: An Assessment Based on Plate Boundary Kinematics, Interseismic Coupling, and Historical Seismicity. Pure and Applied Geophysics. Doi:10.1007/s00024-011-0299-x.

Rawlinsons 2007, New Zealand Construction Handbook. Rawlinson Media Limited, Auckland.

Reese, S., Cousins, W.J., Power, W.L., Palmer, N., Tejakusuma, I.G. & and Nugrahadi, S. 2007. “Tsunami vulnerability of buildings and people in South Java. Field observations after the July 2006 Java Tsunami”. Natural Hazards and Earth Systems Science, 7, 573-589.

Saunders, Wendy (compiler). 2006. “National population casualties resulting from tsunami in New Zealand”. Client Report 2006/107 Institute of Geological & Nuclear Sciences, Lower Hutt.

Saunders, W.S.A., 2011. Innovative land-use planning for natural hazard risk reduction in New Zealand. A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Resource and Environmental Planning, Massey University, Palmerston North.

Schwab, J., Topping, K.C., Eadie, C.C., Deyle, R.E., Smith, R.A., 1998. Planning for Post-Disaster Recovery and Reconstruction PAS Report NO. 483/484. Chicago, Illinois: American Planning Association. Abstract available at: www.planning.org/apapubs/details.asp?Num=1778.

SmartGrowth, May 2007, 50 – Year Strategy and Implementation Plan for the Western Bay of Plenty Su-Region.

Spence, R.J.S., Pomonis, A., Dowrick, D.J. & Cousins, W.J. 1998. *Estimating human casualties in earthquakes: the case of Wellington.* Proceedings, Sixth SECED (Society for Earthquake and Civil Engineering Dynamics) conference *Seismic Design Practice into the Next Century*, Oxford, UK, March 26-27: pages 277-286.

Standards New Zealand, 2000. NZS3604:1999, Timber Framed Buildings, Incorporating Amendment No. 1 (December 2000).

Tauranga City Council 2004, Papamoa East (Wairakei – Te Tumu) Urban Development Strategy.

Tauranga City Council 2005, Proposed Plan Change 44, Wairakei Urban Development Background Summary and Section 32 Report.

Wallace, L.M. et al. (2009). Characterizing the Seismogenic Zone of a Major Plate Boundary Subduction Thrust: Hikurangi Margin, New Zealand. Geochemistry Geophysics and Geosystem – an electronic Journal of the Earth Sciences. Vol.10.No.10. Pages 1-32.doi:10/1029/2009GC002610.ISSN.1525-2027.

Walters, R.A., Goff, J., and Wang, K. (2006). Tsunamigenic Sources in the Bay of Plenty, New Zealand. Science of Tsunami Hazards. Vol.24. No.5. Pages 339 -357. http://www.zoomin.co.nz/map/nz/tauranga/ accessed 12 October 2011.

Wang, X. and Power, W.L. (2011), COMCOT: A Tsunami Generation Propagation and Run-up Model. GNS Science Report 2011/43 in press

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APPENDIX 1 MODELLING METHODOLOGY

A numerical modelling assessment was carried out using a COMCOT tsunami model (Wang, 2010). The grid resolution for this numerical modelling assessment is based on GEBCO 08 3 arc second and SRTM 30 arc second. LIDAR data was used to model the topography of the study area. The regional modelling grid setup was as follows (Figure A1.1):

- Level 1: Grid resolution of 1 arc minutes (~ 1.5 km)
- Level 2: Grid resolution of 0.2 arc minutes (~290 m)
- Level 3: Grid resolution of 0.05 arc minutes (~74 m)
- Level 4: Grid resolution of 0.00833 arc minutes (~12 m)

Note: The Kermadec – Hikurangi Scenario and the local source scenarios use a slightly different grid setup from those described above. These different setups are described with the sections of this report relating to these scenarios.

The Ministry of Civil Defence and Emergency Management recognises four levels of modelling in determining the degree of inundation from a tsunami:

Level 1 is the most basic of the models in which inundation is determined based on a maximum wave height projected inland from the coast to some cut-off elevation.

Level 2 uses a measure of rule-based wave height attenuation inland from the coast. This approach derives a more realistic output than a simple 'bathtub' model but is still a rough estimate which cannot account for physical variations in wave behaviour. The rule is applied to probabilistic wave heights derived separately.

Level 3 is a computer-derived simulation model that theoretically allows for complexities that a simpler 'rule' cannot, such as varied surface roughness from different land uses, and water turning corners and travelling laterally to the coast on its inundation path. The model is applied to probabilistic coastal wave heights derived separately.

Level 4 is the most complete approach, based on an envelope around all inundations from multiple (likely to be many) well-tested computer models covering all credible scenarios and providing the most complex and accurate modelling (MCDEM 2009).

This project involves a partial level 3 modelling, as the calculations which have been undertaken are based on six scenarios for which the shortest possible return periods were estimated; whereas a full Level 3 approach would require that the scenarios be determined from a probabilistic model of wave heights at the coast. The predicted inundation levels are calculated from a recognised tsunami modelling program and accurately incorporates the topography of the local environment based on a LIDAR (Light Detection And Ranging) survey.

All modelling was undertaken using Mean High Water Spring (MHWS) conditions as the ambient water level as this assumes that the tsunami will arrive at high tide, which for a typical day, would represent the greatest potential risk from inundation.

The modelling which has been undertaken has assumed that the integrity of the dune systems are maintained throughout the tsunami event and are not eroded or compromised by the waves coming ashore. If the dune systems were to erode as a result of a tsunami, the levels of inundation for the study area would likely to be greater than those modelled within this report.

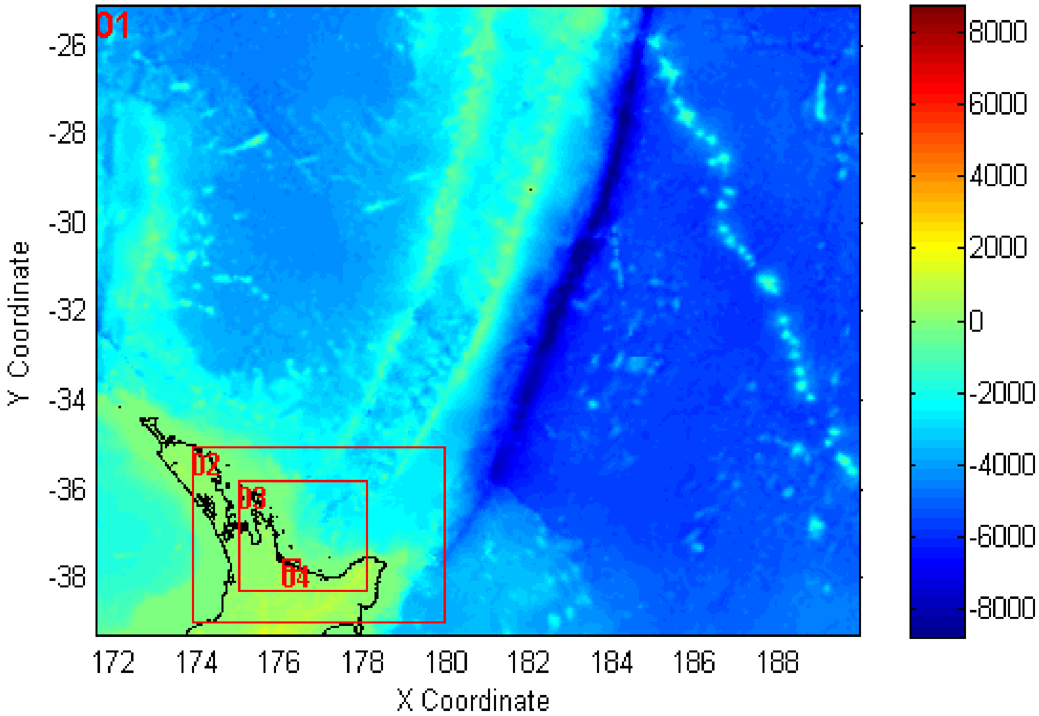

Figure A1.1 The nested grid arrangement for numerical modelling assessments.

APPENDIX 2 REGIONAL INUNDATION RESULTS

A2.1 Southern Kermadec Scenario

The Southern Kermadec Scenario involves the rupture of Segment A along the Kermadec Trench in Power et al. (2011). It has the general fault parameters as identified in Table A2.1. For this scenario it was assumed that an earthquake with a magnitude of Mw 8.5 would occur if this fault ruptured.

The modelling for this scenario involved the source area being divided into six unit sources (100 km x 50 km). These source units had dip angles that varied from 4^{o} to 11^{o}, strike angles that ranged between 202^{o} to 212^{o}, and at depths between 4 km to 10 km. The slip angle was uniform at 90^{o} and a slip of 5.0m was used.

The regional maximum tsunami elevation based on these parameters is shown in Figure A2.2. This figure shows that a tsunami would affect most of the east coast of the North Island, from the East Cape towards the northern end of the North Island. The sub-regional model for the Bay of Plenty shows that the maximum tsunami elevation varies between 1.5m and 3.0m above MHWS along the east coast between the Maketu Estuary and Matakana Island (Figure A2.3). No significant inundation occurs along the Papamoa and Te Tumu coastline, as the sand dunes are high enough to prevent overtopping by the tsunami (Figure A2.4).

Table A2.1 General fault parameters for the Southern Kermadec Scenario

Segment	Length	Width	Slip	Magnitude
A	300 km	100 km	5.0 m	Mw 8.5

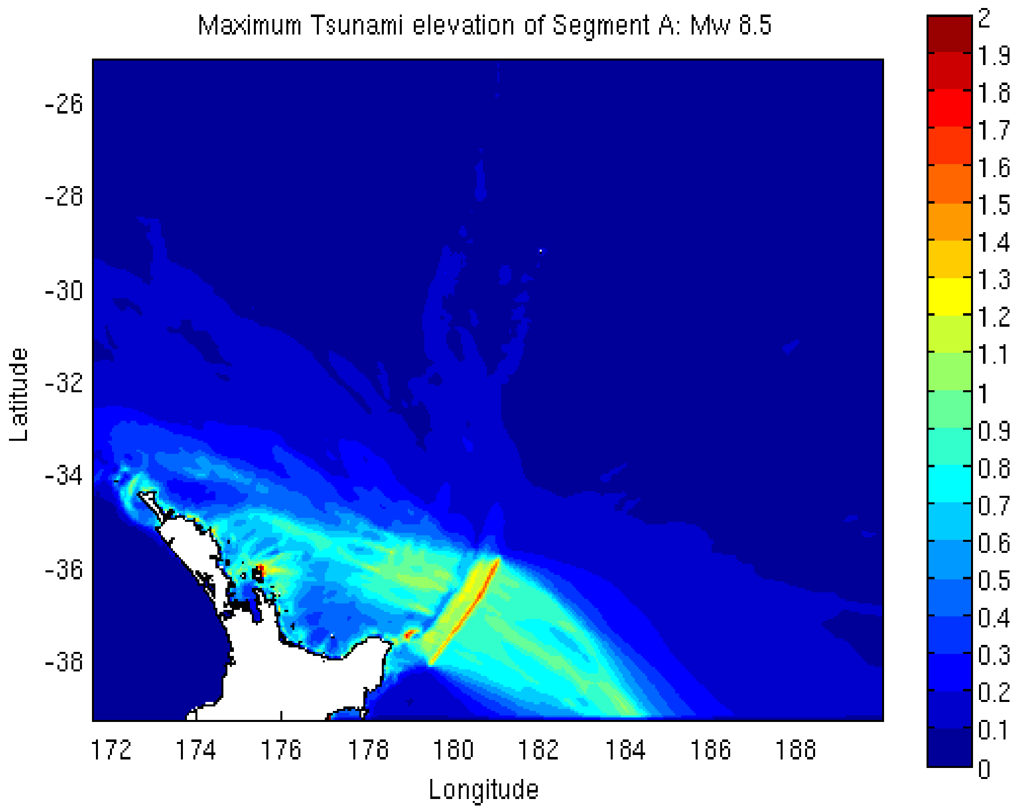

Figure A2.2 The maximum tsunami elevation above MHWS from the Southern Kermadec Scenario. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

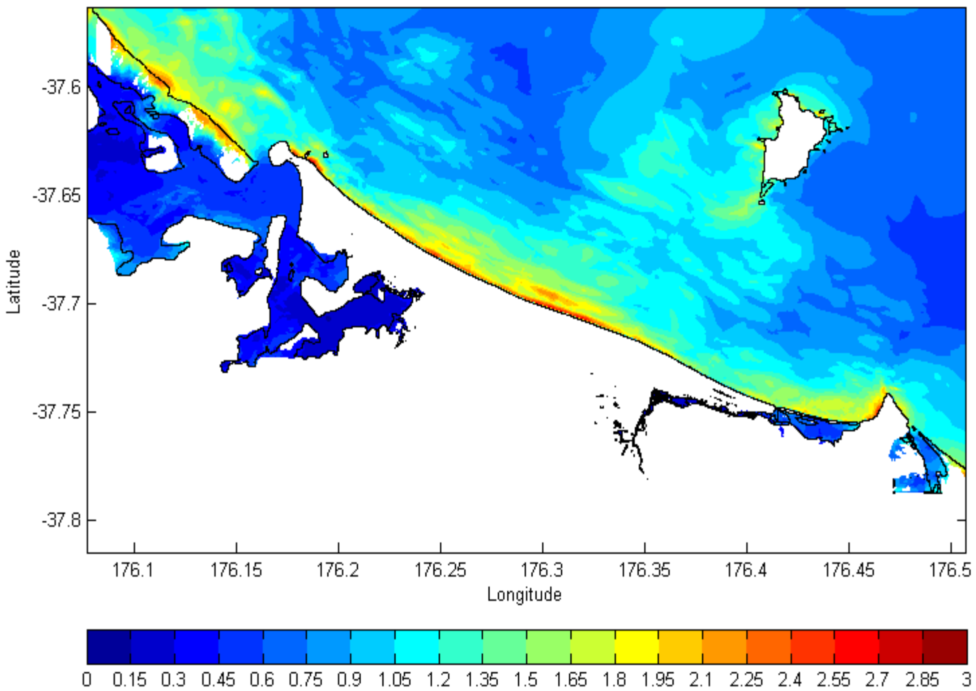

Figure A2.3 The maximum tsunami elevation above MHWS for the Southern Kermadec Scenario for the coastline between the Maketu Estuary and Matakana Island. The colour scale shows the maximum tsunami elevation above MHWS if it is offshore or flow depth if it is on land. Scale bar unit is in metres.

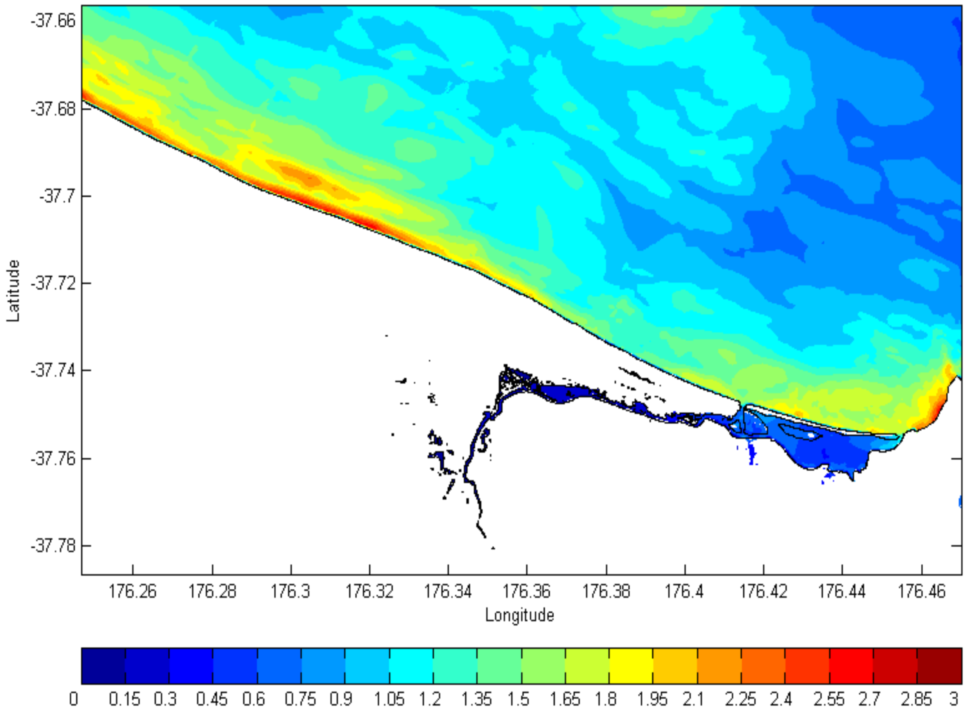

Figure A2.4 The maximum tsunami elevation above MHWS from the Southern Kermadec Scenario for the Papamoa and Te Tumu coastline. This modelling shows that there is no significant inundation except to the area around the Maketu Estuary. Scale bar unit is in metres.

A2.2 Central Kermadec Scenario

The Central Kermadec Scenario involves in the rupture of Segment B along the Kermadec Trench in Power et al. (2011). It has the general fault parameters as identified in Table A2.2. For this scenario, it was assumed that an earthquake with a magnitude of Mw 8.9 would occur if this area ruptured.

The modelling for this scenario involved the source area being divided into 12 unit sources (100 km x 50 km). These source units dip angles that varied from 5^{o} to 17^{o}, strike angles that ranged between 197^{o} to 205^{o}, and at depths between 6 km to 16 km. The slip angle was uniform at 90^{o} and a slip of 10.0m was used.

The regional maximum tsunami elevation based on these parameters is shown in Figure A2.5. This figure shows that a tsunami would affect most of the east coast of the North Island, from the East Cape towards the northern end of the North Island. The sub-regional model for the Bay of Plenty shows that the maximum tsunami elevation varies between 1.5m and3.0m above MHWS along the east coast between the Maketu Estuary and Matakana Island (Figure A2.6). No significant inundation occurs along the Papamoa and Te Tumu coastline, as the sand dunes are high enough to prevent overtopping by the tsunami (Figure A2.7).

