



**West Coast Lifelines
Vulnerability and Interdependency Assessment**

Supplement 4: Tsunami

West Coast Civil Defence Emergency Management Group

August 2017

IMPORTANT NOTES

Disclaimer

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Hazard Maps

The hazard maps contained in this report are regional in scope and detail, and should not be considered as a substitute for site-specific investigations and/or geotechnical engineering assessments for any project. Qualified and experienced practitioners should assess the site-specific hazard potential, including the potential for damage, at a more detailed scale.

Cover Photo: Road Bridge at Okuru River mouth, South Westland

West Coast Lifelines

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Contents

| | | |
|----------|---|-----------|
| 1 | OVERVIEW | 1 |
| 2 | TSUNAMI SCENARIO | 2 |
| 3 | TSUNAMI SCENARIO IN POPULATION CENTRES | 6 |
| 3.1 | INUNDATION MODELLING..... | 6 |
| 3.2 | HOKITIKA..... | 7 |
| 3.3 | GREYMOUTH..... | 9 |
| 3.4 | RAPAHOE..... | 11 |
| 3.5 | WESTPORT..... | 12 |
| 3.6 | GRANITY – NGAKAWAU – HECTOR..... | 13 |
| 3.7 | KARAMEA..... | 13 |
| 4 | EFFECTS ON ENGINEERING LIFELINES | 14 |
| 4.1 | TRANSPORTATION..... | 15 |
| 4.2 | WATER & WASTEWATER..... | 17 |
| 4.3 | TELECOMMUNICATIONS..... | 17 |
| 4.4 | POWER AND FUEL..... | 18 |

REFERENCES

Figures:

Figure 3.1: Hokitika Inundation

Figure 3.2: Greymouth Inundation

Figure 3.3: Rapahoe Inundation

Figure 3.4: Westport Inundation

Figure 3.5: Karamea Inundation

Tables:

Table 2.1: Tsunami Elevations at Shore

Table 2.2: Damage Areas for Tsunami

Tsunami Hazard on the West Coast

1 OVERVIEW

Large tsunami in recent times include the Indian Ocean tsunami of 2004, Samoa, 2011 and Japan, 2011. These events highlighted the potential danger in both the public and government arenas. A considerable amount of research has gone into assessing the tsunami hazard to New Zealand since 2011.

Tsunami large enough to impact adversely on the West Coast can originate from many sources. Power (2013) outlines the sources, both far field across the Pacific Ocean, and closer around New Zealand and that report should be referred to for more detail. It is relevant to note that the major tsunami source is far-field. For example, along the Greymouth – Hokitika coast for a 500 year return period wave, 35% of the potential source is earthquakes on the far rim of the Pacific Ocean (Peru, Alaska, Japan), 24% is in the New Zealand area, and 32% is “others” (Power, 2013, p459; note that this proportion varies with return period). It is also important to recognise that there is a potential tsunami source off the West Coast. Barnes (2013) reports active marine faults aligned approximately parallel to and within 30km of the coastline. Ten earthquake fault sources are recognised in the 320km between Hokitika and Cape Farewell. The faults are reverse fault structures¹ with expected vertical displacement on rupture. At between 10 and 120km in length, they are likely to be capable of generating earthquakes of between M6.4 and M7.8, with recurrence intervals of about 7,500 to 30,000 years. Three additional faults lie offshore between Paringa and Milford, and the Alpine Fault extends offshore south of Milford. No detailed evaluation of potential tsunami generation from these faults appears to have been carried out as yet (Barnes’s work post-dates the national tsunami modelling of Power, 2013) but it does appear that there is a risk of near field tsunami for most of the West Coast shoreline. While a far-field tsunami would have sufficient warning to allow evacuation, a near field event could arrive at the shore with little time for evacuation.

No detailed tsunami inundation modelling has been made for the West Coast as yet, but some basis for assessment is provided in reports by GNS Science in 2013 (Power) and 2014 (Power, and Leonard et al). Horspool & Fraser (2016) also provide a succinct overview of tsunami.

The 2013 report provides a background to tsunami hazard and then outlines tsunami modelling, tsunami sources and probabilities. The modelling carried out for the report divides the entire New Zealand coastline into 20km long sections. The West Coast region is divided into 27 sections, with 22 of these along the inhabited part of the coastline between Jackson Bay and Kohaihai River north of

¹ Movement in compression resulting in a vertical movement and shortening across the fault.

Karamea. Hazard curves giving the median maximum amplitude for tsunami waves plotted against return period are provided for each coastal section in Power (2014) together with the proportion of the hazard from the various sources at both 500 year and 2500 year return periods.

