Tonkin+Taylor

Coastal Assessment

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1 Overview

This assessment covers the proposed minor consent amendments at Mangamaunu, Half Moon Bay and Okiwi Bay South along the coast adjacent to Kaikōura. The assessment is done in accordance with the NZ Transport Agency (2017) guideline for coastal effects assessments, which aims to inform decision making in a risk management context.

2 Coastal environment

The road and rail corridor is located between Goose Bay south of Kaikōura and the Clarence River on the north-eastern coast of the South Island. The transportation corridor follows the coast and is bound on the east by the Pacific Ocean and on the west by the steep ranges that extend along the coast from Oaro to just north of Okiwi Bay (refer Figure 1). These ranges are interrupted by the fluvial plains adjacent to Kaikōura and the Clarence River and have a variety of low standing coastal landforms intersecting them. This includes several small streams and gullies traversing the ranges conveying local catchment dischargers to the coast.

The Kaikōura Peninsula environment is subject to highly energetic processes in terms of both marine and weathering processes. Shore platforms are exposed to the dominant wave directions and are in the intertidal zone. It is exposed to an extremely long fetch from the Pacific Ocean characterized as a high-energy oceanic swell environment, with high-energy storms interrupting long periods of relative calm. High-energy storms due to the passage of cyclonic depressions over New Zealand can occur at any time of the year.

Consequently, both marine erosive forces and sub-aerial weathering processes contribute to erosion. Shore platforms (up to 30 metres depth) range from 40 m to over 200 m wide and are cut in Tertiary aged mudstones and limestones. The shore platform extends to variable drop rapidly in the canyon features of 1 – 1.5 kilometres.

The majority of the site under consideration can be classified as uplifted rock reef shores with small pockets of gravel and cobbles forming upper tide perched beaches in the more embayed parts of the coast. The exception is at Mangamaunu that is on the northern edge of the Hapuku gravel/cobble river delta.

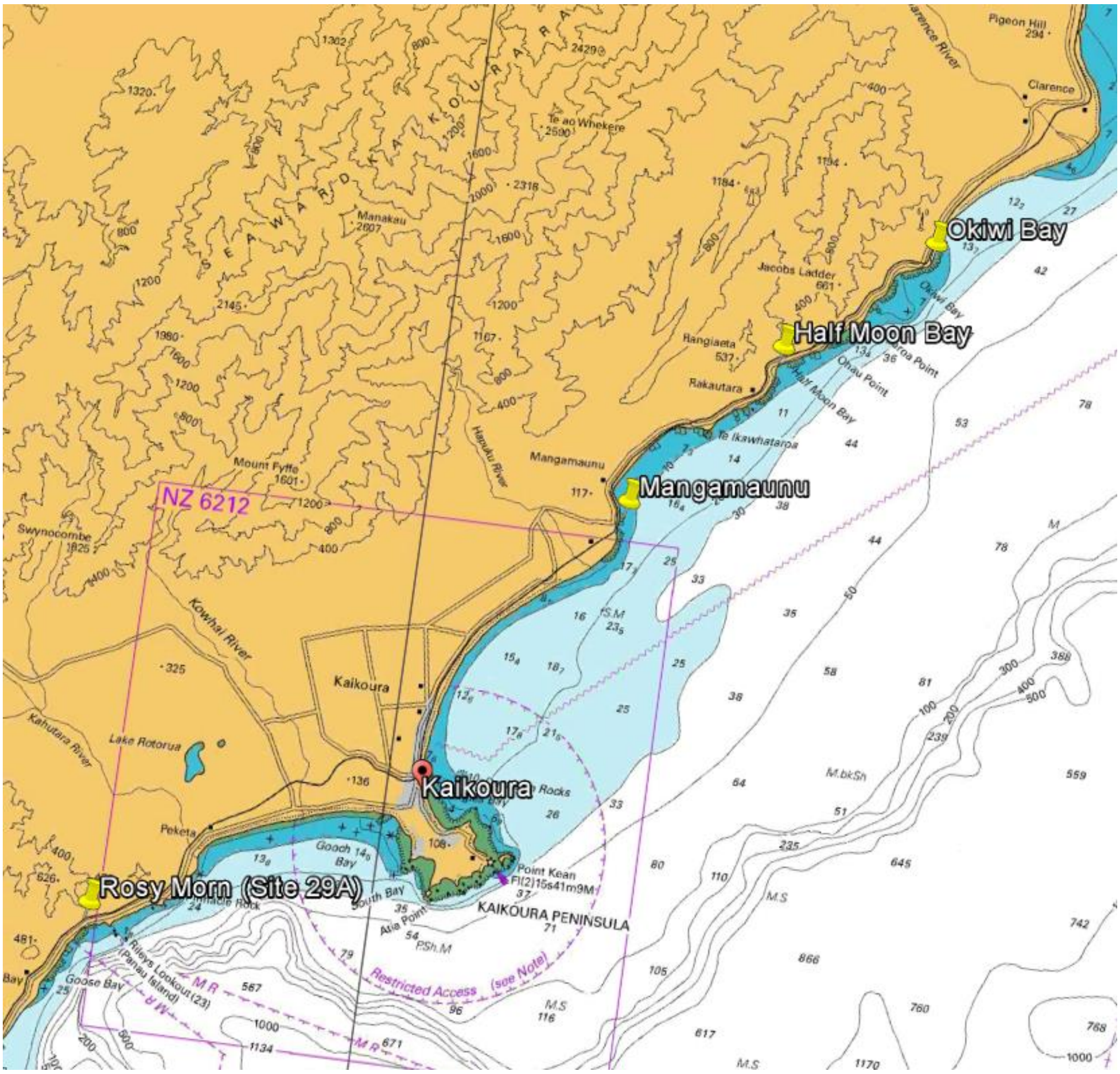

Figure 1 General topographic features and bathymetry along the coastal road and rail route showing locations of amenity and resilience areas (Source: LINZ Hydrographic chart)

3 Describing the assets and activities

The damage to the road and rail network as a result of the Kaikōura earthquake requires significant works to restore the function of both networks. This application provides for design amendments to already authorised works as a result of further detailed design and investigation since the originally consented design was developed. The works will contribute to the full, safe and effective operation of SH1 and the MNL. Detailed design continues on these works including the ongoing involvement of specialists to ensure the best practical design, construction and environmental outcomes.

The three sites/areas assessed in this application are as follows:

1. Mangamaunu
2. Half Moon Bay
3. Okiwi Bay South

Details of the proposed works are described in the AEE.

3.1 General description of the proposed works

The significant majority of works in these areas are located landward of the new Mean High Water Springs (**MHWS**), which has shifted in a seaward direction as a result of uplift following the earthquakes. Notwithstanding this, some works are located in close proximity to and sometimes within the Coastal Marine Area (**CMA**) and involve varying degrees of reclamation and occupation.

The general description of the activities and restoration works for NZ Transport Agency and KiwiRail are included in the Assessment of Environmental Effects (AEE) for the works – refer to the drawings in the appendices of the AEE. The main structural coastal components of the proposed works are:

i A sloping rock armour or concrete armour unit revetment, and where existing beach sediment is available under the proposed road footprint, that this material is excavated and placed seaward of the structures to effectively relocate the beach to form a natural system in front of the revetment.

All works have been designed taking into account the present day geological hazards, coastal processes and forces for construction and long-term resilience needs, sea level rise predictions and landform setting/ visual impacts, using the following design philosophy:

- Limit encroachment of protection structures seaward of the present day Mean High Water Springs (MHWS) where practicable.
- Provide erosion protection to withstand a 100 year joint probability extreme wave and storm surge event inclusive of an additional 0.5 m sea level rise as a result of climate change.
- Maintain existing levels of service with regard to overtopping.
- Retain existing beach form, including beach cobbles, gravels and sand seaward of proposed erosion protection structures.
- Maintain or enhance access to the CMA at selected areas along the route.

Where practicable, any hard engineering should mimic the coastal form and character. The construction phase should be managed to ensure that any high energy events do not compromise the activities.

3.2 Construction process

A Construction Environmental Management Plan (CEMP) is in place for all works to manage the potential effects of the construction activities. The construction process as it applies to the coastal environment includes the following activities:

1. Excavation and transfer of existing beach deposits further down the beach/reef face to prepare subgrades and foundation levels for coastal protection structures. This would largely be done by hydraulic excavators and other earth moving machinery and initially the material would be placed to form a bund to protect the works area from possible wave action while construction activity took place and then redistributed to form a sloping foreshore in front of the protection works.
2. Excavation and works to prepare foundations into the rock reef platform. This would be done by large hydraulic excavators to rip the upper layer of weathered rock and to move existing boulders to form the foundation connection on the rock reef. Excavated rock material would be used as part of the fill while existing boulders would be moved to the seaward side to be retained on the foreshore and reef top areas.
3. Placing the rock armour for toe protection works.
4. Machinery and access for works on the upper beach and reef areas within a 5 m wide corridor seaward of the toe of the protection works. While much of the work will be carried out from

within the construction footprint, some machinery will need to operate on the seaward side of the proposed works.

4 Describing the environment

The shoreline along the transportation route can be characterised as rock foreshore with numerous headlands, platforms and points which create small enclosing bays (Boffa Miskell, 2012). These bays are often the location of small creek outlets or gullies. The main geomorphic features in this area are the steep Kaikōura Ranges that extend along the coast from Te Ikawhataroa Point to just north of Okiwi Bay, and are bound by the fluvial plains adjacent to Kaikōura and the Clarence River. The fluvial plains adjacent to Kaikōura are formed from sediment discharges from the Kahutara, Kowhai, Hapuka and Puhi Puhi Rivers.

4.1 Topography and bathymetry

The ranges extend up to 1100 m in this area, although along the coastal route more typical elevations of the peaks are between 400 to 540 m. There is a very narrow shelf of eroded rock reef platform before depths reach 10 m below Chart Datum as shown on Figure 1. The seabed slopes gently (100H:1V) along the continental shelf from the 10 m to 130 m contour before rapidly reaching depths of more than 3 km along the Hikurangi Trench (refer Figure 1).

The 130 m depth corresponds roughly to the level of the sea during the last glacial maximum 20,000 years ago, when massive ice sheets locked up large volumes of the planet's water. The progradational surface deposits of the shelf are 1–1.5 km thick, having accumulated since the mid-Quaternary, 24 million years ago. Underneath this deposit lie shallow marine sediments up to 138 million years old, from the Oligocene to the Late Cretaceous, above Permo–Jurassic greywacke up to 280 million years old (Herzer, 1979).

