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TE RAUHĪTANGA TAIAO

Auckland Regional Council Tsunami Inundation Study

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NIWA Client Report: CHC2007-126
November 2007
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Contents

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Executive Summary

- Auckland Regional Council contracted NIWA to undertake a study on the risk of tsunami inundation facing communities in the Auckland region. Tsunamis generated by large subduction zone earthquakes in South America have a return period on the order of 50-100 years. As such, a South American tsunami represents the most probable tsunami risk facing the Auckland region in the next 100 years.

- The tsunami scenario chosen has source characteristics of the 1868 Peru (now Chile) tsunami but with an earthquake magnitude of M_w 9.5, similar to that which generated the 1960 Chile tsunami. A tsunami of this size has a slightly longer return period than the average South American tsunami but in most cases represents a worst-case scenario for far-field tsunamis.

- The response of the tsunami at the shoreline is also dependent on the dominant period of the tsunami. While the modelled tsunami does not show significant impact on Great Barrier Island a tsunami with a dominant period around one hour has a much larger effect.

- The tsunami was modelled assuming a sea level of Mean High Water Spring (MHWS), representing a worst-case scenario of a tsunami arriving at high tide. The tsunami was also modelled for MHWS plus 30 cm and MHWS plus 50 cm, representing the predicted sea level rise in 50- and 100-years as assessed by the IPCC Fourth Assessment Report.

- At MHWS the tsunami causes maximum water elevations of 2-3 m above mean sea level throughout the Auckland Region (East Coast), and up to 3.5 m in some bays. Most of the inundation around Auckland is confined to narrow coastal strips, although the tsunami does cause significant inundation in some low-lying areas. Parts of the Northern motorway just north of the Harbour Bridge, the Northwestern motorway between Point Chevalier and Te Atatu, and Tamaki Drive by Hobsons Bay are major transportation links at risk of inundation.

Caveat

This report is based on state-of-the-art knowledge and modelling capabilities of tsunamis and tsunami inundation. While every effort is made to provide accurate information, there are many uncertainties involved including knowledge of potential sources, source characteristics, bathymetry and topography. In addition, while RiCOM captures much of the physics involved in tsunami propagation and inundation, it also includes some simplifying assumptions as with all models. The information provided in this report is of a technical nature and should be viewed with the above limitations in mind

1. Introduction

Auckland Regional Council contracted NIWA to undertake a modelling-based assessment of tsunami hazard for the Auckland region. Based on a tsunami source study (Goff et al. 2006) a distant tsunami from the east, i.e. South America, was identified as the most probable tsunami in the 50-100 year timeframe. The tsunami scenario chosen has source characteristics of the 1868 Peru (now Chile) tsunami with a magnitude M_w9.5 (Note that the 1868 tsunami had a magnitude M_w9.0 and its impact on New Zealand was similar to that of the 1960 Chile tsunami caused by an earthquake of magnitude M_w9.5 but directed further to the north of New Zealand). The combination of size and directionality of the modelled tsunami mean that this specific tsunami would have a slightly longer return period than the average South American tsunami. In most cases this tsunami represents an upper limit for far-field tsunamis however other factors, such as dominant period of the waveform, also come in to play (see comments on Great Barrier Island for example).

The tsunami was modelled assuming a sea level of Mean High Water Spring (MHWS) in the Auckland region and so represents the inundation expected for the worst-case scenario of the maximum wave arriving in conjunction with high tide. Sea level rise scenarios of 30 and 50 cm, which represent the 50- and 100-year projections defined by the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007), were also modelled.

For each of these events NIWA modelled wave propagation up to the shoreline. This modelling was used to identify areas at risk of inundation in the Auckland region. Inundation modelling was subsequently done for areas at high risk of inundation, especially those with low-lying infrastructure.

2. Tsunami Source Details

The Auckland area faces a range of potential tsunamigenic sources that include several local and distant fault systems. A NIWA study (Goff et al. 2006) identified South America as a potential distant source, and the Tonga-Kermadec trench and Solomon Sea/New Hebrides Trench as regional sources. For the purpose of this study we focus on South America as a distant source. The rationale behind this is as follows: the plate boundary along the west coast of South America has a relatively high rate of convergence and is seismically very active. Large subduction earthquakes in this region have return periods of around 50-100 years. Historically, in New Zealand, there have been three moderately large tsunamis from South America: 1868, 1877, and

1960. However, in South America there have been an additional 11 historical tsunamis propagated by M_w8+ events between 1562 and 1859 (ITDB/PAC 2004). Tsunamis originating from South America thus make up the most plausible tsunami scenario facing the Auckland region and can be expected every 50-100 years. Large subduction zone earthquakes in the Tonga-Kermadec Trench (of which the Hikurangi trench is the southern extension) would have a far more extreme impact on the coast, however they occur far less frequently with return periods of 500 to 2000 years (Goff et al. 2006). Solomon Sea and New Hebrides earthquakes are unlikely to produce significant tsunamis on the Auckland coastline e.g. the April 1 2007 Solomon Island earthquake (M_w8.1) produced a tsunami with a maximum amplitude in New Zealand of 50 cm at Charleston and considerably smaller in other places. Submarine landslides can also cause large tsunamis, however the effect is generally more localised than for tsunamis generated by large earthquakes. In what follows we characterise the source details for the event we are focussing on.

2.1. Distant - Eastern source: South America (Chile/Peru): source and wave propagation description

The subduction zone that runs along the west coast of South America is the location of frequent (approximately every 50 years), large ($\geq M_w$ 8.5) earthquakes. The largest-ever recorded earthquake (M_w9.5) occurred in Chile in 1960. Three significant South American tsunamis have impacted the Auckland coast in the last 150 years in 1868, 1877 and 1960 (Goff et al. 2005, Chagué-Goff and Goff 2006). The only other significant tsunami reported in Auckland was in 1883 from the Krakatoa eruption. Tsunamis from the north (e.g. Solomon Islands/Fiji Basin or Indonesia) have not caused significant impact on the Auckland coastline in recorded history. As such, South America represents our most probable source of far-field tsunamis.

Three primary factors determine how New Zealand is affected by tsunamis that travel across the Pacific Ocean: source location and geometry, wave transformations that occur when the tsunami crosses the ocean, and the effects of the bathymetry and geometry of the continental shelf and coastal region.

The size of a tsunami generated by a subduction zone earthquake depends on a number of factors including the magnitude, source geometry and location of the event. The magnitude and source geometry of the earthquake determine the surface deformation, which, in turn, determines the overall size and length scale of the tsunami. Representative source geometry can be calculated via an empirical formula that takes fault length, width, slip and moment magnitude into account. Plate boundaries and convergence rates can be found in Bird (2003) and Pacheco et al (1993) gives information on the fault geometry. A typical fault could be 100 km wide along the dip and extend down to 45 km below the surface. The location of the earthquake also determines the primary direction in which the tsunami will propagate and hence whether the wave will hit or miss New Zealand. A good example of this is a comparison of the tsunamis caused by the 1868 and 1960 Chilean earthquakes. The 1868 earthquake was smaller in magnitude and caused a smaller tsunami in general, however its location meant that it was a direct hit on New Zealand. The 1960 earthquake was bigger; however its source location directed the ensuing tsunami mostly to the north of New Zealand. The overall effect of these two tsunamis on the north of New Zealand was similar.

The tsunami source also sets the dominant period/s (i.e. frequencies) of the tsunami. The dominant periods of the tsunami have implications on the effect of the wave when it reaches land. Bays and harbours have natural resonance periods. When the natural period of a bay is similar to the period of an incoming tsunami, the tsunami waves are amplified and will have a greater effect than in other regions (Walters 2002). Shallow water waves travel at a speed $C = \sqrt{gH}$, where g is acceleration due to gravity and H is water depth. Thus the depth of the water determines the speed of the tsunami. This speed is also related to the wavelength and period by $C = L/T$. The wavelength of the tsunami L is determined by the surface displacement of the earthquake. Thus the period T (which remains constant) can be related to the initial surface displacement and the initial depth of the water. Historical evidence from Lyttelton Harbour gives the dominant period of the 1868 tsunami at around two hours.

Tsunamis generally follow the curvature of the earth across the ocean; however, this path is modified by reflection and refraction when the water depth changes. Waves may also be diffracted as they pass through island chains, but there are no significant islands between South America and New Zealand. Trans-Pacific tsunami propagation is usually modelled using nonlinear shallow water theory with dissipation of short wavelengths, or by linear shallow water theory where all waves travel at the same wave speed. However, this latter approach is not strictly correct since over this great distance the waves are dispersive (long waves travel faster than short waves) and the result is that a wave train is generated rather than a single wave. This behaviour is important when the runup is considered as multiple waves can cause resonance effects.

For the purposes of this report, we have chosen to specify an incident tsunami at the eastern edge of the model grid (210 degrees east longitude) that represents a “direct hit” scenario similar to the 1868 event. We used the concept of inverse modelling to ground truth this scenario using the more reliable historical data for the 1868 event and to a lesser degree the 1960 event. In effect, the model fills in the missing information along the coast using the historical data as a rough guide. We have used a similar approach in the past for other tsunamis (Walters et al 2006c).

3. Tsunami Inundation Modelling

3.1. Model Grid – Topography and Bathymetry

A far-field tsunami grid was developed for the remote tsunami scenario (South America) by refining an existing grid of the Exclusive Economic Zone (EEZ) from previous studies (see Figure 1). This grid spans from approximately 157 to 210 degrees east longitude and 22 to 65 degrees south latitude. The grid was refined in the areas of interest around the Auckland coast and islands in the Hauraki Gulf with a resolution of approximately 100m near the coast. Bathymetric data were derived from a number of sources. Existing data were used for the EEZ area. Digitised RNZN Bathymetry charts were used for various bays and harbours. The far-field tsunami grid has 263,003 nodes and 495,872 elements. The far-field tsunami grid was used to model the tsunami up to the coastline in the Auckland region and identify areas at risk of inundation.

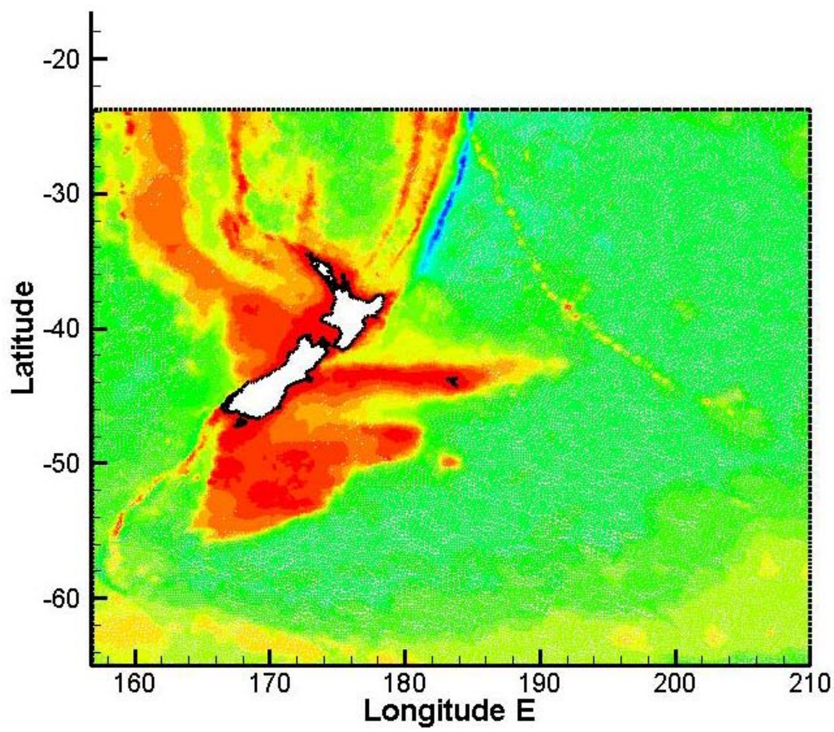


Figure 1 Far-field Tsunami grid. Colour represents water depth. The grid is refined in shallower coastal areas and areas of rapidly changing bathymetry.

An inundation grid was also created for selected areas of the Auckland coastline to model the inundation of land caused by the tsunami. These areas include:

- Omaha
- Snells Beach to Martins Bay
- Waiwera to Whangaparoa Peninsula
- Browns Bay to Devonport
- Point Chevalier to Te Atatu
- CBD to Howick
- Beachlands, Maraetai
- Kaiaua
- Waiheke Island (Oneroa, Surfdale, Onetangi).

The inundation grid was derived from the far-field grid but the coastline was further refined around these locations to a resolution of around 20 metres and a land grid was created for each area. The topography of the land grid was taken from LIDAR data provided by ARC. The grid to the west of New Zealand was removed to reduce the total number of nodes. The final inundation grid has 795,193 nodes and 1,549,757 elements. Figure 2 shows a close up of Auckland including the land grids. The same tsunami scenarios were run on the far-field and inundation grids.

Finite element model grids have a number of requirements to ensure that model calculations will be accurate and free from excessive numerical errors (Henry and Walters, 1993). The primary requirements are that the triangular elements are roughly equilateral in shape and their grading in size is smooth from areas of high resolution (small elements) in the coastal zone and on land grids to areas of low resolution (large elements) offshore.

The grid was generated using the program GridGen (Henry and Walters, 1993) according to the requirements described above. Layers of elements were generated along the boundaries using a frontal marching algorithm (Sadek, 1980). Interior points were filled in using the cluster concept described in Henry and Walters (1993). The grids were then refined by a factor of four by subdividing each grid triangle into 4 new triangles using vertices at the mid-sides of the original triangle. This refinement was continued until the target resolution was obtained. Once a satisfactory computational grid was created and quality assurance tests were performed, water depth and land elevation values were interpolated at each node from the above reference datasets.

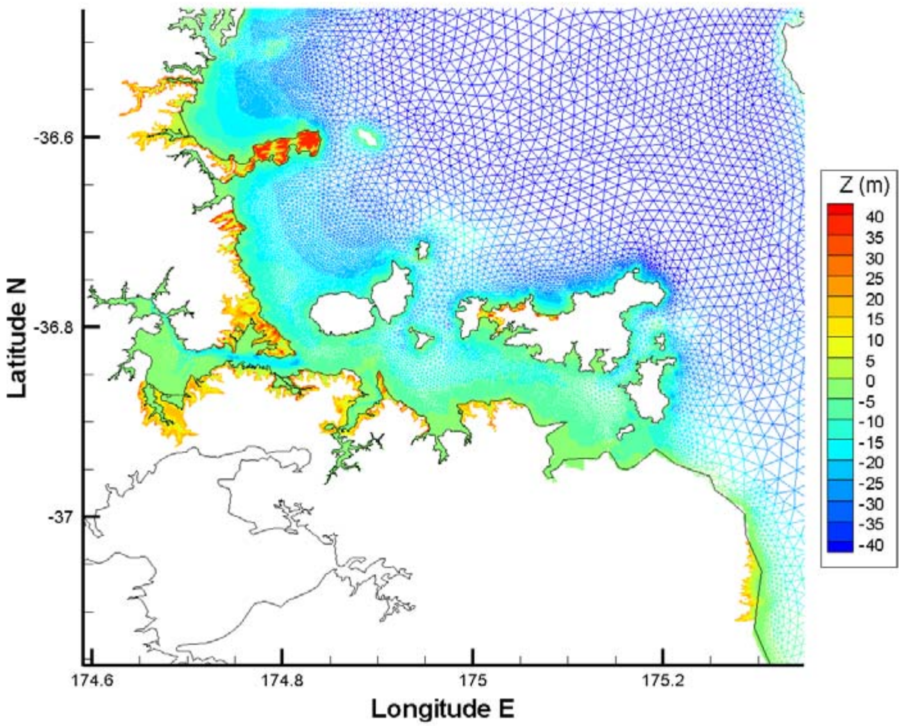


Figure 2 Close-up of the inundation grid around Auckland. Colour represents water depth and land elevation. The size of the elements can clearly be seen to grade in towards the complex coastline.

3.2. Numerical model

The numerical model used in this study is a general-purpose hydrodynamics and transport model known as RiCOM (River and Coastal Ocean Model). The model has been under development for several years and has been evaluated and verified continually during this process (Walters and Casulli, 1998; Walters, 2005; Walters et al., 2006a; 2006b). The hydrodynamics part of this model was used to derive the results described in this report.

The model is based on a standard set of equations - the Reynolds-averaged Navier-Stokes equation (RANS) and the incompressibility condition. In this study, the hydrostatic approximation is used so the equations reduce to the shallow water equations.

To permit flexibility in the creation of the model grid across the continental shelf, finite elements are used to build an unstructured grid of triangular elements of varying-size and shape. The time intervals that the model solves for are handled by a semi-implicit numerical scheme that avoids stability constraints on wave propagation. The advection scheme is semi-Lagrangian, which is robust, stable, and efficient (Staniforth and Côté, 1991). Wetting and drying of intertidal or flooded areas occurs naturally with this formulation and is a consequence of the finite volume form of the continuity equation and method of calculating fluxes (flows) through the triangular element faces. At open (sea) boundaries, a radiation condition is enforced so that outgoing waves will not reflect back into the study area, but instead are allowed to realistically continue "through" this artificial boundary and into the open sea. The equations are solved with a conjugate-gradient iterative solver. The details of the numerical approximations that lead to the required robustness and efficiency may be found in Walters and Casulli (1998) and Walters (2005).

3.3. Tsunami scenarios

As described previously, a tsunami with the source characteristics of the 1868 Peru (now Chile) tsunami but with a magnitude of M_w9.5 was modelled. Three sea-level scenarios were modelled: MHWS, representing a tsunami arriving at high tide; MHWS + 30cm, represent the predicted sea-level rise in 50 years; and MHWS + 50 cm, representing the predicted sea level rise in 100 years.

4. Results

4.1. Outputs

For the areas where inundation modelling was done, the next section gives GIS maps of the maximum water depth for inundated areas and the maximum speed the water attains in the inundated areas and the surrounding estuaries, headlands, river mouths etc. The Auckland region has been broken down into seven separate maps covering:

- Omaha and Snell's Beach (Ti Point to Martins Bay)
- Waiwera to Whangaparoa Peninsula
- North shore
- Te Atatu to Mission Bay
- Mission Bay to Maraetai
- Kaiaua and surrounds

- Waiheke

The extent of the model is shown on the maps as a dashed line. This dashed line is on the coastline in some parts of the maps. This indicates that land inundation was not modelled in these areas, although it is possible that inundation will occur. The sea is masked out a light blue colour to distinguish it from land inundation. Small islands in the gulf and harbour were not modelled and so results from these should be ignored.

Potential Inundation Layers previously provided to ARC, which cover all of the east coast of the Auckland region and major islands, were created by overlaying a surface of the maximum wave height at the coast onto a five-metre resolution DEM provided by ARC. No account was taken for the drop off of water height with distance inland so, if anything, this is likely to be an overestimate of inundation. However, it does provide an indication of the inundation risk for areas where inundation modelling was not carried out.

