Tsunami evacuation zone boundary mapping: West Coast Region

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EXECUTIVE SUMMARY

This project was developed in response to a request from the West Coast Regional Council (WCRC) on behalf of the West Coast CDEM Group. This project is comprised of the following tasks:

1. Determination of elevation thresholds and domain boundaries relevant to the West Coast Region's coast.
2. Derivation of topographic datasets (interpolated 20m contour data) needed to model evacuation zones.
3. Preparation of an evacuation zone ArcGIS shapefile using a GIS-calculated attenuation rule, based on interpolated 20m-elevation contours and 1:50,000 scale topographic hydrography for the whole region, separate evacuation zone files for surveyed areas, and separate evacuation zone shapefiles based on Light Detection and Ranging (LiDAR) survey data where present.
4. Consideration of major harbours and significant rivers separately to the outer coast.

Zone layers are supplied within an ArcMap geodatabase, covering:

1. Zones_Regional – a full regional scale set of zones (see Table 5 below).
2. Raw zones based on each of the two LiDAR areas (Zones_LiDAR_Karamea and Zones LiDAR_Westport; see Table 5).
3. Modified zones in three areas where the LiDAR and/or RTK survey data could be used to improve (Section 4.3) the zone boundaries (Zones_Modified_Westport, Zones_Modified_Greymouth, Zones_Modified_Hokitika; Table 5).

The zone edges for 2 and 3 may not match exactly the zones in the regional model due to differences in accuracies of the elevation models. Local knowledge by WCRC will be needed to join the zones in the most logical way (Section 3.3).

The Orange and Yellow Zones in the GIS dataset supplied are to be used to develop evacuation maps as per MCDEM (2008). The zone layers should be used as follows, in this order of drawing from in-front to behind in GIS:

TOP-MOST:

- Red Zone derived as stated in Section 3.2

IN-FRONT:

- Zones_LiDAR_Karamea
- Zones_LiDAR_Westport – note the Zones_Modified_Westport layer mostly includes this layer, but in one small area the LiDAR zone goes further than the modified zone.
- Zones_Modified_Westport
- Zones_Modified_Greymouth
- Zones_Modified_Hokitika

BEHIND:

- Zones_Regional

1.0 OVERVIEW

This project was developed in response to a request from the West Coast Regional Council (WCRC) on behalf of the West Coast CDEM Group. WCRC were successful in obtaining 2013 Resilience Funding for this project from the Ministry of Civil Defence and Emergency Management (MCDEM). This report and the accompanying GIS dataset have been prepared with consideration of details supplied by WCRC and are based on the WCRC Resilience Fund application.

1.1 BACKGROUND

The West Coast region stretches some 600 km from north to south. Due to the geography of the region, the majority of the population lives along the coast within the major townships of Westport, Greymouth and Hokitika. These towns are adjacent to major river mouths. Smaller communities are also dispersed along the coast, which is at considerable risk from both earthquake and coastal hazards, including tsunami.

While much work has been undertaken to improve the resilience of West Coast communities to earthquakes, very little information is held on the threat from tsunami and the resulting inundation as a result of this hazard. Exercise Tangaroa in 2011 highlighted the inadequacies in information available to assist Controllers and CDEM staff to make robust decisions around which areas to evacuate people from. Furthermore, due to the layout of these towns and communities on and near both flat and variably elevated land, further information is needed to determine safe routes and destinations for evacuees.

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

The maximum tsunami heights shown in Section 1.4 are the maximum amplitudes of modelled tsunami waves before that wave runs onto land (Figure 2). When a tsunami runs onto land the run-up height above sea level it reaches can be up to 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.

1.3 OBJECTIVES AND METHODS

This project has been designed based on the information that is currently available for the West Coast. While there is limited LiDAR information available for Westport and Karamea, elsewhere Geographx DEM will be the primary topographic dataset. Additional GPS survey data were collected to improve the mapping of Greymouth, Hokitika and Carters Beach, in order to provide more robust topographic information in these densely populated areas (Section 2).

This project is comprised of the following tasks:

1. Determination of elevation thresholds and domain boundaries relevant to West Coast Region's coast.
2. Derivation of topographic datasets (interpolated 20m contour data) needed to model evacuation zones (Geographx DEM and LiDAR).
3. Preparation of an evacuation zone ArcGIS shapefile using a GIS-calculated attenuation rule, based on the Geographx DEM and 1:50k topographic hydrography for the whole region, separate evacuation zone shapefiles for surveyed areas, and separate evacuation zone shapefiles based on LiDAR data where present.
4. Consideration of major harbours and significant rivers separately to the outer coast.

The evacuation zones prepared here will better inform communities of the hazards they are threatened with and how to respond through using individual community response plans.

The zones were prepared following the MCDEM Tsunami Evacuation Zones guideline (MCDEM, 2008), and the method in Leonard et al. (2009). This has been further detailed for harbours and validated against the 2011 Tohoku tsunami in Fraser et al. (2013). Near-shore offshore maximum wave height 'amplitudes' from all tsunami sources around the Pacific Ocean (Power, 2013, Section 1.4) were then doubled to give the credible at shore on-shore maximum 'run-up' height above high tide. Doubling the offshore wave height to derive the evacuation zones allows for higher run-up on land due to the nature of tsunami (see Figure 2).

Harbours and Rivers modelled are given in Table 1 and Table 2 respectively, and shown in Appendix 1.

1.4 HAZARD DATA

This report uses the maximum wave heights presented in Power (2013), as shown for 20 km segments of the coast at 100, 500 and 2500 year return periods in Figure 3, Figure 4 and Figure 5, respectively. The maximum height at the shore for each piece of coast is from all of the models run from all known earthquake sources around the Pacific Ocean and close to New Zealand. The report also considered the many uncertainties regarding the potential for tsunami generation by faults around New Zealand and the Pacific Ocean. This is presented in terms of the 'level of confidence'. In simple terms, the 50% confidence results are a best estimate of the tsunami heights, and the 84% confidence results show estimates that assume a pessimistic interpretation of the uncertainties; see Power (2013) for details.

1.5 THREAT LEVELS

The following national warning threat levels (MCDEM, 2012) are referred to here:

Maximum expected amplitude at shore (offshore)*	Threat definition
<20cm	No threat
20cm–1m	Threat to beach, harbours, estuaries and small boats
1m–3m	Minor land threat
3m–5m	Moderate land threat
5m–8m	High land threat
8m+	Severe land threat

*must be doubled when drawing evacuation zones on shore as per explanation in Figure 2 – which has been done for this project.

2.0 SURVEYING

Real Time Kinematic (RTK) GPS methods were used to survey point elevation data of ground levels in the urban areas specified below, to better control flat land and especially the break in slope between flat land and nearby steep slopes – these features are often poorly resolved from 1:50,000 LINZ topographic contours. The data collected were used for the purpose of complementing and improving existing digital elevation data in the completion of the evacuation zones. All surveyed data were referenced to local Land Information NZ benchmarks.

Lines of spot heights were collected along public roads in sufficient density to give, as closely as possible, a general indication of the ground contour within the area surveyed. Particular focus was given to areas of rapidly changing grade and elevation.

Areas surveyed:

- Carters Beach, Westport – The residential area of Carters Beach, plus sufficient elevations within the area of Westport that is covered by existing LiDAR, to allow for consistency between the LiDAR and RTK data to be verified.
- Greymouth – Rapahoe to Camerons, but with most data collected in the central Greymouth urban area where most of the population resides.
- Hokitika – including consideration of outlying communities from Arahura to Ruatapu.