Table A2.2 General fault parameters for The Central Kermadec Scenario

Segment	Length	Width	Slip	Magnitude
B	600 km	100 km	10.0 m	Mw 8.9

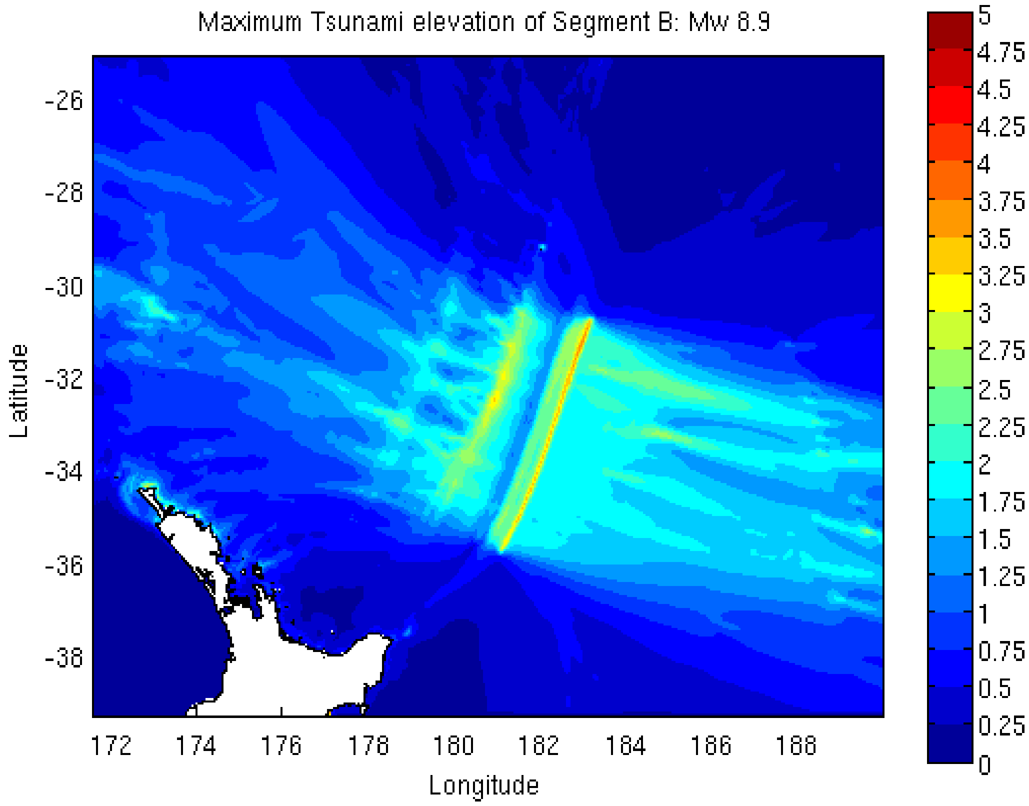

Figure A2.5 The maximum tsunami elevation above MHWS from the Central Kermadec Scenario. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

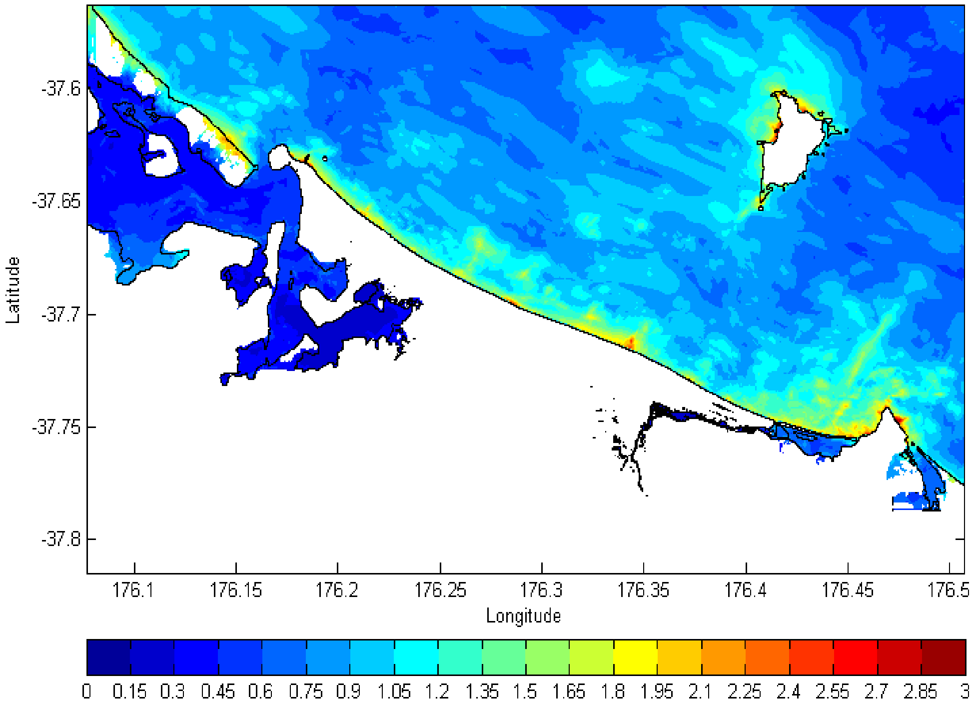

Figure A2.6 The maximum tsunami elevation above MHWS for the Central Kermadec Scenario for the coastline between Maketu Estuary and Matakana Island. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

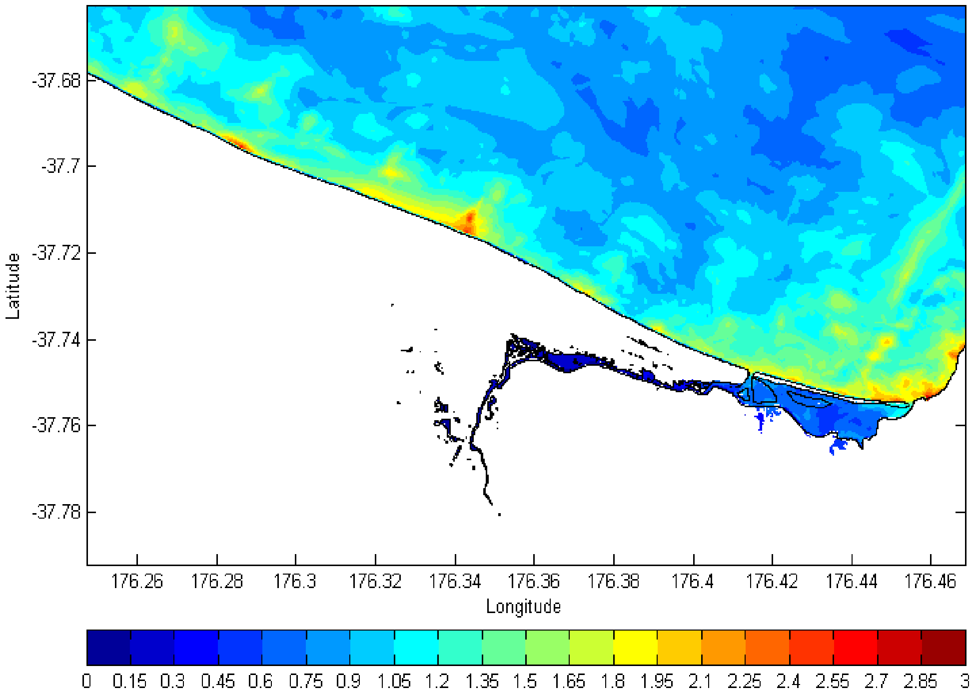

Figure A2.7 The maximum tsunami elevation above MHWS from the Central Kermadec Scenario for the Papamoa and Te Tumu coastlines. This modelling shows that there is no significant inundation except to the area around the Maketu Estuary. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

A2.3 Northern Kermadec Scenario

The Northern Kermadec Scenario involves the rupture of Segment C along the Kermadec Trench in Power et al. (2011). It has the general fault parameters as identified in Table A2.3. For this scenario it was assumed that an earthquake with a magnitude of Mw 8.8 would occur if this area ruptured.

The modelling for this event scenario involved the source area being divided into 10 unit sources (100 km x 50 km). These source units had dip angles that varied from 9^{o} to 17^{o}, strike angles that ranged between 191.7^{o} to 202.8^{o}, and at depths between 6km to 20km. The slip angle was uniform at 90^{o} and a slip of 8m was used

The regional maximum tsunami elevation based on these parameters is shown in Figure A2.8. This figure shows that a tsunami would affect most of the east coast of the North Island from the East Cape towards the northern end of the North Island. The sub-regional model for the Bay of Plenty shows that the maximum tsunami elevation varies from 1.0m to 2.0m above MHWS along the east coast between the Maketu Estuary and Matakana Island (Figure A2.9). No significant inundation occurs along the Papamoa and Te Tumu coastlines, as the sand dunes are high enough to prevent overtopping by the tsunami (Figure A2.10).

Table A2.3 General fault parameters for the Northern Kermadec Scenario

Segment	Length	Width	Slip	Magnitude
C	500 km	100 km	8.0 m	Mw 8.8

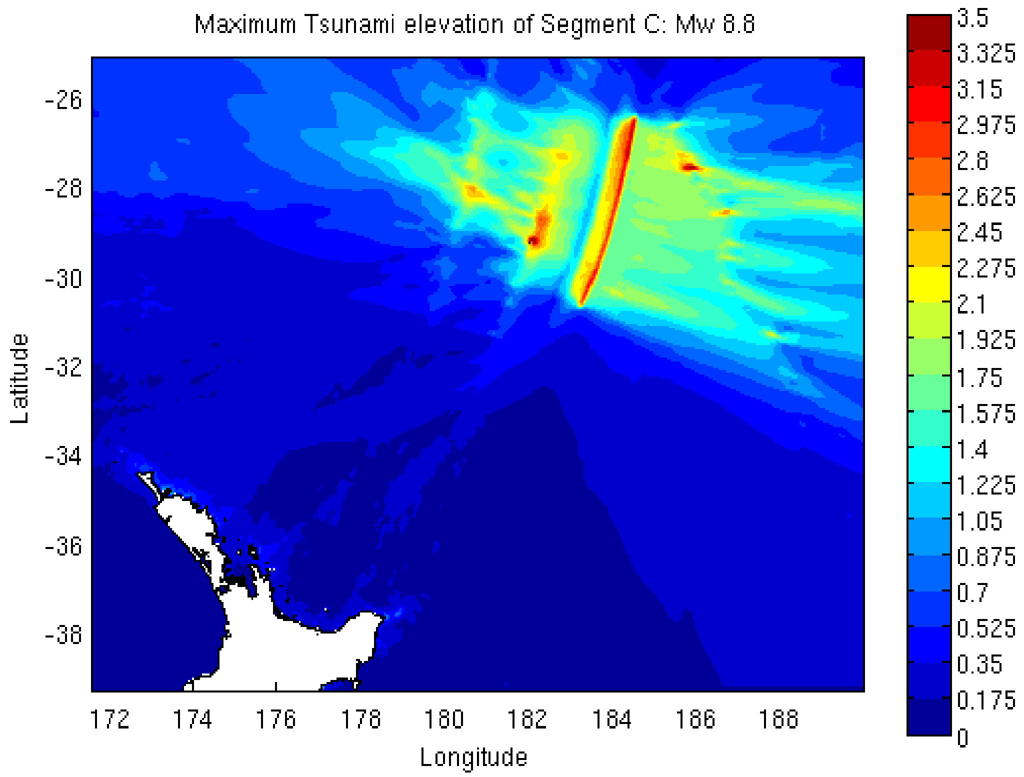

Figure A2.8 The maximum tsunami elevation above MHWS from the Northern Kermadec Scenario. A rupture would direct most of tsunami energy away from New Zealand. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

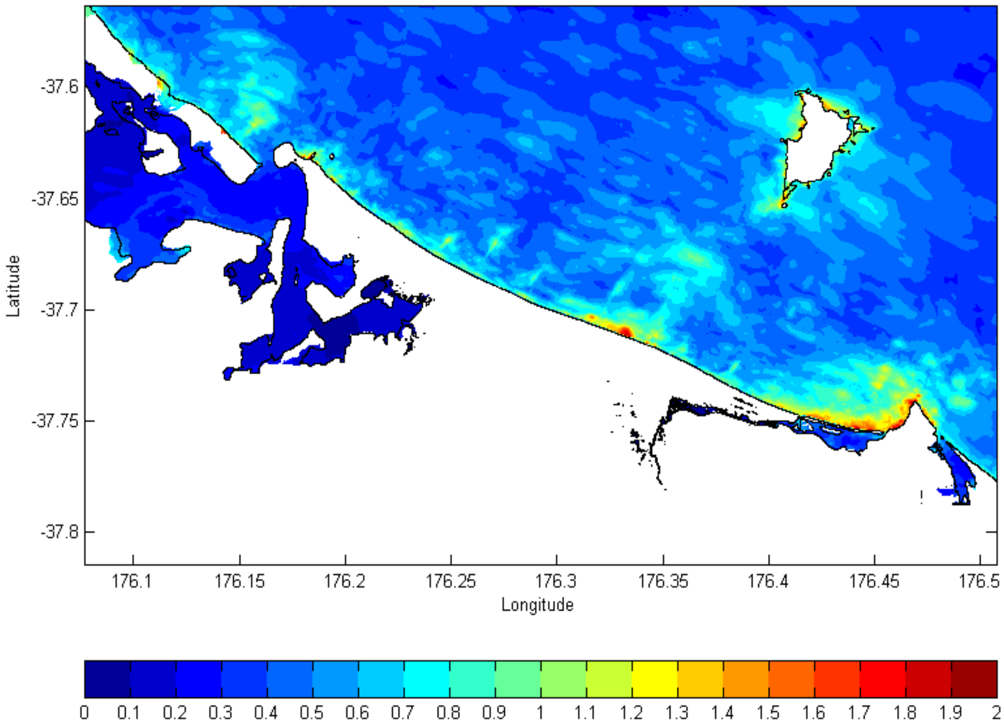

Figure A2.9 The maximum tsunami elevation above MHWS from the Northern Kermadec Scenario for the area between Maketu Estuary and Matakana Island. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

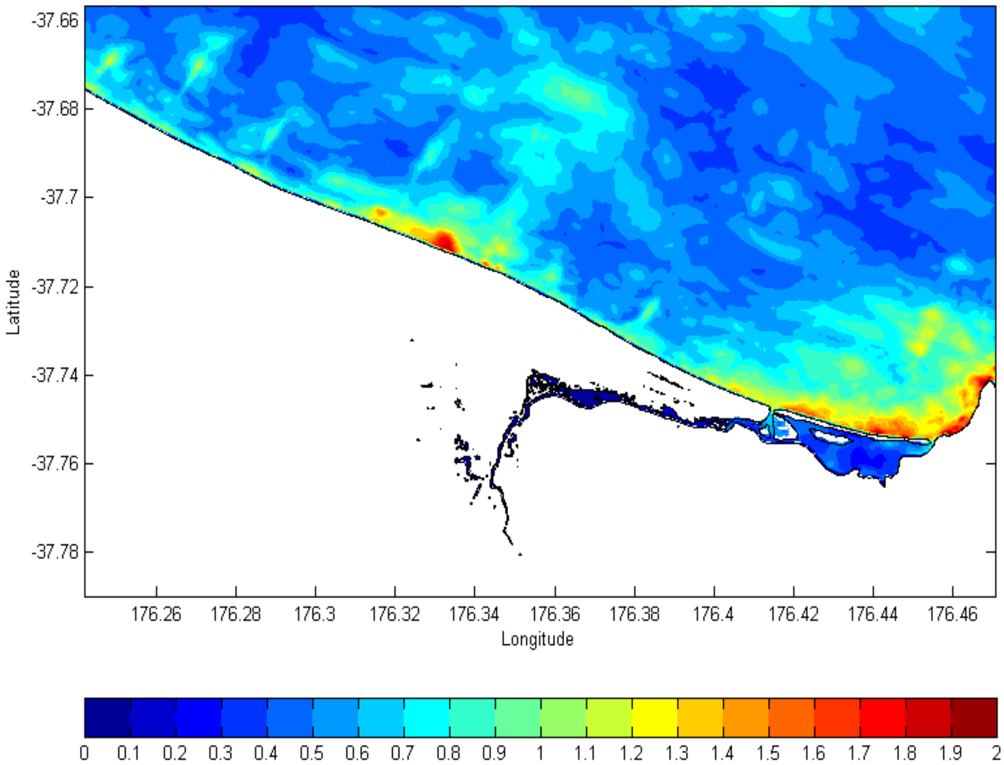

Figure A2.10 The maximum tsunami elevation above MHWS from the Northern Kermadec Scenario for the Papamoa and Te Tumu coastlines. This modelling shows that there is no significant inundation except to the area around the Maketu Estuary. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

A2.4 The Whole Kermadec Trench Scenario

In this scenario it was assumed that an earthquake with a magnitude of 9.4 would rupture the whole Kermadec Trench, i.e., Segments A, B and C along the Kermadec Trench in Power et al. (2011). The general fault parameters for this scenario are identified in Table A2.4.

The modelling for this scenario involved the source area being divided into 28 unit sources (100 km x 50 km). These source units had dip angles that varied from 4^{o} to 17^{o}, strike angles that ranged between 191.7^{o} to 212^{o}, and at depths between 4km to 20km. The slip angle was uniform at 90^{o} and a uniform slip of 22m was used.

The regional maximum tsunami elevation based on these parameters is shown in Figure A2.11. This figure shows that a tsunami would affect most of the east coast of the North Island from the East Cape towards the northern end of North Island as a result of whole Kermadec Trench rupturing. The sub-regional model for Bay of Plenty Region shows that the maximum tsunami elevation varies from 5.0m to 10.0m above MHWS along the east coast (Figure A2.12). Significant inundation occurs at Papamoa (Figure A2.13), with tsunami elevation reaching a maximum height of 10m above MHWS. In contrast, no significant inundation occurs between Te Tumu and the Kaituna River Mouth as the 12m high sand dunes prevent overtopping by the tsunami (which has a maximum elevation of ~ 5.0m to 8.0m above MHWS in this area) (Figures A2.14 and A2.15).

The warning time for a tsunami associated with this scenario is approximately 50 minutes.