An extra tsunami scenario was modelled up to the shoreline for Great Barrier Island. In this scenario the incoming tsunami had a dominant period of 1 hour (as opposed to a dominant period of around 2 hours). This period is closer to the resonance of Great Barrier Island and thus the waves are more strongly amplified around there. The results around Great Barrier are shown in Figure 3. A potential inundation layer for Great Barrier Island for this scenario was also created.

Figure 4 shows an overview of the impact of the modelled South American tsunami. The incident wave has a maximum elevation of about 0.15 m in the open ocean. When the tsunami encounters the continental shelf slope, it is partially reflected and the wave speed decreases and wavelength shortens due to the decreased water depth. As the wavelength becomes shorter the wave height increases. When the wave encounters the Chatham Rise the wave amplitude increases abruptly around the Chatham Islands because of the rapid shoaling effect. After the Chatham Islands the tsunami then makes landfall along the east coast of the North Island due to the waves travelling faster in deep water. When the tsunami reaches East Cape, the crest is aligned roughly with the Kermadec Ridge. The wave front stretches and refracts into the Bay of Plenty and continues on to the Northland coast and into the Hauraki Gulf and the Auckland region. The first wave can be expected to reach Great Barrier Island 30-40 minutes after landfall at East Cape. Over the next half an hour to an hour it reaches the northern part of the main Auckland coastline and then makes its way south. Figure 5 shows the maximum water level for the South American tsunami at MHWS and Figure 6 gives an overview of the arrival times for the first wave. Note that the actual times are only indicative but relative arrival times are more accurate. The modelled tsunami has a dominant period of 2 hours and thus Great Barrier Island does not show significant resonance and wave heights are not significantly amplified there. This should be compared with a dominant period of 1 hour (Figure 3) where significant amplification is seen. The modelled tsunami does however show a resonance effect between Waiheke and the Auckland coastline with the maximum water height there being over 3 m.

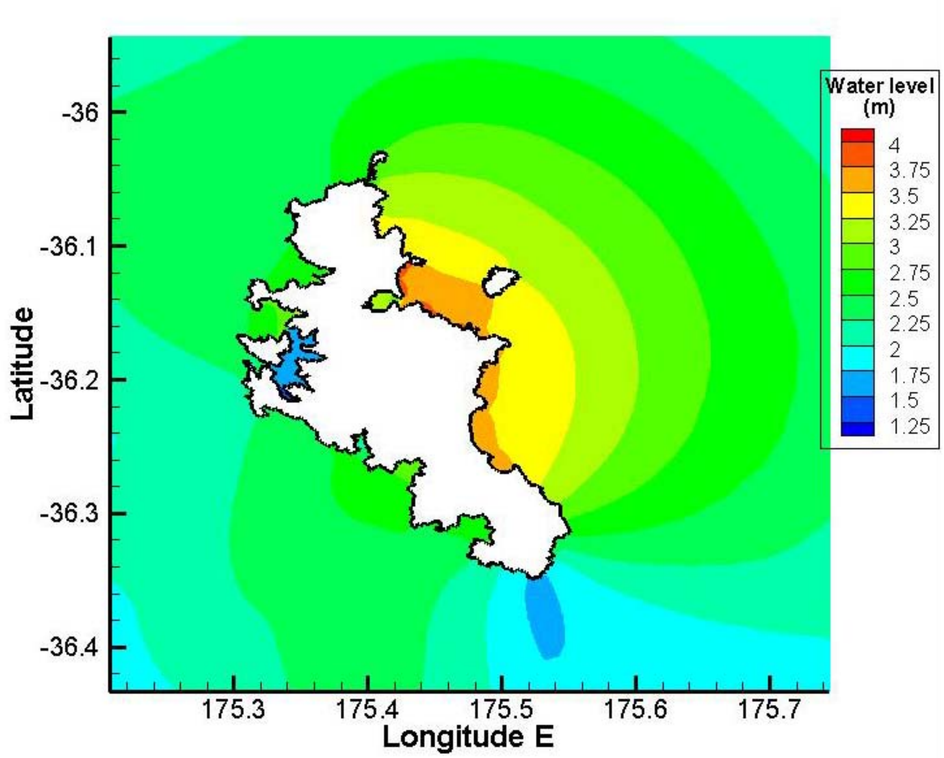


Figure 3 Great Barrier Island. Maximum wave height above sea level at the shoreline for a tsunami with dominant period of one hour-South American tsunami

Even where water levels are not particularly high and there is no significant inundation, high water speeds can cause significant problems through scouring and erosion (which are not specifically modelled in our tsunami simulations). The maximum water speed maps give an indication of where these issues may be a problem.

4.1.1. Inundation Maps – Omaha and Snells Beach (Ti Point to Martins Bay)

Figures 7-9 show the maximum inundation depth and maximum water speed for the area Ti Point to Martins Bay for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. At MHWS the inundation caused by the tsunami is mainly confined to the shoreline area. There is inundation of some low-lying land on either side of Whangateau Harbour and the causeway is at risk. Leigh Road is also at risk where it crosses the mouths of Birdsall Creek and Coxhead Stream. Parts of the coastal strip of Snells Beach are inundated, including the road along the coast. The maximum water speeds are at the entrance to the Whangateau Harbour and the mouth of the Matakana River. Inundation increases for the sea level rise scenarios but the main areas affected are still those mentioned above. There is no significant change in the maximum water speeds. Roads at the northern end of Snells Beach are also inundated for the scenario of a 50 cm sea level rise during the tsunami.

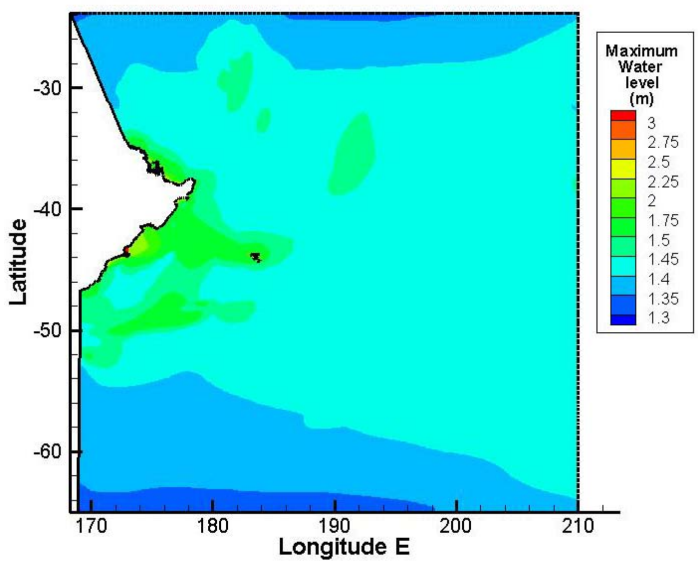


Figure 4: Overview of the maximum water level for the modelled South American tsunami at MHWS. The modelled area extends to the east coast of New Zealand

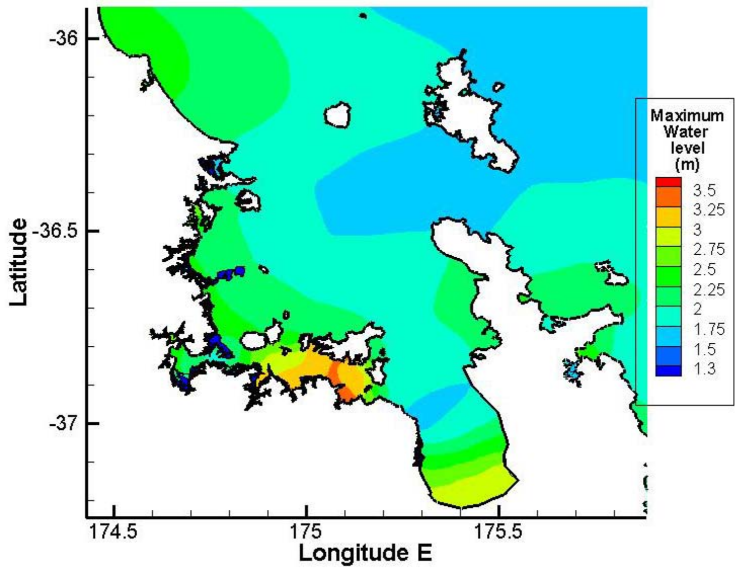


Figure 5: Close up of the Auckland region for the modelled South American tsunami at MHWS. Note that the dark blue areas indicate modelled land areas that were not inundated.

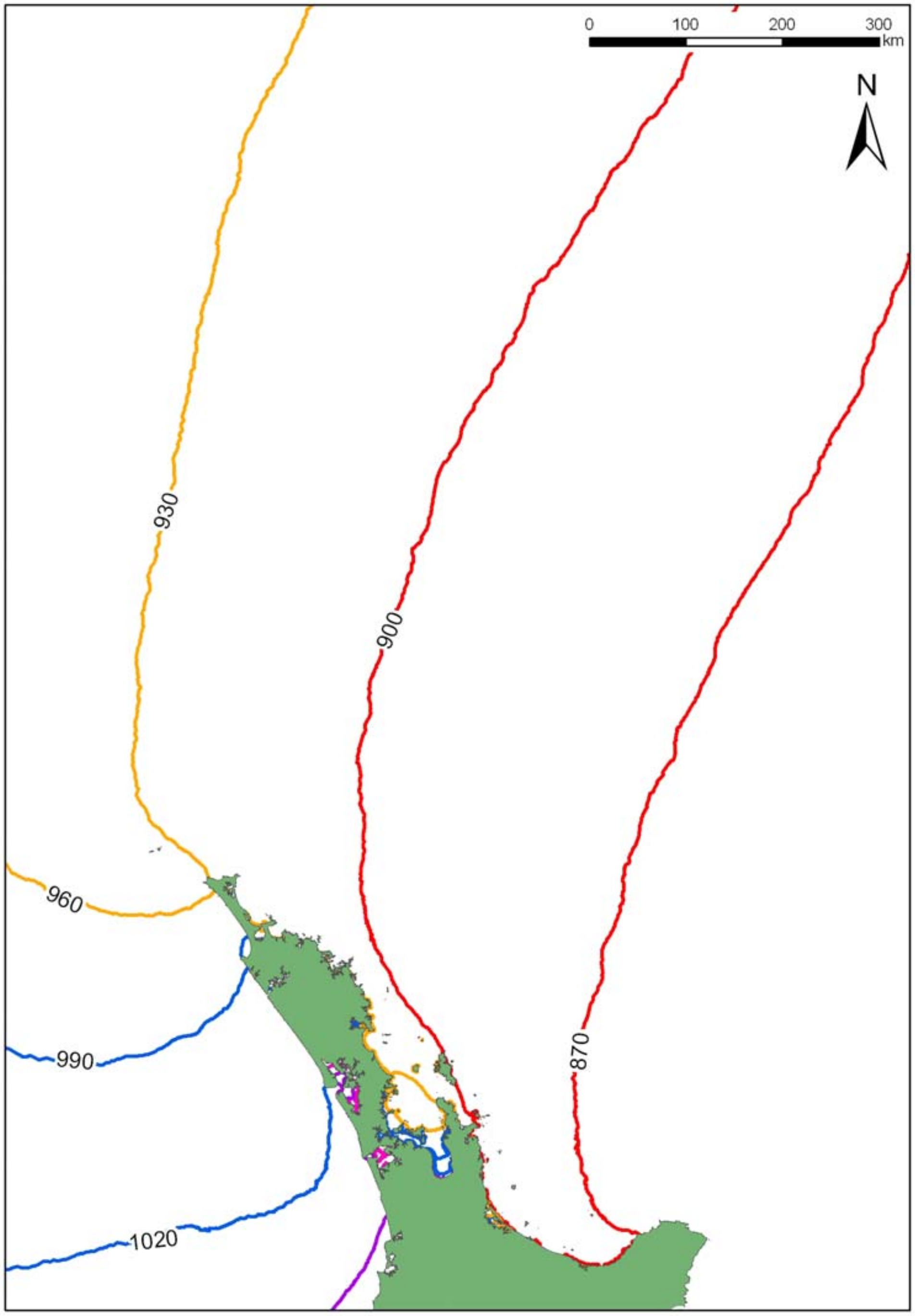
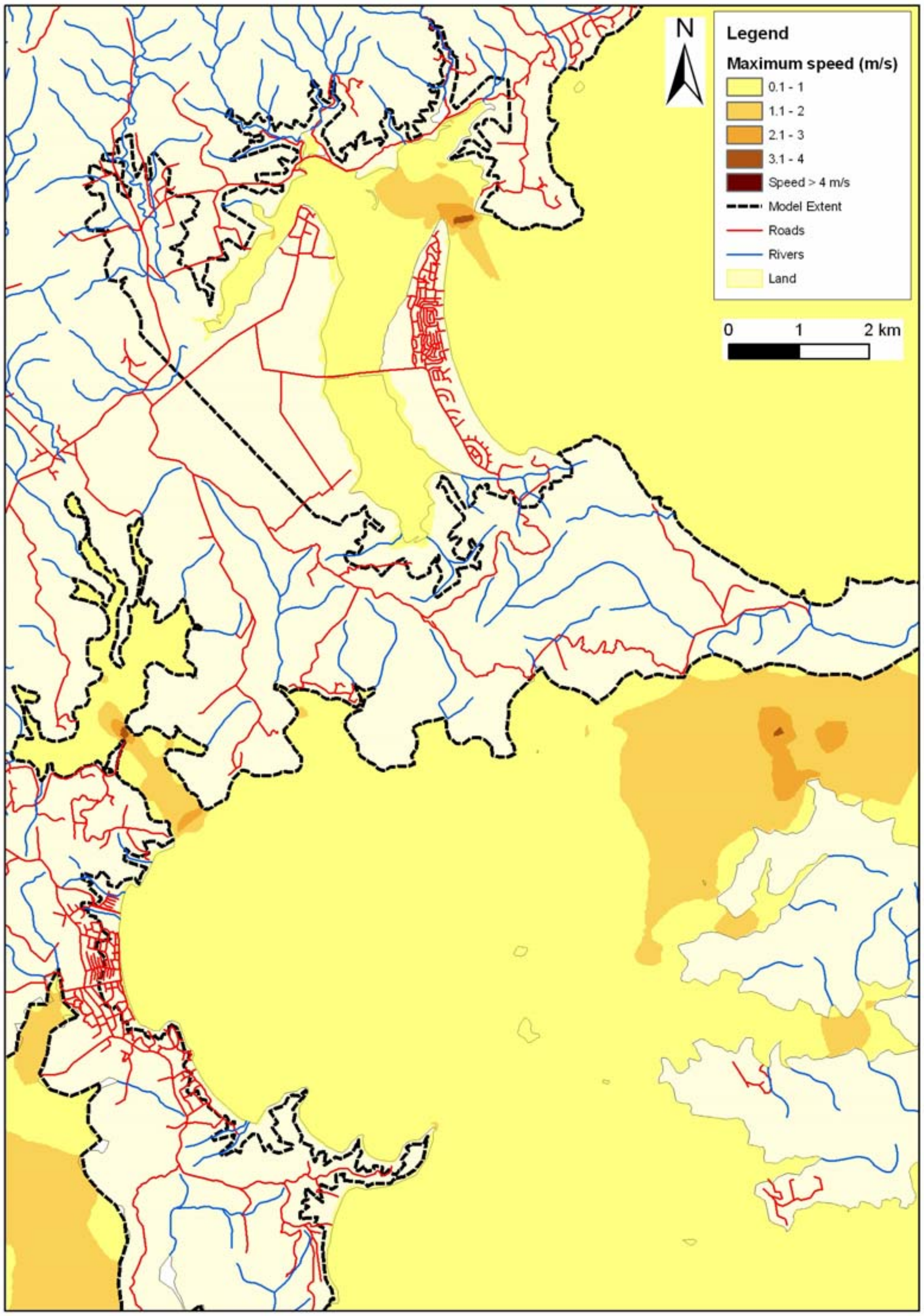


Figure 6: Contours showing arrival times (in minutes) of the first wave for the modelled South American tsunami at MHWS. Note that these times may be shifted depending on the epicentre of the source earthquake but relative times are not expected to change.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
1
2 km

