REPORT

Tsunami evacuation route planning for Tauranga City

Summary Report

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Executive summary

The Bay of Plenty is susceptible to tsunami from both regional and far-field sources with previous work identifying the Kermadec Trench as the most significant source of large tsunami. Initial modelling by NIWA and GNS identified a Mw9.0 fault on the Kermadec Trench as a maximum credible event. This event would reach the Tauranga coastline approximately 60 minutes after generation. Tauranga City has large population residing on a flat coastal plain and in parts of Papamoa, almost the entire back dune landform has been levelled through earthworks to facilitate urban development.

This assessment has considered the impact of a very large, low probability tsunami impacting the Tauranga coastline and the implications for evacuation of the population. Overland flow modelling shows that the majority of inundation occurs within 30 minutes of initial impact (i.e. 90 minutes after generation), although inundation would likely continue for up to 3-6 hours until a maximum inundation extent is reached. Inundation could extend across the entire Main Beach area to the Pilot Bay, up to 1 km inland at Omanu increasing to 3 km inland at Papamoa. Flow depths, velocities and therefore hazard are highest near the coast, decreasing with distance inland as flows become shallower and slower.

Modification of inland landforms such as is found to significantly change flow regimes with the levelling of tertiary dune systems at Wairakei potentially increasing the inland inundation extent by over 1 km.

Nationally compliant maps for evacuation zones have been produced by TCC with red, orange and yellow zones. These correspond to a shore exclusion zone to be designated off limits in the event of any expected tsunami, an orange zone to be evacuated in most, if not all distant and regional source official warnings, and a yellow zone covering the maximum credible tsunami event to be evacuated by self-evacuation or formal evacuation procedures. These zones further correspond to areas of extreme, high and low hazard under a maximum credible event.

Evacuation modelling has been undertaken in two stages; first to evacuate people in high hazard zones (fatality likely) to areas of low hazard (fatality unlikely) and then to evacuation people from all hazard zones to safe zones. Targets evacuation times for these zones are 40 and 60 minutes respectively. Evacuation is assumed to occur by self-evacuation based on natural warning signs and is assumed to occur by walking (or cycling) only with roadways kept clear for emergency vehicles and evacuation of severely mobility impaired. Initial work by NZTA showed roadways to quickly become congested if vehicles are utilised primarily leading to evacuation times of 4-6 hours.

The ArcGIS Network Analyst evacuation routing extension ArcCASPER has been used for evacuation modelling. This model routes evacuees along a network via the shortest path allowing for network congestion and provides evacuation times, densities along the network and populations reaching safe zones.

Findings indicate that the existing evacuation network is not sufficient to successfully evacuate the resident population of the Mount and Papamoa to safe points by foot before arrival of a wave associated with a maximum credible event.

Major issues include:

- Long walking distances to safe locations.
- Cul-de-sac design in roading and subdivision layout preventing interconnectedness within the network.
- Waterways, swampy areas and swales impeding natural evacuation paths.

- Infrastructure impeding natural evacuation paths.

Evacuation network improvements were added to mitigate the major issues identified above and optimise evacuation paths. Additional evacuation safe zones have been added and include natural features on public and private land, as well as structures such as buildings, and road infrastructure. Additional vertical evacuation points are required in Wairakei due to the very long distances inland to natural safe zones clear of the extents of the modelled inundation.

Recommendations of this study include:

- Development of community evacuation maps including the location of safe points and major evacuation routes.
- Safe zone signage and improvements.
- Public education and evacuation trials.
- Emergency management equipped to assist multiple groups of several thousand persons potentially trapped for up to 24-36 hours.
- That the effect of major earthworks on tsunami hazard should be considered during future coastal developments.
- TCC explores plan changes to the City Plan to ensure portions of natural landforms such as tertiary dune systems are retained in future urban growth areas to provide vertical evacuation functionality and/or commercial areas are required to provide buildings and structures that provide vertical evacuation in their design.
- That TCC recommends to NZTA to implement a disaster response traffic management plan to allow the TEL to be used for evacuation and emergency services processes but be unavailable for general traffic.
- That TCC maintain the various tsunami scenarios undertaken in an easily accessible GIS to assist with evacuation and alerting purposes and that these scenarios are shared with Lifelines partners and Police.

1 Introduction

1.1 Background

The Bay of Plenty is susceptible to tsunami from both regional and far-field sources (Power et al., 2014) with previous work identifying the Kermadec Trench as the most significant source of large tsunami (Walters et al., 2006; Power et al., 2011). Initial modelling by NIWA and GNS (Beben et al., 2012a) identified a Mw9.0 fault on the Kermadec Trench as a maximum credible event.

Tauranga City has large population residing on a flat coastal plain (Figure A-0). At Papamoa, almost the entire back dune landform has been levelled through earthworks to facilitate urban development. A large earthquake from a rupture of the Kermadec Trench would potentially reach and inundate parts of Mt Maunganui and Papamoa within 60 minutes of generation. Formal warnings are unlikely to be possible within this time frame and self-evacuation is promoted by the Ministry of Civil Defence and Emergency Management (MCDEM). However, to effectively self-evacuate, a population must be familiar with the location of safe areas, with the route to reach these locations, and be confident that they can be reached before tsunami impact.

The Civil Defence Emergency Management Act (CDEMA, 2002) focuses on the sustainable management of hazards, resilient communities and on ensuring the safety of people, property and infrastructure in an emergency. Furthermore, Local Authorities are required to have particular regard to the avoidance or mitigation of natural hazards, including tsunami. An approach based on risk reduction, readiness, response and recovery is promoted in New Zealand and the guideline for tsunami evacuation zones (MCDEM, 2008) provides guideline for the development of tsunami evacuation zones and evacuation route maps.

Local Authority responsibilities arise through a range of legislation including the Resource Management Act (RMA, 1991), Local Government Act (LGA, 2002), Building Act (BA, 2004), Local Government Official Information and Meetings Act (LGOIMA, 1987) and CDEMA (2002). Proposed changes to the RMA is expected to require that greater emphasis is placed on the management of natural hazards in resource consent decisions and in the planning document preparation processes.

The New Zealand Coastal Policy Statement (NZCPS 2010, Policy 24) requires consideration of all coastal hazards including tsunami, prioritising areas of high risk over at least 100 years and taking a precautionary approach where effects are uncertain, unknown, or little understood, but potentially significant. This is likely to include events with a significantly greater return period than 100 years.

1.2 Objective

Tonkin & Taylor Ltd. (T&T) in association with BECA have been commissioned by Tauranga City Council (TCC) to assist in identifying and optimising evacuation routes for Mt Maunganui and Papamoa for a maximum credible tsunami event.

1.3 Scope of works

The agreed scope of works has included:

a Initial workshop with stakeholders to develop principles around defining areas requiring evacuation, acceptable evacuation location areas and evacuation networks

b Defining and confirming evacuation zones and safe zones with MCDEM based on results of previous tsunami inundation modelling (Tonkin & Taylor, 2013)

c Identifying population characteristics within evacuation zones based on TCC internal databases and identify critical areas such as schools, hospitals and retirement homes

d Producing time of flow maps to demonstrate the inundation sequence to the public e Develop evacuation network dataset, in consultation with TCC staff, including existing roading network with additional network paths such as established walkways and recreation reserves

f Developing assumptions around evacuation timing and evacuation speed (with pedestrian flow specialists at BECA, Tauranga)

g Developing an evacuation model to assess:

- major evacuation routes,
- population on the routes,
- timing to reach evacuation safe zones, and
- evacuated population reaching the safe zones.

h Identifying areas not able to evacuate inland within the necessary period and, in conjunction with TCC staff, considering options such as additional evacuation routes or vertical evacuation within an area that would be inundated

