Claverley Coastal Hazard Assessment Review

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Hurunui District Council

Hurunui District Coastal Hazards
24 November 2023

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Prepared by: Kate MacDonald

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Jacobs New Zealand Limited

Level 2, Wynn Williams Building
47 Hereford Street
Christchurch Central 8013
PO Box 1147
Christchurch 8140
New Zealand

T +64 3 940 4900
www.jacobs.com

Executive summary

In July 2023, following king tides, a coastal storm, and a heavy rainfall event, there was a slope failure in the road embankment along Claverley Road, which backs a mixed sand and gravel beach system. This resulted in 6-8m of horizontal erosion, significant damage to the road restricting access to farms to the north of the slip, and the loss of lateral support to the Main Trunk Railway Line. At the same time, the Claverley community reported anecdotally 7 m of erosion in front of the settlement, and wave runup over topping the beach ridge reaching some properties. This event has prompted a review of the Jacobs (2020) coastal hazard assessment to revisit the appropriateness of the input data and analysis used to map the future inundation and erosion hazard.

An analysis of available data identified that it is likely that the cause of the road slip failure at Claverley Road was a result of a combination of factors. In the days leading up to the road failure, king-tides occurred which elevated astronomical water levels. On the 4th July there was a moderate coastal storm (1 in 2 to 5 year Annual Recurrence Interval). The coupled king tides and moderate storm event likely resulted in combined high water levels and wave run-up elevations that could interact with the toe of the road embankment, which could have resulted in some initial removal of the toe by waves during the highest tides.

Antecedent rainfall conditions over the month prior to the failure event likely caused saturation of the road and rail embankment foundations, possibly contributing to the failure of the slope in the heavy rainfall event on the 8-9th July. Seepage into the road and rail embankment foundations is believed to have led to a reduction in strength of the foundation material, potentially contributing to the failure. However, there is not sufficient data to confirm the significance of this reduction in strength of the foundation material, to the failure at this stage.

In light of the new information gathered through this assessment, the inputs to the Jacobs (2020) coastal hazard assessment were reviewed to identify appropriate updates that could be undertaken to refine the modelling. These updates included:

- Updated SLR increments to account for more recent IPCC (2021) SLR projections, and incorporate Vertical Land Movement (VLM) from the NZSeaRise Programme
- Updated shoreline reference position along Claverley based on recent road slip and improvements.
- The short-term factor was updated to 10 m along Claverley Road to account for the recent slip failure and possibility of a larger event occurring in the future. In front of the Claverley settlement the short-term factor was updated to 7 m to account for anecdotal evidence during the same event.
- A 'short term storm' line was produced which help better communicate the risks of an individual storm happening in the near future.
- Recalculation of erosional impacts of SLR using updated SLR projections.
- Inundation modelling of static water levels re-mapped using more recent 2020 LiDAR.
- Wave runup modelling remapped using combined Powell (1990) wave runup calculations combined with attenuation distance calculations from Cox and Machemehl (1986).

At Claverley settlement the updated projected future shoreline positions indicated that the shoreline could intersect with 1 property boundary over the next 30 years, increasing to 2-3 over the next 50 years, and 7-9 over the next 2120 (e.g. most properties in the seaward row of the settlement). Existing dwellings are not projected to be impacted directly by coastal erosion under any of the SLR scenarios. Due to the increase in the short-term erosion component in light of the July 2023 event, the exposure of Claverley Road has significantly increased, where in a present-day storm up to 185 m of Claverley Road could be exposed to erosion; increasing to 200-210 m over the next 30 years; 240-255 m over the next 50 years; and 290-325 m over the next 100 years. This updated assessment indicates that section of Claverley Road between the rail bridge underpass south to the Settlement is very susceptible to coastal erosion, and if another significant storm were to occur (and protection failed), a significant length of the road would be damaged.

For coastal inundation, the extreme static water levels mapped for a 1% AEP showed results similar to the Jacobs (2020) assessment, that the extreme static water levels under all scenarios do not overtop the gravel beach ridge, and are not projected to reach any properties under any of the timeframes or SLR scenarios assessed. Updated wave runup calculations and mapping indicate that in a present day 1% AEP event waves could overtop the gravel ridge and run up to the most seaward properties, causing temporary inundation. The analysis of wave runup using the new method also showed that wave runup is very sensitive to wave period, and therefore the long wave periods that were recorded on the 4th July 2023 could have produced high wave runup elevations that reached several properties, as observed by residents at the settlement.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to a review of the coastal hazard assessment undertaken in 2020 for Claverley in accordance with the scope of services set out in the contract between Jacobs and Hurunui District Council (‘the Client’). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

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This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

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1. Introduction

In 2020 Jacobs undertook an assessment considering present day coastal hazards and how these hazards could change with projected climate change scenarios over the next 100 years. The assessment considered coastal erosion, coastal inundation and rising groundwater level hazards at six settlements along the Hurunui District coastline. This assessment considered how these hazards would interact with the Claverley Beach settlement, including the 13 dwellings at the settlement, and Claverley Road to the north of the settlement (Figure 1.1).

A summary of the results of the assessment for Claverley is as follows:

- The Claverley settlement resides behind a high elevation (6.5-7m LVD37[1]) beach ridge of a mixed sand and gravel beach system, that has historically been stable/accreting.
- The settlement is unlikely to be at significant risks to coastal hazards with SLR over the next 100 years. Erosion in front of the settlement was projected to be 3-7 m over the next 30 years; 3-10 m over the next 50 years; and 4 to 17 m over the next 100 years. These projected erosion shoreline positions intersected with two properties over the next 50 years, and up to 8 properties over the next 100 years, however the projected shorelines did not intersect with any dwellings across any scenarios.
- Erosion along Claverley Road to the north of the settlement could be between 8-9 m over the next 30 years 10-12 m over the next 50 years, and 19-22 m over the next 100 years. The assessment acknowledged that the rail underpass would be at risk within the next 30 years, 150 m of Claverley Road would be impacted over the next 50 years; and 250 m at risk over the next 100 years. The road at this underpass has been subject to inundation and erosion events prior to the 2020 assessment.
- The erosion effects of short term storms were calculated based on a Environment Canterbury beach profile site to the north of the railway overpass. This short-term storm erosion was calculated to be in the order of 4 m, based on profile changes that occurred between 2010-2011 at this site.
- The inundation assessment identified that inundation in a large storm event with SLR from static water levels did not appear to impact any of the properties, and inundation from wave runup was not anticipated to reach the settlement until the highest SLR scenario over 100 years.

In July 2023, following king tides combined with a coastal storm and a heavy rainfall event, there was a slope failure in the road embankment along Claverley Road to the north of the settlement, which backs the gravel beach system. This resulting in 6-8m of horizontal erosion into Claverley Road. This resulted in significant damage to the road that prevented access to farms to the north. The road is also lateral support for the railway line which runs adjacent to the road, and therefore had the potential to have broader implications to the nation-wide rail network.

At the same time, the Claverley community reported anecdotally 7 m of erosion in front of the settlement, and that wave runup levels reached some properties. Community members reported building driftwood bunds along the front of houses, and them being removed in one tidal cycle. There was no data (photos, measurements, locations) collected of these inundation events.

This event has prompted a review of the 2020 coastal hazard assessment to revisit the appropriateness of the input data and analysis used to map the future inundation and erosion hazard, and to guide council thinking on whether this was a short term episodic event where the beach can be expected to recover; or whether there is a long term change in hazards and environment which was not detected in the initial assessment as a result of data limitations at the site.

[1] Lyttelton Vertical Datum 1937

The purpose of this report is to understand more about the antecedent conditions which lead to this erosion event, and to identify any required updates to the Jacobs (2020) coastal modelling using more recent data and information to have a more informed judgement and estimate of the mapped future erosion and flood hazards.

The report is set out in three stages:

1) A discussion of the July 2023 event and possible antecedent conditions that led to erosion and beach overtopping;

2) A review of the coastal erosion and coastal inundation model inputs to identify potential updates using more recent data and information; and

3) An update of the hazard models where required, and commentary on the flow on impacts of this update to the future hazard risk to the settlement and to Claverley Road.

Figure 1.1: Overview figure showing the location of Claverley Settlement, Claverley Road, and the Environment Canterbury Beach Profile used for this assessment (from Jacobs, 2020).

2. Discussion on July 2023 Erosion Event

In July 2023 a slope failure in the road embankment backing the gravel beach system just north of the Claverley settlement occurred, resulting in 6 to 8 m of horizontal erosion along the Hurunui District Council (HDC) owned Claverley Road. This road runs adjacent to and provides lateral support for the rail embankment of the main trunk railway line. It is understood that the initial erosion occurred some time between the 8-11th July 2023, with continued gradual failure through to the 13th July, where in one section, the total width of the road was eroded (Figure 2.1).

Figure 2.1: Erosion and slope failure of Claverley Road. Photo taken on 13th July 2023.

Based on a geological cross-section produced by KiwiRail (Figure 2.2), the material that was eroded away beneath the road was fill and spoil from the rail cutting, and historic landslide debris beneath from a potential historic failure surface above the rail line. Emergency works were undertaken by KiwiRail and HDC on the 14th-15th July to place rock at the toe of the failure slope to the reduce the probability of further shoreline regression alongshore within this area. This included the placement of Timaru basalt rock armour at the toe of the eroded section, with compaction of the eroded material in behind. Since then, continued works have been undertaken by KiwiRail and HDC to repair the road and lateral support for the railway, including the placement of a short section of more substantial rock revetment where the road failed.