Data acquired are provided as x,y,z point data. Horizontal coordinates are in terms of the New Zealand Transverse Mercator projection, and heights are in terms of the Lyttelton Vertical Datum 1937. Where sufficient information is available, heights are provided in terms of local mean sea level (currently only Westport and Greymouth).

2.1 LIMITATIONS AND USEFULNESS OF SURVEY DATA

The use of survey data was an experimental technique and found to be of limited use to improving the accuracy of evacuation zones. Due to funded time restrictions data were primarily collected along roads. Where points collected along roads are not sufficient to adequately represent the ground contour and where publicly accessible open ground is available, an attempt was made to survey additional points in the areas between roads to improve coverage. Where those roads traversed steep coastal land perpendicular to the slope direction, the data were used to modify elevation models to better represent the topography (Section 3.6).

3.0 ZONES AND EVACUATION

The Red Zone is simply the topographic map coast-line and is to be usually evacuated in response to the 0.2–1m wave height threat level, called ‘threat to beach, harbours, estuaries and small boats’.

The Orange Zone matches the 3–5m wave height threat level, called a ‘moderate land threat’, arriving on or below high tide. In other words, if a moderate land threat level (or a minor land threat level) is determined, only the Red and Orange Zones need be evacuated – even if the wave arrived at high tide.

The Yellow Zone matches the ‘maximum credible tsunami wave height from all sources’ taking into account the worst cases from both modelling and known geological deposits. In an official warning larger than the moderate land threat level, or in the case of a natural or informal warning where the potential wave height is unknown, all zones including the Yellow Zone should be evacuated.

3.1 ORANGE AND YELLOW ZONE ELEVATIONS

Orange Zone

The Orange Zone is intended to be used for official warning and evacuation in the event of a distant source (more than 3 hours travel time from the West Coast) tsunami, for example, from South America, North America, Japan or the Solomon Islands (in terms of travel time the Kermadec-Tonga Trench is also a distant source for the West Coast). It has been constructed so that it should encompass the area that may be inundated by any plausible tsunami that is forecast to have a tsunami height of up to 5 metres (above background water level) at the shore.

In terms of the threat levels used in MCDEM tsunami forecasts, this zone is designed to be evacuated in the event of either the 1–3m, or 3–5m threat level being issued for the relevant section of coast.

Two factors affect the final at-coast elevation used for modelling the Orange Zone (Table 3, ‘Zone elevn. at shore’ column), which is calculated from a maximum 5m tsunami height (the maximum height for the ‘moderate land threat’ in national warnings):

- The zone was modelled above high tide because the timing of the largest waves’ arrival will be highly uncertain in any one event. The high tide used can be found in Appendix 1 and Table 3 as the ‘High Tide’ value for a given coastal section. This is added on to the doubled run-up value to give ‘Zone elevn. at shore’.
- A tsunami can potentially run up on steep coastal land to up to double the tsunami height at shore. So for any forecast tsunami height up to 5m, the corresponding Orange Zone is based on a maximum possible run-up of 10m above the high tide value.

Final elevations at the coast used for modelling this zone are given in Table 3 (‘Zone elevn. at shore’). For example, for the coastal section that encompasses Haast, the zone is at 11.1 m above mean tide (10 m + 1.1 m).

Yellow Zone

The Yellow Zone is designed primarily for use as a **self-evacuation zone** in the event of a strongly felt (or long duration) earthquake. It has been designed to encompass the area inundated by the 2500 year tsunami at the 84% confidence level (Power, 2013).

Final elevations at the coast for this zone are given in Table 4.

The Yellow Zone may also be used for official evacuations in the event of a tsunami forecast that anticipates a tsunami with height of greater than 5 metres (above background water level) at the shore (high and severe land threats).

While the Yellow Zone GIS layer encompasses the Orange and Red Zones, care should be taken when maps show these layers superimposed. 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 RED ZONE

This is simply the coastal foreshore and can be derived by WCRC's GIS staff from the topographic dataset, including the 'coastline' polyline and any coastal polygons for rocks, beach, mudflats, sand etc. that constitute the foreshore.

3.3 APPLICATION OF ZONES TO EVACUATION MAPPING

The Orange and Yellow Zones in the GIS dataset supplied are to be used to develop evacuation maps as per MCDEM (2008). The zone layers should be used as follows, in this order of drawing from in-front to behind in GIS:

TOP-MOST:

- Red Zone derived as stated in Section 3.2

IN-FRONT:

- Zones_LiDAR_Karamea
- Zones_LiDAR_Westport – note the Zones_Modified_Westport layer mostly includes this layer, but in one small area the LiDAR zone goes further than the modified zone.
- Zones_Modified_Westport
- Zones_Modified_Greymouth
- Zones_Modified_Hokitika

BEHIND:

- Zones_Regional

There will be some offset at the edges of the IN-FRONT layers' zones where they meet the BEHIND layer's zones – this is because of the difference in elevation model used to derive the zones. LiDAR-based zones are limited by the extent of the data and in some areas they would go further inland if elevation data which connects these areas with the sea was available for modelling. So it is important to show the regional model (based on 1:50 000 topo data) in the background when creating the final, combined evacuation zone.

It is up to the WCRC or local CDEM office to check this offset and reconcile it using local knowledge of the topography. Any attempt to make this join remotely by the team developing the zones would simply be a guess.

4.0 FURTHER DETAILS AND DELIVERABLES

4.1 TIDES

In determining warning zones the chosen wave height has been added to high tide. This is because it is not possible to state whether the largest tsunami waves will arrive on a particular tide. The elevation of high tide above mean-tide used for modelling can be found as the 'High Tide:' value for each coastal section in Appendix 1. The high tide value used here is Mean High Water Spring (MHWS).

4.2 HARBOURS AND RIVERS

Appendix 1 shows the rivers (blue lines, named in blue) and harbours (purple dots, named in purple) that were separately modelled. The five harbours are listed in Table 1, and the 70 rivers in Table 2. The names for the rivers have been documented visually from the Topo250 LINZ topographic map dataset. River modelling is detailed in Leonard et al. (2009), harbour modelling in Fraser et al. (2013).

4.3 ZONES 'MODIFIED' USING SURVEY DATA

'Modified' zones were created for the Westport, Greymouth and Hokitika areas, to better match the survey point data collected (Section 2.0). The modified input DEM was derived from 20 m contours and survey data and the modelled zones were also slightly manually altered in some areas based on the surveyed elevations. This was done in an attempt to improve the areas below 20 m elevation where inundation was underestimated when the regional DEM was used. The accuracy of 'modified' zones is closely related to the accuracy of the modified DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling, but 'modified' zones are considered to be an improvement over the regional zones and should supersede those in most areas.

This is acknowledged to have been a manual process with some judgement from the specialist having been required. The zones were always moved inland, so were made more conservative (safe) and are therefore considered to be an improvement in terms of the life-safety purpose of this project.

For Westport the LiDAR dataset was also used for deriving the 'modified' elevation model.

4.4 ELEVATION DATA AND LIDAR

For the region-wide Digital Elevation Model the Geographx DEM was used. It is based on 20 m topographic maps contours and improved by Shuttle Radar Topography Mission (SRTM) data. We derived new DEM datasets only in surveyed areas (based on 20 m contours, survey data and LiDAR if existing in that area). The accuracy of zones is closely related to the accuracy of the DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling.