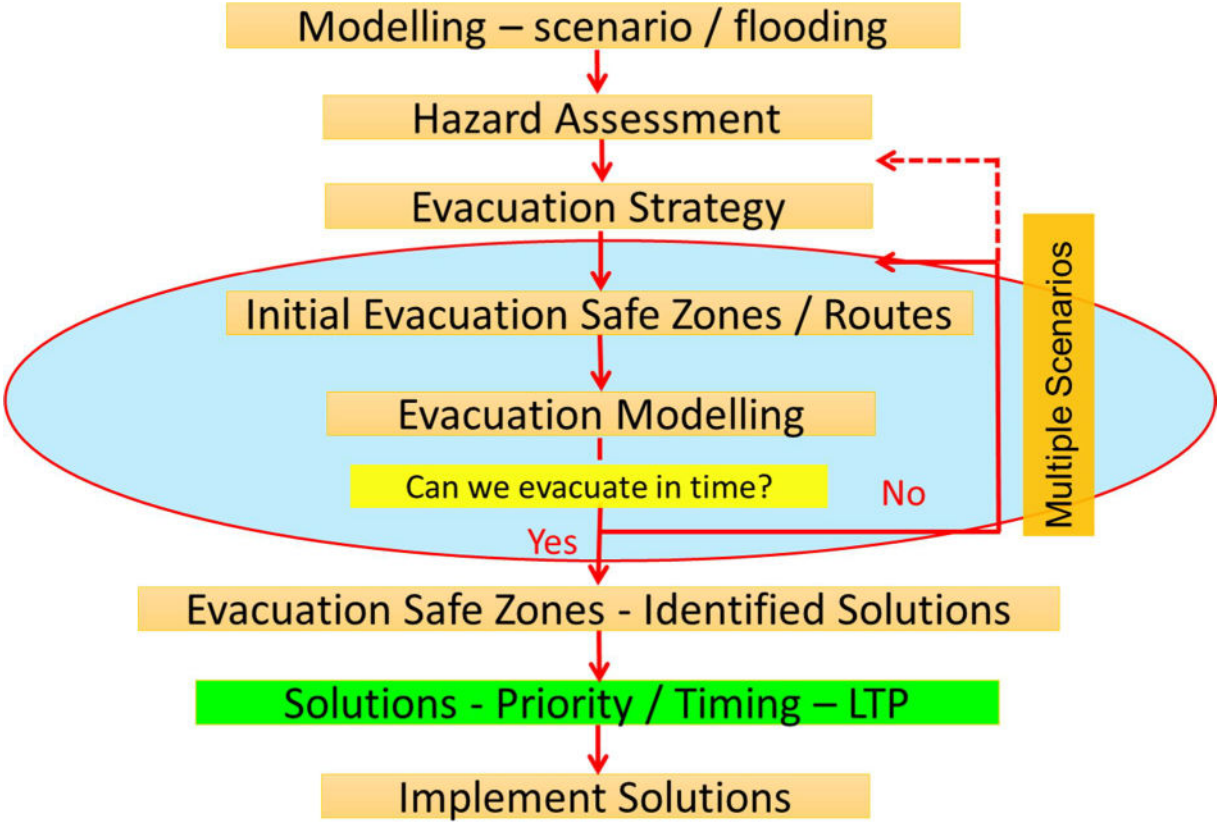
i Re-running evacuation model using these modified inputs to optimise evacuation

j Identifying constraints and opportunities for construction and consenting of evacuation points using a priority ranking score

k Presenting and reporting results to elected members and stakeholders.

1.4 Approach

The following approach to evacuation planning has been developed.



This approach begins by agreeing on the tsunami scenario that evacuation will be based on and evaluating the likely extents and depths of inundation. The hazard from these tsunami inundation events is assessed incorporating the likelihood of the event, the physical characteristics of the flow and likely consequence to inform setting of evacuation zones. An evacuation strategy is then formulated including assumptions for defining evacuation zones, methods of evacuation and requirements for safe zones. The strategy recognises that the solution is likely to be iterative with multiple variations of potential evacuation networks and safe points required to optimise evacuation.

Once optimised, the constraints and opportunities for developing required safe zones are identified and prioritised for inclusion within long-term planning documents leading to implementation.

1.5 Terminology

Commonly used tsunami terminology used within this report is shown in Figure 1-1 and includes:

Wave height	Height of tsunami wave from minimum at trough to maximum at crest
Crest	Maximum elevation of tsunami
Trough	Minimum elevation of tsunami
Mean sea level (MSL)	Average sea level at the time of tsunami arrival
Mean high water spring (MHWS)	Sea level at spring (higher) high tide
Shoreline	Intersection of the mean sea level and land
Amplitude	Maximum tsunami elevation above the shoreline position
Inundation	Horizontal flooding landward of the shoreline
Run-up	Maximum elevation attained by the tsunami landward of the shoreline
Inundation limit	Maximum inland extent of inundation
Time of inundation	Time from tsunami generation until land is inundated

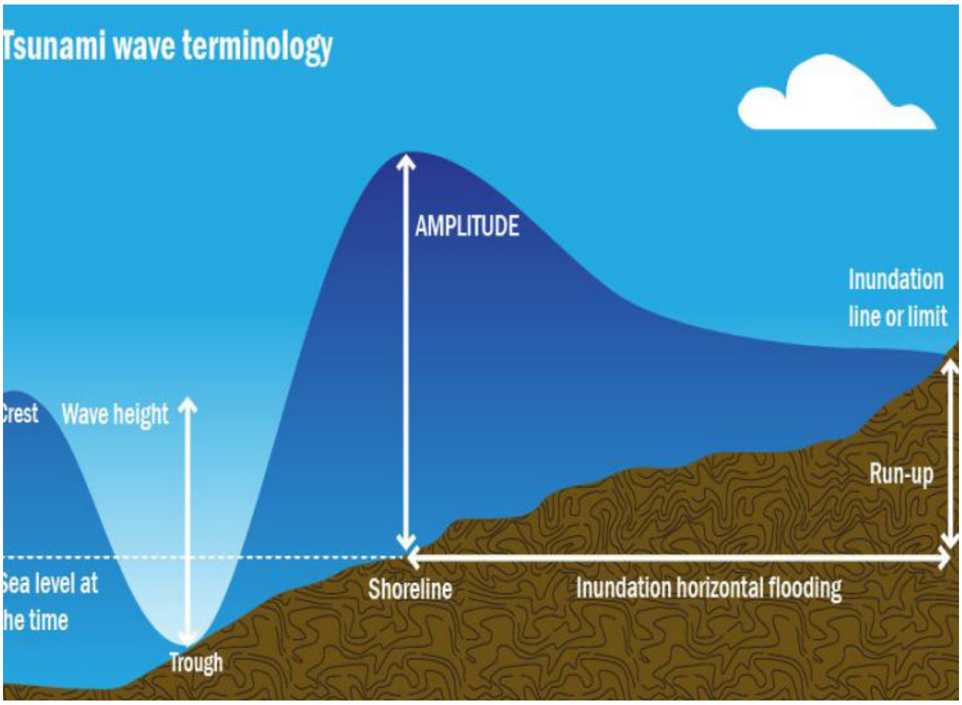


Figure 1-1: Tsunami wave terminology (source: MCDEM)

2 Tsunami inundation modelling

2.1 Previous inundation modelling

A maximum credible tsunami event has previously been identified for the Bay of Plenty (offshore of Tauranga) in a study by GNS science with a shoreline wave amplitude of 13.5 m above MSL (Beban et al., 2012a). This event was found to originate from a large magnitude nearshore event along the southern Kermadec Trench (termed the *Variation of the Southern Kermadec Scenario*) and would likely reach the Tauranga coastline within 60 minutes of generation. T&T (2013) constructed an updated, high-resolution model domain of the Tauranga City region using LiDAR data collected in 2011/2012 and simulated tsunami propagation approaching shore and running up and over land. Modelled wave characteristics at the 50 m depth contour obtained from previous tsunami modelling by GNS was used to provide boundary conditions. Wave heights at five locations within the model domain were compared to GNS model results to verify the high resolution model. Wave crest heights in both models were found to be in agreement to within 5% which provides confidence that the model represents wave transformation in shallow water similar to the GNS model. The physical characteristics of the tsunami over land were identified in terms of flood depth, velocity and flow hazard.

Both existing land conditions and scenarios incorporating future topographic changes near Te Tumu and Wairakei were tested as follows:

- Scenario 0 – Existing ground levels
- Scenario 1 – Flattened earth with mitigation measures
- Scenario 2 – Flattened earth scenario.

These scenarios are shown in Figure 2-1. The “Flat Earth” relates to the current LiDAR ground model for Tauranga City with estimated modified ground levels at Te Tumu and Wairakei to reflect likely cut to fill earthworks to the area to create uniform landform supporting building platform levels of RL (Moturiki Datum) 6.1 m and 5.1 m respectively.

The “Flat Earth with Mitigation” scenario maintains additional parts of the tertiary dune system landward of the main drain (Wairakei Stream) and to the rear of the development blocks. The ground level adjacent to the Kaituna River cut is raised to between RL 7.1 and 8.1 m. The aim of the “Flat Earth with Mitigation” scenario was to see what the impact of retaining some of the back dune as a primary natural defence mechanism would have on the advancing floodwaters, as well as evaluating whether retention of the tertiary dune systems to the rear of the future urban growth areas would offer places of vertical evacuation for the community.