Table A2.4 General fault parameters for the whole Kermadec scenario

Segments	Length	Width	Slip	Magnitude
A+B+C	1400 km	100 km	22.0 m	Mw 9.4

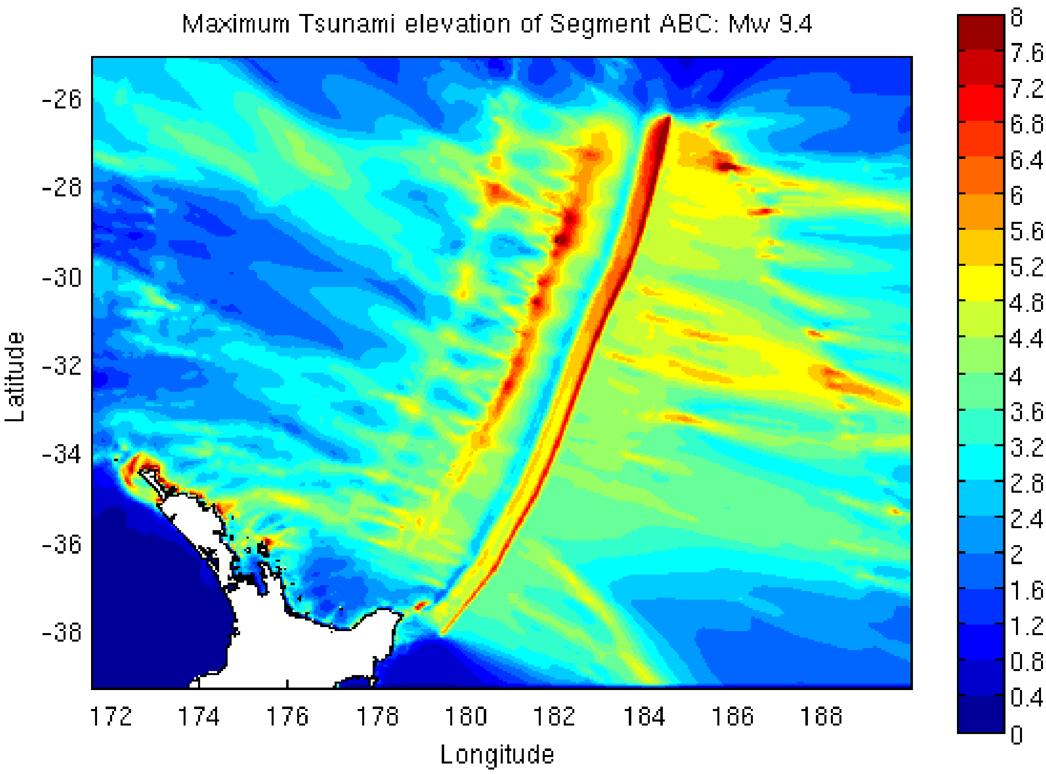

Figure A2.11 The maximum tsunami elevation above MHWS resulting from the whole Kermadec scenario. This modelling shows that the main source of the tsunami to impact the east coast of New Zealand is from the southern and central portions of the trench. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

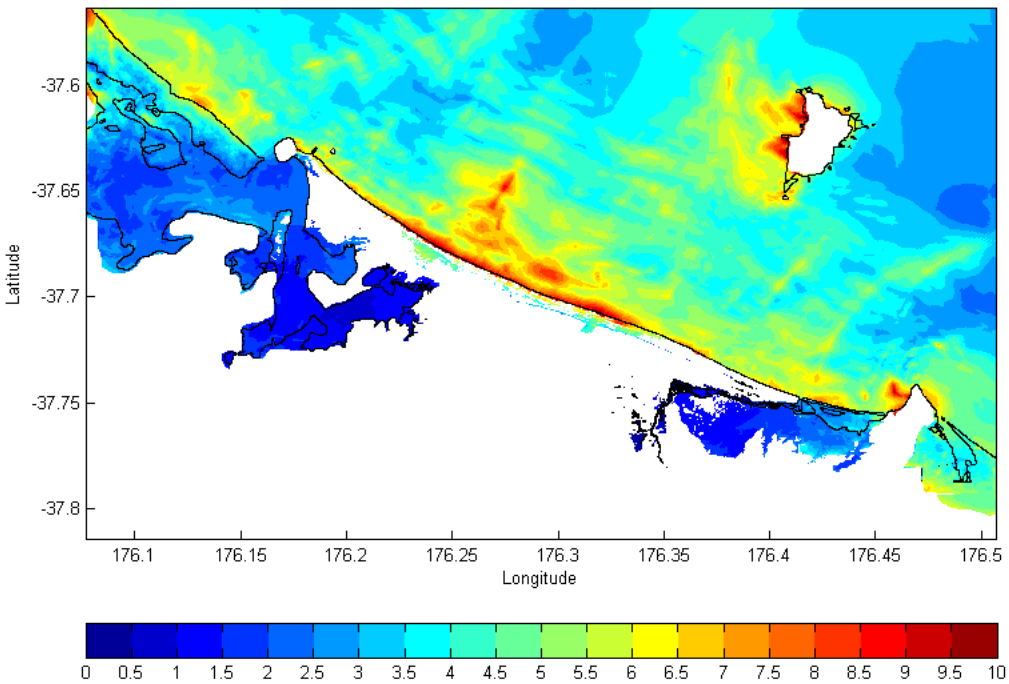

Figure A2.12 The maximum tsunami elevation above MHWS resulting from the whole Kermadec scenario. This modelling shows the maximum tsunami elevation varies from 5.0m – 10m above MHWS for the Bay of Plenty from the Maketu Estuary to Matakana Island. Inundation occurs at some places along the coastline such as Papamoa, Mt Maunganui and Matakana Island. Scale bar unit is in metres.

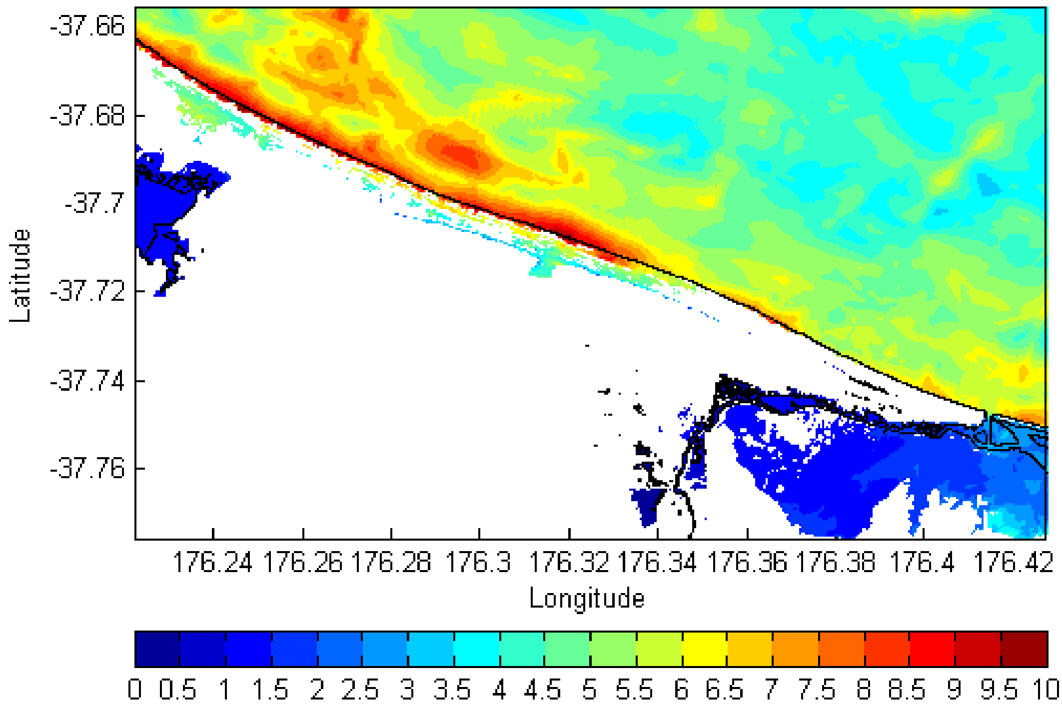

Figure A2.13 The maximum tsunami elevation above MHWS resulting from the the whole Kermadec scenario along the Papamoa and Te Tumu coastlines. No inundation occurs along the Te Tumu coastline as the sand dunes are high enough to prevent overtopping by the tsunami. Scale bar unit is in metres.

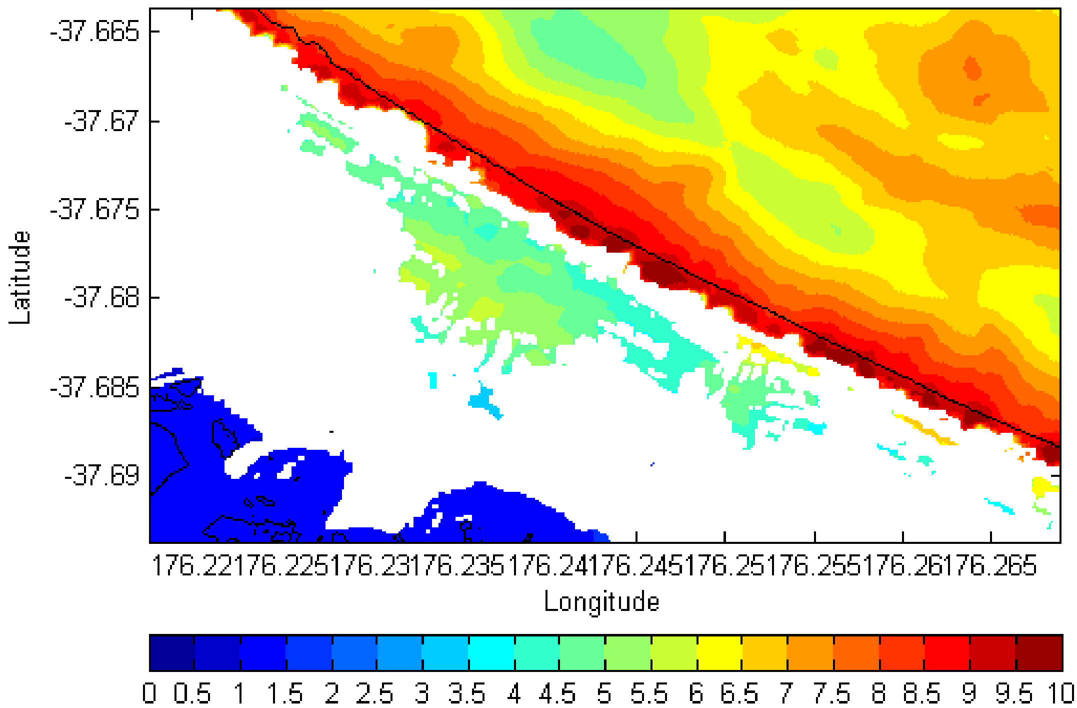

Figure A2.14 The maximum tsunami elevation above MHWS resulting from the whole Kermadec scenario for the Papamoa coastline nearer Mt Maunganui. In this area, the tsunami overtops the sand dunes and inundates the area behind. Scale bar unit is in metres.

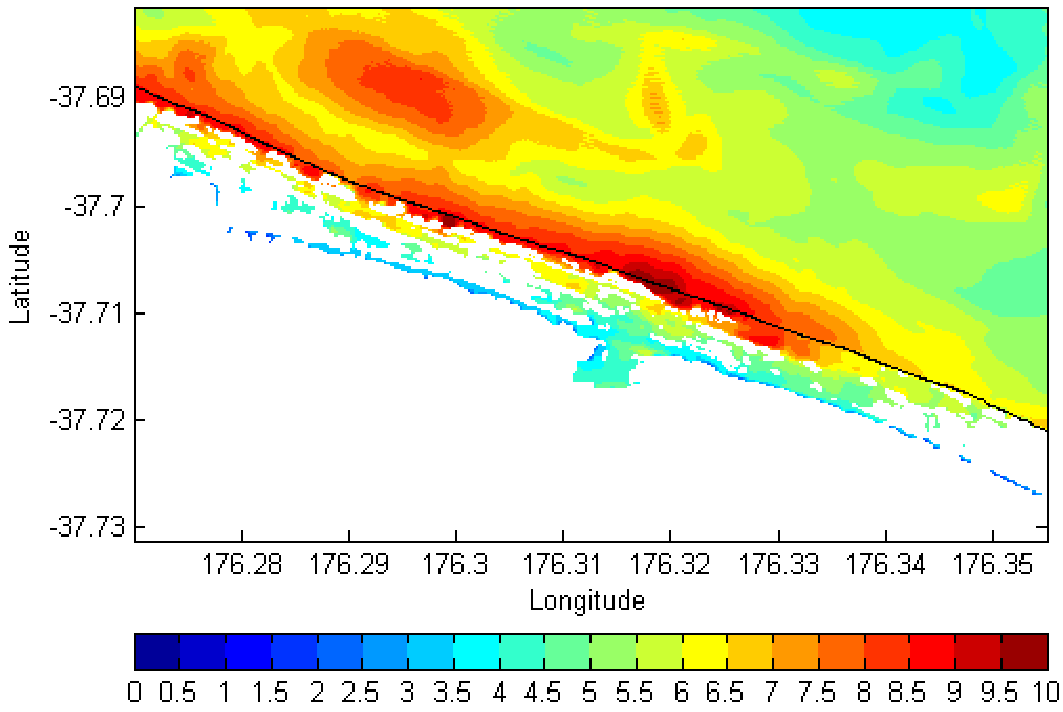

Figure A2.15 The maximum tsunami elevation above MHWS resulting from the whole Kermadec scenario for the Papamoa coastline towards Te Tumu. The tsunami overtops the sand dunes and inundates further inland through gravitational flows. The inundation follows the local terrain conditions such as the low-lying areas between the sand ridges. Scale bar unit is in metres.

A2.5 Worst Case Scenario – Kermadec - Hikurangi Scenario

A Kermadec – Hikurangi scenario was assumed as the worst case scenario for the study area which involves a fault rupture extending from the Kermadec Trench to the south into the Hikurangi Margin as identified by Wallace et al. 2009. The fault ruptures chosen for this study were those that would potentially have the greatest impact on the Bay of Plenty Region. This fault rupture scenario includes a rupture area covering part of the Southern and Central Kermadec scenarios (Segment A + B in Power et al. (2011)) as well as including the northern part of the Hikurangi Margin (Segment H), as illustrated in Figure 2.3. The general fault parameters for this event are identified in Table A2.5.

This source model uses a uniform dip angle of 16^{o}, a strike angle of 210^{o}, and a uniform depth of 5km. The slip angle was uniform at 90^{o} and a slip of 20m was used. The modelled resolution in the study area is 0.007 arc minutes (~10m).

The regional maximum tsunami elevation based on these parameters is shown in Figure A2.16. This figure shows the distribution of the tsunami elevation along the east coast of the North Island of New Zealand. The sub-regional model (nested grid) result shows the maximum tsunami elevation varies between 5.5m – 15m above MHWS for the Bay of Plenty between Maketu Estuary and Matakana Island.

A significant amount of inundation occurs along the Papamoa coastline as the tsunami overtops the sand dunes. This inundation continues towards the north western portion of Te Tumu, which has lower sand dunes than the remainder of the coastline to the south east

(Figure A2.17 – A2.19). Most of the Te Tumu is not inundated by the tsunami as the sand dunes along this part of the coastline are high enough to prevent overtopping. The inundation behind the high sand dunes at Te Tumu is due to the tsunami from Papamoa flowing along an existing creek.

The warning time for a tsunami associated with this scenario is approximately 50 minutes. This scenario identifies the potential worst case scenario for inundation within the study area based on the limitations of the model.

Table A2.5 General fault parameters for the Kermadec – Hikurangi Scenario

Segments	Length	Width	Slip	Magnitude
A, B and H	537 km	97 km	20.0 m	Mw 9.1

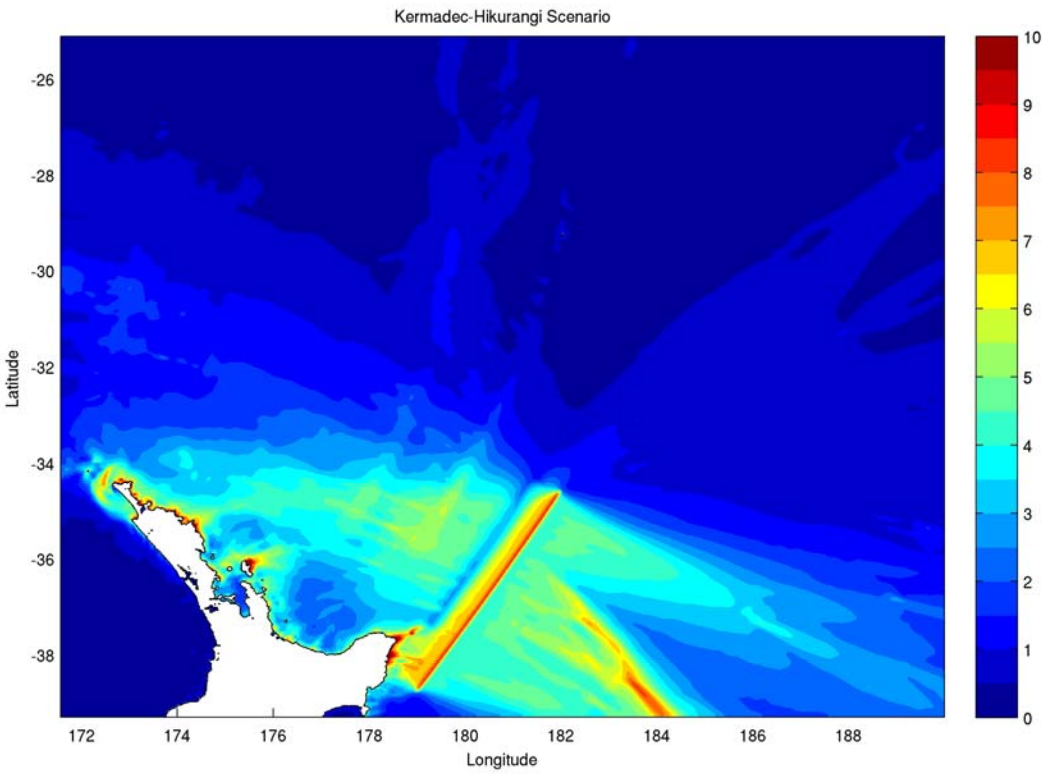

Figure A2.16 The maximum tsunami elevation above MHWS for the Kermadec – Hikurangi Scenario. This scenario shows most of the tsunami impact to the east coast of New Zealand originates from southern and central portions of the Kermadec Trench. East Cape is however significantly impacted as a result of the tsunami generated from the rupture of the northern portion of the Hikurangi Margin. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

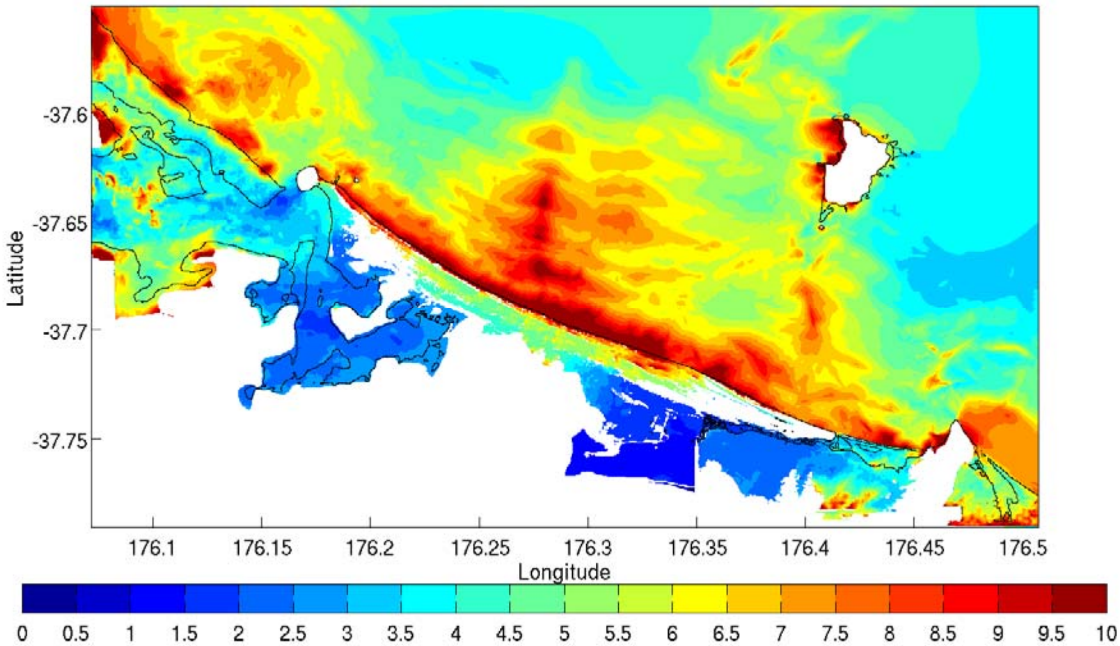

Figure A2.17 The maximum tsunami elevation above MHWS for the Kermadec – Hikurangi Scenario varies between 5.5m and 15.0m above MHWS between the Maketu Estuary and Matakana Island. Inundation occurs at several places along the coastline which includes Papamoa, Mt Maunganui and Matakana Island. Scale bar unit is in metres.

