Tsunami evacuation zone boundary mapping: Manawatu-Wanganui coast update

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EXECUTIVE SUMMARY

This project was developed in response to a request from the Horizons Regional Council. GNS Science developed tsunami evacuation zones for the Horizons Region in 2008 using wave amplitude estimates published in the 2005 ‘Review of tsunami hazard and risk in New Zealand’ (Berryman 2005). In 2011, an update was undertaken to utilise the LiDAR data acquired since 2008 and to include an allowance for tsunami arriving at high tide.

This study is to update the tsunami evacuation zones for the Manawatu-Wanganui portion of the Horizons Region using the most recent wave amplitude estimates published in the 2013 ‘Review of tsunami hazard in New Zealand’ (Power 2013) and using the LiDAR data now available. The project plan comprised the following tasks:

1. Assembling digital elevation models (DEMs) and other data needed to derive evacuation zones.
2. Determining domain boundaries and tsunami wave amplitudes relevant to the Manawatu-Wanganui coast.
3. Deriving the tsunami evacuation zones using a GIS-calculated attenuation rule.

A regional 10 m resolution DEM and more detailed LiDAR-based DEMs provided by Horizons were assembled. In the earlier studies, the Manawatu-Wanganui coastline was treated as a single zone. In the current study, the Manawatu-Wanganui coast was divided into six domains following Power (2013). Two tsunami wave amplitudes were chosen as appropriate for modelling: the 3-5 m Tsunami Threat Level as defined by MCDEM (2012) for developing the Orange Zone and the maximum wave amplitude presented by Power (2013) that equates to the 2500 year return period wave amplitude at the 84% level of confidence for developing the Yellow Zone.

The 3-5 m Tsunami Threat Level wave amplitude is the same as used in the previous studies. For the 2500 year return period, Power (2013) provides separate wave amplitudes for the six domains, which range from 7.3 to 9.4 m, whereas in the previous studies a single wave amplitude of 8 m was used.

A ‘Level 2’ rule-based methodology was used to develop the tsunami evacuation zones. The methodology uses GIS-calculated attenuation rules developed for use in open coast, shallow harbour, and river situations. The differences between the extent of the previous and current evacuation zones developed for the Orange Zone are the result of the better elevation data now available. The differences between the extent of the previous and current evacuation zones developed for the Yellow Zone are the result of a combination of the different wave amplitudes used and the better elevation data now available.

The results indicate that many coastal communities fall inside the evacuation zones (including Waikawa Beach, Hokio Beach, Waitarere, Foxton Beach, Himitangi Beach, Tangimoana, Scotts Ferry, Koitiata, and parts of Wanganui and Castlecliff).

Two evacuation zones are provided in the deliverables, the Orange and Yellow zones. The edges of evacuation zones derived using the regional DEM do not match exactly with those developed from LiDAR due to differences in accuracies of the elevation models used, and Horizons Regional Council should use local knowledge to join the zones in a way that best matches the real local topography.

Horizons Regional Council should also create a Red evacuation zone which covers the area between 2 m above high tide and the open water. Instructions on how to create this zone are provided. Advice to water craft for actions in the open water are in development with MCDEM as part of the revision of MCDEM (2008), which is due for release around October 2015.

The Red Zone is to be evacuated in response to a 0.2–1m threat level warning, defined as a 'Marine and Beach Threat (including harbours, estuaries and small boats)' (MCDEM 2014).

The Orange Zone was developed to match a 3–5m threat level warning, defined as a 'Moderate Marine and Land threat'. This area is to be evacuated in response to a 1-3 m or 3-5 m threat level warning.

The Yellow Zone matches the 'maximum credible tsunami wave amplitude from all sources' and is designed primarily for use as a self-evacuation zone in the event of a strongly felt earthquake (one that it is hard to stand up in) or a long duration earthquake (one that lasts for longer than one minute). The Yellow Zone may also be used for official evacuations in the event of a tsunami forecast that anticipates a tsunami with amplitude of greater than 5 metres at the shore (i.e. threat levels higher than 3-5 m).

The resulting tsunami evacuation zones can be used to create tsunami evacuation maps as described by MCDEM (2008). A revision of that guideline is currently underway and a draft of the revision will be supplied to all CDEM Groups. The zones can also be used by Horizons for official warnings and evacuation planning and will better inform communities of the hazards they are threatened with and how to respond through individual community response plans.

1.0 INTRODUCTION

This project was developed in response to a request from Ian Lowe, Emergency Manager, of Horizons Regional Council. This report and the accompanying GIS dataset have been prepared with consideration of details supplied by Horizons.

1.1 BACKGROUND

The Manawatu-Wanganui portion of the Horizons Region comprises approximately 120 km of coastline. The largest population centres are Levin and Wanganui. Other smaller settlements occur around the coastline, and include Waikawa Beach, Hokio Beach, Waitarere, Foxton and Foxton Beach, Himitangi Beach and Tangimoana.

Following the Boxing Day 2004 Indian Ocean tsunami a review of tsunami hazard and risk was undertaken by GNS Science for the Ministry of Civil Defence and Emergency Management (Berryman 2005, Webb 2005). At that time, inundation models were poorly tested and the results were presented as a best endeavour. Since that early work, GNS Science has refined its tsunami and inundation modelling capabilities and is routinely providing tsunami evacuation zone information to local authorities.

In 2008 Horizons commissioned GNS Science to develop tsunami evacuation zones and this work is detailed in Leonard et al. (2009). In 2011 an update was undertaken to make use of high resolution LiDAR-derived elevation models (Leonard and Lukovic 2011). Since those reports, significant advances have been made concerning the tsunami wave amplitudes considered likely for the 2500 year return period (Power 2013). In addition, on-going acquisition of LiDAR by Horizons and the local councils has resulted in most coastal population centres along the Manawatu-Wanganui coastline now being covered by high-resolution digital elevation models. This project has utilised this new information to develop updated tsunami evacuation zones for the Manawatu-Wanganui coastline using the ‘Level 2’ rule based methodology developed by GNS Science.

1.2 TSUNAMI BASICS

A tsunami is a natural phenomenon consisting of a series of waves generated when a large volume of water in the sea, or in a lake, is rapidly displaced. Tsunami are known for their capacity to violently inundate coastlines, causing devastating property damage, injuries, and loss of life. The principal sources of tsunami are:

- large submarine or coastal earthquakes (in which significant uplift or subsidence of the seafloor or coast occurs) – this is the main source of tsunami and the basis of the evacuation zones defined here;
- underwater landslides (which may be triggered by an earthquake, or volcanic activity);
- large landslides from coastal or lakeside cliffs;
- volcanic eruptions (e.g., underwater explosions or caldera collapse, pyroclastic flows and atmospheric pressure waves); and
- meteor (bolide) splashdown, or an atmospheric air-burst over the ocean.

