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Coastal Hazards Plan Change - Analysis/Technical Advice

Risk Based Coastal Hazard Analysis for Land-use Planning

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Christchurch City Council

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Executive Summary

In July 2021, Christchurch City Council (CCC) commissioned Jacobs to conduct a risk-based coastal erosion and inundation hazard analysis for land-use planning. This sought to identify appropriate risk-based thresholds and scenarios for defining coastal hazard categories for use in land use planning.

New information on the coastal hazards was developed for CCC in the Coastal Hazard Assessment (CHA) by Tonkin and Taylor (Ltd). This data will inform public consultation about adaptation to coastal hazards. It is anticipated that a new Coastal Hazards Plan Change to the District Plan will be required to develop planning provision to address this new hazard information.

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 hazard areas

b) Recommend a preferred approach to the categorising and mapping of 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 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.

To account for climate change and sea level rise (SLR) impacts on increasing hazard exposure, SLR scenarios of 0.6 m SLR by 2080 and 1.2 m SLR by 2130 were selected for both erosion and inundation hazards.

For inundation, the 1% annual exceedance probability - a reasonably foreseeable event and the smallest probability available in the T+T data – and the 1.2m SLR scenario were selected to define the overall extent of inundation hazards. This scenario ensures intergenerational needs, and a precautionary approach are applied to the planning framework.

Thresholds are based on the water depth for the 1% 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 – which allow for a consideration of the change in the flood depth between the higher confidence SLR scenario (0.6m) and the lower confidence, further into the future (1.2m) scenario. The recommended flood risk categories are presented in Table 1.1.

Table 1.1: Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 1% 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 < 0.5m)
Low	Low (d < 0.5m)	Medium (0.5m < d < 1.1m)

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[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.

Coastal flood risk category	Flood hazard with 0.6m SLR	Flood hazard with 1.2m SLR
Medium	Medium (0.5m < d < 1.1m)	High (d > 1.1m)
High	High (d > 1.1m)	High (d > 1.7m)

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 timeframe were tested to assess whether they can meet the requirements under the RMA of defining reasonable foreseeable hazards, and that the resulting hazard zones meet the needs of future generations. The analysis also took into account 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 whole current beach-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 healthy beach factors”.
2) For the Avon-Heathcote Estuary; two erosion zones comprising of:
    a) A High-Medium Hazard Coastal Erosion Zone to a landward limit defined by the 66% probability erosion distance with 0.6 m SLR by 2080, with consideration of a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell under this scenario/threshold option, and
    b) A Low Hazard Coastal Erosion Zone to a landward limit defined by the 10% probability erosion distance with 1.2 m SLR by 2130 with consideration of a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell under this scenario/threshold option
3) For the beaches and bays of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour - a single 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 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.

Maps have been created showing the hazard zones relating to the recommended inundation and erosion risk categories. 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. It is recommended that CCC discuss proposed plan provisions and methods further with the authors to identify whether they are broadly consistent with the reasoning behind the definition of thresholds and choice of scenarios.

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.

Table 1.2: List of Acronyms and Abbreviations used in this report

Acronyms and Abbreviations	Details
AEP	Annual Exceedance Probability
AR6	Six Assessment Report
ASCE	future Areas Susceptible to Coastal Erosion
CCC	Christchurch City Council
CHPC	Coastal Hazards Plan Change
DEFRA	Department of Environment, Food and Rural Affair
DEM	Digital elevation Model
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection And Ranging
LINZ	Land Information New Zealand
LVD (LTN37)	Local Vertical Datum (Lyttelton datum 1937)
MfE	Ministry for the Environment
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

1. Introduction

1.1 Background

CCC are proposing to undertake a plan change to update Coastal Hazards aspects of the Christchurch District Plan. To inform consultation on adaptation to coastal hazards and a future Coastal Hazards Plan Change (CHPC) Tonkin and Taylor (Ltd) (T+T) generated updated coastal hazard assessment data and have provided this to CCC.

CCC propose to use a risk-based approach under which land use, development and subdivision in coastal areas of the district are managed according to the level of risk of coastal inundation and erosion. Under this approach there will be more restrictive controls in high hazard areas, while activities in low and medium hazard areas would be managed according to the level of risk and sensitivity of the activity to the risk.

Under a risk-based approach, there is a need to define appropriate sea level rise (SLR) scenarios and boundary thresholds between hazard levels or categories of risk for areas exposed to coastal inundation and erosion. CCC have commissioned Jacobs to investigate and recommend justifiable and appropriate scenarios and thresholds for defining the coastal hazard categories for land use planning over the whole of the Christchurch District (i.e. both the city urban area and Banks Peninsula).

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. It is understood that this analysis and recommendations will be used in Issues and Options consultation with communities and stakeholders on the CHPC in conjunction with consultation on the Coastal Hazards Adaptation Planning Programme also being undertaken by CCC.

The data provided by CCC to undertake this analysis is from the recent Coastal Hazard Assessment prepared by T+T, which is summarised in Section 3 of this report. It is recognised that the primary purpose of the T+T assessment was to inform the Coastal Hazards Adaptation Planning Programme, however, as explained in the Technical Reporting for the assessment “The results of the assessment could also inform a range of other purposes including review of the coastal hazards provisions in the Christchurch District Plan, provided the uncertainties and limitations are understood and appropriately managed”.

1.2 Framing of Key Terms used in this Report

The scope of our work was to identify a range of high, medium, and low hazard exposure categories for coastal erosion and inundation hazards. Hazard category levels indicate the level at which a hazard factor, could adversely impact different phenomena, such as people’s lives, properties and infrastructure, or cause harmful consequences to them. Hazard thresholds adopted in this study, refer to the boundaries between different hazard categories, where a hazard changes its consequence category level, for example, from medium to high.

Then, hazard exposure categories aimed to be applied to a range of “scenarios”. These scenarios would then be mapped to show the spatial extent of the three hazard exposure category areas.

The application of hazard and risk terms in the literature has always been challenging and these terms have often been used interchangeably. It is therefore important to frame these key terms in this report to avoid further confusion.

We adopted the framing of hazard and risks concepts that is consistent with MfE 2017[2] and 2020[3] and more broadly, with Intergovernmental Panel on Climate Change (IPCC) discourse. This framing acknowledges a conceptual difference between hazard and risk where risk is the outcome of interactions between hazards, exposure, and vulnerability (Figure 1.1).

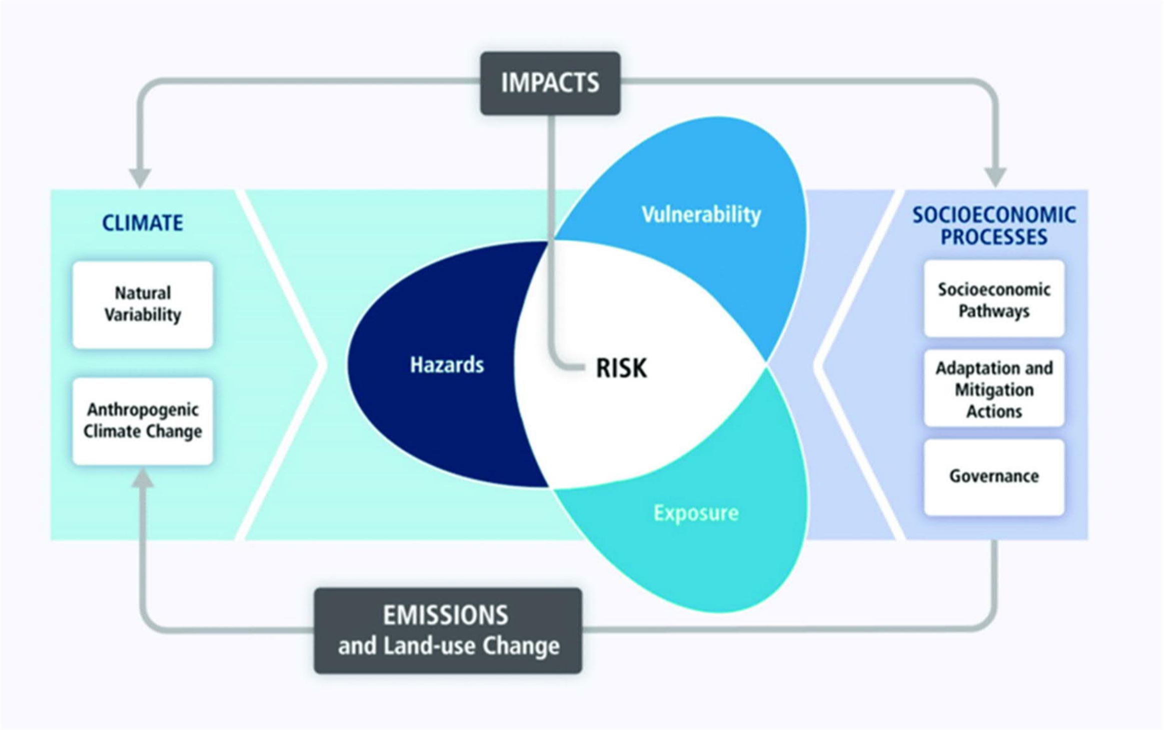

Figure 1.1: Interaction between hazard, exposure and vulnerability create risk (Source: IPCC, 2014) reproduced in (MfE 2020)

Hazard refers to the severity and magnitude of a natural or human or climate change induced driver or trend that causes harmful impacts (consequences) on natural, built environment, or social systems (MfE 2020). Accordingly, exposure is the lack of systems (i.e., property, infrastructure, human) protection against adversity (adverse hazard factors) in a hazard prone area, that could cause negative impacts.