The 2014 report focusses on the West Coast. It contains tables showing tsunami wave heights, allowance for run-up and the high tide, and the elevation of the tsunami wave at the shoreline. The focus of the report was to provide emergency management with an assessment of the areas that would need to be evacuated if there was a tsunami alert. Three tsunami events were considered:

- Wave 0.2m – 1m high presenting “threat to beach, harbours, estuaries and small boats” (red zone)
- Wave 3 – 5m high, or “moderate land threat” (orange zone)
- Maximum credible tsunami wave height from all sources, which is obtained from the modelling as the 84 percentile (mean plus one standard deviation) of the 2500 year return period tsunami wave height added to high tide level (yellow zone)

Maps were prepared for Karamea, Westport, Greymouth and Hokitika for these three threat levels with corresponding red, orange and yellow evacuation zones. The red zone is essentially confined to the beaches, estuaries and lower reaches of rivers. The orange zone is much more extensive, based on a 5m wave height, with land inland from the shore being inundated, and the yellow zone is even more extensive. In determining the evacuation zones, the wave height was doubled to give an upper bound for run-up and added to the high tide level to give the elevation of the tsunami at the shoreline.

2 TSUNAMI SCENARIO

The yellow evacuation zone is a maximum credible estimate. The orange zone is inundation from a “standard” 5m tsunami wave, but has a variable return period of occurrence (refer Table 2.1). For the purposes of this lifeline study, we have considered a 500 year return period event. We have taken the median value wave height and doubled it for run-up (a conservative assumption) to obtain a water elevation at the shore. No allowance for tide has been made, or for wave and any storm surge effects, or sea level rise. The tsunami height at shore varies from RL6.1m (Punakaiki) to RL9.4m (Westport and Jackson Bay) as set out in Table 2.1, which includes the tsunami levels for the orange and yellow evacuation zones for comparison.

The tsunami height is one input, but the effects on land are the more important aspect. We again have little information on which to base any scenario. The main controlling factor is the ground level. There are some spot levels shown on topographical maps and we have LiDAR data for Hokitika and Greymouth. At Hokitika and Greymouth the storm ridge at the back of the beach is generally at RL6 – 7m and it is assumed, as we have no better information to verify this or not, that a similar height applies along most of the coast. For tsunami of less than about 6m in height, it is anticipated that the effects of

the tsunami will be confined to the open beach only, except at estuary and river mouths. With a doubling for run up this corresponds to a 3m tsunami wave with return periods of 100 – 300 years as shown in column 3 of Table 2.1. The tsunami risk to infrastructure really comes with tsunami of greater height and hence longer recurrence intervals. At both Greymouth and Hokitika, the storm ridge is higher than the land immediately landward, so any overtopping of the storm ridge and flow entry into river mouths will cause extensive flooding of the coastal strip.

Table 2.1: Tsunami Elevations at Shore

| Coastal Section Name | Zone Code | High Tide | Return period 3m tsunami | 500 year wave height | Tsunami elevation at shore | | | Return period 5m tsunami |
|----------------------|-----------|-----------|--------------------------|----------------------|----------------------------|------------|--------------|--------------------------|
| | | | | | 500 yr | 5m tsunami | Max credible | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Kongahu | 235 | 1.45 | 260 | 3.7 | 7.4 | 11.45 | 15.05 | 1,400 |
| Mokihinui | 234 | 1.45 | 300 | 3.5 | 7.0 | 11.45 | 14.65 | 1,650 |
| Westport | 232 | 1.45 | 140 | 4.7 | 9.4 | 11.45 | 19.05 | 620 |
| Punakaiki | 230 | 1.4 | 260 | 3.1 | 6.1 | 11.40 | 13.80 | 2,200 |
| Greymouth | 228 | 1.4 | 280 | 3.6 | 7.2 | 11.4 | 15.20 | 1,550 |
| Hokitika | 226 | 1.1 | 280 | 3.6 | 7.2 | 11.1 | 14.70 | 1,500 |
| Mikonui | 225 | 1.1 | 200 | 4.0 | 8.0 | 11.1 | 15.2 | 1,000 |
| Okarito | 222 | 1.1 | 120 | 4.7 | 9.4 | 11.1 | 16.4 | 640 |
| Makawhio | 219 | 1.1 | 110 | 4.9 | 9.8 | 11.1 | 18.6 | 530 |
| Haast Beach | 216 | 1.1 | 160 | 4.6 | 9.2 | 11.1 | 19.5 | 660 |
| Jackson Bay | 215 | 1.1 | 150 | 4.7 | 9.4 | 11.1 | 18.70 | 640 |