4.2 Coastal sediment

The coast between Goose Bay and the Clarence River mouth is generally steep slopes and eroding cliff and shore platform cut largely in Pahau terrane rocks (Rattenbury et al. 2006), composed in part of greywacke and in part of Tertiary sedimentary rocks. With the exception at Kaikōura, rivers and streams flow to the ocean out of incised valleys. The smaller rivers and streams that drain the coastal ranges are typically found ponded behind gravel barrier beaches. At Kaikōura the rivers flow to the ocean across steep alluvial fans. The longest beaches are the barriers of mixed sand and gravel fronting the alluvial fans on either flank of the Kaikōura Peninsula.

Kirk (1985) identified the shore configuration between the Hapuku River and Okiwi Bay were dominated by high wave energy – a function of the direct exposure to the Pacific Ocean and the narrow, embayed continental shelf which focusses wave energy and minimises wave energy losses by sea-bed friction. The shores consist of narrow wave-cut shore platforms and offshore reefs that are the eroded remnants of former shore platforms. Debris from the erosion of the shore-platform are transported into the small pockets and embayments and tectonic uplift has played a role in preserving some of these deposits.

The main sediment source for these coasts are from erosion from the reef, shore platform and backshore deposits and this is supplemented by coarse sediments from streams and landslides from the catchment. There appears to be a delicate state of balance between sediment supply and dispersal by the high wave energy (Hicks, 1988). Mangamaunu is more directly supplied from the Hapuku River, with coarser cobbles, boulders and gravels remaining on the delta and finer sediments being transported along to Mangamaunu Beach.

4.3 Currents

This section regarding the larger scale currents operating off the Canterbury coast is taken from Hart et al. (2008).

Canterbury's diverse continental shelf and coastline are strongly influenced by the position of New Zealand at the crossroads of at least five major oceanic water masses. The ocean's top 200 m consists of the warm, saline and nutrient-poor Subtropical Surface Water (STW) in the north, and the cold, less saline but more nutrient-rich Sub-antarctic Surface Water (SAW) in the south. Vertically stacked in the deeper waters beneath are the Antarctic Intermediate Water, Pacific Deep Water and Bottom Water (refer Figure 2).

The locations and extents of these important water masses are not fixed but, rather, move around both seasonally and from year to year, with mixing occurring across their boundaries. After heating up in the central Pacific, the STW flows south along the east coasts of Australia and New Zealand in the form of the East Australian Current and the East Auckland Current. The latter current gives rise to the East Cape Current, which flows south along the eastern North Island to a transition zone off Canterbury. This forms part of the global Subtropical Front (STF), a large and continuous convergence zone where the warm STW meets the cold SAW moving north from the Southern Ocean. The STF stretches south of Tasmania across the Tasman Sea to southern New Zealand, where it occurs between 40 and 45°S (refer insert Figure 2). Locally referred to as the Southland Front (SF), it wraps around the eastern South Island from Stewart Island to just south of Kaikōura, and then is diverted out across the continental shelf (refer Figure 2).

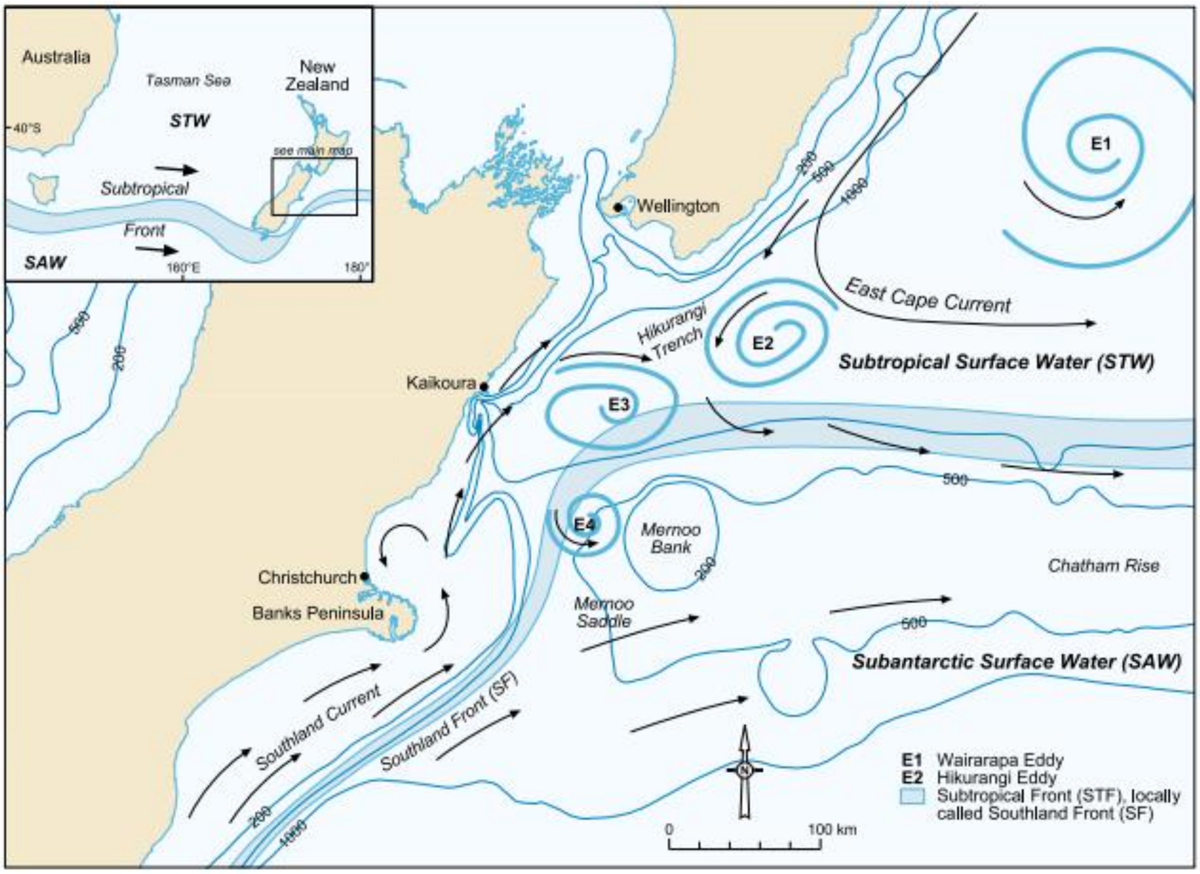

Figure 2 Major ocean current systems along the east coast of central New Zealand (Source: Hart, et al 2008)

Here it follows the 15° and 10°C isotherms in summer and winter respectively, corresponding to waters with 34.7 and 34.8 parts per thousand of salt. Since marked changes in temperature and salinity take place within the water column, the exact geographical location of the front varies from season to season.

Oceanic circulation close to the coast is shaped by the interaction of surface and deep-water masses with the coastal and offshore bathymetry, shallow wind-driven circulations, and the tides. The tidal wave first approaches the south-west coast of the South Island of New Zealand. From there it travels through Foveaux Strait and north along the east coast of the South Island for about two and a half hours to Banks Peninsula, reaching Kaikōura after a further hour. The tidal regime is semidiurnal, with around 12 hours 34 minutes between successive high tides.

4.4 Tide and extreme water levels

Level information is available in NZVD-2016 NZVD, Lyttelton Vertical Datum (LVD-1937) and Lyttelton Chart Datum (LCD). LVD is 0.389 m below NZVD (i.e. add 0.389 to NZVD values to convert to LVD). LCD is 1.15 m below LVD or 1.539 m below NZVD.

4.4.1 Tide levels

Table 1 shows the tidal water levels at Kaikōura from the Nautical Almanac (LINZ, 2016). These levels can be considered representative of the coast between Kaikōura and the Clarence River.

Table 1 Nautical tide water levels calculated at Kaikōura (LINZ, 2016)

Tide stage	m LCD	m LVD	m NZVD
Mean High Water Springs	2.0	0.9	0.5
Mean High Water Neaps	1.6	0.5	0.1
Mean Sea Level	1.1	0.0	-0.4
Mean Low Water Neaps	0.5	-0.7	-1.0
Mean Low Water Springs	0.2	-1.0	-1.3

The nautical Mean High Waster Springs (MHWS) is 0.5 m. ECan's MHWS is 0.625 m NZVD, the pragmatic MHWS10[1] is 0.64 m NZVD and the Highest Astronomic Tide[2] is 0.825 m NZVD. These levels do not take into account wave swash and run-up that can extent landward of these elevations on this open coast location. The ECan level of 0.625 m NZVD is be used to represent the design level of MHWS.

4.4.2 Extreme water levels

Water levels play an important role in determining nearshore coastal processes by controlling the amount of wave energy reaching the backshore during storm events (refer Figure 3). Key components that determine water level are:

- Astronomical tides
- Barometric set-up and wind effects, generally referred to as storm surge
- Medium-term fluctuations, including seasonal effects, El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) effects commonly called mean sea level anomaly (MSLA)
- Onshore wave transformation processes through wave set-up and run-up
- Predicted long-term changes in sea level due to climate change

[1] This is the tide level exceeded by 10% of the high tides each year.
[2] The Highest Astronomic Tide is the highest tide level as determined by the sun, moon and planets that occurs around once every 18.6 years. It does not include for surges and storm tide that occur due to wind and wave breaking processes.