In this report we use wave height to refer to the difference in elevation of a crest and the neighbouring trough. The term wave amplitude refers to the elevation of the crest above the background level (i.e. half that wave height). The wave length is defined as the distance between consecutive crests and the period as time taken for consecutive crests to pass a fixed point.

In a tsunami, the whole water column from the ocean or lake floor to its surface is affected (Figure 1), and tsunami can have periods of many minutes to tens of minutes. This is in stark contrast to wind waves which only disturb the surface of the water and typically have periods of seconds to tens of seconds.

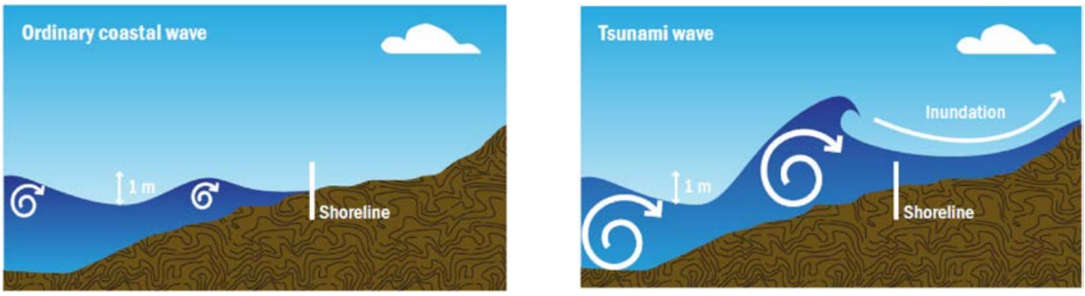

Figure 1 The difference between a coastal wind wave (left) and a tsunami wave (right).

When a tsunami runs onto land, the run-up height above sea level it reaches can be double the at-shore amplitude, because the long wave length of tsunami pushes water up hill (Figure 2). The largest run-ups typically occur where there are narrow valleys on a steep slope, leading to funnelling of the tsunami into a small area.

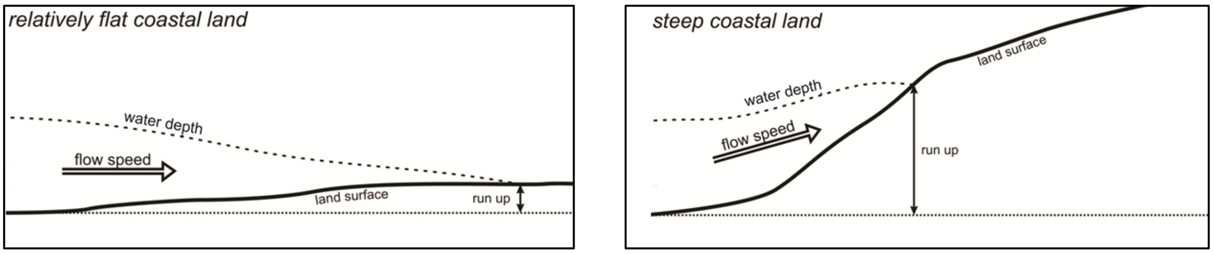

Figure 2 The difference in run-up height and inundation distance on a relatively flat coast land (left) versus steep coastal land (right), for a tsunami of the same wave amplitude at the coast.

1.3 PROJECT DESIGN AND OBJECTIVES

This project has been designed based on the information that is currently available from Horizons Regional Council and GNS Science Ltd. In summary, the project plan comprised the following tasks:

1. Assembling digital elevation models (DEMs) and other data needed to derive evacuation zones.
2. Determining domain boundaries and tsunami wave amplitudes relevant to the Manawatu-Wanganui coast.
3. Deriving the tsunami evacuation zones using a GIS-calculated attenuation rule.

The project objective was to update the previously developed Level-2 rule-based tsunami evacuation zones created for Horizons Regional Council in 2008 (Leonard et al. 2009) and 2011 (Leonard and Lukovic 2011). The evacuation zones provided as deliverables under this study should be modified by Horizons using local knowledge and then can be used in the creation of tsunami evacuation maps. Once developed, these evacuation zones and maps can be used for official warnings and evacuation planning and will better inform communities of the hazards they are threatened with and how to respond through individual community response plans.

The tsunami evacuation zones were prepared following the MCDEM Tsunami Evacuation Zones guideline (MCDEM 2008), and the method described by Leonard et al. (2009). This methodology has been calibrated with data from the 2004 Indian Ocean tsunami and validated using the 2011 Tohoku tsunami (Fraser and Power 2013).

1.4 METHODOLOGY

1.4.1 Assembling the DEMs

The earlier studies used a DEM developed by GNS Science from LINZ 20 m contour data and for consistency this was used as the basis for deriving the district wide tsunami evacuations zones in the current study. This regional DEM has a horizontal resolution of 10 m and a vertical accuracy that varies depending on how close a DEM cell is to one of the source contours. For DEM points between widely spaced contours (hundreds of meters apart) the point can be inaccurate by several metres; in some places near breaks in slope it can be inaccurate by more than 10 metres.

DEMs with a horizontal resolution of 1 m and derived from LiDAR were provided by Horizons for Wanganui, the Whangaehu, Turakina and Rangitikei river mouths and the area from south of Himatangi Beach to south of Waikawa Beach. These elevation models were used to derive additional sets of tsunami evacuation zones for the areas that these datasets cover. LiDAR is typically accurate to about 0.2 m vertically, varying depending on slope and land-cover – it is less accurate where buildings or trees mask the landscape.

Horizons also provided a shapefile defining the river channels which was used for modelling these areas. The LINZ 1:50 000 coastline was used to define the interface between the sea and land.

Inspection of the LiDAR-based DEMs indicated that in some places they do not quite reach the coastline. GNS Science extended the data to the coast, adjusted any data that lay beyond the coastline to zero elevation and adjusted any onshore elevations that were negative to zero elevation. Zero elevation in the DEMs was taken as mean sea level (MSL) in the deriving of the evacuations zones. For computational efficiency the elevation models were resampled to 10 m before being used to derive the evacuation zones.

It was also noted that the Manawatu DEM has a small area of no data near Lake Huritini, south of Waikawa Beach, and the evacuation zones in this area will need to be manually manipulated to address this issue.