Complete results are presented within T&T (2013) with a summary presented in Appendix A showing time of inundation for the existing topography (Figure A-1), maximum flood depth for the 3 scenarios (Figure A-2 to A-4) and maximum velocity and the resulting hazard map for Scenario 2 (Figure A-5 and A-6). Results show that the first land to flood is around the Mount “Main Beach” (between Mauao and Mt Drury) approximately 60 minutes after tsunami generation. A second, larger wave overtops the coastal dunes between Mt Maunganui and Papamoa 5 minutes later and flows overland. As the volume of water able to overtop the fore dune crest during the tsunami crest is finite, the flow reduces in velocity and depth as it floods the backing land. The full extent of flooding takes up to 6hrs to develop. Similarly, flooding of harbour coastlines are delayed from the open coast as the wave propagates through the harbour entrance.

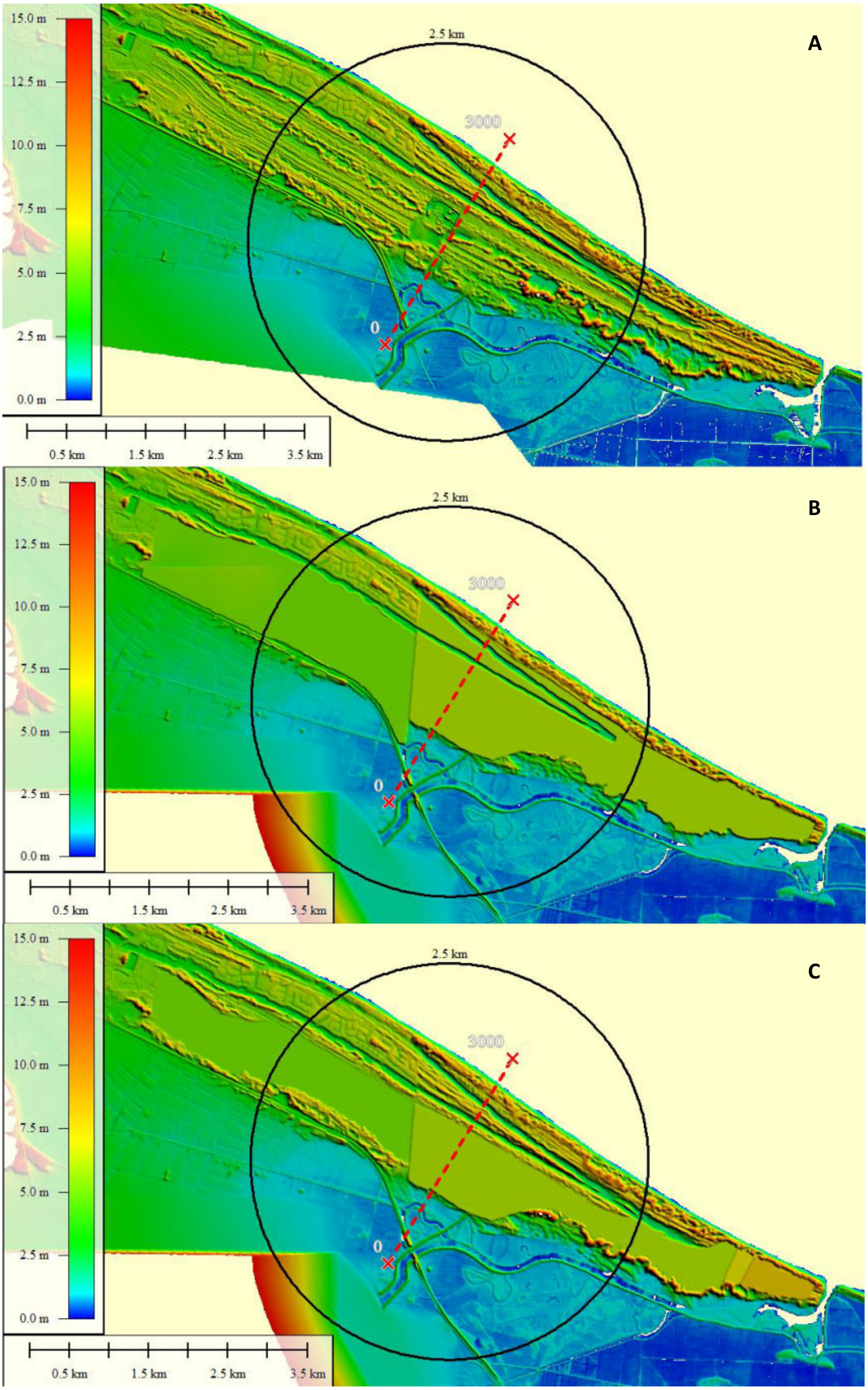


Figure 2-1 Topographic Scenarios Existing (A), Flat Earth (B) and Flat Earth with Mitigation (C)

Flow hazard has been assessed based on safety criteria presented in the Australian Rainfall and Runoff revision project (Cox et al., 2010). Areas with extreme hazard (high flow velocity and depth) are primarily located adjacent to the open coast but may extend to the harbour at Main Beach, up to 500 m inland between Mt Drury (Hopukiore) and Omanu increasing to up to 2 km inland from Omanu to eastern Papamoa and then decreasing towards the Kaituna River Cut at Te Tumu (Figure A-6). Extreme hazard also exists along a narrow strip of the Otumoetai and Matua northern shorelines, along Pilot Bay and the Mt Maunganui wharves, Sulphur Point and the City waterfront.

The 'flat earth with mitigation' land modification scenario (Figure A-3) show localised areas of increased flooding as tsunami flows reach the main drain at eastern Papamoa and, without a complete dunal system on the landward side, are able to move across the backing land at Wairakei relatively unencumbered. In the full 'flattened earth' scenario (Figure A-4 to A-6), flows move landward of Wairakei to land around Bell Road. These scenarios show the importance of maintaining tertiary dune systems as primary natural defences against overland tsunami flow.

2.2 Additional tsunami scenarios

Since the project started, GNS science undertook probabilistic modelling of tsunami occurrence around New Zealand and have produced hazard curves depicting maximum amplitude at the shoreline (note run up may be higher) for sections of the New Zealand coast (Power, 2014). The curves for the Mt Maunganui and Maketu coastlines are presented in Figure 2-2. These figures show a 2500 year return period tsunami amplitude to range from 5.5 to 8.8 m (16 and 84th percentile) for Mount Maunganui with a 50th percentile of 6.9 m and from 7.9 to 12.5 m for Maketu with a 50th percentile value of 9.7 m. Based on this information, the Variation of the Southern Kermadec scenario with shoreline amplitude of 13.5 m is likely have a return period substantially in excess of 2500 years.

The likely inundation resulting from a range of smaller tsunami scenarios have been modelled with an offshore boundary condition based on the GNS *Variation of the Southern Scenario* water level signal, but with modified wave height. The resultant amplitude along the shoreline has been extracted and is used to benchmark the scenario against the hazard curves provided within Power (2013). These results are shown in Table 2-1. Although a possibly more precise method would be to use water levels extracted from the GNS regional models along an offshore boundary for a particular tsunami scenario corresponding to the probabilistic hazard curves, this was not available at the time of assessment. Therefore, the results obtained by matching amplitudes at the shorelines were deemed appropriate for this level of assessment.

A still water elevation of 0.8 m was used in inundation modelling to simulate tsunami impact at high tide consistent with the GNS approach. A flattened earth development scenario has been assumed for the Wairakei and Te Tumu regions, consistent both with previous modelling by Beban et al. (2012a) and T&T (2013) as well as with current practice occurring on site as part of the urban development of these areas. If land use planning rules are modified for these areas in the future then the use of these scenarios can be reviewed and this would likely result in amendments to the extents and depths of modelled inundation in the areas.

Analysis of the results show that inundation of low-lying harbour areas initiates with a tsunami amplitude at the open coast shoreline of around 3 to 4 m (during high tide conditions). Return periods for this event range from 100 to 600 years depending on adopted curve (Mt Maunganui or Maketu) and % exceedance value (16 to 84th percentile).

More significant inundation of Main Beach and Eastern Papamoa occurs with an offshore wave height of 3 m resulting in shoreline tsunami amplitude of 4.5 to 6 m (Figure 2-3). Return periods for this event ranges from 200 to 600 years based on the Maketu hazard curve and 500 to 2500 years for the Mt Maunganui curve.

A tsunami with a 6 m offshore wave creates shoreline amplitudes of 7 to 10 m (1100 to 2500 years return period for Maketu and >2500 years for Mt Maunganui) resulting in hazardous flow through the Main Beach, the beach front at Omanu and parts of Papamoa extending back to the main drain (Figure 2-4). Larger tsunami, with return periods in excess of 2500 years, flood further inland similar to the *Variation on the Southern Kermedec Scenario*.