Notes to Table 2.1

*All data derived from Power 2013b (columns 3 - 8) & Leonard et al 2014 (columns 1 & 2)
 Column 1: refers to approx. 20m long section of shore from national modelling Power 2013b
 Column 3: 3m tsunami is largest likely contained by storm ridges & hence no flooding
 Cols 5 – 7: Wave elevation at shore is run-up height taken as 2 x wave height in ocean
 Column 5: 500 year run-up elevation is assuming mean sea level and mean wave height
 Column 6: 5m and maximum credible run-up elevations assume high tide level
 Column 7: maximum credible wave height is 84 percentile at 2,500 year return period
 Column 8: return period for 5m wave is for mean wave height of 5m*

Based on the above, we have taken a tsunami event of about a 500-year return period that assumes the whole of the coastline is subjected to tsunami depth at the shoreline. This is unlikely to actually occur. The tsunami heights are derived from a probabilistic model and different lengths of shore are exposed differently to the various sources. A single source is unlikely to generate the same return period event on the entire shore. For example the Tangaora exercise of 2016 used a M9.2 earthquake near the Kermadec Islands as the cause of a tsunami. The first landfall in the model was at Whangarei after 1.7 hours. It reached Westport at 6.3 hours and Greymouth 10 minutes later. A wave height of 5m to 8m was modelled for the West Coast north of about Okarito and 3m to 5m south of Okarito. Our scenario is therefore unrealistic in many ways but is intended to identify those areas on the whole of the coast that are exposed to tsunami hazard.

To re-iterate, the scenario is based on:

- Tsunami height on the open shoreline of the 500-year return period for each coast section,
- Open sea tsunami height is doubled to allow run-up effects
- Tsunami height is added to mean sea level with no allowance for high tide (as used for evacuation zoning) or for sea level rise
- A storm ridge is assumed to extend the full length of the coast with a height of 6m (except at river mouths)

The scenario is set out in Table 2.2

Table 2.2: Damage Areas for Tsunami

| | Location | Damage |
|----|---------------------------------|---|
| 1 | Karamea | The township centre escapes flooding but the western end around Wharf Rd and 1km of Waverley St are inundated and buildings damaged. Most of the Karamea – Kohaihai Road is close to the beach and is flooded and damaged, along with the bridges, including Oparara River where flooding extends 0.5km inland from the bridge |
| 2 | Karamea River – Little Wanganui | Most of the 13km of SH 67 is within 0.4km of the shoreline or the edge of the estuary and is flooded and damaged. Two bridges at Granite Creek are damaged. Flooding extends 1km up Granite Creek from SH 67 and 3km up the Karamea River to the SH bridge (not affected) |
| 3 | Little Wanganui | The settlement is within 0.6km of the shore and is flooded, with many houses badly damaged. |
| 4 | Mokihinui River - Granity | Most of the 18km of SH 67 south of Summerlea is within 0.2 – 0.3km of the beach and only a few parts are higher than tsunami run-up. All of Granity, Ngakawau and Hector are flooded and largely destroyed. The coal facilities at the rail head at Ngakawau are flooded and damaged. Several small bridges are affected and the Ngakawau River bridge is affected. |
| 5 | Westport | Two thirds of the town is flooded. There is damage and scour along the Buller River and around Orowaiti Lagoon. SH 67 Buller bridge is little affected but Orowaiti bridge is. Utopia Rd (4km long) east of Orowaiti is flooded. |
| 6 | Carters Beach | Most of the area between the cement works and the Buller River is inundated for a width of up to 1km. The area includes all of Carters beach and the airport. |
| 7 | Carters Beach - Charleston | The Nile River bridge is damaged; council roads along the beaches are affected. |
| 9 | Barrytown - Rapahoe | About 5km of SH 6 are inundated and damaged. Half of Rapahoe township is inundated and destroyed. The bridge at Seven Mile Creek (Raphoe) is damaged |
| 10 | Cobden north | 3.5km of North Beach Rd along the shore is badly damaged and all houses on the flat coastal strip are flooded and damaged. |