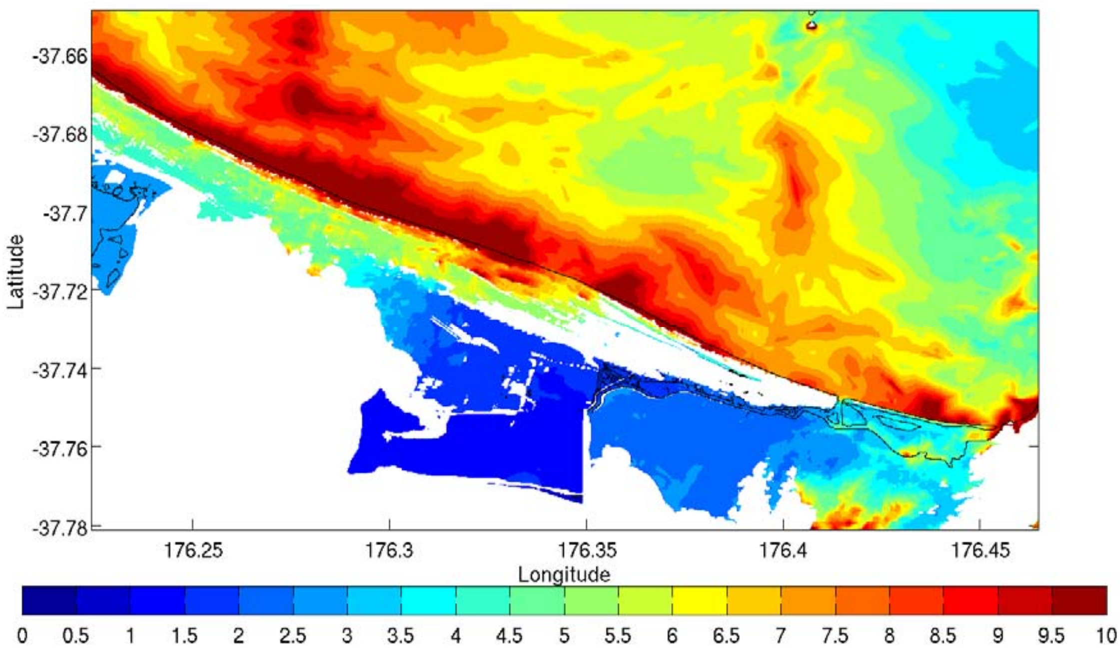

Figure A2.18 The maximum tsunami elevation above MHWS involving the Kermadec – Hikurangi Scenario along the Papamoa Coast near Mt Maunganui which shows extensive inundation occurring between Papamoa and Te Tumu. Scale bar unit is in metres.

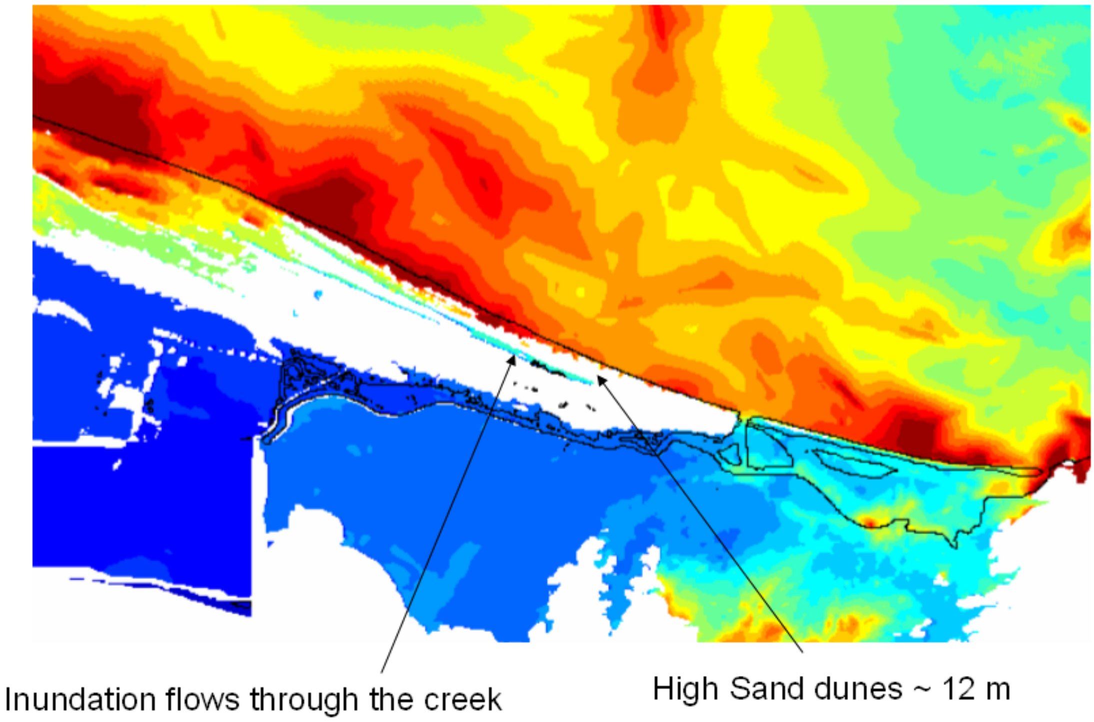

Figure A2.19 The maximum tsunami elevation above MHWS involving the Kermadec – Hikurangi Scenario for Te Tumu. The tsunami flows through the creek at the back of sand dunes at the Te Tumu as the sand dunes are high enough to prevent the tsunami inundating this area. Scale bar unit is in metres.

A2.5 Variation of the Southern Kermadec Scenario

A variation of the Southern Scenario has also been modelled to take into account the evidence of the recent 11 March 2011, Mw 9.0 Tokoku Earthquake in Japan with maximum slip of > 30 m and rupture areas ~ 400 km x 200 km. In this variation of the southern Kermadec scenario, the slip amount in the southern Kermadec scenario was increased to 30m while the other fault parameters were maintained the same as the original.

These parameters resulted in an earthquake with a magnitude of Mw = 9.0. The resulting modelling identified that a tsunami generated from variation of the Southern Kermadec Scenario affects most of the coastal areas along the east coast of the North Island. The sub-regional modelling results show the inundation within the Bay of Plenty coastline between the Maketu Estuary and Matakana Island is greater than the continuous rupture of the whole Kermadec Trench which has been previously modelled (Figures A2.20 to A2.22). The maximum tsunami elevation along the coastline ranges from 8.0m to 15.0m above MHWS. Significant inundation occurs at Papamoa and towards Te Tumu. The ~12m high sand dunes between Te Tumu and the Kaituna River Mouth prevent the tsunami from inundating this part of the coastline. However, most of the low-lying areas along the Maketu Estuary and Kaituna River plain are inundated by the tsunami.

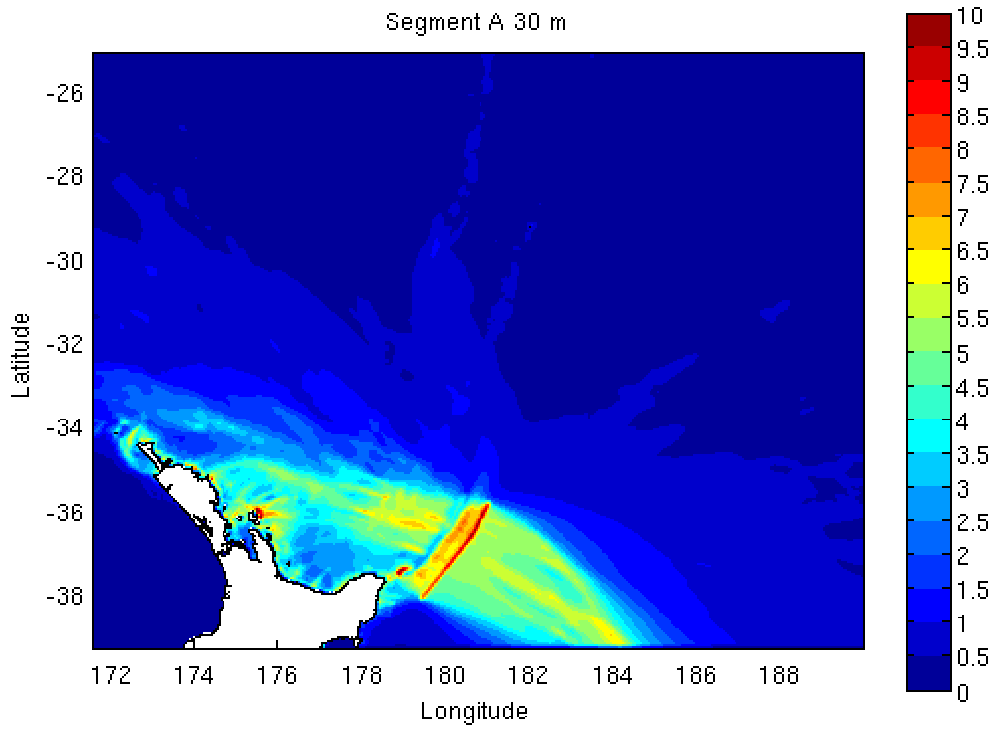

Figure A2.20 The maximum tsunami elevation above MHWS for the variation of the Southern Kermadec Scenario. This modelling shows a tsunami generated from the rupture mostly affects the east coast of the North Island, New Zealand. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

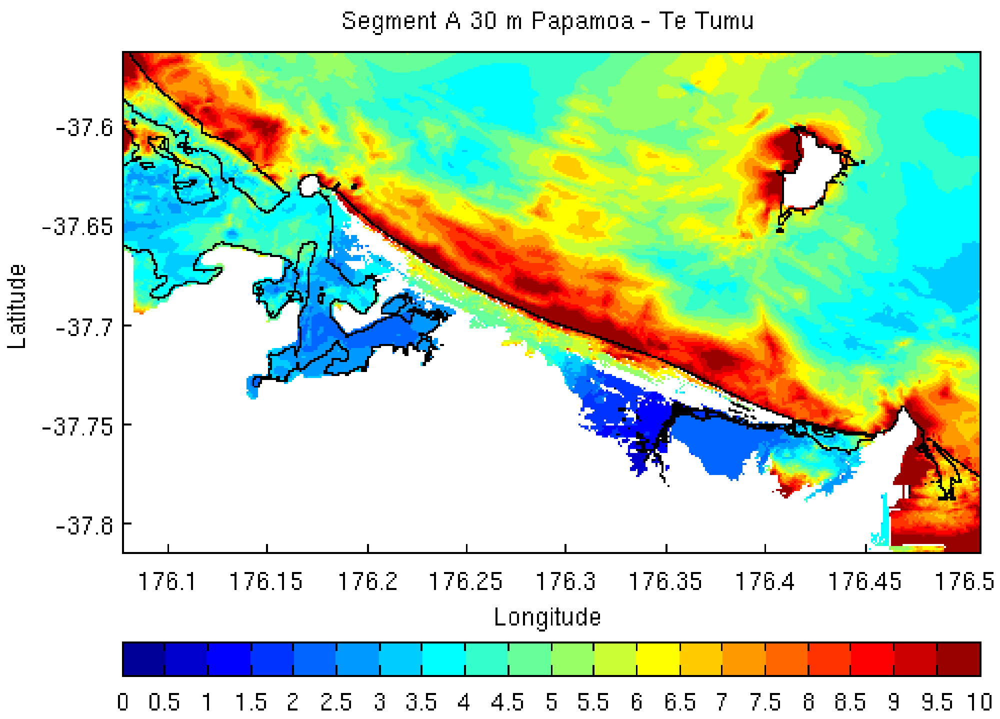

Figure A2.21 The maximum tsunami elevation above MHWS for the variation of the Southern Kermadec Scenario. The sub-regional model shows the maximum tsunami elevation varies between 8.0m and 15.0m above MHWS between Maketu Estuary and Matakana Island. Significant inundation occurs at Papamoa and the north western half of the Te Tumu coastline. Scale bar unit is in metres.

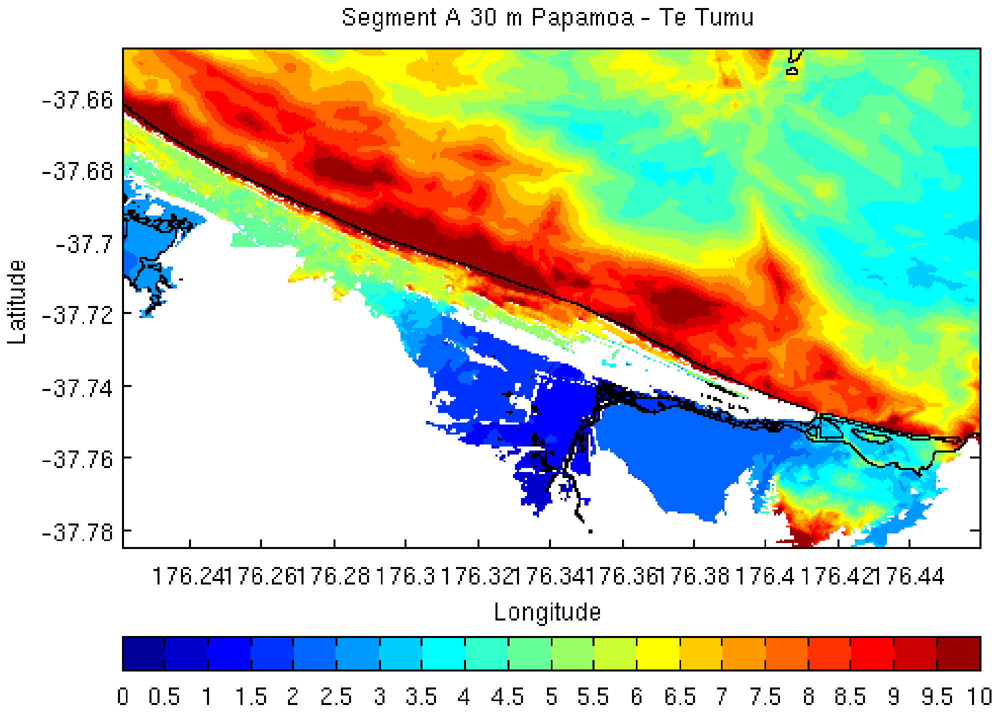

Figure A2.22 The maximum tsunami elevation above MHWS for the variation of the Southern Kermadec Scenario. Detailed inundation modelling shows the extent of inundation inland along the Papamoa and Te Tumu coastline. The ~12m high sand dunes along the coastline of Te Tumu towards the Kaituna River Mouth prevent the tsunami inundating this part of the region. Most of the low-lying areas along the Maketu Estuary and Kaituna River Plain are inundated by the tsunami. Scale bar unit is in metres.

A2.6 Variation of the Central Kermadec Scenario

A variation of the Central Scenario was also modelled to take into account the parameters of the recent 11 March 2011 Mw 9.0 Tokohu Earthquake in Japan. within this scenario, the slip amount in the Central Kermadec Scenario was increased to 30m while the other fault parameters were maintained the same as the original.

These parameters resulted in an earthquake with a magnitude of Mw = 9.2. The modelling identifies that a tsunami generated from this event mostly affects the northern part of the coastal areas along the east coast of the North Island (Figure A2.23). The sub-regional modelling results identifies that the maximum tsunami elevation within the Bay of Plenty varies between 3.0m to 8.0m above MHWS (Figure A2.24). Localised inundation occurs at Papamoa, where a maximum tsunami elevation of 7.0m above MHWS occurs (Figure A2.25). No inundation occurs for most of the Te Tumu coastline due to the presence of the dune systems. The low-lying area behind the Maketu Estuary is inundated to a moderate depth by the tsunami. The tsunami inundation resulting from this event is less than the previous scenario involving the variation of the Southern Kermadec Scenario.

