Akaroa Wharf Coastal Hazards Review

Christchurch City Council

Akaroa Wharf Coastal Hazards Review

6 December 2019

Client Reference

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Executive Summary

The Akaroa Wharf is majority owned and maintained by the Christchurch City Council (the Council). The most recent inspection of this wharf was completed in August 2018, which assessed the wharf as being moderate to poor condition. Following this inspection, the Council made an allowance for a temporary upgrade which will allow the wharf to be used for five more years, and in the meantime will investigate possible replacement of the wharf infrastructure.

Jacobs was commissioned by the Council to review existing literature on the coastal processes in the Akaroa Harbour to provide indicative extreme water elevations that could be used in the consultation stages of the wharf replacement. However, further analysis would be required in order to inform the final design levels of the wharf. The coastal hazards assessed in this review are an extreme combined water level event, which includes tide (MHWS), storm surge, wave set up, and sea level rise using MfE (2017) 100-year projections. Also assessed was the 1:100 year and 1:500-year return period tsunami water level at present day sea level and with 100-year sea level rise.

This review has identified the following various elevations under different scenarios that the wharf would need to be constructed to in order to avoid overtopping of the wharf deck for present day conditions and for 100-year sea level rise. These elevations are indicative and are meant for consultation purposes only. It should also be noted that these elevations do not include any consideration of freeboard, which will need to be added in the design process.

- 2.22m above LVD (Lyttelton Vertical Datum) in order to avoid overtopping in an extreme water level event with a 0.8m storm surge coinciding with a MWHS;
- 3.53m above LVD in order to avoid overtopping in an extreme water level event with a 0.8m storm surge and 1.36m of SLR (100 year RCP8.5+) coinciding with a MWHS;
- 4.87m above LVD in order to avoid overtopping from a 84th percentile 1:100 year return period tsunami event coinciding with MHWS with present day sea level;
- 5.93m above LVD in order to avoid overtopping from a 84th percentile 1:100 year return period tsunami event coinciding with MHWS with 100 year SLR;
- 7m above LVD in order to avoid overtopping from a medium (50th percentile) 1:500-year return period tsunami event coinciding with MHWS with present day sea level; and
- 8m above LVD in order to avoid overtopping from a medium (50th percentile) 1:500-year return period tsunami event coinciding with MHWS with 100 year SLR.

Further analysis would be required to further define the probability of the above extreme water level events.

The review also notes that constructing the wharf to avoid the above sea level rise and tsunami water levels could result in some design issues with connection to the waterfront land, which has elevations in the order of 2.5-3.5m LVD. It is also noted that inundation of the Akaroa waterfront will occur with the above sea level rise and tsunami scenarios, which are likely to provide operational issues even if the wharf is elevated above these water levels. Finally it is noted that shoreline erosion and pressure on current shoreline protection works will also increase with SLR, therefore, there is no guarantee that the shoreline will be in the same place in 100-years' time without further investment in shoreline protection works.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to review relevant literature and determine appropriate indicative elevations for the upgrade of the Akaroa Wharf to avoid coastal inundation in accordance with the scope of services set out in the contract between Jacobs and Christchurch City 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.

Jacobs derived the data in this report from information sourced from the Client and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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

Jacobs New Zealand (Jacobs) have been commissioned by Christchurch City Council (the Council) to provide a coastal hazards assessment for the proposed Akaroa wharf replacement to inform what wharf elevations are required for the replacement wharf to be resilient to sea level rise (SLR) for the next 100 years.

The Akaroa Wharf is currently located on Beach Road, just south of Church Street, Akaroa, New Zealand (Figure 1). The 155m long wharf was constructed in 1888. It is majority owned and maintained by the Council, with significant investment required to maintain it to a safe standard for public use.