| | | |
|----|-----------------------------------|---|
| 11 | Greymouth – Cobden to South Beach | All of the lower lying land is inundated with major damage. The airport is flooded and damaged, as is the lower levels of the Greymouth Hospital, the St John Ambulance Centre, rescue helicopter base, the sewage treatment facility, and the railway. Wharves and boats are damaged or sunk. |
| 12 | South Beach to Camerons | 7km of SH 6 and the railway are 0.2 – 0.6km from the beach and are damaged, as are the bridges at New River and Paroa. Most buildings are flooded and damaged or destroyed. |
| 13 | Taramakau River to Hokitika | 18km of SH 6 and the railway are between 0.2 & 0.6km of the beach and are damaged, as is the bridge at Waimea Creek. The recently built Arahura River Bridge is 1km inland and is little damaged beyond abutment scour, although the Arahura settlement is flooded and largely destroyed. |
| 14 | Hokitika | All of the CBD and the town between SH 6 and the beach is flooded and extensively damaged. Flooding extends on the lower terrace close to the river to 0.5km upstream of the bridge. The oxidation ponds are inundated. |
| 15 | Hokitika to Ruatapu | For the 9km of SH 6 between 0.3 & 0.7km of beach, the road is flooded and damaged; power lines are damaged; all houses and buildings including the Ruatapu settlement are flooded and partially to totally destroyed. |
| 16 | Ross | Beach Rd and 1km of Moorhouse Rd are flooded, with damage to all buildings in the area. |
| 17 | Mokonui to Waitaha | The local coastal road is flooded and damaged. Power lines are damaged with scour causing failure of a few poles |
| 18 | Okarito | All of the settlement is flooded and partially or totally destroyed. The road is damaged by scour alongside the lagoon |
| 19 | Bruce Bay | 5km of SH 6 is within 0.2km of the beach or lower reach of the Mahitahi River. The road is flooded and damaged and the highway is completely destroyed by erosion of the shoreline over two 0.5km sections. All buildings in Bruce Bay settlement are flooded and partially or totally destroyed, as is the settlement at Hunts beach |
| 20 | SH 6 Waita to Haast Rivers | 6km within 0.15 – 0.4km of beach are flooded and damaged. The Waita River bridge is 0.7km from beach and there is some damage to the abutments. All buildings at the mouths of both rivers are flooded and partially or totally destroyed. |
| 21 | Haast to Waitatoto | 24km of coast the road is between 50m and 1.5km of beach. 15km is flooded and damaged, as is the power line alongside. |
| 22 | Haast Beach | Up to 0.2km from beach, buildings are flooded and damaged |
| 23 | Okuru | Bridges on the Okuru and Turnbull Rivers at 1.0 & 0.8km from the beach are both damaged. All houses are flooded and partially destroyed. |
| 24 | Hannah's Clearing | Between 150 & 350m from beach; buildings are flooded and partially destroyed |
| 25 | Waitatoto River | Haast Rd bridge is 1.5km from coast and is not damaged but the road to the lagoon and buildings along it are flooded and partially damaged. A power line crosses the river at 0.5km from shore and is destroyed |

| | | |
|----|---------------------------|---|
| 26 | Neils Beach | Settlement between road and beach 0.4km long; trig at beach end at 3m; all of the village and the airstrip are flooded and partially or totally destroyed. The road to Haast is partially blocked and damaged in places within 2km of the settlement. |
| 27 | Neils Beach – Jackson Bay | The road is inundated, blocked with debris and damaged by scour and slips. |
| 28 | Jackson Bay | The wharf and all buildings are flooded and partially or totally destroyed. |

Given the concentration of population and lifeline services in the main urban areas, it is useful to discuss the impact on these in more detail. These areas have LiDAR ground level data, and we have made some very simplistic modelling of possible tsunami inundation.

3 TSUNAMI SCENARIO IN POPULATION CENTRES

3.1 Inundation modelling

LiDAR survey data is available for the main centres on the West Coast, and this detailed information on ground topography allows a very basic and crude tsunami inundation modelling to be done. We have taken the median 500-year return period tsunami wave height, doubled it to allow for run-up effects, taken mean sea level and thus obtained a wave level at the shoreline. We have then assumed a 1:200 gradient on the water surface as it progresses inland to obtain a wave height plane. Deduction of the ground levels from this plane gives us both the extent and depth of inundation. This simple model ignores the likely inundation from rivers and is confined to a single flow direction in from the shore. It therefore provides only a crude estimation of tsunami inundation. We have applied this simple modelling to all the population centres where there is LiDAR data: Hokitika, Greymouth, Rapahoe, Westport and Karamea.

Maps showing the inundation areas are included below as Figures 3.1 to 3.5. Each map shows:

- The area of inundation with the 500-year return period tsunami, given the simple modelling techniques as outlined above
- Indication of inundation depth from the simple model
- The landward boundary to the orange tsunami evacuation zone (5m wave plus high tide) as produced by NIWA
- The landward boundary to the yellow tsunami evacuation zone (maximum credible wave height plus high tide) as produced by NIWA
- Edges to the inundation areas approximately perpendicular to the shore are due to the limits of the LiDAR survey information or the modelled wave – inundation will continue along the shore beyond these arbitrary edges.

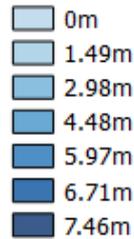
The key to each map is the same as shown here:

Legend

Red line marks edge of orange evacuation zone

Yellow line is edge of yellow evacuation zone (maximum probable)

Indicative inundation depth



The background to all the maps is LINZ topographical maps 1:50,000 series and the grid is at 1km intervals each way to allow distances to be assessed.