LiDAR datasets were supplied by the CDEM Group and used for Karamea and Westport.

WCRC supplied their LiDAR coverage of the region. The LiDAR data grid for Westport was used as supplied.

In the dataset supplied for Karamea the first two tiles were modelled into integer grids while the rest was done as floating point grids. As a consequence there was a step in the resulting combined grid at the boundary between these two tiles and the remainder of the model. The difference at the boundary can be up to 0.5 m (from rounding error). In consultation with WCRC we recreated the grid using the LiDAR point cloud data (also provided). We used the Fledermaus software and the ‘Weighting moving average interpolation algorithm’. We cannot however guarantee that the resulting grid will be the same as the DEM supplied by WCRC in the areas which were correct.

The following extra notes in terms of WCRC actions needed on the LiDAR dataset before delivery were acknowledged by both parties:

> Erroneous elevation points need to be removed. If interpolation has been done in areas where data are missing make sure the interpolated grid values represent the real ground surface. In any areas where LiDAR does not exist and interpolation over the hole will produce an error (e.g., steep hills in the middle of flat land) grid values must be set as ‘null’. Large holes on low ground will cause a poor model result inland of the hole. All spatially connected LiDAR grids need to be merged into a single grid and only LiDAR grids connected to the coast can be used. Water bodies must have appropriate elevation assigned (i.e., not null). The LiDAR dataset perimeter must be clipped to the exact dataset. The datum also needs to be supplied. Everything offshore of the supplied coastline will be treated as ocean. Any onshore elevations that are supplied as negative values will be treated as having zero elevation.

WCRC provided height measurements taken through an area of significant recent erosion along the Hokitika foreshore area but these were deemed not usable or necessary for the modelling.

The initial LiDAR datasets were resampled to 8m resolution (to match the resolution of the regional model), and offshore areas defined using the LINZ Topo50 coastline. All negative elevations in the DEM were set to zero before the zone modelling was undertaken.

4.5 DELIVERABLES (ATTACHED CD)

Zone layers are supplied within an ArcMap geodatabase, covering:

1. Zones_Regional – a full regional scale set of zones (see Table 5 below).
2. Raw zones based on each of the two LiDAR areas (Zones_LiDAR_Karamea and Zones LiDAR_Westport; see Table 5).
3. Modified zones in three areas where the LiDAR and/or RTK survey data could be used to improve (Section 4.3) the zone boundaries (Zones_Modified_Westport, Zones_Modified_Greymouth, Zones_Modified_Hokitika; Table 5).

The zone edges for layer types 2 and 3 above may not match exactly the zones from the regional model (1 above) due to differences in accuracies of the elevation models. Local knowledge will be needed to join the zones in the most logical way by WCRC (Section 3.3).

Other key layers are also supplied (see Table 5 and the Metadata.xls file for a full list and descriptions), especially:

- A copy of the raw surveyed data as per Section 2.0 (SurveyPoints layer).
- A ‘notes’ layer giving points identifying areas where it was noted that the results from modelling are uncertain due to the quality or extent of the underlying DEMs. They were identified only in areas covered by LiDAR data or were the survey was undertaken. Not all areas where these issues occur have been identified.

4.6 PROJECTION

New Zealand Transverse Mercator (NZTM); to re-project these data to New Zealand Map Grid (NZMG) the transformation file New_Zealand_1949_To_NZGD_2000_3_NTv2 must be used.

5.0 ACKNOWLEDGEMENTS

We appreciate the constructive peer reviews of Kim Wright and Dougal Townsend that improved this report.

6.0 REFERENCES

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TABLES

Table 1 Names of features modelled as 'harbours'

Okarito Lagoon
Saltwater Lagoon
Okari Lagoon
Orowaiti Lagoon in Westport (not labelled due to space in Appendix 1)
Buller River port area

Table 2 Names of features modelled as 'rivers'

RVR_ID	Name	RVR_ID	Name
1	Heaphy River	36	Waitangitaona River
2	Kohainai River	37	Otatoki River
3	Oparara River	38	Okarito River
4	[name uncear]	39	Five Mile Lagoon
5	Karamea River	40	Waiho River
6	Granite Creek	41	Omoeroa River
7	Little Wanganui River	42	Waikukupa River
8	Glasseye Creek	43	Waihapi Creek
9	Corbyvale	44	Whelan Creek
10	Mokihinui River	45	Fox River
11	Ngakawau River	46	Cook River
12	Waimangaroa River	47	Ohinetamatea River
13	Orowaiti River	48	Karangarua River
14	Buller River	49	Manakaiaua River
15	Oraki River	50	Makawhaio River
16	Totara River	51	Mahitaki River
17	Waitakere River	52	Ohinemaka River
18	Fox River	53	Paringa River
19	Pororari River	54	Moeraki River
20	Punakaiki River	55	Whakapohai River
21	Ten Mile Creek	56	Ship Creek
22	Grey River	57	Waita River
23	New River	58	Haast River
24	Taramakau River	59	Turnbull River
25	Kumara	59	Okuru River
26	Waimea Creek	60	Waiatoto River
27	Arahura River	61	Arawhata River

RVR_ID	Name	RVR_ID	Name
28	Hokitika River	63	Stafford River
29	Totara River	64	Teer Creek
30	Mikonui River	65	Cascade River
31	Waitaha River	66	Hope River
32	Duffers Creek	67	Spoon River
33	Wanganui River	68	Gorge River
34	Poerua River	69	Ryans Creek
35	Whataroa River	70	Hacket River

Table 3 Orange Zone height derivation

Coastal Section Name	ZoneCode (Power, 2013)	Largest threat level included	Doubled for run-up	High Tide	Zone elevn. at shore
Charleston	231	3–5 m	10	1.45	11.45
Wanganui River	223	3–5 m	10	1.10	11.10
Gorge River	212	3–5 m	10	1.10	11.10
Otukoroiti Point	238	3–5 m	10	1.45	11.45
Wekakura Point	237	3–5 m	10	1.45	11.45
Caldervale	236	3–5 m	10	1.45	11.45
Kongahu	235	3–5 m	10	1.45	11.45
Mokihinui	234	3–5 m	10	1.45	11.45
Waimangaroa River	233	3–5 m	10	1.45	11.45
Westport	232	3–5 m	10	1.45	11.45
Punakaiki	230	3–5 m	10	1.40	11.40
Pakiroa Beach	229	3–5 m	10	1.40	11.40
Greymouth	228	3–5 m	10	1.40	11.40
Camerons	227	3–5 m	10	1.40	11.40
Hokitika	226	3–5 m	10	1.10	11.10
Mikonui River	225	3–5 m	10	1.10	11.10
Waitaha River	224	3–5 m	10	1.10	11.10
Okarito River	222	3–5 m	10	1.10	11.10
Waiho River	221	3–5 m	10	1.10	11.10
Gillespies Point/Kohaihai	220	3–5 m	10	1.10	11.10
Makawhio River (Jacobs River)	219	3–5 m	10	1.10	11.10
Paringa River	218	3–5 m	10	1.10	11.10
Waita River	217	3–5 m	10	1.10	11.10
Haast Beach	216	3–5 m	10	1.10	11.10
Jackson Bay/Okahu	215	3–5 m	10	1.10	11.10
Stafford Bay	214	3–5 m	10	1.10	11.10
Hope River	213	3–5 m	10	1.10	11.10