In this report hazard addresses the physical extent at which erosion or inundation may interact with the land in the future. Therefore, for erosion it is the range of potential future coastline positions which could occur with differing amounts of future erosion. For inundation the hazard is the area potentially susceptible to inundation by water arising from coastal flooding. These hazard areas have been developed for CCC and this report by T+T.

Risk as noted above is typically considered as the interaction between the hazard, exposure of things to that hazard and the vulnerability of the things that are exposed. In this report we are identifying risk “thresholds” to apply broadly across the whole of the city and Banks Peninsula for District Planning purposes to control current and future land-use change and development. As such we are not seeking to consider the specific exposure/vulnerability of current activities to the hazard. For future activities that consideration will be addressed within the planning zoning, plan provisions and future consenting decisions on specific activities. We are however using existing risk categorisation guidelines that consider exposure and vulnerability when

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[2] Ministry for the Environment. (2017) *Coastal Hazards and Climate Change: Guidance for Local Government*, ME1341, December 2017.

[3] Ministry for the Environment. 2020. *National Climate Change Risk Assessment for Aotearoa New Zealand: Main report – Arotakenga Tūraru mō te Huringa Āhuarangi o Āotearoa: Pūrongo whakatōpū*. Wellington: Ministry for the Environment.

developing our thresholds. As an example, international risk categories for flooding depth that are based on the vulnerability of specific age groups are used to underpin our recommendations

A "Threshold" was conceptually to be used in this work as a method of categorising between areas of differing level of risk. This was the method by which some characteristic of the hazard was to be used to determine between high, medium and low risk. "Scenarios" were the range of SLR curves under various RCP emission scenarios, timeframes and event return periods that were considered most suitable for use for District Planning purposes.

These threshold and scenario definitions are easier to consider for inundation hazard risk. As the threshold can be, for instance, a water depth that defines high hazard. Then the scenario is a particular sea level rise at a given point in time applied to a given return period of flood event. For erosion hazards this same distinction between threshold and scenario was not able to be made as the various factors being considered (sea level rise via RCP emission pathway, probability of erosion occurring and timeframe) have to be combined together into one combined risk threshold/scenario. This is further explained in Section 5.

The outcome of this report is therefore the identification and mapping of areas of high, medium, and low risk which we generally refer to as risk "Categories". A glossary of terms is provided in Appendix D.

1.3 Methods

To undertake this analysis of suitable risk based approaches to coastal hazard management for land use planning we had the following approach to the study:

- We assembled a team including coastal science, flood modelling, RMA planning, coastal adaptation and GIS data management skills to all provide input into the options.
- We started with a review of existing approaches to coastal erosion and inundation hazard management within New Zealand District and Regional Plans, guidance documents and also made reference to selected international literature. This information set the scene for our consideration for what may be suitable approaches.
- The new council coastal hazard data was provided by T+T and we developed a web viewer for the project to view this data plus the existing mapped extents of hazards from the existing RPS, District Plan and other flood modelling. This viewer was then used to view and consider our mapped threshold/scenario options. The T+T data was reviewed to consider its suitability for setting different types of thresholds.
- A set of thresholds were developed for inundation and erosion hazards. These were originally intended to be high, medium and low categories but have been modified to better suit the available data and environments. These thresholds were workshopped with CCC.
- Following the workshop, scenarios were developed in which these thresholds would apply, these were generally expected to be chosen ranges of SLR based on RCP emissions pathways and could also include timelines and event magnitudes. In delivery we blended the thresholds and scenarios together to get a better outcome. The identified thresholds and scenarios were mapped to allow an understanding to be made of the spatial extent of each risk category (high, medium and low) and allow comparison of the outcome between the various scenarios. This was used to determine the preferred thresholds and scenarios in a second workshop with CCC.
- Comparison of these thresholds/scenarios was also made to current hazard mapping and using alternative data sets to generate the hazard category maps.

The above work has then been written up in this report with the additional deliverable being a spatial layer of the maps of the preferred threshold/scenario approach.

1.4 Report Structure

The report is presented in the following sections:

- Section 2 documents a high-level overview of our review of other relevant approaches to defining erosion and inundation risk
- Section 3 sets out the planning context of the project, which is important to develop approaches for identifying thresholds and scenarios
- Section 4 discusses the T+T coastal hazard data provided t Jacobs and the processing methodology undertaken by Jacobs to be able to use this data to analyse and map potential thresholds as boundaries to hazard categories
- Section 5 presents a selection of the most appropriate SLR scenarios for use defining the hazard categories,
- Sections 6 presents the results of the analysis to define the thresholds for a risk-based approach to coastal inundation hazard planning
- Sections 7 presents the results of the analysis to define the thresholds for a risk-based approach to coastal erosion hazard planning
- Section 8 provide a brief conclusion and summary of the recommended scenarios- thresholds-categories for use in consultation with communities and stakeholders on the CHPC.

2. New Zealand and International Review of Risk Categorisation Approaches

A review was undertaken of the current range of approaches to assessing and categorising the risk of coastal erosion and inundation hazards within relevant New Zealand local government plans (e.g., District and Regional Plans), relevant New Zealand guidance (e.g., central government guidance and legislation) plus reference was also made to risk classification approaches from selected international hazard management documents. This section provides a high-level summary of the outcome of that review, the detail of the review is provided in Appendix B.

The findings suggest a variety of parameters for categorising hazards[4] and defining associated thresholds in New Zealand and internationally. For flooding and coastal inundation, velocity, depth and likelihood (in form of Annual Exceedance Probability (AEP[5])), were the most frequent parameters.[6]

By way of example, Waikato Regional Council (WRC) used depth as the only parameters for categorising flood hazard within the Waikato River zone (Figure A.3). However, WRC adopted a combination of depth and velocity for the hazard outside the River zone (Figure A.4). By comparison, Waimakariri District Council applied likelihood and depth for categorizing inundation hazard levels. According to these categories, for 0.5% (1 in 200) AEP flooding events, flood depth lower that 0.3 metre (m) is associated with low flood hazard, depth between 0.3 to 1m is associated with medium flood hazard, and more than 1m flood depth was associated with high hazard area. The Christchurch District Plan adopted Canterbury Regional Policy Statement (RPS) recommendations and selected a combination of flood likelihood, velocity and depth to define hazard categories and thresholds. The Plan defined a high flood hazard management area if the depth(m) x velocity(m/s) in a 0.2% (1 in 500) AEP flood is equal or greater than one.

From an international perspective, the Australian Disaster Resilience Handbook Collection 2017,[7] adopted a six-flood hazard vulnerability classification by combining flood depth and velocity (see Table A.1 in Appendix A for more information). DEFRA[8] developed a hazard matrix that accounts for a combination of velocity and depth in categorising flood hazard for people and buildings.

Compared with flood hazard, less information was found on categorizing erosion hazard. However, several documents address likelihood and consequence as useful parameters for categorising erosion hazard. For example, Auckland Unitary Plan adopted likelihood, magnitude and consequence as parameters to define erosion hazard categories. Canterbury Regional Policy Statement (RPS) address likelihood as the best representative of erosion hazard.

Table A.1, Appendix A summarises the findings of the literature review on available methodologies for categorising the hazards and associated thresholds. This review was used to underpin the approach developed within this document by seeking to understand the available relevant and recent approaches to risk categorisation and especially the approaches that are already being used within district or regional planning in New Zealand.

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[4] Some documents adopted hazard synonymously with risk, therefore, they used hazard and risk categories interchangeably

[5] The probability that an event will be exceeded in any one year. So, a 1 % AEP event, has 1% probability of being exceeded in any year.

[6] Some documents also included vulnerability and sensitivity as parameters in categorising hazard/risk. However, according to our framing, incorporation sensitivity and vulnerability require accounting for social, cultural and economic values, which fall beyond hazard assessment/categorisation process.

[7] Australian Government (2017) Supporting document for the implementation of Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR 2017), The Technical flood risk management guideline: Flood hazard Australian Disaster Resilience Handbook Collection 2017

[8] Framework and Guidance for Assessing and Managing Flood Risk for New Development, UK Defra/Environment Agency Flood and Coastal Defence R&D Programme FD2320/TR22

3. The New Zealand Planning Context

This assessment will provide information to inform consultation regarding the proposed CHPC to the Christchurch District Plan and is likely to inform any future plan change. As such, it is important to understand the statutory planning framework and its relevant to hazard assessment. The planning framework provides guidance on the relative importance of addressing hazard impacts, the types of hazard risks/effects that should be considered, and the timeframe for projections. Decisions made under the resource management and planning framework establish a baseline for future outcomes.

This section provides a high-level summary of relevant planning documents and related policies however, it does not provide a determination as to either preferred responses or the level of assessment commensurate with that undertake for a Section 32 assessment.

3.1 The Resource Management Act 1991

The current NZ planning framework has been established under the Resource Management Act 1991 (RMA). The RMA provides the overarching legislation for sustainable management at the national, regional and district/city levels and provides scope, content and outcomes sought in planning documents. A review of the NZ resource management system is currently underway, and an overhaul of the planning framework is proposed. For now, the RMA remains the relevant legislation under which this study has been undertaken.[9]

Part 2 of the RMA details its purpose and principles, with the principles following a hierarchy beneath the purpose (i.e. sections 5 – 8). Part 2 sets out with the purpose of the RMA:

> *(1) The purpose of this Act is to promote the sustainable management of natural and physical resources.*
>
> *(2) In this Act, sustainable management means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while –*
>
> *(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *(b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

As can be seen from above, the purpose of the RMA is focused on the sustainable management of resources, as opposed to “sustainable development” which is more widely used internationally.[10] A key aspect of sustainable management is ensuring that community wellbeing is delivered in a manner which protects their health and safety. This is also linked to providing the reasonably foreseeable needs of future generations.