Table 2-1: Nearshore amplitudes and estimated return period for tsunami scenarios based on Power (2014)

Offshore Tsunami Wave Scenario	Amplitude at shoreline (m above SWL)			Return period range (16-84th %) for max amp at coast for (Power 2013) region:	
	minimum	**mean**	**maximum**	**47. Mt Maunganui**	**48. Maketu**
1 m wave	2.1	1.7	2.2	≤100	≤100
2 m wave	3.2	3.3	4.1	200-600	100-200
3 m wave	4.5	4.7	5.8	500-2500	200-600
4 m wave	5.4	6.0	7.3	1100- >2500	350-1800
5 m wave	5.6	7.3	8.8	≥2500	700- >2500
6 m wave	6.8	8.4	10.1	>2500	1100- >2500
7 m wave	7.7	9.3	11.2	>2500	1750- >2500
8 m wave	8.2	10.4	12.6	>2500	≥2500
9 m wave	9.0	11.2	13.5	>2500	>2500
10 m wave	10.2	12.0	13.7	>2500	>2500
Variation of the Southern Scenario (9.1 M)	9.6	11.1	13.5	>2500	>2500

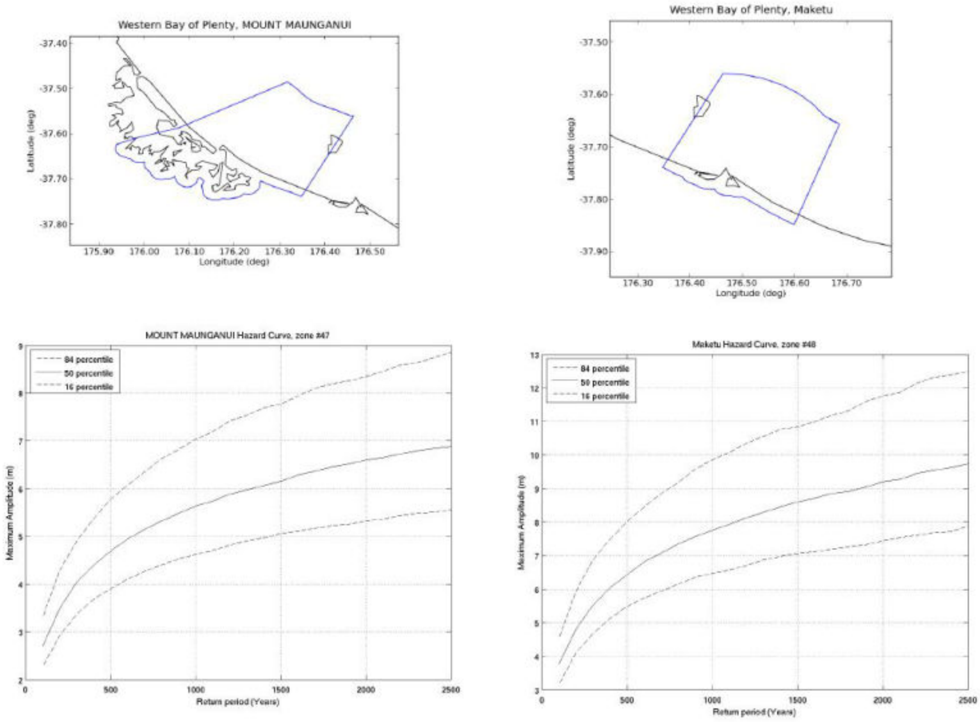


Figure 2-2: Tsunami hazard curves for Mt Maunganui and Maketu (source: Power, 2013)

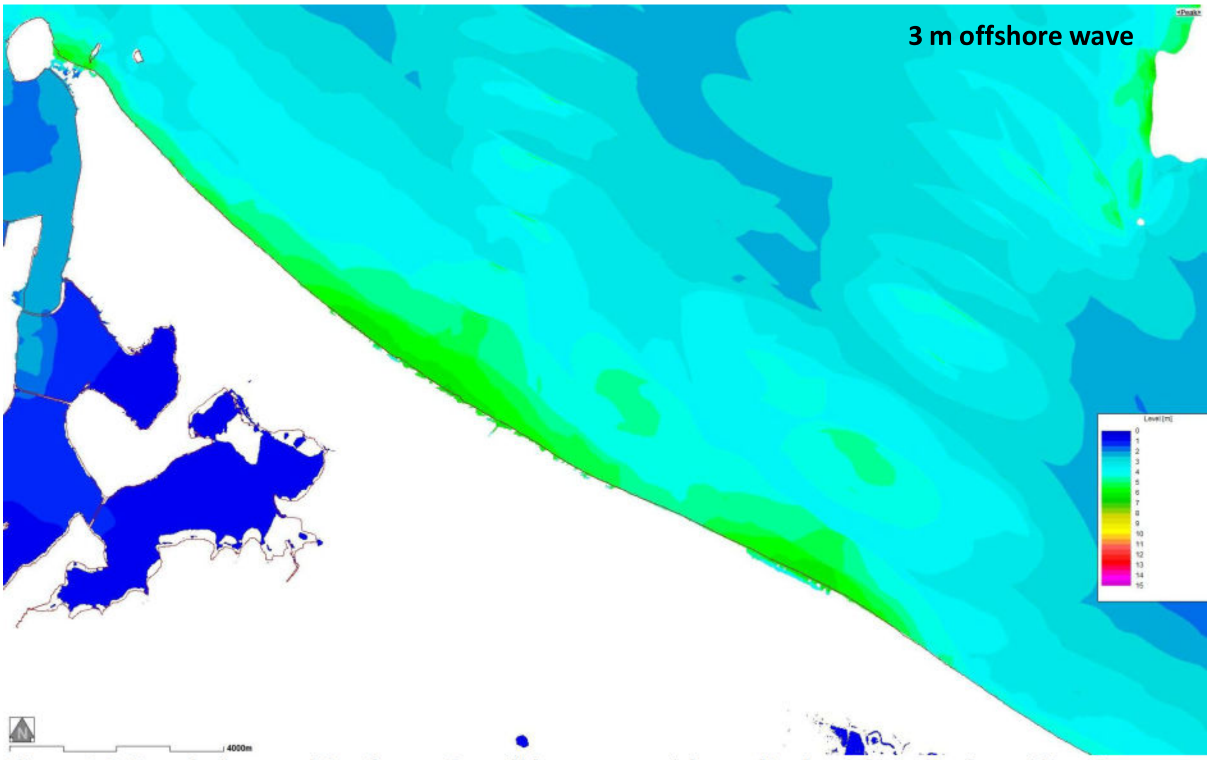


Figure 2-3: Inundation resulting from a 3 m offshore wave with amplitude at the coast from 4.5 to 6 m.

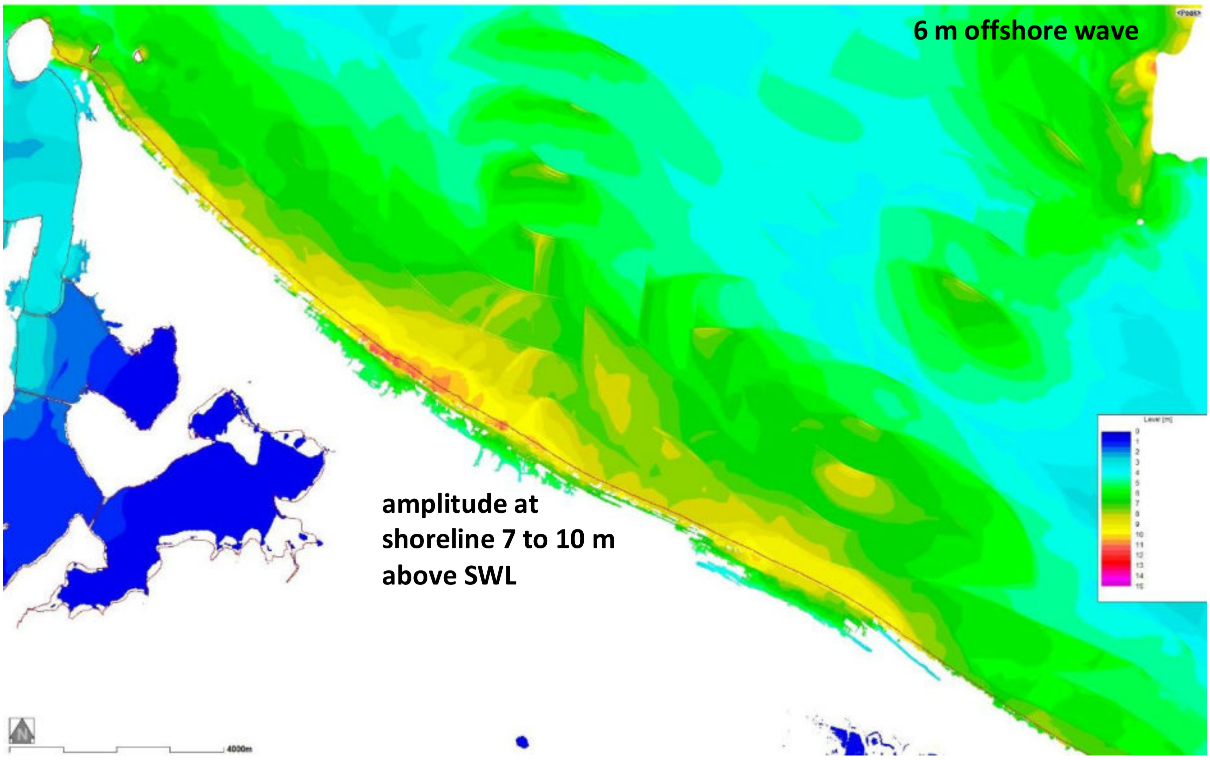


Figure 2-4: Inundation resulting from a 6 m offshore wave with amplitude at the coast from 7 to 10 m.