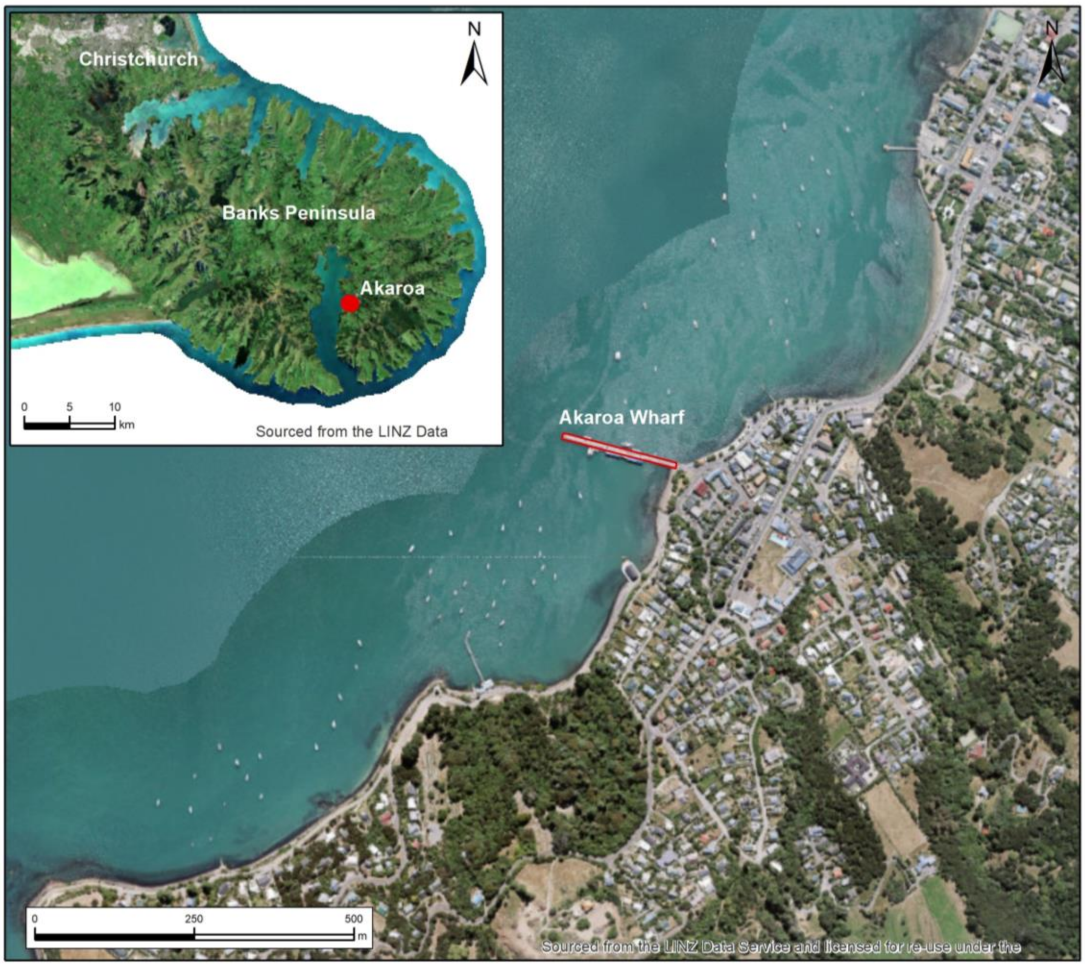

Figure 1.1: Overview map of Akaroa Wharf location. Inset map showing location of Akaroa Wharf in relation to Christchurch City and Banks Peninsula.

The most recent inspection of the wharf was completed in August 2018, which assessed the wharf as being moderate to poor condition. Following this inspection, the Council has made an allowance for a temporary upgrade which will allow the wharf to be in use for five more years, and it is expected that the structure will be upgraded within this timeframe. The wharf was originally constructed for coastal shipping, however the primary use for the wharf is now by tourists, fishermen (sic), cruise ship transfers and recreational walkers.

Sea level rise and king tides have been identified as potential issues for the wharf, which includes the flooding of the floors of the wharf buildings and acceleration of decay of the wharf timbers from higher mean tides. In order for the wharf to be used in the future, especially for commercial use, the height of the Akaroa Wharf will need to be increased in height. As shown in council survey plans, the elevation of the wharf currently is around 2.5m LVD (Lyttelton Vertical Datum 1937), with the land elevation immediately behind the wharf being generally between 2.5-3.5m.

A report by Calibre Consulting Ltd (2019) outlined the options for reconstructing the wharf with minimum disturbance to local use and businesses which reside on the southern edge of the wharf, as well as maintaining the historic values which the wharf holds. The report outlines three options for construction materials, and three options for locations of the replacement structure. The recommendation from this report was to use these options in public consultation.

This assessment will review previous studies which have assessed the coastal process hazards in Akaroa Harbour, including extreme water levels, SLR and tsunami hazards. The assessment will inform what wharf elevations are required for the replacement wharf to be resilient to SLR for the next 100 years for consultation and preliminary design purposes. Further analysis would be required in order to inform the final design levels of the wharf.

2. Extreme Water Levels

2.1 Methodology

An extreme combined water level from tides and storm surge was determined through a review of literature and recent data to inform what an indicative extreme water level could be at the Akaroa Waterfront. This extreme water level does not have an associated AEP (annual exceedance probability) due to it being a combination of conservative estimates without a joint probability analysis. Such an analysis of the likelihood of these events coinciding could be undertaken if an AEP event was required.

The combined parameters used to determine the extreme water level are;

- Mean High Water Spring (MHWS);
- Storm surge;
- Wave setup; and
- Sea Level Rise (when projecting for 100 years).