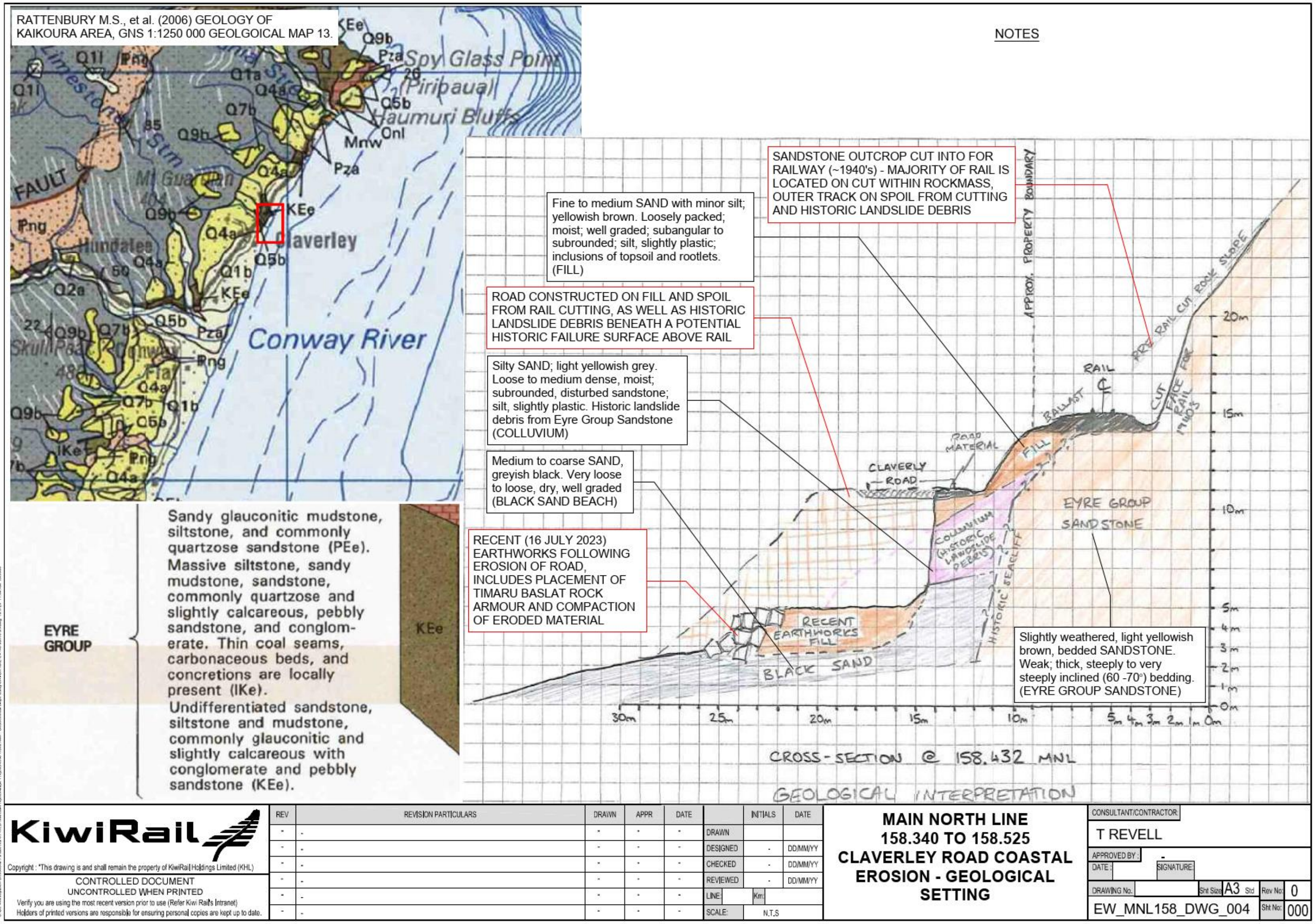

Figure 2.2: Geological cross section of Claverley Road. Information provided by KiwiRail.

Based on the ECan beach profile located approximately 500 m north of the settlement (location shown in Figure 1.1), the Jacobs (2020) report stated that there could be in the order of 4 m of coastal erosion at any time from short-term storm erosion. However, due to the limited data along this section of coastline, the report did not have a good appreciation for the differences in backshore material along the assessed section of coast; with the beach system in front of the settlement and at the profile site being a high gravel beach ridge which erodes by being rolls back when overtopped; whilst the gravel beach that fronts the Claverley Road section of shoreline is backed by the road embankment made from rail cuttings and historic landslide debris.

The recent July 2023 event has identified that the short-term storm erosion component could be higher that previously assessed from the ECan profile data, more in the order of 6-8 m. However for the road section, due to the nature of the road embankment being eroded, this will not recover naturally; whereas, the gravel beach system in front of the settlement could still recover to some degree over time through natural processes.

Antecedent conditions which may have led to the failure of the road embankment include:

- Wave and water level conditions before and during the event;
- Antecedent beach profile conditions
- Saturation of road embankment foundation material in heavy rainfall.

These are discussed below in how they may have influenced this event.

2.1 Wave and Water Level Conditions

NIWA has issued nine ‘red-alert’ intervals for 2023, which represent the timing of the highest astronomical high tides over the year (king tides) that result in high water levels even without the added adverse conditions such as weather (low barometric pressure, onshore winds), river levels, or sea conditions (waves and swell). For Canterbury, a red alert warning was issued for early July, where king tides occurred 5-6th July from the high perigean-spring high tides occurring from 4-8th July 2023 (NIWA, 2023). King tides reached water elevations around 1.18 m (LVD37), approximately 0.17 m above MHWS[2]. The timing of these king tides coincides with the timing of the erosion event on Claverley Road. The higher astronomical tide levels during these king tides mean that a smaller storm surge event is required to result in extreme water levels, and therefore what would normally be considered small or moderate coastal storm conditions (e.g. combination of storm surge and large waves) could reach further up the beach to overtop beach ridges and reach the toe of the road embankment located behind the beach.

The coastal calculator (NIWA, 2015) was developed to identify the joint probability of wave and water level conditions along the Canterbury coast in extreme events. This tool was used to define the extreme water levels used in the Jacobs (2020) assessment of inundation hazards for this coastline. For this current analysis the following inputs were put into the calculator to determine what probability coastal event would need to occur for runup elevations to reach the toe of the road embankment, which as identified by the 2020 LiDAR survey, is at an elevation of around 6.5-7.5 m (LVD37):

- Highest astronomical tide of 1.18 m (0.17m above MHWS);
- An assumed storm surge of 0.15 m, based on barometric air pressure recorded on the ECan wave buoy of 998 mb;
- A beach slope of 0.14 (from 2020 LiDAR).

[2] Mean High Water Spring (MHWS) has been adopted from NIWA (2015) as MHWS-10. This was adopted by NIWA on the basis that it provides a regionally and nationally consistent estimate of MHWS at a specific exceedance frequency that is unaffected by regional changes in individual tidal harmonic constituents

The coastal calculator indicates that in order for runup elevations to reach the same elevations as the toe of the road embankment, coastal conditions would have to have been for a 1% to 2% AEP storm event, with an offshore significant wave height of 6 to 6.2 m, as shown in Table 2.1.

Table 2.1: Coastal Calculator tool outputs.

	Extreme water levels (Setup + runup) (LVD37)	Offshore wave height (m)
1%	6.46 m	6.22 m
2%	6.33 m	6.01 m
5%	6.05 m	5.70 m
10%	5.77 m	5.44 m
18%	5.47 m	5.15 m
39%	**5.07 m**	**4.72 m**
63%	4.74 m	4.36 m

Wave buoy records from Steep Head (ECan Wave Buoy) offshore of Banks Peninsula indicate that significant wave height at the time of the king tides peaked on 4th July at 4.92 m with a wave period of 13 seconds. Significant Wave heights were measured to be above 4 m for 26 hours between the 4th-6th July. This meets the wave height and duration threshold to be considered a storm event, however would likely rank low on the historical storm register, where the highest ranking storms have significant wave heights generally >5.5 m with durations of >70 hours.

The outputs of the coastal calculator (Table 2.1) indicate that the storm on 4th July could be in the range of a 2 to 5 year return interval event (i.e. 39% to 18% AEP) based on offshore wave height alone. When the corresponding wave runup elevations for these size wave events are compared against the 2020 LiDAR beach elevations, the results indicate that the runup elevations do not reach the road embankment toe, however at the northern and southern ends of the Claverley Road stretch to the north of the settlement, it could come close.

Although the calculations of the wave runup levels from the coastal calculator have identified that it would take a significant (i.e. 1% AEP) storm event coupled with king-tides for water to reach the road embankment toe, observations from photographs post the slip event suggest that there could have been some overwash on to the road embankment toe, indicating that the water levels could have reached the road embankment toe at some stage of the event. During this same period, residents at the settlement south of the road failure reported wave runup overtopping the beach crest ridge and reaching to the properties behind, something that was not projected to occur in the Jacobs (2020) report until 2120 with SLR.

It is likely that:

1) Beach morphology has changed since the 2020 LiDAR was captured, where the beach may have lowered or narrowed, meaning that lower water levels would be required to overtop the beach crest and reach the road embankment toe. The ECan wave buoy recorded 7 storms over 2021-2022, of which one of them had easterly waves conditions (others were southerly wave approach conditions), which could have contributed to beach morphology changes since the LiDAR capture. However, this is a limitation that cannot be resolved.

2) The NIWA coastal calculator underestimates the wave-runup elevations at this mixed sand and gravel beach site. This is possible due to the limitations around calculating wave runup water levels on gravel beaches using the Stockdon (2006) empirical formula, where percolation through the gravel

beach face is different to on a sand beach environment. An alternative approach using Powell (1990) formula for gravel beach runup, paired with wave attenuation calculations, are used to re-map the areas potentially impacted by wave runup (Section 3.4.2). The updated approach highlights the relationship between wave period and wave runup, and indicates that the extreme long wave periods (13 seconds) recorded on the 4th July could have led to overtopping of the beach crest at the settlement and water reaching the embankment toe along Claverley Road. This alternative approach is discussed in detail in Section 3.4.2.

3) The wave buoy is located offshore of Banks Peninsula and gives some general indication of wave conditions along the Canterbury coast that were occurring during this time. However, it is recognised that the conditions at the buoy may not be exactly accurate for North Canterbury, and there may be time-lags and changes in wave energy as large systems move up or down the coast.

Based on available data, information and anecdotal observations, we consider that wave runup could have reached the road embankment toe during this coastal storm event resulting in the removal of beach and talus material at the this location (see further discussion in Section 3.4.2). However, it is considered unlikely that waves and high water levels were the only factors resulting in the road embankment failure, with heavy rainfall and poor drainage likely to contributed to the failure and erosion of the road. These are discussed in the following section.