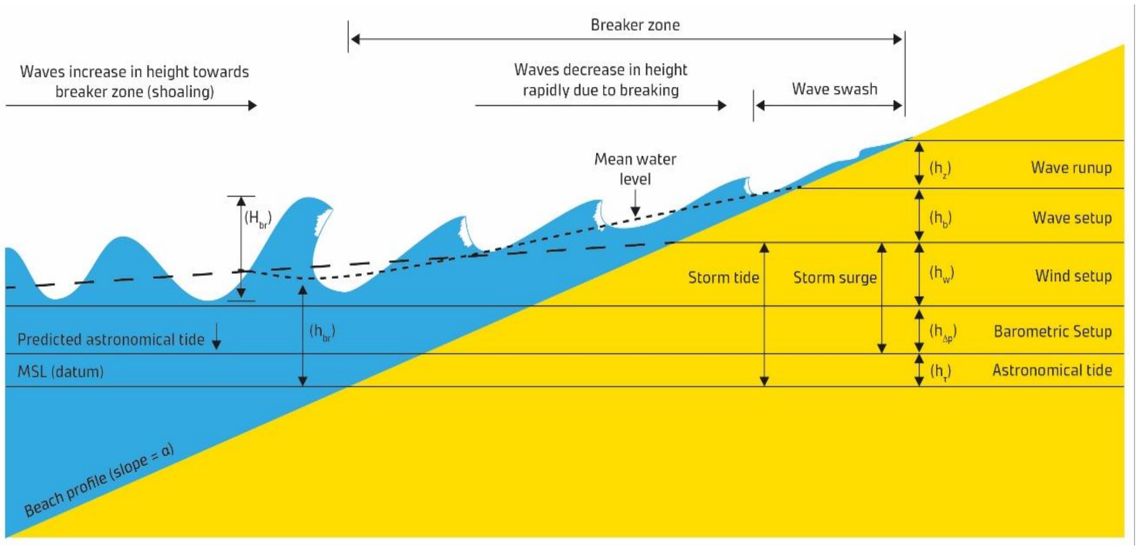

Figure 3 Schematic illustrating sources of coastal-storm inundation

4.4.3 Storm tide

The NIWA coastal calculator shall be used to derive extreme water levels resulting from the joint probability of tide, including inter-decadal oscillations and storm surge and present information in terms of Mean Level of the Sea (MLOS). This calculator interpolates extreme water levels for coastal locations north and south of Kaikōura (see Figure 4). Examples of extreme levels are set out below:

10% AEP Storm tide (from Table 6-4, NIWA 2015) = 1.34 m + 0.189 m = 1.53 m LVD

1% AEP Storm tide (from Table 6-4, NIWA 2015) = 1.43 m + 0.189 m = 1.62 m LVD (1.23 NZVD).

The extreme water levels determined by NIWA's coastal calculator do not take into account wave swash and run-up that can extend landward of these elevations on this open coast location.

4.4.4 Wave set-up

Wave effects include wave set-up and wave run-up. Wave set-up is a local elevation in the mean water level on the foreshore, caused by the reduction in wave height through the surf-zone. Wave run-up is the sum of the wave set-up and the wave swash and is the maximum level that the waves reach on the beach relative to the still water level.

Wave set-up and nearshore wave height will be assessed using a combination of empirical and numerical modelling tools including NIWA's coastal calculator and methods set out in the Rock Manual and Gourlay (1997) specifically for reef coasts, Unibest-LT (numerical wave transformation model) and SBEACH (numerical wave transformation model) to provide nearshore wave heights and wave set-up values to use to develop wave forces and as boundary conditions to assess overtopping.

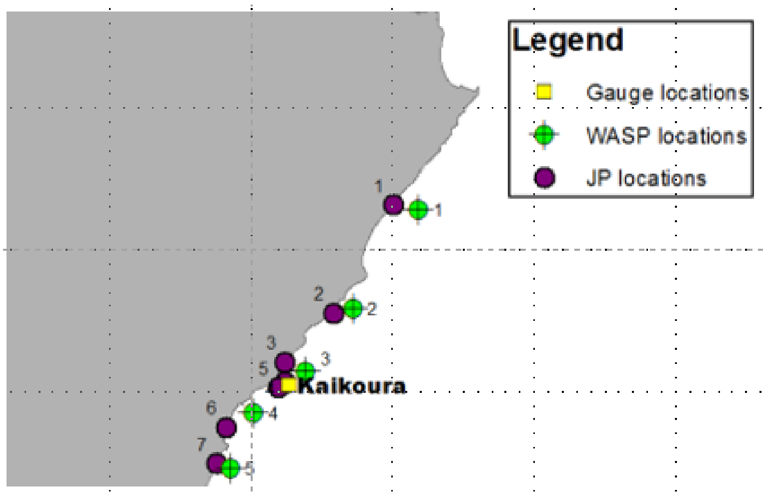

Figure 4 Location of wave output points used in the coastal calculator (Source: NIWA, 2015)

4.4.5 Fluvial flood levels

Due to the absence of significant river systems along the majority of the route, the combination of fluvial flooding with storm surge and high tide is not be considered.

4.4.6 Sea level rise

The effect of these events on coastal protection and coastal processes will change with increasing sea level rise. Sea level rise projections at 2070 for the commonly used emission trajectories (i.e. RCP2.6, RCP4.5, RCP8.5 range from 0.32 to 0.45 m above the 1986-2005 baseline. The sea level rise value for the 83rd percentile of RCP8.5 is 0.48 m. Therefore a value of 0.5 m of sea level rise provides a conservative value for the design life of the works. It is noted that over the next 100 years these values could increase to be between 0.55 m and 1.36 m based modelled projections and therefore the designs will need to be modified/upgraded to take into account the additional wave forces that could occur due to the higher water levels and the associated changes at the coast.

4.5 Wave climate

4.5.1 Offshore wave height

Annual wave heights and directions have been derived from nearshore wave hindcast data from MetOcean Solutions Ltd (MSL). Extreme offshore wave height has been obtained from NIWA as included in the Coastal Calculator and checked with the MSL wave hindcast data.

4.5.1.1 Annual offshore wave climate

A wave rose of wave height and direction plotted from MetOcean's hindcast in shown in Figure 5. Figure 6 shows the relationship with wave height and period. This data is extracted from a hindcast model node at 173.837E, 42.254S, in water depth of 21 metres over a 33 year period (1979 to 2012).

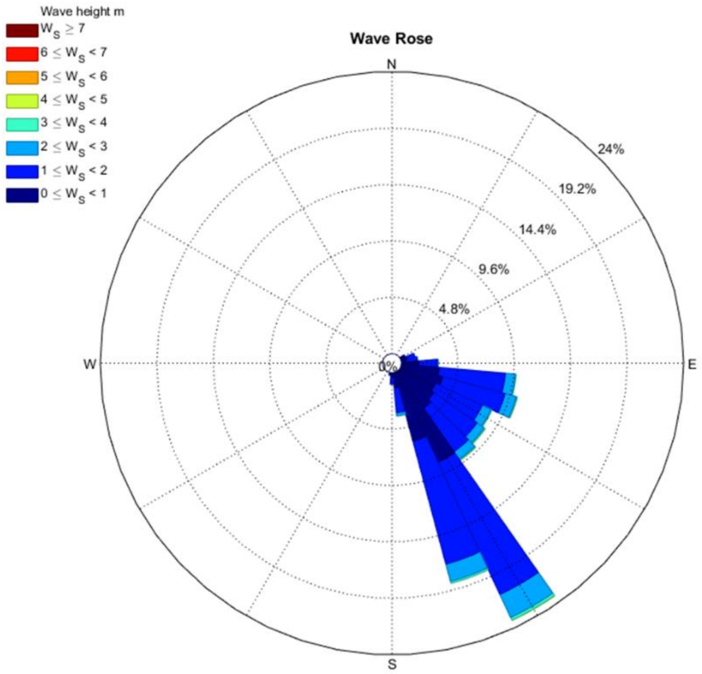

Figure 5 Wave rose showing wave height and direction at output node 173.837E, 42.254S (Source: MSL)

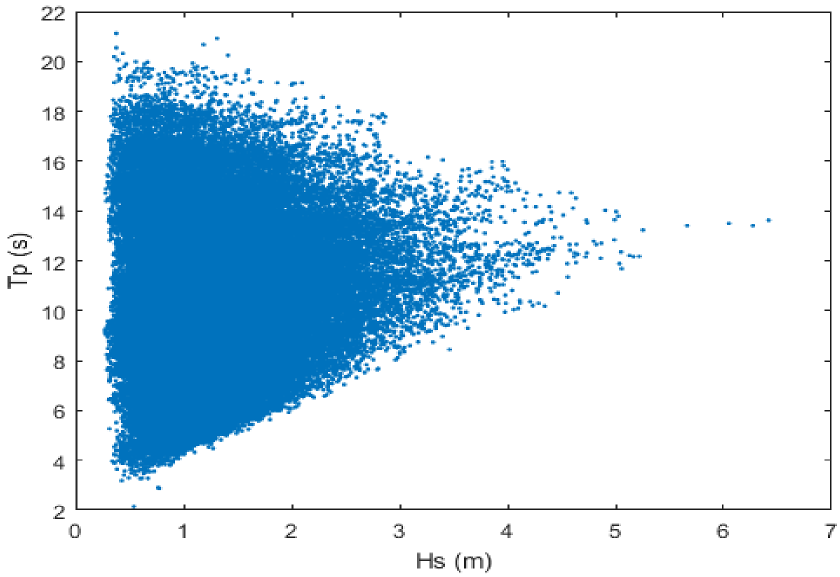

Figure 6 Wave height and period relationship from MSL hindcast data

The results from these figures shows waves are predominantly from the south-east and as wave heights increase the peak wave period goes to around 12 to 14 seconds.

4.5.1.2 Extreme offshore wave heights

Error! Reference source not found.(NIWA, 2015) give joint probability for the significant wave height (Hs) and storm tide level relative to MSL at Location 3, north of Kaikōura. NIWA's extreme wave height assessment has been scaled by 1.5 to provide results they consider more realistic.

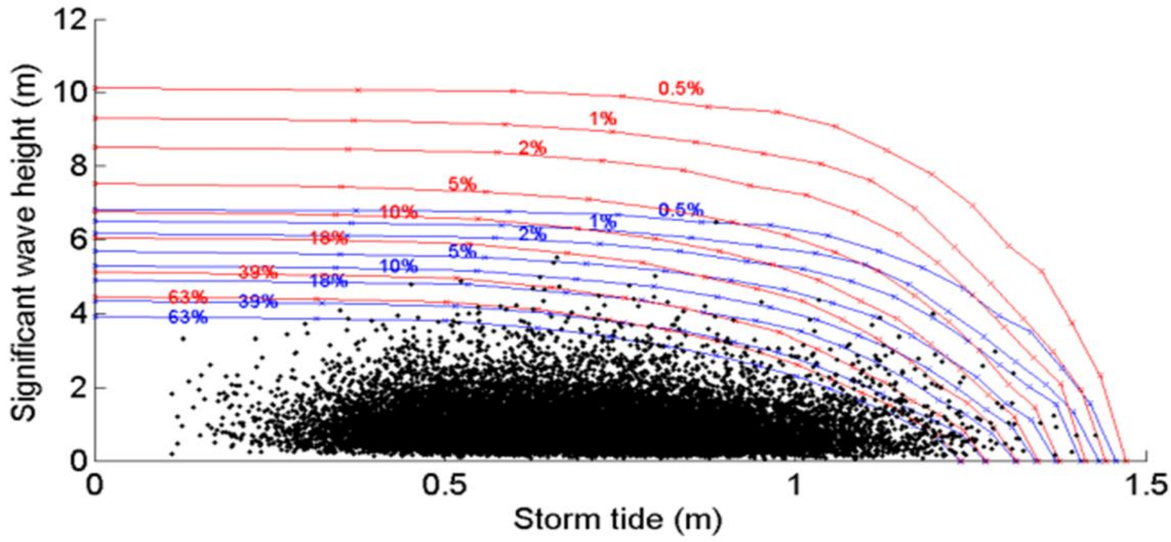

Figure 7 Joint probability of significant wave height and storm tide in terms of MLOS at JP3 north of Kaikōura including model results (blue lines) and scaled results (red lines). (Source: NIWA, 2015)

4.5.1.3 MSL wave hindcast

An extreme event analysis of the MSL hindcast is shown in Figure 8.

