Addendum Report to Risk Based Coastal Hazard Analysis for Land-use Planning Report

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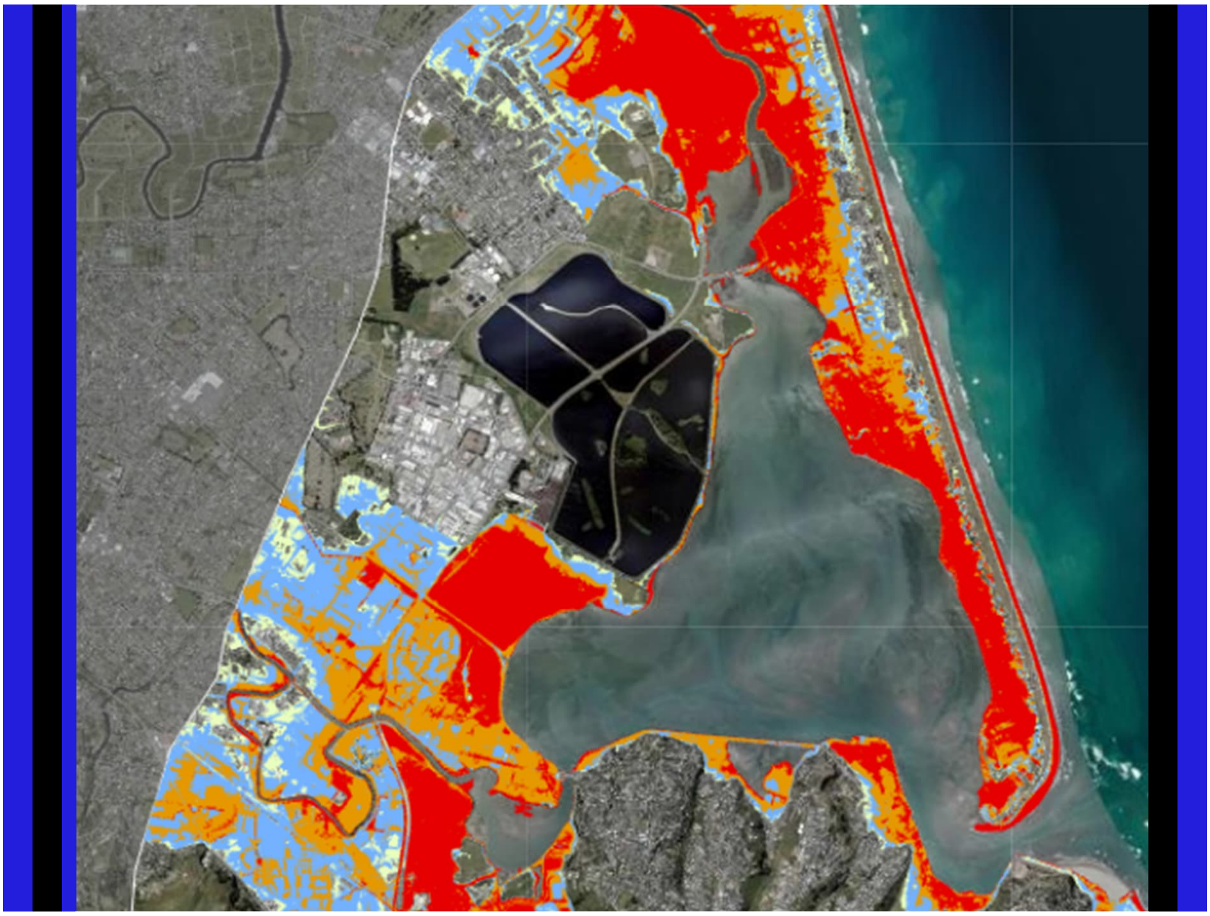
Christchurch City Council

Coastal Hazard Plan Change - Analysis/Technical Advice
24 August 2022



Jacobs

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Revision no:	Rev 0	**Prepared by:**	D Debski, E Scheffler & K MacDonald
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Executive summary

In July 2021, CCC commissioned Jacobs to conduct a risk-based coastal erosion and inundation hazard analysis for land-use planning. The recommendations from the study (Risk Based Coastal Hazard Analysis for Land-use Planning, Jacobs report IS391200-NP-RPT-0001, September 2021) were used by CCC in their Issues and Options paper for consultation with communities and stakeholders on the Coastal Hazards District Plan Change in conjunction with consultation on the Coastal Hazards Adaptation Planning Programme also being undertaken by CCC. The recommendations were externally peer reviewed by Beca. In light of community submissions and external peer review comments, we have updated our recommendations, which are presented in this addendum to the Jacobs (2021) report. The purpose of this addendum report is to present the analysis undertaken to justify the recommended thresholds for the hazard categories and to present the spatial extent of the resulting hazard zones for both coastal inundation and erosion.

Council intend to use this addendum report to support the identification of Qualifying Matters in Plan Change 14 – Housing and Business Choice which is anticipated to be notified in September 2022.

The objectives of our project were to:

a) Define a range of suitable hazard thresholds and applicable scenarios[1] to develop low, medium, and high erosion and inundation hazard areas

b) Recommend a preferred approach to the categorising and mapping of erosion and inundation hazards to inform the drafting of plan change provisions appropriate to the differing levels of risk.

A review of the approaches currently used in District and Regional Plans in New Zealand, non-statutory documents and consideration of international guidance was undertaken to inform the choice of risk thresholds and scenarios.

Thresholds were developed for the new erosion and inundation coastal hazard data from the CHA which was in the form of bathtub modelling data for inundation and a range of methodologies for erosion along differing coastline types. A range of approaches to define areas of low, medium and high risk were developed and compared, from which a preferred approach was recommended.

We have allowed for the increase in hazard exposure due to expected sea level rise (SLR) by assessing both the erosion and inundation hazards for two SLR scenarios - 0.6 m SLR by 2080 and 1.2 m SLR by 2130.

For Inundation, the 0.5% annual exceedance probability – a reasonably foreseeable event and consistent with definitions under the existing District Plan and Regional Policy Statement – and the 1.2 m SLR scenario were selected to define the overall extent of inundation hazard. This scenario ensures intergenerational needs, and a precautionary approach are applied to the planning framework.

Thresholds are based on the water depth for the 0.2% annual exceedance probability with 1.2m SLR and were developed by considering the hazard to people who need to access, egress, or use the buildings during a flood.

The depth threshold values were informed by published guidelines and used to define four coastal flood risk categories – high/medium/low/very low. These categories allow for a consideration of the change in the flood depth between the higher confidence SLR scenario (0.6 m) which is likely to occur sooner, and the lower confidence, but higher consequence, SLR scenario (1.2 m) which may occur further in the future. The recommended flood risk categories are presented in Table 1-1.

[1] "Scenario" refers to a combination of a future time period and climate change scenario (RCP) which together determine a projected rise in mean sea level (SLR) and consequent increase in hazard.

Table 1-1. Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 0.2% annual exceedance probability)

Coastal flood risk category	Flood hazard with 0.6m SLR	Flood hazard with 1.2m SLR
Very low	None (dry)	Low (d < 0.4 m)
Low	Low (d < 0.4 m)	Medium (0.4 m < d < 1.0 m)
Medium	Medium (0.4 m < d < 1.0 m)	High (d > 1.0 m)
High	High (d > 1.0 m)	High (d > 1.6 m)

For Erosion, based on the assumption that the permanent loss of land due to erosion is always high, likelihood was selected as the key determinant of erosion thresholds, being the statistical probability that a certain erosion distance will occur within a given timeframe.

Several thresholds across different SLR timeframes were tested to assess whether they can meet the requirements under the Resource Management Act 1991 (RMA) of defining reasonably foreseeable hazards, and that the resulting hazard zones meet the needs of future generations. The analysis also considered the various assessment methods applied by T+T in different areas of the District. The recommended combination of thresholds and scenarios are:

1) For the Christchurch City urban area open coast; two erosion zones compromising of
   a) A High Hazard Coastal Erosion Zone covering the current beach-primary dune width, and
   b) Where required, A Low Hazard Coastal Erosion Zone to a lowland limit defined by the 10% probability erosion distance with 1.2 m SLR by 2130 and an additional area required for "future dune resilience factor".
2) For the Avon-Heathcote Estuary; two erosion zones comprising of
   a) A High-Medium Hazard Coastal Erosion Zone defined by a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell for the 66% probability erosion distance with 0.6 m SLR by 2080
   b) A Low Hazard Coastal Erosion Zone defined by a generic additional width of 20 m across all cells to be equal to the largest ASCE in any cell for the 10% probability erosion distance with 1.2 m SLR by 2130.
3) For the beaches and bays of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single Banks Peninsula Bays High-Medium Coastal Erosion Hazard Zone, with the landward limit defined for:
   a) Probabilistic assessment cells as the 10% probability of erosion distance for 1.2 m SLR by 2130, and
   b) Deterministic assessment cells as the limit of the ASCE from the 1.5 m SLR by 2130 scenario, which has an assumed probability of 1-5%.
4) For the coastal cliffs of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single Banks Peninsula High-Medium Cliff Erosion Zone of 20-30 m width as defined by the generic T+T cliff erosion setback
5) For assessment cells along the southern shore of the Avon-Heathcote estuary, Sumner Beach, Lyttelton Port and Akaroa township where there are land reclamation and substantial hard protection structures; a single High-Medium Hazard Coastal Erosion Zone hazard zone with a generic width in the order of 20 m based on the short-term erosion response if these reclamation and protection structures failed.

Maps have been created showing the hazard zones relating to the recommended inundation and erosion risk categories as shown in the sample extract in Figure 1-1. These have been provided to CCC as a spatial layer. Maps of all the other options considered are provided in a spatial viewer accessible to the project team.

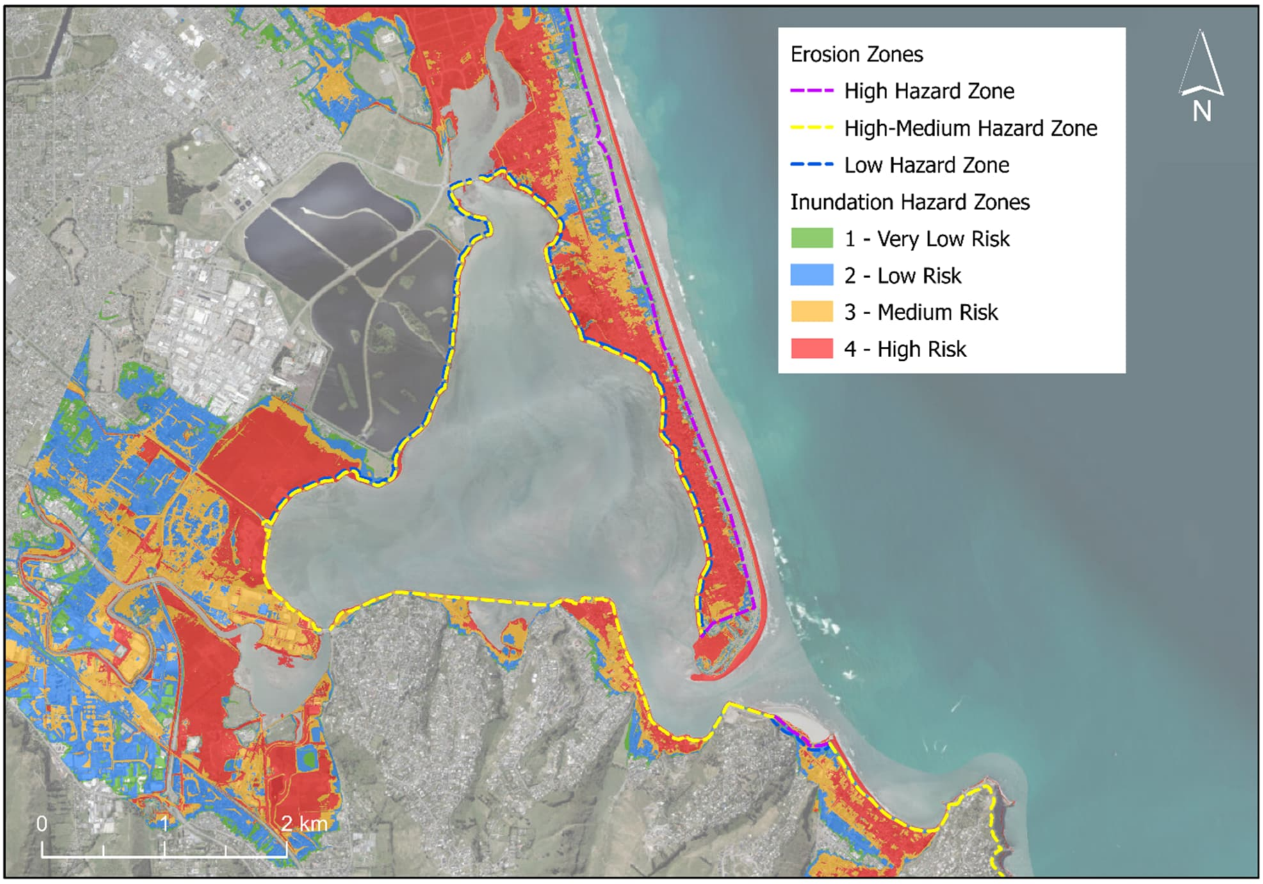

Figure 1-1. Sample extract of mapping of the recommended erosion and inundation zones

ⓘ *Important note about your report*

The sole purpose of this report and the associated services performed by Jacobs is to develop a risk-based approach to analysing coastal hazards to be used in land-use planning 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.

The coastal hazard data and information analysed in this assessment was developed by Tonkin and Taylor Ltd for Christchurch City Council and this information has been used as provided with no review of the accuracy of that information or its method of development.

This report has been prepared on behalf of, and for the exclusive use of, the Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

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Acronyms and abbreviations

AEP	Annual Exceedance Probability
AR6	Six Assessment Report
ASCE	future Areas Susceptible to Coastal Erosion
CCC	Christchurch City Council
DEM	Digital elevation Model
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
LINZ	Land Information New Zealand
NZCPS	New Zealand Coastal Policy Statement
NZVD2016	New Zealand Vertical Datum 2016
RCEP	Regional Coastal Environment Plan for the Canterbury Region
RCP	Representative Concentrations Pathways
RMA	Resource Management Act
RPS	Regional Policy Statement
SLR	Sea Level Rise
SSP	Shared Socio-economic Pathways
T+T	Tonkin & Taylor Ltd
yr	year

1. Introduction

This document is an addendum to the Jacobs report titled "Coastal Hazards Plan Change – Analysis/Technical Advice – Risk Based Coastal Hazard Analysis for Land-use Planning", document reference IS391200-NP-RPT-0001 Final, dated September 17 2021 (referred to in this document as Jacobs, 2021).