3 Evacuation zones

Nationally compliant evacuation zones have been established (Figure B-1 in Appendix B) in keeping with the MCDEM guidance (MCDEM, 2008) as provided in Table 3-1.

A shore exclusion zone (red zone) is intended to designate areas that should be evacuated during all regional and distant tsunami scenarios regardless of size. This zone has been defined as a 10 m buffer from the coastal edge in harbour environments and to the fore dune crest along the open coast. This is to account for potential erosion of the dune toe and destabilisation of the above dune, even for relatively minor events occurring at high tide.

The orange zone is intended to be the area requiring evacuation in most if not all distant and regional-source events where an official warnings is provided. An event with maximum shoreline amplitude of 10 m (1000 to < 2500 year return period depending on adopted zone) was selected for the primary (orange) evacuation area.

Given the recent experience in Japan and Paleo-evidence in the Bay of Plenty (Walters et al., 2006), larger events cannot be ruled out. The Variation of the Southern Kermadec scenario, as defined previously by GNS (Beben et al., 2012a) has been adopted as the maximum credible tsunami as is required by MCDEM (2008). For this event the likely landward extent of inundation is defined by the yellow evacuation area. Evacuation zones along eastern Papamoa and Wairakei are restricted in inland extent to the Tauranga Eastern Link which is expected to provide adequate elevation and a significant barrier to inland tsunami propagation.

Note that the red and orange zones double as ‘extreme’ and ‘high hazard’ zones during the maximum credible event to assist in evacuation planning (refer Section 4).

Table 3-1: Evacuation zone extents proposed for Tauranga City

Evacuation Zone	MCDEM definition (DGL 08/08)	Revised zone extent
Red	The red zone is intended as a shore-exclusion zone that can be designated off limits in the event of any expected tsunami.	10 m buffer from coastline and open coast beach to foredune crest
Orange	The orange zone is intended to be the area evacuated in most if not all distant and regional-source official warnings	Area inundated under a tsunami with maximum shoreline amplitude of 10 m (8 m average). Return period estimated at 1000 to >2500 years depending on hazard curve adopted.
Yellow	The yellow zone should cover all maximum credible tsunami, including the highest impact events.	Area inundated under the *Variation of the Southern Kermadec scenario* occurring at high tide. Revised return period well in excess of 2500 years.

4 Evacuation modelling

4.1 Evacuation strategy

Evacuation modelling has focussed on self-evacuation of all zones during the maximum credible event as this corresponds to the maximum demand on route networks and evacuation safe zones. Procedures for formal evacuation (official warnings) of the red and orange zones only is expected to follow similar procedures outlined here but total evacuation populations will be lower due to smaller areas being evacuated resulting in less network congestion and lower populations reaching evacuation safe zones.

Evacuation modelling has been undertaken in two stages; first to evacuate people in high hazard zones (fatality likely) to areas of low hazard (fatality unlikely) and then to evacuation people from all hazard zones to points of safety (safe zones). This strategy was adopted as preliminary modelling (Tonkin & Taylor, 2013) showed that evacuation of all people within inundation areas directly to safe zones was unlikely achievable due to the long travel distances and the primary focus is on preservation of life. The long travel distances to safe zones become more significant east of Bayfair due to the presence of drainage swales and cul-de-sac road layout creating a lack of conectedness within the access routes.

Evacuation is assumed to occur by self-determination based on natural warnings signs (i.e. sustained or violent ground shaking) for the maximum credible tsunami event as per advice by MCDEM (2008) as waiting for official warning could result in delayed evacuation or non-evacuation.

Evacuation is assumed to occur by walking only as preliminary work by NZTA (pers. comm. 17 Jan 2014) found that road congestion resulted in evacuation times of 4-6 hours for vehicle-based evacuation. This is supported by findings from the 2011 Tohoku tsunami in Japan where roadways quickly exceeded capacity where cars are used (Fraser et al., 2012). This pedestrian evacuation approach is advocated by Fraser et al. (2012) with roadways kept clear for emergency vehicles and evacuation of severely mobility impaired.

Finally, evacuation is assumed to occur along a defined pedestrian network comprised of the existing roads, walkways, cycleways and reserves. While faster evacuation may be possible with 'direct line' evacuation, access across private property, fences, swampy areas and waterways cannot be guaranteed, particularly during night time.

4.2 Evacuation model

Evacuation modelling has been undertaken using the ArcGIS Network Analyst evacuation routing extension ArcCASPER (Shahabi and Wilson, 2014). This model routes evacuees along a network via the shortest path and provides evacuation times, densities along the network and populations reaching safe zones. Assumptions for modelling are set out below.

4.2.1 Evacuation timing

Recent research following the 2011 Tohoku tsunami in Japan has found that there are often significant delays in evacuating caused by a variety of reasons including lack of awareness of tsunami potential and desire to find family members (Sagara, 2011) and that delays significantly increase the likelihood of not reaching safety (Fraser et al., 2012). For modelling purposes it is assumed that people take 10 minutes to feel the earthquake and decide to self-evacuate then an additional 10 minutes to depart based on maximum pre-evacuation times found in Shi et al. (2009). Based on a tsunami arrival time at the coast of 60 minutes for a maximum credible event from the Southern Kermedec region, 40 minutes has been set as a target evacuation time for the extreme and high hazard areas (red and orange) and 60 minutes for the lower hazard (yellow) zone given that the tsunami takes some 10 to 20 minutes to propagate across the foreland.

4.2.2 Walk speed

A mean evacuation speed of 2.5 km/hr has been assumed. While significantly higher speeds are likely to be possible by most of the able bodied population (i.e. Shi et al., 2009, report free movement evacuation walk speeds of 4.3 to 6. km/hour), some of the population will be older or younger, may be carrying baggage, walk distances may be long (> 2 km) and may occur in the dark and some congestion is likely. Sensitivities of 2.0 and 3.0 km/hour have therefore also been tested.

4.2.3 Population

Population density is based on Resident Population Projections for 2016 from the SmartGrowth 2011 Population and Dwelling Forecast at meshblock level. Meshblocks are approximately one residential block and is considered sufficient resolution for the scale of this modelling.

A 'night time' scenario is tested with all residential population being home at the time of evacuation.

A 'day time' scenario is also tested which conservatively assumes that all residential population are home and additionally, that industrial and commercial centres are occupied by employees and beach populations range from 50 persons/100 m (Main Beach, Omanu Surf Club, Papamoa Surf Club) and 10 persons/100 m (other beach area). Additional patrons in commercial areas (i.e. shoppers or diners) are assumed to predominantly come from the residential population with influx from outside the evacuation area balanced by outflux. This is likely a reasonable assumption except for the few busiest days of the year.

4.3 Evacuation network

Initial evacuation modelling has been undertaken using a pedestrian network comprised of:

- Existing local roads
- Walkways
- Cycle ways
- Reserves and esplanades.

The Tauranga Harbour Bridge has not been included in evacuation modelling. While the bridge is likely to be sufficient to withstand tsunami impact, large ships docked on both sides of Stella Passage could potentially be swept into the bridge with unknown consequences. Furthermore, the land adjacent to the Tauranga Bridge Marina is likely to be subject to severe inundation and people should evacuate inland toward the central Mount industrial area rather than through this high hazard area.

Following initial modelling results (Section 5), evacuation network improvements were incorporated to more effectively evacuate the population to safety. This has included foot bridges over swales and waterways and additional path and cycle ways over private land where future roads are planned or negotiations are to be entered into with land owners.