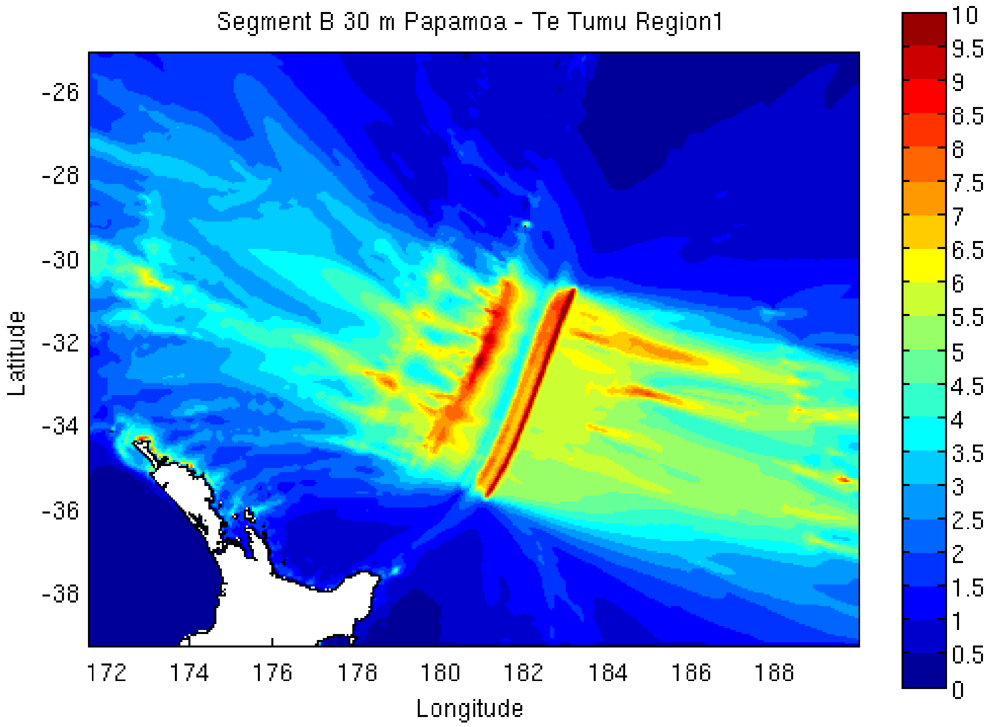

Figure A2.23 The maximum tsunami elevation above MHWS for the variation of the Central Kermadec Scenario. This modelling identifies that a tsunami generated from mostly affects the northern part of the East Coast of the North Island New Zealand. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

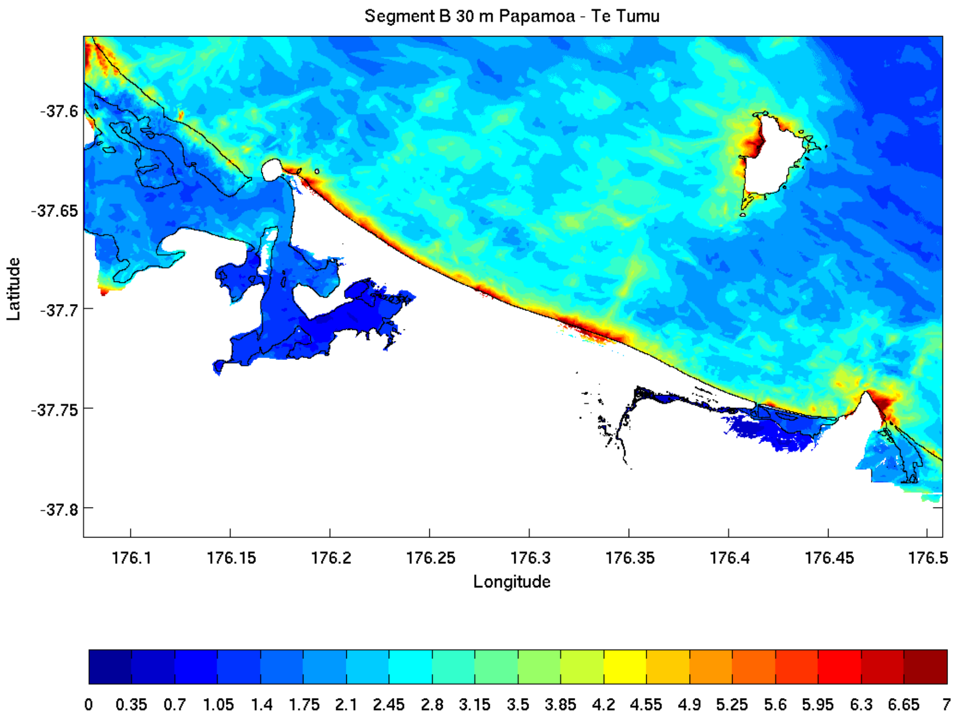

Figure A2.24 The maximum tsunami elevation above MHWS for the variation of the Central Kermadec Scenario. The sub-regional model shows the maximum tsunami elevation above MHWS varies from 3.0m – 8.0m above MHWS between the Maketu Estuary and Matakana Island. Scale bar unit is in metres.

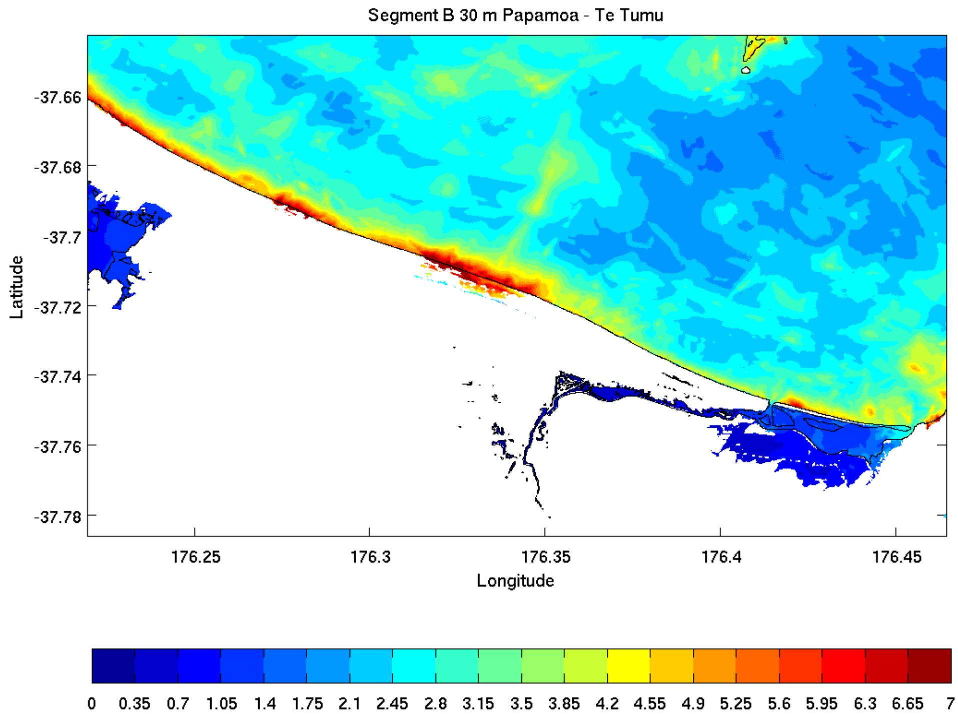

Figure A2.25 The maximum tsunami elevation above MHWS for the variation of the Central Kermadec Scenario. The detailed inundation modelling identifies localised inundation occurring along the Papamoa and Te Tumu coastlines. The tsunami from this event scenario is not capable of overtopping most of the sand dunes at Te Tumu. Localised inundation occurs at the low-lying area behind the Maketu Estuary. Scale bar unit is in metres.

A2.7 Variation of the Whole Kermadec Scenario

A variation of the whole Kermadec scenario has been modelled to take into account the parameters of the recent 11 March 2011 Mw 9.0 Tokoku Earthquake in Japan. In this scenario, the slip amount in the whole Kermadec scenario was increased to 30m on Segments A and B while the slip of Segment C was retained as 22m.

These parameters resulted in an earthquake with a magnitude of Mw = 9.45. The modelling identifies that a tsunami generated from this event affects most of the east coast of the North Island. The sub-regional modelling results show that the inundation within the Bay of Plenty between the Maketu Estuary and Matakana Island is greater than the previous scenario of the continuous rupture of the whole Kermadec Trench. The level of inundation however is similar to the variation of the Southern Kermadec Scenario as illustrated in Figures A2.26 to 2.30.

The maximum tsunami elevation along the coastline ranges from 8.0m to 15.0m above MHWS. Significant inundation occurs at Papamoa as well as the north western half of Te Tumu. The ~12m high sand dunes between Te Tumu and the Kaituna River Mouth prevent the tsunami inundating this part of the coastline. Most of the low-lying areas along the Maketu Estuary and Kaituna River plain are inundated by the tsunami.

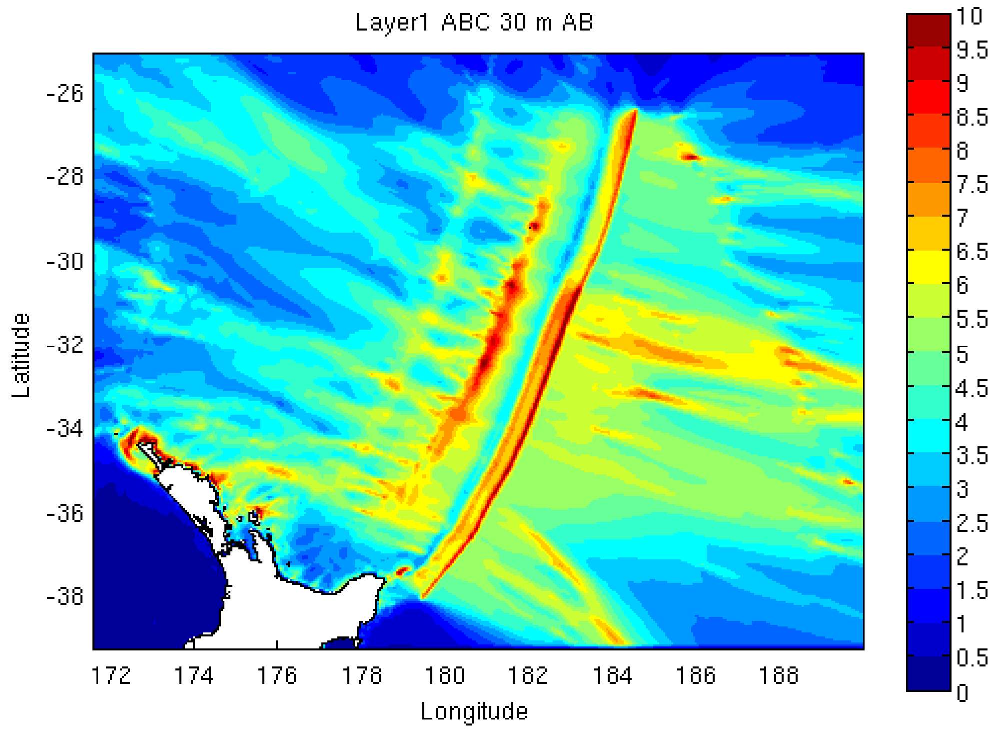

Figure A2.26 The maximum tsunami elevation above MHWS for the variation of the whole Kermadec Scenario. The modelling identifies that a tsunami generated from this event affects most of the east coast of the North Island, New Zealand. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

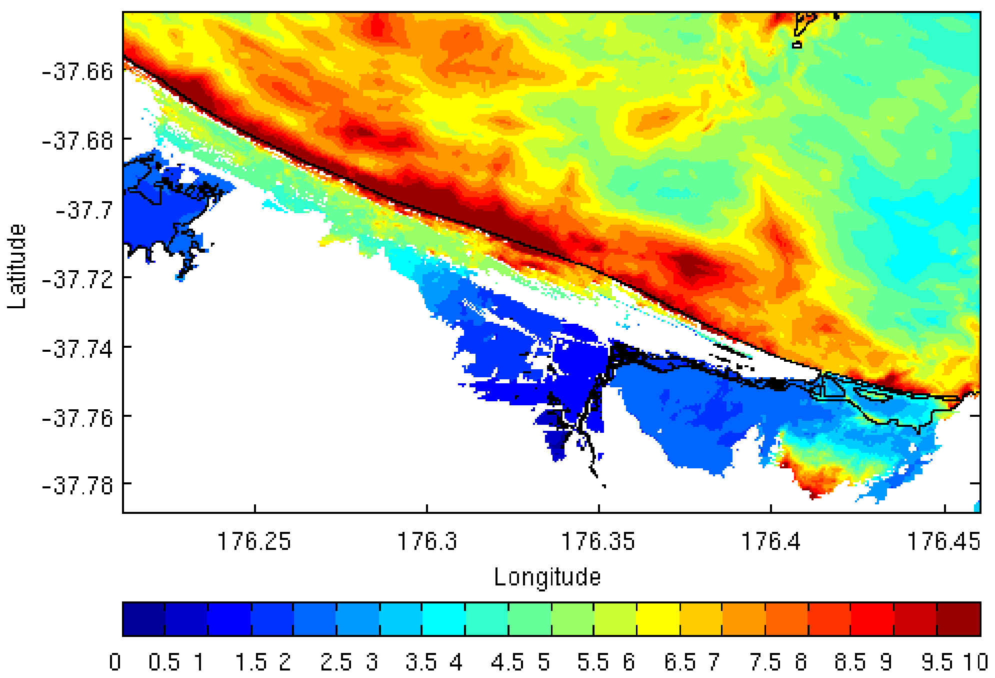

Figure A2.27 The maximum tsunami elevation above MHWS for the variation of the whole Kermadec Scenario. The sub-regional model shows the maximum tsunami elevation above MHWS varies between 8.0m – 15m between the Maketu Estuary and Matakana Island. Large scale inundation occurs at Papamoa and the north western portion of Te Tumu. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

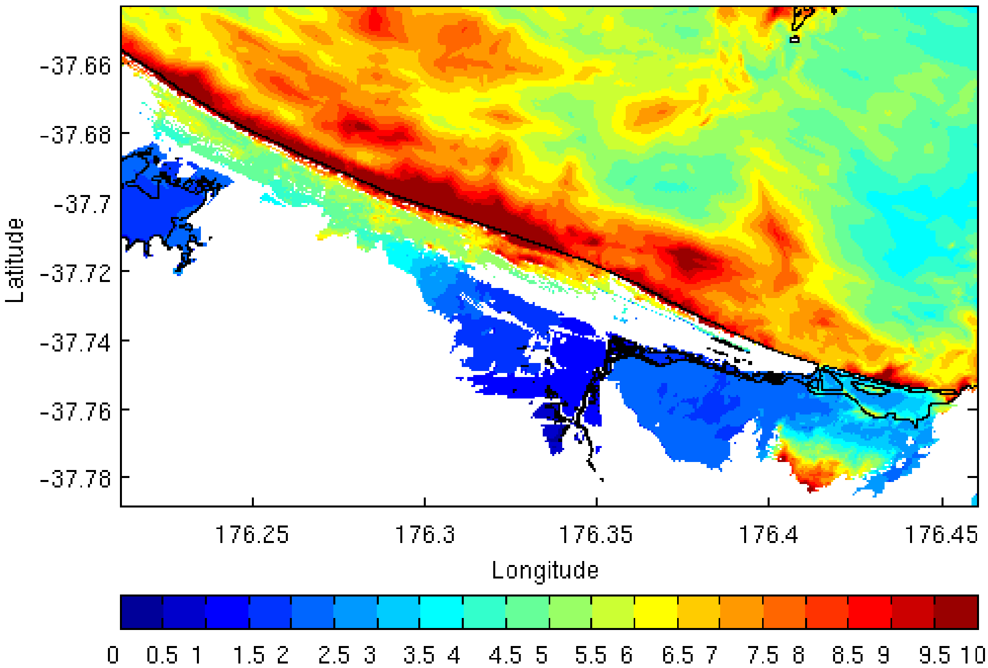

Figure A2.28 The maximum tsunami elevation above MHWS for the variation of the whole Kermadec Scenario. Detailed inundation modelling identifies the extent of inundation inland along the Papamoa and Te Tumu coastlines. The sand dunes between Te Tumu and the Kaituna River Mouth prevent the tsunami from inundating this part of the coastline. Most of the low-lying areas along the Maketu Estuary and Kaituna River Plain are inundated by the tsunami. The colour scale shows the maximum tsunami elevation above MHWS Scale bar unit is in metres.

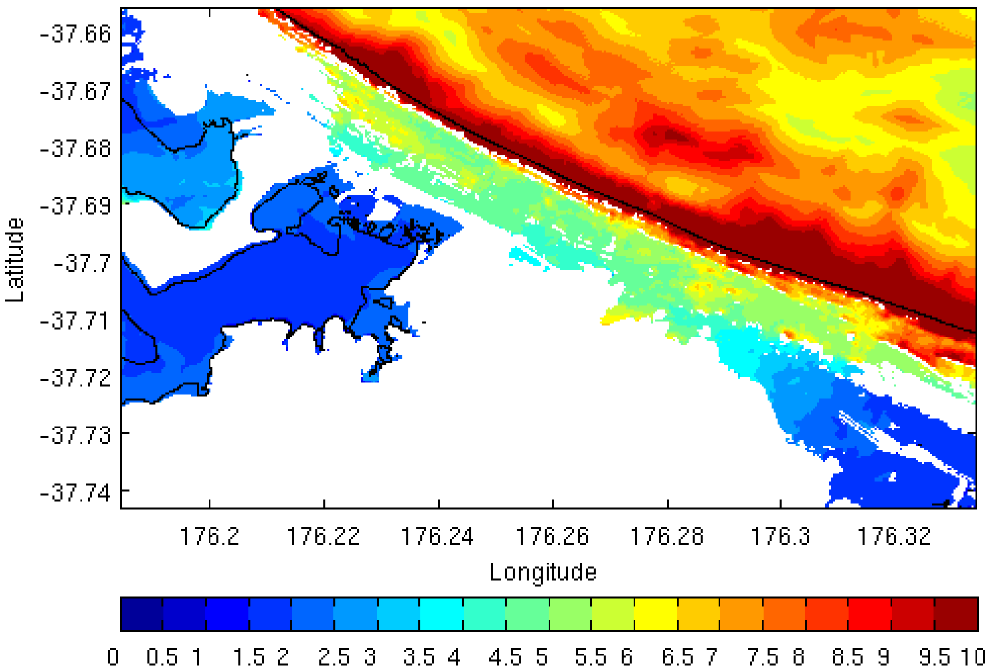

Figure A2.29 The maximum tsunami elevation above MHWS for the variation of the whole Kermadec Scenario. The inundation extends inland at Papamoa indicating that the tsunami has overtopped the sand dunes along the beach. The tsunami overland flows propagate further down to the low-lying areas towards Te Tumu. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

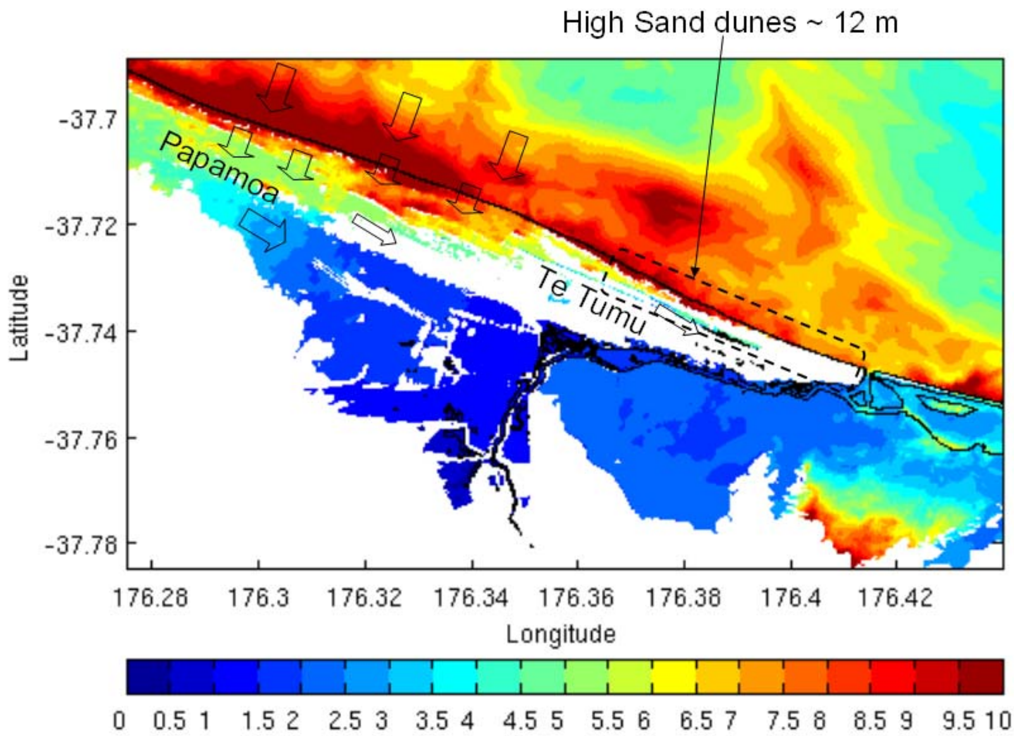

Figure A2.30 The maximum tsunami elevation above MHWS for the variation of the whole Kermadec Scenario. The extent of inundation along the Papamoa – Te Tumu coastline indicates that the tsunami overtopped the sand dunes along the beach in front of Papamoa and the overland flows propagate down to the low-lying areas towards Te Tumu as shown by block arrows. The sand dunes at Te Tumu beach front prevent the tsunami inundating the coastal areas along this part of the coastline. The colour scale shows the maximum tsunami elevation above MHWS. The scale bar unit is in metres.