It should be acknowledged that where the DEM is derived from 20 m contours significant errors can arise between the DEM heights and the true topography. GNS Science uses this data on the basis that it is the data which is currently available, and on the basis that the resulting evacuation zones are ‘better than nothing’ in the interim, until better topographic data becomes available.

1.4.2 Domain boundaries and tsunami wave amplitudes

Power (2013) divided the New Zealand coastline into approximately 20 km long domains, each with a set of maximum tsunami wave amplitudes for selected return periods. This project used six of the domains (Figure 3) defined by Power (2013).

Modelling of tsunami evacuation zones used a set of two tsunami wave amplitudes for each domain. The amplitude used for the Orange Zone is the same for each domain and was based on the 3-5 m Tsunami Threat Level (Table 1) as defined by MCDEM (2012). The second tsunami wave amplitude, used for the Yellow Zone, is the maximum wave amplitude presented by Power (2013) that equates to the 2500 year return period at the 84% level of confidence.

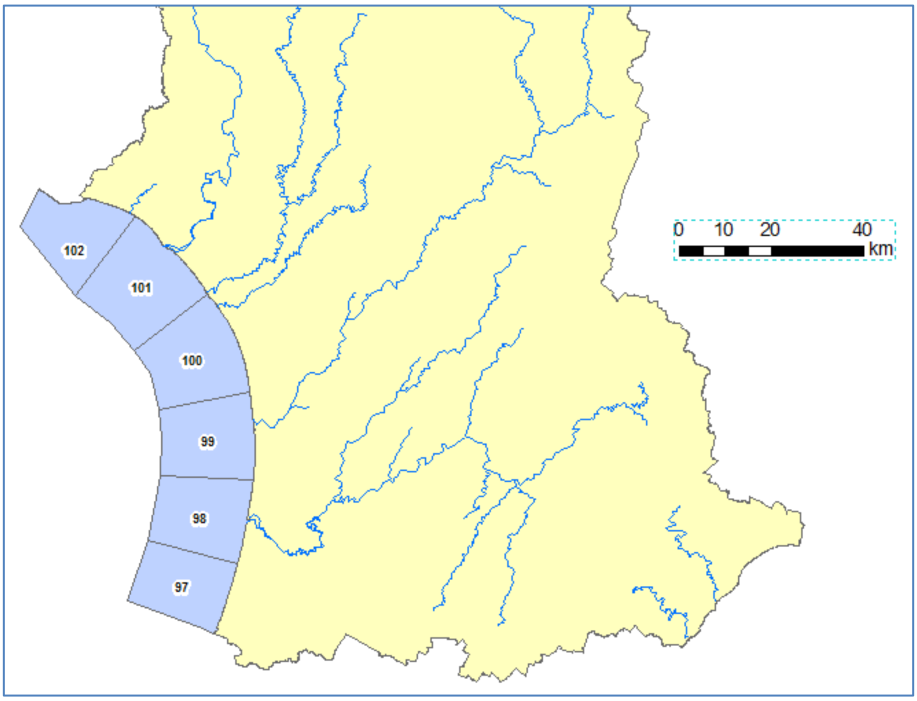

Figure 3 Coastal domains from Power (2013) with codes used in Table 2a and 2b.

Table 1 National tsunami warning threat levels from MCDEM (2014). Note these heights must be doubled and added to the high tide value to give the maximum credible run-up height at the shore.

Maximum expected amplitude (m) at shore	Threat definition
< 0.20	No threat
0.2 – 1	Threat to beach, harbours, estuaries and small boats
1 – 3	Minor land threat
3 – 5	Moderate land threat
5 – 8	High land threat
> 8	Severe land threat

The 2500 year (84% confidence) maximum tsunami amplitude is used as a probabilistic interpretation of the ‘maximum credible event’. It is the most conservative statistic presented in Power (2013) and for which the hazard model was developed. Still larger tsunami are possible at even longer return periods. It would be possible to create another evacuation zone for events with return periods longer than 2500 years, but MCDEM (2008) recommends developing no more than two to three evacuation zones as additional zones create additional complexity in the communication of warnings. Including events with return periods longer than 2500 years in the Yellow Zone would result in a large zone requiring many people to be evacuated every time a tsunami warning above 3-5 m was issued or a strong local earthquake was felt. Evacuating very large areas and populations can result in casualties due to congestion. A precise balancing of these factors is not currently possible, but the use of the 2500 year 84% confidence tsunami amplitude has been widely adopted as an appropriate input for the Yellow Zone in the ‘Level 2’ approach. Also note that the rules used to derive the onshore extent of the evacuation zones from the maximum tsunami amplitudes at the coast introduce additional conservatism (i.e. they are based on cautious assumptions), though this is not quantified.

The maximum wave amplitude at the shore presented by Power (2013) is derived from a probabilistic model that includes all known earthquake sources around the Pacific Ocean and close to New Zealand. There are many uncertainties regarding the potential for tsunami generation and the 84% level of confidence was used to be sure that these uncertainties were allowed for in the evacuation zone derivation. In simple terms, the 50% confidence results are a best estimate of the tsunami amplitudes, and the 84% confidence results show estimates that assume a pessimistic interpretation of the uncertainties; see Power (2013) for details.

The tsunami wave amplitudes from MCDEM (2008) and Power (2013) were doubled to allow for 'run-up'. This doubling of wave amplitude allows for run-up on land due to the nature of tsunami (see Figure 2). This value was then added to the high tide value (Mean High Water Springs (MHWS) adjusted to be relative to Mean Sea Level) to allow for the possibility of a tsunami arriving at high tide. The MHWS values were read from tide tables available from the LINZ website. The maximum high tide value within a domain (or the closest adjacent domain when a value within the domain was not available) was used for that domain. Table 2a and Table 2b show how the 'water elevation at the coast' was derived for each coastal domain using inputs from the MCDEM (2014) threat level for the development of the Orange Zone and Power (2013) for development of the Yellow Zone.

Table 2a Orange Zone height derivation. The domains are depicted in Figure 3.

Coastal Domain Name	Domain Code (Power 2013)	Largest threat level included (from MCDEM 2008)	Doubled for run-up	High Tide	Water elevation at coast
Hokio Beach	97	3–5 m	10.0 m	1.1 m	11.1 m
Foxton Beach	98	3–5 m	10.0 m	1.1 m	11.1 m
Himatangi Beach	99	3–5 m	10.0 m	1.1 m	11.1 m
Koitiata	100	3–5 m	10.0 m	1.1 m	11.1 m
Wanganui	101	3–5 m	10.0 m	1.1 m	11.1 m
Waiinu Beach	102	3–5 m	10.0 m	1.1 m	11.1 m

Table 2b Yellow Zone height derivation. The domains are depicted in Figure 3.