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[9] The NZ Government is currently in the process of replacing the RMA with three new Acts:

- Natural and Built Environments Act (NBA) to provide for land use and environmental regulation (this would be the primary replacement for the RMA).
- Strategic Planning Act (SPA) to integrate with other legislation relevant to development, and require long-term regional spatial strategies; and
- Climate Change Adaptation Act (CAA) to address complex issues associated with managed retreat and funding and financing adaptation.

[10] The key difference between ‘sustainable development’ and ‘sustainable management’ is that the latter removes the presumption that a portion of the environment (e.g. land) can be modified/used by humans as of right.

Also, Section 5 of part 2 indicates the ability of councils to take action to protect communities against hazards (i.e., protect their health and safety). When determining the risks of these hazards, councils should consider those hazards which are reasonably foreseeable. This wording implies that extreme or unlikely hazard scenarios should not be employed in the decision making under the RMA. Rather the application of SLR scenarios and hazard thresholds (e.g. frequency for flooding, probability of occurrence in timeframe for erosion) should be based on certainty and likelihood, the more certain or likely of which should then be employed to develop the content of a future plan change and/or other responses.

Section 4 of this report has detailed how "reasonably foreseeable" has been employed when considering the health and safety risks associated with coastal hazards.

Part 2 then proceeds to the "matters of national importance":

In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall recognise and provide for the following matters of national importance:

> *(a) the preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins, and the protection of them from inappropriate subdivision, use, and development:*
>
> *(b) the protection of outstanding natural features and landscapes from inappropriate subdivision, use, and development:*
>
> *(c) the protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna:*
>
> *(d) the maintenance and enhancement of public access to and along the coastal marine area, lakes, and rivers:*
>
> *(e) the relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga:*
>
> *(f) the protection of historic heritage from inappropriate subdivision, use, and development:*
>
> *(g) the protection of protected customary rights:*
>
> *(h) the management of significant risks from natural hazards.*

Section 6(h) gives direction to both recognise and provide for the management of significant risks from natural hazards. Furthermore, while section 6(h) does not restrict either the type or timeframes associated with natural hazard, it identifies that councils have a duty, at a minimum, to management risks that are significant. However, section 6(h) does not prevent councils from considering other risks (i.e. risks less than significant in scale or risks associated with other types of hazards). Significant risks are not defined within the RMA but are left to non-statutory guidance documents and planning authorities to define and determine (such as National Climate Change Risk Assessment for New Zealand 2020). Significant risk has not been specifically defined in this report however the determination of hazard categories based on thresholds and scenarios determines where the risk is significant and where it may choose to be managed by future Plan provisions.

Section 7 of the RMA details "other matters":

In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall have particular regard to—

(a) kaitiakitanga:

(aa) the ethic of stewardship:

(b) the efficient use and development of natural and physical resources:

(ba) the efficiency of the end use of energy:

(c) the maintenance and enhancement of amenity values:

(d) intrinsic values of ecosystems:

(e)[Repealed]

(f) maintenance and enhancement of the quality of the environment:

(g) any finite characteristics of natural and physical resources:

(h) the protection of the habitat of trout and salmon:

(i) the effects of climate change:

(j) the benefits to be derived from the use and development of renewable energy.

Section 7(i) provides useful guidance to councils, in that it directs them to have particular regard to the effects of climate change. Again, these effects are themselves undefined in the RMA and it is left to planning instruments (e.g. the NZCPS,[11] RPS's[12]) to determine the types and timeframes of such effects. This is discussed in further detail in Section 2.3. This provides further justification to the purpose of this analysis of appropriate scenarios and thresholds for use in risk based coastal hazard planning, bearing in mind that the “effects” should be driven in part by both whether these effects are reasonably foreseeable (RMA section 5) and that the risks are significant (RMA section 6(h)).

The last section (section 8) of RMA Part 2 relates to linking RMA decision-making to the Treaty of Waitangi. In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall take into account the principles of the Treaty of Waitangi (Te Tiriti o Waitangi).

Section 8 highlights the importance of engagement with local iwi to ensure that the full quantum of risk and effects of coastal hazards is complied. This is particularly important given the intrinsic nature of many cultural values which may not be clearly apparent when undertaking hazard assessments in a purely technical manner. It should be noted that this analysis of coastal hazard scenarios/thresholds for a risk based approach to land use planning has not considered effects on cultural values, both physical and intrinsic. Rather, we recommend that the consideration of such effects should be undertaken in direct consultation with the potentially affected hapu and other relevant mana whenua entities.

3.2 Plan Changes

Given this analysis relates to a potential change to the Christchurch District Plan, it is useful to consider the purpose of a district plan. Under section 31 of RMA details the functions of territorial authorities (like CCC):

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[11] New Zealand Coastal Policy Statement, 2010

[12] Regional Policy Statements

(1) Every territorial authority shall have the following functions for the purpose of giving effect to this Act in its district:

> *(a) the establishment, implementation, and review of objectives, policies, and methods to achieve integrated management of the effects of the use, development, or protection of land and associated natural and physical resources of the district:*
>
> *(aa) the establishment, implementation, and review of objectives, policies, and methods to ensure that there is sufficient development capacity in respect of housing and business land to meet the expected demands of the district:*
>
> *(b) the control of any actual or potential effects of the use, development, or protection of land, including for the purpose of—*
>
> > *(i) the avoidance or mitigation of natural hazards; and*
> >
> > *(ii) [Repealed]*
> >
> > *(iia) the prevention or mitigation of any adverse effects of the development, subdivision, or use of contaminated land:*
> >
> > *(iii) the maintenance of indigenous biological diversity:*
>
> *(c) [Repealed]*
>
> *(d) the control of the emission of noise and the mitigation of the effects of noise:*
>
> *(e) the control of any actual or potential effects of activities in relation to the surface of water in rivers and lakes:*
>
> *(f) any other functions specified in this Act.*

(2) The methods used to carry out any functions under subsection (1) may include the control of subdivision.

The above clauses demonstrate why the district plan will address coastal hazards, both through avoidance and mitigation. It also indicates a clear accountability of councils to restrict subdivision in those areas affected by natural hazards.

The assessment process for new district plans and plan changes is detailed in section 32 of the RMA, which requires an evaluation of the extent to which the objectives of the proposal are the most appropriate way to achieve the purpose of the Act (section 32(1)(a)). A plan change will contain the following:

- A description of the environmental issue(s) which are being addressed
- The proposed/altered objectives and policies (i.e. that will be incorporated into the district plan and relate to the outcomes sought)
- Details of the methods that will be employed to achieve the objectives and policies (these may include methods outside of the district plan/RMA)
- Any rules, standards and assessment criteria which will be incorporated into the district plan.

This analysis of potential coastal hazard scenarios and thresholds for a risk-based approach will directly input into consultation for the potential CHPC and its various components and may then be used to support the actual plan change. It is therefore relevant to understand what must be included in plan change reports (known as section 32 reports).

Section 32 of the RMA is broken down into several sub-sections, starting with section 32(1):

(1) An evaluation report required under this Act must—

> *(a) examine the extent to which the objectives of the proposal being evaluated are the most appropriate way to achieve the purpose of this Act; and*
>
> *(b) examine whether the provisions in the proposal are the most appropriate way to achieve the objectives by—*
>
> > *(i) identifying other reasonably practicable options for achieving the objectives; and*
> >
> > *(ii) assessing the efficiency and effectiveness of the provisions in achieving the objectives; and*
> >
> > *(iii) summarising the reasons for deciding on the provisions; and*
>
> *(c) contain a level of detail that corresponds to the scale and significance of the environmental, economic, social, and cultural effects that are anticipated from the implementation of the proposal.*

Section 32(1)(a) provides guidance as to the overall purpose of an evaluation report (section 32 report). It provides a clear link back to section 5 (the purpose of the RMA) by requiring any proposed objectives to be the most appropriate way to achieve the RMA's purpose.

Section 32(1)(b) then sets out how a plan change's provisions (i.e. policies, rules, standards and other methods) are the most appropriate way to achieve a plan change's stated objectives. The "appropriateness" of these provisions is further broken and required them to be reasonably practicable and efficient. There must also be clear and articulate argument provided for how the provisions are both reasonably practicable and efficient. While this analysis will not recommend specific adaptation responses, it does provide the justification of how the hazard categories were defined, and therefore the basis for spatial differences in adaptation responses or planning provisions.

Lastly, section 32(1)(c) requires reporting to be commensurate with the scale of the significance of the effects which may occur from the adoption of a plan change's provisions. This requirement has been considered in the analysis presented in Sections 5 and 6 of this report to define the most appropriate boundaries of different hazard categories.

Section 32(2) provides additional guidance as to how the efficiency and effectiveness of a plan change's provisions should be assessed (i.e. section32(b)(ii)):

An assessment under subsection (1)(b)(ii) must—

> *(a)identify and assess the benefits and costs of the environmental, economic, social, and cultural effects that are anticipated from the implementation of the provisions, including the opportunities for*
>
> > *(i) economic growth that are anticipated to be provided or reduced; and*
> >
> > *(ii) employment that are anticipated to be provided or reduced; and*

> *(b) if practicable, quantify the benefits and costs referred to in paragraph (a); a(c) assess the risk of acting or not acting if there is uncertain or insufficient information about the subject matter of the provisions.*

Section 32 (2) places significant weight on the economic effects of a plan change and, the effects on economic growth and employment. While the analysis presented in this report does not include an economic impact assessment, the following discussion is included here to ensure that such an assessment is included in the CHPC. While the effects on environmental, social and cultural wellbeing are not excluded, the risk assessment should consider the economic effects, for example loss of development rights that may arise from a proposed plan change. As such, the removal of development rights and restrictions of land use activities needs to be balanced against the potential effects arising from reasonably foreseeable and significant natural hazards.