4.4 Evacuation safe areas

'Safe' zones have initially been defined to include areas at least 1.5 m above the maximum flow extents to account for inaccuracies in the tsunami characterisation or in the flow modelling and for potential future sea level rise (i.e. are future-proofed). They should also have either safe connection to inland areas or adequate size and facilities to cater for an evacuated population. FEMA guidance (FEMA, 2008) recommends that at least 1 m^2/person is allowed for stays of 12-24 hours. Additional safe areas have been added iteratively as either additional land, buildings or roadways have been identified as being suitable now, or in the future, for vertical evacuation points as necessary.

4.5 Results

4.5.1 Existing network

Initially defined safe zones in the Mount/Papamoa area (Figure B-2 in Appendix B) are:

- Mauao/Mt Maunganui
- Central parade/South-eastern Blake Park adjacent to the Omanu New World Supermarket
- The Mount industrial area
- Elevated land at Matapihi and south of the airport
- State Highway 2 interchanges leading to the Papamoa foothills (Sandhurst and Domain Rd).

Initial results (Figure B-3) show that people are able to evacuate from medium-high hazard zones to low hazard within 40 minutes in all locations except for at the eastern end of Papamoa. Evacuation times here exceed 40 minutes as people must travel to the west along the roadway before moving inland. Improvements to the inland network through Wairakei are proposed to improve this.

Most of the Mount residential and industrial area is found to be evacuatable to safe areas within 40-50 minutes (Figure B-4). The Bayfair area is evacuatable within 60 minutes, with most of the population moving to the high area at Matapihi. Additional safe points at the Bayfair shopping centre and/or Baypark would assist evacuating this area. Evacuation time between Sandhurst Drive and Domain Road increases up to 90 minutes as populations need to move up to 1.5 km along the coast to reach an inland connector. While this alongshore movement is likely landward of the high hazard zone, an additional inland connector here would improve evacuation.

Evacuation times from the coast increase substantially east of Parton Road (Figure A-0) due to both the evacuation distance required and lack of direct inland connectors at Wairakei. Additional inland connectors should be considered, although evacuation distances are still large and vertical evacuation points may be required.

4.5.2 Developed network

Results for the existing network showed that many areas, particularly through central and eastern Papmoa, were unable to be evacuated before tsunami impact. Progressive additions to the evacuation network were implemented within the model to achieve target evacuation times (Figure B-5). These included:

- Access across the Maranui swale drain behind Gloucester Road to State Highway 2
- Additional foot bridges across the main drain between eastern Papamoa and Wairakei
- Addition of future planned roading in the Wairakei area based on the local structure plan.

1. Additional evacuation safe zones were added where either additional land, buildings or roadways were identified as being suitable now or in the future for evacuation. These included, in addition to the initial points:

- Macville Park
- Bayfair 2nd floor carpark
- Baypark speedway (stands)
- The Sandhurst Drive-TEL interchange

- The State Highway 2 berm behind Gloucester Road after creation of a foot bridge
- Private high elevation land at the Lambert block
- Raised bunds at the Gordon Spratt reserve and Papamoa College
- The Parton Road-TEL interchange
- The Wairakei-TEL interchange once complete.

Due to the long travel distances to suitable evacuation safe points east of Parton Rd, vertical evacuation points were proposed to allow timely evacuation of the resident population. These proposed vertical evacuation points include:

- in Wairakei West by augmentation of an existing relic dune crest
- in Wairakei East by augmentation of an existing relic dune crest
- following development in Wairakei South by augmentation of an existing relic dune crest.

The constraints and opportunities that relate to implementing each of these safe evacuation zones is further discussed within Section 5.

Using this developed evacuation network and safe zones, evacuation of all extreme and high hazard areas was able to be achieved in less than 40 minutes (Figure B-6). Evacuation to safe zones can be achieved in less than 40 minutes for the majority of the population (Figure B-7). Some small pockets near the coastline in Papamoa have evacuation times of up to 60 minutes due to long travel distances to safe points. These people may encounter tsunami water during evacuation, however, flows are likely to be significantly less hazardous away from the coast and not result in fatalities.

Flow densities along major evacuation routes has been analysed to check for points of potential congestion (Figure B-8). While the numbers using some routes are high, the population is moving the same direction and likely spread over the 40 minute time period. Mean flow rates are found to generally be less than 1 person per second and should be manageable for the existing network. There is potential for the walkways up Mauao/Mt Maunganui to become congested and people should be encouraged to walk higher up Mauao to allow people behind to reach safety (above the inundation level), and to spread out beyond the walkways to improve capacity.

Total populations reaching safe points are indicated in Figure B-9 and shown below in Table 4-1. These results show that evacuation populations are generally between 1000 and 8000 people. Emergency management should be equipped to assist these numbers of people for up to 24 hours as tsunami continue to resonate within the Bay of Plenty and ponded floodwaters in the backshore area begin to drain away.

Table 4-1 Safe zone day time and night time populations

Safe Zone Number and Name	**Approximate evacuation area (m^2)**	**Current night time population**	**Current day time population**
1 - Mauao	< 10,000	2200	5100
2 - Central Pde/ SE Blake Park	< 10,000	4100	6100
3 - Macville Park	9,600	1500	1800
4 - Mount industrial area	< 10,000	40	1100
5 - Bayfair carpark 2/3rd level	3000-6000 /level[1]	6000	8100
6 - Matapihi	< 10,000	0	0
7 - Baypark	5,000	1650	1750

Safe Zone Number and Name	**Approximate evacuation area (m²)**	**Current night time population**	**Current day time population**
8 - Sandhurst Interchange	2,500	700	860
9 - State Highway 2 Berm	5,000	4900	5450
10 - Lambert	7,000	4700	5700
11 - Domain Road Interchange	2,500	1700	1950
12 - Gordon Spratt/Papamoa College	5,000[2]	3300	3600
13 - Parton Road Interchange	2,500	280	340
14 - Wairakei West	3,000[2]	2100	2820
15 - Wairakei East	3,000[2]	2100	2400
16 - Wairakei South[3]	TBA	0	0
17 - Wairakei Interchange[3]	TBA	0	0
[1] *Area available influenced by number of cars occupying parks* [2] *Proposed area to be developed* [3] *Safe points to be used by future population in the Wairakei area*			

5 Constraints and opportunities

5.1 Introduction

The section assesses the constraints and opportunities that relate to each of the safe zones and assigns a priority ranking score, with respect to cost and viability, to each zone. We understand that the priority ranking score is intended to inform the Annual and Long Term Planning processes associated with establishing the safe zones.

5.2 Method

Our research is based on a desk top study and site visits to some strategic safe zones. The study has used publicly available information from the following sources:

- TCC web based Mapi GIS server.
- TCC City Plan.
- New Zealand Archaeological Association's GIS Archaeological Site Recording Scheme;
- Terraview for land and property information.
- Google Earth and Streetview.
- Discussions with the New Zealand Transport Agency (NZTA).

5.3 Assumptions

The following assumptions apply to the tables provided within Section 4.1 of this report:

- The safe zones will have an elevation of at least 1.5 m above the elevation of the modelled maximum tsunami inundation and/or be located sufficiently landward of the maximum inundation extents.
- The safe zones have been developed around pedestrian access.
- The safe zones have been developed using an allowance of 1 m^2 per person[1] for the “daytime” population of the given catchment. This area requirement has informed the rough order costs provided with respect to any physical works.
- Some lifeline services[2] will be compromised by tsunami inundation.
- The safe zones may be occupied for an approximate period of 24 hours. This is based on a scenario whereby a tsunami struck the coastline on a high tide and inundation would begin to outflow at low tide six hours later. It is estimated that inundation (including any that results from later successive wave arrivals) is likely to have diminished by the end of a third tidal cycle which would take at least 18 hours.
- Costs provided are rough order, include a 50% contingency and have been provided for provisional budgeting and comparative purposes.
- No safe zones include for the provision of shelter, toilets, potable water, power supplies or emergency food supplies. Providing for these types of services would require significant capital expenditure and also ongoing maintenance, security and replacement costs (for food).
- An opportunity exists to develop a land use planning rule for inclusion via a Plan Change into the City Plan which requires vertical evacuation measures are incorporated into commercially zoned sites as they are redeveloped and/or remnant back dune landforms are retained

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[1] As per Section 5.2.3 of the *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (P646 / June 2008) published by the Federal Emergency Management Agency, United States Department of Homeland Security.

[2] Lifelines are essential infrastructure services to the community such as water, wastewater, transport, energy and telecommunications.

(protected from future earthworks). This potential land use control has been discounted at this time.