Coastal Domain Name	Domain Code (Power 2013)	Largest threat level included (from Power 2013)	Doubled for run-up	High Tide	Water elevation at coast
Hokio Beach	97	9.4 m	18.8 m	1.1 m	19.9 m
Foxton Beach	98	8.5 m	17.0 m	1.1 m	18.1 m
Himatangi Beach	99	7.9 m	15.8 m	1.1 m	16.9 m
Koitiata	100	7.5 m	15.0 m	1.1 m	16.1 m
Wanganui	101	7.3 m	14.6 m	1.1 m	15.7 m
Waiinu Beach	102	7.3 m	14.6 m	1.1 m	15.7 m

1.4.3 Modelling tsunami evacuation zones

The Level-2 rule-based evacuation zoning methodology was developed as a tool for developing evacuation zones in areas where data or cost constraints currently prevent the derivation of zones based on comprehensive hydrodynamic inundation modelling. In this sense, it is an interim approach used to provide evacuation advice in the understanding that it is desirable to refine the zones using a more sophisticated approach at a later time when the necessary requirements for doing so can be fulfilled.

Three types of attenuation rules were applied while deriving tsunami evacuation zones, depending on the landscape (open coast, harbour or river).

Open Coast

Evacuation zones for open coast were derived using the open coast rule. Under the open coast rule the ‘water height’ attenuates at a rate of 0.5% by distance (i.e. by 1 m for every 200 m travelled) inland from the coast.

Harbours

Tsunami waves passing from the open coast into shallow narrow-mouthed harbours, estuaries and lagoons (see Table 3) are derived using the harbour attenuation rule. This is an attenuation rule over water, prior to the wave reaching land. Under the harbour attenuation rule ‘water height’ remains constant for a distance of 1000 m from the mouth of the harbour after which it attenuates by half for every 16 km of travel until the height is less than 2 m above high tide. This rule applies only across the harbour. The open coast attenuation rule is applied across land adjacent to a harbour using the water height derived from the harbour rule at that location. The harbour attenuation rule is described in detail by Fraser and Power (2013).

No areas along the Manawatu-Wanganui coastline were treated as harbours.

Rivers

A river attenuation rule for tsunami waves propagating along water in a river was used for rivers greater than 10 m wide. Under the river rule the ‘water height’ attenuates at a rate 0.25% by distance (i.e. 1 m for every 400 m travelled) upriver. Overbank inundation across land adjacent to the river is derived using a rate of 2% by distance (i.e. 1 m for every 50 m travelled) over land normal to the river. The river attenuation rule is described in detail by Fraser and Power (2013).

The Wanganui, Whangaehu, Turakina, Rangitikei, Manawatu and Ohau rivers and Waikawa Stream were modelled using this rule.

2.0 RESULTS

GNS Science has produced six datasets of tsunami evacuation zones as feature classes in an ESRI geodatabase (HorizonsWestCoastRawTsunamiEvacuationZones.gdb). Other supporting datasets are also included. The tsunami evacuation zones are provided as:

- Raw_Zones_Regional
- Raw_Zones LiDAR_Manawatu
- Raw_Zones_LiDAR_Rangitikei
- Raw_Zones_LiDAR_Turakina
- Raw_Zones_LiDAR_Wanganui
- Raw_Zones_LiDAR_Whangaehu

These feature classes are termed ‘raw’ because they cannot be used as they are at present. The evacuation zone edges derived using the regional elevation data do not match exactly with those derived using the LiDAR due to differences in accuracies of the different elevation models. Local knowledge is needed to join the zones in a way that best matches the real local topography and Horizons or the local CDEM office should check and reconcile the differences. Any attempt to make this join remotely by the authors of this report would simply be a guess. Instructions on how to develop the ‘raw’ zones into the final tsunami evacuation zones and how to develop tsunami evacuation maps are given in Section 3.

Within each feature class are two features, the Orange Zone and Yellow Zone. These datasets form part of the deliverables and are provided with full metadata which is summarised in Table 3.

The availability of new elevation data has resulted in some minor changes to the extent of the evacuation zones. The most noticeable changes are the result of the increased wave amplitudes used for the Yellow Zone in the south of the study area. Many coastal communities fall inside the evacuation zones (including Waikawa Beach, Hokio Beach, Waitarere, Foxton Beach, Himitangi Beach, Tangimoana, Scotts Ferry, Koitiata, and parts of Wanganui and Castlecliff) and it would be prudent to update evacuation plans for these settlements.

3.0 DEVELOPMENT OF TSUNAMI EVACUATION ZONES AND MAPS

GNS Science has delivered raw tsunami evacuation zones that can be used by Horizons to develop Orange and Yellow evacuation zones. Before these can be used to create Tsunami Evacuation Maps, Horizons must merge the ‘raw’ zones developed using the different elevation data and should also develop a Red Zone. Advice on how to achieve these goals is provided below.

3.1 EVACUATION ZONES DEFINITION

The Red Zone

The Red Zone is intended as a shore-area exclusion zone that can be designated off-limits in the event of any expected tsunami. The Red Zone represents the highest risk zone and is the first place people should evacuate from in any sort of tsunami warning. People could expect ‘activation’ of this zone several times during their life.

The Red Zone is to be evacuated in response to the 0.2–1 m threat level warning.

The Orange Zone

The Orange Zone is intended to be the area evacuated in most if not all distant- and regional-source tsunami official warnings (i.e., warnings that extend beyond the Red Zone, for tsunami from sources more than one hour of travel time away from the mapped location).

The Orange Zone developed for Horizons matches the 3–5m threat level warning and is to be evacuated in the event of either the 1–3m, or 3–5m threat level warning being issued.

The Orange Zone encompasses the Red Zone and care should be taken when maps show these layers. In a situation that requires Orange Zone evacuation it is preferable to say ‘**Evacuate Orange and Red Zones**’, rather than ‘Evacuate the Orange Zone’ in order to avoid ambiguity.

The Yellow Zone

The Yellow Zone covers the all maximum credible tsunami, including the highest impact events. People should evacuate this zone in natural or informal warnings from a local source event.

The Yellow Zone takes into account the worst cases from both modelling and known geological deposits and has been designed to encompass the area inundated by the tsunami with a 2500 year return period at the 84% confidence level (Power 2013).