Section 32(3) is also relevant, given that the analysis presented in this report will be employed to support a plan change:

If the proposal (an amending proposal) will amend … plan, or change that is already proposed or that already exists (an existing proposal), the examination under subsection (1)(b) must relate to—

(a) the provisions and objectives of the amending proposal; and

(b) the objectives of the existing proposal to the extent that those objectives—

> *(i) are relevant to the objectives of the amending proposal; and*
>
> *(ii)would remain if the amending proposal were to take effect.*

In essence, the existing District Plan acts as a baseline when considering whether the effects of coastal hazards has been adequately addressed. This would include consideration as to whether the current District Plan has previously identified and addressed the relevant hazards (and associated significant risks). The objectives, policies and standards of the District Plan have been considered, as detailed below, with regard to the currently policy and regulatory framework for coastal hazards in Canterbury.

3.3 Existing Planning Framework

As previously stated, this analysis considered various statutory planning documents and guidance which are relevant to hazard assessment (including coastal hazards). While a detailed review of these documents is required in developing any future section 32 report, it is useful to address the planning framework for coastal hazards in New Zealand, as well as more specifically within Canterbury and Christchurch. The documents considered in this study include:

- New Zealand Coastal Policy Statement 2010 (the NZCPS)
- Canterbury Regional Policy Statement (the RPS)
- Regional Coastal Environment Plan for the Canterbury Region (RCEP)
- Christchurch District Plan
- MfE Guidance for Local Government “Preparing for Climate Change 2017.

These five documents are discussed briefly in turn with more detailed considerations provided in Appendix B.

3.3.1 New Zealand Coastal Policy Statement 2010 (NZCPS)

The NZCPS provides national direction for the management of, and adaption to coastal hazards via:

- *Objective 5: To ensure that coastal hazard risks taking account of climate change, are managed by*
    - *Locating new development away from areas prone to such risks*
    - *Considering responses, including managed retreat, for existing development in this situation; and*
    - *protecting or restoring natural defences to coastal hazards*
- Policy 3: Precautionary approach: (1) Adopt a precautionary approach towards proposed activities whose effects on the coastal environment are uncertain, unknown, or little understood, but potentially significantly adverse. (2) In particular, adopt a precautionary approach to use and management of coastal resources potentially vulnerable to effects from climate change
- Policy 24: The identification of coastal hazards (gives priority to the identification of areas at high risk of being affected over at least 100 years),
- Policy 25: Subdivision, use and development in areas of coastal hazard risk (avoid increasing the risk, encourage reducing the risk by locating outside areas of risk, and discourage hard protection)
- Policy 26: Natural defences against coastal hazards (recognise and provide for)
- Policy 27: Strategies for protecting significant existing development from coastal hazard risk (development of range of options).

3.3.2 Canterbury Regional Policy Statement (RPS)

The objectives and policies of the RPS Chapter 11 “Natural Hazards” are consistent with the direction set by the NZCPS - that land use activities should avoid increasing natural hazard risks. The framework also recognises and provides for the projected increases in sea levels and associated hazards. It sets out the types of risks to be considered, principally loss of life or significant damage to property. The policies are directive and set out specific requirements for building in inundation areas. This direction has been incorporated into this study’s identification of risks. The policy framework also set out the requirement for district and city councils to investigate, map and address natural hazards, with specific regard given to the effects of sea level rise and climate change.

RPS Policy 11.3.1 (Avoidance of inappropriate development in high hazard areas) provides a definition for “high hazard areas” which for the Christchurch District includes:

> *1) flood hazard areas subject to inundation events where the water depth (metres) x velocity (metres per second) is greater than or equal to 1, or where depths are greater than 1 metre, in a 0.2% AEP (1 in 500 year) flood event;*
>
> *3) land within greater Christchurch likely to be subject to coastal erosion including the cumulative effects of sea level rise over the next 100 This includes (but is not limited to) the land located within Hazard Zones 1 and 2 shown on Maps in Appendix 5 of this Regional Policy Statement that have been determined in accordance with Appendix 6; and*
>
> *4) land subject to sea water inundation (excluding tsunami) over the next 100 years. This includes (but is not limited to) the land located within the sea water inundation zone boundary shown on Maps in Appendix 5 of this Regional Policy Statement.*

3.3.3 Regional Coastal Environment Plan for the Canterbury Region (RCEP)

The RCEP recognises the dynamic and connected nature of the coastal environment and includes objectives, policies, and rules for coastal hazards on the landward of the Mean High Water Spring boundary of the Regional

Coastal Plans. The h RCEP pre-dates both the NZCPS and RPS and is less restrictive, however the same guidance as to the importance of identifying, mapping and assessing coastal hazards is included.

The RCEP includes the identification of coastal erosion hazard zones along the majority of the region's coastline which define the areas within which the hazard rules apply and are the hazard zones referred to in point 3 of the RPS definition of *high hazard*. These erosion hazard zones are defined as being:

- Erosion Hazard Zone 1:

  (a) For stable or accretionary shorelines: Where there is no evidence of shoreline erosion, the width of Hazard Zone 1 is the area landward of the Coastal Marine Area boundary to the landward limit of the active beach system. This position is determined either by ground survey, or from aerial photography.

  (b) For most eroding shorelines: The width of Hazard Zone 1 includes the active beach system and the area landward of this, which is likely to be part of the active beach system if contemporary erosion processes continue unaltered for the next 50 years. Hence, the landward limit of Hazard Zone 1 corresponds to the projected position of the landward toes of the active beach system.

The width of hazard zones has been determined by interpolating the rate of shoreline retreat between fixed determination points. For all determination points, except for some special situations listed below, there was no evidence of a change in the long-term rate of shoreline retreat. Therefore, the longest-term historical erosion rates have been used. These will include short term fluctuations.

- Erosion Hazard Zone 2:

  No Hazard Zone 2 is defined for stable or accreting shorelines.

  For eroding shorelines, Hazard Zone 2 is landward of Hazard Zone 1, and covers areas that could become part of the active beach system within 50 to 100 years if the erosion rates used to calculate Hazard Zone 1 were to continue unaltered for 100 years.

it is important to note that they do not include are consideration of the effect of SLR on future coastal erosion.

The RCEP also maps a sea water inundation zone, covering areas known to have been affected by coastal inundation the past, but does not include any policies or rules around this hazard.

3.3.4 The Christchurch District Plan

The Christchurch District Plan includes several objectives and policies relevant to coastal hazards and replicates the language of higher order RMA documents in that hazards should be avoided where the risks generated by these hazards is unacceptable. Specific guidance and policy regarding flooding and sea level rise is provided in Policy 5.2.2.2 (Managing risk from flooding), which defines Flood Management Areas to be:

> *"(i) a modelled 0.5% AEP (1 in 200-year) rainfall event plus a 5% AEP (1 in 20-year) tide event plus 250mm freeboard; OR a modelled 5% AEP (1 in 20-year flood event) plus a 0.5% AEP (1 in 200-year) tide event plus 250mm freeboard; OR 11.9m above Christchurch City Council Datum (the maximum 200-year tidal contour) plus 250mm freeboard; whichever is the greater; and*
>
> *(ii)allowance for 1 metre of sea level rise and an increase in rainfall intensity by 16% through to 2115 as a result of climate change; and..."*

Flood Management Areas are included as a layer on the District Plan maps, as are the High Flood Hazard Management Areas as identified in the RPS. The District Plan does not identify or any Coastal Erosion Hazard

Management Areas and relies on the Erosion Zones and policies of the RPS and the relevant zone rules in the RCEP.

3.3.5 Banks Peninsula District Plan

The Banks Peninsula District Plan (BPDP) also includes objectives and policies relating to natural hazards. While many elements of the BPDP have been superseded following the amalgamation of the Christchurch City and Banks Peninsula District Councils, its coastal hazard content is still operative. Its approach to these hazards is similar to that of the Christchurch District Plan, with a focus on minimising loss of life and property damage. However, its rules focus on surface flooding and not sea level rise, storm surges or coastal erosion.

3.3.6 MfE Guidance for Local Government “Preparing for Climate Change” 2017.

This a non-statutory document provides the most practicable guidance on the methodology assessing and current and future coastal hazard susceptibility, exposure and vulnerability. The T+T Coastal Hazard Assessment use in this report follows the methodology of the MfE (2017) guidance.

4. Data Sources and Processing

This section sets out the data on coastal hazards that was used within this analysis. It notes the sources of data and how this has been processed to produce and map the hazard risk category areas.

All maps produced for this analysis are available in a webviewer accessible to the project team. Maps of the preferred approach has been provided to CCC as a spatial layer.

4.1 Bathtub Modelling Inundation Data

4.1.1 T+T Bathtub modelling data

The T+T coastal inundation data was acquired from their 'bathtub' model, covering the coastal land of the Christchurch City urban area, and Banks Peninsula. The inputs into the bathtub modelling include:

- Peak static water levels comprising storm tide and wave set-up for three water level AEPs: 63% (1 in 1 year), 10% (1 in 10 years), 1% (1 in 100 years) and nine SLR increments from a 2020 base, ranging from 0 m to 2m.
- Water level data provided in look-up tables for 11 discrete areas covering the district coastline as presented in Table 4.1 and mapped in 11 areas shown in Figure 4.1. It is noted that due to differences in the wave set-up values in each area (which depends on wave climate and beach slopes) there is some variation between the resulting water levels in each area for the same SLR increment and water level frequency.
- Ground levels from the 2018 LiDAR survey.

The bathtub modelling does not include dynamic water levels from the inclusion of wave run-up processes to the inundation depths and extents.