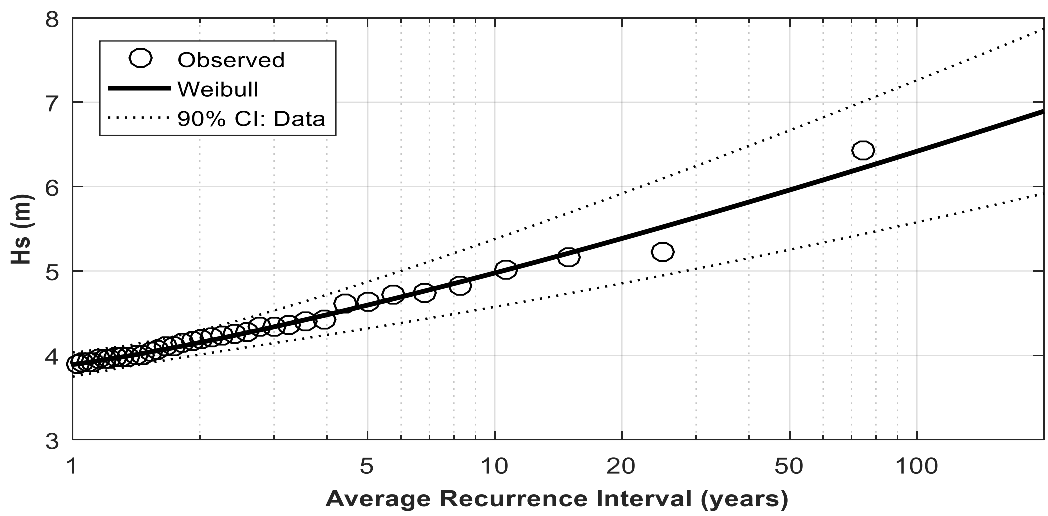

Figure 8: EVA analysis of MSL hindcast data

4.5.1.4 Comparison of NIWA and MSL data

Table 2 shows a comparison of the two hindcast data sets for a range of Annual Recurrence Intervals. The results show NIWA tends to predict higher waves occurring at the more frequent recurrence intervals, but for the 100 year AEI (1%AEP) both hindcasts show reasonable agreement. It is noted that NIWA used a global scaling of 1.5 on all the wave height estimates. This scaling is likely to result in the overestimation at more frequent ARI's.

Table 2 Comparison of extreme event analysis from NIWA and MSL with projected significant wave height (H_s) and confidence intervals (CI)

ARI	NIWA Coastal Calculator		MSL wave hindcast	
	H_s (m)	H_s, 95% CI (m)	H_s (m)	H_s, 90% CI (m)
1	4.7	5.2	3.9	4.0
2	5.1	5.6	4.2	4.3
5	5.5	6.2	4.6	4.9
10	5.8	6.6	5.0	5.5
20	6.0	6.9	5.4	6.1
50	6.3	7.3	6.0	7.0
100	6.5	7.6	6.4	7.7
200	6.6	7.9	6.9	8.4

4.5.1.5 Joint probability of wave and storm tide

Joint probability of wave and storm tide is to be done using the NIWA coastal calculator. It**Error! Reference source not found.** shows a series of lines for different AEP events to evaluate the combined effects of waves and storm tide.

4.5.2 Nearshore wave heights

Wave transformation to the nearshore will be carried out using the same approach used to evaluate wave set-up. This will include a combination of empirical and 1D numerical modelling tools including NIWA's coastal calculator and methods set out in the Rock Manual and Gourlay (1997) specifically for reef coasts, Unibest-LT (numerical wave transformation model) and SBEACH (numerical wave transformation model) to provide nearshore wave heights and wave set-up values to use to develop wave forces and as boundary conditions to assess overtopping. Figure 9 shows an example of the numerical wave transformation model Unibest-LT.

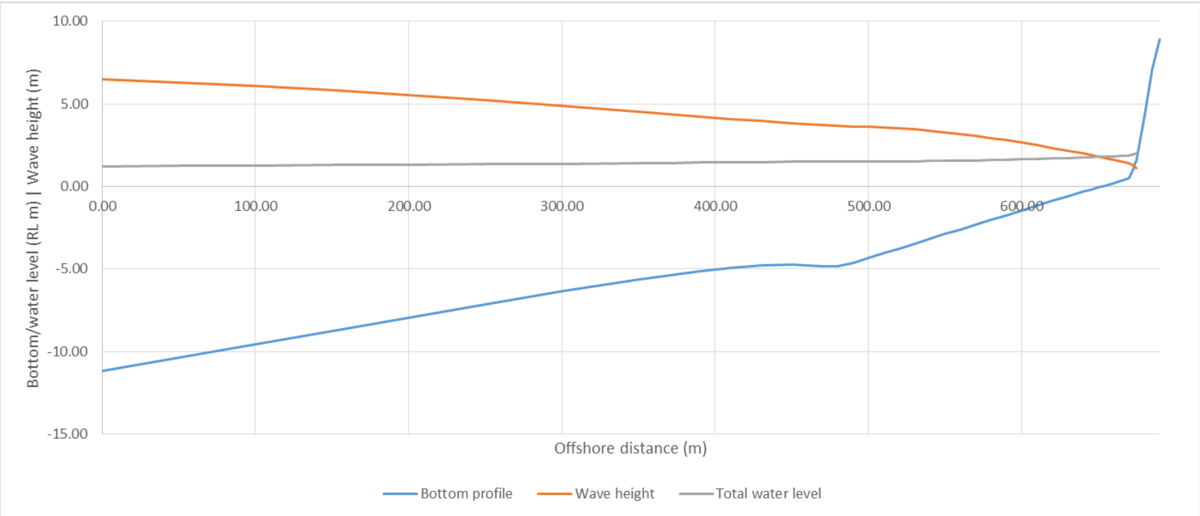

Figure 9 Example of Unibest-LT output showing cross-shore wave height and water level transformation

4.6 Historic storm observations

Historic storm observations were documented in Stephens et al (2015). The only site with observations of the effect of historic storms was at the small embayment just north of Ohau Point. At this location it was noted that the top of the beach overtops regularly in storms and floods where the road had an elevation of 5.8 m LVD or around 5.4 m NZVD. Cyclone Giselle (April 1968) also caused widespread flooding along the coastal route. Just south of the project area and north of Kaikōura, storm debris was observed at 6.64 m LVD (6.251m NZVD) during the February 2002 storm.

4.7 Surf breaks

The earthquake and the associated uplift has changed where the tide levels break on the foreshore, with the high tide now where the low tide used to be. This has created areas where there are now more frequent surf breaks and other areas where surfing is adversely affected with the nearshore raised too high. This prevents wave breaking on the shallower bathymetry.

Within the project area, just south of Site 1, there is a nationally significant surf break at Mangamaunu (refer Figure 1). This break is top rated with a right hand point break with a stone/boulder beach. The uplift will have created a change in the environment and it is likely that some period of adjustment to the cobble foreshore will occur with the change in wave energy within the nearshore environment.

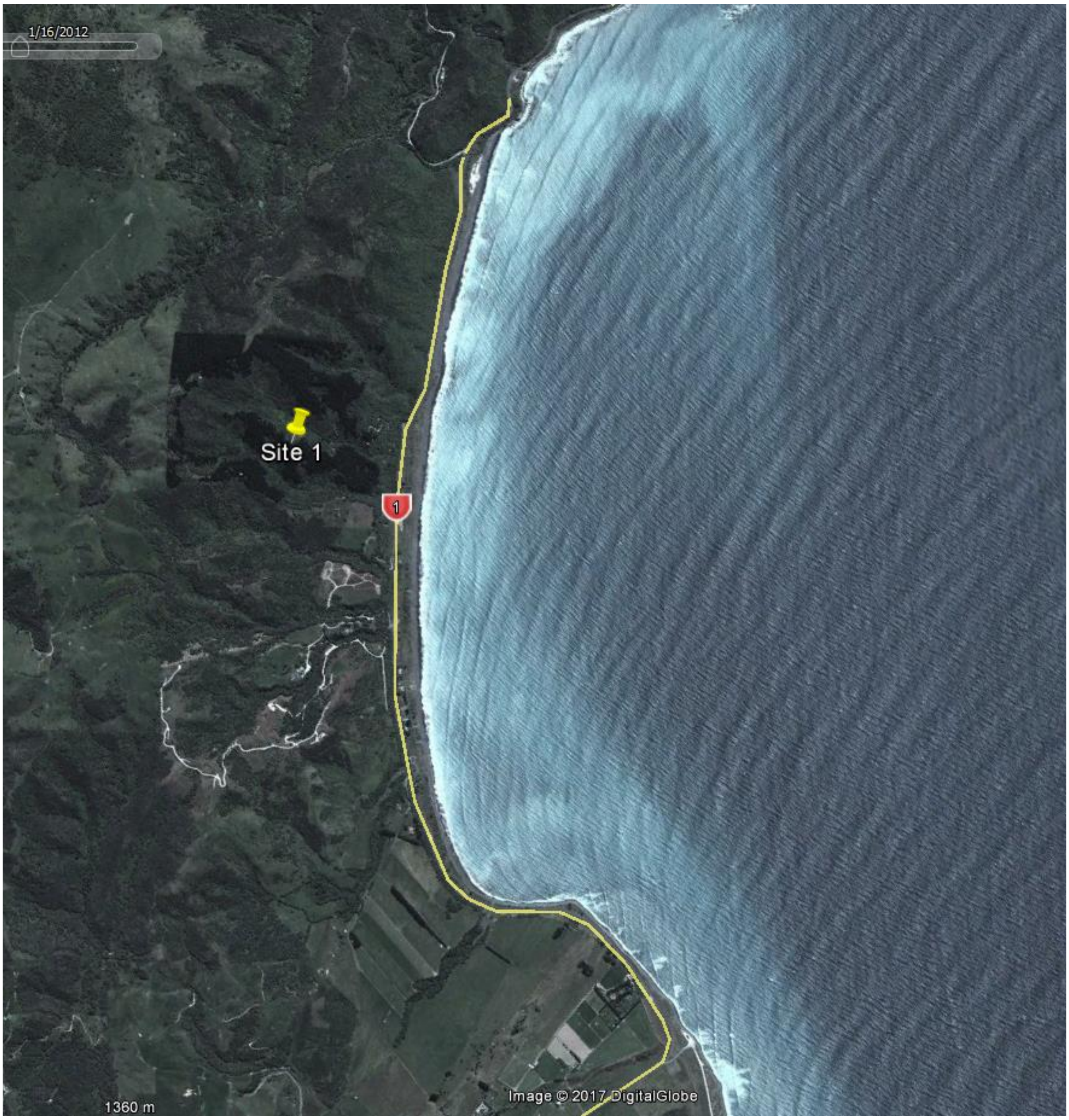

Figure 10 Surf break at Mangamaunu Beach (Source: GoogleEarth dated 16/01/2012)