The Jacobs (2021) document detailed a range of options for using Council's coastal erosion and inundation hazard assessment data within land use planning. Specifically, it sought to develop a risk based approach to identify areas of high, medium and low risk and map extents of these across the city and Banks Peninsula.

Our recommendations from the Jacobs (2021) report were used by CCC in their Issues and Options paper for consultation with communities and stakeholders on the Coastal Hazards District Plan Change in conjunction with consultation on the Coastal Hazards Adaptation Planning Programme also being undertaken by CCC. The recommendations were externally peer reviewed by Beca. In light of community submissions and external peer review comments, we have updated our recommendations, which are presented in this report. The purpose of this report is to present the analysis undertaken to justify the recommended thresholds for the hazard categories and to present the spatial extent of the resulting hazard zones for both coastal inundation and erosion.

Council is initially proposing to use these mapped hazard areas for two purposes. The first is to support the identification of Qualifying Matters in Plan Change 14 – Housing and Business Choice which is anticipated to be notified in September 2022. The second is to support a Coastal Hazards Plan Change (plan change 12) anticipated to be developed further in 2023. It is likely that these two plan changes would use different subsets of the mapped hazard areas due to their different purposes with the later Coastal Hazards Plan Change being likely to include a wider range of hazard areas.

The addendum report presents the updated approaches to the coastal hazards plan change technical advice following the public submissions and peer review. It is specifically focused on providing an update to the Jacobs (2021) report to support the mapped hazard extents used in the Plan Change 14 Coastal Hazard Qualifying Matters.

It is noted that ongoing refinement of the methods may occur as a result of further developing the approach to the Coastal Hazards Plan Change. This may result in changes to the mapped hazard areas developed by using the approaches noted in this report.

2. Consideration of NZSeaRise Data

This section is an addendum to section 5 of the Jacobs (2021) report. It discusses the sea level rise scenarios selected in light of this more recent data on vertical land movement (VLM).

Data compiled by GNS and NIWA which considers the recent AR6 (2021) SLR projections and local VLM was released in 2022 as part of the NZSeaRise programme. The data shows relative sea level rise projections at 2 km intervals along the entire New Zealand coastline. The VLM was able to be captured at high resolution using InSAR – a satellite based technique which can measure ground deformation using radar images of the earth's surface.

For the NZSeaRise programme, information on VLM has been gathered from a relatively short 8-year period from 2003-2011. This data capture period lacks inclusion of data from the post Christchurch Earthquake Sequence (including instantaneous land movement in the earthquake sequence), which for some sites are contrary to the results of the pre-quake InSAR analysis. Therefore, there is little confidence at this time of including these rates to medium and long-term projections of sea level rise.

However, if the NZSeaRise data was to be included, it was considered that further analysis was required to determine(a) how the spatial variation in VLM across the district would influence the magnitude of projected SLR ; and (b) what the practical implications of that were on the mapping of hazards for planning purposes.

The NZSeaRise data shows that there is significant variation in the amount of vertical land movement that occurs around the Christchurch and Banks Peninsula coastline, as shown in Figure 2-1. Across the total area, the mean VLM is -1.508 mm/yr, with a maximum uplift of +1.917 mm/yr; and a maximum subsidence of -4.010 mm/yr. The variation in VLM is broader over the Banks Peninsula coastline compared to the Christchurch Metropolitan area, as can be seen in Figure 2-1, where the 50% of sites have VLM between -0.8 mm/yr to +0.225 mm/yr.

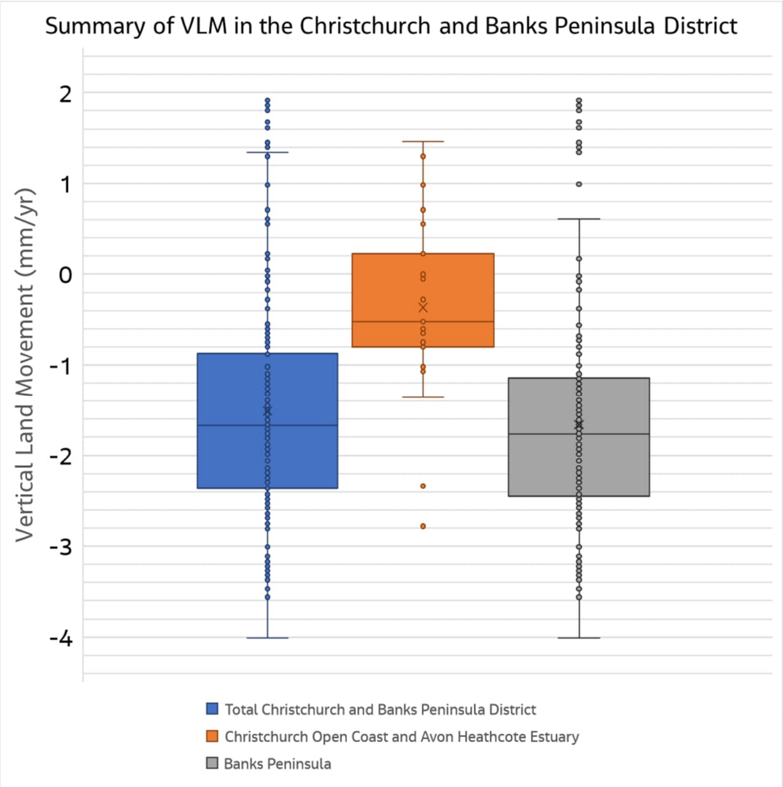

Figure 2-1. Summary of Vertical Land Movements (VLM) in the Christchurch and Banks Peninsula District from NZSeaRise.

Boxplots show the interquartile range (middle 50%) within the box, the line within the box is the median and the whisker bars show the upper and lower quartiles. Outliers are shown as dots.

When looking at the extreme VLMs in the Christchurch Open Coast/ Avon Heathcote Estuary, the implications of incorporating the VLM data into the planning assessment can be summarised as:

- For maximum subsidence of -2.78 mm/yr (Site 4303), the selected 0.6 m SLR by 2080 is 0.06 m below SSP5-8.5, and above the projection for SSP2-4.5. For 1.2 m SLR by 2130, the increment is below SSP5-8.5 by 0.27 m, above SSP2-4.5, and within the SSP5-8.5 17th – 83rd Percentile range. The impact of including VLM would:
  - be negligible on the high flood risk category (0.6 m SLR by 2080) due to the little difference between the increment and the SSP5-8.5 projection.
  - Increase the extent of the low flood risk categories (1.2 m SLR by 2130) due to the 0.27 m difference between the increment used and the SSP5-8.5 scenario.
  - Have no impact on the erosion risk categories.
- For maximum uplift of +1.46 mm/yr (Site 4320), the selected 0.6 m SLR by 2080 is at the SSP5-8.5 83rd percentile (essentially RCP8.5 H+), and is above SSP5-8.5 by 0.19 m. For 1.2 m SLR by 2130, the increment is above the SSP5-8.5 by 0.2 m, but below the SSP5-8.5 83rd percentile. The impact of including VLM would:
  - Reduce the extent of the high and low flood risk categories due to the increment being higher than the SSP5-8.5 projection.
  - Have no impact on the erosion risk categories.

Therefore, due to the lack of confidence in the applicability of the short pre-quake data set used to predict VLM, the difficulty of applying the spatial variations in VLM data on a district wide basis, and the negligible impact on the extent of the proposed risk areas from including the VLM effect on SLR, particularly for high risk areas, the inclusion of the VLM from NZSeaRise data is not justified for use in the plan change.

3. Coastal Inundation Hazard Thresholds

This section is an addendum to Section 6 of the Jacobs (2021) report.

This section sets out our approach to developing appropriate thresholds for defining inundation hazards and consequently our recommended approach to defining coastal flood risk.

An overall summary of the recommended approach is provided in Section 3.1.

A discussion of the reasoning behind this recommendation in light of submissions to an initial 'Issues and options discussion paper' presenting the proposed method, are provided in Sections 3.2 to 3.3.

3.1 Summary of Recommended Approach

The main coastal processes which cause inundation are storm surge and wave setup, combined with the astronomical tide and SLR. Inundation has the potential to result in loss of, or damage to, properties, possessions, buildings, and infrastructure, and could cause injury to people or loss of life. The consequence of inundation depends on the nature of the flooding – primarily the depth of water and speed of flow – and the vulnerability of people and assets to flooding.

Land use planning seeks to limit these consequences through risk-based control of development under the RMA. Several methods for mapping coastal inundation to inform planning decisions have been considered. The purpose is to define a simple set of thresholds which

1. are consistent with the RMA requirements to consider only risks which are 'reasonably foreseeable' and 'significant' in effect
2. can be applied to the 'bathtub' inundation depth outputs of the 2021 Coastal Hazard Assessment for Christchurch District ('the CHA').

The methods take into account three main factors which define flood risk:

- likelihood of flooding
- consequence of flooding
- change in likelihood and consequence in the future with SLR

The recommended method for defining flood risk takes account of these factors and is set out in Table 3-1. Four categories of flood risk, defined by thresholds of water depth, are proposed.

Table 3-1. Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 0.2% annual exceedance probability)

Coastal flood risk category	Flood hazard with 0.6m SLR	Flood hazard with 1.2m SLR
Very low	None (dry)	Low (d < 0.4 m)
Low	Low (d < 0.4 m)	Medium (0.4 m < d < 1.0 m)
Medium	Medium (0.4 m < d < 1.0 m)	High (d > 1.0 m)
High	High (d > 1.0 m)	High (d > 1.6 m)

The definitions in Table 3-1 have been applied to the CHA inundation depth data to produce a map showing the proposed four coastal flood risk categories along the entire coastline of the district. The CHA inundation maps also include the shorelines of Te Waihora (Lake Ellesmere) and Wairewa (Lake Forsyth). However, we have excluded these sites from our risk based coastal mapping because flooding from the lakes is not significantly influenced by coastal conditions, i.e., storm surge, waves, and sea level rise, for the range of scenarios we have adopted.

Figure 3-1 below shows an example extract of the map in the area around the Avon-Heathcote estuary.

Section 3.2 summarises the outcome of consultation on the proposed method and Sections 3.3 and 3.4 presents the recommended definitions of risk and the method we have used to map these areas.

As noted, the bathtub method used in the CHA to calculate flood depths does not take account of the hydrodynamic behaviour of inundation or the contribution to coastal inundation from coincident rainfall and river flow.

In the CHA data provided for our assessment, land lying below the Mean High Water Springs (MHWS) tide level was excluded for presentation purposes in order to differentiate areas which are regularly inundated without any storm tide effects. These areas are generally located within the river estuaries and along the shoreline of the sea. However, along the Styx River there are some areas of very low-lying land outside of the river channel and lagoons which have also been excluded. This means that the flood risk cannot be fully mapped using the data provided. In these areas we have directly mapped the risk areas using LiDAR ground level data and the coastal water level in order to capture all the land at risk of flooding. This masking has been removed from the low-lying land around the Styx River for the final CHA outputs.

In Section 6.5 of Jacobs (2021) we discuss the implications of the limitations in the bathtub method, data uncertainties, application of freeboard and thresholds for 'nuisance flooding' in more detail.

Maps of the recommended risk categories are available in a CCC webviewer and have been provided to CCC as a digital spatial layer.

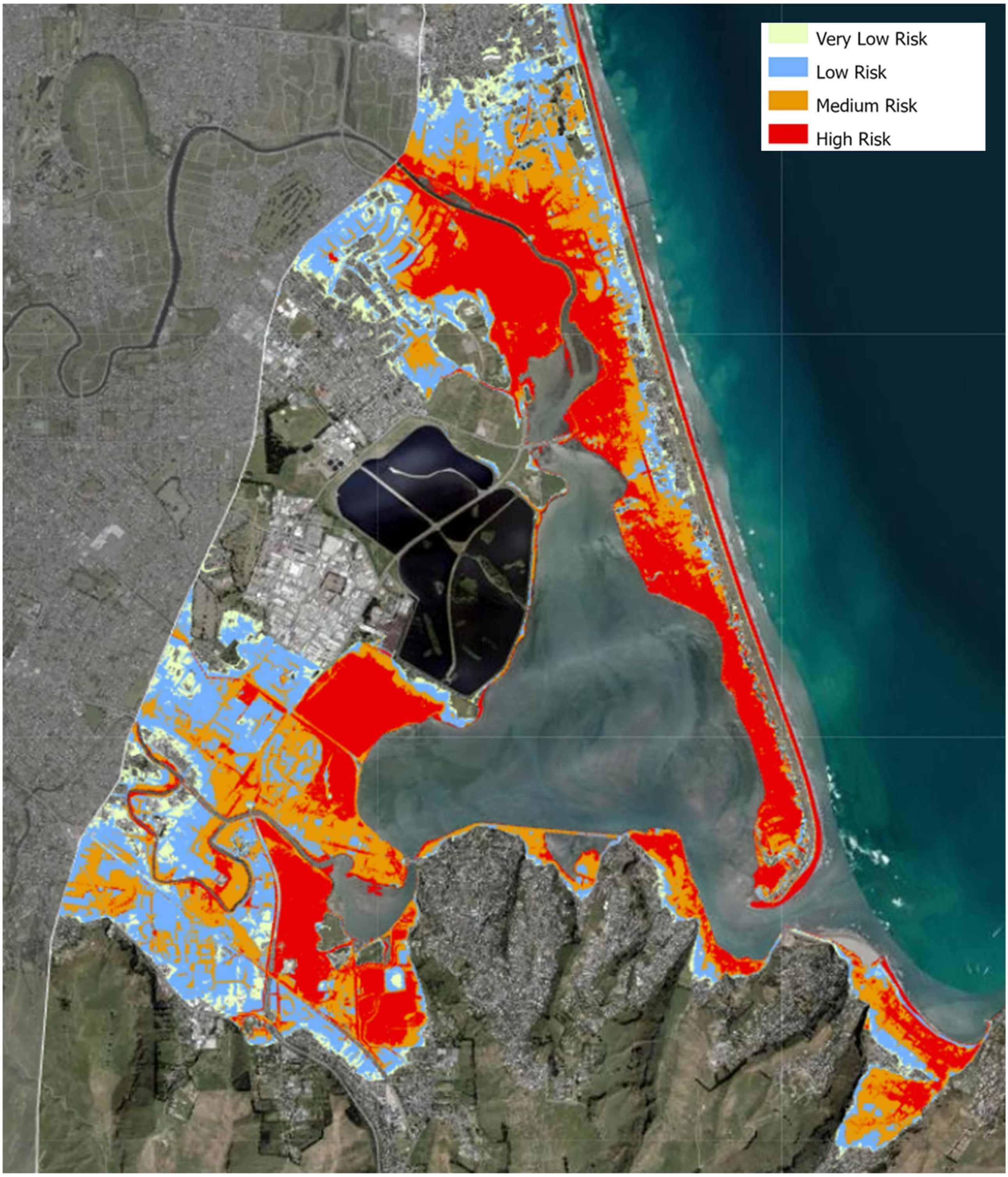

Figure 3-1. Coastal flood risk categories mapped using the CHA inundation data and recommended definitions of flood risk using the 0.2%/0.5% AEP approach (example extract of mapping for the district)

3.2 Review of proposed Coastal Hazards Plan Change method in Jacobs (2021)

The proposed method and thresholds set out in Sections 6.5 and 6.6 of Jacobs (2021) were presented in an Issues and Options Discussion Paper by Christchurch City Council in 2021 to support the Coastal Hazards District Plan Change.