The assessment scenarios proposed by T+T to inform adaptation planning in relation to coastal inundation are presented in Table 4.2. Although an assessment of the potential effect of erosion on inundation was made, this was not included in the bathtub mapping.

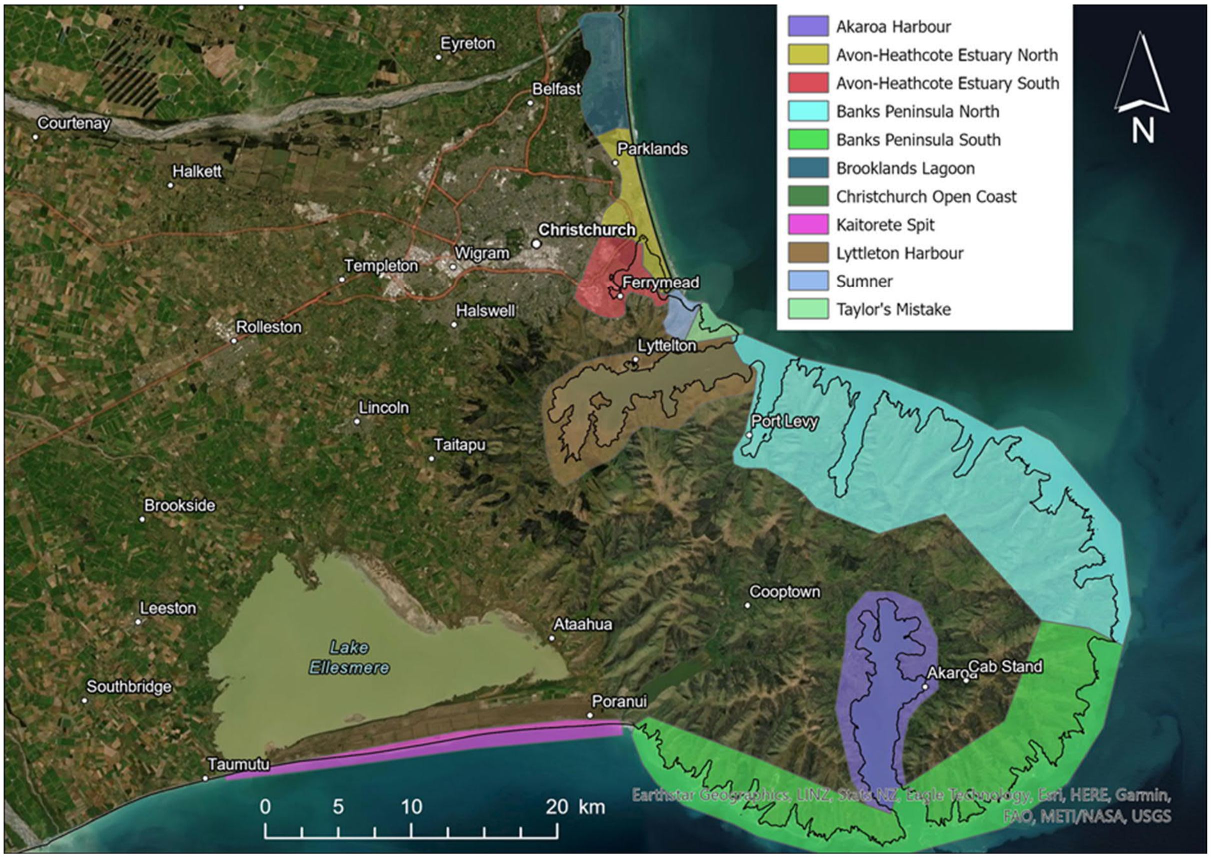


Figure 4.1: Discrete areas of extreme water levels from look-up Tables in Table 4.1

Table 4.1: Look up Table of extreme static sea levels supplied by T+T for combination of water level frequencies and SLR's. Levels in NZVD2016.

	Water Level Frequency		Sea Level Rise (SLR) (m)								
Area	% Annual Exceedance Probability (AEP)	Average Recurrence Interval (ARI)	0.0	0.2	0.4	0.6	0.8	1.2	1.4	1.5	2.0
Christchurch Open Coast	63%	1 year	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.3	3.8
	10%	10 year	2.0	2.2	2.4	2.6	2.8	3.2	3.4	3.5	4.0
	1%	100 year	2.3	2.5	2.7	2.9	3.1	3.5	3.7	3.8	4.3
Sumner	63%	1 year	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.3	3.8
	10%	10 year	2.0	2.2	2.4	2.6	2.8	3.2	3.4	3.5	4.0
	1%	100 year	2.3	2.5	2.7	2.9	3.1	3.5	3.7	3.8	4.3
Taylor's Mistake	63%	1 year	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.3	3.8
	10%	10 year	2.0	2.2	2.4	2.6	2.8	3.2	3.4	3.5	4.0
	1%	100 year	2.3	2.5	2.7	2.9	3.1	3.5	3.7	3.8	4.3
Brooklands Lagoon	63%	1 year	1.4	1.6	1.8	2.0	2.2	2.6	2.8	2.9	3.4
	10%	10 year	1.6	1.8	2.0	2.2	2.4	2.8	3.0	3.1	3.6
	1%	100 year	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.3	3.8
Avon-Heathcote Estuary North	63%	1 year	1.5	1.7	1.9	2.1	2.3	2.7	2.9	3.0	3.5
	10%	10 year	1.7	1.9	2.1	2.3	2.5	2.9	3.1	3.2	3.7
	1%	100 year	2.0	2.2	2.4	2.6	2.8	3.2	3.4	3.5	4.0
Avon-Heathcote Estuary South	63%	1 year	1.5	1.7	1.9	2.1	2.3	2.7	2.9	3.0	3.5
	10%	10 year	1.6	1.8	2.0	2.2	2.4	2.8	3.0	3.1	3.6
	1%	100 year	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.3	3.8
Lyttelton Harbour	63%	1 year	1.6	1.8	2.0	2.2	2.4	2.8	3.0	3.1	3.6
	10%	10 year	1.7	1.9	2.1	2.3	2.5	2.9	3.1	3.2	3.7
	1%	100 year	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.3	3.8
Akaroa Harbour	63%	1 year	1.9	2.1	2.3	2.5	2.7	3.1	3.3	3.4	3.9
	10%	10 year	2.1	2.3	2.5	2.7	2.9	3.3	3.5	3.6	4.1
	1%	100 year	2.3	2.5	2.7	2.9	3.1	3.5	3.7	3.8	4.3
Banks Peninsula North	63%	1 year	2.2	2.4	2.6	2.8	3.0	3.4	3.6	3.7	4.2
	10%	10 year	2.5	2.7	2.9	3.1	3.3	3.7	3.9	4.0	4.5

	Water Level Frequency		Sea Level Rise (SLR) (m)								
Area	% Annual Exceedance Probability (AEP)	Average Recurrence Interval (ARI)	0.0	0.2	0.4	0.6	0.8	1.2	1.4	1.5	2.0
	1%	100 year	2.8	3.0	3.2	3.4	3.6	4.0	4.2	4.3	4.8
Banks Peninsula South	63%	1 year	2.9	3.1	3.3	3.5	3.7	4.1	4.3	4.4	4.9
	10%	10 year	3.4	3.6	3.8	4.0	4.2	4.6	4.8	4.9	5.4
	1%	100 year	3.9	4.1	4.3	4.5	4.7	5.1	5.3	5.4	5.9
Kaitorete Spit	63%	1 year	2.2	2.4	2.6	2.8	3.0	3.4	3.6	3.7	4.2
	10%	10 year	2.6	2.8	3.0	3.2	3.4	3.8	4.0	4.1	4.6
	1%	100 year	2.8	3.0	3.2	3.4	3.6	4.0	4.2	4.3	4.8

Table 4.2: Assessment scenarios proposed by T+T for inundation lookup tables

Assessment	SLR (m)	Average Recurrence Interval (ARI)	Effect of erosion
Detailed assessment	0 +0.2 +0.4 +0.6 +0.8 +1.0 +1.2 +1.5 +2.0	1 year 10 year 100 year	n/a
	+1.5	100 year	Future P5% and P50% erosion for same scenario
Regional screening assessment	0 +0.4 +1.5	1 year 10 year 100 year	n/a

For the Avon, Heathcote and Styx catchments within the Christchurch City urban area, the spatial extent of the bathtub modelling was limited to the area to the east of the modelling boundary shown in Figure 4.2. To the west of this boundary, T+T assessed that

…extreme inundation level is increasingly influenced by river/stream flow, with lesser reliance on the sea level applied and that the bathtub model generally overestimates the extent of inundation because it applies a water level derived at the coast which is too high for the area further inland.

T+T concluded that:

...extreme inundation of areas upstream of these locations is best derived through joint probability modelling assessment, taking into account both sea level and river flow state

The bathtub model outputs that were provided to Jacobs included the following:

- Polygons of the extents of the 11 discrete areas (Figure 4.1).
- Mask of the useable bathtub model area within the Christchurch City Urban area (Figure 4.2).
- Raster datasets representing inundation depth at a spatial ground resolution of 1x1m from water levels at 0.1 m intervals from 0.9 m to 6.0 m relative to NZVD2016 datum. The raster outputs were divided into ‘connected’ and ‘disconnected’ flooded areas, with disconnected areas not having a direct pathway of flooding to the coastline.

Determining the inundation extent and depth for a particular frequency and SLR scenario within a specified area required obtaining the resulting water level for that scenario and area from the look-up tables, then interrogating the appropriate raster for that water level to obtain the inundation extent and depths.