A review of a report by DTec Consulting Ltd (2008) which assessed the coastal erosion and inundation hazards in Akaroa Harbour was undertaken to inform the indicative extreme water levels which can occur along the Akaroa Township Waterfront. The report calculated inundation levels by using historical air pressure, wind and wave records to inform the level of storm surge and wave run up at the shoreline. The parameters used by DTec (2008) to calculate extreme water level have been reviewed to determine if they still represent an extreme water level in the Akaroa Harbour.

2.1.1 Calculating combined extreme water level for present day

Mean High Water Spring (MHWS)

MHWS describes the highest level that spring tides reach on average over a long timescale (18-20 years). In the DTec (2008) report, MHWS elevation was considered to be 0.9m above MSL, which is now considered to be more indicative of Mean High Water elevation rather than MHWS. For this report, MHWS has been taken from the LINZ secondary ports dataset, which gives the MSL for Akaroa to be 1.5m (CD) and MHWS to be 2.7m (CD), hence MHWS of 1.2m above MSL. For reference to land elevation datum (LVD), we have used 1.37m as the elevation of the MHWS, which takes into account the +0.17m SLR from when the vertical datum was set 1937 to present (Stephens et al, 2015).

Storm surge

Storm surge is the elevation of sea level above astronomical tide due to the combined effects of low atmospheric pressure and high onshore, or in the case of Akaroa, up-harbour winds.

Barometric lift is the term used to describe the adjustment of sea level in response to air pressure changes, which generally equates to 1cm rise in sea level for every millibar (mb) drop in air pressure below the mean value at the sea surface of 1014 mb. The response generally takes place over a 2-12 hours time period, and effects a body of water in a fairly uniform manner. In the DTec (2008) report, barometric lift was set at the mean annual minimum air pressure recorded at Christchurch Airport from 1960-2007.

Wind stress was calculated by the equation given in Vant (1985):

$$\Delta D = W^2 \left(\frac{L}{D}\right) (1 + 0.07W) \times 10^{-4}$$

Where ∆D is the change in water level, W is wind speed, L is fetch length and D is water depth (taken as mean depth in harbour). This equation was calculated using the maximum southerly wind blowing up the Harbour measured at the Akaroa MetService site over the period November 1977 to May 2001.

An appropriate storm surge component of extreme water levels was assessed to be the addition of the mean annual maximum barometric lift over a nearly 50 year period, and the maximum wind stress over a nearly 25 year period. The mean annual minimum air pressure at the Christchurch Airport (1960-2007) is 981 mb, giving mean annual maximum barometric lift in the order of 0.33m. Maximum southerly winds recorded at Akaroa from 1977-2001 was 26.8m/s, which would result in a rise in water level of 0.28m at the head of the harbour. The resulting component of storm surge calculated from this method was in the order of 0.6m. The return period was assumed to be the product of two individual events (e.g. 1 year and 23 years), therefore was considered to be a one in 20-25 year event. This frequency is now considered to probably is too high, and a longer return considered to be more realistic.

In this report, the calculations for the present day storm surge hazard are made for both 0.6m (as calculated by DTec, 2008), and 0.8m being the commonly applied upper level of storm surge in New Zealand (Bell et al, 2000)

Further analysis of more recent air pressure, wind and wave records would be required to determine the level of storm surge in a 1% AEP event and recalculate the combined extreme water level.

Waves

Theoretical maximum waves were calculated in DTec (2008) due to there not being any direct measurements of the wave climate within the Akaroa Harbour. Large waves are generated mostly from the south west (blowing up the harbour) and from the north west (blowing down the harbour). Large waves generated from the south west can be associated with storm surge given that low barometric pressure is generally associated with weather systems coming from the south.

From the information presented in DTec (2008), a theoretical maximum wave height of 1.08m, and wave period of 2.62 seconds from the south west was input into the wave setup equation from Holman (1986) [1] (from Komar (1998) to give a wave set up of 0.01m. When the slope of the seabed (0.01) was input into the NIWA Coastal Calculator, a wave set up for a similar wave height was estimated to be 0.03m. Applying a conservative approach, wave setup around the wharf is therefore estimated to be no more than 0.05m.

Wave runup was calculated in DTec (2008), however, it was determined that this was not necessary in this assessment given that there is not likely to be any runup on the wharf structure as water will flow around it, and therefore this component is not necessary to add to the extreme water level.