The Yellow Zone is designed primarily for use as a **self-evacuation zone** in the event of a strongly felt earthquake (one in which it is hard to stand up) or a long duration earthquake (one that lasts for longer than one minute). The earthquake does not need to be both long and strong; in many cases it will be one or the other and making this clearly understood by the public is an education challenge. These earthquakes usually have a local source and if they generate a tsunami it will have a quite short arrival time for which immediate self-evacuation is necessary. The Yellow Zone should also be evacuated in an official warning for the ‘larger than 3–5 m threat level’ or, in the case of a natural or informal warning, where the potential wave height is unknown.

While the Yellow Zone encompasses the Orange and Red zones, care should be taken when maps show these layers. In a situation that requires Yellow Zone evacuation it is preferable to say '**Evacuate All Zones**', rather than 'Evacuate the Yellow Zone' in order to avoid ambiguity.

3.2 DEVELOPING THE RED ZONE

Horizons must develop the Red Zone. The draft revision of MCDEM (2008) makes recommendations for developing the Red Zone and these are summarised here. The revision is planned to be finalised in September 2015 and it is recommended that Horizons consult the guidelines to ensure that these have remained unchanged before developing the Red Zone.

When developing the Red Zone it is best to think in terms of the elevation data available at a location:

a) In areas with high resolution data (e.g. LiDAR) the ideal method would be to use the 2 m above high tide contour, but extended to make sure it covers the beach and rocky foreshore in any locations where these are not encompassed by the 2 m above high tide contour.

b) In areas where the LINZ topographic data is used, the beach and foreshore is generally expected to approximate 2 m above high tide so the beach and rocky foreshore area should simply be coloured red. Local emergency managers should verify the red zone and move it inland in any areas where they feel the beach/foreshore polygon area on topographic maps is unusually close to high tide. In addition:

    1. The 1:50,000 scale beach/rocks/sand/mud/lagoon/swamp/mangroves /estuary polygons can be used to define the Red Zone.

    2. Tidal parts of rivers and estuaries should be included in the Red Zone, along with the above same polygon classes where they border rivers and estuaries. Local knowledge may be used to buffer areas alongside rivers where these are estimated to be less than 2m above high tide level. In the absence of local information, a buffer of the tidal part of rivers can be used that extends 100m perpendicular to the river at the coast, tapers to 50m wide at 400m inland, and to no buffer at 800m inland

The Red Zone needs to be wide enough to be clearly seen along the whole coast at all viewing scales.

NOTE: The high tide level used in the development of the Yellow and Orange zones was Mean High Water Springs (MHWS) adjusted to be relative to Mean Sea Level and it is expected that the Red Zone be developed in the same manner. Care should be taken when using MHWS as the values given on charts and in tables are usually relative to the nautical chart datum (the lowest astronomical tide) rather than Mean Sea Level. In general, all elevation data used for developing any of the zones should be measured from the same vertical datum and it is recommended to use MSL when defining evacuation zones.

3.3 MERGING OF EVACUATION ZONES

There are noticeable differences in the location of the zone boundaries derived using the regional elevation data and the LiDAR data due to differences in accuracies of the different elevation models. Local knowledge is needed to join the zones in the most logical way.

In areas where there is LiDAR coverage, the zones created using this data should take precedence over the zones created using the regional elevation data. In Figure 4 the Yellow Zone extent derived from the LiDAR data is shown in blue and the extent derived from the regional elevation data is shown in red. The background shade model is derived from the LiDAR data. Note that the evacuation zone extent defined using the LiDAR (blue) extends further inland (right) than that defined using the regional elevation data (red) because the regional elevation model is poorly controlled in these relatively flat areas. In other areas the evacuation zone extent defined using the regional elevation data may extend beyond the inland extent defined using the LiDAR.

The zone edge derived from LiDAR can be very detailed and simplification is recommended, such as removal of the small “islands” and intricate detail.