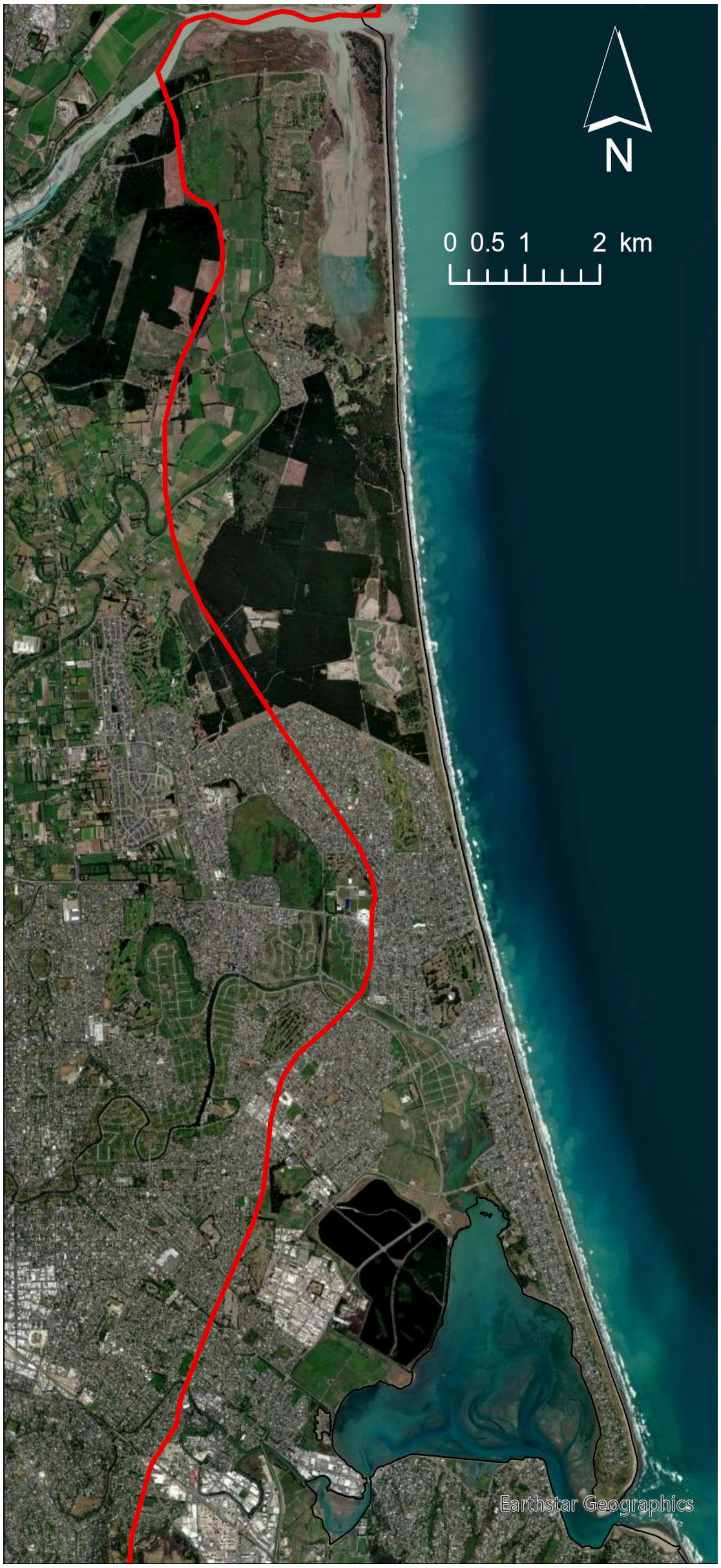


Figure 4.2: Bathtub modelling boundary position for Christchurch City urban area

4.1.2 Inundation Data Processing

The raster data of the bathtub model outputs were combined based on the selected AEP, SLR, and for all 11 areas around Christchurch and Banks Peninsula. The required water flood level rasters were clipped to their relevant location extents, and all non-usable model area was removed using the provided polygons and mask. This included both 'connected' and 'disconnected' inundation areas from the static water levels. To test the different potential flood depth thresholds for setting planning categories, each resulting raster was classified to the desired flood depth intervals and dissolved into polygon areas.

4.1.3 TUFLOW Model Inundation Data

We received outputs from T+T's TUFLOW model dated 2017, which covered the Christchurch City urban area. The model was run with zero rainfall to assess hydrodynamic response to storm tide applied at the seaward model boundary. Under this assumption, there was no flow in the waterways draining into the Avon-Heathcote Estuary and Brooklands Lagoon at the time of the extreme sea level event.

The flood level data have a ground resolution of 5x5m and are relative to the LVD37[13] datum. They were provided for two different flood scenarios as shown in Table 4.3. For the conversion of TUFLOW flood level data into flood depth data, we obtained the 2018 Canterbury, Christchurch and Ashley River LiDAR DEM with a spatial ground resolution of 1x1m[14] and the datum conversion grid from LVD37 to NZVD2016 datum.[15]

Table 4.3: Water Levels from T+T TUFLOW 2017 model

Year	Water Level Frequency (ARI in years)	Representative Concentration Pathway (RCP) used to determine SLR	Peak water level within model (LVD37)		
			Bridge St	Ferrymead Bridge	Styx tide gate
2065	100	RCP 4.5	2.52	2.53	2.54
2115	100	RCP 8.5H+	3.0	3.18	3.1

For data processing and comparison to the bathtub data, we converted the TUFLOW flood level data from LVD37 to NZVD2016 datum using LINZ's conversion grid. For that purpose, an offset raster was calculated from the grid points by applying a surface triangulation in combination with a barycentric interpolation which was then used to convert the TUFLOW levels to NZVD2016. Flood depth was calculated against the 2018 LiDAR DEM.

4.2 Coastal Erosion Data

4.2.1 T+T Erosion Modelling Data

The coastal erosion modelling undertaken by T+T involved calculating the current and future Areas Susceptible to Coastal Erosion (ASCE) across the beaches and coastal banks of the whole district from the following standard formula relevant to each coastal morphology:

$Current\ ASCE_{Beach} = ST + DS$, and

$$Future\ ASCE_{Beach} = (LT \times T) + SL + ST + DS$$

$$Current\ ASCE_{Bank} = (H_C/\tan\alpha)$$

---

[13] Lyttelton Vertical Datum 1937

[14] (https://data.linz.govt.nz/layer/104497-canterbury-christchurch-and-ashley-river-lidar-1m-dem-2018-2019/)

[15] (https://data.linz.govt.nz/layer/53432-lyttelton-1937-to-nzvd2016-conversion/)

$$Future\ ASCE_{Bank} = (LT\ x\ T)\ x\ SL + (HC/tan\alpha)$$

Where;

ST is the short-term storm erosion in 100 year wave and water level event combined probability event,

DS is a dune stability factor for dune face collapse following over-steepening a storm event,

LT is the historical long-term rate of shoreline retreat or advance,

T is the time frame of the assessment,

SL is the erosion resulting from SLR within the time frame,

Hc is the height of the bank,

α is the characteristic stable angle of the bank in degrees

To account for the different coastal morphologies and erosion responses to coastal processes operating within the study area, the coastline was dividied into 100 cells, with the calculated ASCE being constant within each cell. For 52 of the cells covering, the Christchurch City urban area (30 cells), beach or bank shorelines along the existing larger settlements within Lyttelton (10) and Akaroa Harbours (12), a detailed probabilistic erosion assessment was carried out. These assessments involved calculating the full range of statistical probability of erosion distances resulting from a range of input parameter values for each of sixteen different combinations of time frame and SLR magnitude scenarios as presented in Table 4.4. The results were presented to Jacobs as raster data, representing erosion probabilities at a spatial ground resolution of 1x1m, with a gradual decrease of probability with increasing distance from the shoreline. These probability values can therefore be interpreted as being the probability that the erosion will reach or be greater than the calculated ASCE to that location.

Within the detailed assessment there are several cells where future erosion is not considered to be acceptable. This includes areas where there is land reclamation and substantial hard protection structures that protect critically important infrastructure or significant development. Therefore, the Future ASCE is assessed as the same as Current ASCE (e.g. erosion resulting from structure damage/failure before repair) and there is no change in ASCE with SLR scenario, and very little change in erosion distance with probability. These cells include the southern shore of the Avon-Heathcote estuary, Sumner Beach, Lyttelton Port and Akaroa township.

For the remaining 48 cells in other bays within Banks Peninsula, Lyttelton and Akaroa Harbours, and along Kaitorete Spit, a less detailed deterministic erosion hazard screening approach was taken due to insufficient data for a full probabilistic approach. For these cells single value input parameters were used with only five combinations of time frame and sea level rise magnitude as shown in Table 4.4. The resulting ASCE are assumed to be very conservative, with an assumed probability of being exceeded in the range of 1-5%. In these cells the ASCE results were presented to us as lines of the future shoreline position for each SLR scenario.