2.1.2 Calculating extreme water level with sea level rise

IPCC AR5 (2014) developed four climate change and sea level rise (SLR) projections, termed RCP's (Representative Concentration Pathways), based on different global emission scenarios. MfE (2017) developed four sea level rise scenarios based on three of the IPCC scenarios (RCP2.6, RCP4.5 and RCP8.5) and a higher 8.5+ scenario which takes into account the possible instabilities in the polar ice sheets. These scenarios presented in MfE (2017) extend out to 2150 and include a small additional sea level rise above the global projections to account for New Zealand wide regional offset in rates of historical sea level rise. These scenarios are presented in Figure 2.1. The RCP8.5+ scenario is the recommended minimum transitional SLR allowance in MfE (2017) to avoid hazard risk in coastal subdivision, greenfield developments and new major infrastructure

[1] Wave setup calculated as $\eta_{max} = 0.18 g^{1/2} S H_{\infty}^{1/2} T$ where S is slope, H is maximum wave height, and T is wave period.

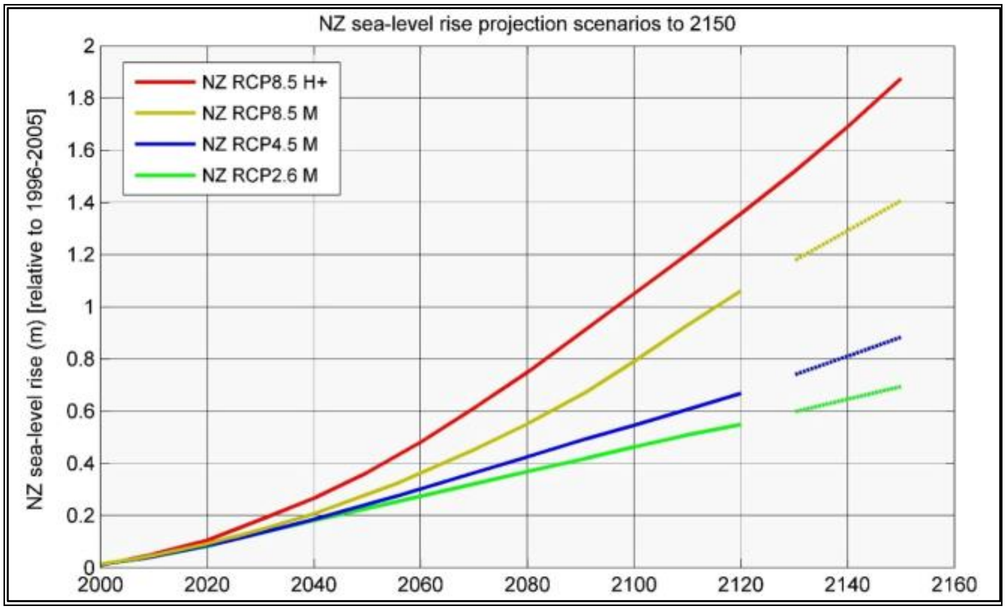

Figure 2.1: Four scenarios of New Zealand wide regional SLR projection based on IPCC (2014). From MfE (2017, Figure 27).

For this assessment, all four SLR projections presented in MfE (2017) are used, as shown in Table 2.1. Projections for 2120 were used as the 100 year projections.

Table 2.1: RCP scenarios for SLR projections above MSL from MfE (2017)

Scenario	Projection of SLR (m)
RCP2.6	+0.55
RCP4.5	+0.67
RCP 8.5	+1.06
RCP 8.5+	+1.36

Therefore, the parameters used for determining the elevation of water when assessing coastal inundation in an extreme water level event at the Akaroa Wharf are;

- Tide (MHWS) 1.37m above LVD;
- Storm surge 0.6-0.8m;
- Wave setup 0.05m; and
- SLR (100 years) 0.55-1.36m.

2.2 Results

2.2.1 Extreme water level event present day

From the parameters outlined in Section 2.1, extreme water levels with present day sea level are predicted to be in the order of **2.0m to 2.2m** (LVD). It is considered that a water level of 2.22m above LVD is likely to be a conservative upper estimate of water levels in 1% AEP event.

The nature of the wharf means that waves overtopping the deck and hydrodynamic pressure from waves interacting with the wharf deck and piles from below also need to be considered in design. As mentioned in Section 2.1.1, wave runup will also intermittently affect the water levels for short periods of time, however this process only occurs at the shoreline, and therefore will only be relevant for where the structure intersects the shoreline.

2.2.2 Extreme water level event with SLR

The results for water levels in a nominal 1% AEP event with sea level rise are presented in Table 2.2. These results show that using the four RCP SLR projections for 100-years (e.g. 2120), the extreme water level ranges from **2.57m to 3.58m** above LVD, with the range being dependent on the elevation of storm surge and the RCP scenario used.

Table 2.2: Extreme combined water level elevations above MSL with various RCP Sea Level Rise projections to 2120.