Table 4 Yellow Zone height derivation

Coastal Section Name	ZoneCode (Power, 2013)	Water Height	Doubled for run-up	High Tide	Zone elevn. at shore
Charleston	231	7.2	14.4	1.45	15.85
Wanganui River	223	7.2	14.4	1.10	15.50
Gorge River	212	7.0	14.0	1.10	15.10
Otukoroiti Point	238	5.7	11.4	1.45	12.85
Wekakura Point	237	6.0	12.0	1.45	13.45
Caldervale	236	6.2	12.4	1.45	13.85
Kongahu	235	6.8	13.6	1.45	15.05
Mokihinui	234	6.6	13.2	1.45	14.65
Waimangaroa River	233	8.1	16.2	1.45	17.65
Westport	232	8.8	17.6	1.45	19.05
Punakaiki	230	6.2	12.4	1.40	13.80
Pakiroa Beach	229	7.4	14.8	1.40	16.20
Greymouth	228	6.9	13.8	1.40	15.20
Camerons	227	6.8	13.6	1.40	15.00
Hokitika	226	6.8	13.6	1.10	14.70
Mikonui River	225	7.6	15.2	1.10	16.30
Waitaha River	224	10.1	20.2	1.10	21.30
Okarito River	222	8.2	16.4	1.10	17.50
Waiho River	221	7.1	14.2	1.10	15.30
Gillespies Point/Kohaihai	220	8.1	16.2	1.10	17.30
Makawhio River (Jacobs River)	219	9.3	18.6	1.10	19.70
Paringa River	218	6.5	13.0	1.10	14.10
Waita River	217	6.4	12.8	1.10	13.90
Haast Beach	216	9.2	18.4	1.10	19.50
Jackson Bay/Okahu	215	8.8	17.6	1.10	18.70
Stafford Bay	214	7.6	15.2	1.10	16.30
Hope River	213	6.8	13.6	1.10	14.70

Table 5 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 West Coast Regional Council. The zones were defined as a conservative estimate of the possible inundated area 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 rules for land, harbours and rivers.
Zones_Regional	Interim Tsunami Evacuation Zones (regional zones) for the West Coast based on a region-wide DEM derived from Geographx New Zealand DEM (version 2.1). Modelling done using a GIS method implementing attenuation relationships for land, harbours and rivers. The 8 m resolution DEM based on LINZ Topo50 topographic 20 m contours, spot heights and SRTM satellite data 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 topographic features (coastline, harbours and rivers) used for modelling. Because of the mismatch between the DEM and river location, the DEM was not used when modelling river inundation but the approximate fall of the river was estimated from the distance along the river from the coastline to the 20 m contour. The output river inundated areas were clipped with 20 m elevation contour which, in most cases, overestimates the inundated areas around rivers.
Zones_LiDAR_Karamea	Interim Tsunami Evacuation Zones for part of Karamea based on a LiDAR derived DEM supplied by WCRC. Modelling done using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was resampled to 8 m resolution, and offshore areas defined using the LINZ Topo50 coastline and negative elevations in DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
Zones_LiDAR_Westport	Interim Tsunami Evacuation Zones for part of Westport based on a LiDAR derived DEM supplied by WCRC. Modelling done using a GIS method implementing attenuation relationships for land, harbours and rivers. The DEM was resampled to 8 m resolution, and offshore areas defined using the LINZ Topo50 coastline and negative elevations in DEM were set to zero. The accuracy of the zones is closely related to the accuracy of the DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.

Zones_Modified_Westport	Interim Tsunami Evacuation Zones in Westport in the areas were the RTK GPS survey was undertaken. The model is based on a modified regional DEM and the modelled zones were also slightly altered in some areas based on the survey data. Modelling was done using a GIS method implementing attenuation relationships for land, harbours and rivers. The input DEM was developed from LINZ Topo50 data, RTK GPS survey points collected by GNS Science and the LiDAR DEM supplied by WCRC. This was done in an attempt to improve the areas below 20 m elevation where inundation was underestimated when the regional DEM was used. The accuracy of the zones is closely related to the accuracy of the DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
Zones_Modified_Greymouth	Interim Tsunami Evacuation Zones in Greymouth in the areas were the RTK GPS survey was undertaken. The model is based on a modified regional DEM and the modelled zones were also slightly altered in some areas based on the survey data. Modelling was done using a GIS method implementing attenuation relationships for land, harbours and rivers. The input DEM was developed from LINZ Topo50 data and RTK GPS survey points collected by GNS Science. This was done in an attempt to improve the areas below 20 m elevation where inundation was underestimated when the regional DEM was used. The accuracy of the zones is closely related to the accuracy of the DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
Zones_Modified_Hokitika	Interim Tsunami Evacuation Zones in Hokitika in the areas were the RTK GPS survey was undertaken. The model is based on a modified regional DEM and the modelled zones were also slightly altered in some areas based on the survey data. Modelling was done using a GIS method implementing attenuation relationships for land, harbours and rivers. The input DEM was developed from LINZ Topo50 data and RTK GPS survey points collected by GNS Science. This was done in an attempt to improve the areas below 20 m elevation where inundation was underestimated when the regional DEM was used. The accuracy of the zones is closely related to the accuracy of the DEM and LINZ Topo50 topographic features (coastline, harbours and rivers) used for modelling, but is considered to be better than the accuracy of the regional zones and should supersede those in most areas.
CoastZones	Approximately 20 km wide West Coast coastal zones for which tsunami wave heights were determined to match the 2500 year tsunami at the 84% confidence level (Power, 2013).
Harbour	Topographic features which were modelled as shallow harbours. It includes 4 lagoons from LINZ Topo50 NZ Mainland Lagoon Polygons dataset and Buller River port area clipped from LINZ Topo50 NZ Mainland River Polygons dataset.
RiverPoly	Topographic features from LINZ Topo50 NZ Mainland River Polygons dataset used to create river layer used for modelling tsunami inundation.
RiverLine	Topographic features from LINZ Topo50 NZ Mainland River Centrelines dataset used to create river layer used for modelling tsunami inundation.
Coastline	Coastline from LINZ Topo50 NZ Mainland Coastlines dataset.

SurveyPoints	Results of RTK GPS surveys carried out in Westport, Hokitika and Greymouth areas.
shade_reg	Hillshade model covering the areas prone to inundation in the West Coast Region. It was derived from Geographx New Zealand DEM (version 2.1) based on LINZ Topo50 topographic 20 m contours, spot heights and SRTM satellite data. The 8 m resolution DEM was modified by setting sea areas and negative DEM elevations to zero before the shade model was created.
shade_lidar_westport	Hillshade model derived from Westport LiDAR DEM supplied by WCRC. The original DEM was resampled to an 8 m resolution and modified by setting sea areas and negative DEM elevations to zero before the shade model was created.
shade_lidar_karamea	Hillshade model derived from Karamea LiDAR DEM supplied by WCRC. The original DEM was resampled to an 8 m resolution and modified by setting sea areas and negative DEM elevations to zero before the shade model was created.
Notes	Points identifying areas where it was noted that the results from modelling are uncertain due to the quality or extent of the underlying DEMs. They were identified only in areas covered by LiDAR data or where the survey was undertaken. Not all areas where these issues occur have been identified.