3.2 Hokitika

The beach ridge at Hokitika is about 5m elevation south of the end of Stafford St, 6 – 6.5m to the north of Stafford St and 6 – 7m to the north of the urban area. The stopbank on the Hokitika River is little more than 3.5m elevation between the bridge and the beach, about 4m upstream of the bridge and increasing to 5m elevation by the diary factory. The tsunami wave plus run-up height of 7.2m therefore overtops the beach ridge by 1 – 2m over the full length of the town, and by perhaps 3.5m across the stopbank west of the bridge (Figure 3.1).

The flow paths and inundation will be complex and the tsunami is likely to extend much further up the river than through the town, not only because of the lower ground (river bed) level but also because of lower friction and fewer obstructions. A 1m drop in tsunami level for every 400m upriver is generally assumed for rivers (Power, 2013a, p81), or about half the overland rate. It is therefore likely that the stopbank will be overtopped all the way up to the diary factory and the town is thus flooded from two sides. If a typical 1:200 reduction in water level with distance from the shore is assumed, the whole of the lower part of town west of Fitzherbert Street (SH 6) is flooded, as well as the area between Stafford St and the river as far up as about Sale Street as shown on Figure 3.1. When flooding from over the river stopbank is allowed, most of the lower area between the river and Stafford Street west of the diary factory will be flooded, and water levels west of SH 6 are also likely to be greater.

Figure 3.1. Hokitika Inundation

Possible areas of Hokitika inundated with 500 year recurrence interval tsunami (7.2m run-up at shore) No allowance for inundations from the river

See 3.1 for key and limitations



As the ground level in the CBD area is as low as about 2m, inundation depths are likely to be large: 4 – 5m is quite possible in the lower parts of the CBD. Ground levels are about 2m higher at the north end of town, and water depths are likely to be more like 2m. The tsunami wave that affects this degree of flooding will also result in scouring of the beach ridge and the river stopbank. While this will allow more of the flood waters to drain, it also exposes the area to repeated flooding with lower tsunami waves following the largest wave.

The affected part of the town will be subject to:

- Flooding with salt water. Depths will vary from very little at the eastern extremity near the dairy factory to 4 – 5m in the CBD, sufficient to completely fill ground floor spaces and flood second storey spaces.
- Scour of ground on embankments and slopes and around buildings wherever water velocities are high enough.
- Sand and gravel washed from the beach and stopbank redeposited throughout parts of the flooded area.
- Non-fixed items such as vehicles and building contents floating throughout the area and in areas of sufficient velocity causing impact damage to structures.
- Lightweight buildings which are not securely fixed to foundations will be washed away throughout the area west of SH 6. Most timber framed buildings in this area will be destroyed.

- Structural damage is likely to many buildings, particularly in the CBD area, from water pressures, scour and impact.
- Large amounts of debris will be left throughout the affected area.
- The CBD area is likely to be left with salt water ponded to up to 1m depth after the final inundations have ceased.

Some specific infrastructure damage is likely to include

- Both abutments to the Hokitika Bridge are scoured out and the bridge is inaccessible. The tsunami depth is about 5.6m at the bridge, 1m above the soffit at the north abutment but below the soffit at mid length (6.5m). Some structural damage occurs to span seatings and linkages.
- Roads throughout the affected area are littered with debris, (some with buildings).
- Sewer pipes throughout the worst impacted areas are flooded and partially filled with sand.
- The oxidation ponds are flooded with salt water and partially filled with sand and gravel from the beach, and all above ground assets are destroyed.

3.3 Greymouth

The beach ridge is overtopped and water floods over all the land between the beach and the flood wall around the lagoon, up to the railway at Raleigh Street and across the whole of the airport to the base of the higher land at the hospital. Some of Preston Road is flooded as far as Leonard Street. In Cobden, the water floods in as far as close to and parallel to Firth Street, diagonally across to the intersection of Blackett and Bright Street and across to the flood wall at Blackett Street. The tsunami extends upriver to beyond the Cobden Bridge but is contained within the river bed between the floodwalls (Figure 3.2).

Figure 3.2: Greymouth Inundation

Possible areas of Greymouth inundated with 500 year recurrence interval tsunami (7.2m run-up at shore)

Red line marks edge of orange evacuation zone

Yellow line is edge of yellow evacuation zone

See 3.1 for key and limitations



The affected part of the town will be subject to:

- Flooding with salt water. Depths will vary from very little at the eastern extremity to 3 - 4m in lower parts of Blaketown.
- Scour of ground on embankments and slopes and around buildings wherever water velocities are high enough.
- Sand and gravel washed from the beach and redeposited throughout parts of the flooded area.
- Non-fixed items such as vehicles and building contents floated throughout the area and in areas of sufficient velocity causing impact damage to structures.
- Lightweight buildings which are not securely fixed to foundations will be washed away throughout the area and many timber framed buildings in the Blaketown area will be destroyed. Structural damage is likely to remaining buildings from water pressure, scour and impact.
- Large amounts of debris will be left throughout the affected area.