RCP Scenario	MHWS (m above MSL)	Wave set up (m)	Storm surge elevation (m)	SLR (m)	Total combined extreme water level (m above MSL)
2.6	1.37	0.05	0.6	+0.55	**2.57**
	1.37	0.05	0.8	+0.55	**2.77**
4.5	1.37	0.05	0.6	+0.67	**2.69**
	1.37	0.05	0.8	+0.67	**2.89**
8.5	1.37	0.05	0.6	+1.06	**3.08**
	1.37	0.05	0.8	+1.06	**3.28**
8.5+	1.37	0.05	0.6	+1.36	**3.38**
	1.37	0.05	0.8	+1.36	**3.58**

Using the most extreme RCP8.5+ SLR scenario and a storm surge elevation of 0.8m provides a conservative estimate as to what the future extreme water level could be in Akaroa. The RCP 8.5+ SLR scenario is also considered to be conservative, but is the recommended scenario in the MfE (2017) guidance for developing new infrastructure. However, constructing a replacement wharf to a 3.60m (LVD) elevation to account for this water level elevation would reduce the likelihood that the wharf would be impacted by extreme water levels.

Therefore, under this most conservative approach, the wharf would need to be elevated in the order of 1m higher than its current elevation, raising possible practically issues with the connection to the surrounding land (2.5-3.5m LVD) which would be taken into account in design considerations. Additionally, the elevation does not include any freeboard for wave action which would need to be considered in design.

To reduce the uncertainty surrounding the elevation of storm surge, further analysis could be undertaken with more recent wind, wave and air pressure data to extend the period of data reviewed. However, it is likely that this elevation of the storm surge will be between 0.6-0.8m.

It should also be noted that shoreline erosion and pressure on current shoreline protection works will also increase with SLR, therefore, there is no guarantee that the shoreline will be in the same place in 100-years' time without further investment in shoreline protection works.

3. Tsunami Inundation

3.1 Methodology

A review of literature was undertaken to determine the likely inundation caused by a 1 in 100 and a 1 in 500-year tsunami event in Akaroa Harbour. This included a review of the previously mentioned DTec (2008), the most recent 1:500-year return period tsunami inundation modelling for Akaroa Harbour produced by NIWA for Christchurch City Council (2018), and nation-wide wave at shore modelling from Power (2013) for tsunamis with return periods from 1:100 to 1:2500 years.

The modelling produced by NIWA investigated a 1:500-year event from a South American earthquake arriving at MHWS for present day, 2065 (+0.41m) and 2120 (+1.06m-e.g. RCP8.5 scenario). The modelling was based on an 9.28M_w earthquake event involving 13 SIFT (Short-Term Inundation Forecast for Tsunamis Database) fault segments, and a uniform slip of 35.89m along each segment. This event was identified in Power (2013) as being the most likely source scenario for the 1:500-year event for Christchurch City. By modelling the tsunamis to arrive at MHWS it produces a worst-case scenario with maximum inundation in that magnitude event.

The modelling shows water levels at two locations in the harbour (Wainui and Duvauchelle), and inundation depths at different settlements throughout the harbour. It is noticeable that these depths infer different water levels as the tsunami travels up the harbour basin, therefore the presented water levels at Wainui and Duvauchelle are unlikely to be applicable to Akaroa township. Water levels at shore at Akaroa are therefore induced from the inundation depths along the waterfront of the township.

The modelling by Power (2013) presents hazard curves for 20km sections of shoreline including for Akaroa which illustrated the maximum expected tsunami amplitude at shore for 16,. 50 and 84 percentile exceedance as a function of tsunami return periods from 1:100 to 1:2500 year. The maximum tsunami amplitudes are presented as height is above water level at the time of arrival, therefore can be used as a proxy for bathtub type inundation levels in these magnitude tsunami events.

It is notable that the results from the GNS (Power 2013), and NIWA (2018) differ due to the use of different models.

3.2 Results

3.2.1 Historical tsunami events

There are records of four tsunamis which have occurred in Akaroa Harbour. These events occurred in August 1868, May 1877, May 1960 and February 2010, all of which were distal source tsunamis generated off the coast of South America. Importantly, none of the tsunami peaks coincided with high tide. The changes in water levels from these events were recorded as follows;

- August 1868 – Rise and fall of 3.9m of water at the Akaroa Jetty, which is not the current wharf as this structure was only constructed in 1888. Inundation reported in parts of the township;
- May 1877 – Rise and fall of water reported to be 2.4m in five minutes. This event also pre-dates the current wharf, but inundation of some houses in the township was reported;
- May 1960 – Sea level rose an estimate 1.8-2.4m above normal. Water overtopping of seawalls and inundation of the main street was reported, but water did not appear to cover the main wharf; and
- February 2010 – 1m event wave reported on the Canterbury Coast and Lyttelton Harbour. It is unknown what the water levels in Akaroa reached during this event. People started to self-evacuate from Banks Peninsula settlements following warnings, but there were no indications of inundation following its arrival.