We have considered the submissions received on this paper and the proposed Jacobs (2021) risk-based method to identify whether there are benefits in adapting the method in response to the submissions. We have also reviewed the compatibility of the proposed method with existing flood hazard mapping and planning approaches across coastal, fluvial and pluvial sources, including provisions and the thresholds for the levels of risk, to identify and resolve any differences in approach. In light of this review changes to the Jacobs (2021) method are proposed as outlined in Section 3.3.

3.2.1 Definitions of risk and hazard

The submissions generally support a risk-based approach – i.e., a planning framework where areas in which the flood hazard is less severe, or the hazard occurs only further in the future or is less certain to occur are classified as at a lower risk and activities are less restricted than areas where the hazard is higher or more immediate or more certain.

The submissions, and our review of the existing flood hazard overlays, identify the main differences in the Jacobs (2021) proposed risk-based approach in the coastal area and the existing overlays as being:

- that the existing overlays do not differentiate the differences in risk due to the timing of or uncertainty in sea level rise or differentiate hazard beyond a 'high hazard' area;
- that the likelihood of flooding used for mapping the existing overlays (0.5% and 0.2% AEP) differs from that in the Jacobs (2021) proposed risk-based approach (1% AEP);
- that the threshold values of water depth used to define the severity of hazard in the existing overlays (1 m for high hazard) differs to those in the proposed Jacobs (2021) risk-based approach (1.1 m for high hazard and 0.5 m for medium hazard).

In the submissions, consistency of approach between the coastal area and other areas is identified as important. The likelihoods of flooding (0.2% AEP)and high hazard (>1m) depth threshold which are currently adopted in the District Plan are consistent with the definitions of the Canterbury Regional Policy Statement (CRPS). The proposed risk-based approach can be adapted to align with current definitions in the District Plan and CRPS.

Submissions also highlight the need to consider all sources of flooding in the coastal zone, not just flooding from the sea. The 2021 CHA data does not address sources other than storm tides and groundwater. We have reviewed the CHA groundwater hazard outputs and do not consider the data appropriate for use with the bathtub coastal flooding data to take account of combined hazard.

3.2.2 Method of deriving the flood extent

Risk-based flood mapping of the entire coastal area of the district is needed for the Coastal Hazards Plan Change. New hydrodynamic modelling which is currently in progress will provide more detailed definitions of flood extents, depths and velocities, including within the coastal area, using up to date estimates of extreme tidal water levels. The model outputs will generally be used to update flood hazard overlays in the district and could be used as the basis for applying a risk-based approach in the coastal area. However, the model outputs will not cover the whole district.

The proposed approach will allow mapping of coastal risk over the whole coastal area within the timescale of the Coastal Hazards Plan Change. Adopting multi-hazard modelling of flooding in the coastal area when and where it becomes available should improve the level of detail in the mapping and will help to address those submissions expressing the need to consider all sources of flooding in the coastal area, even if this is dominated by flooding from the sea. If a risk-based approach is to be taken for the coastal area, then ideally the method for defining flood risk should be applicable to both the 2021 CHA bathtub data and future model outputs.

3.2.3 Sea level rise

The proposed method uses two values of sea level rise to allow the level of risk to reflect both the severity of the hazard and the certainty in or timing of the hazard occurring. This approach is supported by submissions expressing the need for greater weight to be placed on hazards which are more likely to occur and to occur soon, under lower values of sea level rise, over those which are less certain to occur and will occur further in the future, under higher values of sea level rise.

We consider the proposed upper value of sea level rise of 1.2 m to be appropriate and is consistent with our erosion risk assessment. This value is higher than the current District Plan allowance (1 m), but we consider this is justified. It is not clear if the current allowance for flood hazard in the District Plan will be reviewed.

3.2.4 Freeboard

There can be value in including an allowance for the effects of uncertainty in flood levels, ground levels and flooding mechanisms on the extent of the risk area by applying a freeboard to mapped water levels. The freeboard currently applied for mapping the Flood Management Area (250 mm as outlined in Policy 5.2.2.2.1.a.i of the District Plan) covers the likely combined uncertainties in storm tide level and LiDAR ground level data.

The benefit of applying freeboard to the mapped flood risk areas under a risk-based approach is considered further in Section 3.3.1.

3.2.5 Shallow flooding

It is not clear if or how areas of shallow flooding (e.g., water depth less than 50 mm or 100 mm) are excluded from the existing overlays in the District Plan. We do not see a need to exclude areas of shallow flooding under the risk-based approach since the depth of flooding (hazard) is one of the factors considered in defining the risk level.

3.3 Recommended definitions of inundation risk

3.3.1 Definitions of risk and freeboard

For consistency with the definitions in the current District Plan overlays, we recommend mapping the proposed coastal flood management area as the extent of the 0.5% AEP coastal water level.

We recommend using the two proposed SLR values of 0.6 m and 1.2 m to define a higher level of risk in areas where a hazard may occur sooner, in a more certain SLR scenario (0.6 m), than in areas where the same hazard is as likely to occur only further in the future, in a less certain SLR scenario (1.2 m). The overall extent of the flood management area is defined using the lower certainty SLR scenario (1.2 m) in recognition of the need to consider the significant consequences that could arise in less certain events.

For consistency with the Canterbury Regional Policy Statement (CRPS) definitions of hazard we recommend using:

i) water depths under the 0.2% AEP coastal water level to define the severity of flood hazard; and

ii) a water depth of 1 m to define 'high' hazard.

The threshold water depth of 1 m for 'high hazard' is slightly lower than both the value we proposed (1.1 m) and the H4 hazard vulnerability threshold depth for people and vehicles (1.2 m) in still water under the AR&R guidelines. Adopting a limiting depth of 1 m allows for the additional hazard of a water velocity of up to 0.6 m/s under these guidelines (refer to Figure 6.5 in Jacobs (2021)).

We also recommend adjusting the depth threshold for 'medium' hazard to 0.4 m so that the difference in hazard thresholds aligns with the difference in SLR values (0.6 m). This threshold is slightly lower than the value we proposed (0.5 m), which corresponded to the H3 hazard vulnerability threshold depth for large 4WD vehicles in still water and for velocities up to 1.2 m/s. A depth of 0.4 m corresponds to the vulnerability threshold for larger passenger vehicles in still water and for velocities up to 1.1 m/s. This depth also allows for the additional hazard of velocities up to 1.5 m/s for large 4WD vehicles.

The recommended definitions of coastal flood risk are shown in Table 3-2 and illustrated diagrammatically in Figure 3-2.

Table 3-2. Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 0.2% annual exceedance probability)

Coastal flood risk category	Flood hazard with 0.6m SLR	Flood hazard with 1.2m SLR
Very low	None (dry)	Low (d < 0.4 m)
Low	Low (d < 0.4 m)	Medium (0.4 m < d < 1.0 m)
Medium	Medium (0.4 m < d < 1.0 m)	High (d > 1.0 m)
High	High (d > 1.0 m)	High (d > 1.6 m)

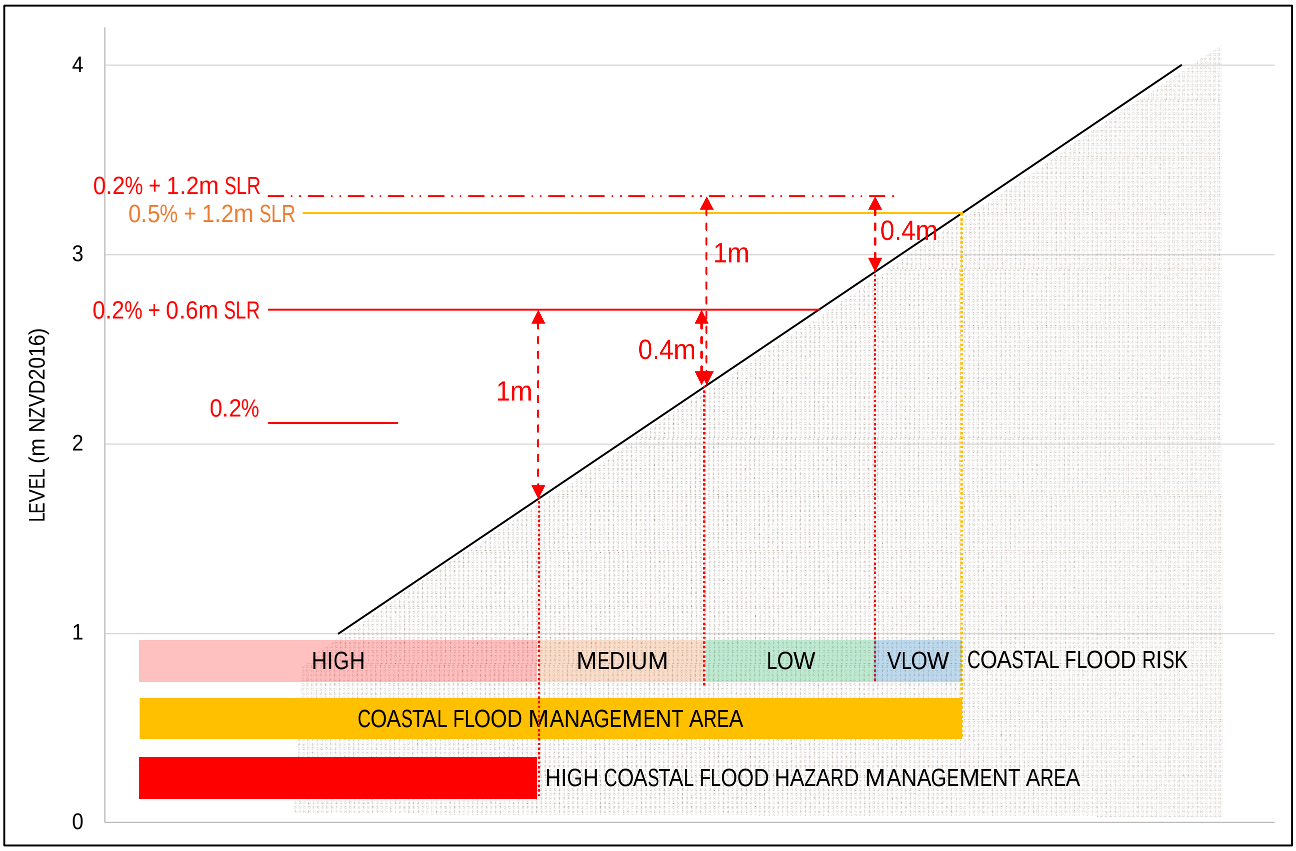

Figure 3-2. Recommended definitions of coastal flood risk.

The coastal flood management area is defined by the 0.5% AEP coastal water level with 1.2 m of sea level rise (SLR). Flood hazards are defined by the water depth under the 0.2% AEP coastal water level. Flood risk is defined by the combination of hazard (water depth) and the certainty in and timing of sea level rise.

The recommended definitions do not include a ‘freeboard’ to the water levels used to define hazard or the overall extent of the flood management area. This is consistent with the CRPS method of defining severity of hazard which does not include a freeboard allowance.

As shown in Section 3.3.2 the difference between 0.5% and 0.2% AEP water levels is no greater than 0.1 m in all but one of the CHA coastal areas and, overall, does not exceed 0.2 m. These differences in water levels are less than the value of freeboard that would typically be applied – e.g., 0.25 m on the 0.5% AEP water level as per the current District Plan overlays (Policy 5.2.2.2.1.a.i). Therefore, the additional area which would be mapped through the addition of a freeboard to the 0.5% AEP water level would be largely dry in the 0.2% AEP event with 1.2 m SLR scenario – which we use to define risk – with any water depths being less than 0.1 m to 0.2 m. As shown in Table 3-2 and Figure 3-2 this would correspond to a risk level less than 'very low' in most of the additional area mapped, noting that under the AR&R guidelines a still water depth of less than 0.3 m is classified as 'generally safe for vehicles, people and buildings'.

3.3.2 Derivation of coastal water levels

Estimates of the 0.5% AEP and 0.2% AEP coastal water levels are needed to map the flood risk management area and the flood risk categories as defined in Figure 3-2. The 2021 CHA does not generally report water levels for probabilities less than 1% AEP. The method used to derive the static water levels varies between the three types of inundation sites – open coast, harbours and estuaries, and regional hazard screening sites. For consistency with the CHA, we have derived water levels for each of the same coastal sites defined in the CHA, using the same methodology where the necessary source data are available and/or by extrapolating values from the CHA data where required.