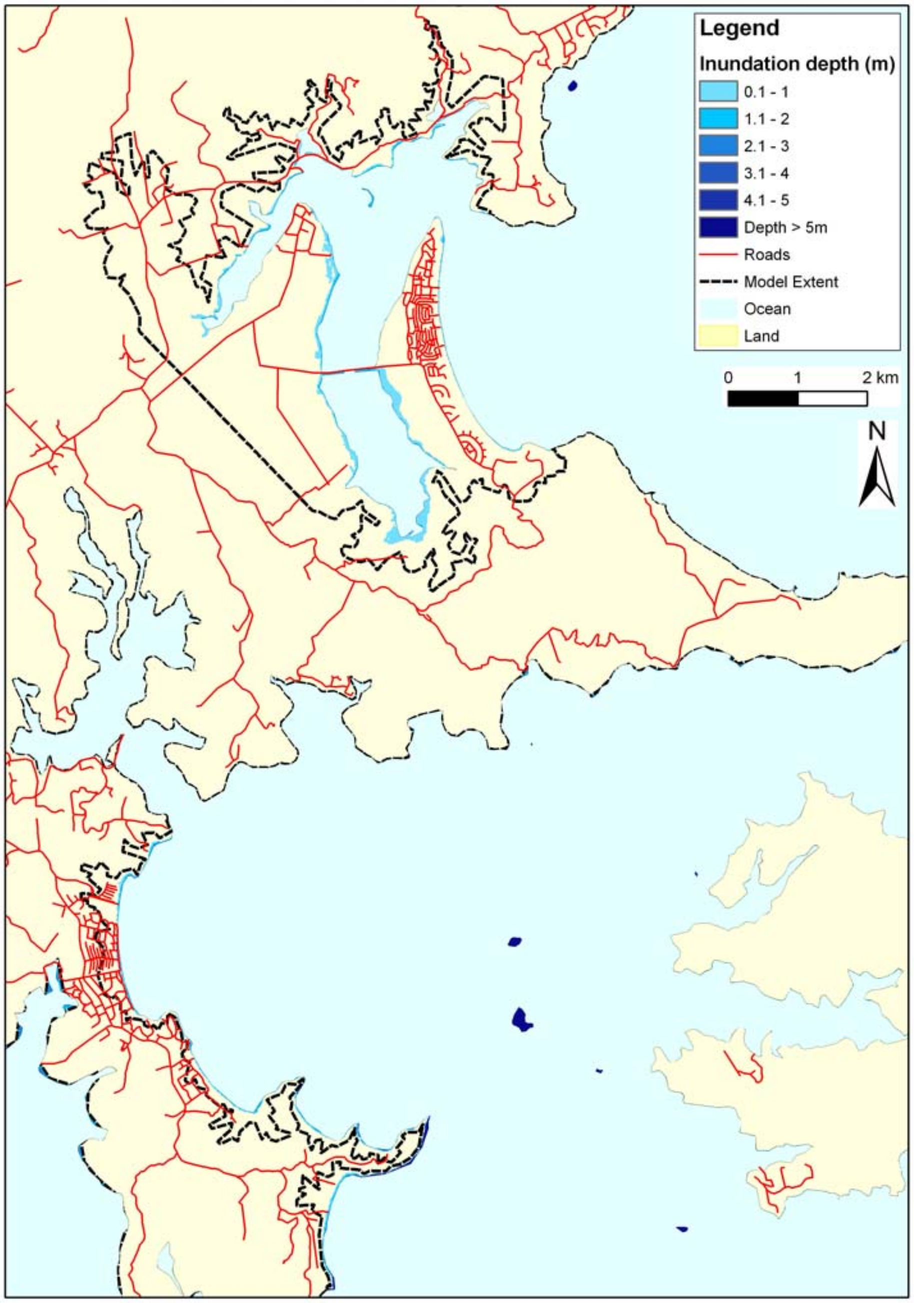
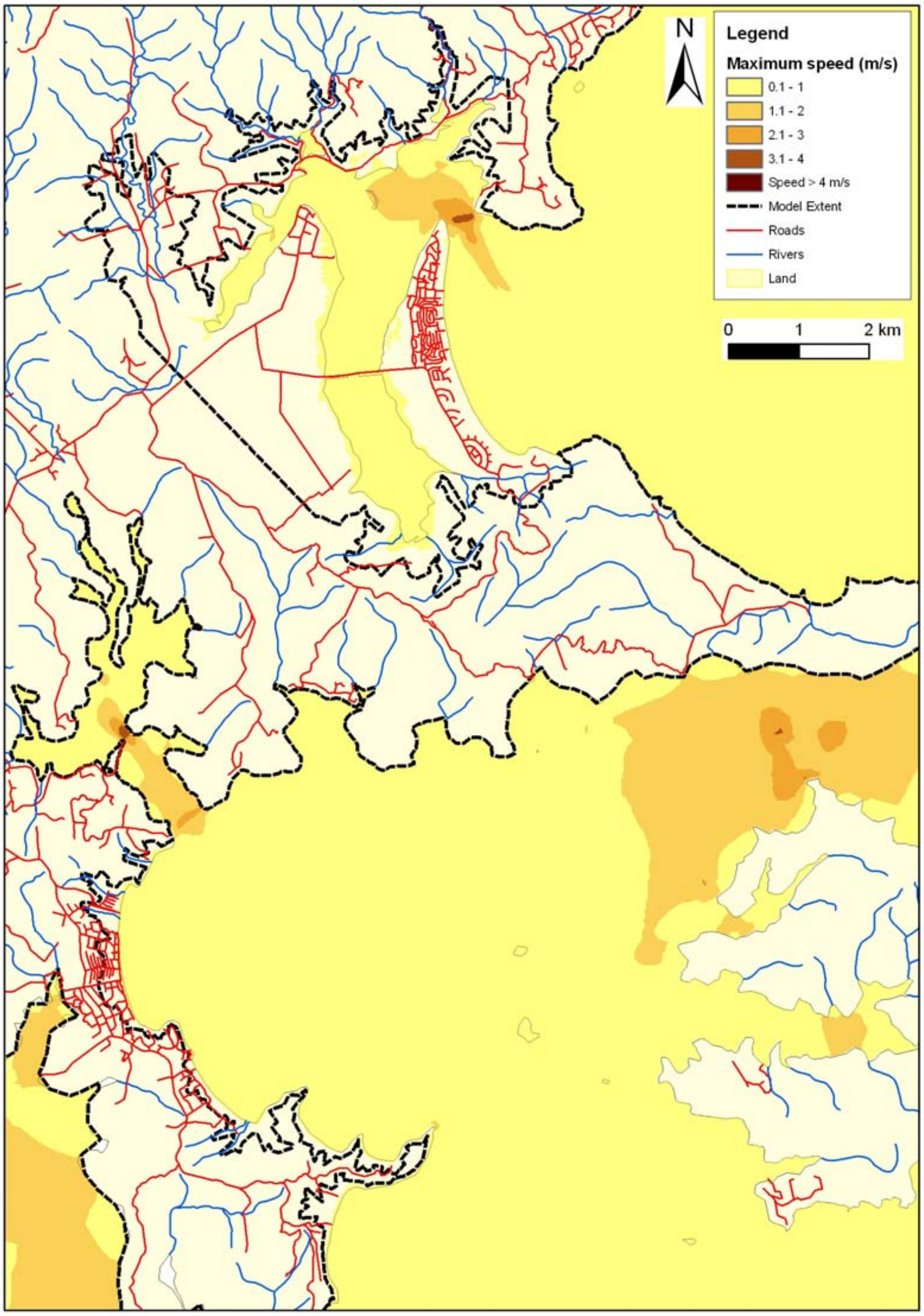


Figure 7: Omaha and Snell's Beach. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
1
2 km

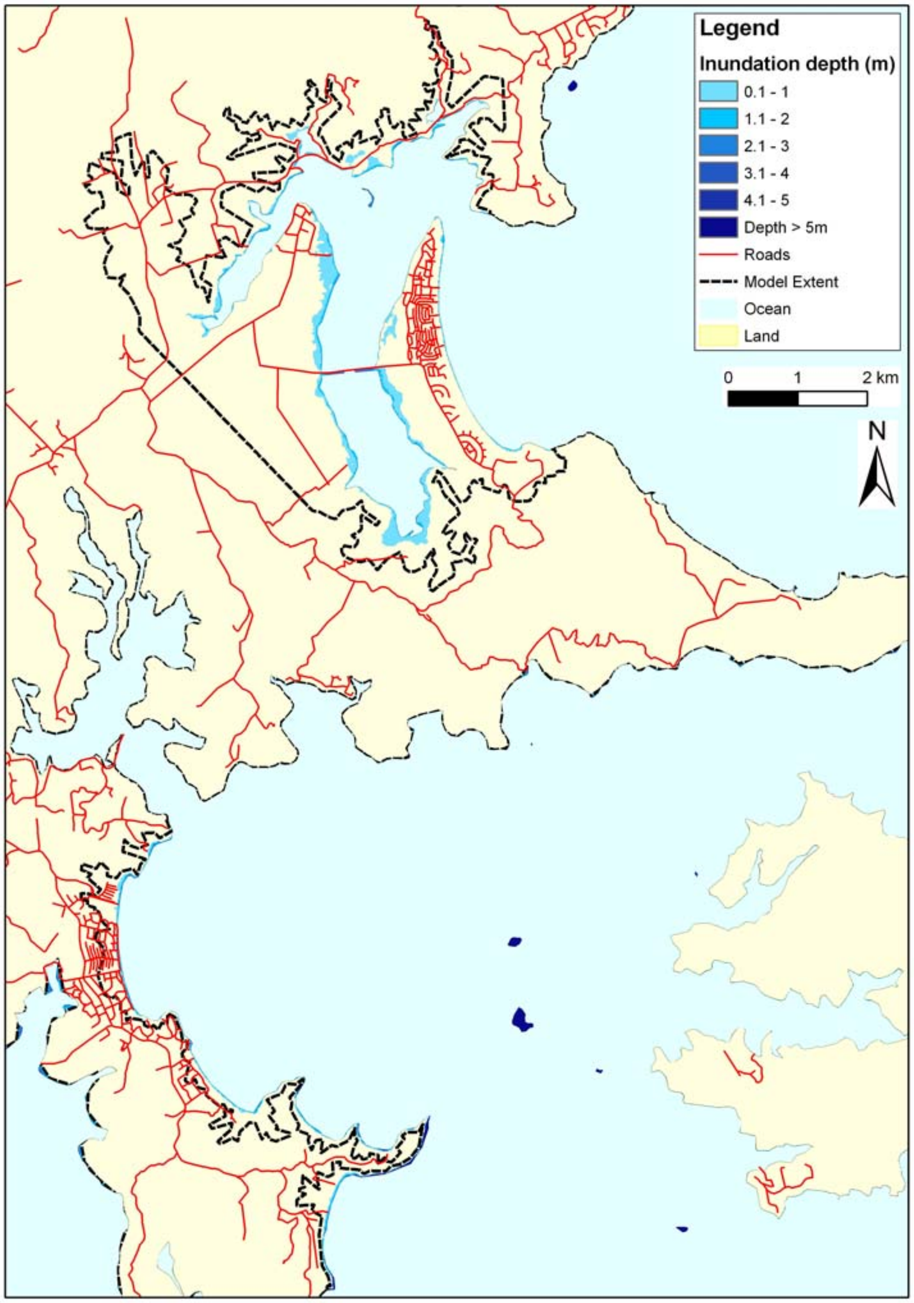
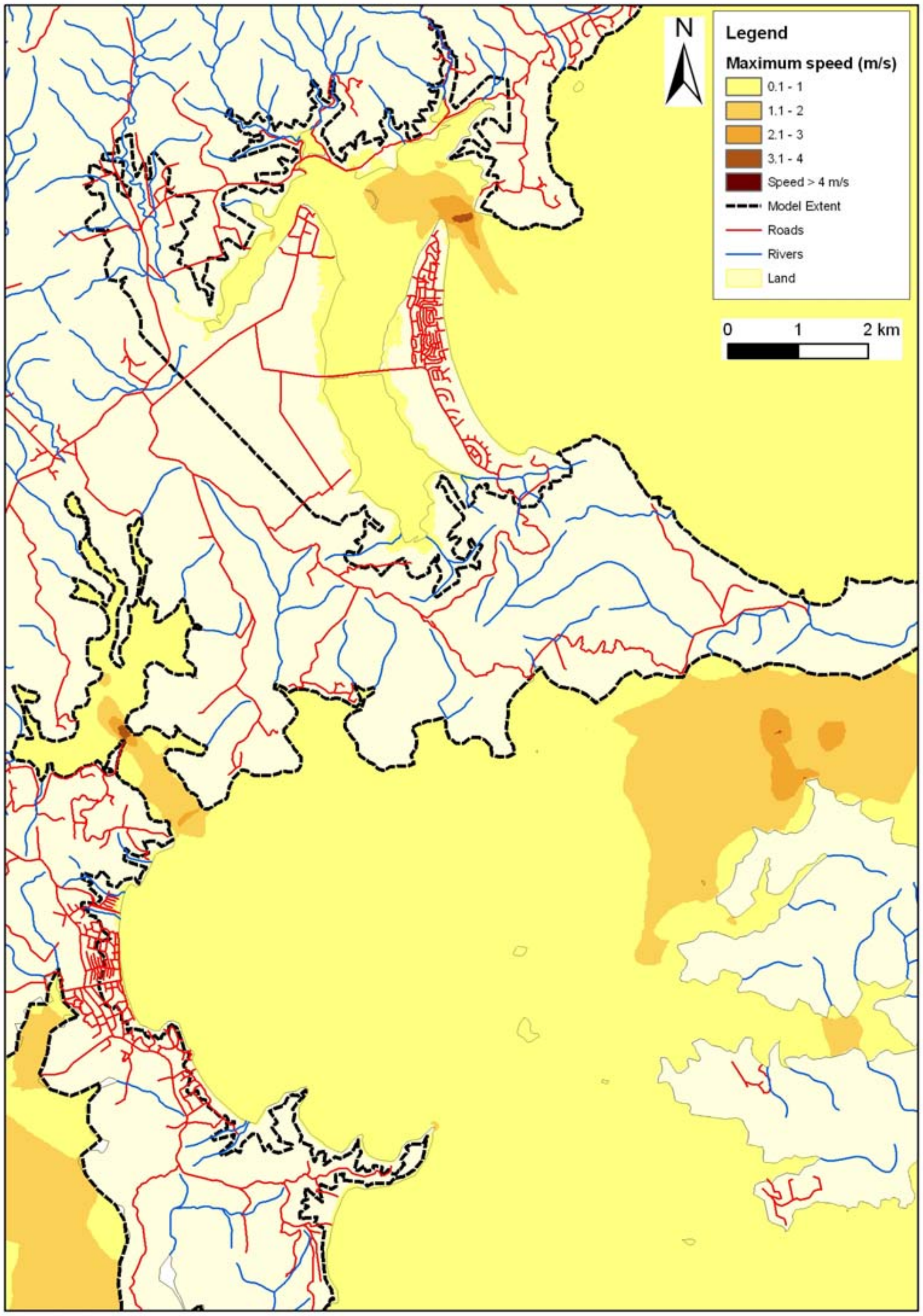


Figure 8: Omaha and Snell's Beach. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
1
2 km

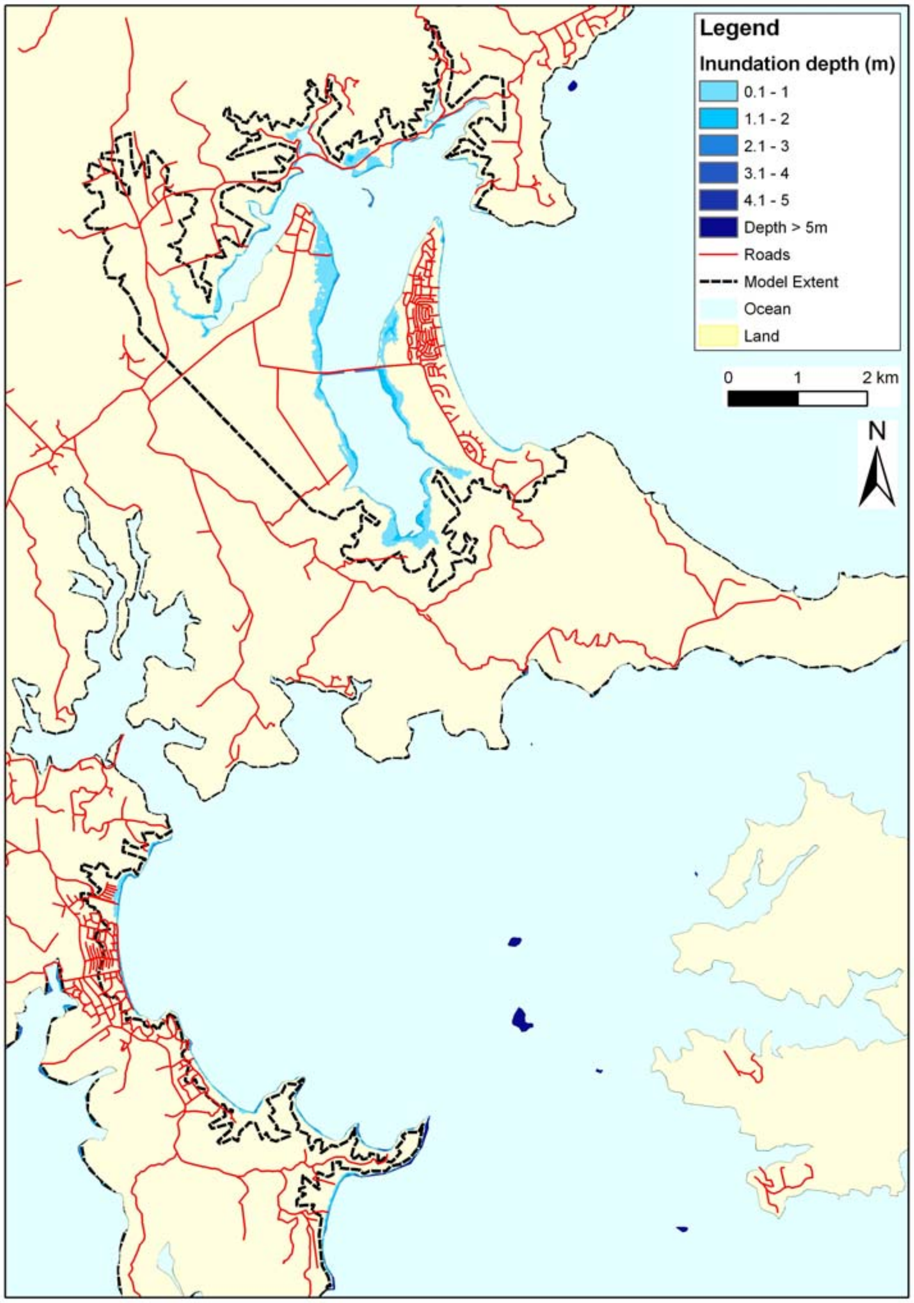


Figure 9: Omaha and Snell's Beach. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.

4.1.2. Inundation Maps – Waiwera to Whangaparoa Peninsula.

Figures 10-12 show the maximum water depth and water speed for the area Waiwera to Whangaparoa Peninsula for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. The tsunami at MHWS inundates some of the Waiwera Township and low-lying regions in the Waiwera estuary. There is also inundation up the Otanerua Stream, at the south end of Orewa, the oxidation ponds adjacent to the Orewa River, and at the south end of Stanmore Bay. Okoromai Bay and Hobbs Bay also have inundation and water speeds may be an issue in the marina at Hobbs Bay. The Coastal road along Matakatia Bay is at risk as well as along the coast at Little Manly and Arkles Bay. The sea level rise scenarios cause deeper and more extensive inundation and large amounts of the Waiwera Township are inundated in the 50cm sea level rise scenario along with the south of Stanmore Bay and the coastal road in Arkles Bay.

4.1.3. Inundation Maps – North Shore.

Figures 13-15 show the maximum water depth and water speed for the Northshore area from Browns Bay to Birkenhead for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. Inundation is mainly confined to the coast but there is some inland inundation especially where there are streams at Long Bay, Winstones Cove and Deep Creek at Torbay, and up the Wairau Creek at Milford. Low lying areas of Browns Bay, Mairangi Bay and the beaches along the coast are inundated. The Devonport Wharf and the Naval Base show some inundation (although the area inundated at the Naval Base may be a dry dock). Within the Waitemata harbour, low-lying areas of Ngataringa Bay and Shoal Bay are inundated, including the golf course, and parts of the Northern motorway are at risk. There are high water speeds just off Stokes Point. The sea level rise scenarios increase the amount of inundation and the maximum water speeds. Devonport is almost completely cut off at Narrow Neck in the 50cm sea level rise scenario.

4.1.4. Inundation Maps – CBD, Te Atatu to Mission Bay

Figures 16-18 show the maximum water depth and water speed for the area Te Atatu to Mission Bay for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. There are large maximum water speeds under the NW motorway (SH16) between Te Atatu and Point Chevalier, under Tamaki drive into Hobson bay, and also around Westhaven Marina and by the wharves, which could cause erosion and risk to shipping.