4.8 Sediment transport

As discussed in Section 4.2 the sediment supply to this area is generally from streams discharging to the coast and from landslides and cliff erosion as well as from supply from the more major rivers system. The rate of supply is limited to episodic events. The sediment transport pathways are both offshore and alongshore. The high energy wave climate combined with a narrow and relatively steeply sloping foreshore results in offshore directed transport for the finer sediments with the net northward directed sediment transport direction along this coast is largely driven by wave climate and the prevailing northward direction of the Southland Current (Cochrane and Male, 1977). This transport of finer sediments creates turbid water in the nearshore area that can be clearly seen in the satellite image in Figure 10.

4.9 Erosion rates

4.9.1 Reef edge coasts

There is no detailed information on erosion rates in published literature. However, the width of the reef platforms can give an indication of erosion rates along cliff coasts by assuming that these shelfs were at a similar location around 6,500 years ago when sea levels reached around the present location after the Holocene rise. This assumption does not take into account the potential for uplift and extension that may offset. Using Google Earth and making an estimate of the seaward extent of the reefs along the coastline suggests typical erosion rates of 2 to 3 m per century and possibly up to 5 m per century. At Ohau Point where more detailed bathymetric survey data is available, the same analysis process suggests an erosion rate of 2.5 m per century. Downcutting of the reef platform is also anticipated. However there is less reliable information on rates for this. Assuming 10% of the horizontal erosion rate suggests downcutting in the order of 0.2 to 0.5m per century.

4.9.2 Soft shores

Erosion can occur both on hard coasts (cliffs) and soft coasts (beaches). For the Hapuku delta, the location of the surf break, erosion is more a function of changes to the sediment supply from the river system. While no data exists for sediment discharge rate, experience from other catchments that have experienced uplift, suggest there will be a period of time of lower rates of supply to the coast while the river cuts down to pre uplift levels.

At Mangamaunu Beach, cliff erosion at the northern end of the beach can influence the long term trend of the beach, as with the cliff eroding there is increased potential for sediment from the beach to be transported to the north. There is no detailed information on erosion rates in published literature.

There is no clear indication from the limited historic aerial imagery that the beach is suffering long term erosion. This intuitively seems likely as the beach is close to a potential source of sediment from the Hapuku River. This means that the most likely cause of erosion is due to storm events which can be temporal, causing erosion of the beach and then the beach recovering after the storm. However visual inspection shows that edges around the delta experience episodic erosion during significant events and this may become more likely in the future as a result of sea level rise.

We have calculated the potential erosion of the beach profile under storm conditions using Shingle-B, an empirical shingle beach profile tool developed by Wallingford http://www.coastalmonitoring.org/shingle/. This has been run using a profile from the site in front the landslide at Site 1 (Chainage 600) with a storm wave height of $H_{m,o}$ = 6.24 m, a still water level of RL1.23m and a period of 9.5s (i.e. 1% AEP storm conditions).

The before and after storm profiles below show that up to 10m of landward erosion could occur at the 4m contour during a 1% AEP storm event with the elevation dropping over 1 m to RL2.75m. Figure 11 also shows the gravels and sand move down the beach and are available for returning to the upper beach after the storm event, although some sediment may also be lost to alongshore drift.

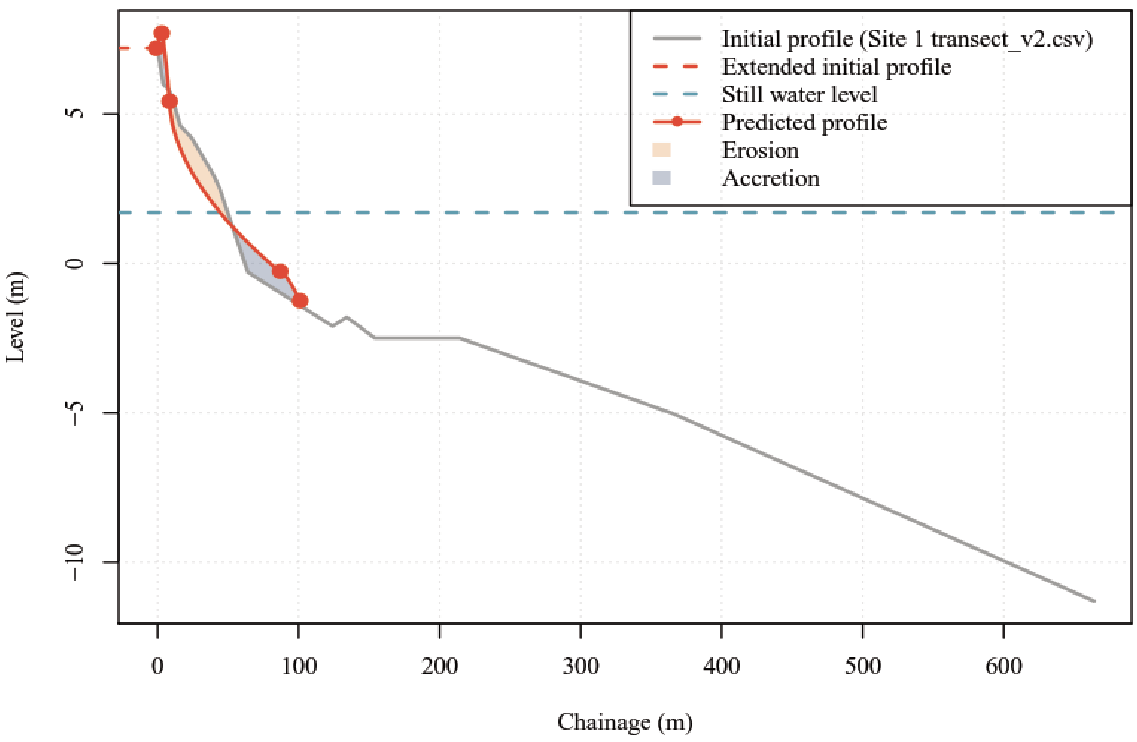

Figure 11: Modelled profile change using the empirical model Shingle-B

4.10 Effect of the Kaikōura earthquake

The Kaikōura earthquake has resulted in uplift along the coast with the location of MHWS effectively moving seaward. This occurred both along the sandy/gravel beaches as well as on the rock reef outcrops.

Figure 12 shows the general coastal uplift recorded along the coastline and Table 3 shows the translations required to apply to the pre-earthquake LiDAR data to match the post-earthquake road position. Translations were required along the x and y axis (horizontal) as well as vertical axis (z) to match the road position and elevation. This table shows that the uplift ranged from around 0.6 m at Mangamaunu and increasing up to 3.05 m at Site 8 then reducing towards Site 9. Based on the results at Site 1 and the information on Figure 12 it has been assumed that similar uplifts occurred at Site 28A. It is noted that Mangamaunu had the lowest level of uplift. This may be because the depth of alluvial sediment at the river mouth delta offsetting some of the uplift with settlement of the granular layers compared to those areas where the rock platform was more directly exposed on the foreshore.

The uplifts resulted in a seaward movement of MHWS ranges between 5 to 40 m, with the average change in the order of 20 m. To the north of Ohau Point MHWS moved more significantly, ranging from around 20 to 100 m with an average change of around 30 m.

In areas where uplift of the rock platform has occurred there will be increased reduction in wave energy on the beach face with the coastal processes effectively moving seaward. However, it is likely that this movement is limited to the rock mass, with the softer sediments on the seabed offshore unlikely to have been uplifted to the same degree, or if they have been, that wave processes will cause erosion of the seabed in the shallower areas to occur, reducing levels to pre-earthquake conditions.

The earthquake has created the likelihood of significant increases to the volume of sediment supplied to the coast over time from catchment landslides, with the coarser faction likely to remain on the upper beach shelf and finer sediment transported offshore. It is uncertain how long this additional sediment supply would continue for, but it is likely in the more embayed area that the increased supply to the coast could result in accretion.