It is acknowledged that by using different methods in the three groups of inundation sites there may be differing uncertainties and levels of confidence in the data. The uncertainties are also a result of the range of historical data available in each area relative to the small probabilities of the water levels required for mapping. Alternative methods of analysis using the same data may not therefore necessarily reduce the uncertainty in the estimated water levels.

- Open coast sites: Christchurch, Sumner, Taylors Mistake

In these areas the static water levels were derived in the CHA from a statistical analysis ('extreme value analysis') of a synthetic time series of historical tidal water level and wave setup. Figure 3-3 shows an example of the outputs of the extreme value analysis for one of the sites. It would be possible to obtain estimates of the 0.5% and 0.2% AEP water levels from the results of the analysis already undertaken - for example, the red circle in Figure 3-3 indicates the 0.5% AEP water level (2.4 m NZVD2016) in this cell. However, since the full results of the analyses are not available, we have estimated the required water levels by fitting a trendline to the reported values of the 1-year, 10-year and 100-year Average Recurrence Interval (ARI) water levels and using this to extrapolate the required values.

Figure 3-3 shows that the uncertainty in the water levels estimated through the CHA analysis, as indicated by the 90% confidence interval ('90% CI') lines, tends to increase with the value of ARI. The 90% confidence interval for the 1% AEP water level adopted in the CHA is approximately +/- 0.25 m. For the 0.5% AEP water level the corresponding confidence interval is a little larger, approximately +/- 0.30 m. The uncertainty in the estimates of the water levels proposed for mapping the coastal flood risk areas is therefore a little greater than that in the water levels adopted for mapping in the CHA but this is largely due to the inherent increase in uncertainty in estimating smaller probability water levels. Alternative methods are unlikely to significantly reduce the uncertainty in these estimates if using the same historical data.

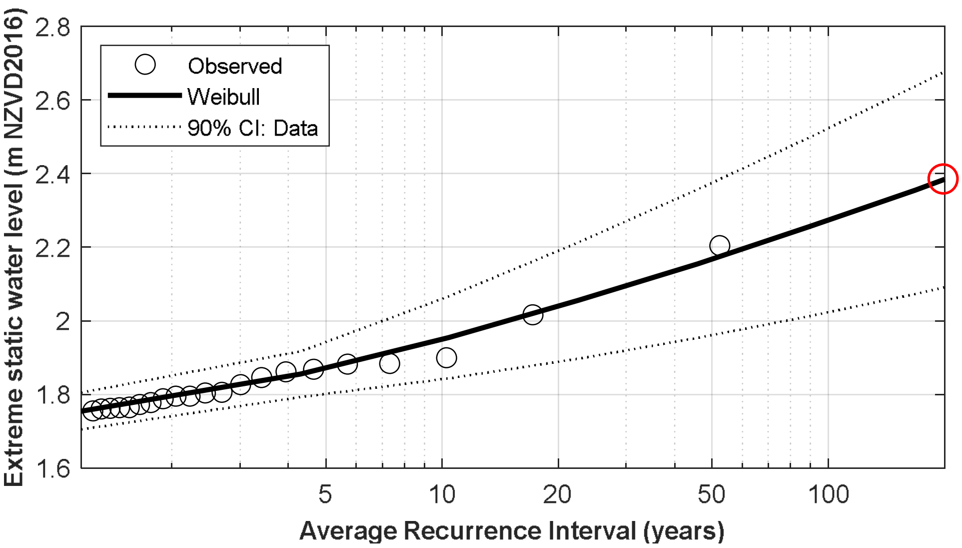

Figure 3-3. Example of extreme value analysis of static water level for open coast cells (Christchurch open coast cell) (Figure 7-6 of the 2021 CHA Technical Report).
Red circle indicates the 0.5% AEP water level.

The water levels for the three open coast sites are provided in Table 8.1 of the CHA Technical Report. Since the reported water levels for each ARI are the same at all three sites, we have used a single set of water levels to estimate the 0.5% and 0.2% AEP water levels for all three sites.

The CHA water levels, and our corresponding estimated water levels are compared in Table 3-3. The water levels and fitted trendline are plotted in Figure 3-4.

Table 3-3. Estimates of the 0.5% and 0.2% AEP coastal water levels at open coast sites.

ARI (AEP)	Water level reported in Table 8.1 of CHA Technical Report (m NZVD2016)	Water level estimated from trendline to CHA data (see Figure 6.22) for risk-based coastal inundation mapping (m NZVD2106)
1-year (63%)	1.8	1.8
10-year (10%)	2.0	2.0
100-year (1%)	2.3	2.3
200-year (0.5%)	n/a	2.4
500-year (0.2%)	n/a	2.5

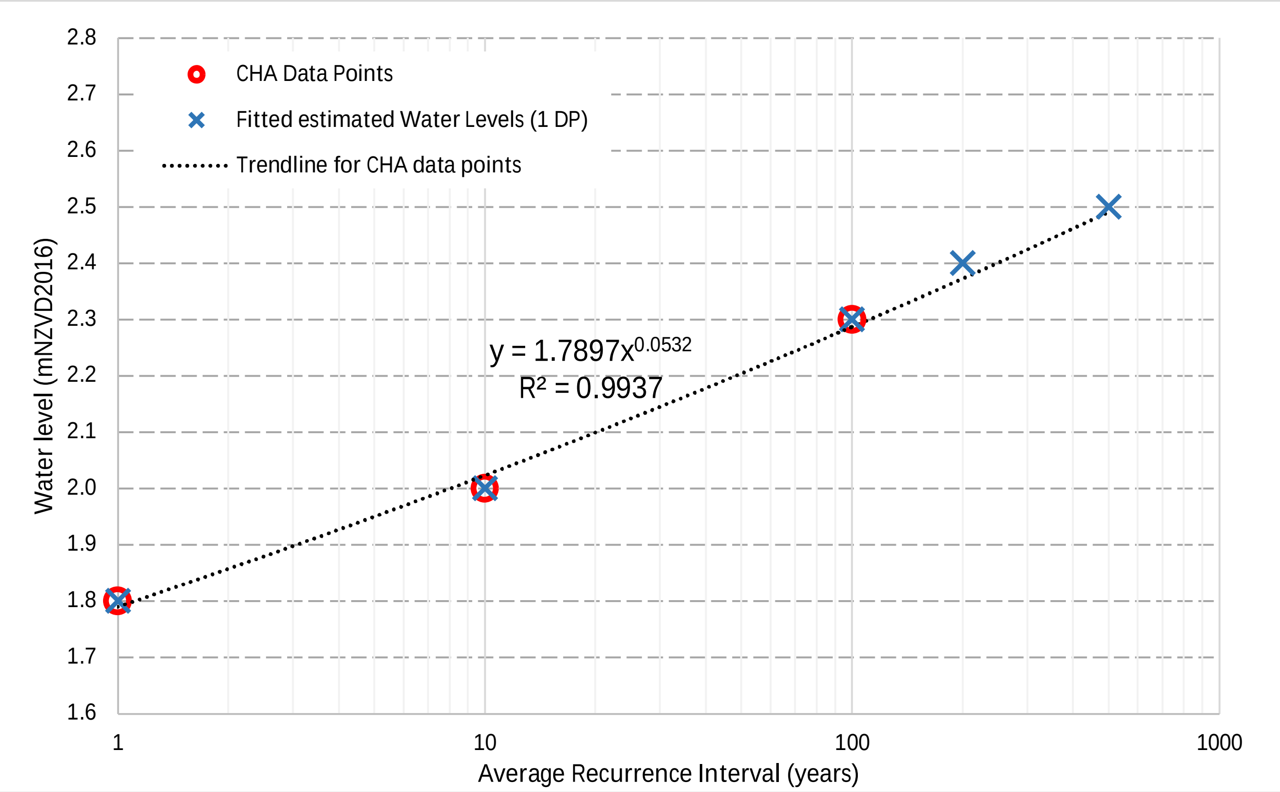

Figure 3-4. Estimates of 0.5% and 0.2% AEP (200-year and 500-year ARI) water levels using a trendline fitted to the CHA water levels for the 1-year, 10-year and 100-year ARI water levels for the open coast sites (Table 8.1 of the CHA Technical Report).

- Harbour and estuary sites: Avon-Heathcote, Akaroa, Lyttelton, Brooklands Lagoon

In these cells the static water levels were derived in the CHA using a statistical 'extreme value analysis' of water level records at gauges in the estuaries and harbours undertaken by GHD[2]. An estimate of the 1% AEP wave setup height at each site (Table 7.4 of the CHA Technical Report) was added to the extreme values for each probability considered in the CHA.

The GHD report includes values for the 0.5% and 0.2% AEP water levels at the gauges. We have used these water levels together with the wave setup values derived in the CHA to provide estimates of coastal water levels for these cells as shown in Table 3-4. For the Akaroa harbour site, we have used the method reported in the CHA Technical Report (Section 7.2.1) and used the extreme values derived for the Lyttelton gauge combined with an offset of +0.24 m to allow for the difference in astronomical tide levels between the two sites.

Table 3-4. Estimates of the 0.5% and 0.2% AEP coastal water levels at harbour and estuary sites.

CHA site	Gauge location[(1)]	GHD extreme values[(1)] (m CDD)		Conversion CDD to Lyttelton 1937 datum[(2)] (m)	Conversion Lyttelton 1937 to NZVD2016 datum[(3)] (m)	CHA Wave setup[(4)] (m)	Total coastal water level (m NZVD2016)	
		0.5% AEP	0.2% AEP				0.5% AEP	0.2% AEP
Brooklands Lagoon	Styx	11.294	11.373	-9.043	-0.363	0	1.9	2.0
Avon-Heathcote north	Bridge Street	11.265	11.359	-9.043	-0.346	0.15	2.0	2.1
Avon-Heathcote south	Ferrymead	11.141	11.217	-9.043	-0.341	0.15	1.9	2.0
Lyttelton	Lyttelton	11.057	11.110	-9.043	-0.394	0.25	1.9	1.9
Akaroa	Lyttelton (+0.24m offset as per CHA)	11.297	11.350	-9.043	-0.365	0.25	2.1	2.2

(1) Table 5 of Christchurch City Council LDRP097 Multi-Hazard Baseline Modelling, Joint Risks of Pluvial and Tidal Flooding, Rev 0 (GHD, February 2021); (2) Waterways, Wetlands and Drainage Guide - Part B: Design, Appendix I (Christchurch City Council, December 2011); (3) LINZ LTN37-NZVD2016 grid (https://data.linz.govt.nz/layer/53432-lyttelton-1937-to-nzvd2016-conversion/); (4)Table 7.4 of CHA Technical Report.

- Regional hazard screening sites: Banks Peninsula, Kaitorete Spit, Te Waihora (Lake Ellesmere), Wairewa (Lake Forsyth)

For the coastal regional hazard screening sites at Banks Peninsula and Kaitorete Spit, the static water levels were derived in the CHA using the GHD extreme values for the Sumner gauge and estimates of the individual wave setup at each site for each probability considered. No correction is applied to the extreme values at the Sumner gauge for the difference in site locations since the astronomical tide levels at all sites are reported to

[2] Christchurch City Council LDRP097 Multi-Hazard Baseline Modelling, Joint Risks of Pluvial and Tidal Flooding, Rev 0 (GHD, February 2021)

be similar. The wave setup values were calculated by applying an empirical formula to extreme values of wave heights derived from a statistical analysis of hindcast wave time series records at these sites.

The GHD report includes values for the 0.5% and 0.2% AEP water levels at Sumner, both including and excluding the contributions of far infra-gravity (FIG) waves. The water levels quoted in Table 7.5 of the CHA for Banks Peninsula and Kaitorete Spit correspond to those in the GHD report for Sumner including the effects of FIG waves and we have therefore also adopted values for the 0.5% and 0.2% AEP which include FIG effects.

It would be possible to obtain estimates of the 0.5% and 0.2% AEP significant wave heights from the results of the analysis already undertaken for the CHA and hence estimate the corresponding wave setup values using the same empirical method. However, although the significant wave heights and corresponding wave setup values for the 1-year, 10-year and 100-year ARI are reported in the CHA (Tables 2.8 and 7.6 of the CHA Technical Report), full results of the analyses are not available. We have therefore estimated the required wave setup by fitting a trendline to the reported values of the 1-year, 10-year and 100-year ARI wave setup values and used this to extrapolate the required values as shown in Table 3-5 and Figure 3-5. We have then added the estimated wave setup values to the GHD extreme water levels at Sumner (including FIG wave allowance) to obtain the total water levels for the 0.5% and 0.2% AEP as shown in Table 3-6.

Table 3-5. Estimates of the 0.5% and 0.2% AEP wave setup at coastal regional hazard screening sites.