APPENDIX 3 INUNDATION – LOCAL SOURCES

The faults described by Lamarche and Barnes (2005) have been used by Walters et al. (2006) to assess the impact from a tsunami generated locally within the Bay of Plenty region. These local faults are as follows:

- A composite Astrolabe Fault (AST-C1);
- The Volkner Fault (VOLC-C1); and
- The White Island Fault (WIF-C1)

Numerical modelling of tsunami generation, propagation and inundation at a regional scale from these local sources towards the study area has been undertaken with COMCOT (Wang and Power 2011). The parameters from each of the faultlines are derived from Lamarche and Barnes (2005). Four levels of grid resolutions were developed to model tsunami impacts from these local sources. The first level of grid covered both the generation region and the studies areas with a grid spacing of 10 arc second (~240m), derived from Geo 08. The fourth level of grids covers the studied areas with a resolution of 0.37 arc-seconds (~9m).

A3.1 The Composite Astrolabe Fault (AST-C1) Mw = 7.1

The initial condition of the tsunami is illustrated in Figure A3.1. The modelling shows that the maximum tsunami elevations for the Bay of Plenty between the Maketu Estuary and Matakana Island range from 0.5m to 1.0m above MHWS (Figure A3.2 and A3.3). The highest maximum tsunami elevation of ~ 1.0 m occurs near the entrance to the Maketu Estuary. No inundation occurs along the Papamoa and Te Tumu coastline as the dune systems will not be overtopped by this event.

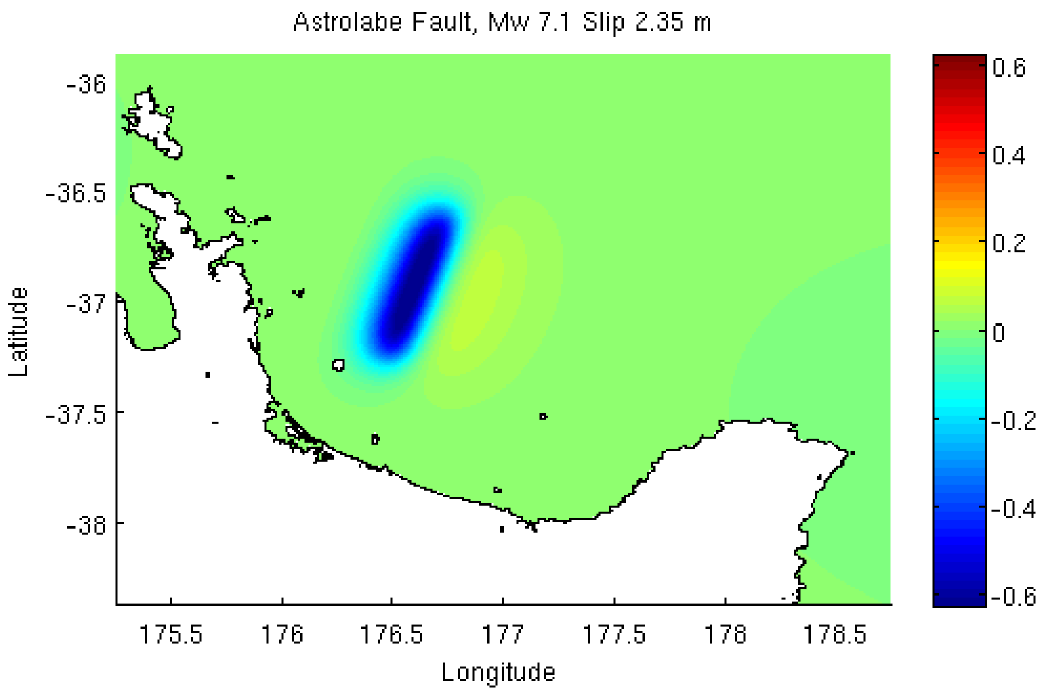

Figure A3.1 The initial condition of the tsunami elevation above MHWS from the Astrolabe Fault at the source region. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

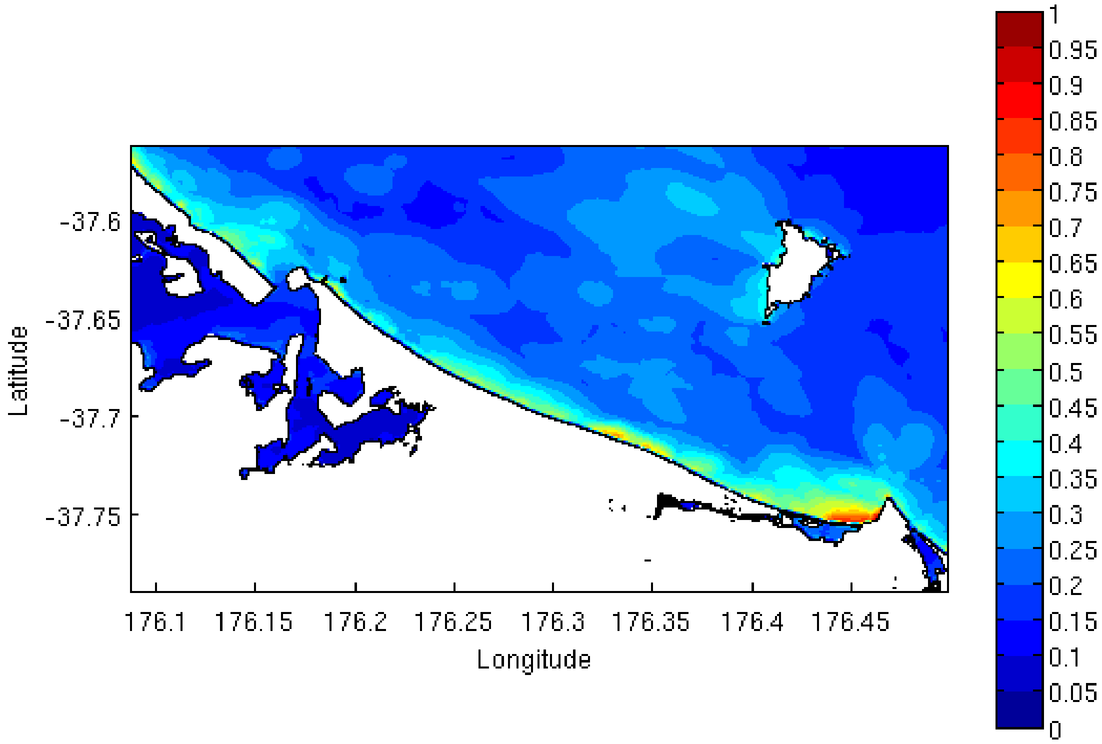

Figure A3.2 The maximum tsunami elevation for the Astrolabe Fault varies from 0.5m to 1.0m above MHWS along the east coast of the Bay of Plenty. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

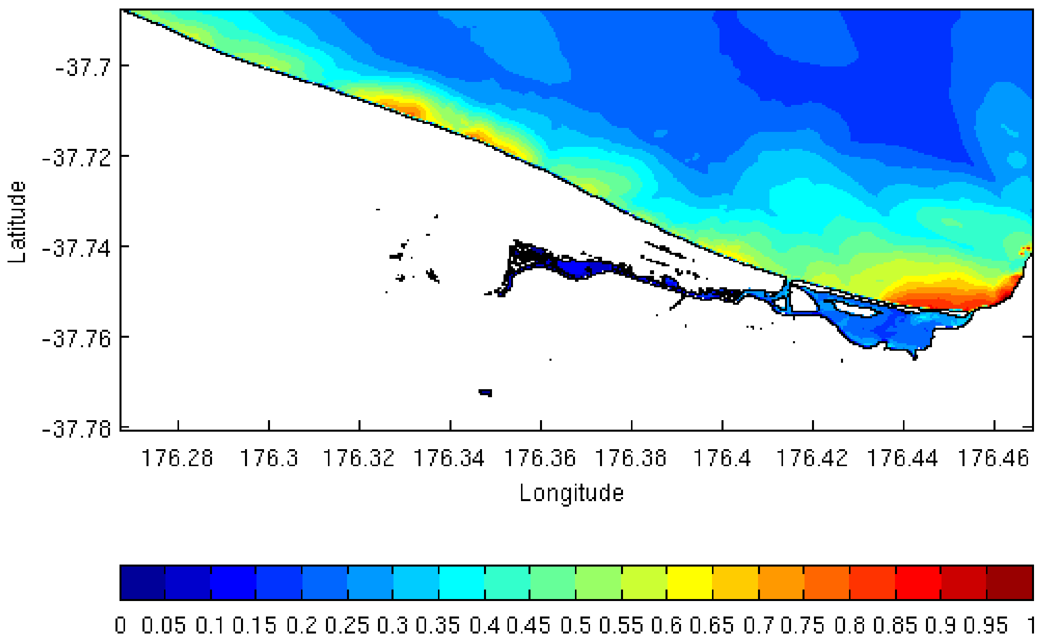

Figure A3.3 The maximum tsunami elevation varies from 0.2m – 0.6m above MHWS for the Astrolabe Fault along the Papamoa – Te Tumu coastline. At the Maketu Estuary the inundation may be up to 1.0m deep. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

A3.2 The Composite Volkner Fault (VOLC-C1) Mw = 6.79

The modelling for this event was based on a fault length of 34.6km, with a dip angle of 50^o, a strike angle 25.46^o, and at a depth of 8km. The slip angle was uniform at 90^o and a slip displacement of 1.39m was used.

The initial condition of the tsunami is illustrated in Figure A3.4. The modelling shows that the maximum tsunami elevations within the Bay of Plenty between the Maketu Estuary and Matakana Island vary between 0.2m to 0.7m above MHWS (Figures A3.5 and A3.6). The highest maximum tsunami elevation of ~ 0.7 m occurs at the entrance to the Maketu Estuary. No inundation occurs at Papamoa and Te Tumu as the dune systems will not be overtopped by this event.

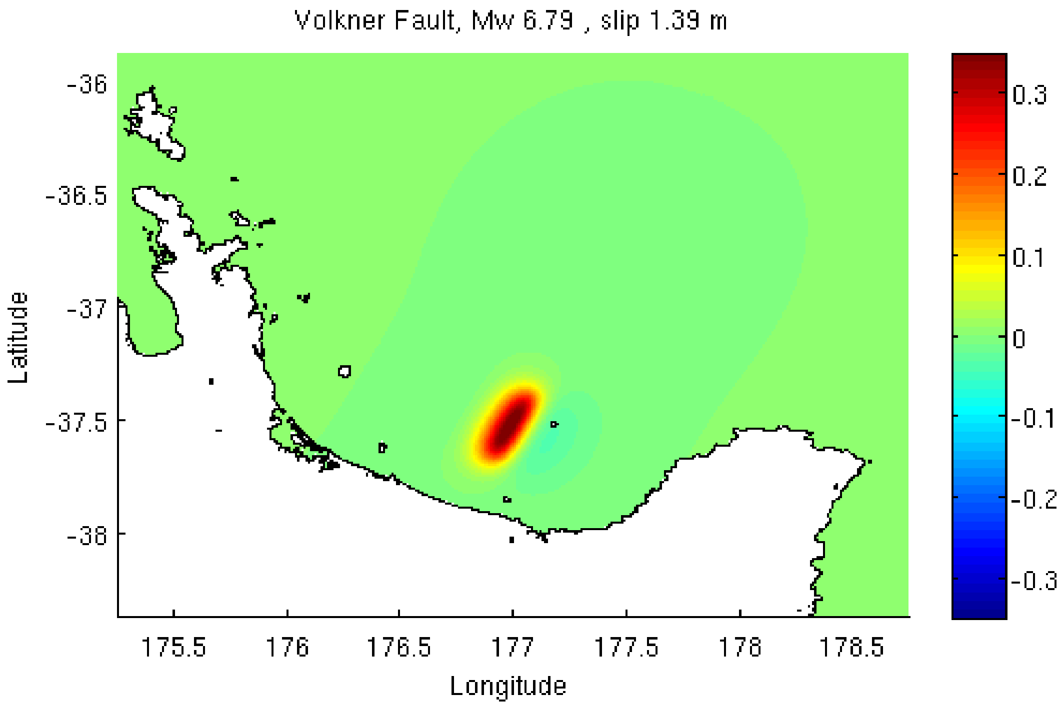

Figure A3.4 The initial condition of the tsunami elevation above MHWS for the Volkner Fault at the source region. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

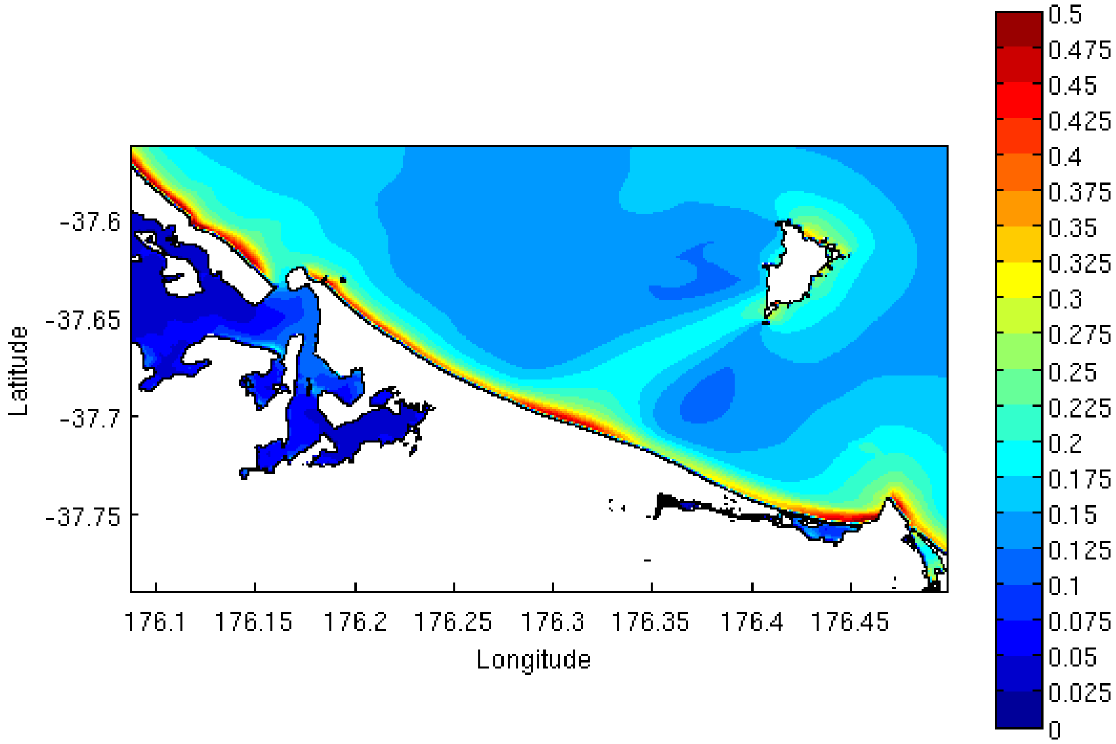

Figure A3.5 The maximum tsunami elevation varies from 0.3m to 0.7m above MHWS for the Volkner Fault along the Bay of Plenty coastline between the Maketu Estuary and Matakana Island. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

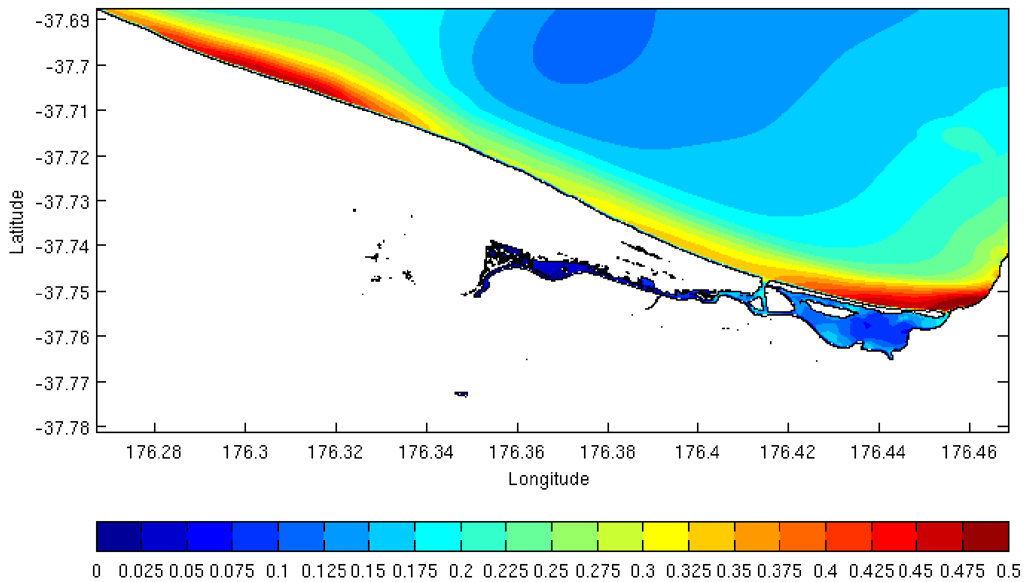

Figure A3.6 The maximum tsunami elevation varies from 0.2m – 0.5m above MHWS for the Volkner Fault along the Papamoa – Te Tumu coastline. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

A3.3 The Composite White Island Fault (WIF-C1) Mw = 7.01

The modelling for this event was based on a fault length of 50.6km, with a dip angle of 50°, a strike angle 36.76.°, and at a depth of 8km. The slip angle was uniform at 90° and a slip of 2.03m was used.