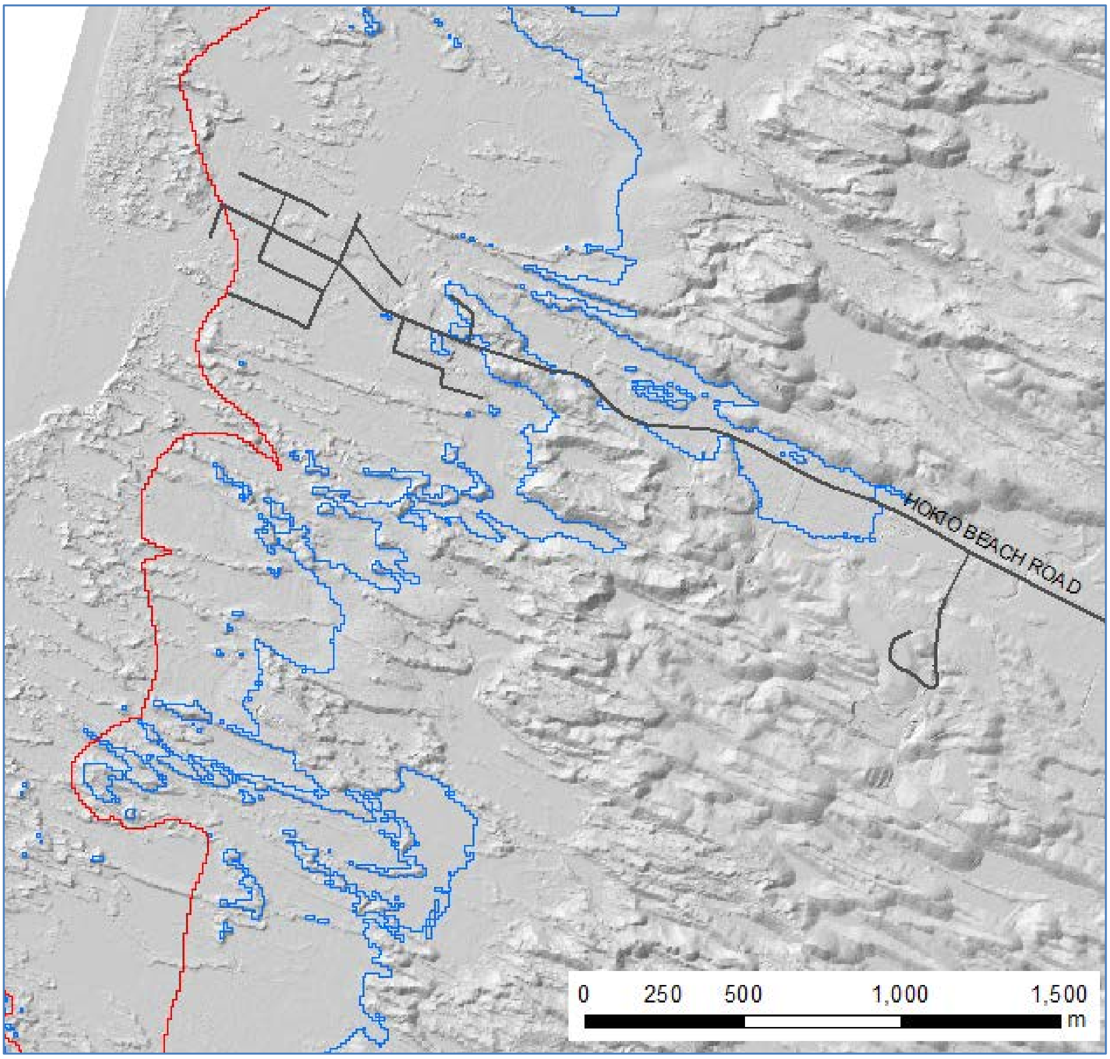

Figure 4 Example of the differences between the Yellow Zone extent for the Hokio Beach area using the regional elevation (red line) and LiDAR (blue line) data. The coastline is towards the left and the difference in the position of the two zone extents is as much as 2000 m as measured along Hokio Beach Road.

Care should be taken at the edge of the LiDAR coverage as the zones will terminate at the extent of the data and the zone from the regional dataset should be used if it extends further inland. If it does not extend further inland it may be necessary to manually adjust the evacuation zone defined by regional data to fit the more detailed evacuation zones defined by LiDAR. In Figure 5 the shade models derived from the LiDAR data are shown in grey and the shade model derived from the regional elevation data is in brown. The Yellow Zone boundary derived from the LiDAR data (shown in blue) is truncated by the extent of the LiDAR data and the zone derived from the regional elevation data (shown in red) should be used as a guide to join the two areas.

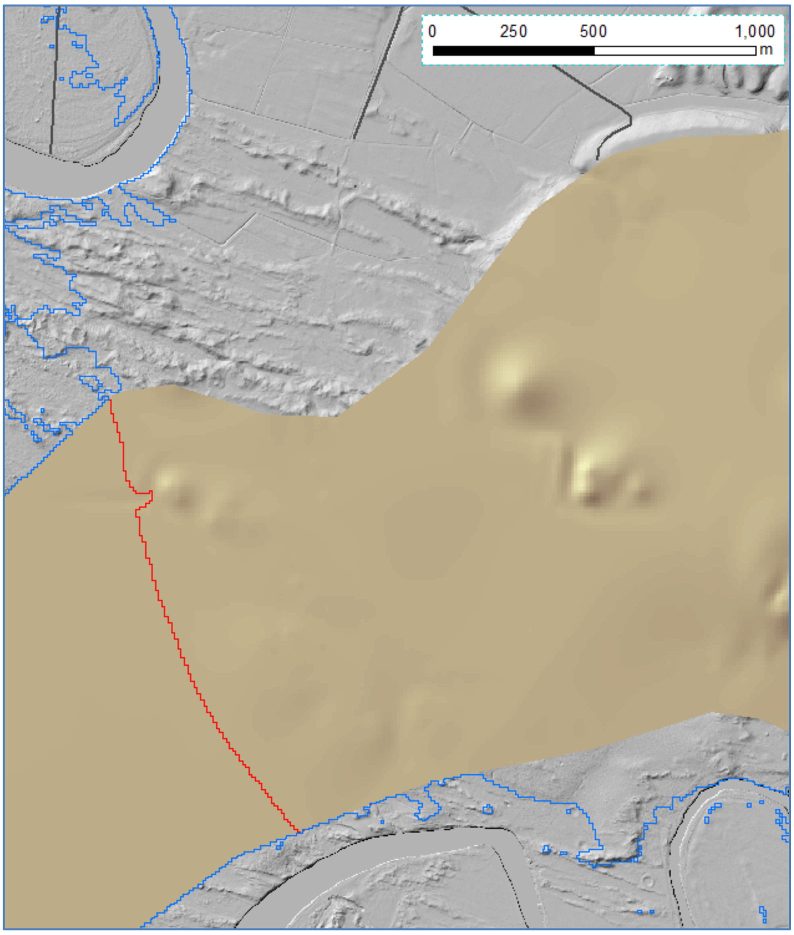

Figure 5 Example of an area where the Yellow Zone derived using the LiDAR (blue line) is truncated by the data extent. The upper grey shade model is derived from the Whangaehu LiDAR data. The lower grey shade model is derived from the Turakina LiDAR data. The intervening brown area is that derived from the regional DEM. The coast is to the left. Note the truncation of the blue evacuation zones where the grey shade models meet the regional model and how the evacuation zone derived from the regional model does not extend as far inland as the adjacent LiDAR-derived evacuation zones. In this case, the lower part of the red line should be manually edited to match the inland extend of the zone defined by LiDAR on the lower shade model.

GNS Science is available to assist with advice on how to interpret and modify the 'raw' evacuation zones if needed.

3.4 OTHER CONSIDERATIONS

In modelling the rivers it was noted that most river channels are meandering and change position from time to time. Modelling of the evacuation zones used the river channel position as defined by the LiDAR data and its position might have changed since the data was collected. Under the river rule the 'water height' attenuates at a rate of 1 m for every 400 m travelled upriver. Overbank inundation across land adjacent to the river is derived using a rate of 1 m for every 50 m travelled over land normal to the river. A consequence of this is that the evacuation zone extent is highly influenced by the river channel position and any change in the river channel position will make the evacuation zone extent incorrect. It is recommended that in these areas the zone be extended to encompass the entire width of the adjacent low lying area that could be the location of future river channels (Figure 6).