2.2 Rainfall and Slope Failure

A heavy rainfall event occurred at Claverley on the 8th-9th July 2023, where 105.5 mm was recorded at the rainfall gauge at Tea Tree Terrace, approximately 15 km north of Claverley. This amount of rainfall is greater than the monthly average (90.9 mm) recorded since the site record began in 2011. This event was the third highest 24-hour rainfall on record, behind 146 mm (17/04/2014); and 301.5 mm (20/02/2018). On the day prior to this event (7th July), there was 33 mm of rain recorded, and in the month prior to the event, 142 mm was recorded (approximately 50 mm above the monthly average).

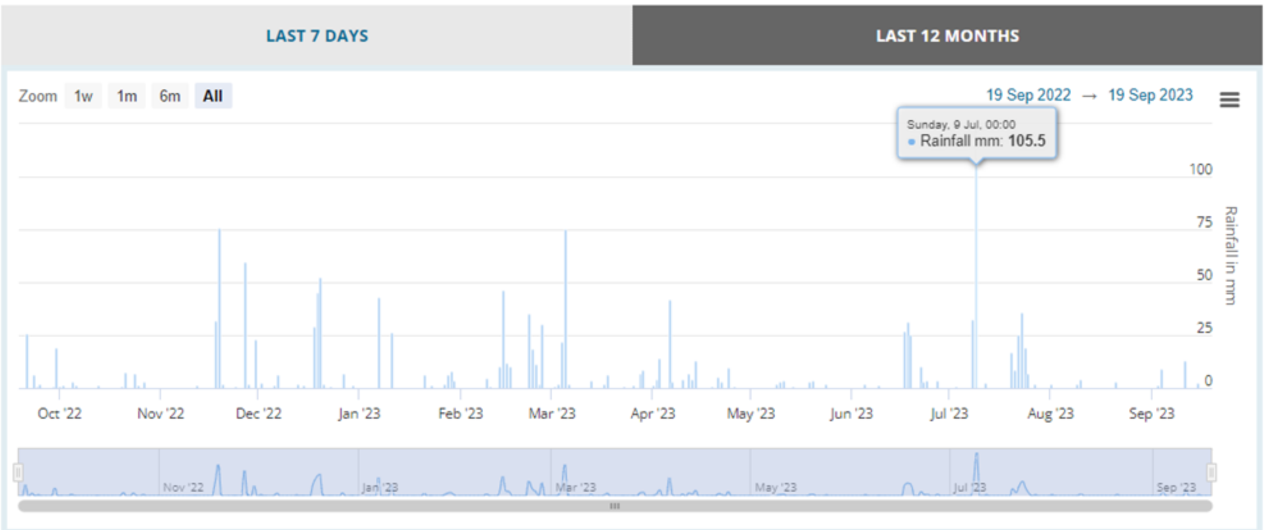

Figure 2.2: Rainfall record for the 12 month period from September 2022-September 2023 for Tea Tree Terrace, a rainfall gauge located approximately 15 km north of Claverley. Record highlighted on 9th July 2023, which shows the peak rainfall reading over the past 12 months at 105.5 mm. Information sourced from Environment Canterbury.

It is considered that antecedent rainfall conditions over the month prior to the failure event likely caused saturation of the road and rail embankment foundations, possibly contributing to the failure of the slope in the heavy rainfall event on the 8-9th July. Seepage into the road and rail embankment foundations is believed to have led to a reduction in strength of the foundation material, potentially contributing to the failure. However, there is not sufficient data to confirm the significance of this reduction in strength of the foundation material, to the failure at this stage. Further, there appears to be a recent slip upslope of the railway line. This slip may be concentrating flows, causing increased infiltration and runoff in the vicinity of the failure. In the case of increased infiltration, pore pressures will increase, thus decreasing the effective stress in the soil and resulting in a reduction in the shear strength (Wang and Sassa, 2003).

As noted at the beginning of this section, the material which was eroded away beneath the road was fill and spoil from the rail cutting, as well as historic landslide debris beneath a potential historic failure surface above the rail line. The material itself is generally weak and unconsolidated, and therefore the high rainfall volume prior to the failure likely caused a decrease in the shear strength of the soil, ultimately resulting in the failure of the slope.

Open source satellite imagery was obtained between January 2022 and September 2023 to identify whether there were any significant shoreline changes in the area prior to the July 2023 event, however the resolution of this imagery was poor in relation to the scale of the slip, and therefore provided no additional useful information.

2.3 Conclusions

It is likely that cause of the road slip failure at Claverley Road was a result of a combination of factors:

- King tides (4^{th} – 8^{th} July)
- Moderate coastal storm event (4^{th} July)
- Heavy rainfall event (8-9^{th} July)
- Saturation of foundation material of the road and rail embankment, decreasing the strength of underlying material.

In the days leading up to the road failure, king-tides occurred which elevated astronomical tide levels. On the 4^{th} July there was a moderate coastal storm (1 in 2 to 5 year Annual Recurrence Interval). The coupled king tides and moderate storm event likely resulted in combined high water levels and wave run-up elevations that could interact with the toe of the road embankment. While the previous tool used to calculate the wave runup elevations in the Jacobs (2020) assessment suggested that water would not reach the road embankment in these conditions, an alternative approach to calculating wave runup with better consideration of gravel beach processes has suggested that due to the long wave periods recorded by the ECan wave buoy on 4^{th} July, wave run up could have reached the road embankment toe (see Section 3.4.2 for further discussion). These higher combined water levels and wave run-up could have resulted in some initial removal of the road embankment toe during the highest tides, prior to the failure event.

Antecedent rainfall conditions over the month prior to the failure event likely caused saturation of the road and rail embankment foundations, possibly contributing to the failure of the slope in the heavy rainfall event on the 8-9^{th} July. Seepage into the road and rail embankment foundations is believed to have led to a reduction in strength of the foundation material, potentially contributing to the failure. However, there is not sufficient data to confirm the significance of this reduction in strength of the foundation material, to the failure at this stage. Following the failure, the wave buoy recorded significant wave heights >4 m with 13 second periods on the 10^{th} July, indicating that continued elevated water levels from wave run-up may have removed some of the talus material of the slip. Photos post event suggest that failure material has been removed, however it is unknown whether this was through natural processes, or if this material was cleared as works began to stabilise the road embankment toe.

The findings of this analysis have helped Inform updated components of the coastal modelling undertaken in 2020. These updates are discussed in the following section.

3. Review of Model Components

The following sections identifies the limitations of the Jacobs (2020) assessment, as well as a review of each of the modelling components used to assess the exposure to coastal hazards, and provides a summary of the recommended updates to the Jacobs (2020) modelling.

3.1 Limitations of the Previous Assessment

The Jacobs (2020) acknowledged several limitations with the assessment, which are generally due to data availability and the models that can be employed along this type of coastline. These limitations include:

- It is a rural area with limited data sets – including recent aerial imagery, lidar, and beach profile data. Aerial imagery and LiDAR used in the 2020 assessment was sufficient at the time of the report (LiDAR from 2017, aerial imagery from 2019). Beach profile information for the site relevant to Claverley has only been collected through to 2016 pre-Kaikoura earthquake, and therefore beach profile information and response to the earthquake here is not well understood. This beach profile site is also located approximately 1 km north of the settlement, so there is some uncertainty of how relevant the site is to the settlement or the road.
- The assessment was primarily focused on the settlement at Claverley, with commentary on the road, and therefore it did not have a good appreciation for the change in backshore morphology behind the beach from the high gravel ridge in front of the settlement, to the road embankment backed gravel beach along Claverley Road.
- The assessment considered and used an adjusted Bruun Rule approach to calculating the erosion impacts of SLR on mixed sand and gravel beaches; however globally this beach type is rare and not well researched, and therefore there is more uncertainty in how these beach types will respond to SLR in the future. But, currently there are not any alternative methods to include in the re-assessment.
- The tool used to calculate the extreme water levels and wave runup (Coastal Calculator) uses empirical formulas that are more representative of sand beach environments.
- The assessment did not consider whether there were any impacts from the Kaikoura earthquake in 2016, which may have weakened unconsolidated embankment foundation material or cliff material.

3.2 Review of Sea Level Rise Projections and Vertical Land Movement

SLR scenarios used in the Jacobs (2020) assessment were based on the MfE (2017) Guidance, which was reliant on the SLR projections developed by IPCC (2014). This assessment used the two higher SLR projection scenarios, being RCP8.5 and RCP8.5+. The acceleration of SLR for these scenarios for a 2030, 2050, and 2120 timeframe used in the Jacobs (2020) assessment is presented in Table 3.1.

Table 3.1: Rates of SLR used in the Jacobs (2020) assessments based on MfE (2017) Guidance.

Year	RCP8.5 SLR Scenario		RCP8.5+ SLR Scenario	
	SLR from 2020 Baseline	Rate of accelerated rise	SLR from 2020 Baseline	Rate of accelerated rise
2050 (30 Year)	+0.23 m	5.7 mm/yr	+0.32 m	8.7 mm/yr
2070 (50 Year)	+0.40 m	6.0 mm/yr	+0.56 m	9.2 mm/yr
2120 (100 Year)	+1.01 m	8.1 mm/yr	+1.31 m	11.1 mm/yr

MfE (2022) *Interim guidance on the use of new sea-level rise projections* was released to update MfE's (2017) Guidance in response to the updated SLR projections produced by IPCC (2021). These updated projections indicated that SLR estimates at the end of the century had increased by 0.03 to 0.14 m. These increases are shown in Figure 3.1. The updated projections also moved from the use of 'RCP'[3] scenarios, to the use of 'SSP-RCP'[4] scenarios.