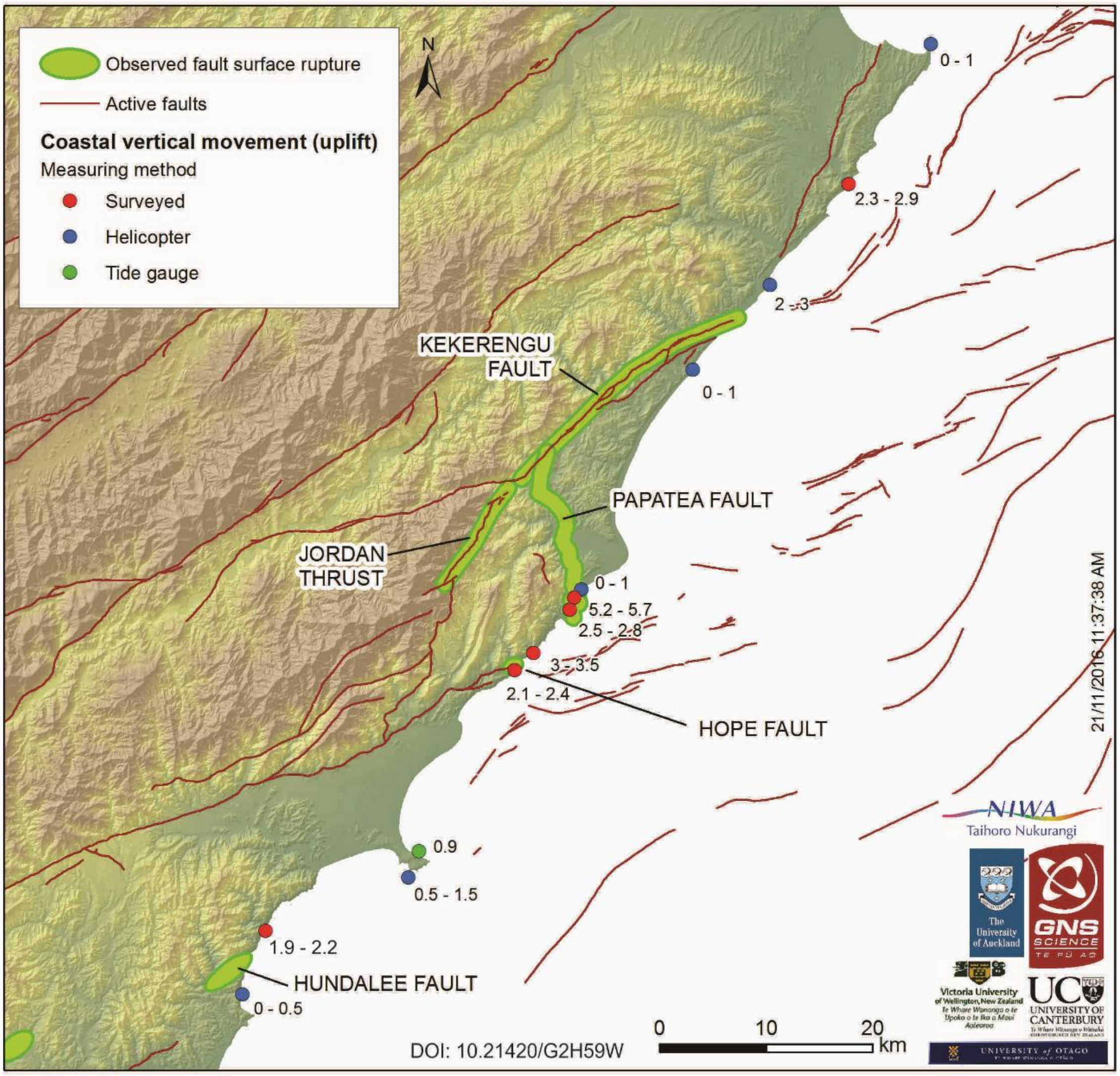

Figure 12 Coastal vertical movement along the Kaikōura coast (Source: Clark et al., 2016)

Table 3 Translations required at each site to match road position with the pre and post LiDAR surveys

Site Name	Delta X (m)	Delta Y (m)	Delta Z (m)
Site 1 and Site 29A	0.65	-2.15	0.80
Mangamaunu	N.D.	N.D.	0.60
Site 2	1.87	-2.64	0.80
Site 3	0.95	-2.43	2.37
Site 4 & 5	1.51	-2.62	2.40
Site 6	1.26	-3.28	2.35

Site Name	Delta X (m)	Delta Y (m)	Delta Z (m)
Site 7	1.32	-3.63	2.35
Site 8	1.45	-3.58	3.05
Site 9	2.23	-4.50	2.30

4.11 Tsunami

The Kaikōura coast is different from the rest of the Canterbury coast as the biggest threat is from tsunamis generated close to the coast that could reach shore in less than one hour[3]. While there are no written records of a destructive tsunami from close to shore hitting the Kaikōura coast, there are purakau (Maori stories) of taniwha coming out of the sea and grabbing people off the beach. Kaikōura could also be affected by tsunamis from the south of Fiordland, northeast of the North Island or from across the Pacific Ocean.

GNS Science prepared *Review of Tsunami Hazard in New Zealand (2013 Update)*. It uses modelling to calculate probable tsunami heights around the New Zealand coast over 500 year and 2500 year time periods, taking into account a range of different tsunami sources. Information on the maximum tsunami amplitude at the coast within a 20 km open coast cell is provided around the country. Table 4 provides the 500 and 2,500 year return period tsunami amplitude (P50%) for the Clarence and Kaikōura coastal cells. The 500 year return period tsunami is around 5 m and the 2,500 year tsunami is around 8 m.

Table 4 Summary of the maximum 500 and 2,500 tsunami amplitude for the Clarence and Kaikōura coastal cells (Source: GNS, 2013)

Coastal cell	500 year	2,500 year
Clarence River	4.9 m	7.9 m
Kaikōura coast	5.0 m	7.8 m

4.12 Summary of coastal process and hazards

4.12.1 General assessment

Generally the locations considered in this application are characterised by an exposed steep and eroding rocky foreshore with small pockets of cobble beach environments in embayed locations that are sheltered by the reef environments and the various headlands along the coast.

The coast is exposed to relatively high wave energy, particularly during southerly storm conditions, but low tidal currents. Historically there has been limited sediment supply to the area. The wave energy was balanced with sediment supply to create an environment where finer sediment is transported both offshore and alongshore and the coastline is in a slight erosional state. The erosion rates are typically low due to the rocky nature of the shoreline.

Historically the coastal hazards that affected the transportation route have been storm effects that damage the edge of the road corridor. The main erosion damage occurred in areas where the road corridor had been formed by a cut to fill embankment that was impacted by wave action during storm events at high tides. Coastal inundation and wave overtopping the road has also occurred

[3] http://www.crc.govt.nz/advice/emergencies-and-hazard/tsunami/pages/kaikoura.aspx

during storms with documented debris lines that reached elevations of 6.3 m NZVD in embayed areas.

The earthquake has resulted in an effective seaward translation of coastal processes due to the uplift experienced. This has resulted in less wave effects on the higher parts of the uplifted coastline. It has also generated significant sediment supply due to landslips both along the coast and within the catchments that discharge to the coast. This is likely to result in increased sediment supply over a period of decades since the earthquake compared to the previous period of time.

4.12.2 Mangaumanu

Mangamaunu Beach is located on the northern edge of the Hapuku River Delta. The coast at this location comprises moraine deposits, glacial outwash gravel and local fan gravels at silts at the delta some of which have been transported along the coast to form the beach. The beach is backed by moderately steep ranges with numerous small valleys that drain to the coast.

The coast is exposed to relatively high wave energy, particularly during southerly storm conditions, but low tidal currents. The beach has been supplied by sediment discharged from the Hapuku River and from transport from the delta. The beach growth is limited due to episodic sediment supply from the river and the headland control to the north.

The earthquake has resulted in an effective seaward translation of coastal processes due to the 0.6 m uplift experienced in this area. This has resulted in less wave effects on the higher parts of the uplifted coastline. It has also generated significant sediment supply due to landslips both along the coast and within the catchments that discharge to the coast. This is likely to result in increased sediment supply over a period of decades since the earthquake compared to the previous period of time.

Historically the coastal hazards that affected the transportation route have been storm effects that damage the edge of the road corridor. Coastal inundation and wave overtopping the road has also occurred during storms with documented debris lines that reached elevations of 6.3 m NZVD in embayed areas.

Based on an assessment of storm cut and sea level rise effects, the present profile has the potential to retreat by up to 15 m over the next 50 years at the RL4m contour due to storm processes and 0.5 m sea level rise, the majority of this retreat (10m) is storm induced and episodic, with the beach likely to recover after storms.

5 Option consideration

More detailed descriptions of the preferred options are presented in Section 3 of the AEE. The following options were considered:

I. Do nothing

II. Rock armour revetment

III. Berm (dynamic) revetment

IV. Concrete armour units (Xbloc)

5.1 Rock armour revetment

A rock revetment is formed from a geotextile filter fabric overlain by a cushioning layer of small rock and protected from wave energy by larger rock armour placed on a formed slope. They are conventional land protection structures that have been used widely internationally and there are detailed and accepted standards for their design (CIRIA C683, 2007, USACE, 2006). The high porosity provided by the voids (typically 40%) between the rocks, together with the slope, provide a form of wave energy dissipation reducing both the reflected wave and wave overtopping. Rock armour slopes typically range from 1.5(H):1(V) to 3.0(H):1(V) with lower slopes requiring more construction material but enabling the use of smaller rock and resulting in less overtopping.

Rock revetments are widely used in areas with important backshore assets subject to erosion and their function is to reduce the erosive power of waves by means of energy dissipation. They have a medium to high capital cost, but low ongoing maintenance costs. They provide good long term protection to the land behind the structure and are able to be extended or modified for future shoreline change and are typically lower cost than grouted stone walls.

Kraus and McDougal (1996) attributed much of the concerns about the potential adverse effects of seawalls and revetments on beaches to a lack of distinguishing between 'passive erosion' and 'active erosion'. Passive erosion is defined as being caused by "*tendencies which existed before the wall was in place*" and active erosion as being "*due to the interaction of the wall with local coastal processes*". Of passive erosion, Kraus and McDougal stated that whenever a seawall is built along a shoreline undergoing long-term net erosion (recession), the shoreline will eventually migrate landward behind the structure resulting in the gradual loss of beach in front of the seawall as the water deepens and the shore face profile migrates landward.

Dean (1986) presented a list of nine possible and often suggested effects of seawalls on adjacent shorelines and beaches then critically examined these postulations and concluded (Basco et al., 1996, Basco, 2004) the following (bracketed numbers are potential effects as shown in Figure 13):

Dean found that armouring of a beach does NOT cause:

- Profile steepening (6)
- Delayed beach recovery after storms (5)
- Increased longshore transport (8)
- Sand transport further offshore (9)
- Increase in long-term average erosion rate (3).

Dean found that armouring of the beach CAN contribute to:

- Frontal effects (toe scour, depth increases, 1a)
- End-of-wall effects (flanking; 1b)
- Blockage of littoral drift when projecting in surf zone (groyne effect; 4)
- Reduced beach width fronting armouring (2).