- Lower lying areas are likely to be left with salt water ponded to up to 1m depth after the final inundations have ceased.

Some specific infrastructure damage is likely to include:

- The airport runway is littered with debris. There is some damage to edges, and the lighting system damaged.
- Some sections of the floodwall are damaged by scour, and the corner near Raleigh and Preston Roads is overtopped and partially destroyed over a 200m long section.
- The boat harbour is badly damaged with boats washed against wharfs and each other; wharf structures are damaged. Erosion and aggradation occur in different parts of the lagoon and river from the strong currents from the tsunami.
- Roads throughout the affected area are littered with debris, (some with buildings).
- Buildings at the mouth of Mill Creek are destroyed and the debris is washed against the railway bridge with the loss of both spans and the abutment fill on each side. SH 6 bridge is not structurally damaged but the guardrails are ripped off and the bridge and waterway blocked with debris.
- The sewer line across the tidal flat is 70% destroyed.
- The sewage treatment facility is flooded with salt water, partially filled with sand and gravel from the beach and the embankment on the north side is washed out. Many above ground assets are destroyed.

3.4 Rapahoe

Rapahoe is only a small settlement, but is included in the Greymouth LiDAR survey area, and we have modelled the tsunami impact here as well. Evacuation zones were not modelled for Rapahoe and are therefore not shown in Figure 3.3. The lower part of the settlement is flooded, as is a section of SH 6 and the bridge.

Figure 3.3: Rapahoe Inundation

Possible areas of Rapahoe inundated with 500 year recurrence interval tsunami (7.2m run-up at shore) No allowance for additional inundation from Seven Mile Creek

See 3.1 for key and limitations



3.5 Westport

Westport has been modelled with tsunami coming over the open shoreline only. Westport is exposed on three sides: tsunami overtopping the beach directly at the north end of the town, overflowing from the Buller River on the west and from the Orowaiti estuary on the east, and therefore this inundation area is likely to be under-predicted in at least some areas. Flow patterns are likely to be complex.



Figure 3.4: Westport Inundation

Possible areas of Westport inundated with 500 year recurrence interval tsunami (9.4m run-up at shore) No allowance for additional inundation from river or Orowaiti estuary. See 3.1 for key and limitations

The tsunami comes inland about 3km from the beach but floods only the northern extremity of the main urban area. Parts of Buller High School may have shallow flooding but the hospital is

unlikely to be flooded at this particular size event as modelled. Waves are likely to create surges up the Buller River as far as the bridge, and some damage along the banks and to, bank structures and outfalls is also likely.

The boat harbour at the north end of the town is likely to be significantly damaged with boats and debris impacting on each other and the wharves.

The airport is flooded with up to 5m of water and some damage to the runway must be expected. Carters Beach settlement is similarly flooded and likely to be largely destroyed.

3.6 Granity – Ngakawau – Hector

Tsunami for this township has not been modelled but is worthy of some comment. The built up area extends for about 5.5km along the coast on a narrow strip of gravel and sand beach deposits between the current shoreline and the toe of the steep escarpment forming the coastal hills. This strip varies between little more than 100m to about 500m in width and is low lying. Bench mark data indicates most of the area is between 3m and 5m in elevation. The coastline is eroding and there is no beach ridge as found in other parts of the coast. The 500 year tsunami wave is 3.5m and with run-up is 7m, which will overtop the shore and flood across the area. The Ngakawau River provides additional ingress. In the areas where the hills are closest, the tsunami surge is likely to be reflected off the hill, increasing water depths and velocities. It is expected that most of the buildings will be badly damaged and many destroyed. With houses between the sea and the road, debris will impact on power poles and lines and obstruct the road. Scour to the road and railway must be expected, and while the Ngakawau Bridge is of modern design and should survive, some damage can be expected to the end spans which are likely to be within the inundation depth, and the abutment fill is likely to be scoured out. Scour and possible loss of the smaller bridges across the small streams in Granity is likely. The substation is also vulnerable.

3.7 Karamea

Karamea is inland of a large estuary area, behind a beach ridge and with wide openings to the sea south of the river. We have modelled this assuming the full wave run-up height at the beach, followed by a 1:400 gradient to the wave height across the estuary area, and the 1:200 gradient commencing at about the 1m contour on the land side. This is obviously a crude simplification, but allows some assessment of the inundation area.

The tsunami is expected to flood about 1.5km inland from the shore, getting close to the school and inundating the lower settlement along Wharf Street. Waves and surges are likely to reach upstream of the Karamea Bridge with some scour and damage to the riverbed and banks. The main road to Westport is likely to remain above the tsunami level in the area modelled. The airstrip north of the township is likely to be flooded as it is only about 0.5km from the shore.