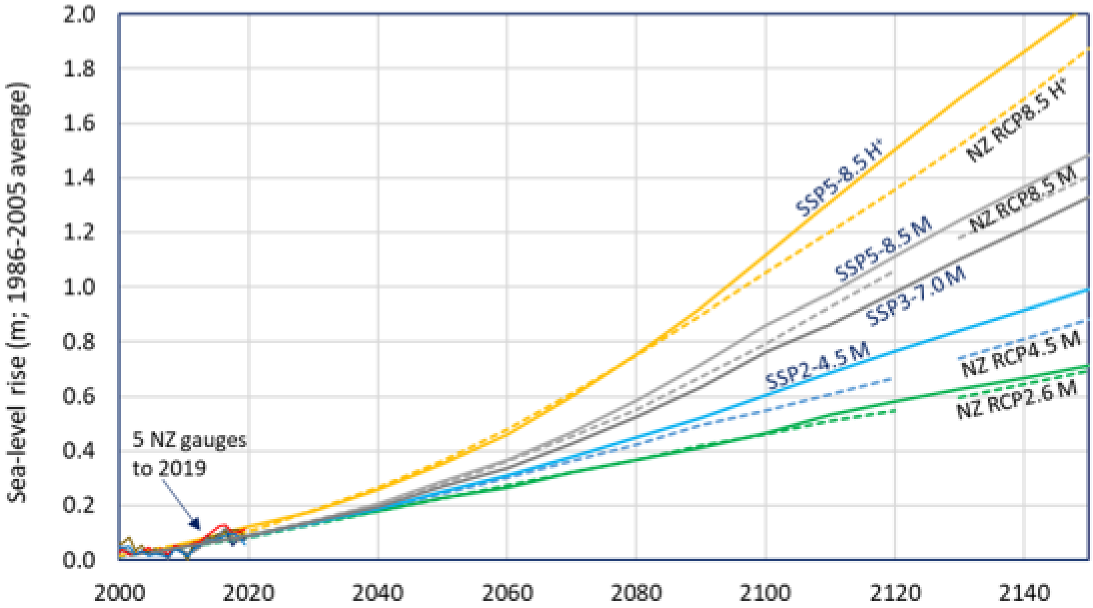

Figure 3.1: Comparison of new NZSeaRise projections (without vertical land movement) with 2017 coastal hazards guidance (MfE 2022)

At a similar time, vertical land movement rates were calculated based on high-spatial resolution estimates of Vertical Land Movement (in mm/yr) for 2003-11 at 2km spacings along the NZ coastline through the NZSeaRise Programme (https://searise.takiwa.co/). The Interim MfE (2022) Guidance states that VLM should be incorporated into the projections in hazard and risk assessments, and if more detailed information for the site is not available, the information from NZSeaRise should be adopted.

The most relevent NZSeaRise site for Claverley Settlement and Road (site 4240, located approximately 400m south of the Claverley Settlement) is subsiding at rate of -2.18 mm/yr. This will mean that overall there will be a higher relative rate of sea level rise.

Table 3.2: Comparison of SLR estimates for RCP8.5 and RCP8.5+ scenarios used in the 2020 to the updated equivalent scenarios from NZSeaRise with inclusion of VLM and updated IPCC (2022) SLR projections.

	Jacobs (2020) SLR Estimates (from 2020 baseline)		Updated NZSeaRise Estimates (from 2020 baseline)	
Year	RCP8.5	RCP8.5+	RCP8.5 (SSP5-8.5)	RCP8.5+ (SSP5-8.5 83rd Percentile)
2020	0 m	0 m	**0 m**	**0 m**
2050	0.23 m	0.32 m	**0.26 m**	**0.37 m**
2070	0.4 m	0.56 m	**0.49 m**	**0.69 m**
2120	1.01 m	1.31 m	**1.25 m**	**1.76 m**

The updated estimates from NZSeaRise show a general increase in SLR projections when including the recent IPCC (2022) updates and VLM. These estimates have increased by 0.03-0.05 m over the next 30 years; 0.09-

[3] Representative Concentration Pathways – Climate change scenarios based on how future greenhouse gas concentrations will change.

[4] Shared Socioeconomic Pathways – Climate change scenarios based on how the climate will change in response to socioeconomic indicators such as population, economy, land use, and energy changes.

0.13 m over the next 50 years; and 0.24-0.45 m over the next 100 years. The difference that these estimates will make to projected shoreline position over the next 30 years is likely to be negligible, however will impact the shoreline positions over the 50-100 year timeframes.

The most recent information from IPCC (2021); MfE (2022) and the NZSeaRise programme will be used to update the erosion and inundation mapping. The SLR scenarios used which are equivalent to the previous assessment are:

- *RCP8.5 = SSP5-8.5*
- *RCP8.5+ = SSP5-8.5 (83rd Percentile)*

3.3 Review of Coastal Erosion Model

For the Jacobs (2020) assessment, a deterministic coastal erosion assessment was used considering the historical long-term erosion, current short-term storm erosion, and estimated future erosion from projected sea level rise was applied to produce a 'Projected Further Shoreline Position' (PFSP) for 30, 50 and 100-year scenarios.

PFSP = (LT x T) + SL + ST

Where:

PFSP = the Projected Further Shoreline Position;

T = Timeframe considered.

LT = Extrapolation of the rate of historical long-term shoreline movement (m/yr);

SL = Estimated erosion due to accelerated sea level rise (SLR) over time frame (T); and

ST = Storm term storm erosion.

This deterministic approach is still considered appropriate due to limited data availability (i.e. aerial imagery, beach profile surveys). It does not appear that there has been a significant increase in data availability over the 3-year period following the original assessment which would warrant changing the approach to being a detailed probabilistic assessment.

3.3.1 Long-term Historical Shoreline Movement

A previous analysis of shoreline stability at Claverley by DTec (2004) found five independent lines of evidence which all indicated that the shoreline that been accreting since 1897, with rates of advance in the order of 0.5 m/yr to 0.6 m/yr being measured from aerial photograph analysis between 1950 and 2003.

The Jacobs (2020) assessment analysed five aerial photographs between 1950 and 2019. Figure 3.2 shows the historical trends identified from these images. The assessment showed that all transects along the frontage of the settlement had experienced net accretion since 1950, however areas north of the rail underpass, and the shoreline along Claverley Road had been generally stable/slightly erosional. A review of the aerial imagery suggests that the magnitude of failure that occurred along the road in July 2023 had not been observed before along this section of coast. However, failure of a smaller and undetectable magnitudes could have occurred, or failure which was followed by repair between aerial images being taken.

There is no new publicly available aerial imagery that has been captured that covers the entire Claverley settlement through to Claverley Road since the 2019 dataset used in the original assessment. KiwiRail undertook a drone survey following the July 2023 slip event, which has captured the short section of road shoreline which failed during the event described in Section 2. However as described in Section 2, the road failure is more likely to be caused by a combination of high sea water levels and waves prior to failure, and slip failure mechanisms as a result of saturation from both antecedent conditions and the recent high rainfall event. In our opinion, it is more appropriate to incorporate this drone imagery and recent shoreline position update into the 'short term' factor (Section 3.3.3) than in the long-term movements.

The drone survey does not cover the settlement and therefore no updates could be undertaken to inform to long term rates or shoreline change in front of the settlement.

Due to there being no new aerial imagery at the settlement, and limited post-slip amount of aerial imagery in front of Claverley Road, there is not sufficient additional information to update the long-term trends for the model.

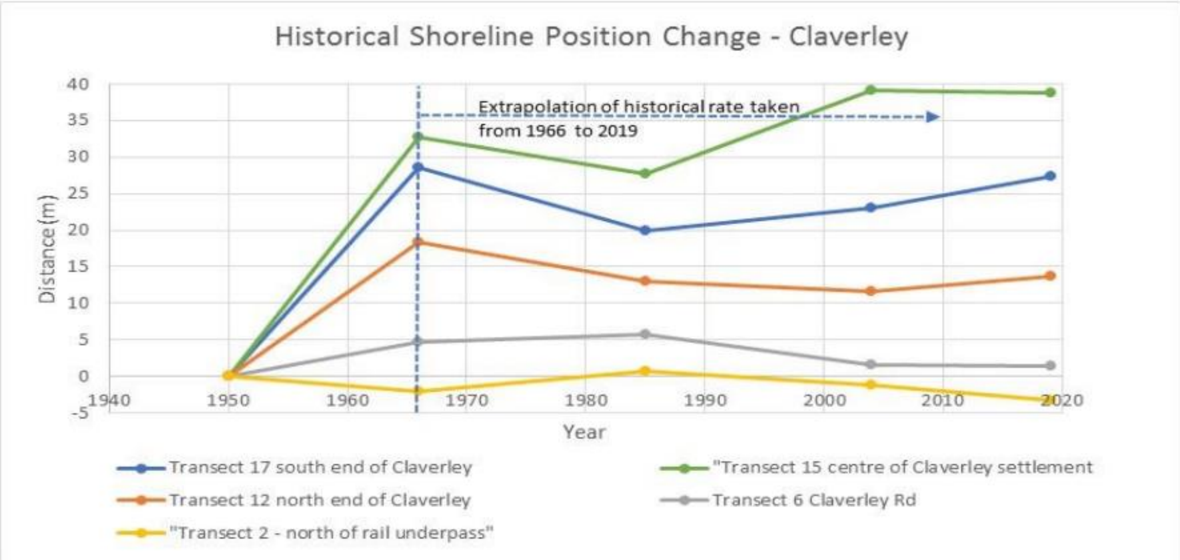

Figure 3.2: Historical shoreline position change at Claverley from Jacobs (2020).

3.3.2 Estimated Erosion Due to Accelerated Sea Level Rise

The effects of projected accelerated SLR on erosion of the beach at Claverley was calculated using the modified Bruun rate for MGS beaches, using the following parameters:

- Closure depth at the base of the nearshore step being assumed from nearshore surveys of this feature at Washdyke, Timaru to be 5 m (below MSL) with a 1:10 slope.
- Beach crest height from Environment Canterbury profile surveys (profile HCK9150) was set at 6.8 m (AMSL).
- Closure slope[5] distance of 125 m.

A shallow closure depth and steep slopes resulted in minimal effects of accelerated SLR on future coastal erosion over 30, 50, and 100-year timeframes. The results of the Jacobs (2020) assessment indicated that in 30 years (by 2050) the direct effects of SLR were anticipated to result in 1.6-2.6 m of erosion; in 50 years (by 2070) 2.9-4.6 m of erosion; and in 100 years (by 2120) -8 to -11.2 m of erosion.

Since the Jacobs (2020), there has been no updated shoreline response models which better predict the future impacts of SLR on mixed sand and gravel beaches at an empirical level of detail. Therefore, we do not think it is necessary to change the geometric model used at this point in time. We also do not have any more

[5] Closure slope is the total slope between the beach crest and the closure depth. Because Claverley Beach is a mixed sand and gravel beach, the closure depth is assumed to be at the toe of the nearshore step.

recent or updated information on the positions of the closure depth specific to the Claverley site, and therefore this will not be changed in the model.