FIGURES

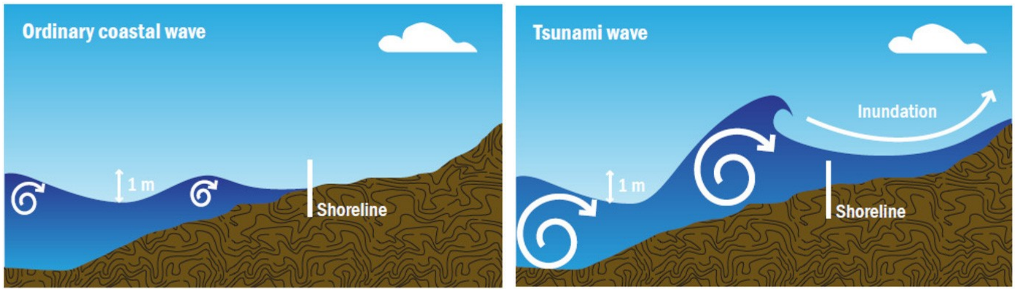


Figure 1 The difference between coastal wind wave and a tsunami wave.

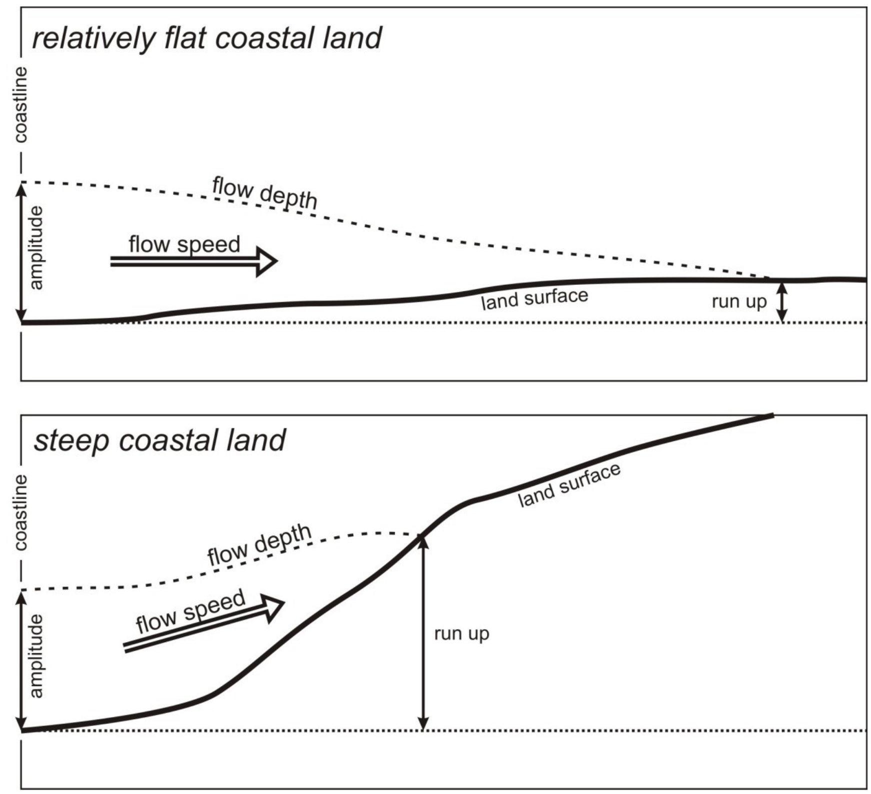
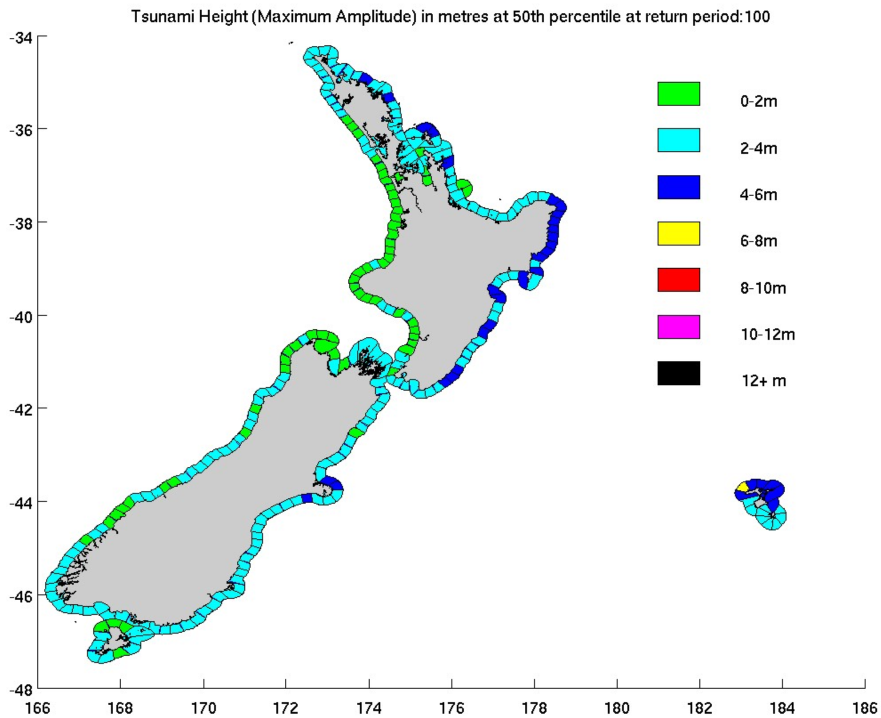


Figure 2 The difference in run-up height and inundation distance on relatively flat coast land versus steep coastal land, for a tsunami of the same wave amplitude at the coast.



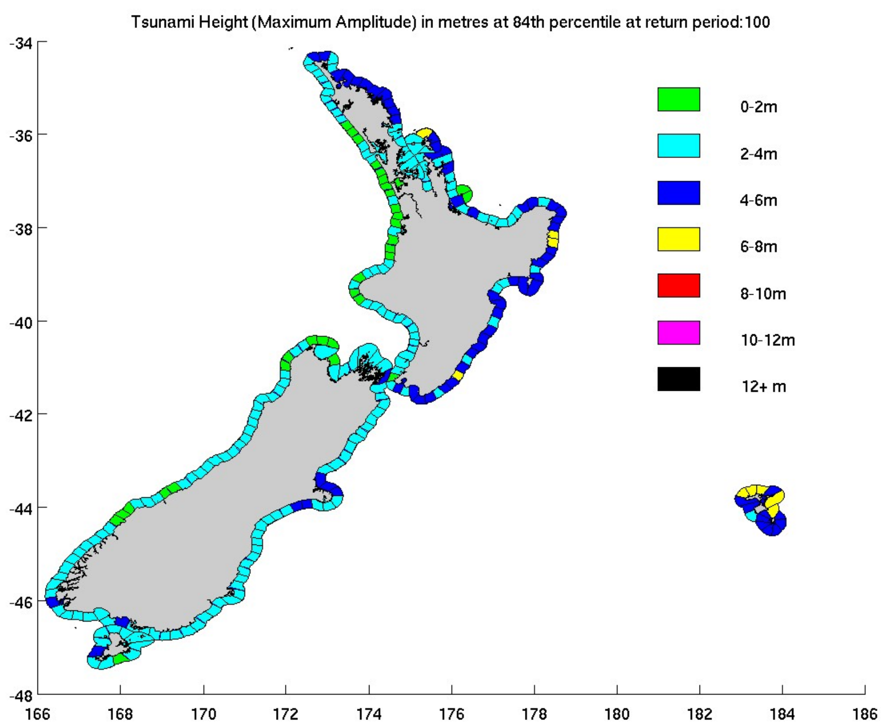


Figure 3 **(Power, 2013; their Figure 6.37)** Expected maximum tsunami height in metres at 100 year return period, shown at median (50th percentile) and 84th percentile of epistemic uncertainty.