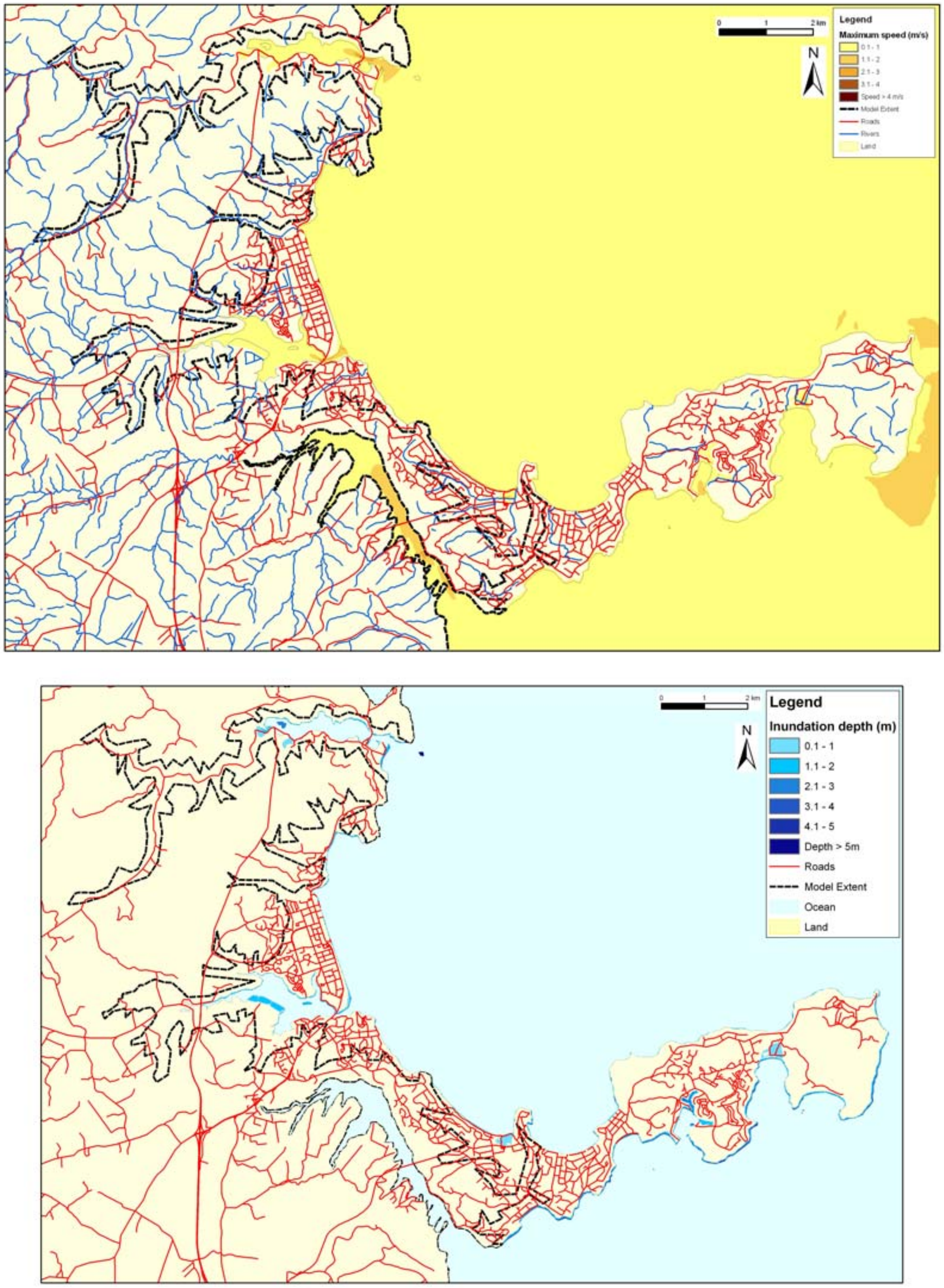


Figure 10: Waiwera to Whangaparoa Peninsula. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS.

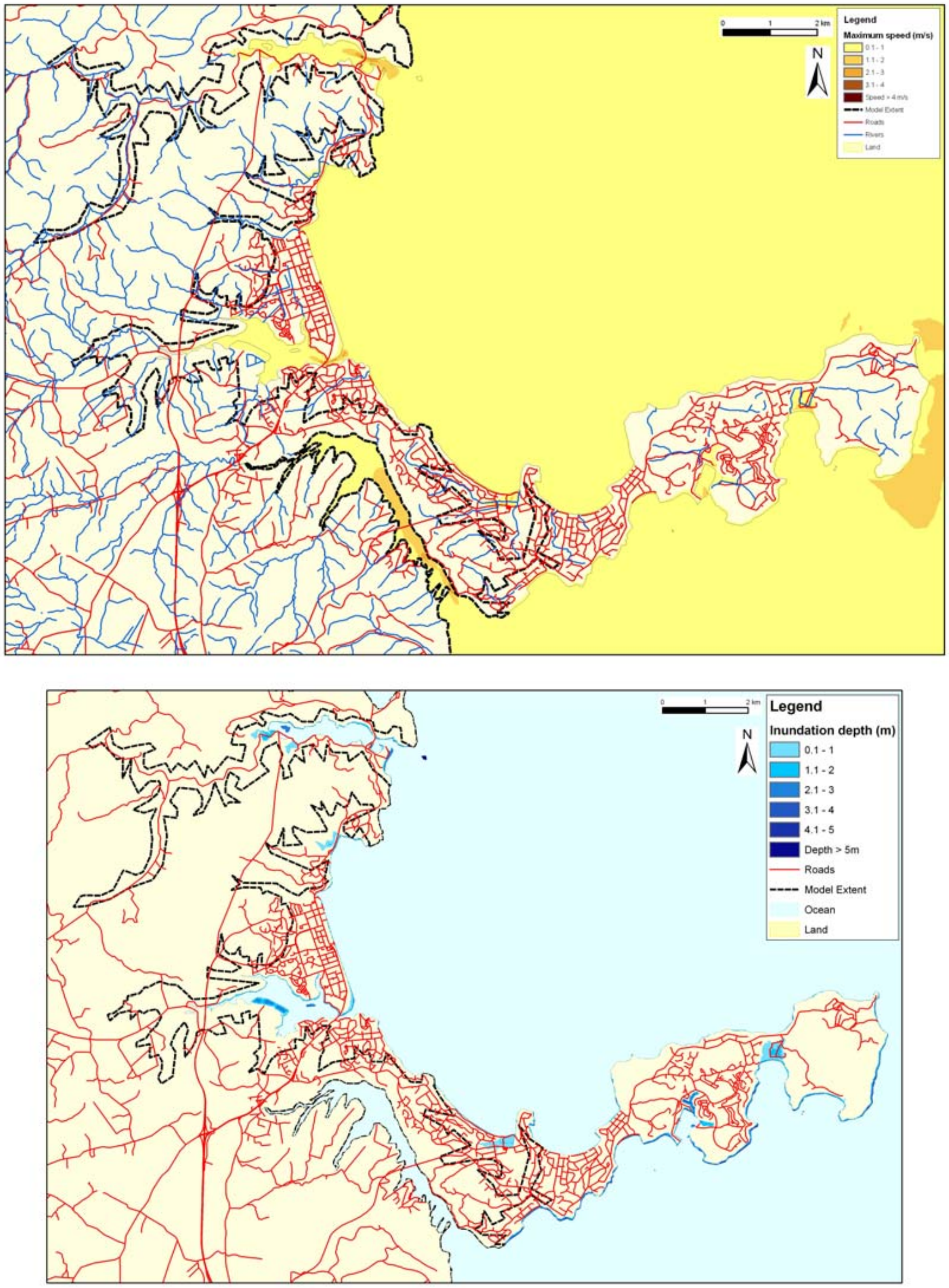


Figure 11: Waiwera to Whangaparoa Peninsula. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.

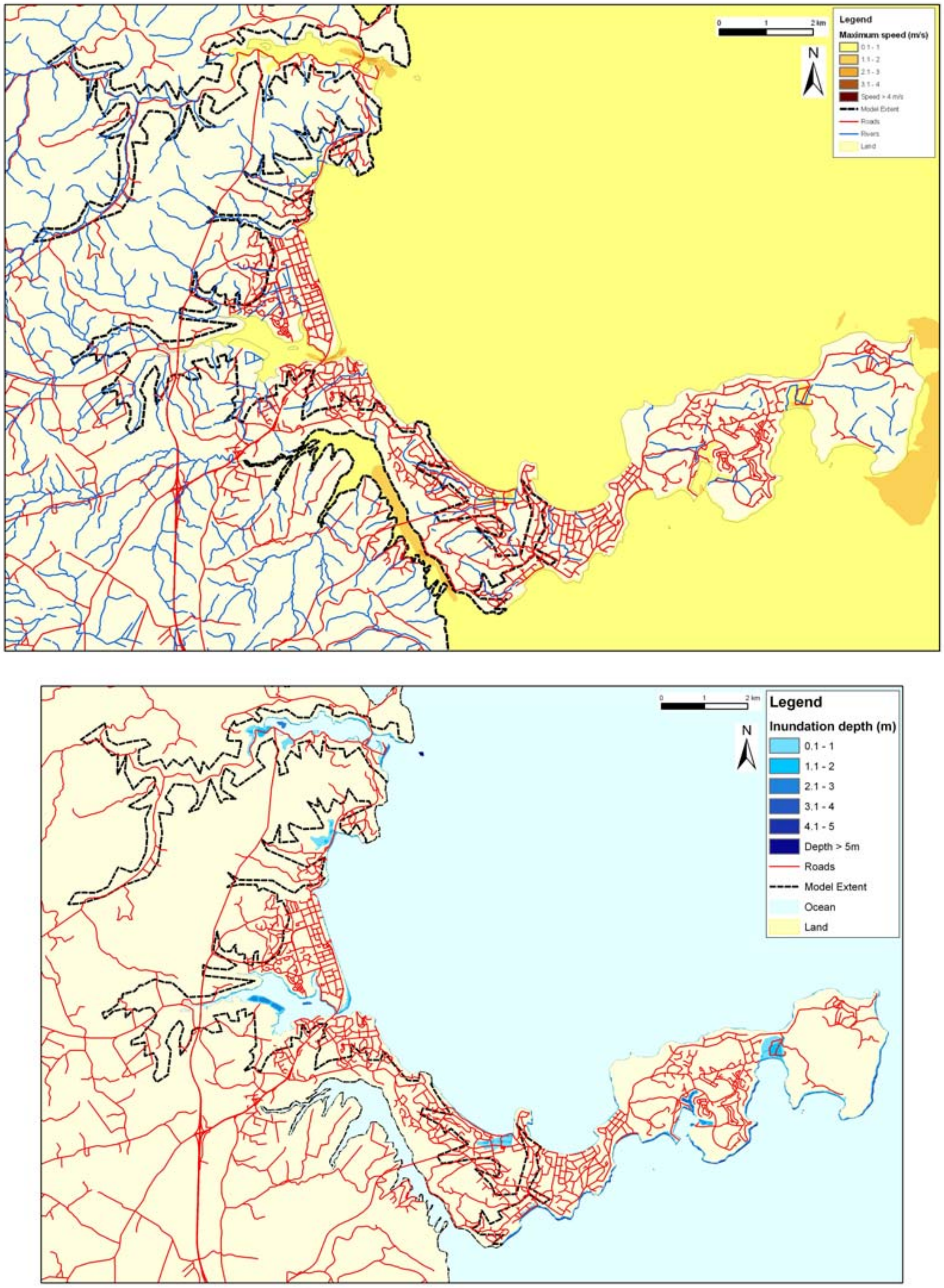
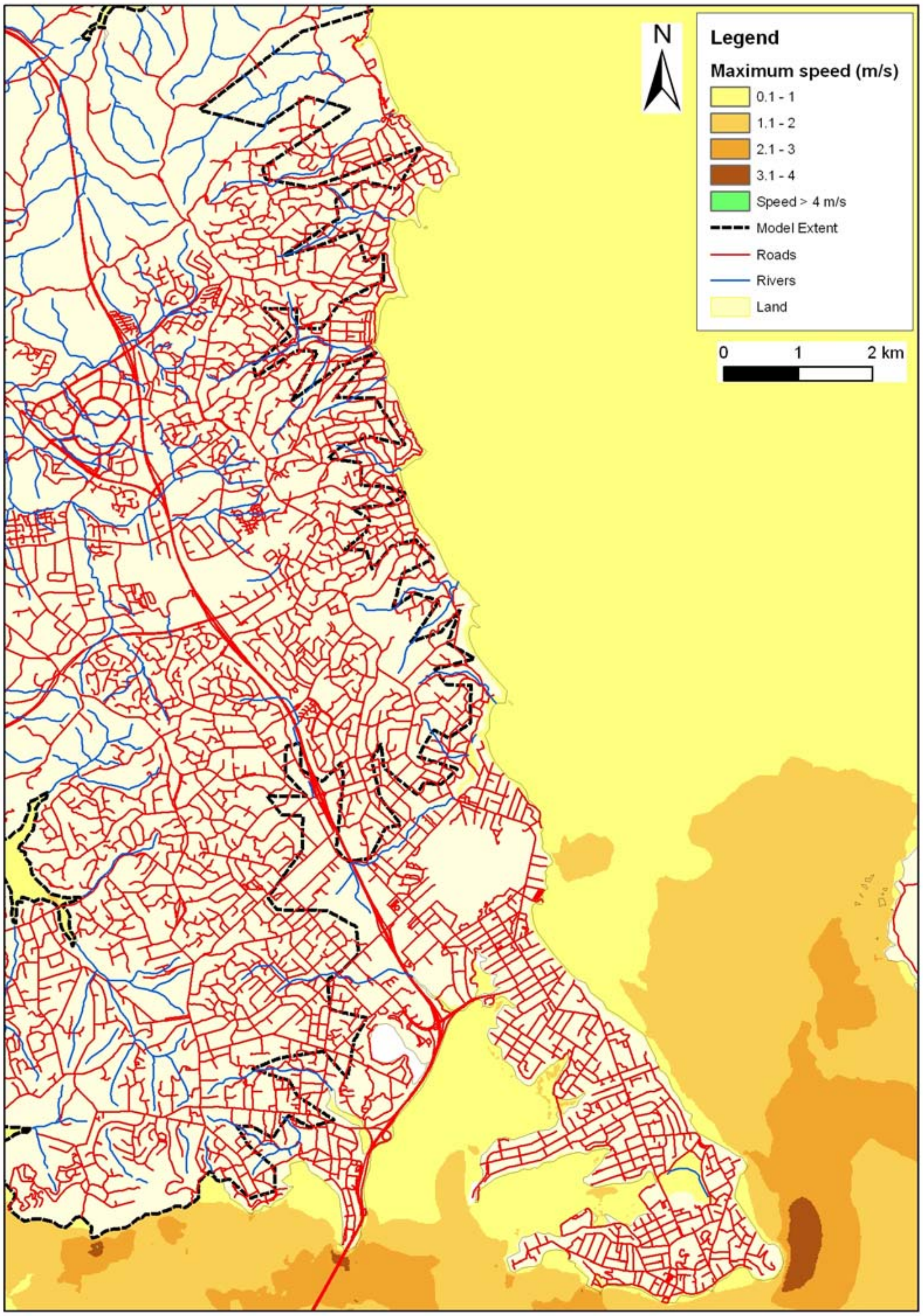


Figure 12: Waiwera to Whangaparoa Peninsula. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
1
2 km

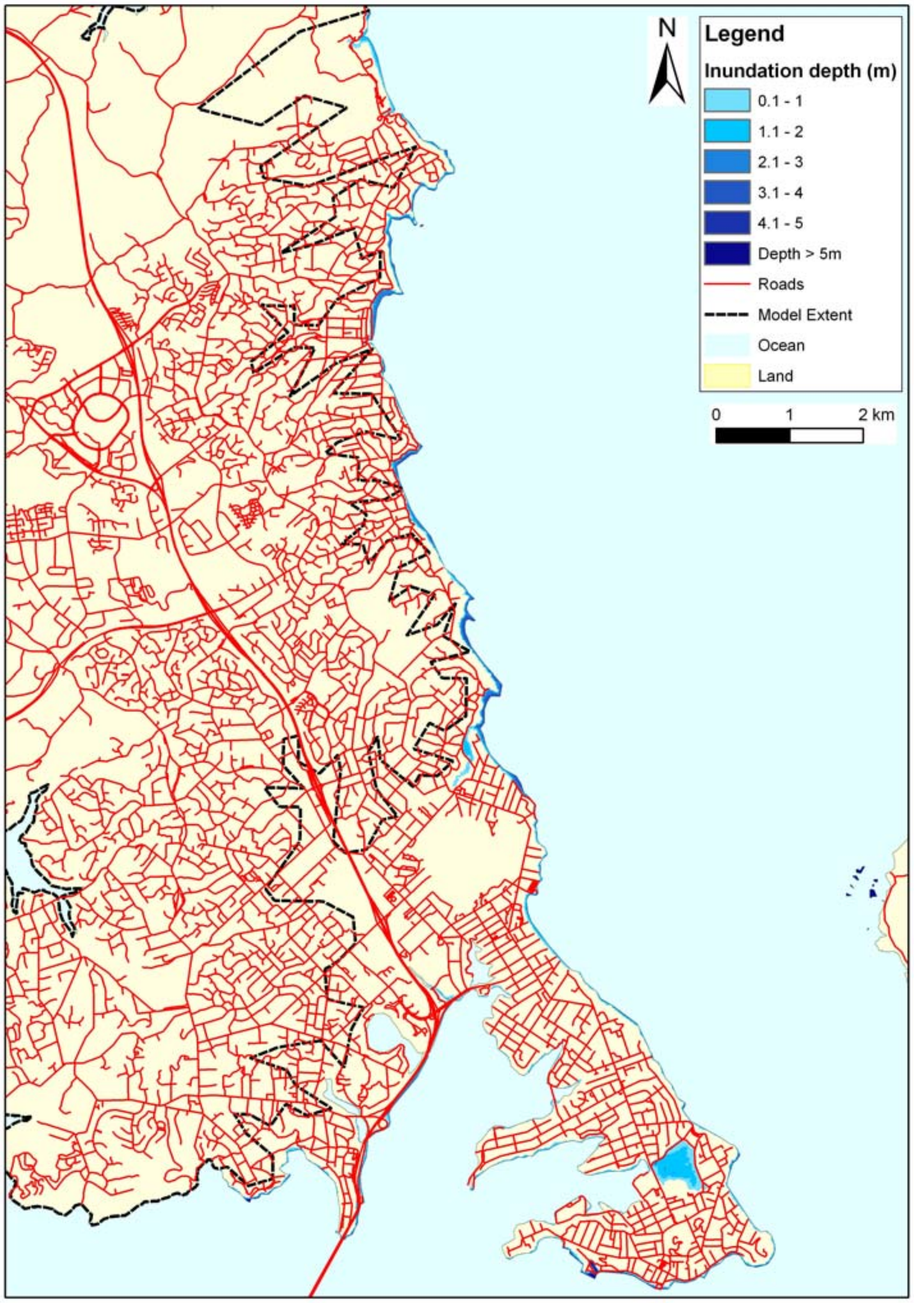
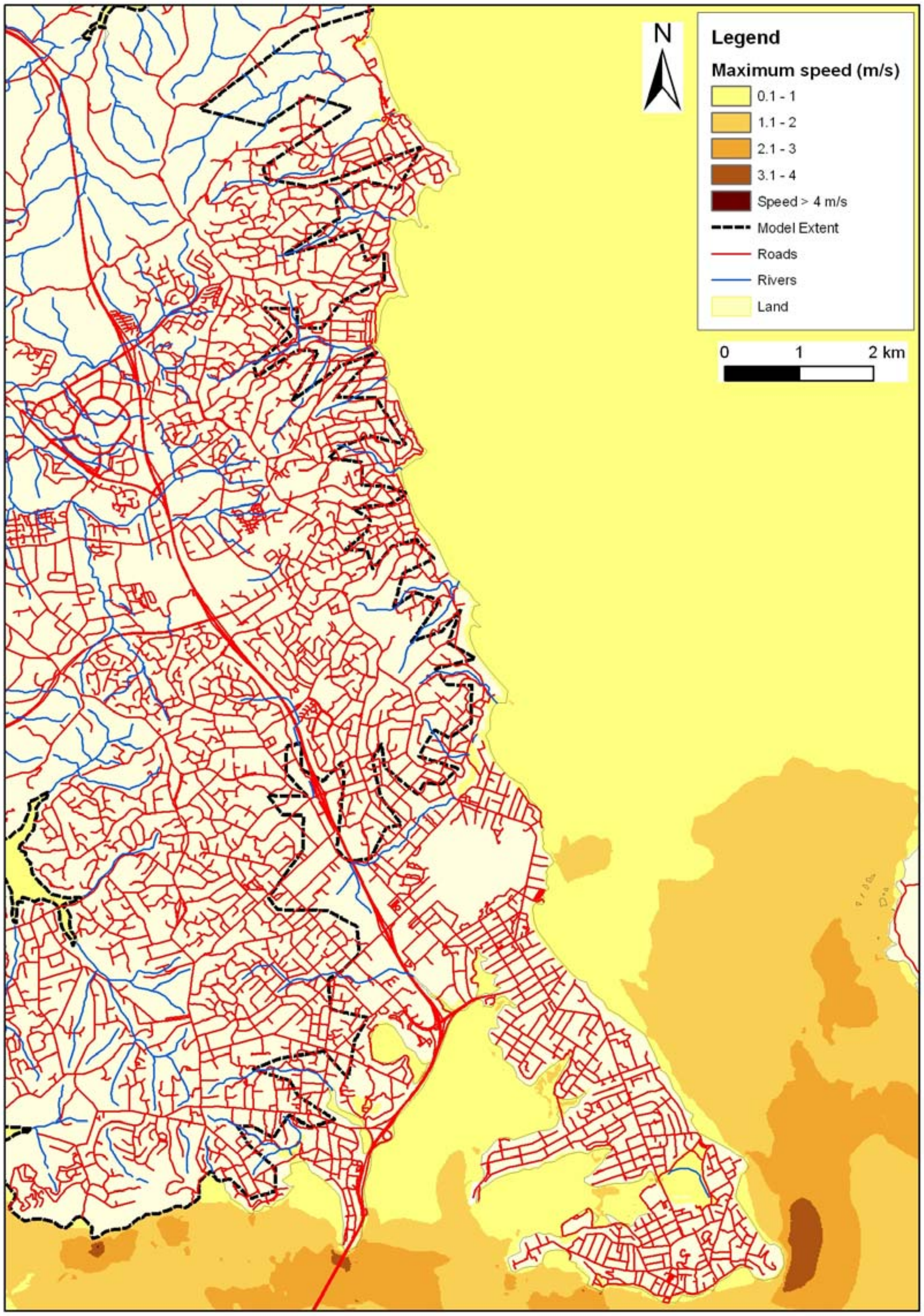