Figure 3.5: Karamea Inundation

Possible areas of Karamea inundated with 500 year recurrence interval tsunami (7.4m run-up at shore) No allowance for additional inundation from Karamea River

See 3.1 for key and limitations



Beyond the area modelled, the Karamea Highway between Little Wanganui and Karamea runs for 11km at between 0.1 and 0.5km of the shore, and most of this length can be expected to be inundated. The substation part way along this length at Kongahu is about 0.4km inland and is also likely to be within the inundation zone, as is the main power line to the district.

4 EFFECTS ON ENGINEERING LIFELINES

The following is sourced principally from the report prepared for the Auckland and Wellington lifeline groups by GNS Science (Horspool & Fraser, 2016). This is a particularly useful reference and is recommended to anyone needing further background and details. It contains several fragility curves relating probability of various levels of damage to tsunami water depth for a range of structures and lifelines, and there is a comprehensive table of expected damage levels in Appendix A.

Horspool and Fraser conclude their summary with the following:

A salient observation across all lifeline sectors was that often back-up services, such as generators, were often located on the ground outside of buildings, on ground floors or in basements. Such locations put this critical equipment in the direct path of even small tsunami. It is recommended that back-up generators be raised above ground level or located on at least the second floor of buildings. Furthermore, tsunami damage 'hotspots' were identified where multiple lifeline damage and failure can occur. Bridges are lifeline components that are vulnerable to tsunami and often have co-location of other lifeline services, which if damaged

can cause failure of these other lifeline services. Hotspots also occurred on coastal roads, where culverts or wastewater outflows run beneath roads and through sea walls. These water channels are a site of high scour, which often results in scouring of the seawall, roadway and any underground or overhead services. Identifying and increasing the resilience of these tsunami 'hotspots' should be a priority for lifeline operators.

4.1 Transportation

Transportation networks, such as roads, bridges, and rail will likely be damaged disrupted by even small tsunami (tsunami depths ~ 1m) due to scouring and deposition of debris.

(a) Roads

Damage

- Scour: particularly when elevated or close to topographic relief. Scouring is greatest with the receding waves, and is related to flow velocity. Roads are most vulnerable when located near the shoreline, adjacent to drains, rivers and culverts (where flow is concentrated and hence velocity is higher), on elevated ridges, and on poorly compacted subbase.
- Debris: tsunami-affected roads must be expected to be littered with debris carried by the tsunami waves. Flow depths greater than 2m can suspend most objects and above 2m depth damage to buildings increases significantly, thereby increasing the amount of debris in the flow. Areas of severe inundation (> 2m) often have coincident scouring.

Measures to increase resilience:

- Increase redundancy into the road network to provide multiple routes.
- Use well-compacted granular bases to better resist scour.
- Protect coastal roads with sea walls, riprap etc.
- Carry out tsunami inundation modelling to better understand the hazard, likelihood of scour and most vulnerable areas

(b) Bridges

Damage:

- Scour and erosion of fill around abutments and piers: this is extremely common in overseas events. New Zealand bridges are usually protected against scour, but higher than design velocity flows can occur with tsunami, and incoming waves are opposite to the direction of normal flood flows.
- Debris impact damage to the superstructure: this occurs when the flow depth reaches close to the bridge deck level, but damage is usually superficial with loss of guardrails or services attached to the bridge.
- Complete washout of bridge superstructure: loads from hydrodynamic, buoyancy and debris impact can exceed the structural capacity of bridge members or connections. Bridges

designed for seismic loads are usually more resilient, as are reinforced concrete compared with steel and truss bridges.

- Bridges often carry other services which are also vulnerable to damage as above.

Measures to increase resilience:

- Use deep foundations which are less susceptible to scour and provide erosion protection around abutments, usually in excess of flood requirements.
- Seismically strengthen bridges as seismic and tsunami loads are similar, and ensure continuity to benefit both vertical and lateral loading.
- For new bridges within tsunami zones, consider raising superstructure to above tsunami level (if practical), design cross section profile to reduce drag, and install strong uplift and longitudinal restraint.
- Use reinforced concrete in preference to steel or truss bridges.

(c) Rail

Railways in tsunami inundation zones are subject to damage to rail tracks and ballast, debris over the tracks, bridges, trains, overhead lines, stations and facilities. In Japan in 2011, 80% of the damage was to tracks, with the equivalent of a site of damage on average every 190m of track. Track is vulnerable as it is usually raised on ballast on low embankments and thus exposed to scouring.

Measures to increase resilience:

- Strengthen rail bridges.
- Have spare parts etc. stockpiled outside tsunami zones.

(d) Airports

Airports that are in tsunami inundation zones will be inundated. However services can be restored quickly once debris has been cleared from the runway. Scour of the runway is possible but the large area of level ground associated with them reduces the likelihood of appreciable scour developing. Inundation of airport buildings can damage or destroy equipment, electrical fittings etc.