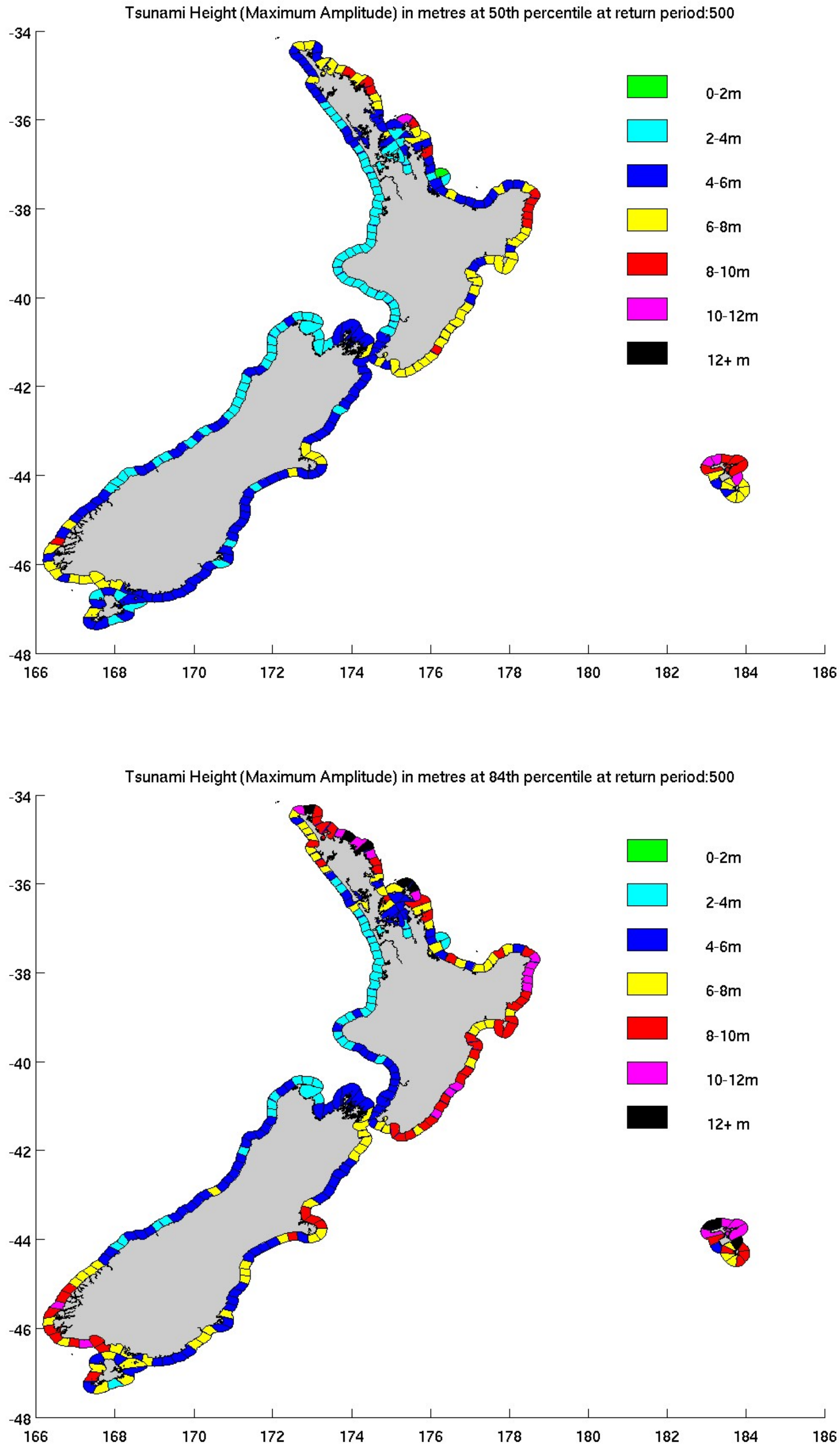
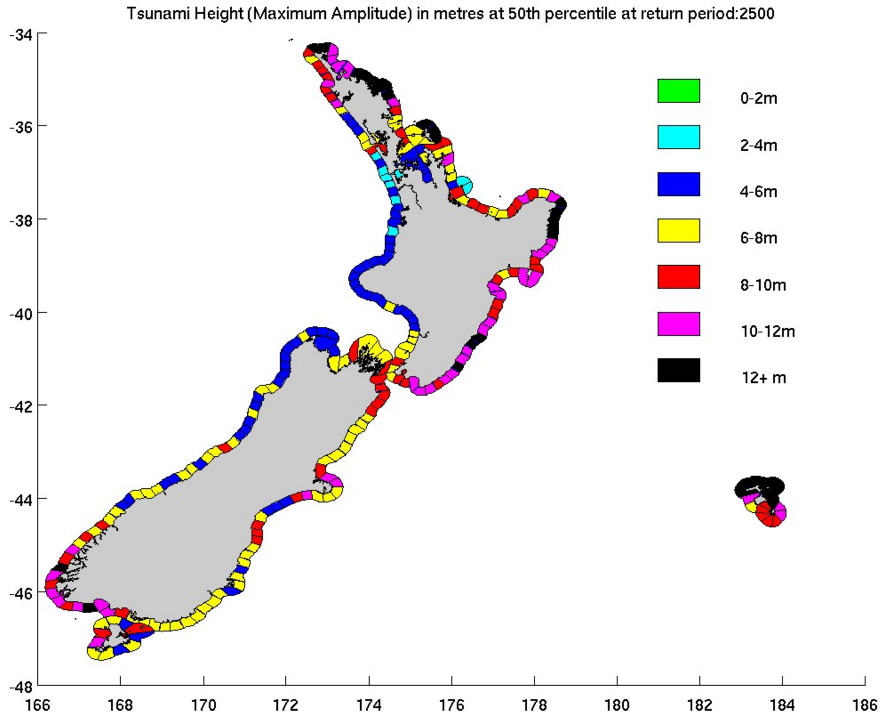


Figure 4 **(Power, 2013; their Figure 6.38)** Expected maximum tsunami height in metres at 500 year return period, shown at median (50th percentile) and 84th percentile of epistemic uncertainty.