Figure 13: North Shore. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
1
2 km

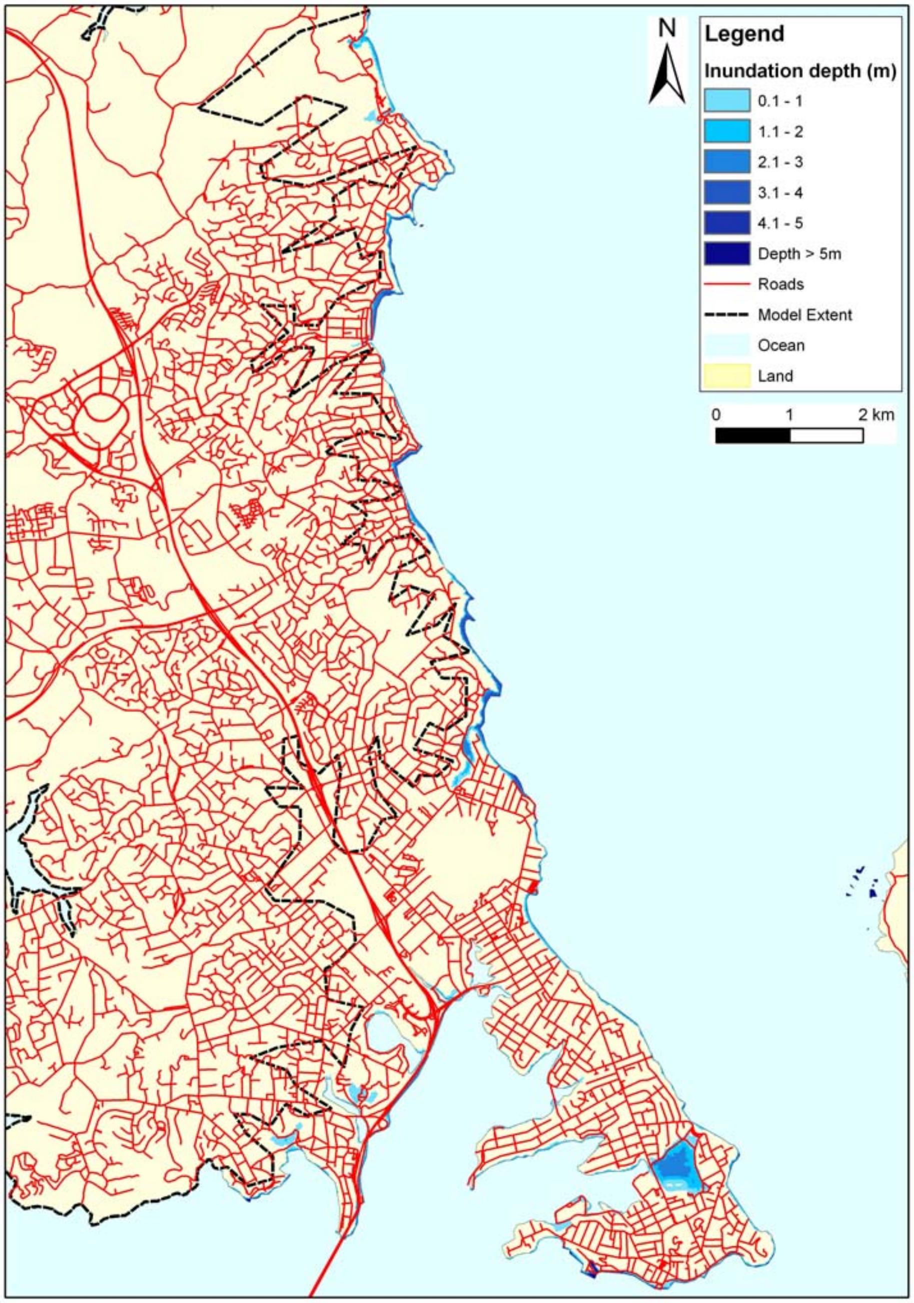
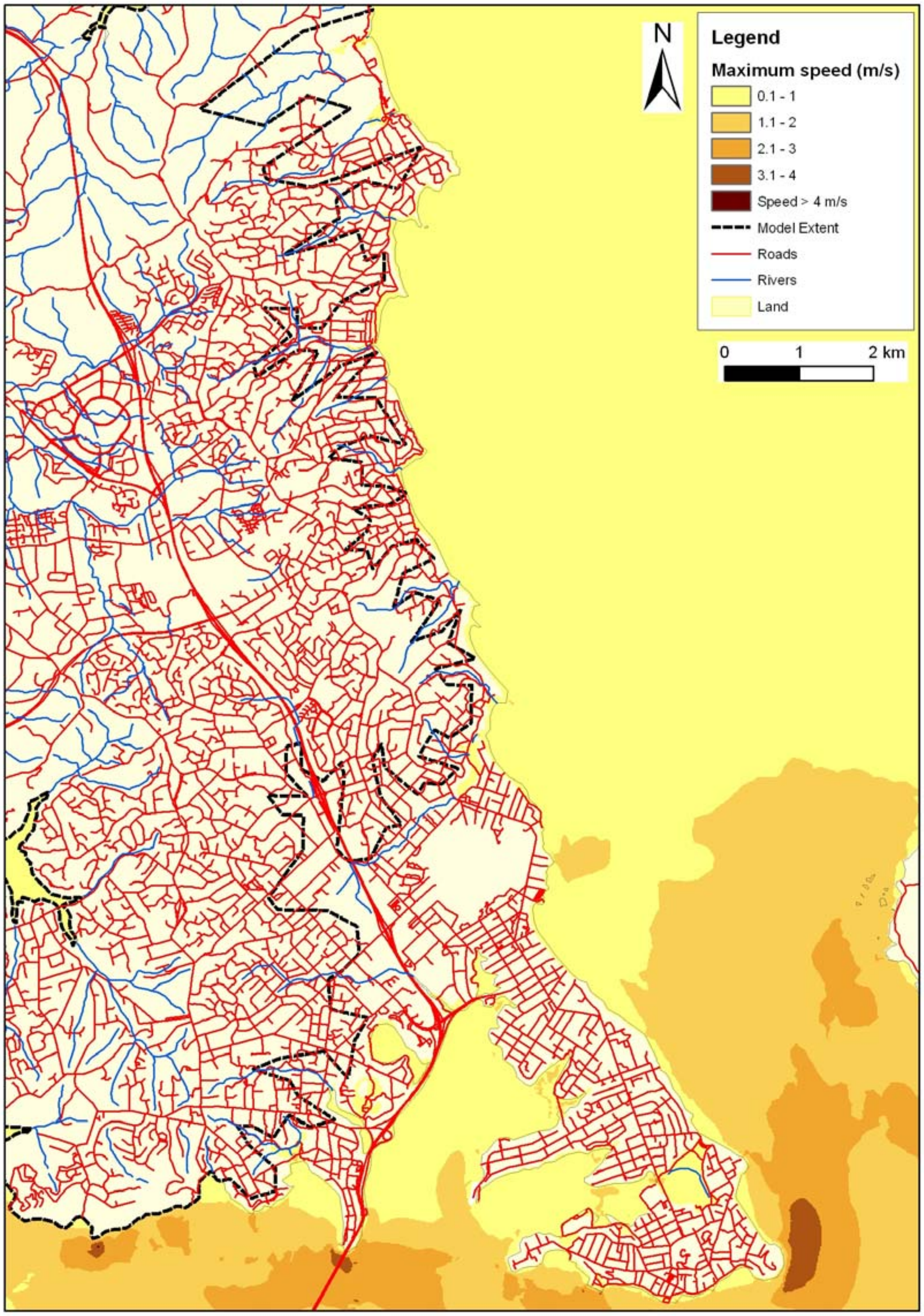


Figure 14: North Shore. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
1
2 km

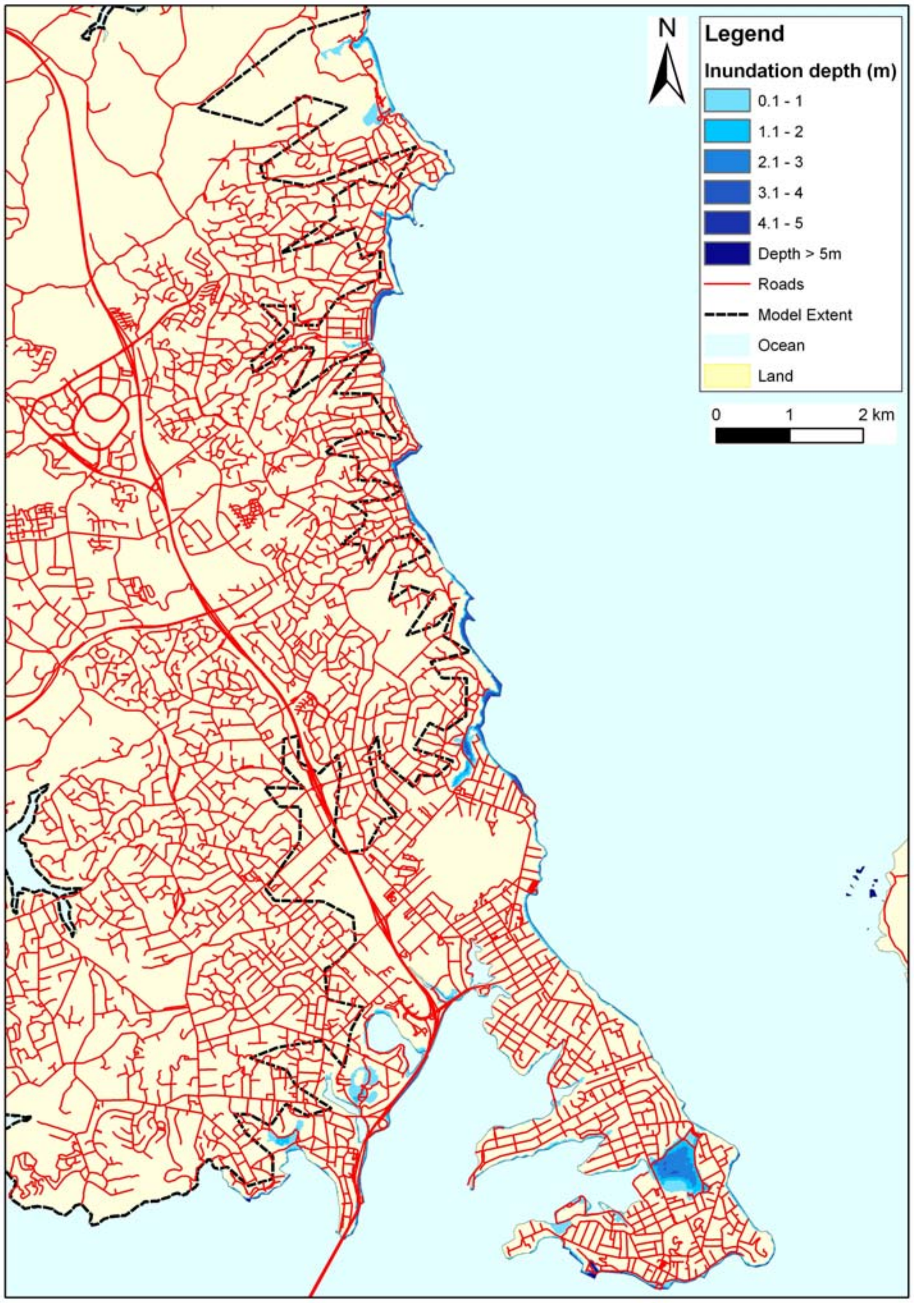


Figure 15: North Shore. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.

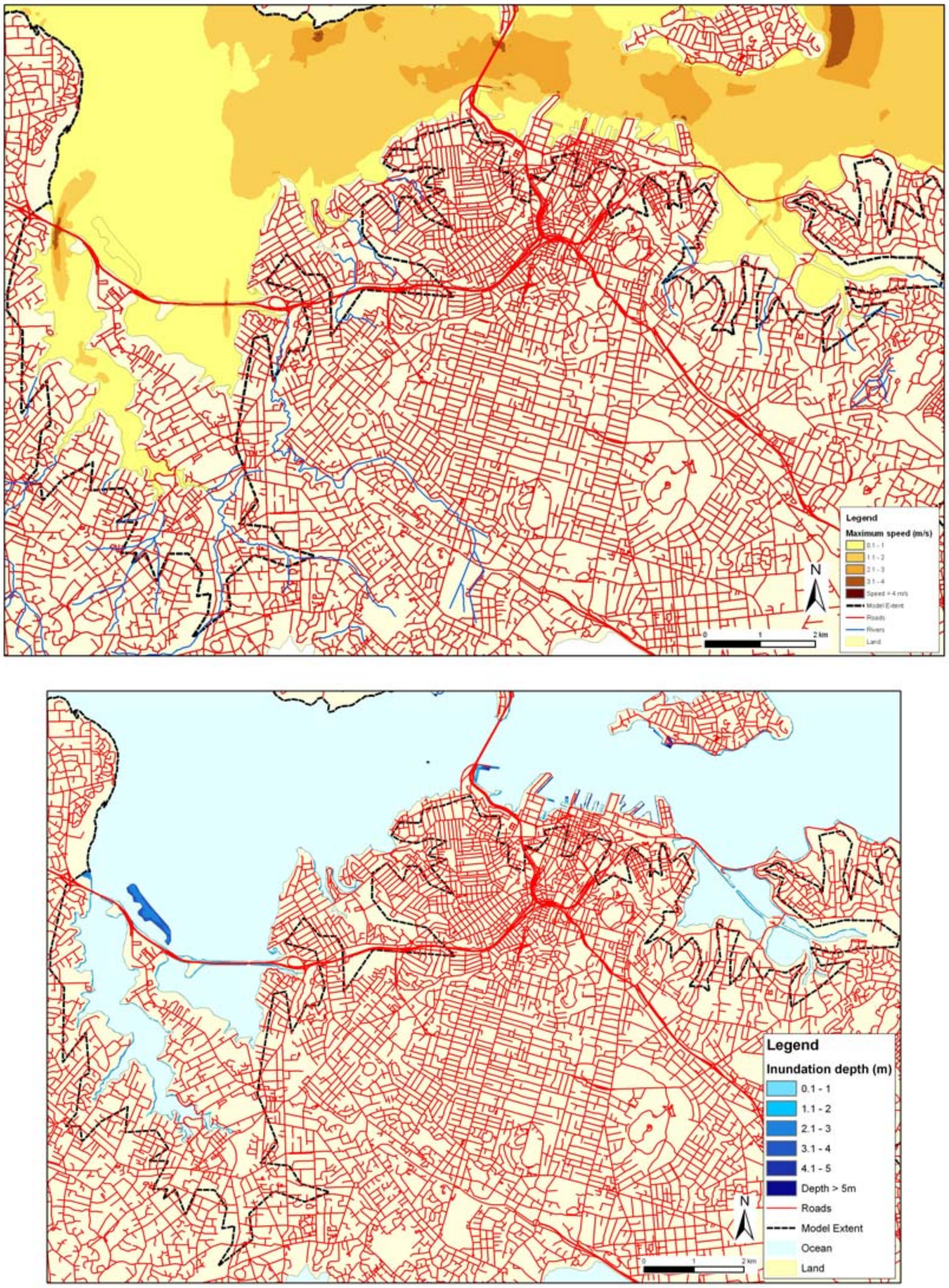


Figure 16: CBD, Te Atatu to Mission Bay. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS.