- Multiple safe zones have sewer manholes both adjacent to and up slope of them which could bubble up raw sewage (as a result of being surcharged by floodwaters) and result in unsanitary conditions adjacent to the safe zones. This issue has not been investigated or commented on for any of the safe zones proposed.
- Signage mounting locations and attachment methods will be designed to be as resilient as possible to floodwater and debris impact damage.
- The Tauranga Eastern Link (TEL) forms a strategic element for safe zones and evacuation purposes. A Traffic Management Plan will need to be developed by NZTA for the TEL and agreed to by the New Zealand Police for implementation. This will allow the network to be closed between Te Puke and Maungatapu during tsunami related emergency circumstances.

5.4 Findings

The findings of our study are presented below. The constraints and opportunities that specifically relate to each of the safe zones are presented within Appendix C. Section 6.5 assigns a priority ranking score, with respect to cost and viability, for each safe zone. Section 6.6 recommends works to be undertaken within the 2014 financial year in the context of funding that has been approved.

5.5 Priority ranking table

The Table below assigns a priority ranking score with respect to cost, viability and necessity for each safe zone. Note that the cost and viability scores are based on the long term safe zone solution at individual sites and not the interim solutions discussed for immediate action. The points are as follows:

Financial cost

1	**2**	**3**	**4**	**5**
$0	< $100,000	$100,000-$400,000	$400,000-$800,000	>$800,000

Viability

1	**2**	**3**	**4**	**5**
Easily achievable or certain	Achievable or probable	Complex or possible	Very complex or uncertain	Unachievable or near impossible

Current necessity

1	**2**	**3**
Required immediately	Required in the short term	Required in the long term

Safe Zone Number and Name	**Financial Cost**	**Cost Ranking**	**Viability Ranking**	**Current necessity ranking**	**Aggregate Score**	**Priority Ranking**
1 - Mauao	$5,000	2	1	1	4	**1**

2 - Blake Park	$5,000	2	1	1	4	**1**
3 - Macville Park	$5,000	2	1	1	4	**1**
4 - Mount industrial area	$5,000	2	1	1	4	**1**
5 - Bayfair	$10,000	2	2	1	5	**2**
6 - Matapihi	$5,000	2	1	2	5	**2**
7 - Baypark	$5,000	2	3	2	7	**4**
8 - Sandhurst Interchange	$5,000	2	1	1	4	**1**
9 - State Highway 2 Berm	$365,000	3	2	2	7	**4**
10 - Lambert	$75,000	2	3	1	6	**3**
11 - Domain Road Interchange	$5,000	2	1	1	4	**1**
12 - Gordon Spratt/Papamoa College	$566,000	4[3]	2	1	7	**4**
13 - Parton Road Interchange	$5,000	2	1	1	4	**1**
14 - Wairakei West	$764,000	4	4	1	9	**5**
15 - Wairakei East	$389,000	3	3	1	7	**4**
16 - Wairakei South	$373,000	3	3	3	9	**5**
17 - Wairakei Interchange	$976,000	5[4]	4	3	12	**6**

5.6 2014 Annual Plan works

We understand that TCC has allocated through the current Annual Plan $375,000 for establishment of tsunami evacuation safe zones. To optimise the safety benefits from the funding currently in place and prioritise the most critical safe zones, we recommended the works set out in the Table below are undertaken as soon as practicable.

Safe Zone Name	**Immediate establishment requirement**	**Cost**
Blake Park, Macville Park, Bayfair carpark, Mataphi Road, Baypark, Sandhurst Drive Interchange, State Highway 2 Berm, Lambert	Signage.	$45,000

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[3] If the Papamoa College building is used for vertical evacuation and the reserve earthworks are deferred until such time as funding becomes available through the LTP then the short term costs will be significantly cheaper.

[4] This is based on the assumption TCC would be responsible for all costs of filling due to the interchange not forming part of the Tauranga Eastern Link project. Providing an accessway to the TEL cycleway and Kaituna Bridge would be cheaper and easier than undertaking the earthworks required for long term Safe Point 17.

Block, Domain Road Interchange, Gordon Spratt Reserve/Papamoa College, Parton Road Interchange, Wairakei West and Wairakei East.		
Bayfair car park, Lambert, Wairakei West and Wairakei East.	Legal mechanism.	$20,000
State Highway 2 Berm.	Two pedestrian bridges over main swale and one pedestrian bridge over smaller swale.	$275,000
Lambert Block.	Access point through fence.	$10,000
Total costs		**$350,000**

For the Lambert Safe Zone the balance of physical works (being the culvert for the farm drain and marker device on knoll) can be deferred until such time as funding becomes available through the LTP. For the Wairakei West and East Safe Zones the balance of physical works (being clearance of farm fences, installation of new gates and route markers) can be deferred until such time as funding becomes available through the LTP.

We understand that TCC has budgeted $25,000 for community engagement.

6 Conclusions and recommendations

This assessment has considered the impact of a very large, low probability tsunami impacting the Tauranga coastline and the implications for evacuation of the population. This maximum credible event was found to originate from a large magnitude nearshore event along the Southern Kermadec Trench and would likely reach the Tauranga coastline within 60 minutes of generation.

Overland flow modelling shows that the majority of inundation occurs within 30 minutes of initial impact (i.e. 90 minutes after generation) and that inundation could extend up to 3 km inland at Papamoa. Flow depths, velocities and therefore hazard are highest near the coast, decreasing with distance inland as flows become shallower and slower.

Modification of inland landforms such as is found to significantly change flow regimes with the levelling of tertiary dune systems at Wairakei potentially increasing the inland inundation extent by over 1 km.

Nationally compliant maps for evacuation zones have been produced by TCC with red, orange and yellow zones. These correspond to a shore exclusion zone to be designated off limits in the event of any expected tsunami, an orange zone to be evacuated in most, if not all distant and regional source official warnings, and a yellow zone covering the maximum credible tsunami event to be evacuated by self-evacuation or formal evacuation procedures. These zones further correspond to areas of extreme, high and low hazard under a maximum credible event.

Evacuation modelling has been undertaken in two stages; first to evacuate people in high hazard zones (fatality likely) to areas of low hazard (fatality unlikely) and then to evacuation people from all hazard zones to safe zones. Targets for evacuation of these zones are 40 and 60 minutes respectively. Evacuation is assumed to occur by self-evacuation based on natural warning signs and is assumed to occur by walking (or cycling) only with roadways kept clear for emergency vehicles and evacuation of severely mobility impaired.

Evacuation modelling has been undertaken using the ArcGIS Network Analyst evacuation routing extension ArcCASPER. This model routes evacuees along a network via the shortest path and provides evacuation times, densities along the network and populations reaching safe zones.

Evacuation modelling has been undertaken in two stages; first to evacuate people in high hazard zones (fatality likely) to areas of low hazard (fatality unlikely) and then to evacuation people from all hazard zones to safe zones. Targets evacuation times for these zones are 40 and 60 minutes respectively.

Findings indicate that the existing evacuation network is not sufficient to successfully evacuate the resident population of the Mount and Papamoa to safe points before arrival of a wave associated with a maximum credible event. Major issues include:

- Long distances to safe locations
- Cul-de-sac design in roading and subdivision layout preventing interconnectedness within the network
- Waterways, swampy areas and swales impeding natural evacuation paths
- Infrastructure impeding natural evacuation paths.

Evacuation network improvements were added to mitigate the major issues identified above and optimise evacuation paths. Additional evacuation safe zones have been added and include natural features on public and private land, as well as structures such as buildings, and road infrastructure. Additional vertical evacuation points are required in Wairakei due to the very long distances inland to natural safe zones clear of the extents of the modelled inundation.

Recommendations of this study include:

- Development of community evacuation maps including the location of safe points and major evacuation routes
- Safe zone signage and improvements
- Public education and evacuation trials
- Emergency management equipped to assist multiple groups of several thousand persons potentially trapped for up to 24-36 hours.
- That the effect of major earthworks on tsunami hazard should be considered during future coastal developments
- TCC explores plan changes to the City Plan to ensure portions of natural landforms such as tertiary dune systems are retained in future urban growth areas to provide vertical evacuation functionality and/or commercial areas are required to provide buildings and structures that provide vertical evacuation in their design
- That TCC recommends to NZTA to implement a disaster response traffic management plan to allow the TEL to be used for evacuation and emergency services processes but be unavailable for general traffic
- That TCC maintain the various tsunami scenarios undertaken in an easily accessible GIS to assist with evacuation and alerting purposes and that these scenarios are shared with Lifelines partners and Police.