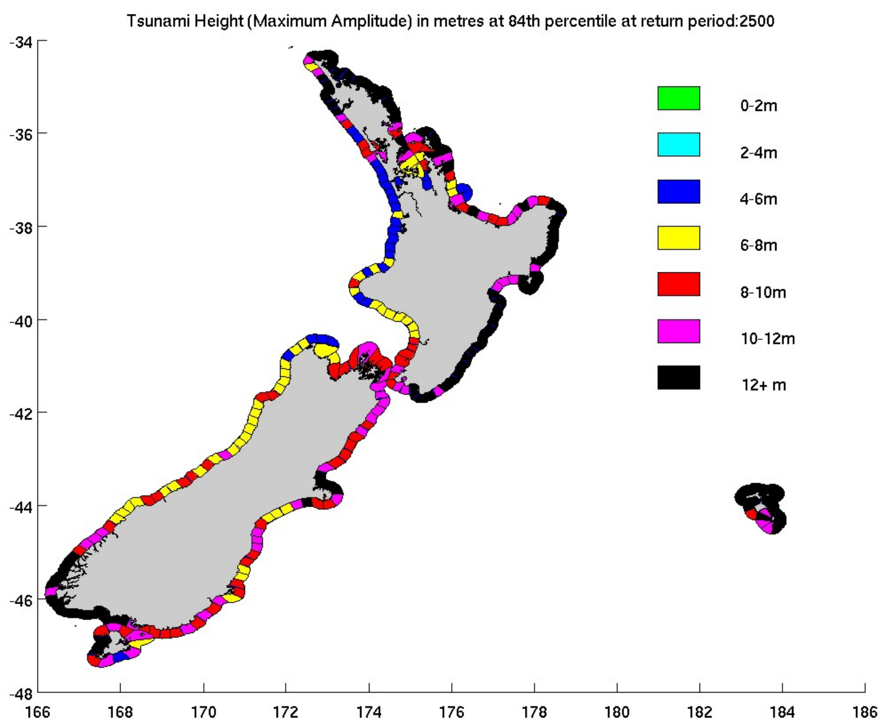


Figure 5 **(Power, 2013; their Figure 6.39)** Expected maximum tsunami height in metres at 2500 year return period, shown at median (50th percentile) and 84th percentile of epistemic uncertainty.

APPENDICES

APPENDIX 1: DATA USED ALONG THE COAST

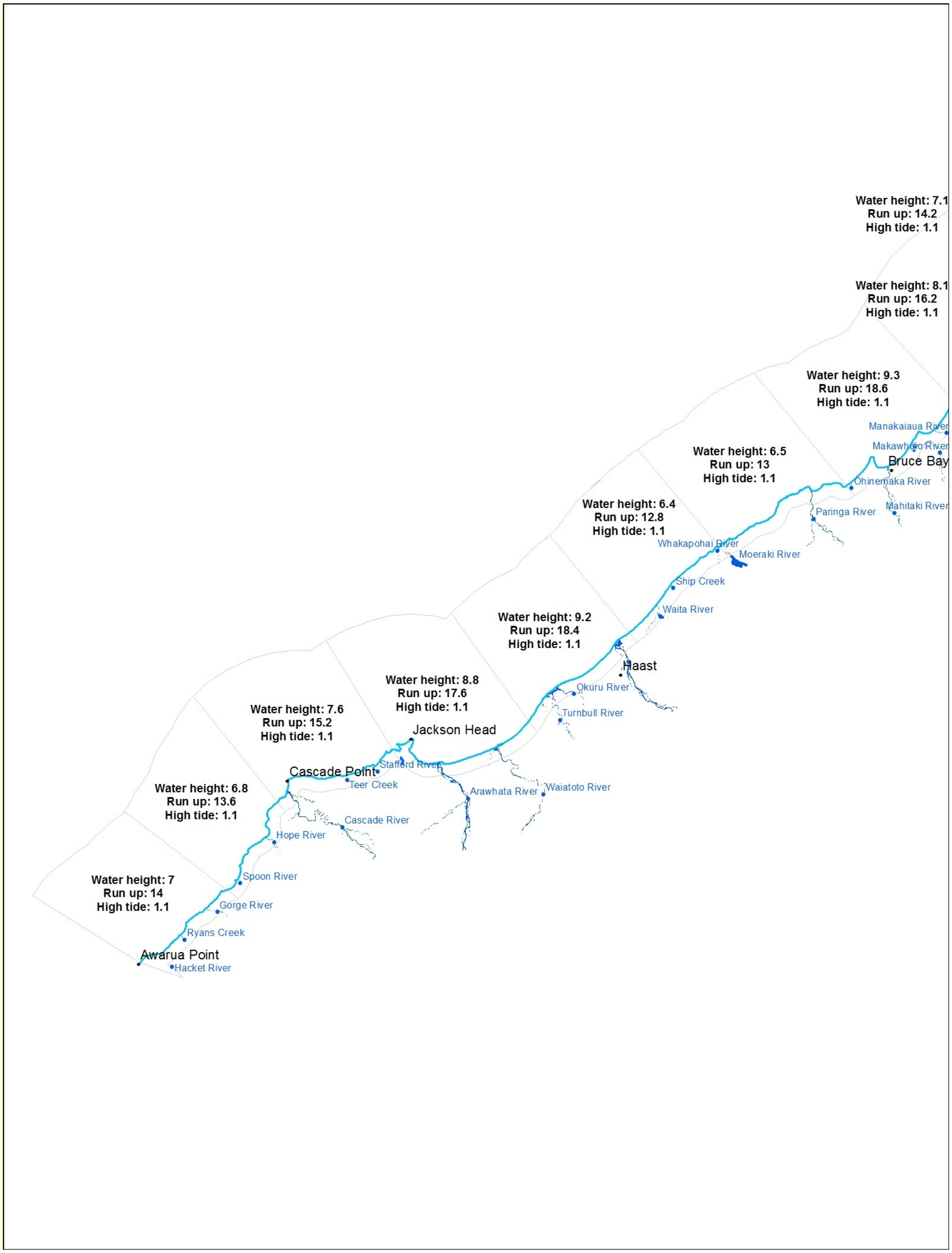


Figure A1 **Tile 1 of 3 southwest** Water height at coast, run up height, and high tide (over mean tide) in metres for each coastal domain used to generate the height at coast for the Yellow Zone (water heights and domain boundaries after Power, 2013). Modelled rivers are labelled in blue and locations modelled as 'harbours' (Table 1) are shown as purple dots.