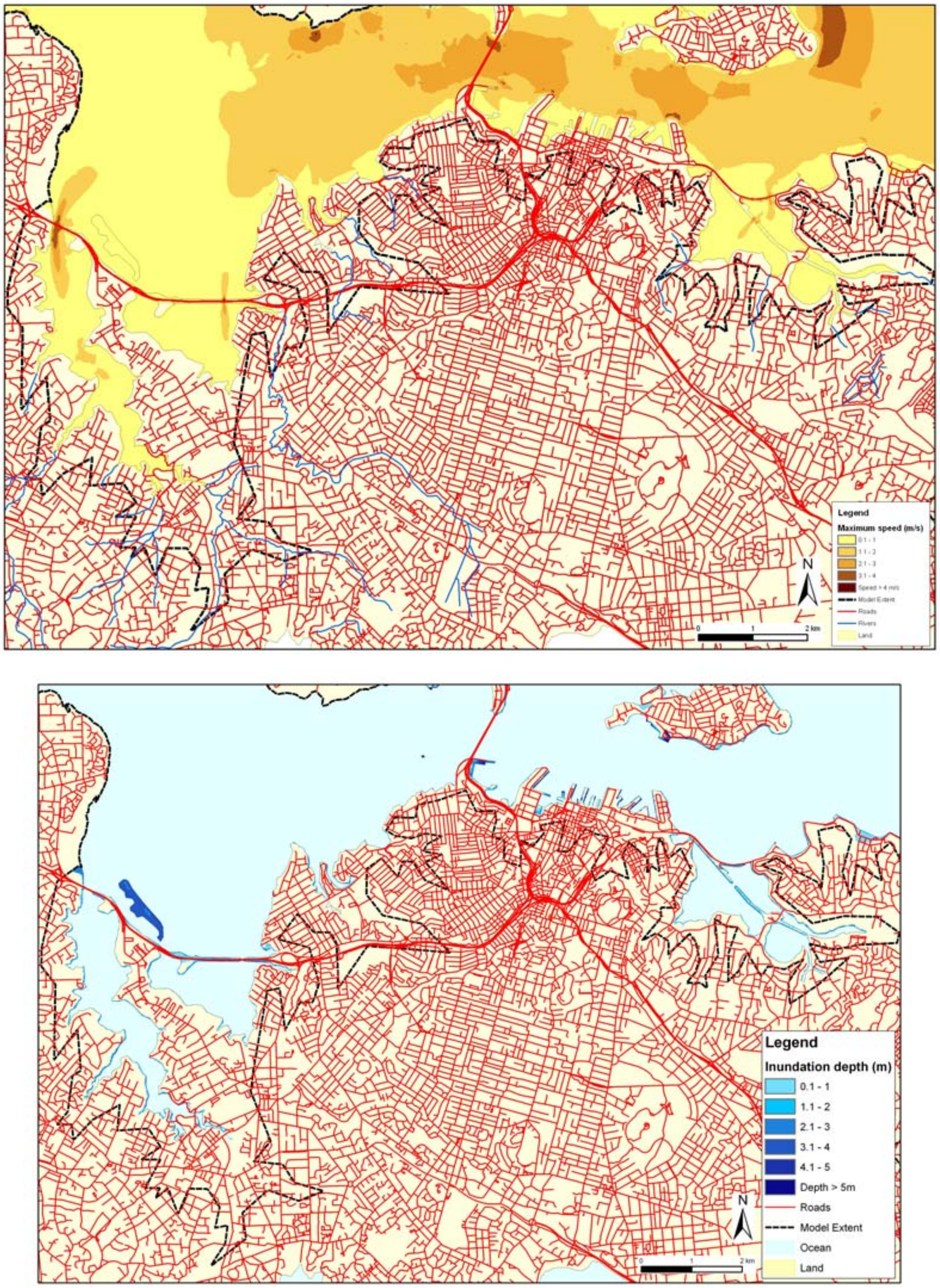


Figure 17: CBD, Te Atatu to Mission Bay. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.

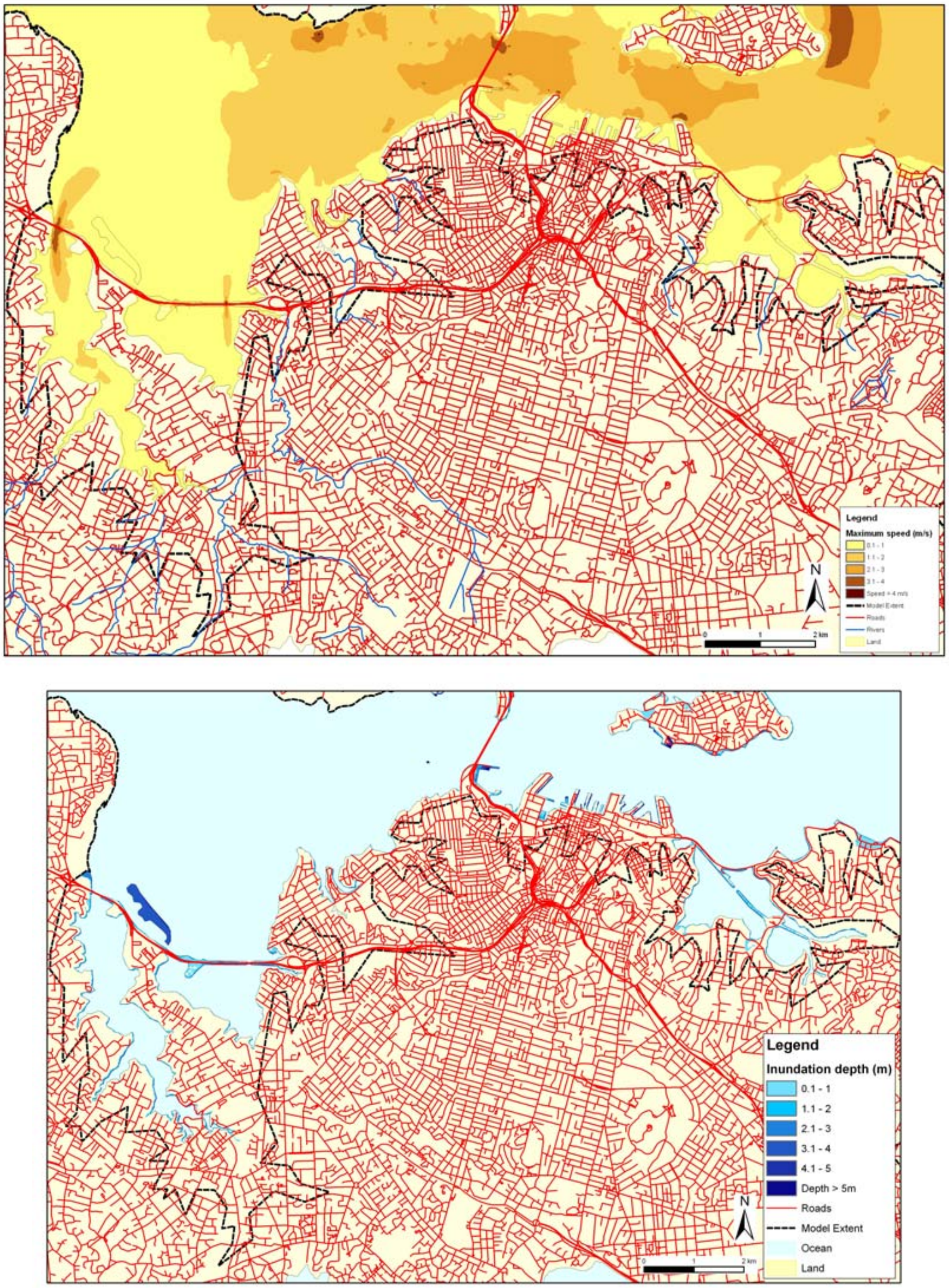


Figure 18: CBD, Te Atatu to Mission Bay. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.

Inundation is very much confined to the coast. The NW motorway (SH16) shows some inundation. Inundation at the edge of the grid by Te Atatu seems to be an interpolation problem and should be disregarded. Westhaven Marina, Freemans Bay, the causeway on Tamaki Drive and a small amount of Mission Bay have some inundation.

Sea level rise causes deeper and more extensive inundation, especially in the places mentioned above. In the 50 cm sea level rise scenario SH16 has considerable inundation along the causeway. There is also considerable inundation of Mission Bay over Tamaki Drive and up to Marau Crescent.

4.1.5. Inundation Maps – Mission Bay to Maraetai

Figures 19-21 show the maximum water depth and maximum water speed for the area Mission Bay to Maraetai for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. There are high water speeds in the Tamaki Estuary and the Turanga River. There is inundation in Glendowie up to low-lying parts of Glendowie Rd, and Tahuna Torea is also inundated. The water crosses Dunkirk road in Panmure at a couple of points as well as the coastal roads along Bucklands Beach and Eastern Beach. There is also inundation of parts of Cockle Bay, Beachlands Marina (although the LIDAR may not cover the outer edge of the marina), Kellys Beach, Te Puru Stream and Maraetai Beach. The sea level rise scenarios increase the inundation of Bucklands Beach and Eastern Beach to more than a block inland. They do not change the water speeds appreciably however.

4.1.6. Inundation Maps – Kaiaua

Figures 22-24 show the maximum water depth and speed for the Kaiaua area and surrounds for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. Maximum water speeds are not large with all speeds less than 2 m/s. At MHWS there is inundation over the road at southern end of the land grid (near Kaiaua) and close to road in several places. With sea level rise there is extensive inundation of settlements along the coast and over the coastal road.

4.1.7. Inundation Maps – Waiheke Island

Figures 25-27 show the maximum water depth and speed water for Waiheke Island for the three sea level scenarios of MHWS and MHWS plus sea level rises of 30 and 50 cm respectively. There is extensive inundation of Blackpool and some inundation of Surfdale. The sea level rise scenarios exacerbate this.

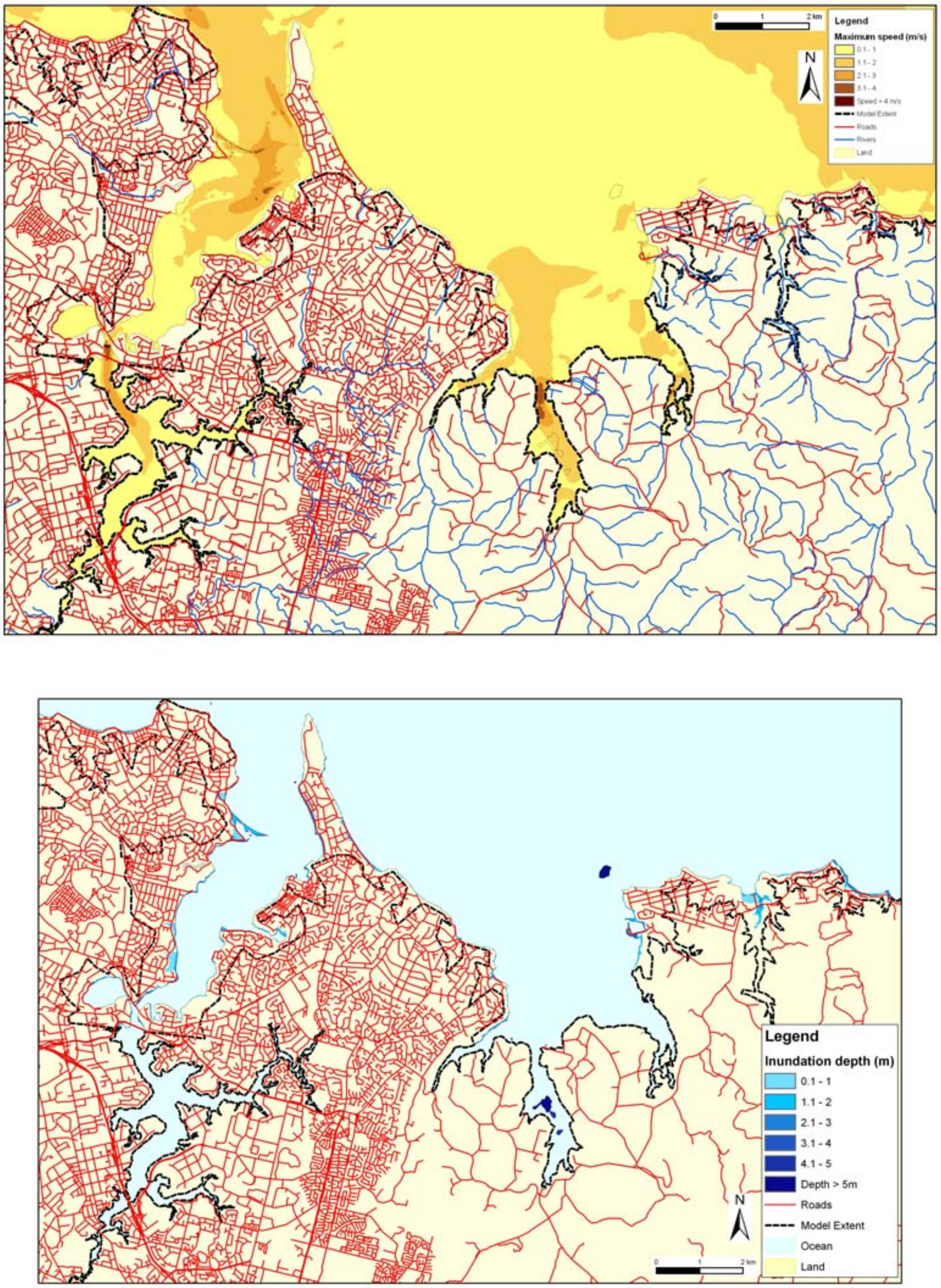


Figure 19: Mission Bay to Maraetai. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS.

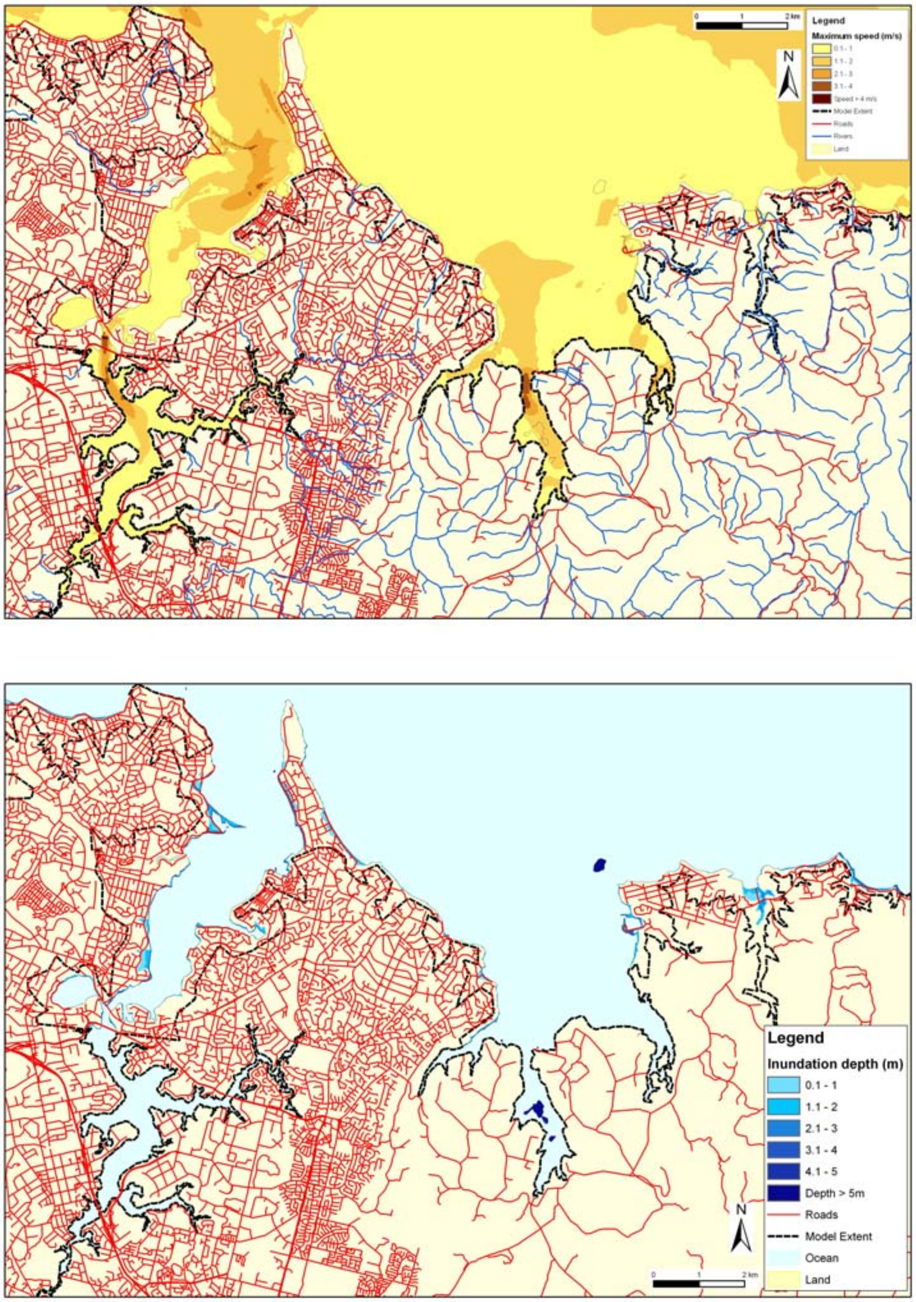


Figure 20: Mission Bay to Maraetai. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.