LiDAR captured in 2020 is more up to date than what has been used in the Jacobs (2020) assessment, where 2017 information was used. The updated LiDAR information indicates that the beach height varies alongshore at the settlement and in front of Claverley Road, but is generally between 6-7 m above MSL. Sensitivity testing of changing these beach elevation bounds in the model result in less than a 1 m change in the estimate of horizontal erosion distances. Therefore, we do not believe it is necessary to change the beach height input into the model.

Overall, the only updates that will be made to the assessment of erosion due to accelerated SLR will be to incorporate the updated SLR projections (Section 3.2). We do not believe that based on the available information other input parameters require updating at this time.

3.3.3 Short-term Erosion

The short-term storm effect measured from one Environment Canterbury profile north of the settlement showed that between 1997-2019, the maximum inter-survey change was -3.8 m at the landward beach toe. A rounded upper rate of -4 m was adopted as the short-term erosion rate.

As noted in Section 3.1, the original assessment was largely focused on the Claverley settlement, and hence the geomorphology along the assessed section of coast was taken as a mixed sand and gravel beach with a wide backshore behind the beach crest ridge. The assessment did not have a good appreciation for the change in backshore morphology as it transitions into a road embankment backed gravel beach in front of Claverley Road. The short-term storm factor was based on historical records of storm impacts on a high gravel ridge beach with backshore, however this is not representative of the Claverley Road section of shoreline, or the potential slip failure mechanisms that could occur along this section of coast.

Numerical modelling of cross-shore gravel beach storm response is possible using XBeach-G, however this type of modelling is reliant on time series wave and water level condition data, and beach morphology information (e.g. beach profiles). For reliable results using this model, more data than is available would be required, therefore we would have low levels of confidence in the results given the assumptions and data limitations. The results from an XBeach-G model could be used to inform the gravel beach rollover at the settlement, however would not be suitable for understanding the erosion of the road embankment, due to the different processes causing the failure.

The information gathered by KiwiRail following the July 2023 event calculated that the slip resulted in 6-8 horizontal erosion of the road embankment line. A comparison of the shoreline position in the imagery taken in 2019 (with an approximate road embankment top edge position taken from 2020 LiDAR) and the erosion scarp edge following the slip event in July 2023, is shown in Figure 3.3. This imagery confirms that at its widest point the erosion distance from the 2020 embankment edge to the 2023 erosion scarp was 7.5 m Along the stretch of embankment backed beach, we will update the short-term factor to account for this recent multi-hazard event.

We should also consider whether this is the maximum erosion response that could occur from the combined rainfall/coastal events. Based on the information presented in Section 2 on the likely factors which lead to the 6-8 m of storm erosion estimated, the rainfall event that coincided with the slip was not the most significant event recorded on the rain gauge over the 12 year record. The wave conditions recorded in the coastal storm in the lead up to the slip were also not of the magnitude of more extreme storm events since wave buoy records began in 1999. With climate change, rainfall intensity is expected to increase in significant events – e.g. NIWA has estimates that one degree of warming translates to 13.5% increase in rainfall per hour in a one in 50 year event (MfE, 2018). It is difficult to determine how coastal storm frequency will change with climate change, however as noted in the Jacobs (2020), with SLR, water levels in a coastal storm event that is currently an assumed 1 in 100 year event (1% AEP) could become a 1 in 12-16 year event by 2050, 5-10 year event by 2070, and have an annual recurrence interval by 2120. Therefore, it would be appropriate to assume that for both coastal storm and rainfall hazards, larger magnitude events could occur.

Consideration was also had to the natural angle of repose of the embankment. Following geotechnical advice, it was assumed that natural angle of repose was likely to be similar to that of wet sand, as it is likely make-up from landslide debris and uncompacted material (i.e. 30 degrees). When projecting this across a 4 m high embankment, this results in an erosion distance of 3.5 m. While this method can sometimes be appropriate for estimating short term erosion of soft banks (e.g. Tonkin and Taylor, 2021), the July 2023 event indicated that short-term storm erosion of this embankment can exceed this.

From the new information of the geological/geomorphic make-up of the embankment being generally uncompacted material, in a worst-case scenario, the embankment could erode back to the historical sea cliff shoreline (e.g. back to the rail line). At which point, erosion processes against the sandstone cliff would be different and likely to have a less storm response than the approximate 250 m stretch of road embankment that is currently eroding.

While we cannot quantify what this increase in future storm response may look like within the scope of this project, we consider it would be inappropriate to assume that an 8 m storm cut into the embankment is the largest cut that could occur here. Therefore, we suggest adding a 25% increase to the storm cut that has already been experienced in order to account for the impact of future SLR, as well as the possibility of a combined higher intensity events coinciding.

There is no new information available for storm response of the gravel ridge in front of the settlement, except for anecdotal evidence from the community which indicated there had been around 7 m of erosion during this storm, 3 m more that the largest storm cut assessed at the ECan profile and used as the ‘short term’ component in the 2020 assessment. This anecdotal evidence has been stress tested against other mixed sand and gravel ridge sites along the Canterbury coast to verify whether this 7 m ridge movement is possible. This sensitivity test identified that:

- At a natural gravel ridge site at Amberley Beach, maximum inter-survey changes were in the order of 3-4 m. This site is geographically close relative to the other gravel beach ridges used in the sensitivity test, however has a much lower beach crest than Claverley Beach at 3.8 m (LVD).
- At nine low gravel ridge sites in the Timaru District (crest heights between 4-5 m) surveyed annually by Environment Canterbury, were between 3-13 m. Whilst geographically these sites are distal from Claverley Beach, they have very similar morphologies and elevations, and signal that 7 m of crest movement between annual surveys (e.g. caused by one or multiple storms) is possible.

Along the 250 m stretch of road embankment, the short-term factor will be updated to 10 m to account for the erosion observed in the recent slip with a 25% increase to have consideration that the magnitude of the factors which drove the slip are likely to be greater in the future. The short term factor will be taken from where the toe of the recent protection works has been put in place, and the toe of the embankment where protection has not been put in place as of 13/9/2023. The short-term storm assumes that protection has failed.

Along the gravel beach ridges to the north and south of the road embankment, and in front of the settlement, the short term factor will be updated to 7 m based on the observations from members of the community, and sensitivity testing against other similar sites.

Along with the update PFSP lines, we will produce a ‘short term storm’ line which will show where this storm could erode in the short term, to help better communicate the risks of an individual storm or cluster of storms, and how it differs from long term shoreline position projections.

Figure 3.3: Comparison of shoreline reference positions and underlying aerial imagery from 2019 and post-slip in July 2023

3.4 Review of Coastal Inundation Model

In the 2020 assessment, a "bathtub" model approach was used to identify the potential extent of inundation from a 1% AEP coastal storm (e.g. approximately 1 in 100 year event), and therefore the risk of coastal flooding to infrastructure and properties. The timeframes assessed for the inundation model were the same as those used for coastal erosion modelling – present day, 30, 50 and 100-year SLR under the RCP 8.5 and RCP8.5+ scenarios. This modelling was undertaken in GIS with the output being identified areas of land which are below the design 'static' water level for each scenario, and therefore infer that the land would be inundated to a certain depth. The LiDAR data used for Claverley was captured in 2017, and therefore inundation was mapped relative to the morphology and development present in 2017.

We believe the overall bathtub approach is still suitable for the scale of assessment being undertaken at Claverley, and with generally low risks to inundation given the high beach ridge elevations. There is now more recent LiDAR information available (2020) that gives a more recent appreciation for the morphology and development, which will be used to update the inundation hazard maps.

3.4.1 1% AEP Static Water Level

The static water level used in the analysis was made up of the joint probability 1% AEP level from combined storm tide (e.g. astronomical tide, storm surge and wind set-up), wave set-up (super elevation of water level close to the shore with wave breaking processes), and the SLR component. These static water levels were calculated using the Canterbury Coastal Calculator, as noted in Section 2.1 (Stephens et al, 2015). It is noted that the difference between the RCP8.5 and RCP8.5+ scenario in 2050 is <0.09 m, and for these estimates we previously took a middle estimate, given that the mapped water depths would be at a scale greater than 0.1 m.

The static water levels used at Claverley are shown in Table 3.3., and are still considered to be appropriate for use. The beach slope used in the Canterbury Coastal Calculator to calculate the wave step up is for the steep gravel foreshore. While wave setup should typically be derived from the nearshore surf zone slope, the steep foreshore of the gravel beach is likely to replicate the nearshore wave break step present on mixed sand and gravel beach profiles. These 1% AEP water levels use a slope of 0.14 (storm gradient).

Table 3.3: 1% AEP event static water levels used (LVD37)

	Present day	2050	2070		2120	
		RCP 8.5	RCP 8.5	RCP 8.5+	RCP 8.5	RCP 8.5+
Claverley	2.95 m	3.23 m	3.4 m	3.56 m	4.01 m	4.31 m

There is no new information available which would better estimate the joint probability of the extreme static water levels than the Coastal Calculator, and therefore the water levels have been reviewed and confirmed that no change is necessary at this time. However, as noted in Section 3.2 SLR projections since the original assessment have increased due to the release of the IPCC (2021) report, and inclusion of VLM for Claverley. Updated 1% AEP values that will be mapped to incorporate new relative sea level rise estimates are presented in Table 3.4.

Table 3.4: Updated 1% AEP event static water levels to incorporate new RSLR estimates for Claverley (LVD37)

	Present day	2050	2070		2120	
		SSP5-8.5	SSP5-8.5	SSP5-8.5 (83rd Pecentile)	SSP5-8.5	SSP5-8.5 (83rd Pecentile)

Water Level (LVD37)	2.95 m	3.21 m	3.44 m	3.64 m	4.2 m	4.71 m

3.4.2 Additional Wave Run-up Calculations

The Jacobs (2020) assessment of inundation hazards also considered the effect of beach overtopping from wave run-up (maximum vertical extent of wave "up-rush" on a beach above storm-tide level) on inundation extents and depths. It is known that for beaches where wave overtopping occurs, this process can result in inundation in areas where the beach ridge is above the static water level and add to the inundation volumes for areas with lower beach ridges. In the previous assessment, the run-up contribution to the inundation hazard was calculated using the overtopping volume calculator in the Canterbury Coastal Calculator (NIWA, 2015) with the static 1% AEP water level used in the calculations varying on an hourly basis over a twelve-hour high tide cycle to calculate the total overtop volume over the beach ridge.