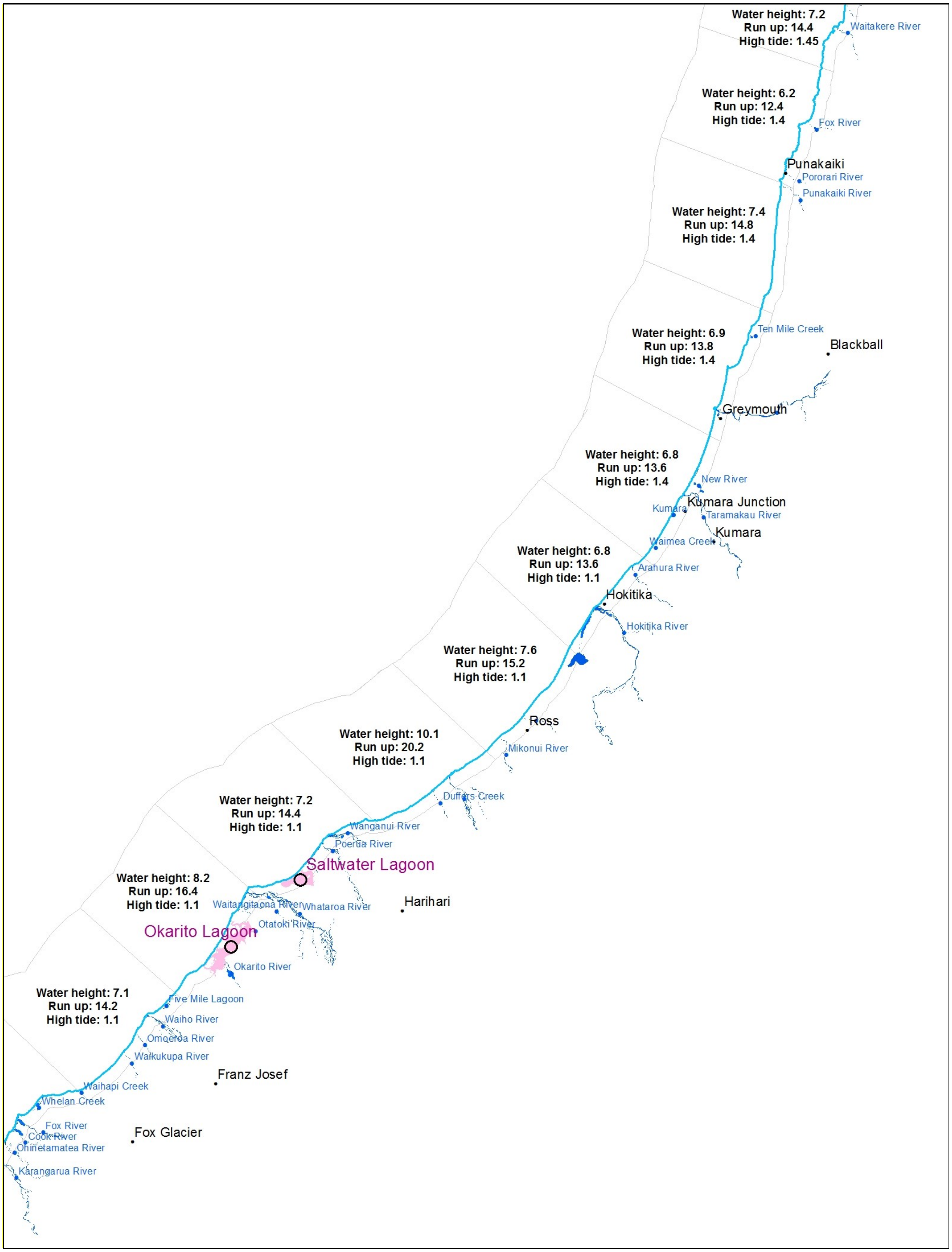


Figure A1 **Tile 2 of 3 central** Water height at coast, run up height, and high tide (over mean tide) in metres for each coastal domain used to generate the height at coast for the Yellow Zone (water heights and domain boundaries after Power, 2013). Modelled rivers are labelled in blue and locations modelled as 'harbours' (Table 1) are shown as purple dots.

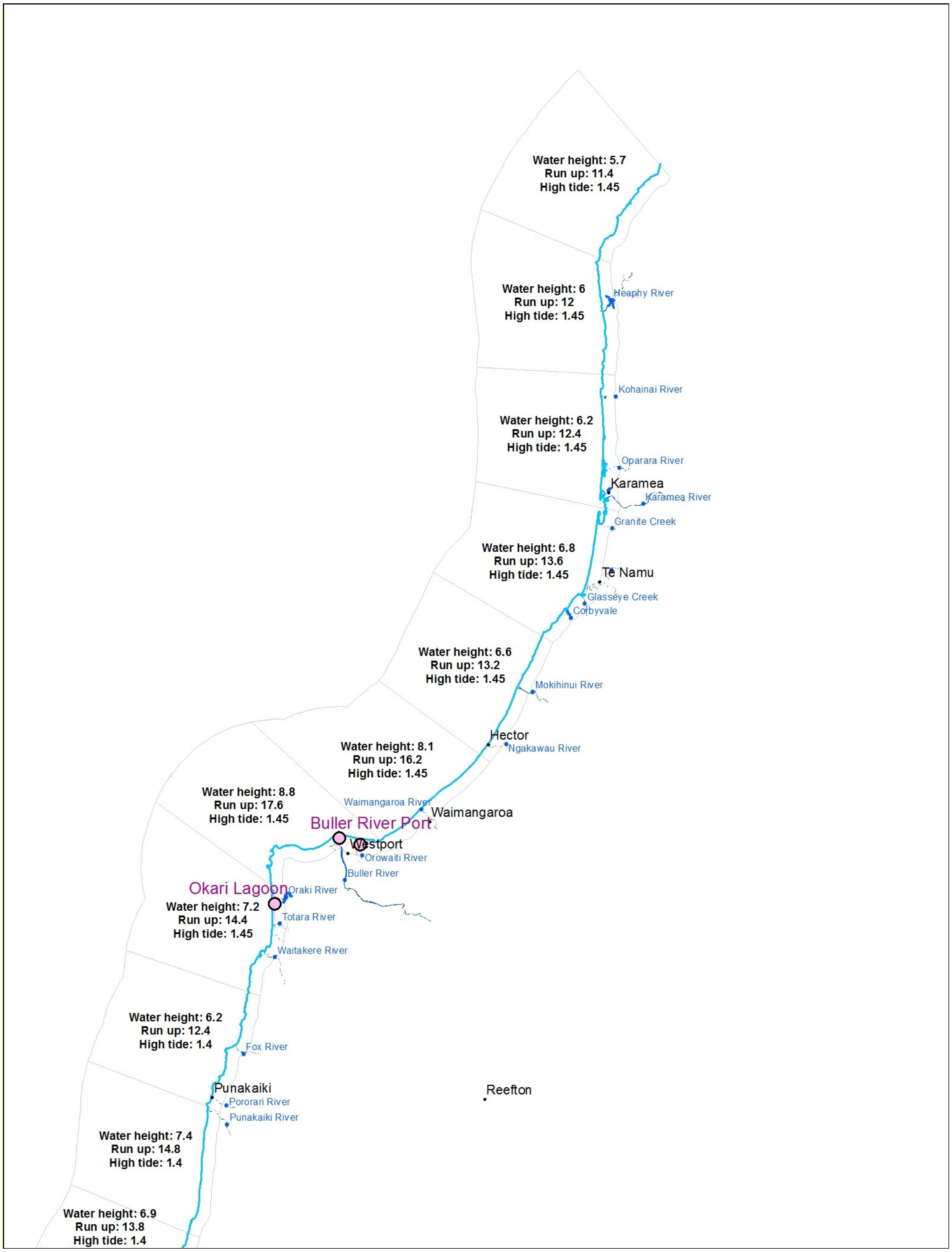


Figure A1 **Tile 3 of 3 northeast** Water height at coast, run up height, and high tide (over mean tide) in metres for each coastal domain used to generate the height at coast for the Yellow Zone (water heights and domain boundaries after Power, 2013). Modelled rivers are labelled in blue and locations modelled as 'harbours' (Table 1) are shown as purple dots.

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Principal Location	Other Locations		
1 Fairway Drive	Dunedin Research Centre	Wairakei Research Centre	National Isotope Centre
Avalon	764 Cumberland Street	114 Karetoto Road	30 Gracefield Road
PO Box 30368	Private Bag 1930	Wairakei	PO Box 31312
Lower Hutt	Dunedin	Private Bag 2000, Taupo	Lower Hutt
New Zealand	New Zealand	New Zealand	New Zealand
T +64-4-570 1444	T +64-3-477 4050	T +64-7-374 8211	T +64-4-570 1444
F +64-4-570 4600	F +64-3-477 5232	F +64-7-374 8199	F +64-4-570 4657