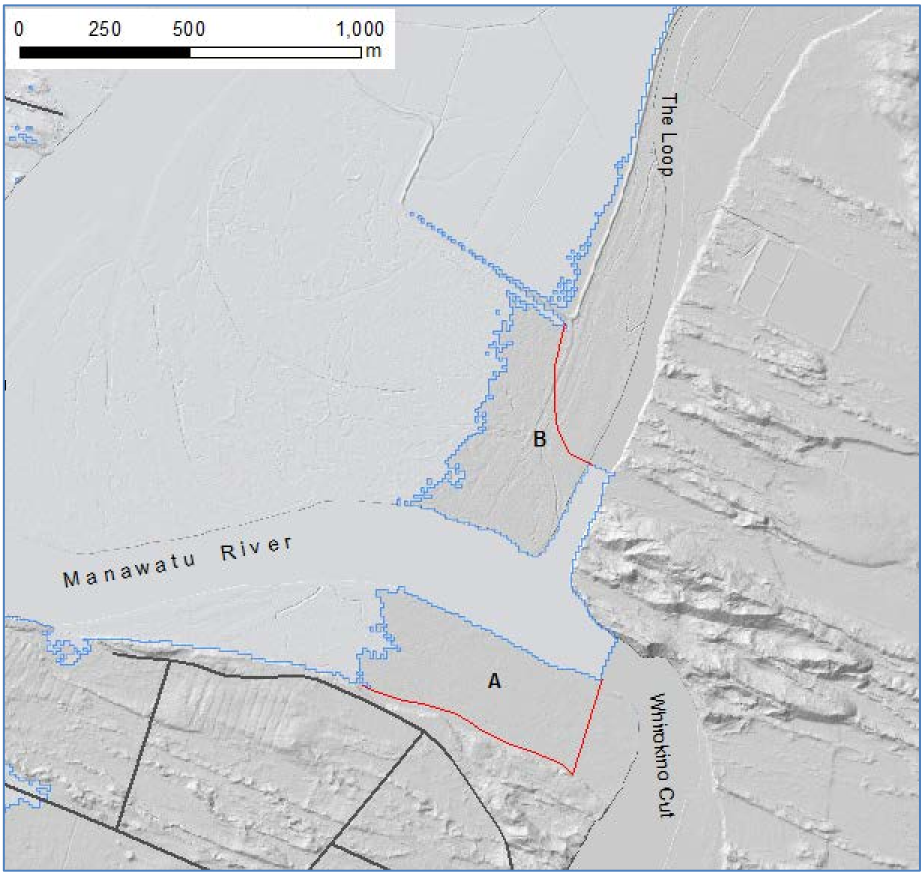

Figure 6 Example of an area where the evacuation zone derived using the LiDAR (blue line) is influenced by the position of the river channel. The area shown is the west side of the Whirokino Cut on the Manawatu River. The low lying areas adjacent to the current river channel (marked A and B) are potential future river positions and would then be inside the evacuation zone. In these and similar areas it is recommended the evacuation zone be manually widened (as shown in red) to allow for this possibility.

The Manawatu DEM has a small area of no data near Lake Huritini, south of Waikawa Beach. This has caused the evacuation zone to be truncated and manual editing is needed to correct this issue.

3.5 CONSTRUCTION OF TSUNAMI EVACUATION MAPS

The Red Zone to be developed by Horizons together with the Orange and Yellow zones developed from the interim evacuation zones supplied by GNS Science can be used to develop evacuation maps as described by MCDEM (2008). The zone layers should be added to a map and ordered so that the Red Zone is on top, the Orange Zone is beneath the Red Zone and the Yellow Zone is at the bottom as shown in Figure 7.

Evacuation routes and safe locations can also be depicted on the maps (see Figure 7) and GNS Science is available to assist with symbology and advice, if needed.

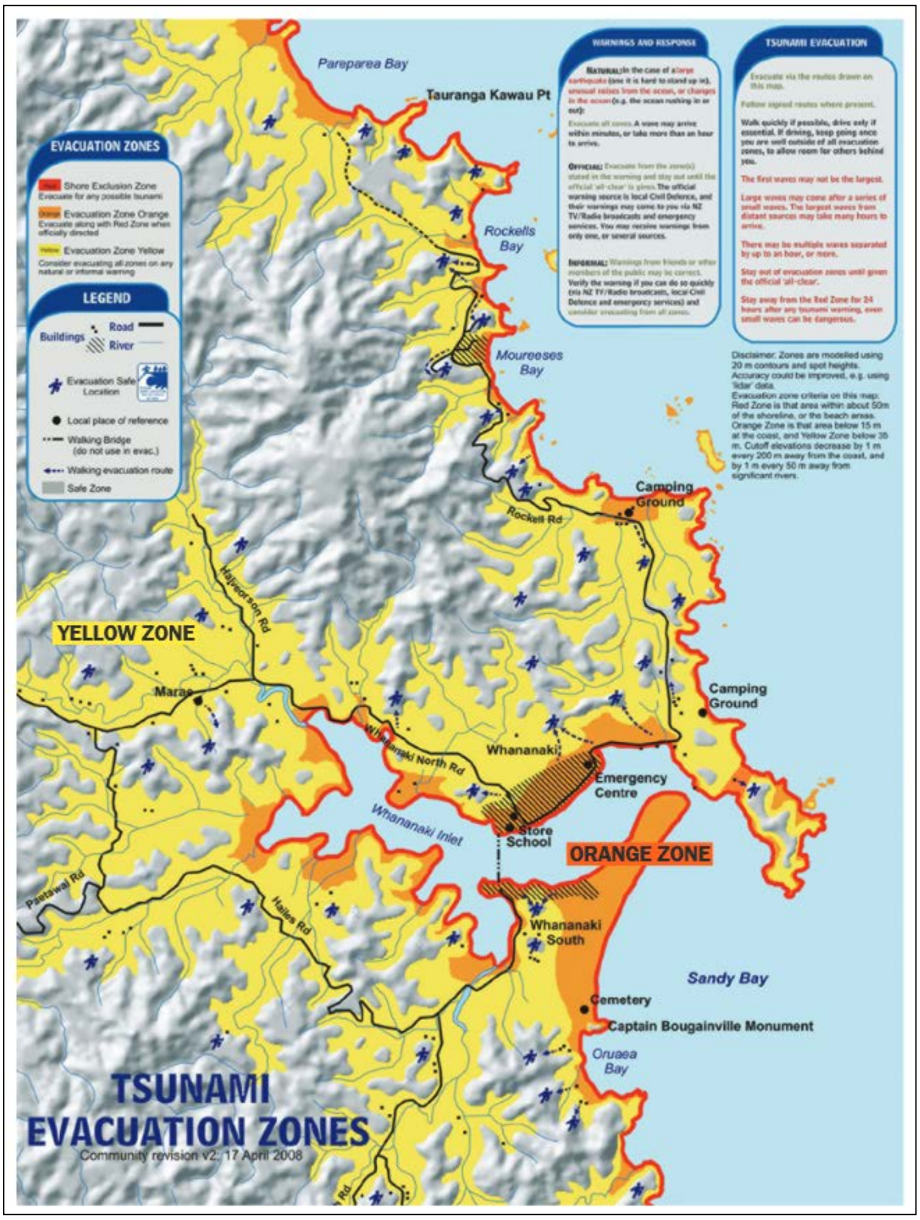

Figure 7 Example of a tsunami evacuation map showing evacuation zones, evacuation routes and safe locations and appropriate explanations.

4.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

An updated GIS dataset of raw tsunami evacuation zones for Horizons Regional Council has been prepared. The tsunami evacuation zones indicate that a number of communities are at risk from even moderate sized tsunami.