ARI (AEP)	Wave setup reported in Table 7.6 of CHA Technical Report (m)			Wave setup estimated from trendline to CHA data (Figure 3-4) for risk-based coastal inundation mapping (m)		
	Banks Peninsula - North	Banks Peninsula - South	Kaitorete Spit	Banks Peninsula - North	Banks Peninsula - South	Kaitorete Spit
1-year (63%)	0.84	1.54	1.24	0.85	1.55	1.24
10-year (10%)	0.96	1.84	1.35	0.94	1.81	1.36
100-year (1%)	1.02	2.08	1.5	1.03	2.10	1.49
200-year (0.5%)	n/a	n/a	n/a	1.06	2.20	1.54
500-year (0.2%)	n/a	n/a	n/a	1.11	2.33	1.60

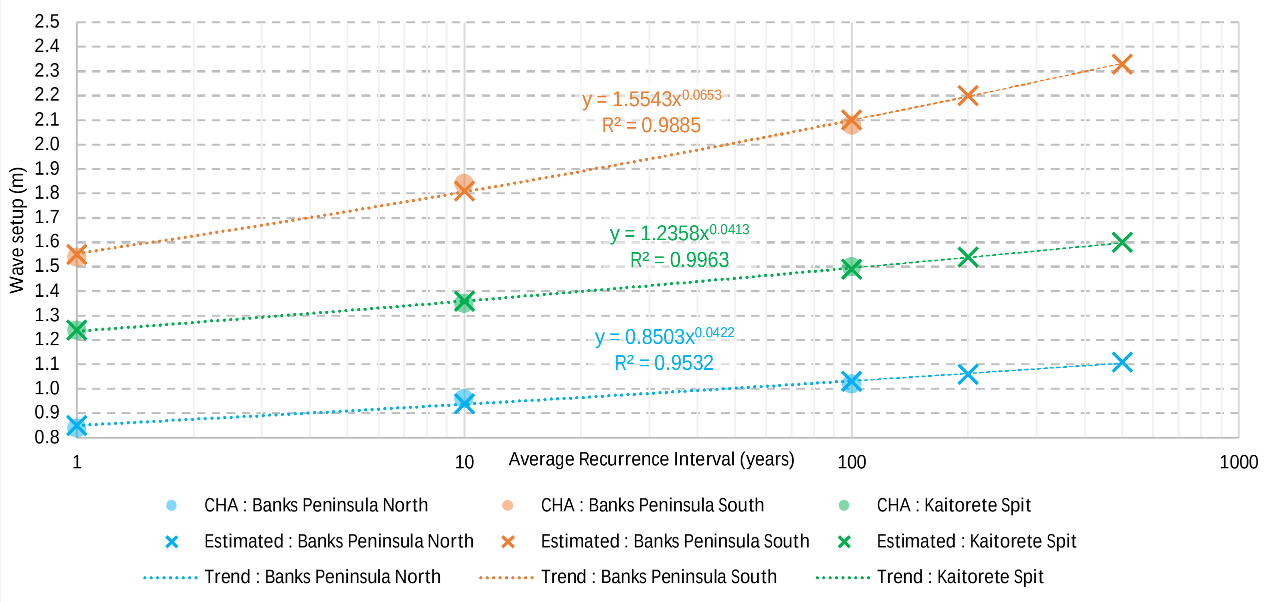

Figure 3-5. Estimates of 0.5% and 0.2% AEP (200-year and 500-year ARI) wave setup using a trendline fitted to the CHA estimates of the 1-year, 10-year and 100-year ARI wave setup for the coastal regional hazard screening sites (Table 7.6 of the CHA Technical Report).

Table 3-6. Estimates of the 0.5% and 0.2% AEP static water levels at coastal regional hazard screening sites.

CHA site	Gauge location[1]	GHD extreme values[1] (m CDD)		Conversion CDD to Lyttelton 1937 datum[2]	Conversion Lyttelton 1937 to NZVD2016 datum[3]	Estimated wave setup (Figure 3-4) (m)		Total coastal water level (mNZVD2016)	
		0.5% AEP	0.2% AEP	(m)	(m)	0.5% AEP	0.2% AEP	0.5% AEP	0.2% AEP
Banks Peninsula - North	Sumner incl. FIG	11.289	11.374	-9.043	-0.388	1.06	1.11	2.9	3.0
Banks Peninsula - South	Sumner incl. FIG	11.289	11.374	-9.043	-0.388	2.20	2.33	4.1	4.3
Kaitorete Spit	Sumner incl. FIG	11.289	11.374	-9.043	-0.388	1.54	1.60	3.4	3.5

[1] Table 5 of Christchurch City Council LDRP097 Multi-Hazard Baseline Modelling, Joint Risks of Pluvial and Tidal Flooding, Rev 0 (GHD, February 2021); [2] Waterways, Wetlands and Drainage Guide - Part B: Design, Appendix I (Christchurch City Council, December 2011); [3] LINZ LTN37-NZVD2016 grid (https://data.linz.govt.nz/layer/53432-lyttelton-1937-to-nzvd2016-conversion/)

- Summary

The coastal water levels we have used for the risk-based coastal inundation maps are summarised in Table 3-7.

Table 3-7. Estimates of the 0.5% and 0.2% AEP static water levels at each of the CHA sites included in the risk-based coastal inundation maps.

CHA Site		Static coastal water level for risk-based mapping (m NZVD2016)	
		0.5% AEP	0.2% AEP
Open coast	Christchurch Open Coast	2.4	2.5
	Sumner	2.4	2.5
	Taylor's Mistake	2.4	2.5
Harbour & estuary	Brooklands Lagoon	1.9	2.0
	Avon-Heathcote north	2.0	2.1
	Avon-Heathcote south	1.9	2.0
	Lyttelton	1.9	1.9
	Akaroa	2.1	2.2
Regional hazard screening	Banks Peninsula - North	2.9	3.0
	Banks Peninsula - South	4.1	4.3
	Kaitorete Spit	3.4	3.5

3.4 Mapping of risk layers

3.4.1 Ground data

For consistency, we have used the water depth grids prepared for the CHA 'bathtub' coastal inundation maps to map the risk categories defined by the water levels in Table 3-7 and the depth classes in Table 3-1 for all CHA sites except the two lake sites (Te Waihora and Wairewa) and Brooklands Lagoon. These depth grids have a spatial resolution of 1 m.

We have excluded the lake sites from our mapping because flooding from the lakes is not significantly influenced by coastal conditions – storm surge, waves, and sea level rise.

In the bathtub depth grids originally provided from the CHA, large areas of Brooklands Lagoon were excluded from the grid where ground levels are lower than present day astronomical tide levels and are therefore potentially regularly submerged. To capture all the land at risk of flooding we have directly mapped the risk areas at this site using LiDAR ground level data[3] at 1m spatial resolution and the estimated coastal water level.

For all sites our mapping is limited to the inland limit of coastal inundation boundary defined in the CHA.

[3] Canterbury - Christchurch and Ashley River LiDAR 1m DEM (2018-2019), Environment Canterbury/Land Information New Zealand

3.4.2 Smoothing

We have smoothed the resulting boundaries of each flood risk area using ArcGIS Pro v2.8.1.

The raw flood risk area polygons have been smoothed with the 'Smooth Polygon' tool. The PAEK (Polynomial Approximation Exponential Kernel) algorithm has been used with a tolerance of 2 (twice the cell-size of the original dataset). This is a different algorithm than previously used by Christchurch City Council for the existing District Plan flood extents, but the results of the smoothing are quite comparable and retain a similar appearance.

A key part of the Council's smoothing methodology was to ensure that no new parcels were inundated due to the smoothing approach. To ensure this the Council have applied a small negative buffer to shrink the final smoothed inundated area. Because the flood risk areas contain four separate classes, we could not directly apply a negative buffer, as this would introduce gaps between the classes.

Our approach to ensuring that no new parcels have been inundated due to the smoothing is a refinement of this method. We have dissolved the flood risk area data and created a smoothed output of just the extent. We have then applied a negative buffer to this smoothed extent and used this buffered extent to clip the original smoothed polygons. This approach has ensured no new parcels are inundated without creating gaps between the classes and retaining a similar appearance to the Council's existing District Plan flood extents.

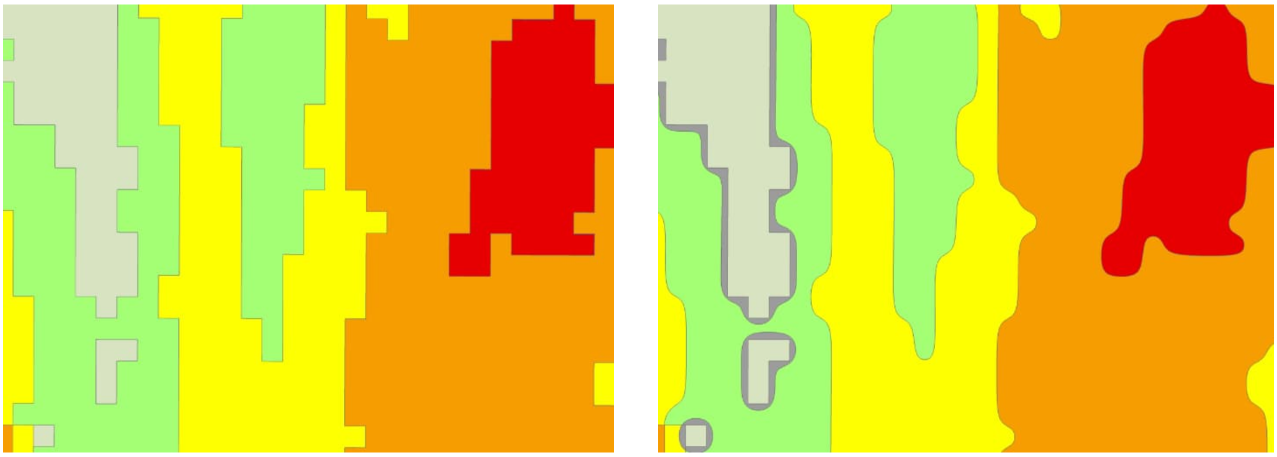

Figure 3-6. Comparison of the raw flood risk polygons on the left, and the smoothed result on the right. The original raw extent is shown in grey to illustrate that the smoothed result does not cross over it.

4. Coastal Erosion Hazard Thresholds

This section is an update to Section 7 of the Jacobs (2021) report. It has been updated to reflect updates and modifications based on submissions and peer review comments.

4.1 Summary of Erosion Recommendations

Based on the different coastal morphologies within the Christchurch district and the various assessment methods applied by T+T in different areas, the following are the recommended thresholds from the T+T data for determining coastal erosion hazard zones:

1) For the Christchurch City urban area open coast; two erosion zones compromising of

   a) A High Hazard Coastal Erosion Zone covering the current beach- primary dune width, and

   b) Where required, a Low Hazard Coastal Erosion Zone to a lowland limit defined by the 10% probability erosion distance with 1.2 m SLR by 2130 and an additional area required for "future dune resilience factor".

2) For the Avon-Heathcote Estuary; two erosion zones comprising of

   a) A High-Medium Hazard Coastal Erosion Zone defined by a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell for the 66% probability erosion distance with 0.6 m SLR by 2080

   b) A Low Hazard Coastal Erosion Zone defined by a generic additional width of 20 m across all cells to be equal to the largest ASCE in any cell for the 10% probability erosion distance with 1.2 m SLR by 2130.

3) For the beaches and bays of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single High-Medium Banks Peninsula Bays Coastal Erosion Hazard Zone, with the landward limit defined for:

   a) Probabilistic assessment cells, as the 10% probability of erosion distance for 1.2 m SLR by 2130, and

   b) Deterministic assessment cells, the limit of the ASCE from the 1.5 m SLR by 2130 scenario, which has an assumed probability of 1-5%.

4) For the coastal cliffs of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single High-Medium Banks Peninsula Cliff Erosion Zone of 20-30 m width as defined by the generic T+T cliff erosion setback

5) For assessment cells along the southern shore of the Avon-Heathcote estuary, Sumner Beach, Lyttelton Port and Akaroa township where there are land reclamation and substantial hard protection structures; a single High Hazard Coastal Erosion Zone hazard zone with a generic width in the order of 20 m based on the short-term erosion response if these reclamation and protection structures failed.

The following provides the discussion and justifications behind these recommended addendums to the Jacobs (2021) report.

4.1.1 Critical thinking

As an addendum to point 5 of Section 7.2 "critical thinking" of the Jacobs (2021) report the following additional commentary on a "dune resilience factor" has been provided.

In addition to the need to protect the current open coast beach environments, there may also be a need to provide an additional width within erosion set-back zones for future dune resilience to hazards. For example, once the ASCE positions reach beyond the current beach/bank position they do not include any consideration for the distance required to have a resilient dune or beach ridge environment, or stable bank slope. The absence of these natural hazard protection environments would result in an increase in the consequences of erosion in storm events and an increase in the frequency, extent, magnitude and consequence of inundation events, or result in the need for more engineered protected structures. In more layman terms this means allowing within district planning zones not only for where the erosion of the seaward dune edge may be predicted to reach by the chosen scenario/threshold combination, but also allowing for the dune systems to also move inland as the front of these features erode so that they can still provide the same level of erosion protection. Hence the outcome may be mapped hazard areas and district planning controls further inland from the T+T mapped erosion extents. This additional factor has been termed the 'dune resilience factor'.

4.2 Christchurch City open coast (T+T Cells 1-14)

This section is an addendum to Section 7.3.1 of the Jacobs (2021) report, specifically the section titled "Christchurch City open coast (T+ Cells 1-14).

Figure 4-1 shows examples on how the high, medium, and low hazard zones would look at North Brighton and Southshore from applying the possible threshold options under the preferred approach in Jacobs (2021). Maps of the preferred approach has been provided to CCC as a spatial layer.

4.2.1 High Hazard Zone

As can be seen from Figure 4-1, the options for high and medium hazard categories are largely within the existing dune environment. This outcome is consistent along the whole of the Christchurch open coast, with the only locations where this doesn't occur being where the dunes have been removed at North Brighton and New Brighton. A similar result was obtained from the alternative approach.

It is therefore considered that to ensure that the full natural protection ability of the dune system against coastal hazards is not compromised, the High Hazard Zone include all or at least some component of the whole beach-dune width as a 'dune resilience factor', and a Medium Hazard Zone is not required.

There are two options for determining what component of the 'whole beach-primary dune' environment is included in the high hazard zone:

a) Inclusion of the primary dune only for hazard protection purposes; or

b) Inclusion of the whole of the total dune system, including primary and secondary dunes, up to where infrastructure starts to interact with the back of the dune, or where there is an obvious change in the vegetation type.

When assessing these two options against one another, it is clear that in some areas when using the whole of the dune system as the high hazard zone (e.g. option b) the width exceeds what is required for coastal hazard protection reasons. The primary dune has sufficient width to protect the integrity of the natural coastal dune system against activities that could reduce its ability to act as an effective buffer against erosion and inundation hazards, and to be consistent with the requirements of Policy 26 of the NZCPS. This approach is also consistent with Coastal Erosion Hazard Zone 1 in both the RPS and the RCEP. Protection of these areas beyond the primary dune are generally protected more appropriately through other planning mechanisms such as natural character and landscape controls.

It is therefore recommended that the high hazard zone be defined as a smoothed width of the primary dune environment.

The primary dune area is defined by the physical primary dune extent in 2018/2019 LiDAR. The landward extent was mapped in detail by analysing the change in backshore slope behind the dune. LiDAR was reclassified into 1 m elevation intervals, and where there was a flattening or reversal of the slope (which generally occurred around 3 m contour NZVD2016) this was determined to be the landward boundary of the primary dune.