The initial condition of the tsunami is illustrated in Figure A3.7. The modelling shows that the maximum tsunami elevations within the Bay of Plenty between Maketu Estuary and Matakana Island range from 0.3m to 0.7m above MHWS (Figures A3.8 and A3.9). The highest maximum tsunami elevation of ~ 0.7m occurs at the entrance to the Maketu Estuary. No inundation occurs at Papamoa and Te Tumu as the dune systems will not be overtopped by this event.

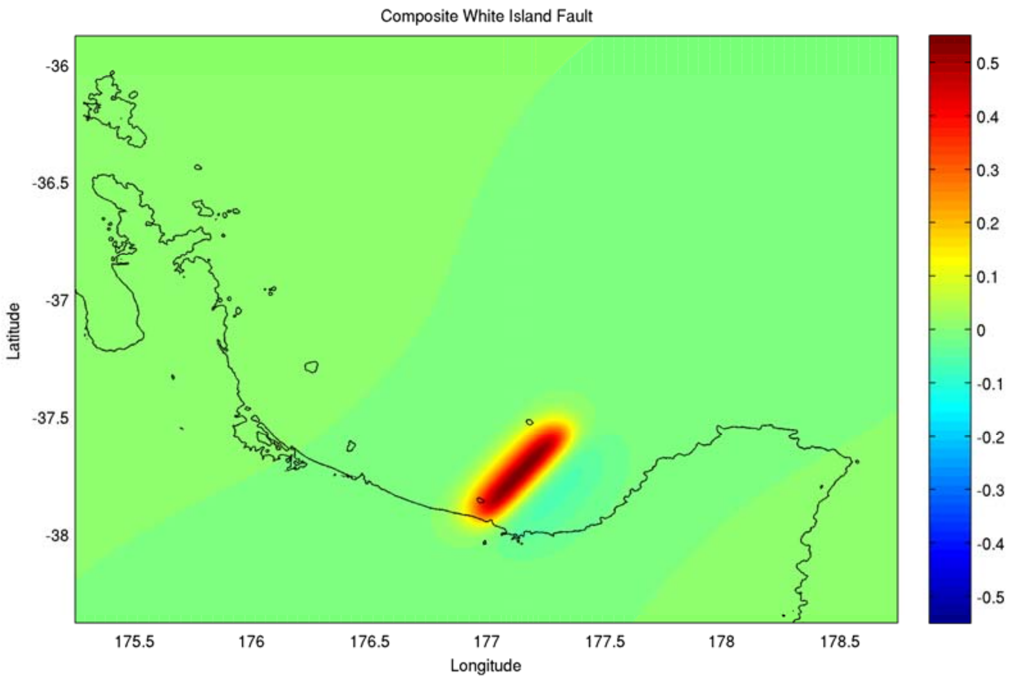

Figure A3.7 The initial condition of the tsunami elevation above MHWS for the Composite White Island Fault at the source region. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

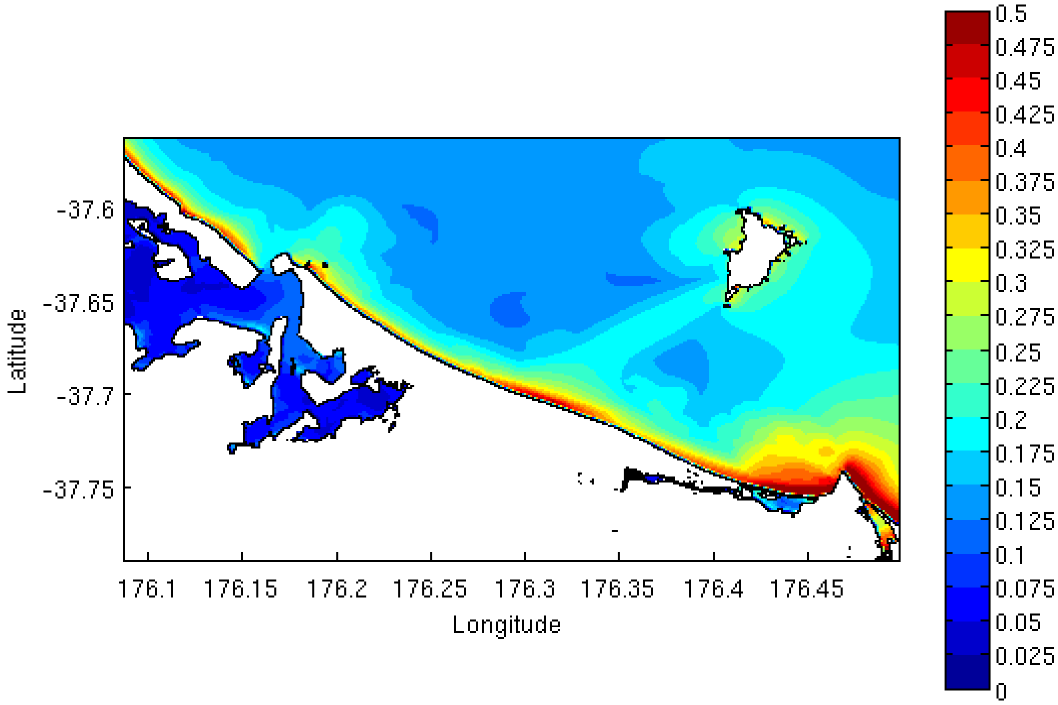

Figure A3.8 The maximum tsunami elevation varies between 0.2m and 0.7m above MHWS for the Composite White Island Fault along the Bay of Plenty coastline between the Maketu Estuary and Matakana Island. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

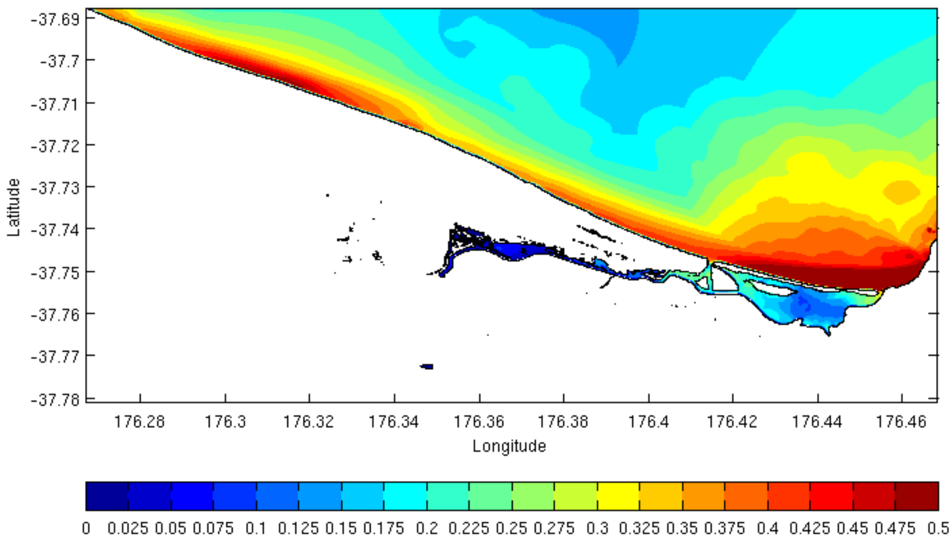

Figure A3.9 The maximum tsunami elevation varies between 0.2m and 0.7m above MHWS for the Composite White Island Fault along the Papamoa and Te Tumu coastlines. The colour scale shows the maximum tsunami elevation above MHWS. Scale bar unit is in metres.

APPENDIX 4 DAMAGE AND CASUALTY RESULTS – LOW DENSITY MODEL

There were four basic steps in the loss modelling, the tsunami modelling was used to estimate water depths for every building and person location in the assets model, (b) the damage and casualty rates were calculated using the functions illustrated in Figures 3.2 to 3.6, (c) the damage rates were multiplied by the building values to give the direct damage costs, and (d) the casualty rates were combined with a random number to determine whether a particular person was killed or injured.

A4.1 Southern Kermadec Scenario

Table A4.1.1 Southern Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	3	5	0	0	0
Wairakei	2	0	1	0	0
Te Tumu	4	2	4	10	9
Totals	9	7	5	10	9

Table A4.1.2 Southern Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.04	0.06	0	0	0
Wairakei	0.02	0	0.02	0	0
Te Tumu	0.03	0.01	0.02	0.05	0.25

Table A4.1.3 Southern Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	1	2	4	9
Outdoors	0	0	1	0
Beach	8	5	1	1

Table A4.1.4 Southern Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.004	0.004	0.009	0.02
Outdoors	0	0	0.2	0
Beach	8	5	17	17

A4.2 Central Kermadec Scenario

Table A4.2.1 Central Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	4	3	0	0	0
Wairakei	2	1	0	1	0
Te Tumu	4	3	2	3	8
Totals	10	7	2	4	8

Table A4.2.2 Central Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.05	0.04	0	0	0
Wairakei	0.02	0.01	0	0.02	0
Te Tumu	0.03	0.02	0.01	0.01	0.2

Table A4.2.3 Central Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	2	0	2	2
Outdoors	1	0	0	0
Beach	7	7	0	2

Table A4.2.4 Central Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.008	0	0.005	0.005
Outdoors	0.02	0	0	0
Beach	7	7	0	33

A4.3 Northern Kermadec Scenario

Table A4.3.1 Northern Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	4	3	0	0	0
Wairakei	0	3	0	0	0
Te Tumu	4	1	1	2	4
Totals	8	7	1	2	4

Table A4.3.2 Northern Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.05	0.04	0	0	0
Wairakei	0	0.03	0	0	0
Te Tumu	0.03	0.01	0	0.01	0.1

Table A4.3.3 Northern Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	0	0	1	1
Outdoors	1	0	0	0
Beach	7	7	0	1

Table A4.3.4 Northern Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0	0	0.002	0.002
Outdoors	0.02	0	0	0
Beach	7	7	0	17

A4.4 Whole Kermadec Scenario

Table A4.4.1 Whole Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	70	60	170	200	290
Wairakei	10	1	0	0	0
Te Tumu	20	20	50	50	90
Totals	100	80	220	250	380

Table A4.4.2 Whole Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.8	0.7	1	1	11
Wairakei	0.1	0.01	0	0	0
Te Tumu	0.2	0.2	0.2	0.3	3

Table A4.4.3 Whole Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	50	50	220	240
Outdoors	10	15	3	5
Beach	30	20	1	2

Table A4.4.4 Whole Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.2	0.2	0.5	0.6
Outdoors	0	0	0.7	1
Beach	34	19%	17	3

A4.5 Worst Case Scenario: Kermadec-Hikurangi Scenario

Table A4.5.1 Worst Case Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	620	620	1230	1120	1820
Wairakei	320	300	260	260	540
Te Tumu	240	230	430	410	720
Totals	1180	1150	1920	1790	3080

Table A4.5.2 Worst Case Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	7	7	7	7	71
Wairakei	3	3	4	4	38
Te Tumu	2	2	2	2	20

Table A4.5.3 Worst Case Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	850	910	1890	1770
Outdoors	290	220	30	20
Beach	40	20	3	1

Table A4.5.4 Worst Case Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	3	3	5	4
Outdoors	4	3	7	6
Beach	41	24	50	17

APPENDIX 5 DAMAGE AND CASUALTY RESULTS – HIGH DENSITY MODEL

There were four basic steps in the loss modelling, the tsunami modelling was used to estimate water depths for every building and person location in the assets model, (b) the damage and casualty rates were calculated using the functions illustrated in Figures 3.2 to 3.6, (c) the damage rates were multiplied by the building values to give the direct damage costs, and (d) the casualty rates were combined with a random number to determine whether a particular person was killed or injured.

A5.1 Southern Kermadec Scenario

Table A5.1.1 Southern Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	7	9	1	0	0
Wairakei	1	3	1	0	0
Te Tumu	5	7	3	5	11
Totals	13	19	5	5	11

Table A5.1.2 Southern Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.08	0.10	0.01	0	0
Wairakei	0.01	0.02	0.01	0	0
Te Tumu	0.02	0.03	0.01	0.02	0.19

Table A5.1.3 Southern Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	1	1	3	5
Outdoors	0	2	0	0
Beach	12	16	2	0

Table A5.1.4 Southern Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.003	0.003	0.005	0.009
Outdoors	0	0.021	0	0
Beach	7	9	22	0

A5.2 Central Kermadec Scenario

Table A5.2.1 Central Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	11	7	1	2	0
Wairakei	4	2	0	0	0
Te Tumu	8	3	5	0	11
Totals	23	12	6	2	11

Table A5.2.2 Central Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.13	0.08	0.006	0.01	0
Wairakei	0.02	0.01	0	0	0
Te Tumu	0.04	0.01	0.02	0	0.2

Table A5.2.3 Central Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	2	0	5	0
Outdoors	0	2	0	0
Beach	21	10	1	2

Table A5.2.4 Central Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.005	0	0.009	0
Outdoors	0	0.02	0	0
Beach	12	6	11	22

A5.3 Northern Kermadec Scenario

Table A5.3.1 Northern Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	5	4	0	0	0
Wairakei	2	1	0	0	0
Te Tumu	7	3	2	0	5
Totals	14	8	2	0	5

Table A5.3.2 Northern Kermadec Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	0.06	0.05	0	0	0
Wairakei	0.012	0.006	0	0	0
Te Tumu	0.03	0.013	0.007	0	0.09

Table A5.3.3 Northern Kermadec Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	1	0	1	0
Outdoors	1	0	0	0
Beach	12	8	1	0

Table A5.3.4 Northern Kermadec Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.003	0	0.002	0
Outdoors	0.01	0	0	0
Beach	7	5	11	0

A5.4 Whole Kermadec Scenario

Table A5.4.1 Whole Kermadec Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	100	70	200	200	290
Wairakei	10	5	1	0	0
Te Tumu	30	30	30	30	120
Totals	140	105	231	230	410

Table A5.4.2 Whole Kermadec Scenario– casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	1	1	1	1	12
Wairakei	0.05	0.02	0.01	0	0
Te Tumu	0.1	0.1	0.1	0.1	2

Table A5.4.3 Whole Kermadec Scenario– casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	60	50	230	225
Outdoors	25	20	2	0
Beach	55	35	5	1

Table A5.4.4 Whole Kermadec Scenario– casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	0.2	0.1	0.4	0.4
Outdoors	0.3	0.2	0.3	0
Beach	30	20	60	10

A5.5 Worst Case Scenario: Kermadec-Hikurangi Scenario

Table A5.5.1 Worst Case Scenario – casualties and losses by suburb.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries	Building Damage ($m)
Papamoa	680	610	1260	1100	1800
Wairakei	470	470	400	350	1200
Te Tumu	310	260	570	460	1000
Totals	1460	1340	2230	1910	4000

Table A5.5.2 Worst Case Scenario – casualty and loss rates by suburb.

Suburb	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)	Building Damage (%)
Papamoa	8	7	8	7	71
Wairakei	3	3	3	3	36
Te Tumu	1.4	1.2	1.9	1.5	18

Table A5.5.3 Worst Case Scenario – casualties and losses by location

Location	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Indoors	1090	990	2200	1880
Outdoors	290	310	30	30
Beach	80	40	3	2

Table A5.5.4 Worst Case Scenario – casualty and loss rates by location

Location	Daytime Deaths (%)	Daytime Injuries (%)	Night-time Deaths (%)	Night-time Injuries (%)
Indoors	3	2	4	3
Outdoors	3	3	5	5
Beach	43	25	33	22

APPENDIX 6 ANNUAL PROBABILITY OF DEATH OR INJURY FOR PERSON

Annual probabilities of death or injury for individuals were obtained by dividing the numbers of deaths or injuries by the populations exposed (Tables 3.13 and 3.15) and then by the return period for the scenario (Table 2.3). Note that “Papamoa” includes the existing suburbs of Papamoa and Papamoa Beach.

A6.1 Southern Kermadec Scenario, low- and high-density models

Table A6.1.1 Individual annual casualty probabilities, low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	3×10^{-6}	6×10^{-6}	0	0
Wairakei	2×10^{-6}	0	2×10^{-6}	0
Te Tumu	3×10^{-6}	7×10^{-7}	2×10^{-6}	5×10^{-6}

Table A6.1.2 Individual annual casualty probabilities, high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	8×10^{-6}	1×10^{-5}	6×10^{-7}	0
Wairakei	6×10^{-7}	2×10^{-6}	8×10^{-7}	0
Te Tumu	2×10^{-6}	3×10^{-6}	1×10^{-6}	2×10^{-6}

A6.2 Central Kermadec, Low and High-Density Models

Table A6.2.1 Individual annual casualty probabilities, low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	3×10^{-6}	2×10^{-6}	0	0
Wairakei	1×10^{-6}	5×10^{-7}	0	9×10^{-7}
Te Tumu	2×10^{-6}	1×10^{-7}	6×10^{-7}	8×10^{-7}

Table A6.2.2 Individual annual casualty probabilities, high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	7×10^{-6}	4×10^{-6}	3×10^{-7}	7×10^{-7}
Wairakei	1×10^{-6}	7×10^{-7}	0	0
Te Tumu	2×10^{-6}	7×10^{-7}	9×10^{-7}	0

A6.3 Northern Kermadec, Low and High-Density Models

Table A6.3.1 Individual annual casualty probabilities, low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	4×10^{-6}	3×10^{-6}	0	0
Wairakei	0	2×10^{-6}	0	0
Te Tumu	2×10^{-6}	6×10^{-7}	4×10^{-7}	8×10^{-7}

Table A6.3.2 Individual annual casualty probabilities, high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	4×10^{-6}	4×10^{-6}	0	0
Wairakei	9×10^{-7}	5×10^{-7}	0	0
Te Tumu	2×10^{-6}	1×10^{-6}	5×10^{-7}	0

A6.4 Whole Kermadec Scenario, Low and High-Density Models

Table A6.4.1 Individual annual casualty probabilities, low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	2×10^{-5}	2×10^{-5}	3×10^{-5}	3×10^{-5}
Wairakei	2×10^{-6}	3×10^{-7}	0	0
Te Tumu	4×10^{-6}	4×10^{-6}	6×10^{-6}	7×10^{-6}

Table A6.4.2 Individual annual casualty probabilities, high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	3×10^{-5}	2×10^{-5}	3×10^{-5}	3×10^{-5}
Wairakei	1×10^{-6}	6×10^{-7}	2×10^{-7}	0
Te Tumu	3×10^{-6}	3×10^{-6}	3×10^{-6}	2×10^{-6}

A6.5 Worst Case Scenario, Low and High-Density Models

Table A6.5.1 Individual annual casualty probabilities, low-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	$2 \text{ X } 10^{-4}$	$2 \text{ X } 10^{-4}$	$2 \text{ X } 10^{-4}$	$2 \text{ X } 10^{-4}$
Wairakei	$9 \text{ X } 10^{-5}$	$8 \text{ X } 10^{-5}$	$1 \text{ X } 10^{-4}$	$1 \text{ X } 10^{-4}$
Te Tumu	$5 \text{ X } 10^{-5}$	$5 \text{ X } 10^{-5}$	$6 \text{ X } 10^{-5}$	$6 \text{ X } 10^{-5}$

Table A6.5.2 Individual annual casualty probabilities, high-density model.