This method indicated that only small areas north of the settlement in gullies draining to the beach are potentially inundated in scenarios up to 100-year RCP8.5. For the 100-year RCP8.5+ SLR scenario, wave run-up overtopping during a 1% AEP storm event (projected to reach elevations in the order of 7.3 m LVD) was modelled to potentially inundate parts of the settlement, however inundation depths were not calculated.

Based on anecdotal evidence from residents at Claverley communicated to HDC at the same time as the slip event in July 2023, water levels over washed the beach crest, and appeared to runup close to the front row of houses. As noted in Section 2.1, this observation suggests that the formula used to calculate the wave runup elevations (i.e. Stockdon, 2006) in the coastal calculator is less appropriate for gravel beach environments than sandy flat beaches (e.g. New Brighton). Powell (1990) defined an empirical relationship of offshore wave height and period to the maximum elevation of the crest, therefore, a proxy for where wave processes could runup to. The formula is highly sensitivity to wave period, and therefore storms with long wave periods and moderate waves heights are predicted to reach higher elevations that storms where high significant wave height and moderate wave periods.

Using a 1% AEP significant wave height from the Coastal Calculator (6.2 m) and the maximum mean wave period (12 seconds) from the ECan Storm Summary to be representative of an extreme storm, the formula from Powell (1990) suggests that wave run-up of up to 9 m could occur under these conditions. It is likely that the Powell (1990) formula over-predicts the wave runup elevations, however based on the observations of the community, it is also likely that the Stockdon (2006) formula under-predicts wave runup levels for gravel coasts. It is noted that the wave conditions recorded on the wave buoy in July 2023 had a significant wave height of 4.2 m and a wave period of 13 seconds, which when using Powell (1990) produces a similar wave runup elevation to the proxy 1% AEP runup levels mapped.

The calculations using Powell (1990) suggest that wave runup could overtop the existing beach crest. However, consideration must also be had for how far inland that water will be able to travel once it has overtopped the crest. Behind the existing crest there is vegetation which creates roughness and friction to reduce the overland flow energy, as well as the high percolation rates of the gravel material which that reduces over wash distances. Cox and Machemehl (1986) wave attenuation distance formula is a way of quantifying the potential inland distance a wave could travel over it over tops the beach crest. Along this section of coast, the backslope of the beach varies; in front of the settlement there is a gentle landward slope (0.05), and in front of Claverley Road there is a steep near-vertical face. These equations, using beach profile data from the 2020 LiDAR and wave conditions from the ECan Wave Buoy, indicate that wave attenuation distances inland could be in the order of 15-20 m inland of the beach crest in front of the settlement, and 5-6 m inland of the crest along Claverley Road.

As a result of the observations of wave overtopping the beach crest and reaching some properties in July 2023, we will test a different approach to mapping wave runup areas that we have recently adopted for the Kaikoura District. This approach will utilise the calculations of Powell (1990) for gravel beach runup to indicate whether the beach crest can be overtopped, and then use the calculated wave attenuation distance *from Cox and Machemehl (1986) to determine how far inland the run-up may be able to travel. For mapping, the most seaward position of either the wave runup elevation, or the wave attenuation distance is mapped. This is mapped as an area of potential inundation from wave runup but does not include water depths. This mapping assumes that the beach morphology in the 2020 LiDAR is consistent for the whole assessment period.*

3.5 Summary of Updates Required

Based on the new information available, the following updates will be undertaken to the respective coastal erosion and coastal inundation models to update hazard mapping:

Sea level rise projections update:

- For both coastal erosion and coastal inundation assessment, we will use updated SLR increments to account for more recent IPCC (2021) SLR projections, and incorporate Vertical Land Movement (VLM) from the NZSeaRise Programme:

Year	Updated NZSeaRise Estimates (from 2020 baseline)	
	RCP8.5 (SSP5-8.5)	RCP8.5+ (SSP5-8.5 83rd Percentile)
2020	0 m	0 m
2050	0.26 m	0.37 m
2070	0.49 m	0.69 m
2120	1.25 m	1.76 m

Coastal Erosion Model Updates:

- Updated shoreline reference position along Claverley Road based on recent road slip and improvements.
- The short-term factor will be updated to 10 m along Claverley Road to account for the recent slip failure and possibility of a larger event occurring in the future. The short-term factor in front of the settlement will be updated to 7 m to account for anecdotal evidence during the same event.
- A ‘short term storm’ line will be produced which help better communicate the risks of an individual storm happening in the near future.
- Recalculation of erosional impacts of SLR using updated SLR projections.

Coastal Inundation Model Updates:

- Inundation modelling of static water levels will be re-mapped using more recent 2020 LiDAR.
- Wave runup modelling will be remapped using combined Powell (1990) wave runup calculations combined with attenuation distance calculations from Cox and Machemehl (1986).

4. Updated Coastal Hazard Model Outputs

4.1 Coastal Erosion Assessment

The coastal erosion assessment has been updated to account for a greater possible short term storm erosion, and to account for increases in SLR projections to include VLM. Updated averaged projected erosion distances are presented below in Table 4.1, and a breakdown of components is included in Appendix A. The main increase in projected erosion distances is the increase from the 4 m short term storm erosion in the original assessment, to 10 m for the section along Claverley Road, and 7 m for the section of shoreline in front of the settlement. The mapped projected shoreline erosions are presented in Figure 4.1, Figure 4.2, and Figure 4.3.

Table 4.1: Averaged PFSP distances along the Claverley Road section of coast and in front of the settlement for various SLR scenarios to 2120.

Shoreline Section	Short-term storm erosion (all scenarios)	2050 SSP5-8.5	2050 SSP5-8.5 (83rd Percentile)	2070 SSP5-8.5	2070 SSP5-8.5 (83rd Percentile)	2120 SSP5-8.5	2120 SSP5-8.5 (83rd Percentile)
Road	-10 m	-13 m	-14 m	-16 m	-18 m	-25 m	-30 m
Settlement	-7 m	-8 m	-10 m	-10 m	-12 m	-16 m	-21 m

The largest component contributing to the erosion distances is the short-term erosion factor. It accounts for 70-85% of the total erosion distances projected over the 2050 period; 55-70% by 2070; and 30-45% by 2120.

It is important to note that in the later timeframes assessed, the projected shoreline positions exceed the rail line into the sandstone cliffs. We have not assessed how the cliff environment would respond to erosion at this time, however it is likely that once the embankment eroded and coastal processes were acting on eroding the sandstone cliff, rates of change would be slower.

Updated exposure to the number of properties and length of Claverley Road that could be exposed to coastal hazards across the assessed scenarios is presented in Table 4.2. Coastal erosion intersects with 1 property boundary over the next 30 years, increasing to 2-3 over the next 50 years, and 7-9 over the next 2120 (e.g. most properties in the seaward row of the settlement). Dwellings are not projected to be impacted directly by coastal erosion under any of the SLR scenarios.

Due to the increase in the short-term erosion component, the exposure of Claverley Road has significantly increased, where in a present day storm up to 185 m of Claverley Road could be exposed to erosion; increasing to 200-210 m over the next 30 years; 240-255 m over the next 50 years; and 290-325 m over the next 100 years. This updated assessment indicates that the section of Claverley Road between the rail bridge underpass south to the Settlement is very susceptible to coastal erosion if another significant storm were to occur (and protection failed).. Over a 100 year timeframe, only an additional 100-150 m of road would be impacted from long term erosion trends and impacts of SLR.

Table 4.2: Updated risk table for properties and Claverley Road.

		Timeframe	2050		2070		2120	
Scenario	**Total**	**Present day Storm**	**SSP5-8.5**	**SSP5-8.5 (83rd Percentile)**	**SSP5-8.5**	**SSP5-8.5 (83rd Percentile)**	**SSP5-8.5**	**SSP5-8.5 (83rd Percentile)**
Number of Properties exposed to erosion	19*	0	1	1	2	3	7	9

Claverley Road lengths exposed to erosion (m)		185 m	200 m	210 m	240 m	255 m	290 m	325 m
*Note the previous assessment stated there were 13 properties. This was an error and should have been in reference to there being 13 dwellings, and 19 properties (e.g. 6 properties were unoccupied). As of the 2023, only 2 of the 19 properties within the settlement boundary are unoccupied.								