Overall, Dean recommended seawalls should be used only:

1 On a hard rock shoreline to limit flooding by wave overtopping or erosion of an overlying softer material

2 On a soft shore coast when a coastline is generally in a state of dynamic equilibrium and the wall is intended to stop the most landward extent of erosion during storm events, with the expectation that the fronting beach will recover over time (i.e. a backstop wall)

3 On a soft coast where long-term erosion is occurring but there is a significant asset to protect which cannot be relocated. In this case it should be accepted that the fronting beach will be lost and erosion of adjacent land may be increased. The structure should therefore be continued alongshore until it abuts an erosion-resistant structure such as headland, or to a point where continued erosion is permissible.

For the transport corridor situation 1 largely applies.

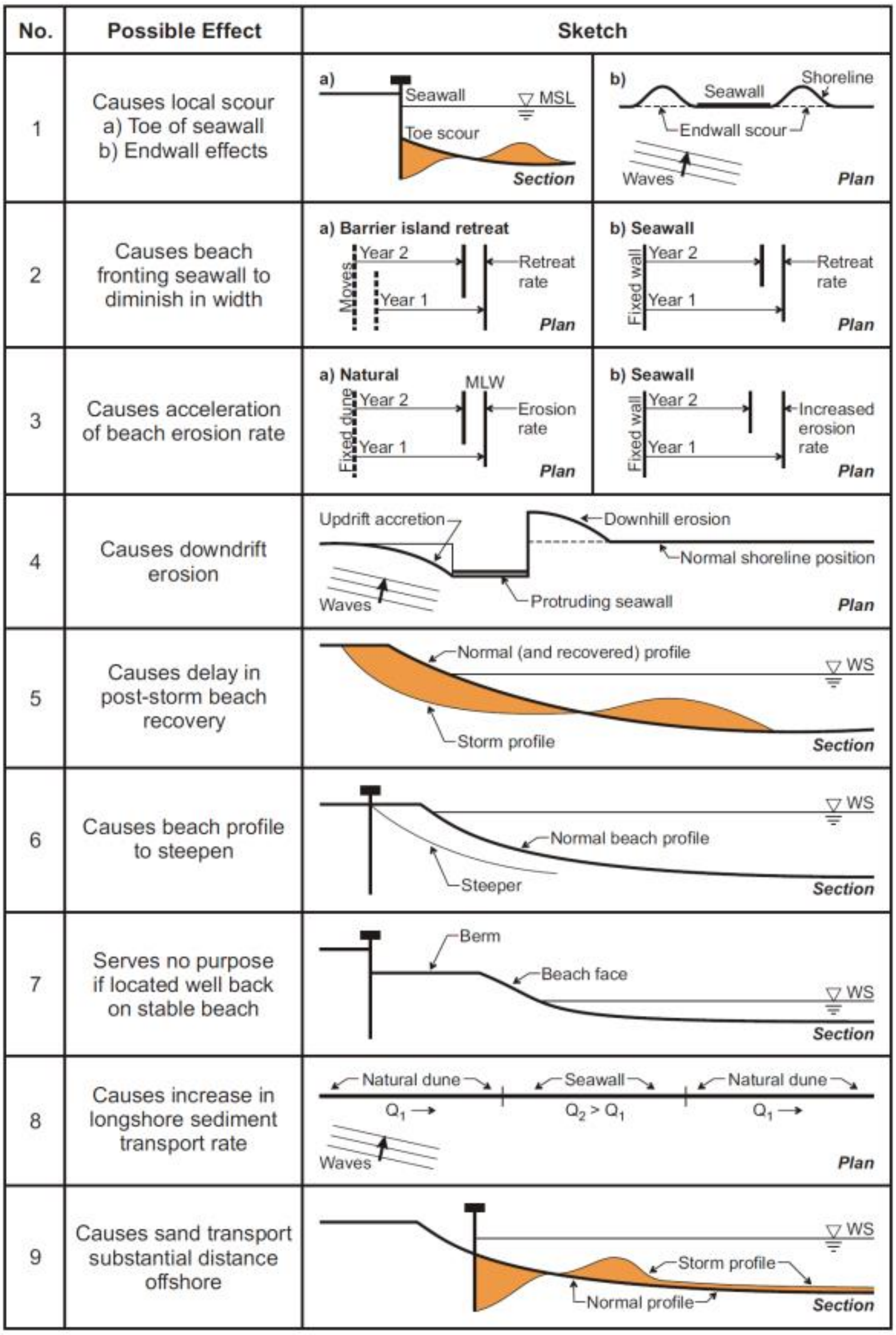

Figure 13: Commonly stated effects of seawalls on adjacent shorelines and beaches (Carley et al., 2010 after Dean, 1986)

5.2 Berm (dynamic) revetment

A berm (dynamic) revetment are a credible option for these locations. This structure uses smaller more homogenous mound of rock that can adjust to the incident wave climate. The advantage of this structure is the use of smaller rock. The disadvantage is that they can take more room on the seabed/foreshore than a more steeply sloping revetment.

A preliminary assessment of dynamic revetment design using the method of Van Der Meer based on an average rock armour mass (W50) of 300 kg. This shows a dynamically stable structure could be feasible in terms of rock size, but the width of the structure increases the risk of losing material offshore. However, the volume of well graded rock required is between 50 and 80 m^3/m length of shoreline. This option requires a larger volume and occupies more space than a conventional revetment, extending well seaward of the MHWS position and was not considered suitable for that reason.

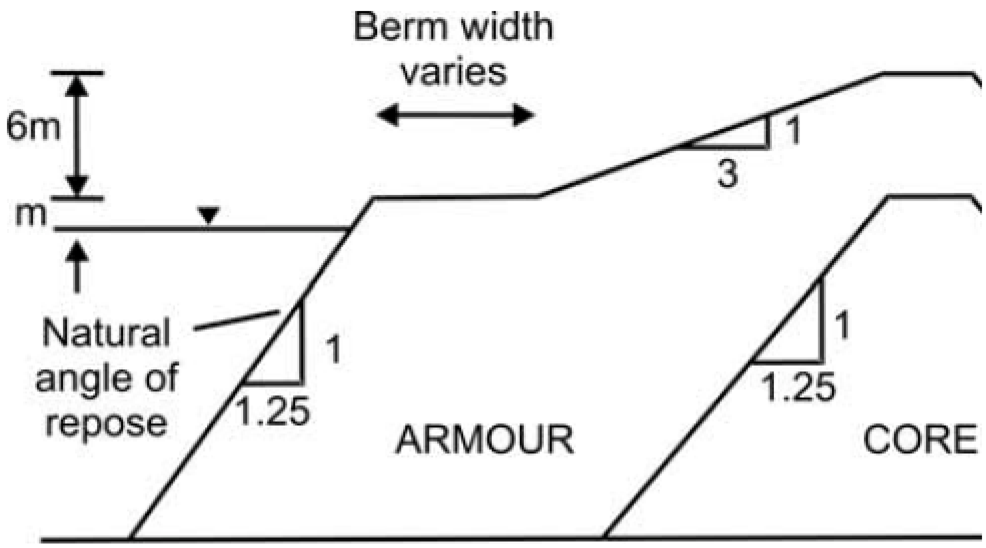

Figure 14 Typical features of a berm breakwater (Source: CIRIA/CUR C683, 2007)

5.3 Concrete armour unit (Xbloc)

Xbloc is a single layer interlocking concrete armour unit that has been designed to protect breakwaters and shores over the long term and in extreme conditions (http://www.xbloc.com/). This system could be considered to form a revetment if rock armour of a suitable size was not available.

Design guidance suggest their smallest unit, a 0.75 m^3 block on a 1(V):1.5(H) slope can withstand a design significant wave height of 3.35 m. While a technically feasible option provided a robust key in detail was developed to anchor the toe units, advice from the contractors is that due to the limited number of moulds available to form the structure, that it would take too long to cast the units for the length of shoreline that is required to be protected and were not considered practicable.

5.4 Discussion of options

The results of this assessment show that a conventional rock armour or concrete armour unit revetments are feasible solutions at these locations where structural protection is required. This is due to there being a rock reef platform that is wider resulting in greater wave breaking. Xblocs will be likely at Half Moon Bay, while rock armour revetments are feasible at other locations.

For the amenity areas the footprint of the rock revetment is kept as small as practicable by:

a Locating the path as landward as practicable

b Lowering the path and crest or armour level accepting overtopping rates similar to present day

c Retaining any excavated beach sediment seaward of the revetment structure.

6 Effects on the coastal environment

This section identifies actual and potential effects that the coastal environment may have on the assets and their function over the asset lifetime as well as effects of the asset on coastal processes.

In consideration of the potential effects, all potential effects are considered negative.

6.1 Effects of coastal environment on proposed works

It is recognised that the proposed structures will occupy the upper beach and foreshore areas. The other actual and potential effects that the coastal environment may have on the assets and their function over the asset lifetime (considered at 50+ years) include:

- Storm waves with increasing wave height in the nearshore due to sea level rise resulting in erosion and damage to assets and infrastructure
- Wave run-up and overtopping causing flooding, debris accumulation and damage and maintenance requirements for assets on the transport corridor
- Tsunami damage.

These actual and potential effects are discussed in the following sections.

6.1.1 Erosion and damage to revetments

The transportation corridor is bounded by the coast and the steep ranges. Both the proximity to the coast and the reasonably energetic wave environment present at this location means that the entire corridor is potentially susceptible to coastal process effects either now, or in the future as part of sea level rise.

The Kaikōura earthquake has alleviated some of these effects both by the uplift experienced, the associated seaward movement of the MHWS and the expected ongoing increased supply of sediment to the coast from the catchments as a result of landslides and stream and gulley erosion processes. Some of these effects are expected to be more temporary than others. Uplift of the rock reef areas are expected to provide increased reduction in wave height and overtopping for a reasonably long time period due to the low rates of erosion and downcutting. In alluvial areas the uplift effects may be more transient, although it is expected that the benefits will be present for at least several decades.

However, where the proposed works extend closer towards or seaward of the MHWS boundary they will be subject to increased wave energy and this wave energy is likely to increase over time as a result of sea level rise increasing the water depth in the nearshore that allows greater wave heights to reach the coastline.

The increased wave energy may potentially:

- increase instability of rock armour on the coastal revetments
- increase the rate of shoreline erosion on the alluvial (mixed sand gravel) shores
- increase the rate of downcutting and erosion of the rock reef.

The potential risks to the assets, including effects of sea level rise have been considered in the design of these assets over the expected design life of around 50 years. The other risks of increased erosion and downcutting of the natural system should be monitored and the effects reviewed at no less than 10 yearly increments.