Suburb	Daytime Deaths	Daytime Injuries	Night-time Deaths	Night-time Injuries
Papamoa	2 X 10^{-4}	2 X 10^{-4}	2 X 10^{-4}	2 X 10^{-4}
Wairakei	8 X 10^{-5}	8 X 10^{-5}	9 X 10^{-5}	8 X 10^{-5}
Te Tumu	4 X 10^{-5}	3 X 10^{-5}	5 X 10^{-5}	4 X 10^{-5}

APPENDIX 7 SUGGESTED POTENTIAL PRE-EVENT RECOVERY PLANNING CONSIDERATIONS (TAKEN DIRECTLY FROM BECKER ET AL. 2008)

The following tables (Tables A7.1 and A7.2) outline some specific measures that can be used to help with land-use recovery after an event. Alongside each measure, the planning frameworks in which these can be incorporated are suggested. If consideration is given to these measures prior to an event, it will allow more efficient implementation after an event has occurred, leading to a more efficient recovery.

Table A7.1 General planning measures which can be of use for **immediate** land-use recovery purposes after an event (after Schwab et al., 1998)

Measures	Framework for incorporation	Examples of measures
Damage assessments after an event (which can be integrated with Global Positioning Systems (GPS) and Geographical Information Systems (GIS))	CDEM (damage assessments)	**Before an event:** • Identify the impact of potential events and implications for recovery. In doing so, make use of tools such as scenario planning; simulation modelling; vulnerability and economic impact studies. • Identify procedures and tools (such as GPS to gather spatial data and GIS to visually depict and analyse the data) to be used for damage assessment post-event. • Identify potential actions that might be required to assess the damage and assist with recovery. • Incorporate any relevant procedures to carry out these tasks post-event in the CDEM plan.
Identify sites for emergency operations	CDEM, DP, BUS	**Before an event:** • Identify and provide for sites for temporary emergency operation centres (EOCs) including provisions for emergency electricity etc. • Ensure that procedures are in place (e.g. Bylaws, resources) to allow these facilities to operate in those locations and that EOCs meet the specific building codes required.
Feasibility of emergency evacuation	CDEM, linking to the DP	**Before an event:** • Investigate and test (including making use of exercises) the feasibility of emergency evacuation (CDEM). • Consider the relocation of people (e.g. Will people need temporary housing? Will they need to be billeted in a separate town?

Measures	Framework for incorporation	Examples of measures
		• Make any changes required to evacuation planning (CDEM) to ensure evacuation is successful. • Document evacuation procedures and disseminate to required groups (CDEM). • Ensure evacuation routes/assembly areas are accommodated for (e.g. through DP processes).
Identify new lessons discovered during response and initial recovery after the event	Primarily CDEM, with support from RES, ASSET, DP, RP, RPS.	**Before an event:** • Consider how new lessons might be documented after an event (e.g. What resources will be required to collect and record information? What personnel will be required to collect/record information? What format should this be in? How should information on the lessons learned be disseminated? What information will be required by MCDEM?). Account for these requirements in appropriate places e.g. CDEM plans, MOUs with research institutions, ASSET management plans. • Consider where information about new lessons should be documented, and if possible, put in place procedures for this to happen. Some documents may need to be amended to account for new information e.g. CDEM plans, district plans and regional policy statements/plans, hazard registers.
Development moratorium, whereby development decisions are halted for a period of time after an event.	DP, RP and linked with CDEM	**Before an event:** • A development moratorium at the district and regional level can place a hold on applications for development for a specified length of time or for certain activities until the Council and community have the ability to recover from a significant event and determine whether new development is appropriate. The presence, nature and timing of a moratorium could be agreed upon before an event and identified in the DP or RP and linked with the CDEM plan.
Emergency consents	DP, CDEM Act, RP, BUS, and linking to ASSET	**Before an event:** • Consents for emergency activities (e.g. related to debris storage, repairs to infrastructure, buildings and other facilities) may be needed when responding to and recovering from an event. • Before an event, give consideration to the types of activities that may need emergency consents post-event and prepare a draft for any that you can beforehand. • Processing of emergency consents is likely to be required by district and regional council following an event. Emergency consents fall under the emergency provisions of the Resource Management Act and Civil Defence and Emergency Management Act. • The MfE Guidance note for RMA emergency Works Provisions (Quality Planning 2008) suggests that a number of tasks can be carried out before an event occurs, including:-

Measures	Framework for incorporation	Examples of measures
		- Identify potential incidents or sites that might require emergency works; - Check contractual arrangements and organise if necessary; - Discuss with a consent authority the form, extent, and response requirements for an emergency event; - Seek advice and/or gain agreement on mitigation options or procedures to follow that will assist your decision-making and response post-event. - If practicable seek consents in advance e.g. for soil disposal sites. • It may also be possible to streamline or adapt current consenting and consultation procedures to match what might be experienced in an emergency situation, so that a "Business as Usual" approach is followed if an event does occur. This method was employed at Horizons Regional council following the 2004 Manawatu-Wanganui flooding.
Setting priorities for infrastructure repairs before an event.	ASSET, LTCCP, CDEM	**Before an event:** • Set levels of service for existing infrastructure. • Identify critical infrastructure, and identify priorities for repair should damage occur during an event. Set out priorities in the LTCCP. • Prepare a long-term vision for an area and identify activities associated with natural hazards (LTCCP). • Ensure current reduction and community development work, as well as recovery work after an event is linked to a funding source (LTCCP, ASSET). • Work with lifeline utility providers to establish priority repairs and MOUs (via Engineering Lifeline Groups). • Have regular contact with the local Engineering Lifeline Group.
Regulations which deal with demolition and debris disposal issues	DP, BA	**Before an event:** • Determine if there are any Codes of Practice and/or Bylaws that already exist that relate to building demolition and similar activities after an event. • Ensure that any Codes of Practice or existing Bylaws are accounted for in terms of procedures post-event. • If necessary, put additional Bylaws into place which deal with demolition issues post-event.

Measures	Framework for incorporation	Examples of measures
		• Ensure issues associated with public safety during demolition are addressed. • Ensure the health and safety of workers is addressed i.e. asbestos dust management
Zoning for temporary housing	DP	**Before an event:** • Allow temporary housing areas for emergencies within some zones in the city (e.g. through the DP), so that separate/emergency provisions do not need to be undertaken immediately following and event. • Check that arrangements for obtaining temporary housing are in place before an emergency (e.g. though contractual arrangements). • Ensure that the special issues for longer-term housing as opposed to evacuation shelter are planned for (e.g. access and transport, security, children, disabled).
Historic preservation (e.g. What to do with a historic building that has been damaged?)	DP, LTCCP	**Before an event:** • Include rules within the district plan for the repair and/or demolition of the historic structures following major events. Address issues including public safety, building integrity, function etc. Canvass community views about the importance of historic buildings and their long term wishes for the management of these structures with respect to hazards (LTCCP).

Key: DP – District Plan, RP - Regional Plan, RPS – Regional Policy Statement, CDEM – CDEM Group Plan, BA- Building Act, LTCCP – Long Term Council Community Plan, HAZ – Hazard Mitigation Plans, ASSET – Asset Management Plans, RES – general research, BUS – Business continuity plans, OTHER – Other non-statutory plans.

Table A7.2 **Longer term** planning measures which can be used as part of pre-event preparation (after Schwab et al., 1998)

Measures	Framework for incorporation	Examples of measures
Zoning tools (for example, zoning can be used to prevent new development in hazardous areas, minimise densities in hazardous areas, etc.).	DP	**Before an event:** • Tsunami inundation zones can be mapped and rules provided for these areas. Tools which can be used through the District Plan include hazard setbacks, control of structures, minimum floor heights, and maximum densities.
Subdivision control and design. Requirements may be placed on an approved development only allowing particular design features, etc., in order to mitigate the risk to hazards.	DP	**Before an event:** • Enforce specific requirements at the time of subdivision to mitigate the effects of hazards including identification and assessment for areas subject to known hazards, lot sizes, infrastructure type, building platform, road layout (e.g. for easy evacuation).
Use of easements.	DP	**Before an event:** • When creating new easements, think about what might be needed with respect to recovery (e.g. Does the easement cover the correct/right amount of area to ensure access for recovery operations, etc.). • Also consider what additional easements might be needed during the recovery process? For example, a large earthquake may rupture a pipeline crossing the fault. When putting the pipeline back after the earthquake it may be better to put it in a different location, for which an easement may be required. Consider the effects of possible events and create any additional easements prior to an event occurring. • NOTE: Easements are legal agreements, and can be difficult to alter once an agreement has been made.
Design controls may also be placed on the	DP, RP	**Before an event:** • Enforce specific landscape requirements at the time of subdivision to mitigate the effects of hazards (e.g.

Measures	Framework for incorporation	Examples of measures
landscape in order to mitigate a hazard.		Ensure the developer keeps a setback from the dune to reduce the hazard from storm surge and erosion). • Place design controls on mitigation structures, e.g. stopbanks, bunds , etc.
Assessment of Environmental Effects (AEE's)	DP, RP	**Before an event:** • AEEs are required to accompany resource consent applications for activities. As part of an AEE, specific hazards may be addressed and applicants will be required to provide solutions toward avoiding, mitigating or remedying the effects of the hazard. • The information in an AEE could be linked back to other sources of hazard information within a council, such as the Hazards Register. This would provide a more complete database of potential hazards, and assist with reduction and recovery. It should be noted however that as each AEE is completed by a different developer, or consultant working for the developer, the accuracy and completeness of any AEE cannot be guaranteed. However the information could still be used as a 'flag' to highlight potential hazards, which may then require more investigation.
Acquisition of property in hazardous zones.	DP, LTCCP, growth strategies, Local Government Act	**Before an event:** • Make use of measures within the District Plan including financial contributions, open space and reserve requirements to acquire areas of a hazardous nature that have not been developed yet. • LTCCP – Identify priorities for acquiring properties including identifying a budget for purchasing properties in high risk areas. • Growth strategies and structure plans – Identify hazard zones (e.g. floodplains) and avoid these areas for new development.
Examination of street patterns for access	DP, linking to CDEM, structure planning	**Before an event:** • Examine current street patterns, to ensure that access to these areas during and after an event is possible. • Make provisions to ensure that access is possible (through CDEM and DP). • For any new development, use development codes and set specific requirements in the District Plan so that access requirements are achieved, e.g. roads are wide enough for emergency service access, and orientation within coastal areas is appropriate so that evacuation can occur away from the coast.

Measures	Framework for incorporation	Examples of measures
Re-planning of areas which may be stricken by an event	DP, RP, linking to LTCCP, ASSET, CDEM	**Before an event:** • Consider the effects that different natural events might have on the environment, and give some thought to how an area might be re-planned after a disaster. • Make provisions in the DP or RP for allowing the re-planning to occur after an event. • Engage with the community about how they want their community to look now and in the future (LTCCP). • Link with current community development programmes to improve resilience. Link with funding sources (e.g. LTCCP, ASSET) to ensure that any re-planning after an event can take place as per recovery plans. • Establish inter-agency working groups of skilled people to address specific recovery issues for the economic environment, social environment, rural environment, built environment etc.
Use of GIS and GPS	DP, HAZ, RP, CDEM	**Before an event:** • Identify the impact of potential events and implications for recovery. Identify any tools (e.g. GPS, GIS) which can be used for hazard/risk assessment before an event, and impact assessment post-event. • Before an event use any gathered GIS and GPS data to supplement hazard and risk assessments and incorporate new information (or actions) into relevant documents (DP, RP, CDEM). • Incorporate any relevant procedures needed to make use of these tools after an event in the CDEM plan.
Identification of hazards, and use of that information in planning	RPS, RP, DP, CDEM, RES, OTHER	**Before an event:** • Use research to identify the extent and nature of hazards in an area. • Use that information for land-use planning by incorporating it in documents such as the RPS, RP, DP and CDEM plans. • Ensure that CDEM planners and land-use planners (along with other relevant parties) talk together about the hazards to ensure that both understand what the information means, how it can be applied and what roles each will be taking on. • Ensure hazard registers are regularly maintained with processes for including and verifying information.
Infrastructure development policies,	ASSET, LTCCP, HAZ,	**Before an event:** • Regional plans – Set specific performance requirements for stormwater and wastewater infrastructure

Measures	Framework for incorporation	Examples of measures
which restrict the development or replacement of infrastructure in hazardous areas.	RP, DP, BA	and discharges. Ensure new key infrastructural facilities are not located in hazardous zones. For existing at-risk sites, consider where infrastructure might be relocated to after an event and make provisions for this. • District plans – Set specific performance requirements for key infrastructural facilities. Make use of methods in the District Plan (e.g. rules) to ensure new key facilities are not located in hazardous zones. For existing at-risk sites, consider where infrastructure might be relocated to after an event and make provisions for this. • Make use of hazard mitigation plans (e.g. Lifelines, or specific hazard mitigation plans e.g. for earthquake, flooding, etc.) to note the importance of infrastructure, the requirement for its continued operation after an event, and the actions required for this to occur (including the importance of being in an appropriate location). Link to other tools such as the RP, DP, LTCCP and ASSET. • Link hazard-related infrastructure policies with overall long term development and growth strategies for infrastructure (LTCCP, structure plans). Ensure that appropriate funding is allocated both for the continued improvement and development of infrastructure, and for recovery operations after an event (LTCCP, ASSET).
Floodplain management plans (and flood insurance regulations).	HAZ, ASSET, linking to DP, RES, ICMP (integrated catchment management plan)	**Before an event:** • Identify the flood hazard through research. Outline the management approach to be taken in a floodplain management plan. • Link management approach identified in the floodplain management plan to the DP (e.g. requirements for minimum floor levels, zoning, requirements to raise property, relocation pre- and post-event, structural mitigation measures, etc.). • Link floodplain management plan to funding sources (e.g. LTCCP, ASSET) to ensure that the documented management approach can be carried out. • In addition, there is also the potential to link flood insurance requirements with land-use planning requirements.
Stormwater management plans	ASSET, HAZ, LTCCP, OTHER	**Before an event:** • Use stormwater management plans to plan for hazard-related stormwater issues. Link back to other hazard mitigation plans, such as flood mitigation and catchment management plans.

Measures	Framework for incorporation	Examples of measures
		• Ensure new systems are not located in hazardous zones. Also, ensure these systems are not exacerbating existing problems (e.g. making flooding worse), or creating new problems. Consider the issue of climate change exacerbating stormwater impacts. • Consider where stormwater infrastructure might need to be relocated to after an event and make provisions for this. • Link stormwater policies with overall long term development and growth strategies for infrastructure (LTCCP, structure plans). • Ensure that appropriate funding is allocated both for the continued improvement and development of stormwater infrastructure, and for recovery operations after an event (LTCCP, ASSET).
Financial tools	LTCCP, ASSET,	**Before an event:** • Ensure that recovery after an event has a funding source, or that there is a process set up that covers this. • Financial tools could include specifically allocating funds for recovery, ensuring relocation assistance is available, implementing taxation or fee-based systems to collect revenue for the upgrade of facilities or recovery purposes, ensuring an adequate insurance system is set up, etc. • Make the best use of finances prior to an event to ensure that general community development is of a good standard as this will reduce recovery costs in the long term.
Increase resilience (and thus reducing recovery time and costs) by carrying out community development/ empowerment/ education strategies prior to an event (for examples, see McClure et al., 1999; Finnis, 2004; Paton	LTCCP, CDEM	**Before an event:** • Undertake community development programmes - 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 - On-going programme evaluation should take place - Provide resources and mechanisms to facilitate community development and empowerment. - Enable community-led risk reduction, rather than institution led. - Ensure that development is undertaken at all levels – individual, community and institutional (and

Measures	Framework for incorporation	Examples of measures
2006)		integrated across different institutions) – to ensure resilience within all spheres. • Encourage Community Participation - Encourage involvement in local community activities and functions - Involve community leaders in emergency planning and other resilience activities • Ensure the use of comprehensive communication strategies: - Target at risk groups; use preferred media types; use many media types; use many credible sources; provide information frequently; provide booklets with specific information and instructional pictures; provide different sources of information; have a performance target; monitor effectiveness. - Ensure that any education / information program outlines the complex nature of natural hazards, rather than focusing on widespread damage and destruction. - Demonstrate that some losses are avoidable, and show how people can practically avoid losses. - Engender a belief in people that mitigation measures can be effective. - Emphasise an immediate benefit from carrying out protective actions e.g. “It will save you money”.
Ensuring there is co-ordination between organisations and agencies that may be involved in emergency management.	CDEM	**Before an event:** • Ensure that co-ordination with respect to CDEM and recovery is present within agencies themselves and between organisations. • In particular there should be a dialogue between those who are involved in land-use planning (e.g. policy planners, consent planners, etc.) civil defence emergency management (e.g. general CDEM planning, recovery planning, lifelines, CEG groups, welfare groups, etc.) and other people who have a role to play (engineers, hydrologists, asset managers, community development staff, researchers). • Agreed roles should be written into the CDEM plan.
Training programmes for those involved with emergency management	CDEM	**Before an event:** • Ensure that planners are given some training by CDEM staff to understand the nature of hazards in the area, the role of CDEM, and the role that planners have to play with respect to reducing risk through land-use planning.
Re-evaluation and	All plans	**Before an event:**

Measures	Framework for incorporation	Examples of measures
update of plans		• Update plans with new hazard information as it becomes available. Change plans to address lessons learnt. Where changes to plans may take a while, non-statutory guidelines can be used as a stop gap.
Compliance of rebuilding with new regulations formulated from lessons learned (e.g. Account for any new regulations added to the Building Act, Building Standards, etc., after the event, or any completely new Acts/standards created).	When rebuilding, account for any new regulations, as part of the consent process.	**Before an event:** • Require compliance with new building standards for redevelopment including design loads for gravity, wind, earthquakes etc. • Require compliance with other new regulations and standards pre- and post-event.

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