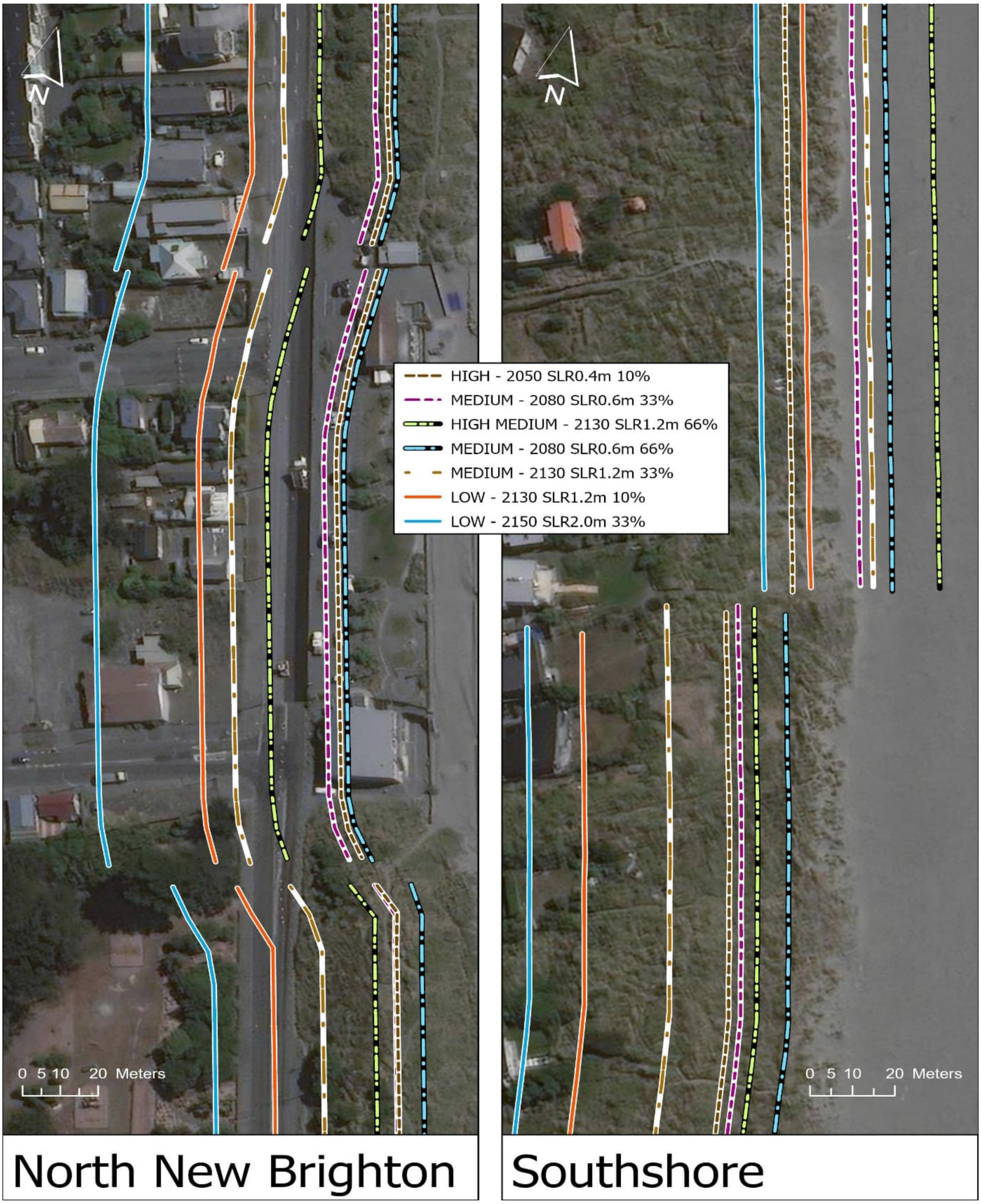

Figure 4-1. Possible options for High, Medium and Low Coastal Erosion Hazard Categories at North Brighton (left) and Southshore (right). Not recommended due to High and Medium zones being within the beach system

Where the dune system was not confined by roads, the primary dune was defined using this technique, as shown in the left example in Figure 4-2. Where the dune system was confined by roads, (e.g., Marine Parade) and the landward limit of the primary dune from the above technique was close to the position of the road, the extent of the dune system has been mapped up to the road edge. Where the primary dune has been removed for buildings (e.g., North New Brighton, New Brighton, South Brighton Surf Club) the landward boundary was extrapolated along the edge of Marine Parade.

For planning purposes, the mapped landward primary dune extent has been smoothed to removed local anomalies in the landward edge of the primary dune system, as shown in Figure 4-3. Further consideration of how the primary dune is defined and smoothed will be considered as part of the Coastal Hazards Plan Change.

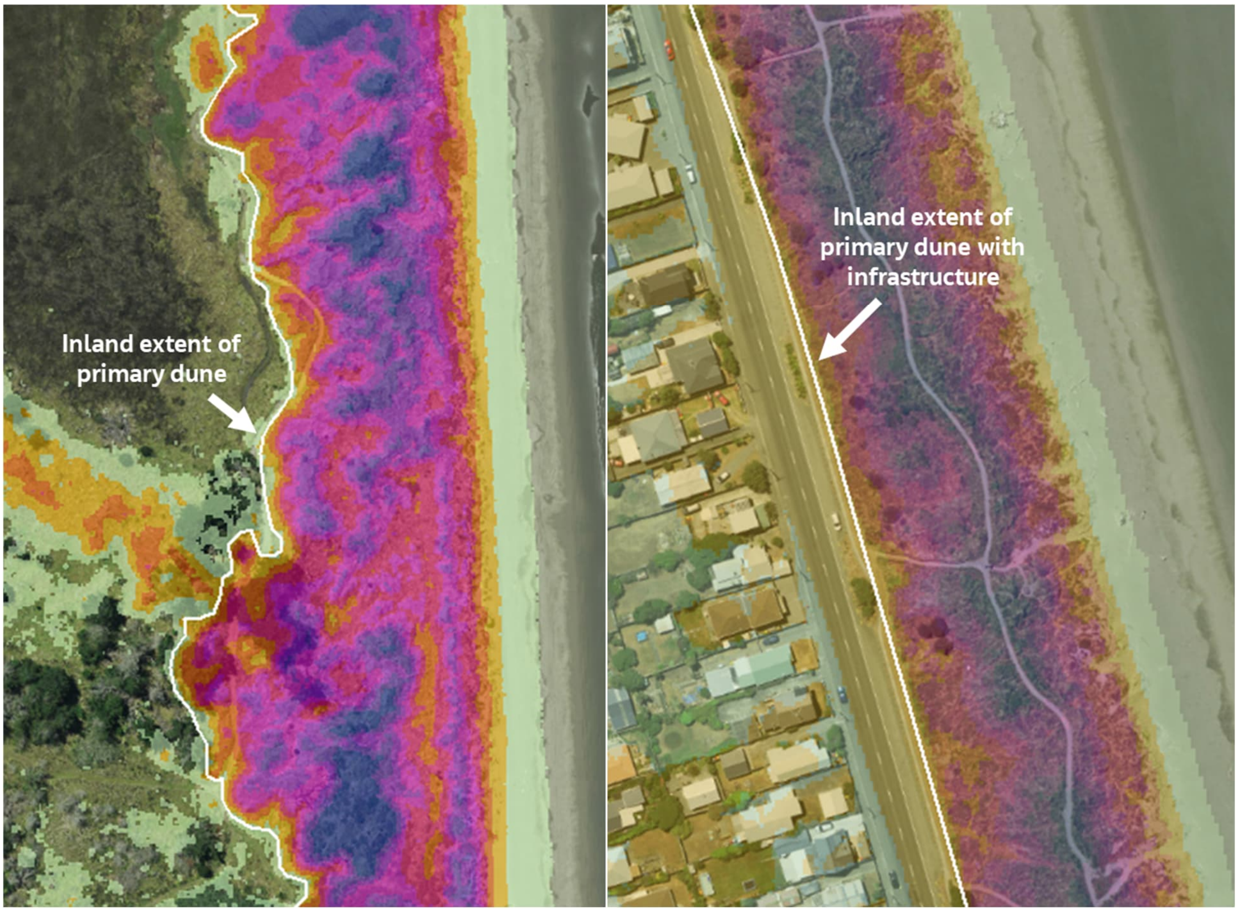

Figure 4-2. Example of reclassified lidar showing location of back of dune for dune system no confined by infrastructure (left) and confined by infrastructure (right).

When compared to the T&T (2021) CHA 0.6 m SLR by 2080 coastal erosion line of the seaward edge of the dune, the mapping of the current primary dune extent provides a sufficient buffer to still have at least some dune remaining if a 100 year ARI storm event as defined by the CHA occurred following the shoreline retreat to the 2080 position seaward dune edge.

It is noted that this beach/primary dune width approach to the High Hazard zone removes the issue with inconsistent zone boundaries across the assessment cell boundaries as shown at South Brighton Spit in the right pane in Figure 4-2.

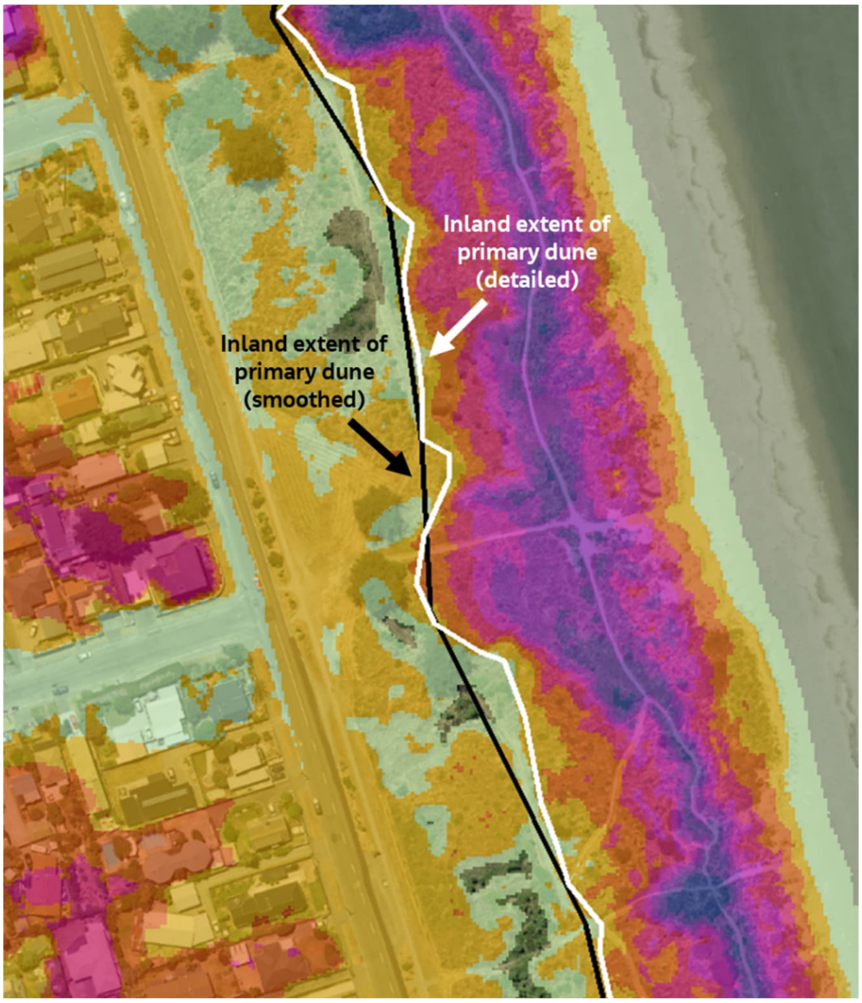

Figure 4-3. Example of area where smoothing has been undertaken along the landward extent of the dune.

The defined high hazard zone at the end of the Southshore spit is not related to the T&T (2021) CHA erosion lines or the existing primary dune extent. The T&T CHA (2021) coastal erosion lines assume that the current distal tip of the spit will be stable into the future. However, this is a dynamic environment where as recently as 1948 (74 years ago) the shoreline was located at the end of Rocking Horse Road (Figure 4-4). This extreme northward retreat of the spit occurred even after long periods of being at a more southern position (e.g., 1849, 99 years earlier). In these dynamic environments of sand spits at river mouths, we should anticipate that if the shoreline has been located there before, there is a high likelihood that it could retreat to there in the future, and therefore development and activity should be restricted across this reserve area.

As shown in Figure 4-5, the resulting high hazard zone at the Southshore Spit runs along the reserve boundary at the end of Rocking Horse Road to join the open coast primary dune area and the high hazard zone around the Avon Heathcote Estuary.

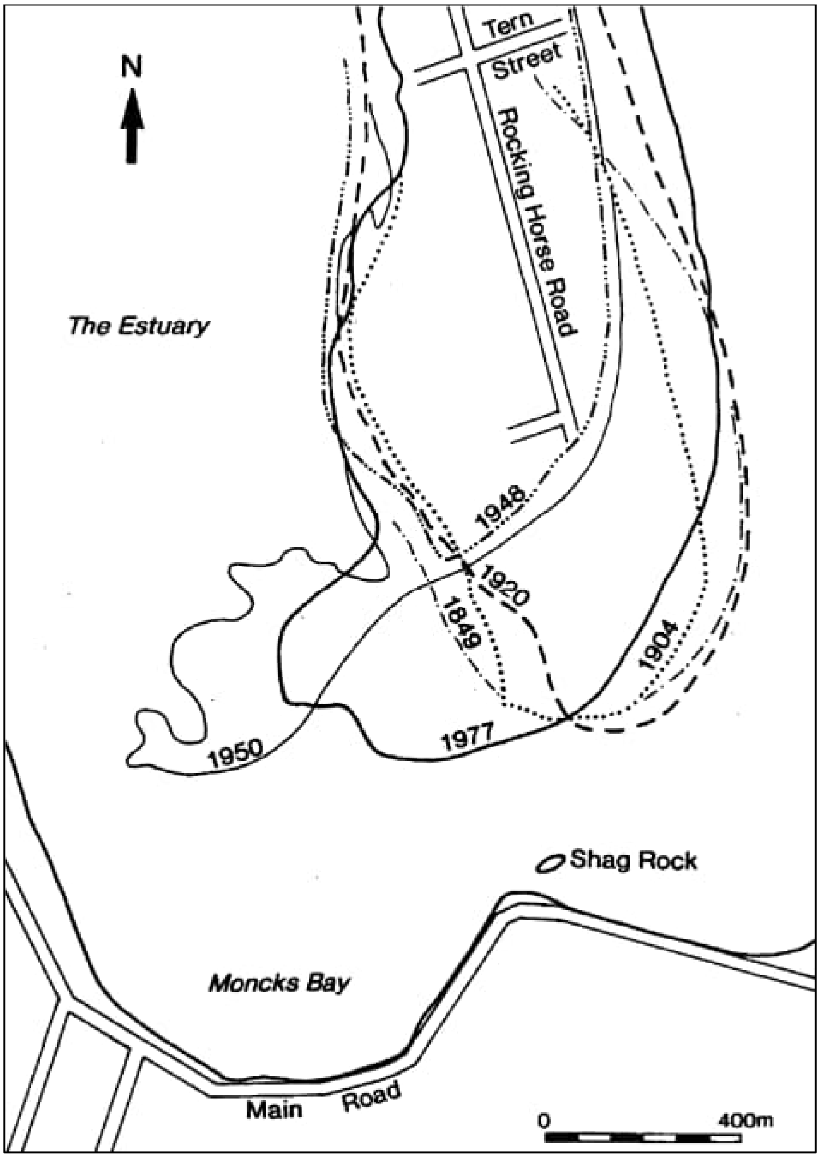

Figure 4-4. Morphological changes to the Southshore Spit from 1849-1950 (Kirk and Todd, 1994[4]).