The exact return period of these tsunamis is unknown, as are the water levels in Akaroa at the time of their arrival. However, from these records it is estimated that the water elevations around the wharf in historic tsunami events has been less than 4m.

3.2.2 1:100 year tsunami modelling

The results of Power (2013) for the 20km section of coast around Akaroa are presented in Figure 3.1, which shows that in a 1:100 year return period event there is an 16% probability that the maximum amplitude of the tsunami wave would be less than 2.5m above water level at the time, and a 84% probability that the maximum amplitude would be below 3.5m above water level at the time of arrival. The 50th percentile (Median) curve indicates that the maximum wave amplitude would be in the order of 2.9m above water level at the time of arrival. Therefore, in a worst-case scenario, if the tsunami occurred at MWHS, there is a 16% probability that the maximum water level at the shore could reach 4.87m LVD, which is in the order of 2.35m above the current wharf deck. Even occurring at half-tide, the median 100-year return period tsunami would overtop the current wharf deck by 0.4m.

Given that the maximum water level change recorded in historical events was 3.9m and was not at high tide, the results of Power (2013) align well with historical accounts.

While the level of detail used in this modelling is significantly less than the NIWA (2018) report used to determine inundation risk from a 1:500 return period tsunami, it gives an indicative height of 4.87m (LVD) that a replacement wharf would need to be built to in order to prevent it from being overtopped in a 1:100 return period event.

The water levels in this event when combined with 100 year of sea level rise could increase this estimate by 1.06m (RCP8.5 scenario for consistency with NIWA, 2018), with the wharf therefore needing to be constructed at an elevation in the order of 5.93m to prevent overtopping under these conditions.

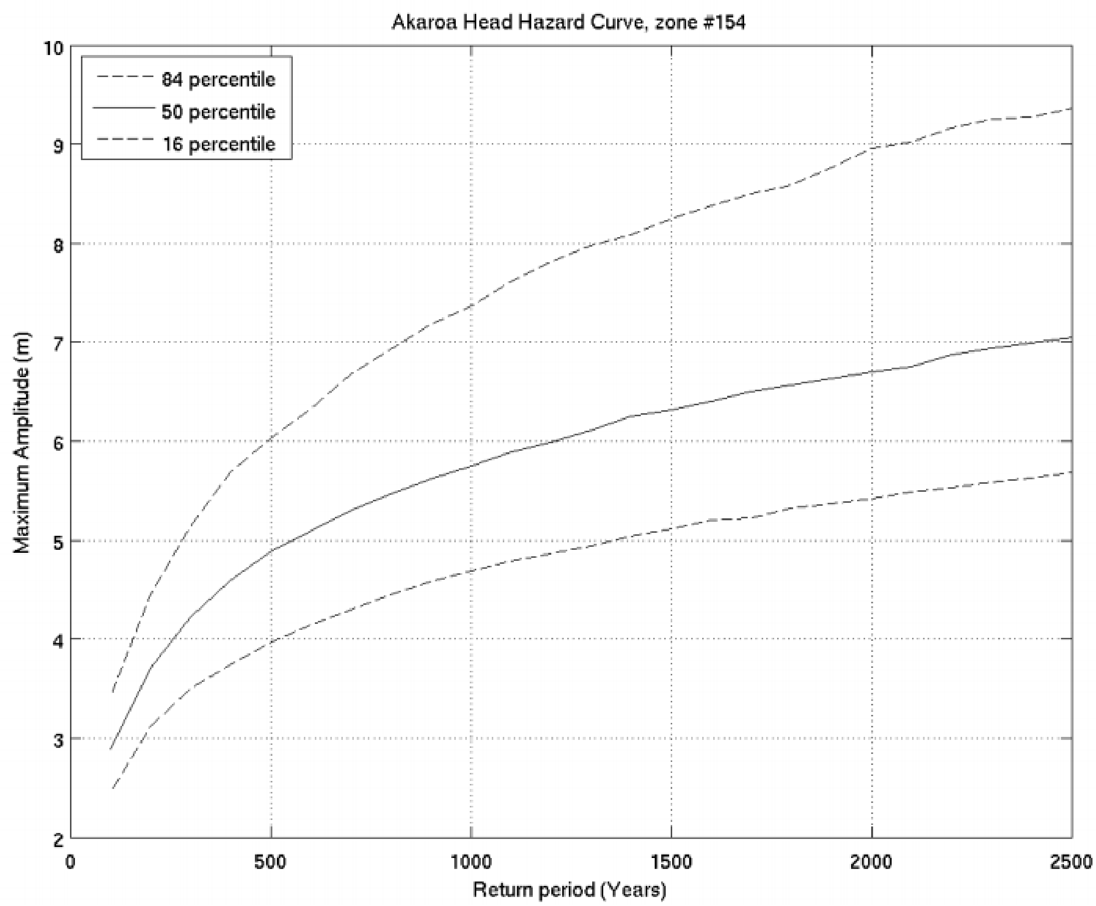

Figure 3.1: Maximum wave amplitudes at shore for Akaroa Harbour with return periods of modelled tsunamis (From Power, 2013)