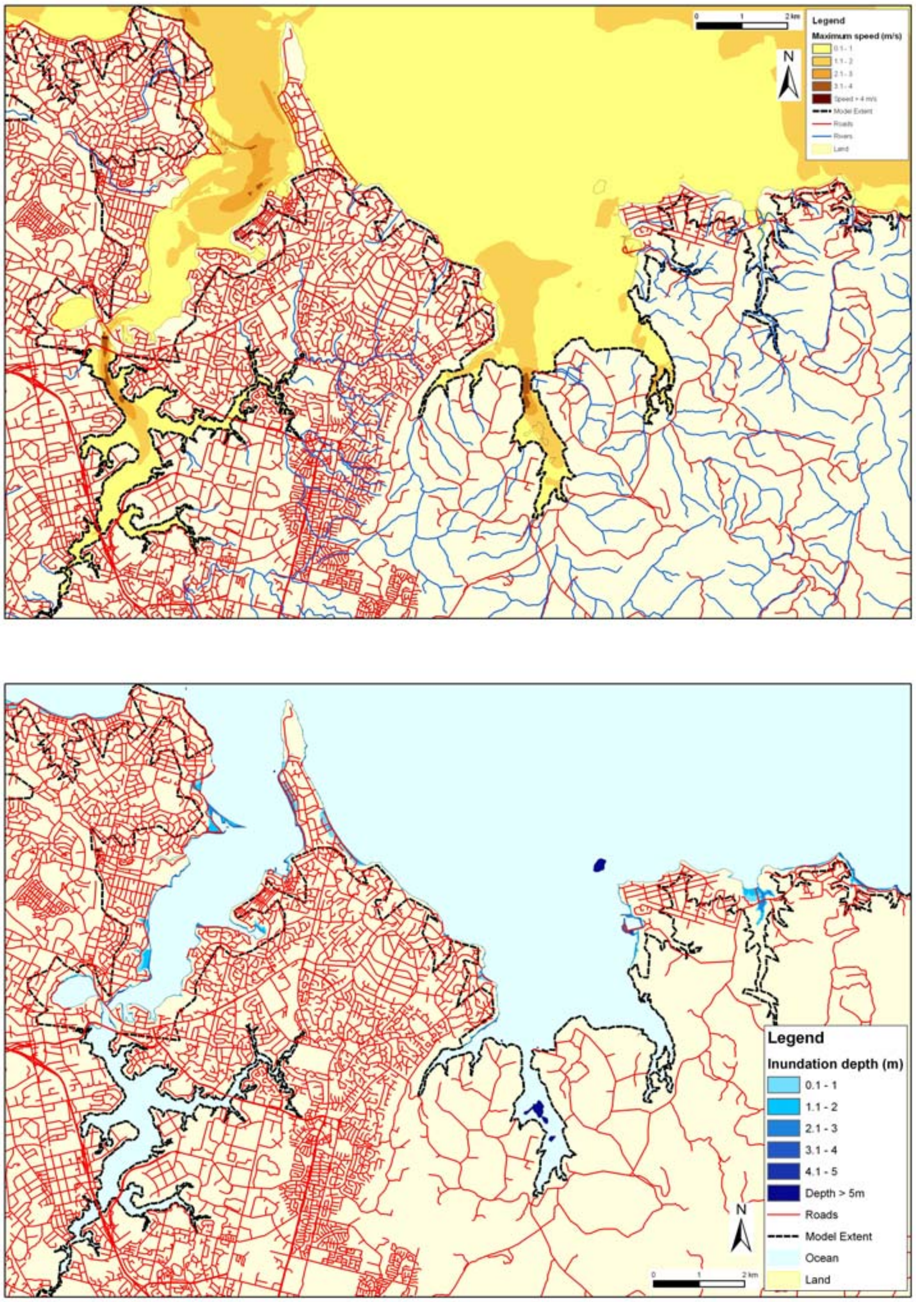
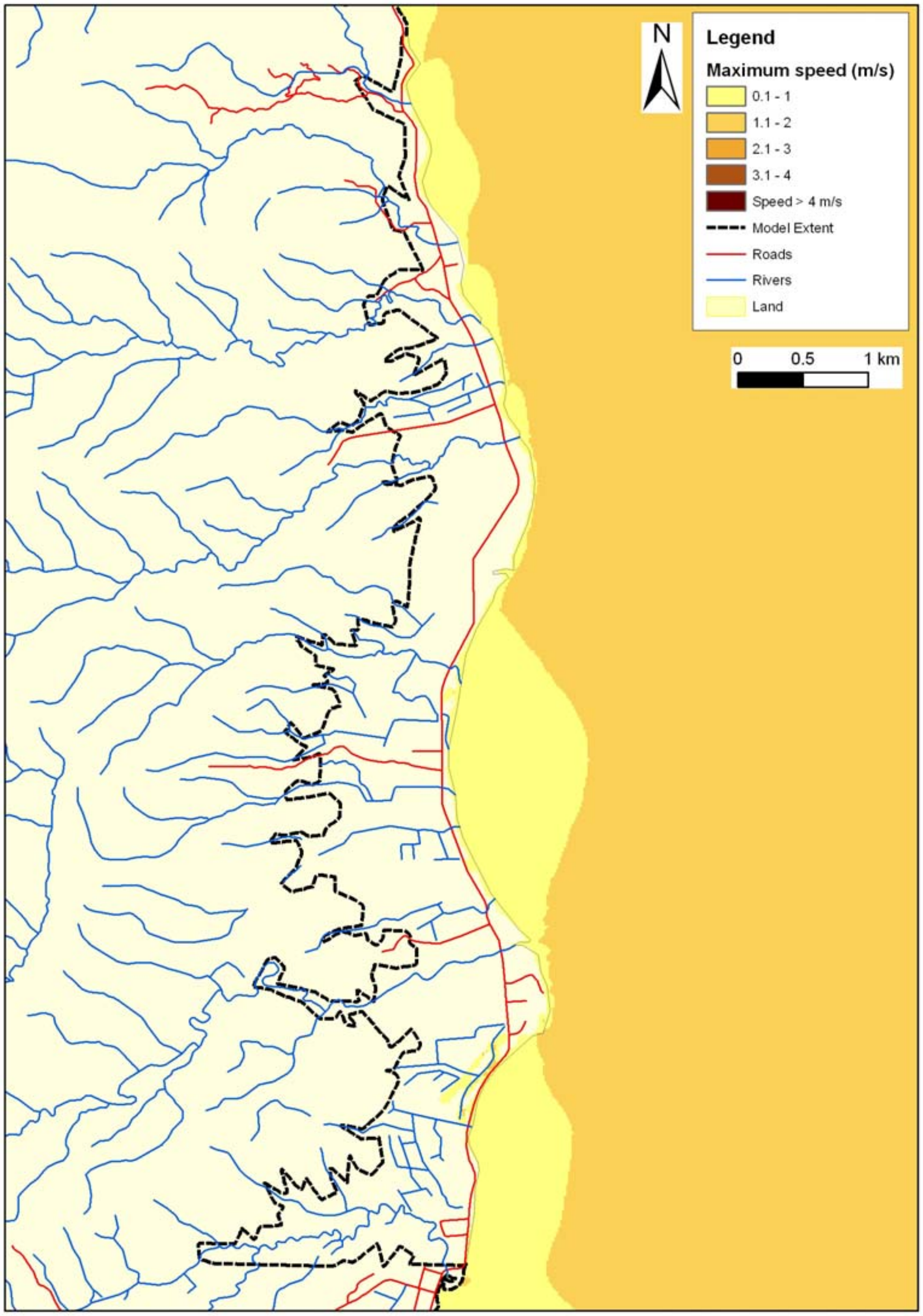


Figure 21: Mission Bay to Maraetai. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
0.5
1 km

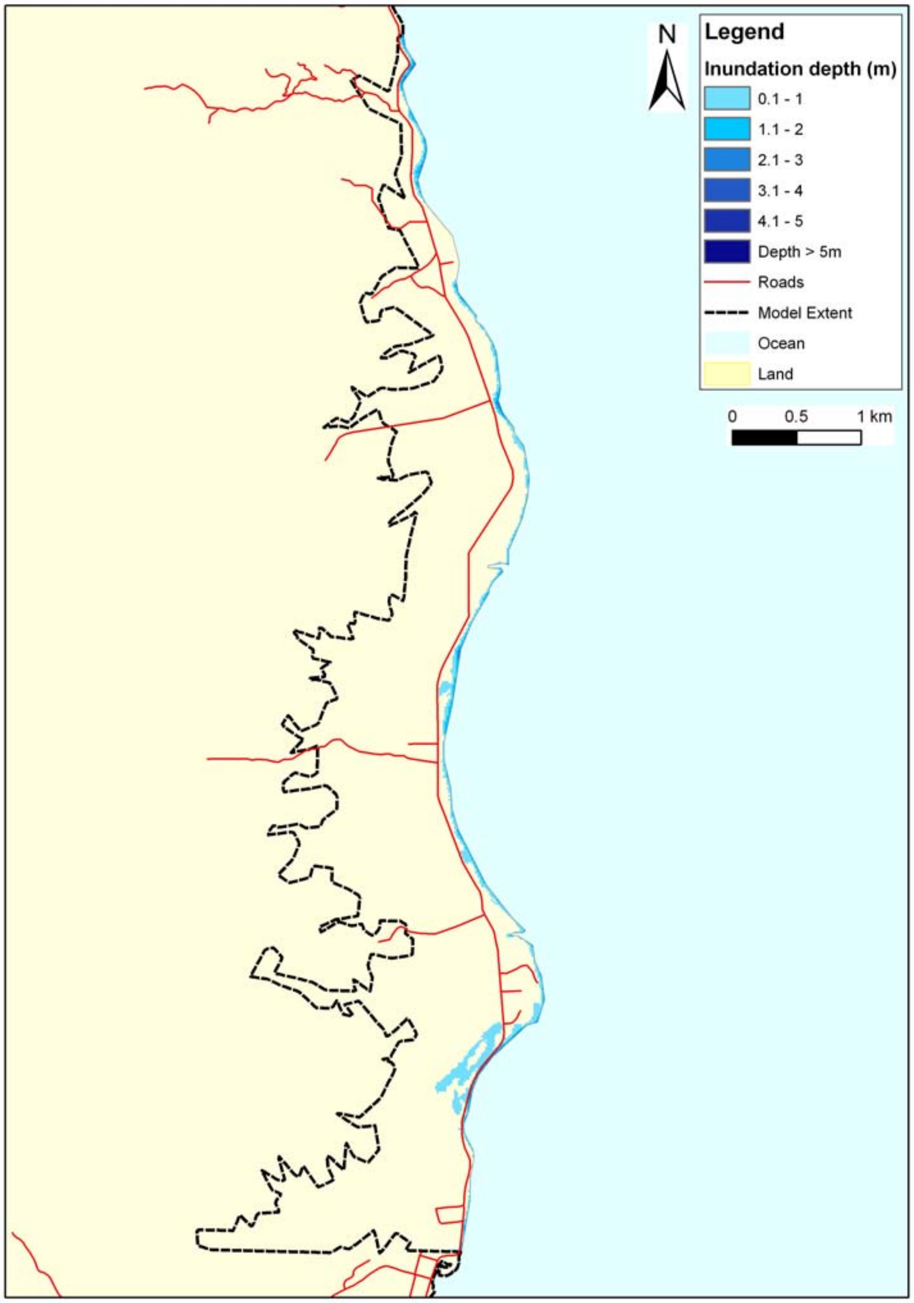
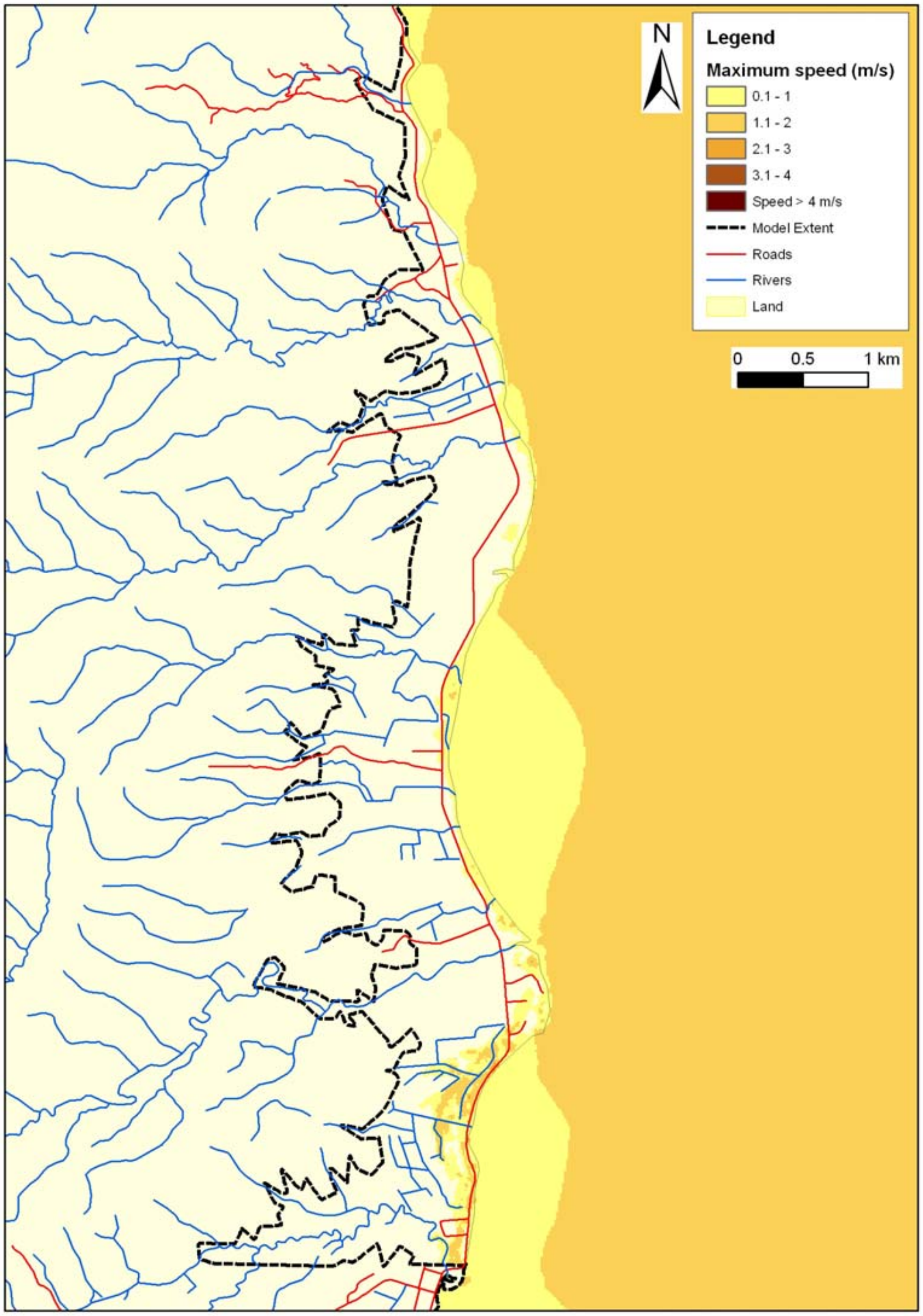


Figure 22: Kaiaua. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
0.5
1 km

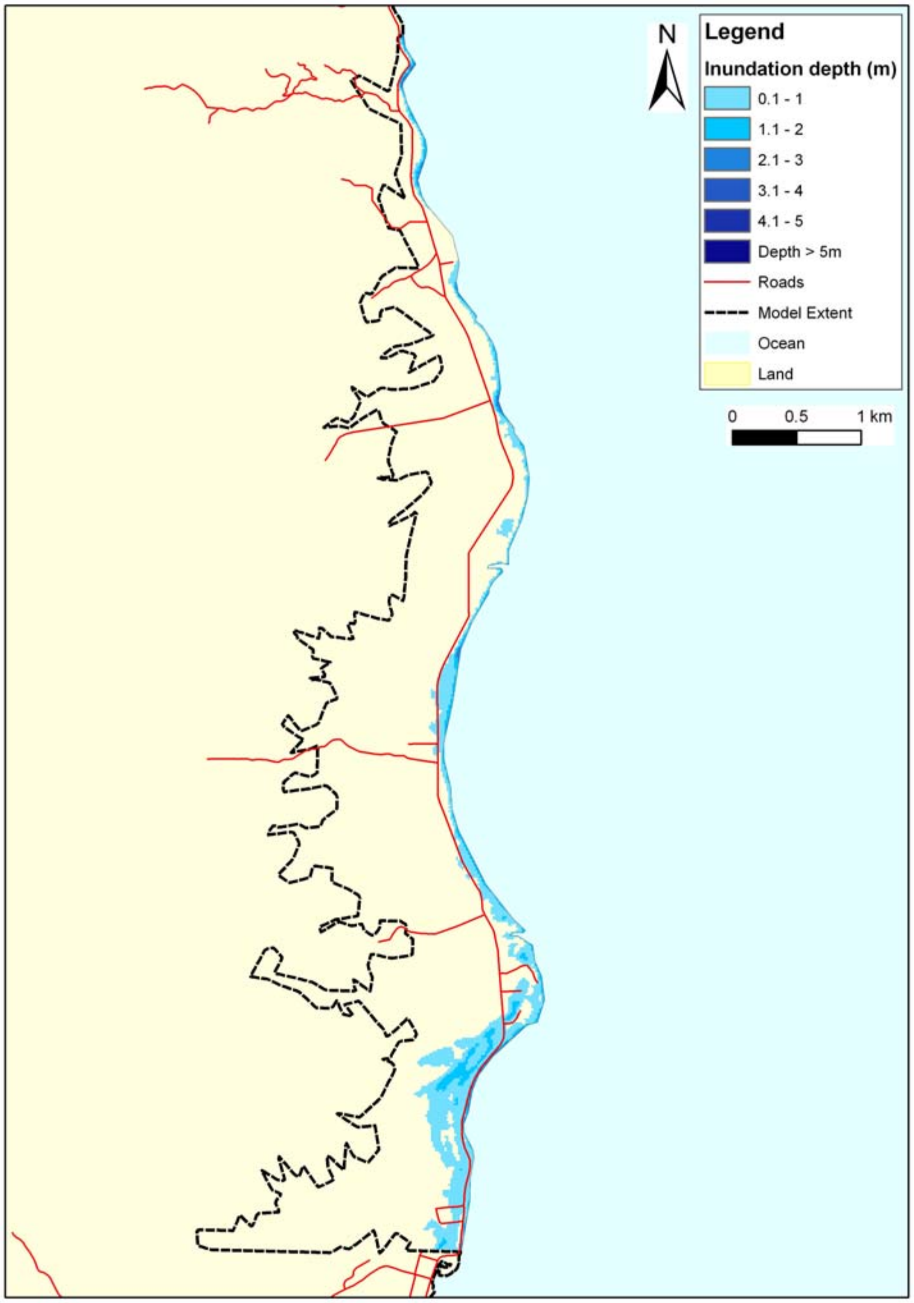
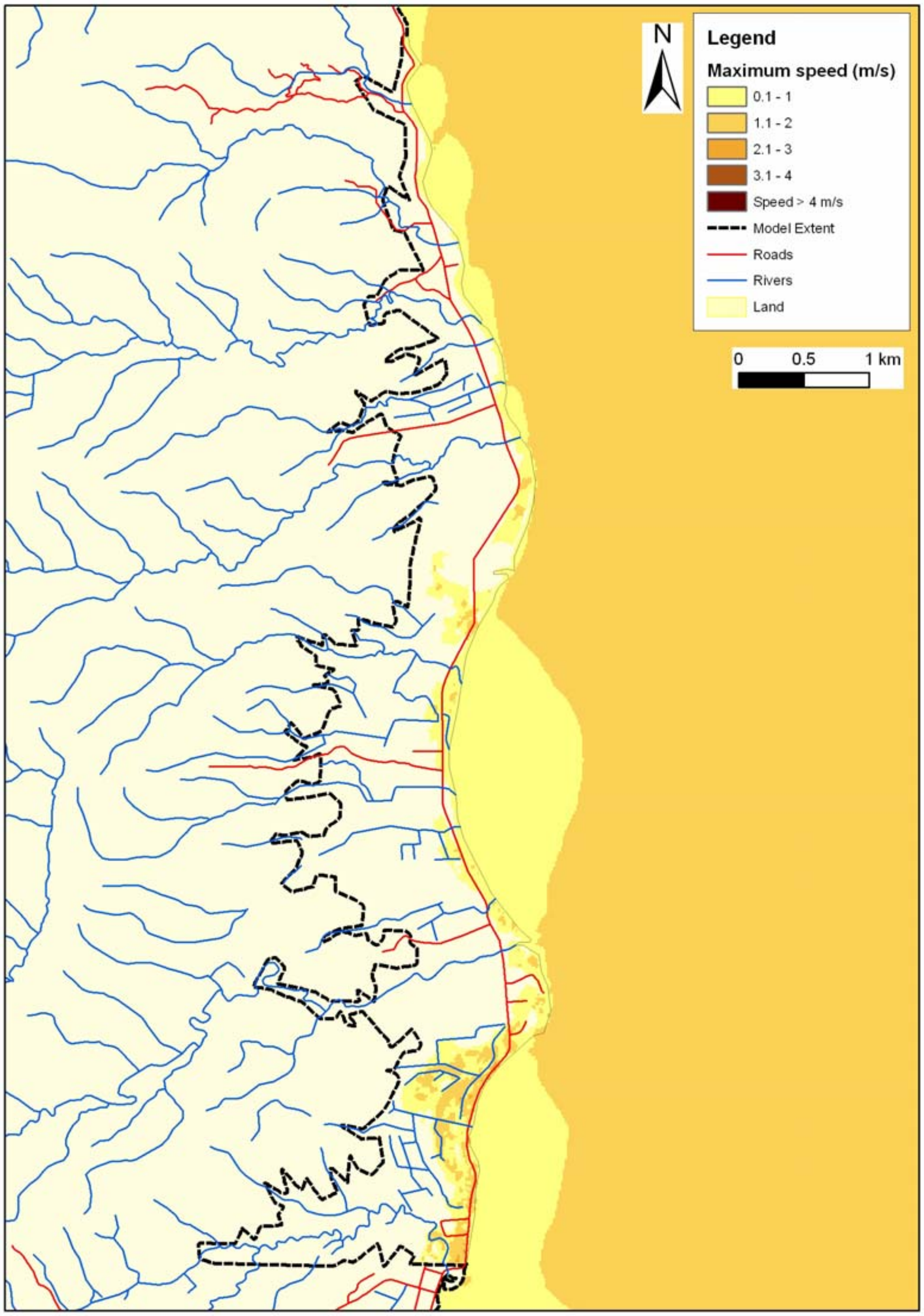


Figure 23: Kaiaua. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.