Table 4.4: SLR Scenarios used in the T+T coastal erosion modelling

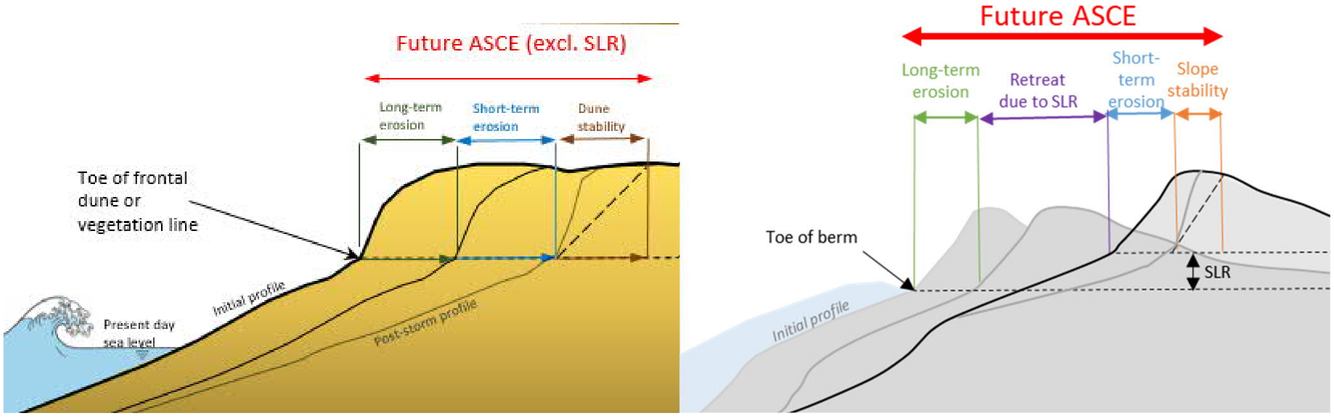
Detailed Probabilistic Cells				Deterministic Screening Cells		
Year	SLR (m)	Probability	Sediment Supply	Year	SLR (m)	Probability
2020	0.0	A range of probabilities mapped as a gradient from 99% to 1%	No change	2020	0.0	Assumed to be in range 1 -5 % probability
2050	0.2			2080	0.4	
	0.4			2150	0.4	
2080	0.4				1.5	
	0.6					
	0.8					
2130	0.4					
	0.6					
	0.8					
	1.0					
	1.2					
	1.5					
2150	2.0					
2130	1.5		Reduced by 11%			
2130	1.5		Increased by 28%			

The origin position for the ASCE calculations for beaches and banks is the seaward toe of the dune, beach berm or bank as shown in Figure 4.3. Therefore, when interpreting these future erosion positions for determining setback distances for planning purposes, there is a need to allow for natural backshore environments (for example dunes and beach ridges), bank slopes, and potential protection works within the setback distance.

For cliff shorelines around the Banks Peninsula, the Future ASCE is defined as a generic setback distance, the width of which is dependent on the current cliff slope as follows:

- Where current cliff slope is equal or steeper than 1:1slope: Future ASCE $_{\text{Cliff}}$= 20 m set back from top of the cliff
- Where current cliff slope is flatter than 1:1slope: Future ASCE $_{\text{Cliff}}$ = 30 m set back from toe of the cliff.

The locations of Future ASCE $_{\text{Cliff}}$ were provided by T+T as a smoothed line offset by the appropriate distance from a mapped cliff baseline position, assumed to be the current toe of the cliff.



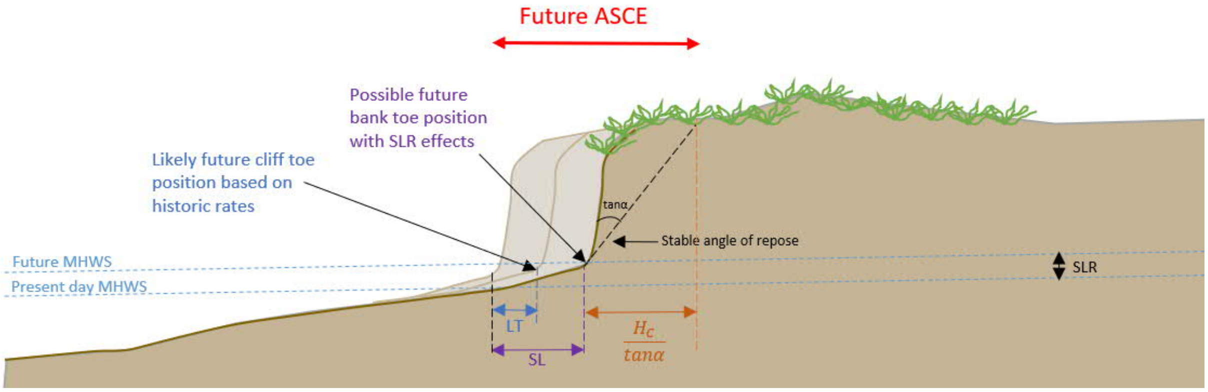


Figure 4.3: Position of origin position for ASCE on beach and bank profiles (Source T+T Technical Report)

4.2.2 Erosion Data Processing

For the detailed assessment of cells, lines of erosion probability were extracted from various scenarios provided as “probabilistic raster data”. Lines were created by tracing raster values of the probability of interest. Where rasters did not contain the exact probability value, a linear interpolation between raster cells was carried out, assuming that the probability location is represented by the centre of each raster cell.

As a result of the T+T cell wide approach to the ASCE calculations, there are discontinuities in the lines of equal probability for the same SLR scenario across the cell boundaries as shown in Figure 4.4.

For deterministic screening cells and cliff locations, no processing of the received erosion lines was requested. However, it is noted that there is potential inconsistency in the widths of the ASCE within the bays of Lyttelton and Akaroa Harbours compared to adjoining bays where the detailed probabilistic approach was used.

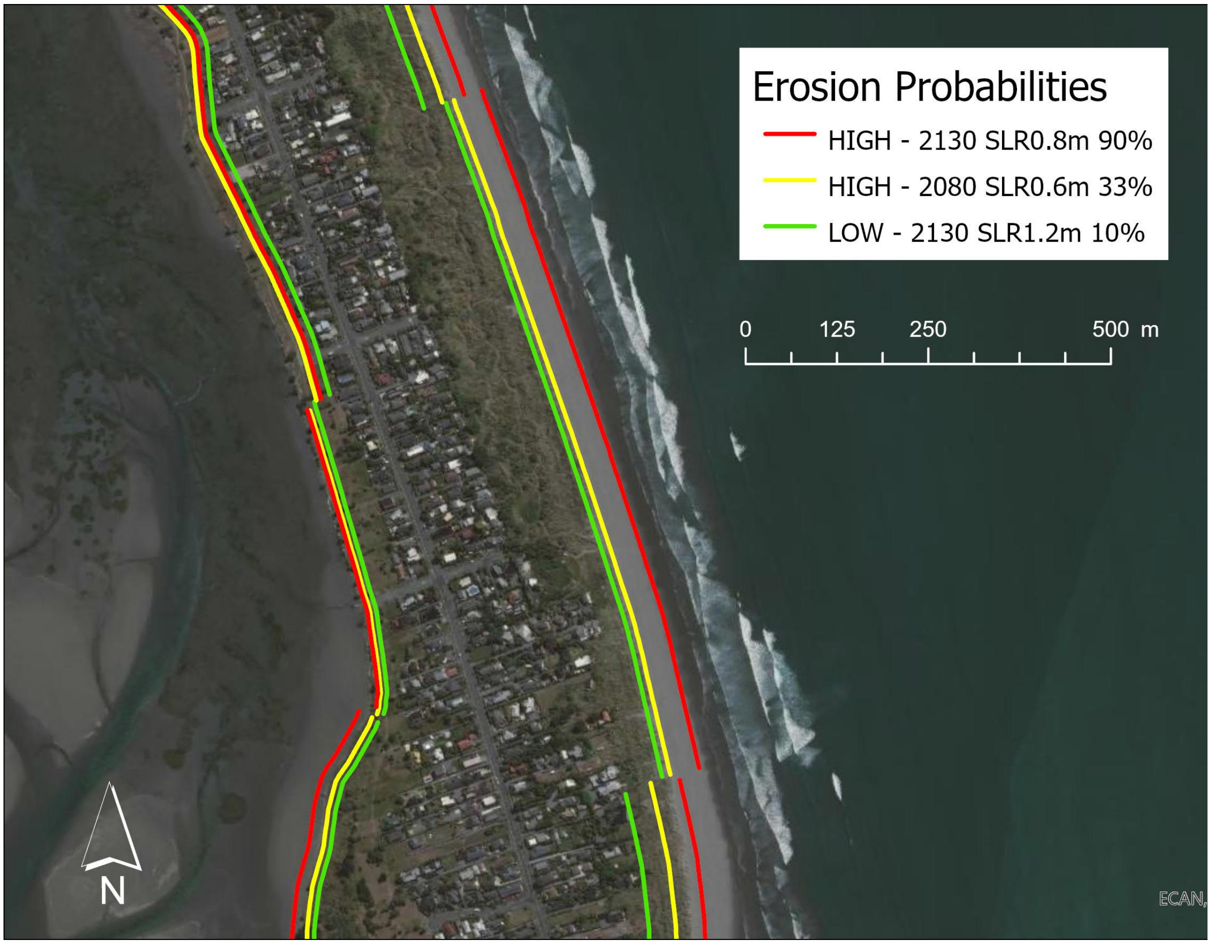


Figure 4.4: Inconsistencies in ASCE probability across cell boundaries

4.2.3 RPS/RCEP Erosion Hazard Zone Data

The Coastal Erosion Hazard Zone data from the RPS was provided as polygons for a comparison to erosion hazard zones proposed in Section 7. As noted in Section 3.3.2, these erosion hazard data did not include any reference to future erosion from SLR. The RPS defines High Hazard areas within greater Christchurch to include land likely to be subject to coastal erosion including the cumulative effects of SLR over the next 100 years, which includes, but is not limited to, the land located within the Hazard Zones 1 and 2.

For the Christchurch City district these coastal erosion hazard zones only exist along the open coast of the Christchurch City urban area and along Kaitorete Spit, with no erosion zones beginning defined in the Avon-Heathcote Estuary or Banks Peninsula. Since the shoreline in both the Christchurch City open coast and along Kaitorete Spit are long-term accretionary, only Erosion Hazard Zone 1 is present. This is the width of the active beach, which is defined as back of the dune system in Christchurch city and the back of the beach ridge at Kaitorete Spit.