[4] Kirk, R.M., and Todd, Derek, 1994, "Coastal Hazards", in Canterbury Regional Council (ed) Natural Hazards in Canterbury, Report 94(19), Christchurch, Canterbury Regional Council, pp 33-51

Figure 4-5. High hazard area at distal tip of Southshore Spit.

4.2.2 Low Hazard Zone

For the Low Hazard zone, Figure 4-1 suggests that spatially the 33% probability with 1.5 m SLR by 2150 provides a more appropriate zone width for land use planning, however as stated in Section 7.3.1 of Jacobs (2021) this scenario is conservative and it is more uncertain whether this magnitude of SLR will occur within a reasonable timeframe for land-use planning.

Therefore the 10% probability with 1.2 m SLR by 2130 is considered a more appropriate landward boundary for the Low Hazard Zone and has a higher degree of consistency with the maximum scenario from the deterministic assessment.

The position of the recommended Low Hazard boundary based directly on the position of 10% probability with 1.2 m SLR by 2130 from the T+T data is shown in Figure 4-1. As can be seem from the right pane in Figure 4-1 (Southshore), there are locations where this recommended Low Hazard Category is also totally contained within the current dune system that would be zoned as High Hazard Coastal Erosion, in which case it is recommended that no Low Hazard Coastal Erosion Zone is required.

However, it is noted that where the 1.2 m SLR by 2130 erosion line falls close to or landward of the high hazard zone, this represents a future shoreline where the entire primary dune system has been eroded as the erosion line produced by T+T represents the dune toe, not the back of the dune. If the dune was to erode back to this position, the risk profile in the area will increase due to the loss of hazard protection provided for by the dunes to both inundation and erosion. Therefore, it is recommended that the low hazard zone should include an allowance for dune migration in order for the dune system be maintained in the future to provide resilience to coastal hazards. This additional factor is termed the 'dune resilience factor' and should be offset from the 1.2 m SLR by 2130 erosion line. The purpose of applying this additional dune width is to ensure that there is sufficient dune form to provide hazard protection should a large storm with a return period of around 100 years occur following the end of the planning timeframe.

The dune resilience factor has been defined using the T&T (2021) CHA data for the open coast 'short term' (ST) and 'dune stability' (DS) factors. These two factors take into account the erosion which would occur in a 1 in 100 year storm event on the open coast. While these factors are included in the calculation of the CHA coastal erosion lines, the mapped T&T (2021) line shows where the seaward toe of the dune would be following such an event, with no consideration on whether there is sufficient dune to provide protection following the event. Due to the very high degree of dune vegetation cover, the landward toe of the primary dune is essentially locked in position and does not migrate with erosion of the front of the dune, resulting in long-term reduction in dune widths and ability to act as an effective buffer against coastal hazards. Failure to provide for this could result in the dune being totally breached in such an extreme storm event, leading to coastal inundation in areas not mapped for this to occur, and making it very difficult for natural dune rehabilitation to occur following the event. So, the intention of the dune resilience factor is to ensure that an additional dune area continues to exist following such a large event. Therefore, providing the possibility that the dune environment could still effectively provide a hazard protection function for the land behind, as well as provide an environment for the dune to recover and rebuild following the storm event.

The CHA shows that there is longshore variation in the ST and DS factors, with there being higher projected storm cuts at the southern end of the spit, and lower projected storm cuts at the northern end. The resulting dune resilience factor has been averaged across similar cell responses, as is seen below in Table 4-1. At the northern end of the open coast (cells 1-4) the dune resilience is calculated to be 25 m; through the central area (cells 5-13) the dune resilience factor is 32 m; and at the southern end of the spit (cell 14) the dune resilience factor is 43 m.

Table 4-1. Dune Stability (DS) and Short Term (ST) factors from T&T (2021) CHA with averaged Dune Resilience factors used for the low hazard zone is presented on the column on the right.

Cell	DS (m)	ST (m)	Combined ST and DS (m)	Dune Resilience Factor (m)
1	2	22	24	25
2	4	22	26	
3	3	22	25	
4	3	22	25	
5	4	29	33	32
6	4	29	33	
7	1	29	30	
8	4	29	33	
9	1	29	30	
10	4	29	33	
11	3	29	32	
12	2	29	31	
13	2	29	31	
14	2	41	43	43

The low hazard areas only exist where the current primary dune extent (e.g., the high hazard zone) is both (a) narrow; and (b) projected to erode through all or most of the existing primary dune area with 1.2 m SLR by 2130. A schematic of the way the low hazard area has been mapped relative to the high hazard zone and 1.2 m SLR 2130 shoreline is shown in Figure 4-6.

Due to the inclusion of the total primary dune in the high hazard area, and the small amount of projected erosion in some areas, the low hazard only occurs along the coast from around North New Brighton Surf Club to Waimairi Beach Surf Club, as can be seen in Figure 4-7. This is due to both (a) the narrow dune along Marine Parade at this location; and (b) the projected front of dune position for 1.2 m SLR by 2130 being located near the landward edge of the existing dune extent, and therefore should the dune be eroded to this position, there would be a significant change in the risk profile and exposure to coastal inundation and erosion hazards at this timeframe.

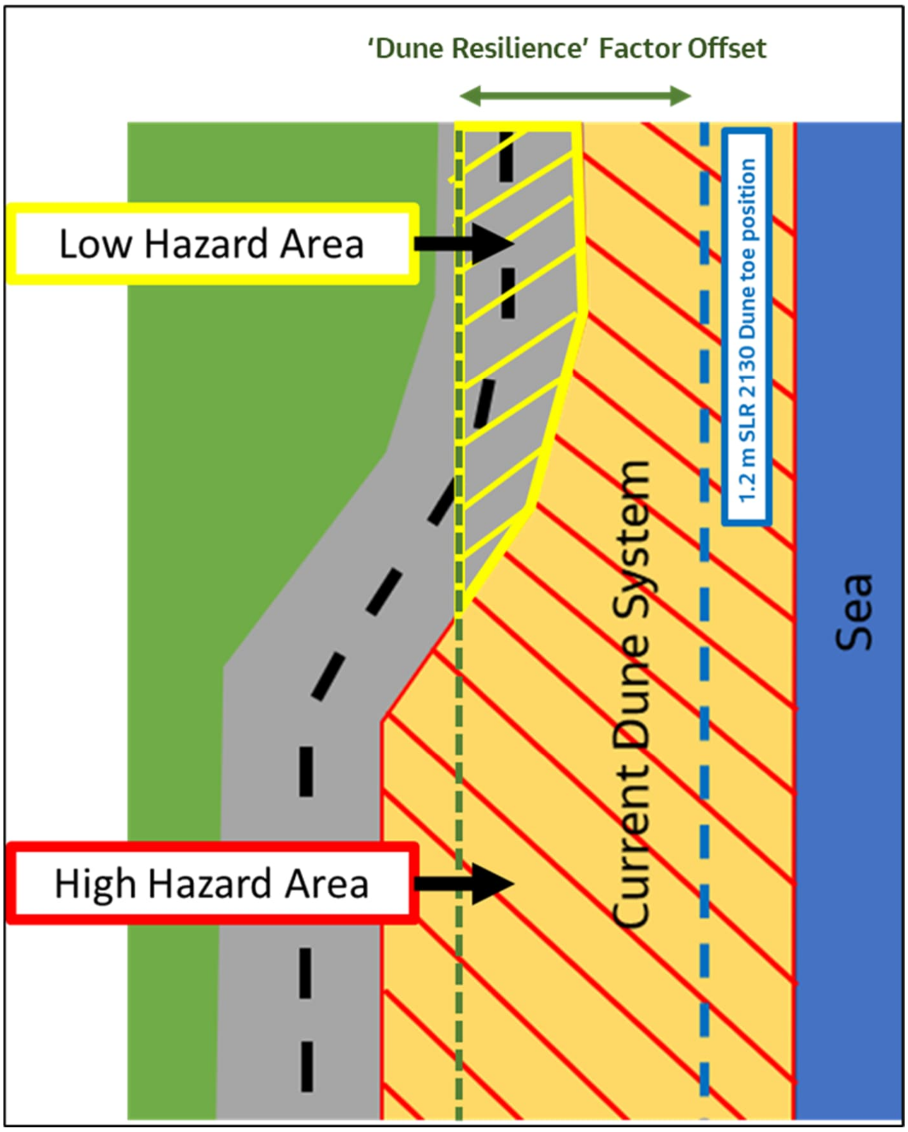

Figure 4-6. Schematic of where the high and low hazard areas are mapped in relation to the 1.2 m SLR (2130) dune toe position.

Figure 4-7. High and low hazard zones in North New Brighton/Waimairi Beach relative to the 1.2 m SLR 2130 erosion projection lines from T&T (2021).

4.2.2.1 Avon-Heathcote Estuary (T+T Cells 15 to 24)

Figure 4-8 shows examples of how the high, medium, and low hazard zones would look at two locations in the Avon-Heathcote Estuary from applying the possible threshold options from Table 7.1 of Jacobs (2021).

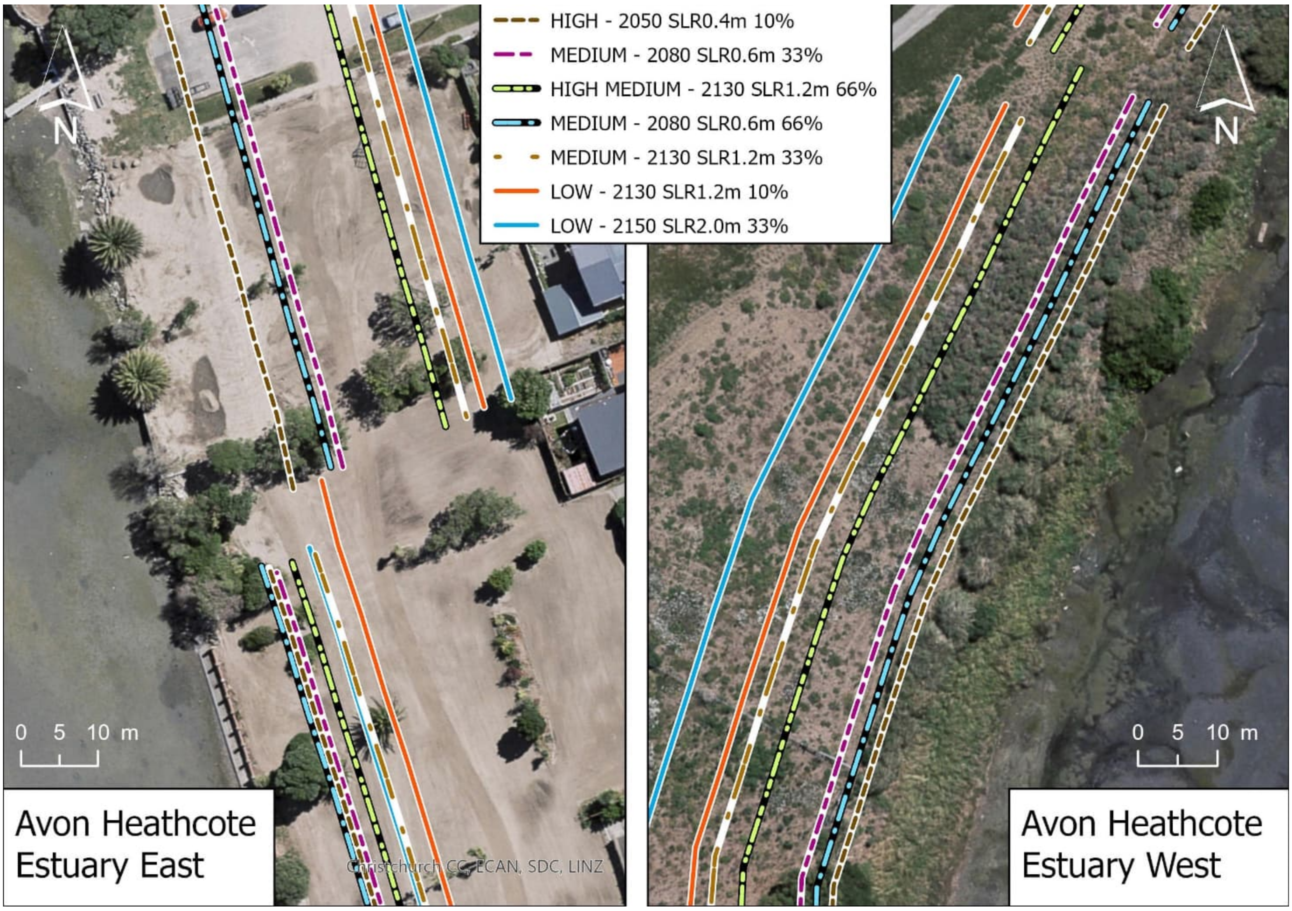

Figure 4-8. **Possible options for High, Medium and Low Coastal Erosion Hazard Categories at Southshore (left) and Oxidation ponds (right) around the Avon-Heathcote Estuary. Not recommended due to zones being too narrow.**

As can be seen from Figure 4-8, the resulting zones are narrow, being in the order of 10-20 m for the High Hazard options, 5-10 m width for the Medium zone options, and 5-20 m widths for the Low hazard zone depending on location around the estuary. These widths are considered to be too narrow for effective land-use planning provisions, so the following two zone approach is recommended.