N
Legend
Maximum speed (m/s)
0.1 - 1
1.1 - 2
2.1 - 3
3.1 - 4
Speed > 4 m/s
Model Extent
Roads
Rivers
Land
0
0.5
1 km

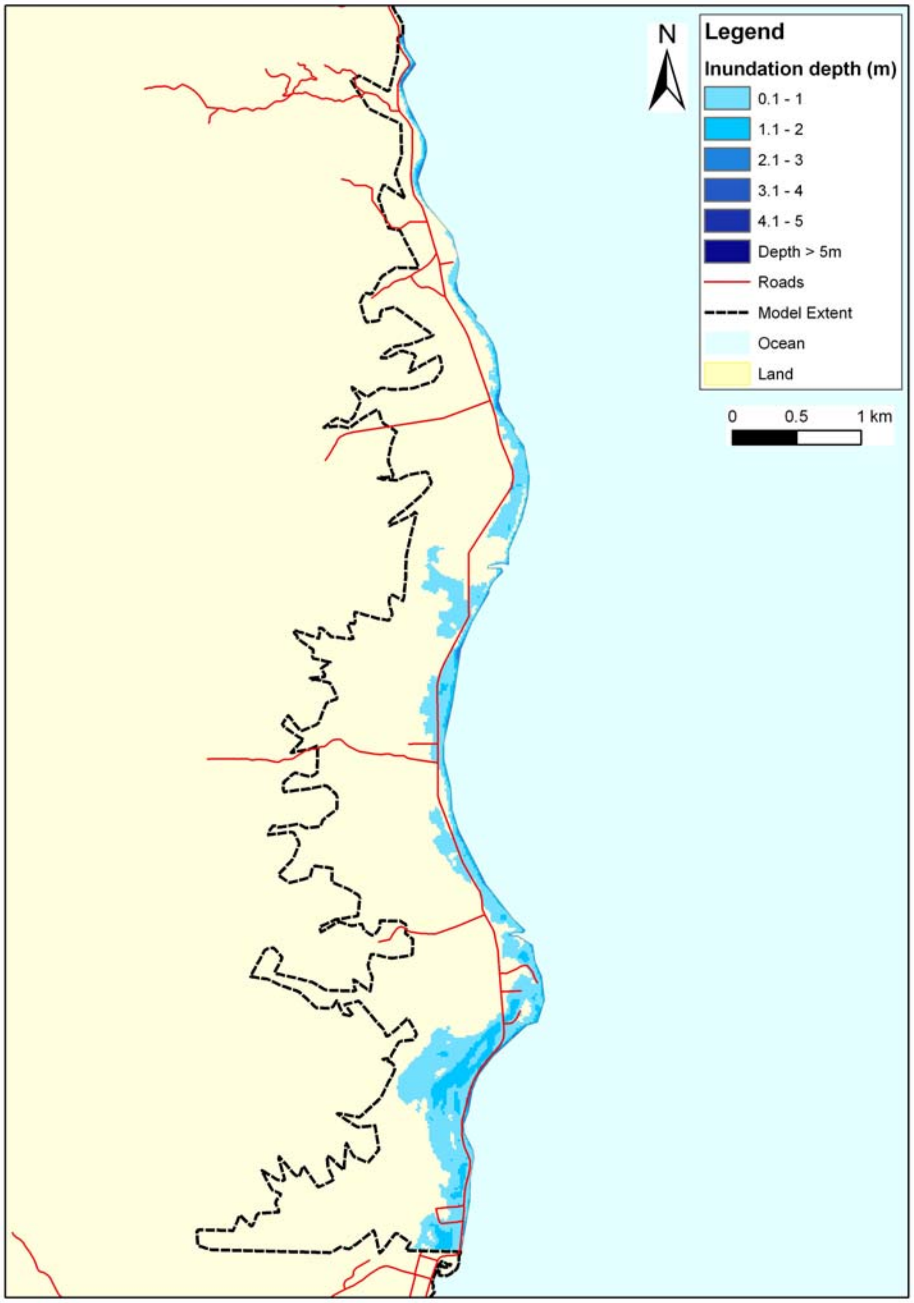


Figure 24: Kaiaua. Maximum inundation speed (previous page) and depth (this page) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.

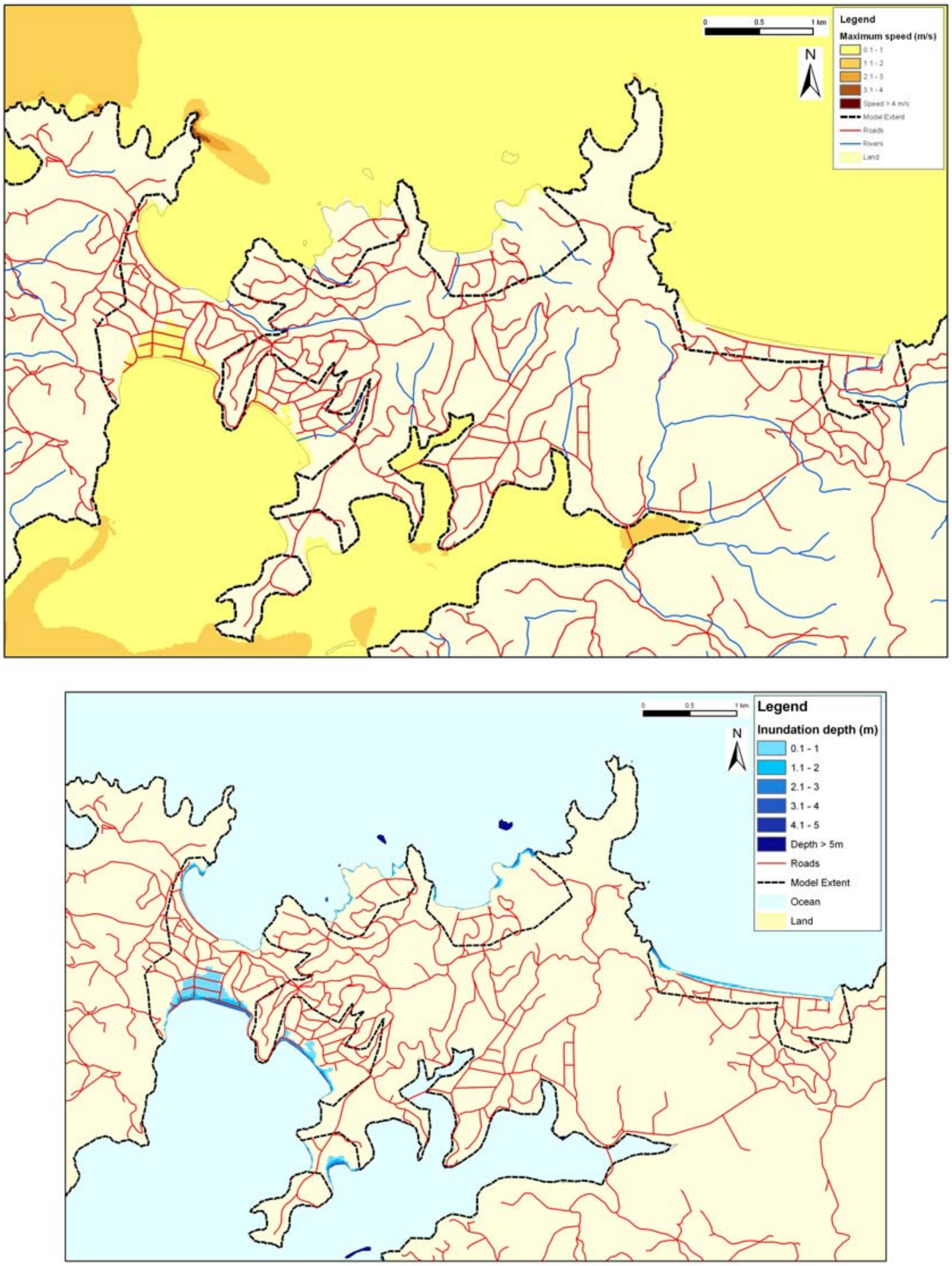


Figure 25: Waiheke Island. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS.

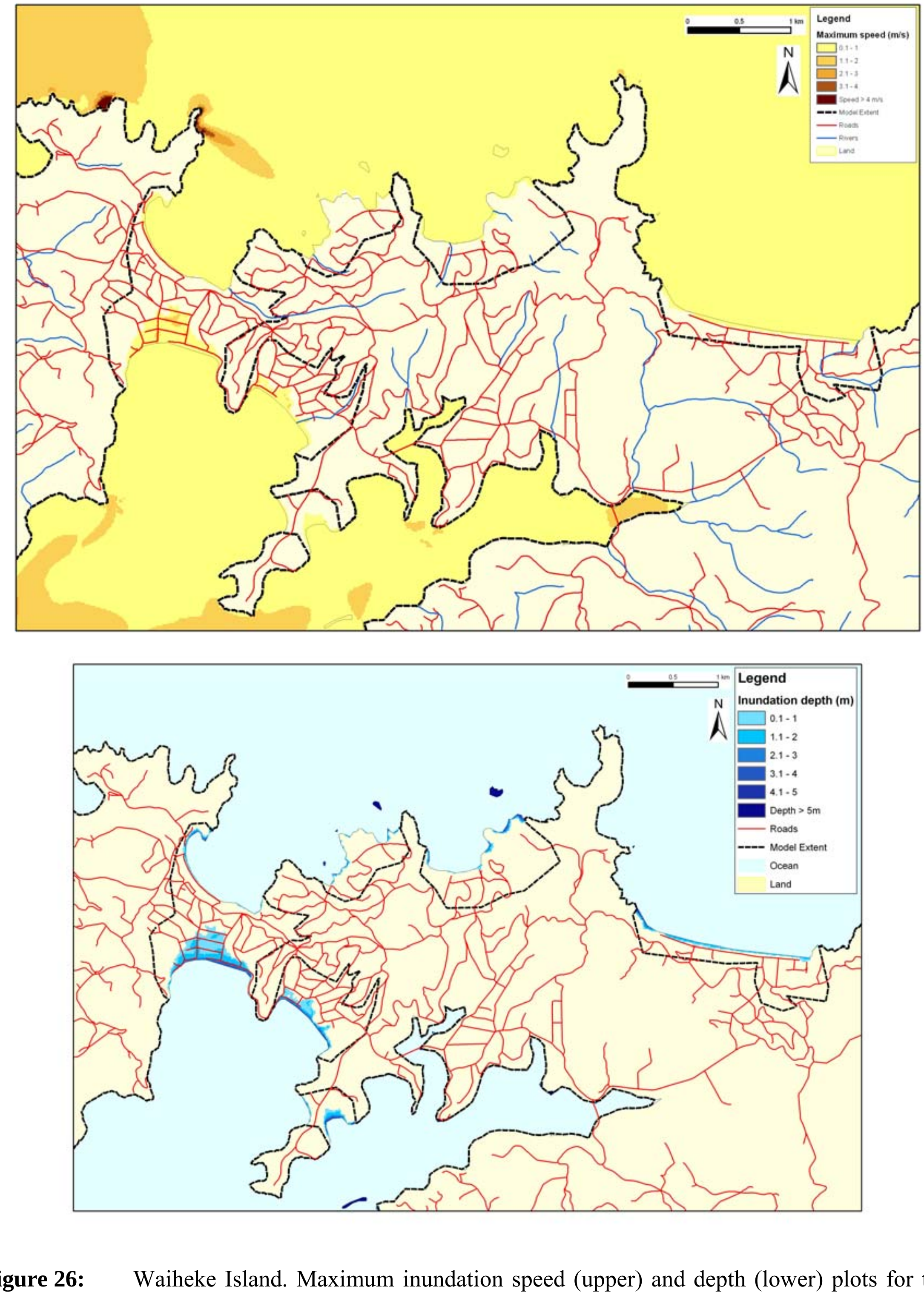


Figure 26: Waiheke Island. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 30 cm sea level rise.

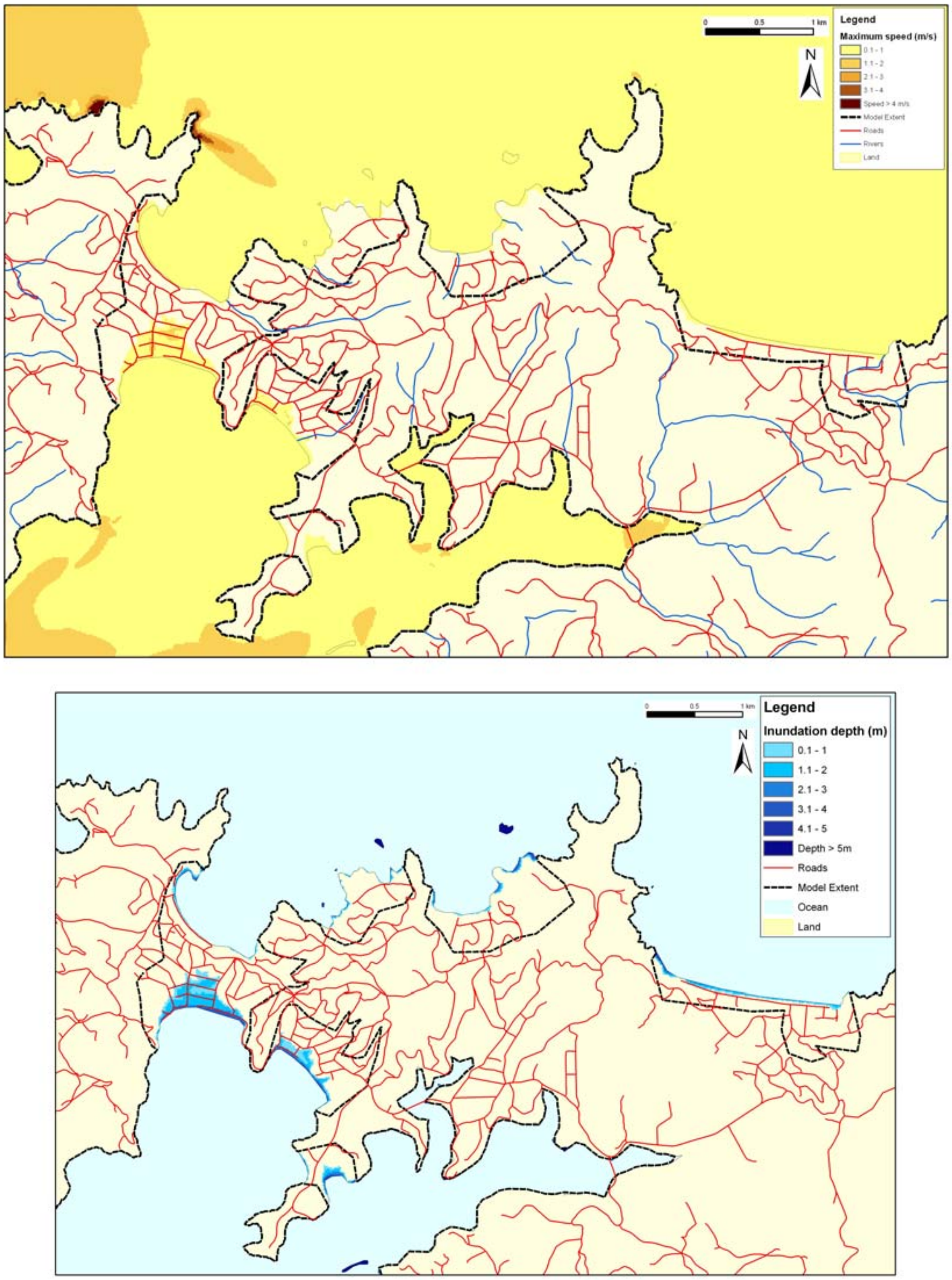


Figure 27: Waiheke Island. Maximum inundation speed (upper) and depth (lower) plots for the South American tsunami scenario at MHWS plus 50 cm sea level rise.

5. Discussion

A remotely generated South American tsunami is the most probable tsunami risk facing the Auckland region in the next 50-100 years. A tsunami from South America takes on the order of 15 hours to reach New Zealand, providing some time to implement contingency plans. The tsunami would hit other areas of New Zealand such as East Cape and Northland before reaching the Auckland region. However, the Auckland region is also exposed to other regional sources such as the Tonga-Kermadec Trench. Tsunamis generated there are likely to cause greater inundation and may arrive in as little as 1 hour, providing very little time for evacuation. Historically, tsunami events generated by activity along the Tonga-Kermadec Trench occur less frequently, and this and other regional sources have not been modelled as part of this project.

A remote, South American tsunami was modelled for three sea levels heights. The sea levels were current MHWS (representing the 'worst-case' for the tsunami where its maximum wave coincides with high tide) and MHWS with sea level rises of 30 and 50 cm representing 50- and 100-year projections for sea level as assessed by the IPCC Fourth Assessment Report.

At Mean High Water Spring this tsunami causes maximum water elevations of around 2-3m above Mean Sea Level and up to 3.5m in some bays. Most of the inundation around Auckland is confined to fairly narrow coastal strips, although in some low-lying places the tsunami could cause significant inundation. Several low-lying coastal roads including the Northern motorway just north of the Harbour Bridge, the Northwestern motorway over the causeway between Point Chevalier and Te Atatu, and Tamaki Drive by Hobsons Bay are also at risk of inundation.

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