Measures to increase resilience:

- Plan for equipment to clear the runway.
- Place critical equipment on second floors above inundation levels, if possible.
- Locate spare parts outside the tsunami inundation area.

(e) Ports

Ports can be damaged even in non-inundating tsunami due to strong currents.

Damage:

- Wharf damage from buoyancy and hydrodynamic loads.

- Scour of piers and breakwaters, and deposition of sediment.
- Impact damage to wharves and structures from debris and boats.
- Damage to vessels.

Measures to increase resilience:

- Response plan to move vessels into deep water, if sufficient warning.
- Design wharfs to withstand tsunami forces (designing for ship impact is not practically feasible).

4.2 Water & Wastewater

Wastewater and potable water networks are particularly vulnerable to tsunami at their facility buildings and pipe intake and outflow sites. Damage to building structures or electrical equipment can cause significant service disruptions while repairs are undertaken. Furthermore, contamination of drinking water supplies (wells) or sewerage containment ponds can occur with even small amounts of intrusion of seawater from a tsunami. Less data is available regarding the susceptibility of buried pipelines to tsunami. However it appears that such infrastructure is less vulnerable to tsunami than above ground facilities. Pipes are vulnerable to scour at locations where high velocities could occur, particularly around drainage channels and of course bridge abutments, and especially where the pipe is above ground such as attached to a bridge or across waterways. Storm water pipes can be blocked with silt, sand and sediment, and drain outfalls and culverts can be damaged by scour and erosion as well as blockage by debris.

Measures to increase resilience:

- Locate key facilities, water supply sources and treatment outside the tsunami inundation zone.
- Construct facility buildings of reinforced concrete and place power and electrical equipment in watertight areas or at a height above inundation.
- Use sealed lids on tanks and pumps to reduce contamination from saltwater, sediment and debris.
- Bury pipes across waterways (with allowance for scour) or attach them to sound bridges with protection from debris impact.
- Use seismically resilient pipes (HDPE).
- Locate spare parts outside the tsunami zone.
- Ensure well heads are watertight to stop saltwater entering the water supply.

4.3 Telecommunications

Telecommunication networks will most likely be disrupted locally due to damage to buildings and electrical equipment at exchanges. Failure of cellular sites can occur at standalone towers that are toppled by debris strikes or scouring, as well as those located on buildings that are damaged. Again,

little information is available regarding the performance of buried cables in tsunami. However it appears that buried cables are less susceptible from tsunami than overhead lines.

Damage:

- Damage to cellular sites: standalone towers in Japan are often badly damaged or destroyed with tsunami heights of more than 2m by loss of electrical equipment, foundation scour, or debris impact. Sites mounted on buildings are dependent on building performance.
- Damage/outages to exchanges, with resulting issues in switching functions: vulnerabilities are to the building itself when subject to inundation and hydrodynamic and impact loading, and to the electrical equipment from inundation.
- Power outages from loss of network power, limited battery life, or from electrical or generator failure if at ground level and inundated.
- Damage to radio communications if facilities are within the tsunami zone. Towers are vulnerable to debris or scour.
- Damage to overhead lines from scour at pole bases and debris impact, or from submergence of wires.
- Damage to underground lines at locations vulnerable to scour, including bridge abutments and where cables enter at building foundations.

Measures to increase resilience:

- Relocate exchanges out of the tsunami zone or in sufficiently robust multi-storey buildings above possible tsunami height.
- Waterproof critical electrical equipment and switches and locate at higher levels.
- Locate cell towers on suitable buildings.
- Locate backup generators above ground level and preferably above tsunami height.
- Relocate overhead lines to underground.
- Stockpile spares outside the tsunami zone.

4.4 Power and Fuel

Energy networks, particularly electricity, will be impacted due to shorting of buried cables if they become exposed to the water and have pre-existing casing damage. Buried cables are vulnerable at places exposed to scour, such as bridge abutments and connections in buildings at foundation level. Also, overhead lines are susceptible to failure by toppling of poles from scour and or debris impact. Substations are also vulnerable to foundation scour, debris impact and submergence in saltwater. Petroleum and gas terminals, often located in coastal areas, may suffer damage to their pipe networks and tank farms in tsunami depths of 2m or greater.

Measures to increase resilience:

- Relocate fuel tanks to outside the tsunami zone, or raise foundations to increase height against tsunami flooding.
- Protect foundations from scour.
- Construct tanks to seismic design standards to better withstand tsunami forces.
- Locate substations outside the tsunami area.
- Raise equipment, placing equipment in strong buildings.
- Build redundancy into networks.
- Stockpile spare parts, mobile generators and mobile substations.

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