3.2.3 1:500 year tsunami modelling

The Power (2013) report indicates that for a 1:500-year return period tsunami event with no sea level rise component, there is a 84% probability (e.g. 16^{th} percentile) that the maximum wave amplitude would be above 4m, and a 16% probability (e.g. 84^{th} percentile) that the maximum wave amplitude would be above 6m. The 50^{th} percentile (Median) maximum wave amplitude is modeled to be in the order of 4.9m. Using a conservative approach of the 84^{th} percentile event coinciding with MHWS, the wave amplitude could be expected to reach 7.37m above LVD.

NIWA (2018) modelling in the Akaroa Harbour for 1:500-year distal source tsunami event is a more detailed modelling assessment of the tsunami risk, which largely focusses on the inundation risks to the settlement. The relevant inundation maps for Akaroa presented in the NIWA (2018) study are attached in Appendix A. These maps show that the inundation depth along the waterfront in Akaroa township under present sea level conditions would be in the order of 3.5 -4.5m, and reaches as far as 250m inland for tsunami coinciding with MHWS. Based on the land elevation at the waterfront (2.5-3.5m LVD), this implies that under this modelling approach water levels at the shore would be in the order of 7m above LVD, and wave amplitude at shore in the order of 5.6m. It is noted that waves at this amplitude are between the 50^{th} and 84^{th} percentile amplitudes reported by Power (2013) for a 1:500-year tsunami event at Akaroa.

The NIWA (2018) modelling also showed that higher sea levels will amplify tsunami inundation in a non-linear matter in the lower harbour, including at Akaroa township where a 1.06m increase in water level due to SLR (e.g. to 2120) would increase inundation extents by up to 100m. The modelling suggests that under this scenario, tsunami inundation depths at the Akaroa waterfront would be in the order of 4.5-5m, hence water levels in the order of 8m LVD for a tsunami coinciding with MHWS.

The NIWA (2018) report also presented maximum flow velocities and shear stress as a proxy for erosion potential for the modelled 1:500-year tsunami event. The results showed that that under current sea levels maximum velocities in Akaroa Bay would be in the order of 0.3 m/s and would not greatly increase for higher sea levels. However, the shear stress produced would exceed the critical limits necessary to transport the soft sediments present on the sea bed, therefore the wharf pile design needs to account for this erosion potential.

4. Conclusions

This desktop review has identified the following various elevations under different scenarios that the wharf would need to be constructed to in order to avoid overtopping of the wharf deck for present day conditions and for 100-year sea level rise. These elevations are indicative and are meant for consultation purposes only. It should also be noted that these elevations do not include any consideration of freeboard, which will need to be added in the design process.

- 2.22m above LVD in order to avoid overtopping in an extreme water level event with a 0.8m storm surge coinciding with a MWHS;
- 3.53m above LVD in order to avoid overtopping in an extreme water level event with a 0.8m storm surge and 1.36m of SLR (100 year RCP8.5+) coinciding with a MWHS;
- 4.87m above LVD in order to avoid overtopping from a 84th percentile 1:100 year return period tsunami event coinciding with MHWS with present day sea level;
- 5.93m above LVD in order to avoid overtopping from a 84th percentile 1:100 year return period tsunami event coinciding with MHWS with 100 year SLR;
- 7m above LVD in order to avoid overtopping from a medium (50th percentile) 1:500-year return period tsunami event coinciding with MHWS with present day sea level; and
- 8m above LVD in order to avoid overtopping from a medium (50th percentile) 1:500-year return period tsunami event coinciding with MHWS with 100-year SLR.

Further analysis would be required to further define the probability of the above extreme water level events.

The current elevation of the wharf is in the order of 2.5m, with the elevation of the land immediately behind the structures being similar, in the order of 2.5-3.5m. If the wharf was only constructed to be protected from an extreme water level event with 100 years of SLR, the wharf would need to be raised in the order of 1m from its current elevation, with additional freeboard in the order of 1m for wave impacts. Constructing the wharf to this elevation would mean there would need to be some consideration in the wharf design of how it connected to the land which is at a lower elevation.