6.1.2 Wave run-up and overtopping effects

Due to the existing elevations there is no likelihood of permanent inundation (i.e. the parts of the transport corridor becoming permanently situated under future MHWS) occurring along the transport corridor as a result of sea level rise over the expected life of the asset.

Wave run-up and overtopping during significant onshore storms are physical processes that are unlikely to be able to be totally avoided due to the coastal location of the transport corridor. These processes are also likely to increase in the future as a result of sea level rise as nearshore wave heights are likely to increase. These processes have the potential to cause flooding, debris accumulation and damage and maintenance requirements for assets on the transport corridor.

In the present day the uplift and seaward progradation of the MHWS experienced as a result of the Kaikōura earthquake has largely mitigated the likelihood of the frequent run-up and overtopping that was observed along the lower elevations of the transport corridor. However, there are locations where this may still occur during the more extreme storm events coinciding with a high tide.

As the works are largely located at existing ground levels, a similar overtopping environment will occur at the location of these works, requiring maintenance and clean up after significant events.

6.1.3 Tsunami effect on the design

Predicted tsunami heights are of a similar magnitude to wind induced waves, but due to the tsunami wavelength there are significantly different forces. The proposed structures are not specifically designed to withstand full tsunami forces. However, based on the observation of seawall and revetment failure following the tsunami generated by a 9.0 MW earthquake in Japan (Kata et al. 2012) the following failure modes were identified in order of significance:

1. Failure from scouring at the landward toe – this is applicable to raised dykes and bunds which are not a feature of the proposed design.
2. Failure from the crown or the top of landward armour – this is caused by the fast flow at the top of the landward slope. If there is no landward slope this feature is not likely to be significant.
3. Failure from scouring at seaward toe – the revetments are largely to be founded on the rock reef so scouring is not likely to be a significant issue. However, the tsunami is likely to remove any beach deposits and could dislodge some armour units resulting in localised failure of parts of the seawall.
4. Seismic motion – this needs to be considered in the geotechnical design of the fills.

The structures proposed generally do not have the features that resulted in the observed failure in Japan.

6.2 Long term effects of the assets on the coastal environment

This section describes the long term effects of the proposed coastal protection works specifically in relation to coastal processes operating along this area.

Generally the effects are limited due to the proposed design being set back (landward) of the present MHWS location (and generally around the MHWS location prior to the earthquake) and the use of a sloping relatively permeable rock armour or concrete armour unit fronted by a cobble remnant beach. The rock armour toe and remnant beach will perform very similarly to the previous coastal edge and no significant change to wave processes are expected. Wave reflection rates are likely to be in the order of 20 to 40% (CIRIA/CUR, 2007). These rates are similar to the reflection rates of mixed sand gravel beaches that tend to reflect more energy than both sand and shingle beaches (De San Román Blanco, 2003).

6.3 Potential effects on nationally significant surf break at Mangamaunu Point

The proposed works around Mangamaunu Point and the surf break are associated with the provision of a shared cycle/footpath and an amenity area. Due to the constraints of the rail corridor and the narrow reserve in this area, the revetment works associated with protecting the edge of the shared path will extend onto the upper beach system, but will not extend seaward of MHWS. As discussed in Section 6.2 above, the rock revetment is likely to reflect slightly more energy than the existing cobble beach, but will not be exposed to wave energy apart from during significant onshore storm events when wave set-up and run-up exceed around 3.5 m RL. This is likely to occur once or twice a year. During storm events the crest of gravel and cobble beaches tend to move landward.

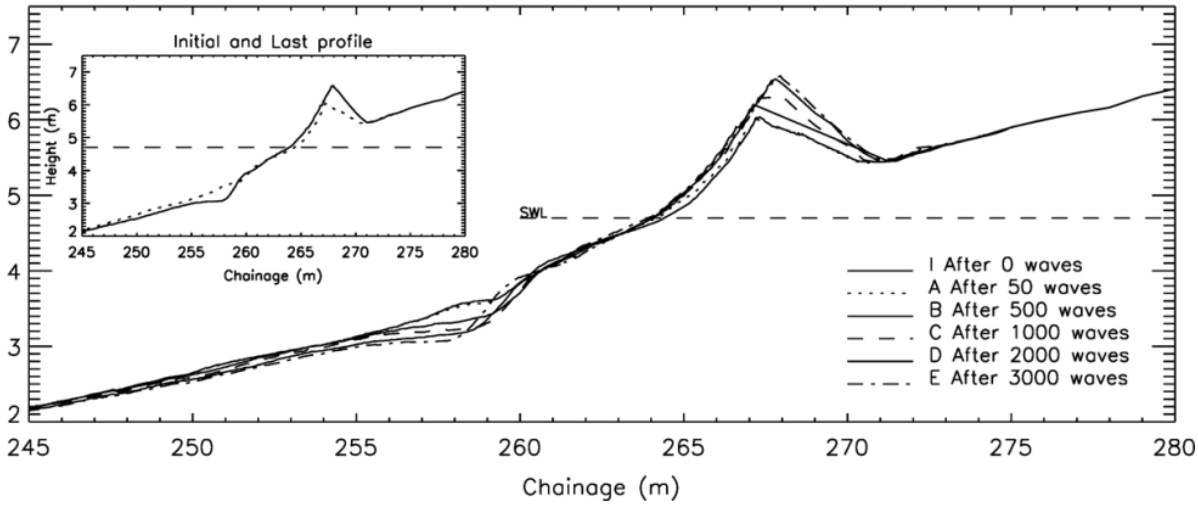

Figure 15 Physical model study showing the crest profile of gravel beaches increasing during storm events (De San Roman Blanco, 2003)

The process of landward migration of gravels and cobbles during storms will assist in screening the rock revetments, further minimising the potential effect of wave reflection.

The potential adverse effects of the rock revetment on reflected waves is limited by the combination of:

- Limiting the footprint of the rock revetment by locating as far landward as practical
- Keeping the crest elevation low
- Relocating any beach sediment excavated in the formation of the subgrade of the revetment to the seaward side of the placed revetment
- The natural process of onshore gravel migration during storm events.

As a result of the above any small increase in wave reflection that occurs during significant onshore wave events at high tide levels is not anticipated to result in adverse effects seaward of MHWS.

6.4 Construction effects

The majority of construction processes on the upper foreshore areas is related to excavation and movement of existing beach sediment and rock boulders that occupy some areas proposed to form the road and rail corridor and the foundations of the protection works. These works occur over a relatively short length of the route and will be carried out over short sections to manage the risk of storm damage and sediment discharge.

The beach sediments that originally were acted on by tidal and wave forces are expected to be largely free from fines and silts, although there may be a greater proportion of finer sediments in the upper part of the beach systems which may have been delivered to the area by landslides and from abrasion and wind-blown material from the intertidal beach/reef face. Based on visual observation during the site visit, the amount of fine sediments is still expected to be low in these area.

The result of moving the existing beach sediment to clear the construction area is likely to release some fines to the coastal marine area where the bund is within the swash zone of the beach/reef system and can be periodically be acted on by waves. This is likely to manifest as a zone of slightly higher turbidity in the wave breaking zone. However, during higher wave energy events there is also likely to be significantly greater turbidity in the nearshore surf zone with higher levels of suspended sediment concentrations resulting from natural wave breaking processes and abrasion.

Overall the construction effects on the coastal processes operating on this area are anticipated to be less than minor.

7 Assessing the risk of coastal effects

This section provides a qualitative risk assessment of the effects of coastal erosion, inundation and tsunami to the infrastructure corridor and proposed works near to, and influenced by, the coastal environment over the intended 50 year design life. The assessment criteria is as set out in the coastal effects assessment guideline (NZ Transport Agency, 2017).

Table 5 Risk assessment of coastal effects at the sites where works are proposed

Description of coastal effects	**Risk assessment**			**Risk mitigation/comment**
	Likelihood	**Consequence**	**Risk level**	
Coastal erosion	Unlikely	Medium	Moderate	The rock and concrete armour unit sloping revetment will reduce erosion risk, but due to lower crest elevations, a lower level of service is provided for shared path assets compared to the road asset.
Inundation and overtopping associated with storm surge, wave run-up, set up and sea level rise.	Likely	Low	Moderate	Inundation to the road assets will be reduced, but due to lower crest elevations, a lower level of service is provided for shared path assets compared to the road asset.
Structural damage to revetments from wave energy, including allowance for sea level rise.	Unlikely	High	High	Size rock and armour units to withstand 1%AEP storm event with 0.5 m Sea Level Rise.

Description of coastal effects	Risk assessment			Risk mitigation/comment
	Likelihood	Consequence	Risk level	
Structural damage to Revetments through scour and downcutting.	Unlikely	High	High	Risk mitigated be having foundations keyed into rock or below typical beach envelope.
Adverse effect on nationally significant surf break due to coastal processes	Unlikely	High	High	Avoiding any works below MHWS.
Adverse effect on nationally significant surf break due to occupation of beach area above MHWS	Likely	Moderate	High	Reduce crest elevation and shared path width, locate as far landward as practicable.
Tsunami induced damage	Unlikely	High	High	The design has not specifically considered tsunami, but key design features included in the design should assist in limiting the effect in those areas where works are done. Risks exist in other areas of the transport corridor.
Tsunami induced inundation	Unlikely	High	High	Managed through civil defence and emergency response.

Table 6 Risk assessment of effects on coastal processes at sites where works proposed

Description of coastal effects	Risk assessment			Risk mitigation/comment
	Likelihood	Consequence	Risk level	
Exacerbate coastal erosion in adjacent and adjoining areas at rocky reef sites.	Low	Low	Low	Rock coast, location of proposed works generally above MHWS and retaining beach sediments in front of assets minimise the potential risk.

Description of coastal effects	Risk assessment			Risk mitigation/comment
	Likelihood	Consequence	Risk level	
Exacerbate coastal erosion in adjacent and adjoining areas at Mangamaunu.	Low	Low	Low	Works generally above MHWS and retaining beach sediments in front of assets minimise the potential risk.
Impact on wave run-up and set-up at rocky reef sites	Low	Low	Low	Rock coast, location of proposed works generally above MHWS and retaining beach sediments in front of assets minimise the potential risk.
Impact on wave run-up and set-up at Mangamaunu	Low	Low	Low	Location of proposed works generally above MHWS and retaining beach sediments in front of assets minimise the potential risk.
Construction effects resulting in discharge of sediments to the CMA	Low	Low	Low	Proposed construction approach and retaining beach sediment seaward of constructed works minimises this potential risk.

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