Raw evacuation zones were developed at a regional level, for the whole coastline, using the low resolution regional elevation model. Zones were also created for all areas where more accurate and detailed elevation data are available. Horizons should use local knowledge and the guidance provided by GNS Science to merge the tsunami evacuation zones derived from the two sources of elevation data used in this study.

Horizons should also develop updated tsunami evacuation maps following the guidelines presented by MCDEM (2008, and the revision due in September 2015) and, after community consultation, define safe evacuation routes and destinations and install appropriate signage. GNS Science is available to assist in development of definitions for use on maps and other public materials, provide advice on how the zones can also be used for official warnings and evacuation planning and how they could be incorporated in individual community response plans, if required.

During preparation of the proposal for this work it was noted that Horizons is planning on flying LiDAR along the coastal strip in 2015-16. Comparison of the evacuation zones developed from low resolution and high resolution elevation data near Hokio Beach show differences in their inland extent of almost 2 km. It is recommended that the width of the strip of new LiDAR be compared to the evacuation zones and the location of population centres and that consideration be given to extending the coverage, if feasible, to allow the tsunami evacuation zones be more accurately assessed in areas of significant population (e.g., Himitangi Beach).

5.0 DELIVERABLES (ATTACHED CD)

The study undertaken by GNS Science has produced three sets of tsunami evacuation zones as feature classes in an ESRI geodatabase:

- Raw_Zones_Regional
- Raw_Zones LiDAR_Manawatu
- Raw_Zones_LiDAR_Rangitikei
- Raw_Zones_LiDAR_Turakina
- Raw_Zones_LiDAR_Wanganui
- Raw_Zones_LiDAR_Whangaehu

These feature classes are termed 'raw' because they cannot be used as they are at present. Instructions on how to develop the 'raw' zones into the final tsunami evacuation zones and how to develop tsunami evacuation maps are given in Section 3.

The supporting datasets included in the geodatabase are:

- CoastalDomains (domains used in this study)
- Rivers (inputs used to define areas treated as rivers)
- Coastline (coastline used in this study)
- shade_lidar_manawatu (shade model developed from LiDAR of the area from south of Himitangi to south of the Waikawa Stream)
- shade_lidar_rangitikei (shade model developed from LiDAR of Rangitikei valley)
- shade_lidar_turakina (shade model developed from LiDAR of Turakina valley)
- shade_lidar_wanganui (shade model developed from LiDAR of Wanganui area)
- shade_lidar_whangaehu (shade model developed from LiDAR of Whangaehu valley)
- shade_regional (shade model developed from DEM of the region)

Table 3 Metadata for the layers within the GIS dataset delivered accompanying this report.

Database	The results and inputs used in development of Interim Tsunami Evacuation Zones for the Horizons Regional Council. The zones were defined using a conservative estimate of the area possibly inundated using a GIS method based on the attenuation relationship between water height at the coast, distance from the coast and elevation, and which applies different attenuation rules for land, harbours and rivers.
Raw_Zones_Regional	Raw Tsunami Evacuation Zones (regional zones) for the Manawatu-Wanganui coast created using a region-wide DEM derived from LINZ topographic data. The zones were derived using a GIS method implementing attenuation relationships for land, harbours and rivers. The 10 m resolution DEM is based on LINZ Topo50 topographic 20 m contours and spot heights and was modified by setting sea areas and negative DEM elevations to zero. The accuracy of the zones is closely related to the accuracy of the DEM and other features (coastline, harbours and rivers) used.
Raw_Zones_LiDAR_Manawatu	Raw Tsunami Evacuation Zones for the area south of Himitangi to south of the Waikawa Stream based on a LiDAR derived DEM supplied by Horizons. The zones were derived using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was supplied at 1 m resolution and resampled to 10 m, and offshore areas defined using the LINZ coastline. Negative elevations in the DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and other features (coastline and rivers) used, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
Raw_Zones_LiDAR_Rangitikei	Raw Tsunami Evacuation Zones for the Rangitikei River valley based on a LiDAR derived DEM supplied by Horizons. The zones were derived using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was supplied at 1 m resolution and resampled to 10 m, and offshore areas defined using the LINZ coastline. Negative elevations in the DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and other features (coastline and rivers) used, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
Raw_Zones_LiDAR_Turakina	Raw Tsunami Evacuation Zones for the Turakina River valley based on a LiDAR derived DEM supplied by Horizons. The zones were derived using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was supplied at 1 m resolution and resampled to 10 m, and offshore areas defined using the LINZ coastline. Negative elevations in the DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and other features (coastline and rivers) used, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.

Raw_Zones_LiDAR_Wanganui	Raw Tsunami Evacuation Zones for Wanganui based on a LiDAR derived DEM supplied by Horizons. The zones were derived using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was supplied at 1 m resolution and resampled to 10 m, and offshore areas defined using the LINZ coastline. Negative elevations in the DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and other features (coastline and rivers) used, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
Raw_Zones_LiDAR_Whangaehu	Raw Tsunami Evacuation Zones for the area south of Whangaehu River valley based on a LiDAR derived DEM supplied by Horizons. The zones were derived using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was supplied at 1 m resolution and resampled to 10 m, and offshore areas defined using the LINZ coastline. Negative elevations in the DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and other features (coastline and rivers) used, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
CoastalDomains	Approximately 20 km wide coastal domains for which tsunami wave heights were determined to match the maximum credible tsunami (one with a 2500 year return period) at the 84% confidence level (Power 2013).
Rivers	River layer supplied by Horizons and used for deriving tsunami inundation.
Coastline	Coastline derived from LINZ 1:50 000 topo database.
shade_regional	Hill shade model covering the areas prone to inundation in the Horizons Region. The model was derived from LINZ Topo50 topographic 20 m contours and spot heights. The 10 m resolution DEM was modified by setting sea areas and negative DEM elevations to zero before the shade model was created.
shade_lidar_manawatu	Hill shade model derived from Manawatu LiDAR DEM supplied by Horizons at 1 m resolution.
shade_lidar_rangitikei	Hill shade model derived from Rangitikei LiDAR DEM supplied by Horizons at 1 m resolution.
shade_lidar_turakina	Hillshade model derived from Turakina LiDAR DEM supplied by Horizons at 1 m resolution.
shade_lidar_wanganui	Hillshade model derived from Wanganui LiDAR DEM supplied by Horizons at 1 m resolution.
shade_lidar_whangaehu	Hillshade model derived from Whangaehu LiDAR DEM supplied by Horizons at 1 m resolution.

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