If the replacement wharf is constructed to an elevation which would prevent overtopping in a 1:100 or 1:500-year return period tsunami, it will need to be to an elevation which is significantly higher than the land behind. This may raise practical issues that need to be taken into account in the design and location of the wharf especially if designing to protect from a 1:500-year return period tsunami (7-8m depending on present or 100-year sea level). Additionally, building to this elevation will mean that while the wharf should not be overtopped in these events, the land behind will be inundated, and therefore the access to the wharf is likely to be limited.

It is noted that these elevations are indicative and meant for consultation purposes only. It is also noted that shoreline erosion and pressure on current shoreline protection works will also increase with SLR, therefore, there is no guarantee that the shoreline will be in the same place in 100-years' time without further investment in shoreline protection works.

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Appendix A. NIWA (2018) 500 year tsunami inundation maps

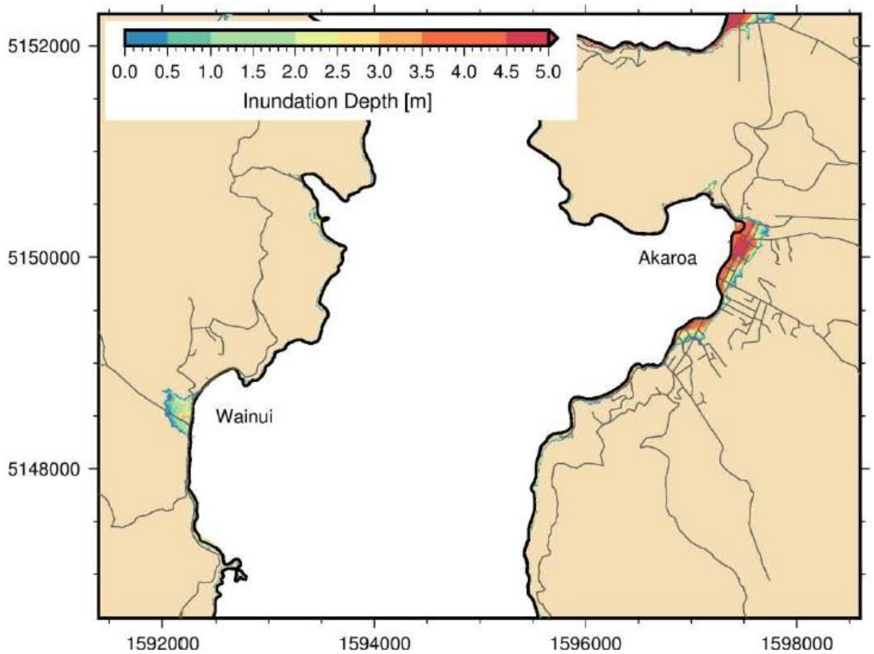

Figure 1: Maximum inundation depth (height above ground) for 1:500 year return period event at current sea level.

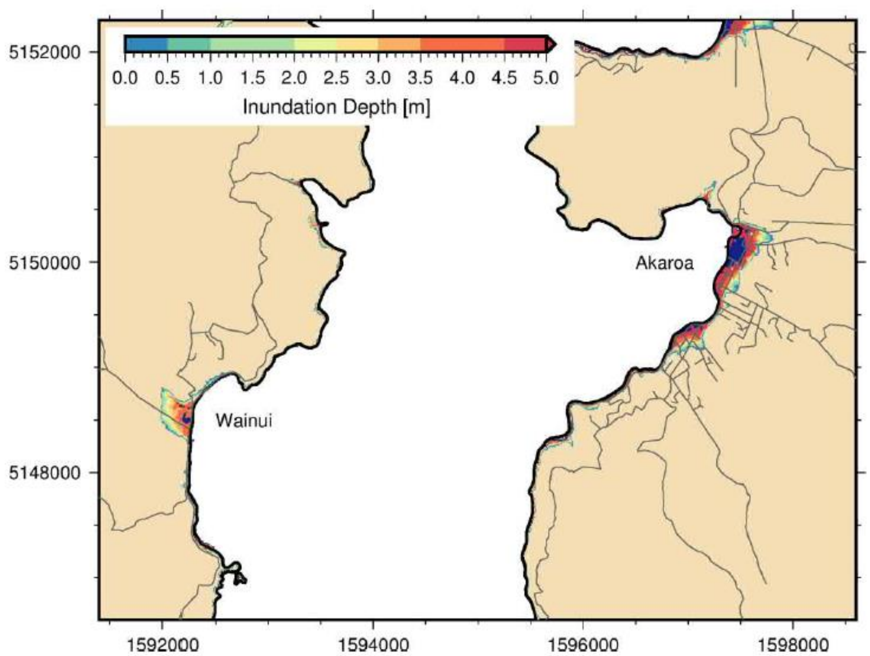

Figure 2: Maximum inundation depth (height above grounf) for 1:500 year return period event in a 100 year RCP8.5 sea level rise scenario.