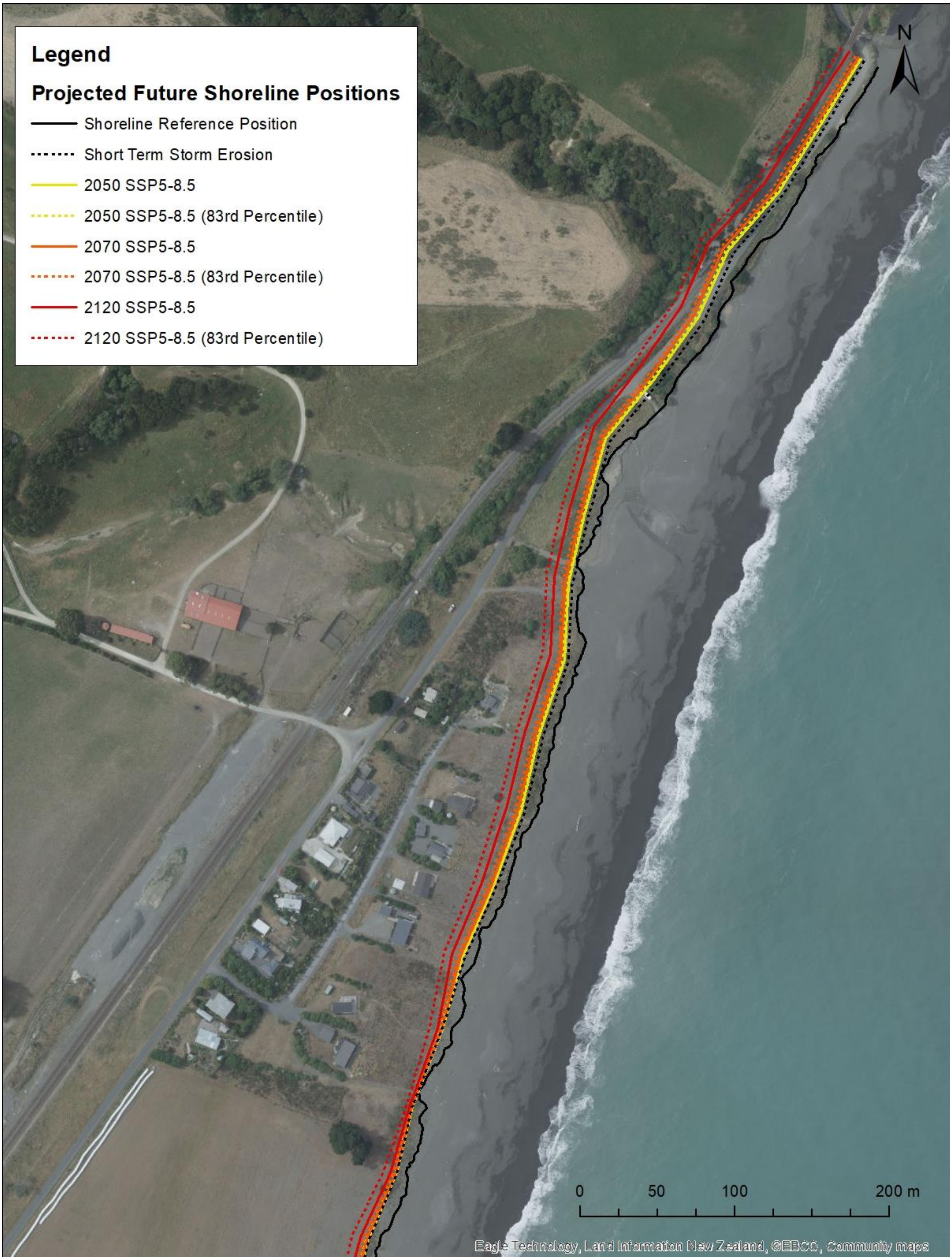

Figure 4.1: Updated Projected Future Shoreline Positions along Claverley Road and in front of the Claverley Settlement.

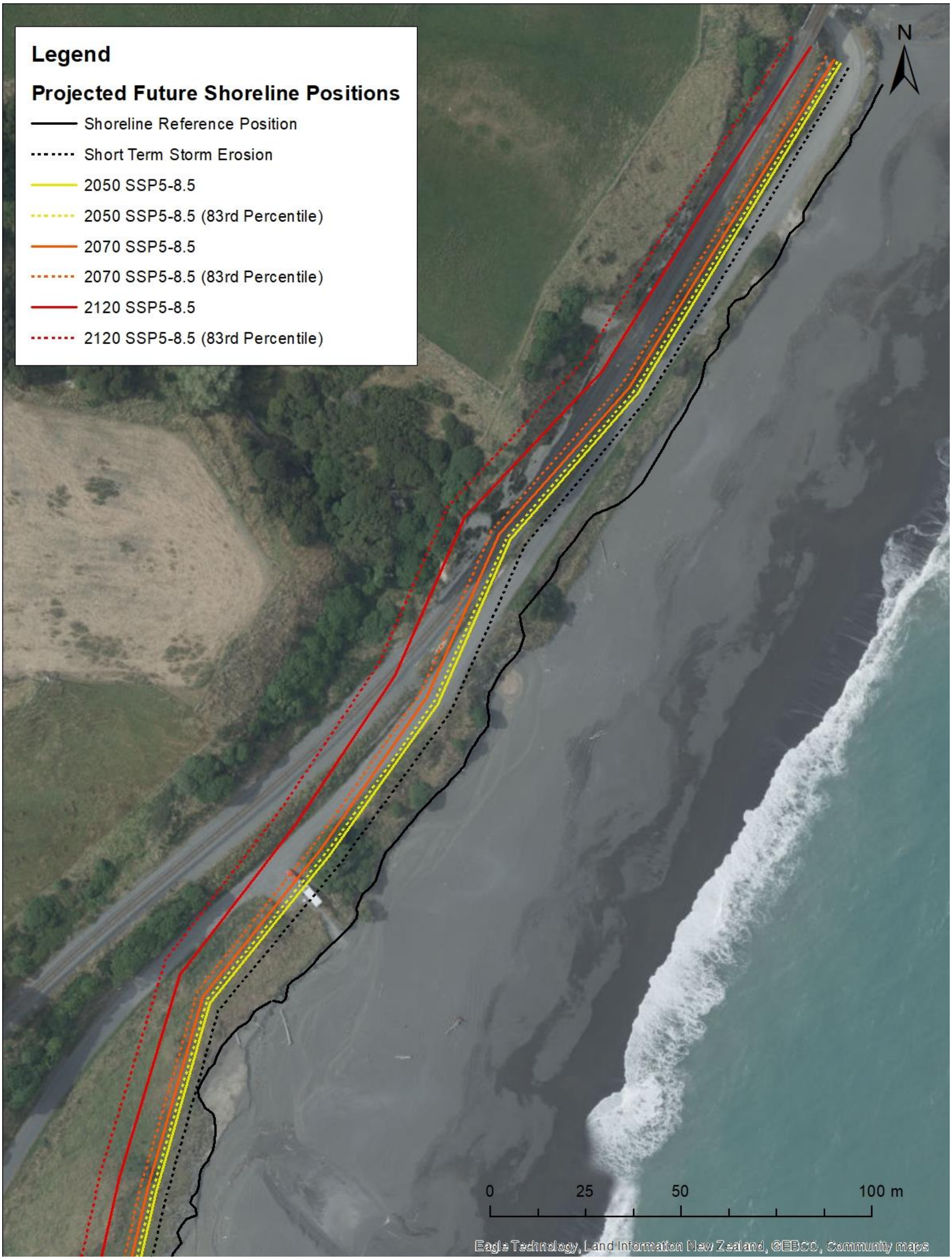

Figure 4.2: Updated Projected Future Shoreline Positions along Claverley Road.

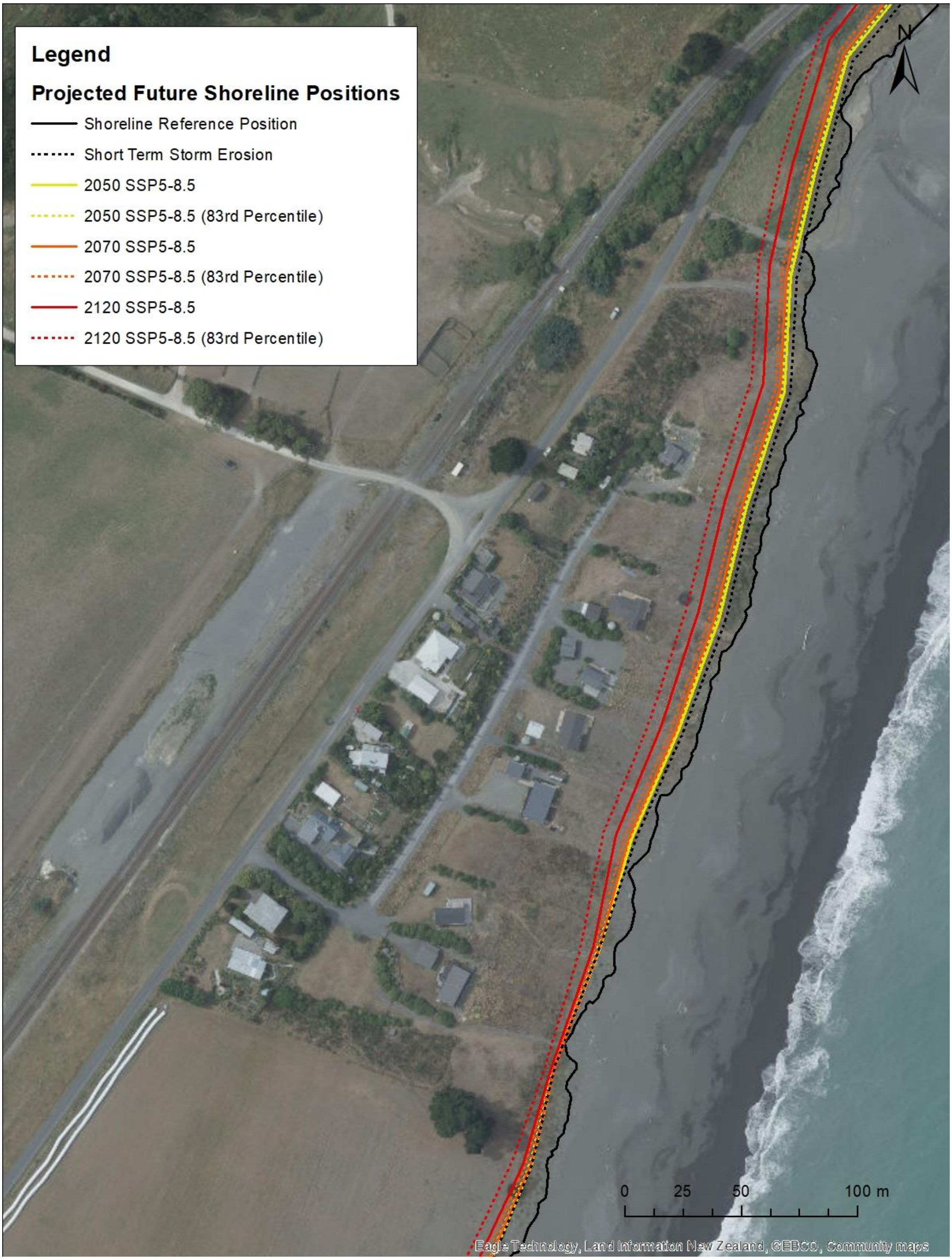

Figure 4.3: Updated Projected Future Shoreline Positions in front of the Claverley Settlement.