7 Applicability

This report has been prepared for the benefit of Tauranga City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

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Environmental and Engineering Consultants

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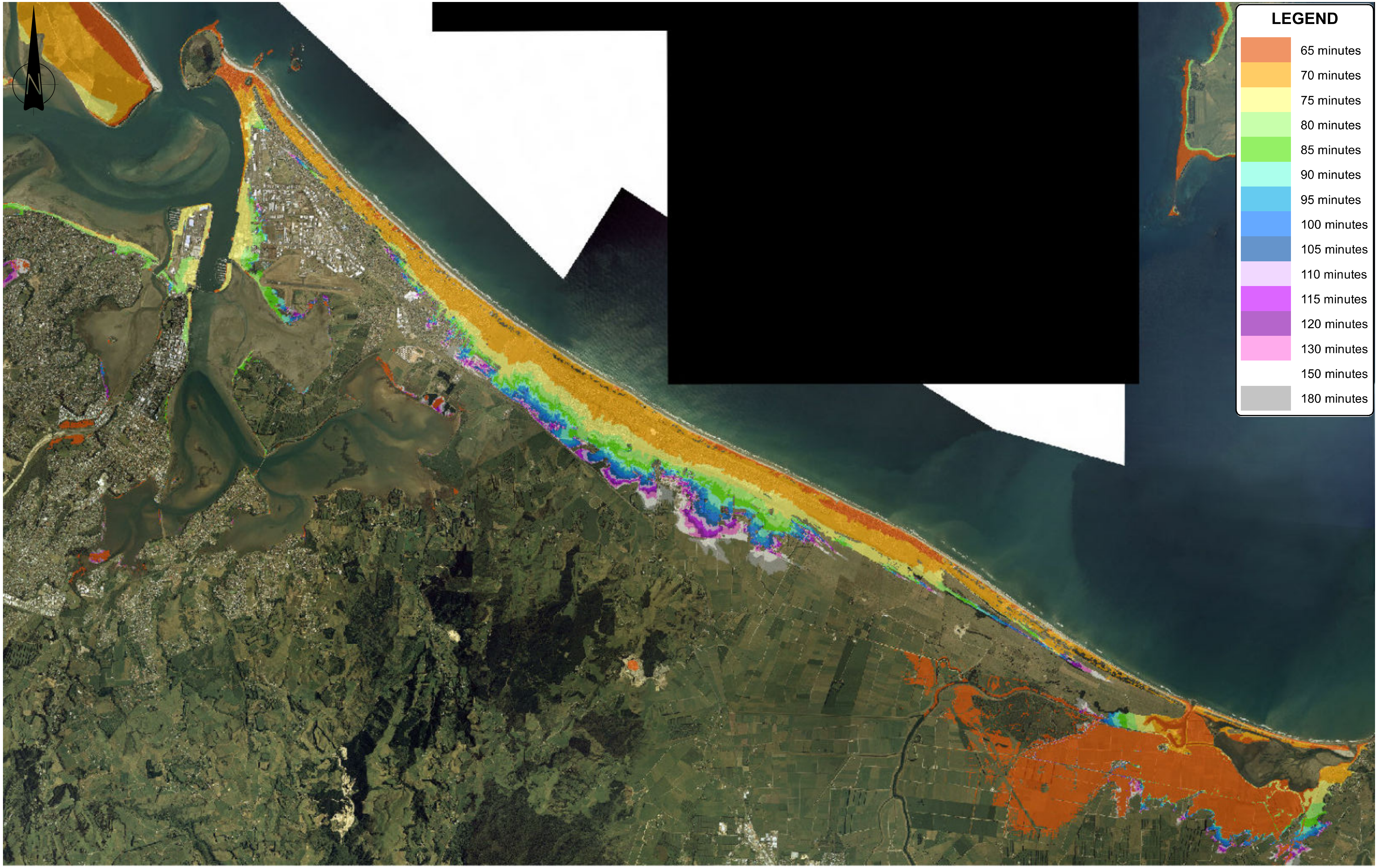
Appendix A: Summary of tsunami inundation modelling results

•	A-0	Areas of Interest
•	A-1	Time of inundation: Scenario 0 – Existing Ground
•	A-2	Maximum Flood Depth: Scenario 0 – Existing
•	A-3	Maximum Flood Depth: Scenario 1 – Flattened Earth with Mitigation
•	A-4	Maximum Flood Depth: Scenario 2 – Flattened Earth
•	A-5	Maximum Velocity: Scenario 2 – Flattened Earth
•	A-6	Maximum Hazard Map: Scenario 2 – Flattened Earth



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A3 SCALE 1:75,000

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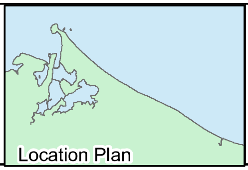

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TAURANGA TSUNAMI
Scenario 0 - Existing ground
Time of inundation

FIGURE No. Figure A-1

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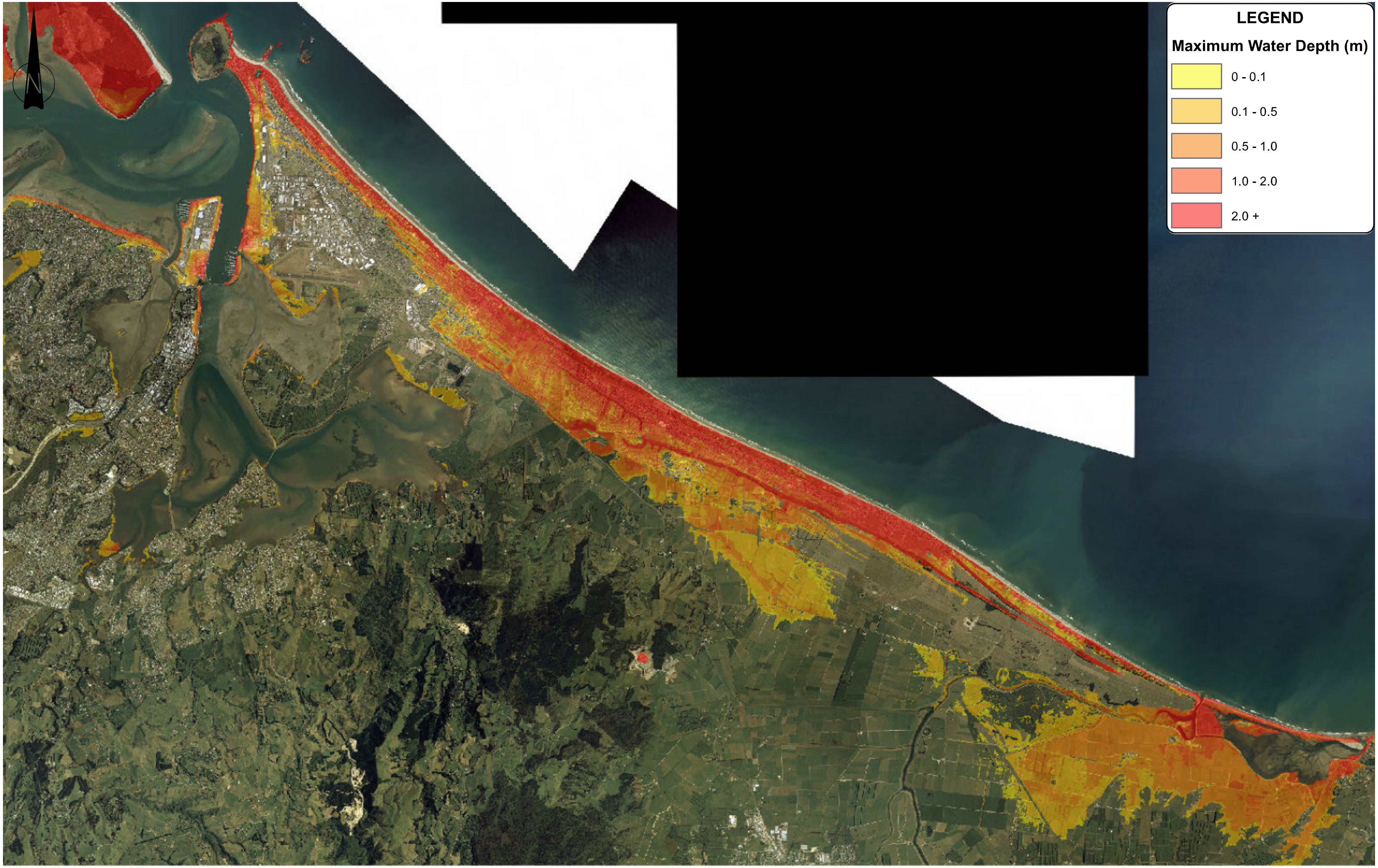

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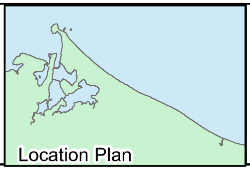
A3 SCALE 1:75,000

0 1 2 3 4 5 (km)



Location Plan

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TAURANGA TSUNAMI
Maximum Flood Depth
Scenario 0 : Existing Topography

FIGURE No. Figure A-2

Rev. 1

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