- High-Medium Coastal Erosion Hazard Zone Boundary: 66% probability of erosion with 0.6 m SLR by 2080
- Low Coastal Erosion Hazard Boundary: 10% probability of erosion with 1.2 m SLR by 2130.

It is noticeable from the left pane of Figure 4-8 that these recommended thresholds would result in inconsistent erosion hazard zone widths within different cells around the estuary and there will need to be in some locations large adjustments and smoothing of the hazard zones across the cell boundaries.

Therefore, it was considered that applying a consistent erosion hazard width across all estuary assessment cells, with the generic width for the zones being equal to the largest ASCE in any cell under the recommended scenario/threshold option, was an appropriate approach to dealing with smoothing across cell boundaries. This also ensured that the distance between the thresholds defining different hazard risk categories is sufficient for likely land-use activity to be reasonably able to be carried out in the zone between the thresholds.

Under this approach, the width of the high-medium coastal erosion hazard zone is 20 m, and low coastal erosion hazard zone is an additional 20 m from the medium-high zone. The position of the recommended Coastal Erosion Hazard Zone boundaries under this approach for selected locations around the estuary is shown in Figure 4-9.

Figure 4-9. Recommended High-Medium and Low Coastal Erosion Hazard Categories at Southshore (left) and Oxidation ponds (right) around the Avon-Heathcote Estuary.

As seen in Figure 4-9, 20 m setbacks align closely to the ASCE lines in most areas of shoreline around the estuary. However, it is recognised that using this generic approach could be seen as precautionary at the southern end of Southshore Spit, where properties that were not identified as being included in the ASCE (due to low erosion projected erosion distances) could be included in a high-medium or low hazard zone as a result of the higher generic setback distances being used.

A sensitivity test was undertaken to identify how many additional properties could be included within the defined high-medium and low hazard zones, which were not included in the ASCE for the corresponding timeframes and SLR scenarios used. The results of this sensitivity testing showed:

- When comparing the high-medium hazard zone (e.g., 20 m setback) to the ASCE for 0.6 m SLR by 2080 (66th Percentile), the same land parcels are projected to be affected (51 land parcels) for both lines, and therefore the use of the 20 m setback for the high hazard does not intersect with any additional land parcels. This finding for the high hazard zone is a result of majority of the setback area being located through parks, reserves, and through the Southshore Residential Redzone where council now has ownership of the land
- For the low hazard zone (e.g., additional 20 m setback), there are an additional three land parcels which are projected to be in the low hazard zone but are not shown as being affected by projected erosion hazard in the ASCE for 1.2 m SLR by 2130, all of which are located at the southern end of the Southshore Spit (Figure 4-10).

For the additional three land parcels that are affected, the low hazard zone line only intersects with a very small portion of the land parcel:

- For one of the land parcels, the low hazard zone appears to intersect with a garden shed;
- For one of the land parcels, the low hazard zone appears to intersect with the main dwelling on the property; and
- For one of the land parcels the low hazard zone cuts the corner of an empty property with no dwellings

There are also two land parcels where the low hazard line intersects with an accessway, however these appear to be a shared accessway to properties that now form part of the red zone.

- The additional three land parcels affected by the 40 m low hazard set back are south of Tern Street at the southern end of Cell 16 from the CHA assessment. It is noted that these parcels occur around the southern limit of former private shoreline protection structures. Therefore, there is uncertainty in the CHA assessment results on the effect of the demolition of these structures on the future shoreline movements, and a precautionary approach is justified here to take into account these additional factors.

Figure 4-10. Three land parcels and two accessways intersect with the 40 m setback area and not with the 1.2 m SLR by 2130 CHA erosion line shown as the properties in red.

Therefore, as a result of this analysis, due to there being (a) no additional private properties effected by the use of the 20 m setback for the high hazard zone; and (b) only three additional properties being affected by the low hazard zone (and to a small extent), it is recommended that the generic approach in the Avon Heathcote Estuary for the high-medium and low hazard zones is used.

4.3 For Erosion Protection Cells

This section is an addendum to Section 7.3.4 of Jacobs (2021). As indicated in Section 4.2 of Jacobs (2021) there are a number of cells along the southern shore of the Avon-Heathcote Estuary, Sumner Beach, Lyttelton Port and Akaroa township where due to land reclamation and substantial hard protection structures, the future ASCE's have been assessed as being the same as Current ASCE (e.g., erosion resulting from structure damage/failure before repair). As such there is no change in ASCE with SLR scenario, and very little change in erosion distance with probability.

For these protection cells, it is recommended that a generic single erosion hazard zone width in the order of 20 m be applied as a High hazard Zone. This zone would reflect the consequences of erosion should the protection structures fail and allow for the control of activities in these areas.

Christchurch City Council planning staff confirmed that they were comfortable that the infrastructure protected by the listed protection structures meet the criteria of national and regional importance, and therefore the continued reliance and maintenance of these structures is consistent with the NZCPS. Therefore, no low hazard zone is required to be mapped along the length of these structures behind the generic 20 m high-medium hazard zone.

5. Conclusions and Recommendations

A preferred approach to risk thresholds has been developed for recommended scenarios for both the erosion and inundation hazards. These have been mapped to show the resulting low, medium and high risk category areas. This mapping is available in a webviewer and digital spatial datafiles. These preferred approaches were compared to other scenarios and existing mapped hazards areas during the process of this analysis. The preferred approaches for each aspect are:

5.1 Inundation

Table 5-1 provides the recommended definitions for coastal flood risk mapping and Figure 5-1and Figure 5-2 provide graphical examples of these four flood risk categories.

Table 5-1. Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 0.2% annual exceedance probability)

Coastal flood risk category	Flood hazard with 0.6m SLR	Flood hazard with 1.2m SLR
Very low	None (dry)	Low (d < 0.4 m)
Low	Low (d < 0.4 m)	Medium (0.4 m < d < 1.0 m)
Medium	Medium (0.4 m < d < 1.0 m)	High (d > 1.0 m)
High	High (d > 1.0 m)	High (d > 1.6 m)

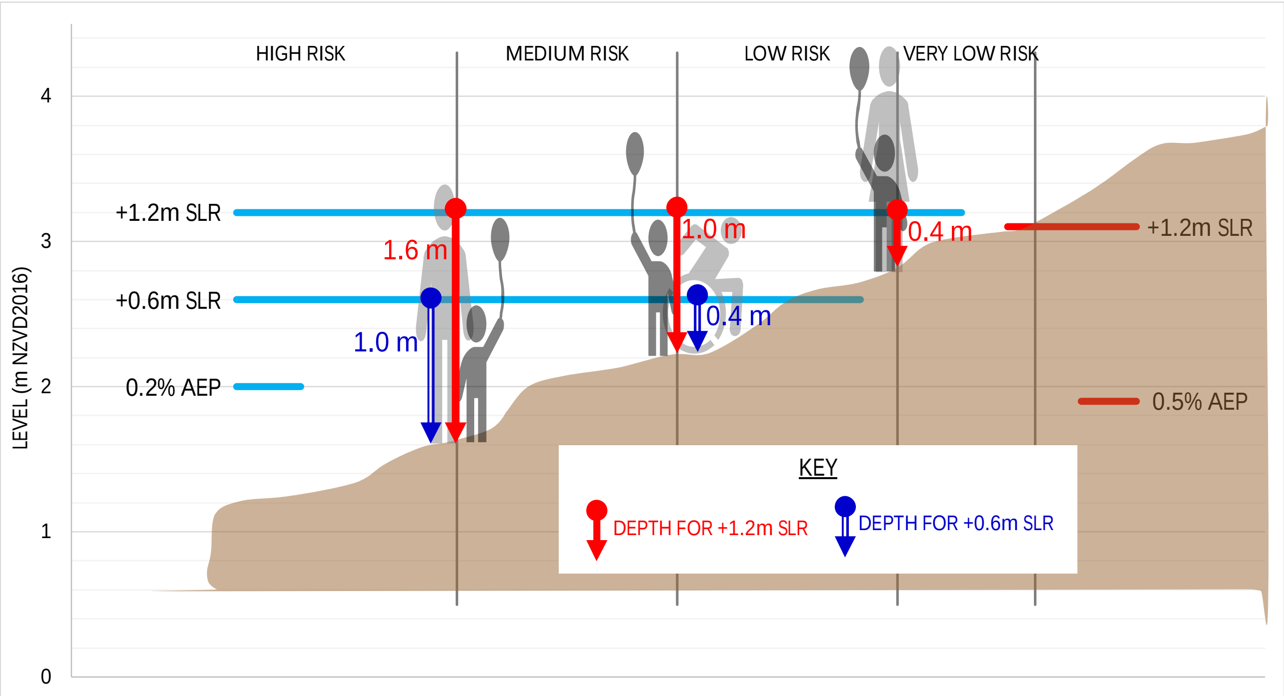

Figure 5-1. Recommended definitions of coastal flood risk. The coastal flood management area is defined by the 0.5% AEP coastal water level with 1.2 m of sea level rise (SLR). Flood hazards are defined by the water depth under the 0.2% AEP coastal water level. Flood risk is defined by the combination of hazard (water depth) and the certainty in and timing of sea level rise.

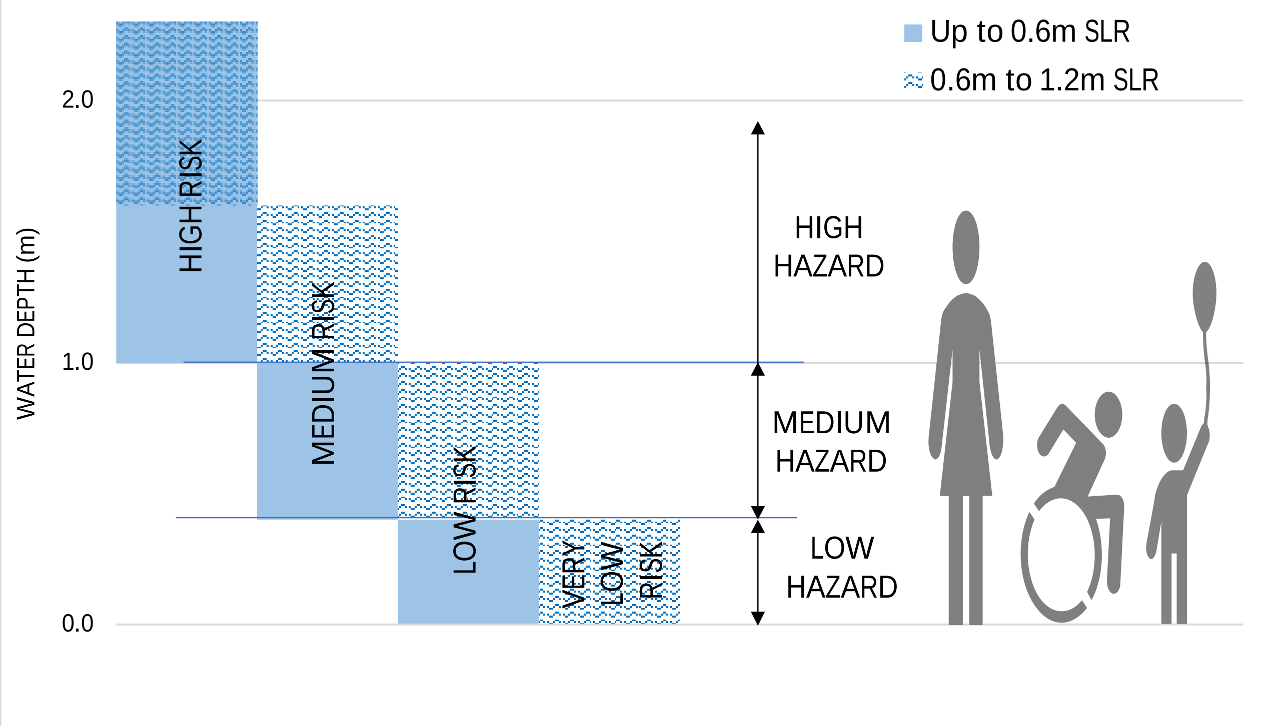

Figure 5-2. Flood risk categories based on the thresholds defined in Figure 5-1

5.2 Erosion

Based on the different coastal morphologies within the Christchurch district and the various assessment methods applied by T+T in different areas, the following are the recommended thresholds from the T+T data for determining coastal erosion hazard zones:

1) For the Christchurch City urban area open coast; two erosion zones compromising of
   - a) A High Hazard Coastal Erosion Zone covering the current beach-primary dune width, and
   - b) Where required, A Low Hazard Coastal Erosion Zone to a lowland limit defined by the 10% probability erosion distance with 1.2 m SLR by 2130 and an additional area required for "future dune resilience factor".
2) For the Avon-Heathcote Estuary; two erosion zones comprising of
   - a) A High-Medium Hazard Coastal Erosion Zone defined by a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell for the 66% probability erosion distance with 0.6 m SLR by 2080
   - b) A Low Hazard Coastal Erosion Zone defined by a generic additional width of 20 m across all cells to be equal to the largest ASCE in any cell for the 10% probability erosion distance with 1.2 m SLR by 2130.
3) For the beaches and bays of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single Banks Peninsula Bays High-Medium Coastal Erosion Hazard Zone, with the landward limit defined for:
   - a) Probabilistic assessment cells as the 10% probability of erosion distance for 1.2 m SLR by 2130, and
   - b) Deterministic assessment cells as the limit of the ASCE from the 1.5 m SLR by 2130 scenario, which has an assumed probability of 1-5%.

4) For the coastal cliffs of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single Banks Peninsula High-Medium Cliff Erosion Zone of 20-30 m width as defined by the generic T+T cliff erosion setback

5) For assessment cells along the southern shore of the Avon-Heathcote estuary, Sumner Beach, Lyttelton Port and Akaroa township where there are land reclamation and substantial hard protection structures; a single High-Medium Hazard Coastal Erosion Zone hazard zone with a generic width in the order of 20 m.