4.2 Coastal Inundation Assessment

The coastal inundation assessment has been updated using more recent relative sea level rise projections, and more recent LiDAR information (2020) than was available in the previous assessment. The re-mapping of the inundation is presented in Appendix A.

The extreme static water levels mapped, and presented as the ‘blue’ colourations in Appendix A represent the combined storm tide and wave set up level. Similar to the Jacobs (2020) assessment, the extreme water levels under all scenarios to not overtop the gravel beach ridge, and are not projected to reach any properties under any of the timeframes or SLR scenarios assessed.

Under the higher SLR scenario in 2070 (0.69 m RSLR, SSP5-8.5 (83rd Percentile)), ground levels in the water small gully immediately to the north of the settlement area are below the projected water levels, but are not directly connected to the sea. However, by 2120 these areas become connected to the sea by wave run-up.. Both scenarios do not indicate that properties would be impacted by the static water levels due to the high elevations of the land and high elevations of the gravel ridge in front of the settlement. Despite the higher SSP5-8.5 (83rd Percentile) being updated to be significantly higher than the originally mapped RCP8.5+ Scenario in 2120 by approximately 0.5 m, the static extreme water levels are not projected to overtop the gravel ridge or reach the properties.

Anecdotal evidence from residents in Claverley noted that during the same king-tide period as the road failure in July 2023, wave runup reached the houses. This would imply that wave runup was overtopping the 6.5-7 m (LVD) gravel ridge. It is unknown what houses water reached, however from the 2020 lidar it appears that the northern properties have a lower beach ridge elevations for water to overtop than at the southern end of the settlement, therefore it is assumed that it was these northern houses.

The re-mapped wave runup levels for present day through to 2120 show that wave runup could overtop the ridge and intersect with the front nine properties of the Claverley Settlement (Table 4.3), and could reach the road edge along the Claverley Road stretch of shoreline. This is more indicative of what the community experienced in July. As noted in Section 3.4.2, wave runup is largely driven by wave period, and therefore the long period waves that occurred in July could have produced similar runup elevations to the mapped 1% AEP storm for the present day.

Table 4.3: Updated number of properties impacted by coastal inundation hazards.

		Timeframe	2050		2070		2120	
Scenario	**Total**	**Present day Storm**	**SSP5-8.5**	**SSP5-8.5 (83rd Percentile)**	**SSP5-8.5**	**SSP5-8.5 (83rd Percentile)**	**SSP5-8.5**	**SSP5-8.5 (83rd Percentile)**
Number of Properties exposed from static water level	19*	0	0	0	0	0	0	0
Number of Properties exposed from wave runup	19*	9	9	9	9	9	9	9

*Note the previous assessment stated there were 13 properties. This was an error and should have been in reference to there being 13 dwellings, and 19 properties (e.g. 6 properties were unoccupied). As of the 2023, only 2 of the 19 properties within the settlement boundary are unoccupied.

5. Conclusions

In July 2023, following king tides, a coastal storm, and a heavy rainfall event, there was a slope failure in the road embankment along Claverley Road, which backs a mixed sand and gravel beach system. This resulted in 6-8m of horizontal erosion, significant damage to the road restricting access to farms to the north of the slip, and the loss of lateral support to the Main Trunk Railway Line. At the same time, the Claverley community reported anecdotally 7 m of erosion in front of the settlement, and wave runup over topping the beach ridge reaching some properties. This event has prompted a review of the Jacobs (2020) coastal hazard assessment to revisit the appropriateness of the input data and analysis used to map the future inundation and erosion hazard.

It is likely that cause of the road slip failure at Claverley Road was a result of a combination of factors:

- King tides (4th – 8th July)
- Moderate storm event (4th July)
- Heavy rainfall event (8-9th July)
- Saturation of foundation material of the road and rail embankment, decreasing the strength of road and rail embankment foundations.

In the days leading up to the road failure, king-tides occurred which elevated astronomical water levels. On the 4th July there was a moderate coastal storm (1 in 2 to 5 year Annual Recurrence Interval). The coupled king tides and moderate storm event likely resulted in combined high water levels and wave run-up elevations that could interact with the toe of the road embankment. While the previous tool used to calculate the wave runup elevations in the Jacobs (2020) assessment suggested that water would not reach the road embankment in these conditions, an alternative approach to calculating wave runup with better consideration of gravel beach processes has suggested that due to the long wave periods recorded by the ECan wave buoy on 4th July, wave run up could have reached the road embankment toe. These higher combined water levels could have resulted in some initial removal of the road embankment toe by waves during the highest tides.

Antecedent rainfall conditions over the month prior to the failure event likely caused saturation of the road and rail embankment foundations, possibly contributing to the failure of the slope in the heavy rainfall event on the 8-9th July. Seepage into the road and rail embankment foundations is believed to have led to a reduction in strength of the foundation material, potentially contributing to the failure. However, there is not sufficient data to confirm the significance of this reduction in strength of the foundation material, to the failure at this stage. Following the slip event, the wave buoy recorded significant wave heights >4 m with 13 second periods on the 10th July, indicating that continued elevated water levels from wave run-up may have removed some of the talus material of the slip.

In light of the new information gathered through this assessment, the inputs to the Jacobs (2020) coastal hazard assessment were reviewed to identify appropriate updates that could be undertaken to refine the modelling. These updates include:

Sea Level Rise Projections

- Updated SLR increments to account for more recent IPCC (2021) SLR projections, and incorporate Vertical Land Movement (VLM) from the NZSeaRise Programme

Coastal Erosion Model Updates:

- Updated shoreline reference position along Claverley based on recent road slip and improvements.
- The short-term factor was updated to 10 m along Claverley Road to account for the recent slip failure and possibility of a larger event occurring in the future. In front of the Claverley settlement the short-term factor was updated to 7 m to account for anecdotal evidence during the same event.
- A ‘short term storm’ line was produced which help better communicate the risks of an individual storm happening in the near future.

- Recalculation of erosional impacts of SLR using updated SLR projections.

Coastal Inundation Model Updates:

- Inundation modelling of static water levels re-mapped using more recent 2020 LiDAR.
- Wave runup modelling remapped using combined Powell (1990) wave runup calculations combined with attenuation distance calculations from Cox and Machemehl (1986).

At Claverley settlement the updated projected future shoreline positions indicated that the shoreline could intersect with 1 property boundary over the next 30 years, increasing to 2-3 over the next 50 years, and 7-9 over the next 2120 (e.g. most properties in the seaward row of the settlement). Existing dwellings are not projected to be impacted directly by coastal erosion under any of the SLR scenarios.

Due to the increase in the short-term erosion component, the exposure of Claverley Road has significantly increased, where in a present-day storm up to 185 m of Claverley Road could be exposed to erosion if protection failed; increasing to 200-210 m over the next 30 years; 240-255 m over the next 50 years; and 290-325 m over the next 100 years. This updated assessment indicates that section of Claverley Road between the rail bridge underpass south to the Settlement is very susceptible to coastal erosion, and if another significant storm were to occur (and protection failed), a significant length of the road would be damaged.

For coastal inundation, the extreme static water levels mapped for a 1% AEP showed results similar to the Jacobs (2020) assessment, that the extreme static water levels under all scenarios do not overtop the gravel beach ridge, and are not projected to reach any properties under any of the timeframes or SLR scenarios assessed. Updated wave runup calculations and mapping indicate that in a present day 1% AEP event waves could overtop the gravel ridge and run up to the most seaward properties, causing temporary inundation. The analysis of wave runup using the new method also showed that wave runup is very sensitive to wave period, and therefore the long wave periods that were recorded on the 4th July 2023 could have produced high wave runup elevations that reached several properties, as observed by residents at the settlement.

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Appendix A. Updated PFSP Distances Table

	LT	ST	SLR						PFSP Distance					
Transect	Running Average Long Term Annual Rate (m/yr)	Short term Change from Profile Analysis (m)	2050 RCP 8.5 (m)	2050 RCP 8.5+ (m)	2070 RCP 8.5 (m)	2070 RCP 8.5+ (m)	2120 RCP 8.5 (m)	2120 RCP 8.5+ (m)	**2050 RCP 8.5 (m)**	**2050 RCP 8.5+ (m)**	**2070 RCP 8.5 (m)**	**2070 RCP 8.5+ (m)**	**2120 RCP 8.5 (m)**	**2120 RCP 8.5+ (m)**
3	-0.01	-10.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-12.2	-13.3	-14.2	-16.4	-21.3	-26.8
4	-0.03	-10.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-12.8	-14.0	-15.3	-17.4	-23.5	-28.9
5	-0.03	-10.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-13.0	-14.1	-15.6	-17.7	-24.0	-29.4
6	-0.07	-10.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-13.9	-15.1	-17.2	-19.3	-27.2	-32.6
7	-0.07	-10.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-14.0	-15.2	-17.3	-19.4	-27.4	-32.8
8	-0.05	-10.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-13.4	-14.6	-16.3	-18.5	-25.6	-31.0
9	-0.03	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-9.9	-11.0	-12.4	-14.5	-20.7	-26.1
10	-0.02	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-9.7	-10.8	-12.1	-14.2	-20.0	-25.4
11	-0.02	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-9.7	-10.8	-12.0	-14.1	-19.9	-25.3
12	-0.02	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-9.5	-10.7	-11.8	-13.9	-19.4	-24.8
13	-0.01	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-9.4	-10.5	-11.5	-13.7	-18.9	-24.4
14	-0.01	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-9.4	-10.5	-11.6	-13.7	-19.0	-24.4
15	0.01	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-8.7	-9.8	-10.4	-12.5	-16.7	-22.1
16	0.02	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-8.3	-9.4	-9.8	-11.9	-15.4	-20.8
17	0.08	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-6.6	-7.7	-6.9	-9.0	-9.7	-15.1
18	0.08	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-6.6	-7.7	-6.9	-9.0	-9.7	-15.1
19	0.07	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-6.9	-8.1	-7.5	-9.6	-10.8	-16.2
20	0.05	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-7.4	-8.5	-8.2	-10.4	-12.3	-17.7
21	0.04	-7.0	-2.0	-3.1	-3.9	-6.0	-10.6	-16.0	-7.7	-8.8	-8.7	-10.9	-13.4	-18.8

Appendix B. Updated Coastal Inundation Maps