5. Sea Level Rise Scenario Selection

This section discusses the range of SLR scenarios that were available for consideration within this study and identifies is considered to be most applicable for use within this district plan risk analysis framework.

SLR projections, both globally and locally, are developed according to the scenarios of greenhouse gas (GHG) emissions in the future, and associated global temperature change. Under the previous IPCC assessment report(AR5 2014)[16] , each scenario represents the assumptions of GHG concentrations in the atmosphere for different future timeframes.[17] These scenarios are called 'Representative Concentrations Pathways' (RCPs), ranging from RCP2.6 (the lowest concentrations scenario), to RCP8.5 (the highest concentration scenario). RCP4.5 and RCP6.0 are the two mid-range RCPs.[18] Each scenario is considered plausible to at least 2100, but they do not have probabilities attached to them, so quantifying an overall likelihood distribution for SLR to a future date next century (e.g.2120 or 2130) is not possible. There is increasing uncertainty all the projections with time.

Within New Zealand, RCPs 2.6, 4.5 and 8.5 were adopted in central government guidance[19] to develop SLR scenarios.[20] A fourth higher projection, RCP8.5H+, was added to the scenarios, presenting the 83rd percentile of the RCP8.5. The guidance notes:

> *this higher scenario reflects the possibility of future surprises towards the upper range in SLR projections of an RCP8.5 scenario, being representative of a situation where more rapid rates of SLR could occur early next century due to dynamic ice sheet processes and instability thresholds that were not fully quantified in the IPCC AR5 projections*[21]

The MfE Coastal Hazards Guidance notes that RCP8.5 H+

> *should be used to stress-test dynamic adaptive pathways, policies and new greenfield and major infrastructure developments.*[22]

The guidance suggests that under RCP8.5H+ scenario, local/district planning instruments should consider SLR projections over longer periods than 100 years, to avoid or mitigate adverse hazard impacts to coastal subdivisions, greenfield developments and major new infrastructure. To account for regional factors, New Zealand's SLR scenarios applied in the guidance are 5cm higher than the IPCC global projections and were extended in time through to 2150 to provide a longer view over 130 years.

In the most recent IPCC assessment report (AR6 2021)[23], the scenarios were reshaped to integrate different levels of emissions and climate change against multiple socio-economic development pathways. These are referred to as SSP's (Shared Socio-economic Pathways). There are five SSP scenario families which IPCC assess a medium confidence of occurring. The last two numbers of each scenario refer to radiative forcing by 2100 in the same way as the RCP scenarios. Hence SSP5-8.5 could be associated with RCP 8.5, SSP2-4.5 with RCP4.5, and SSP1-2.6 with RCP2.6. The additional scenario from the AR6 assessment is SSP1-1.9, which is a lower carbon emission than SSP1-2.6. In addition, RCP 6.0 was replaced with the SSP3-7.0 scenario. There are also two

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[16] AR5, 2014

[17] Including 2030, 2050, 2100, etc.

[18] (for more information about RCPs, please refer to Intergovernmental Panel on Climate Chane. 2014. Long-term Climate Change: Projections, Commitments and Irreversibility, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

[19] Coastal Hazards and Climate Change: Guidance for local governments, 2017, Ministry for the Environment, Wellington 6143, New Zealand, Publication number: ME 1341

[20] RCP6.0 was dropped as it was close to the RCP4.5 projection.

[21] MFE. (2017) op. cit.

[22] MFE. Op cit. p104

[23] Climate Change 2021 The Physical Science Basis. Working Group I contribution to the sixth Assessment Report of the Intergovernmental Panel on Climate Change

additional low confidence scenarios, indicating the potential effect of low likelihood, high impact ice sheet processes that cannot be ruled out. For SLR, all the SSP projections are slightly higher than the corresponding RCP projection (Figure 5.1).

NASA developed a sea level change tool[24] which provides regional projections from the IPCC SSP global scenarios. The regional projections for New Zealand are presented at eight port sites around the country, including Lyttelton Harbour. For all the New Zealand sites, the regional SSP projections are also slightly above the global projections, but by less than the standard 5 cm as per MfE guidance for the RCP projections.

5.1 Comparison of T+T SLR Increments to RCP/SSP levels

The T+T assessment used increments of SLR at three timeframes (2050, 2080, 2130) as presented in Table 4.4 and covering the range of New Zealand RCP projections (including RCP8.5H+). As per the recommendation in MfE Guidance additional higher SLR projection over a longer time frame (2150) is also included.

The comparison of the T+T increments to the upper and lower range of the RCP and SSP projections is presented in Figure 5.1. The SSP scenarios have slightly higher magnitudes of SLR than the corresponding RCP scenarios, the 83rd percentile SSP5-8.5 values are higher than the RCP8.5H+ values. As can also be seen, the range of T+T increments are still relevant under the SSP scenarios, appropriately covering the full range of the scenarios. However, what is required for land use planning is the selection of the most applicable scenario for a risk-based approach.

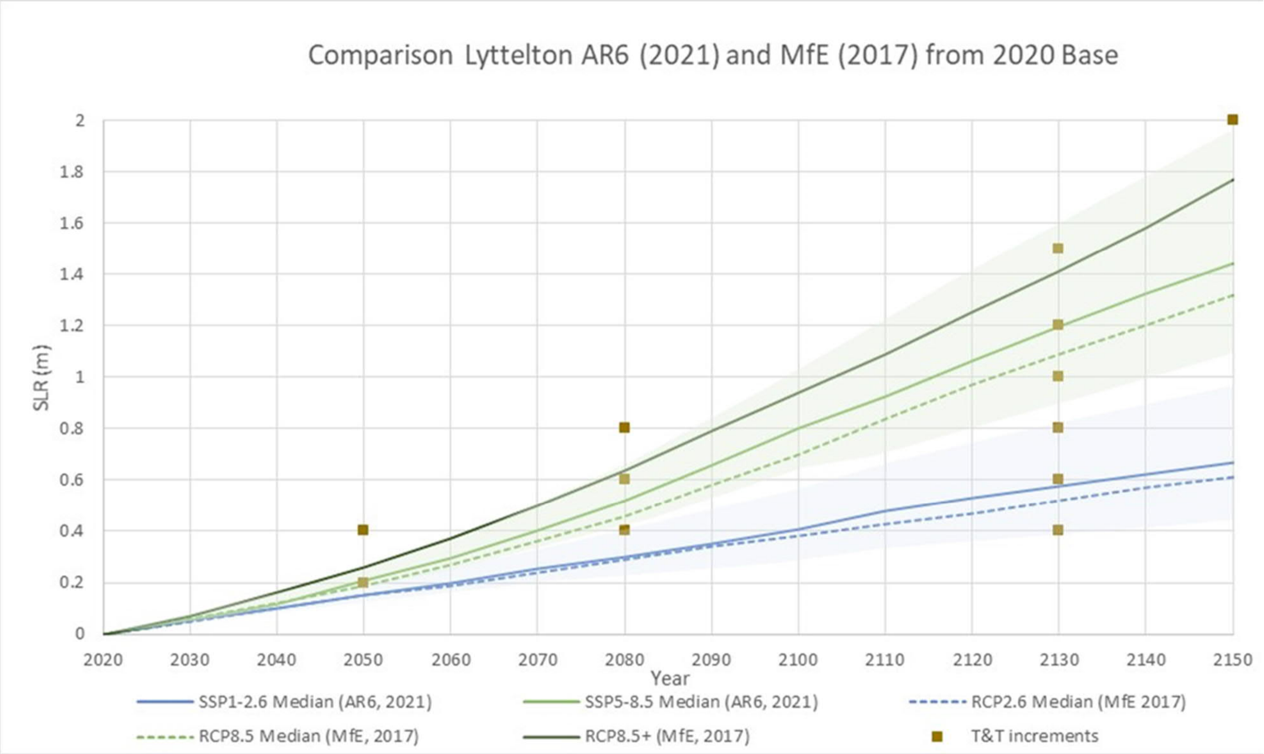

Figure 5.1: Comparison of T+T SLR increments to SSP and RCP scenarios. Note shaded areas represent the17th to 83rd Percentile of AR6 (2021) SSP1-2.6 (Blue) and SSP5-8.5 (Green) Projections.

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[24] https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

5.2 Selection of SLR Increments for Planning Purposes Within this Study

The selection of an SLR scenario for use in this report, is limited to the increments presented by T+T shown in Table 4.4. The following underlying principles were applied to select the most appropriate T+T SLR increments for use in land-use planning:

1) There needs to be consistency between the selected scenarios for both inundation and erosion planning.
2) The scenarios need to reflect both timeframe and SLR magnitude, as it is the rate of SLR that is important in determining future erosion.
3) The timeframe is important as need to ensure that any land use activities allowed under the rules in various hazard categories have sufficient and reasonable time (for erosion), or lack of frequency of hazard (for inundation) for that activity to be carried out in an appropriate manner without the need for hazard mitigation measures.
4) Timeframes are also important for defining the 'certainty' of the magnitude of SLR. While all scenario pathways have the same assumed likelihood of occurrence, there is much greater certainty in the lower projected magnitudes occurring over the shorter timeframes.

Applying a risk-based approach to select a SLR magnitude is shown schematically in Figure 5.2. The upper pane shows that for a specified planning timeframe, there is a generalised probability distribution of possible SLR magnitudes, peaking with a 'most likely' SLR value and a skewed-tail distribution influenced by a wider range of process responses to climate change. The lower pane shows that a generalised SLR risk profile can also be obtained by multiplying the likelihood of SLR distribution curve by the consequences curve. This simplified example demonstrates that, in most cases, the peak of the risk curve within the specified timeframe will typically occur at a SLR above the mid-range SLR value.

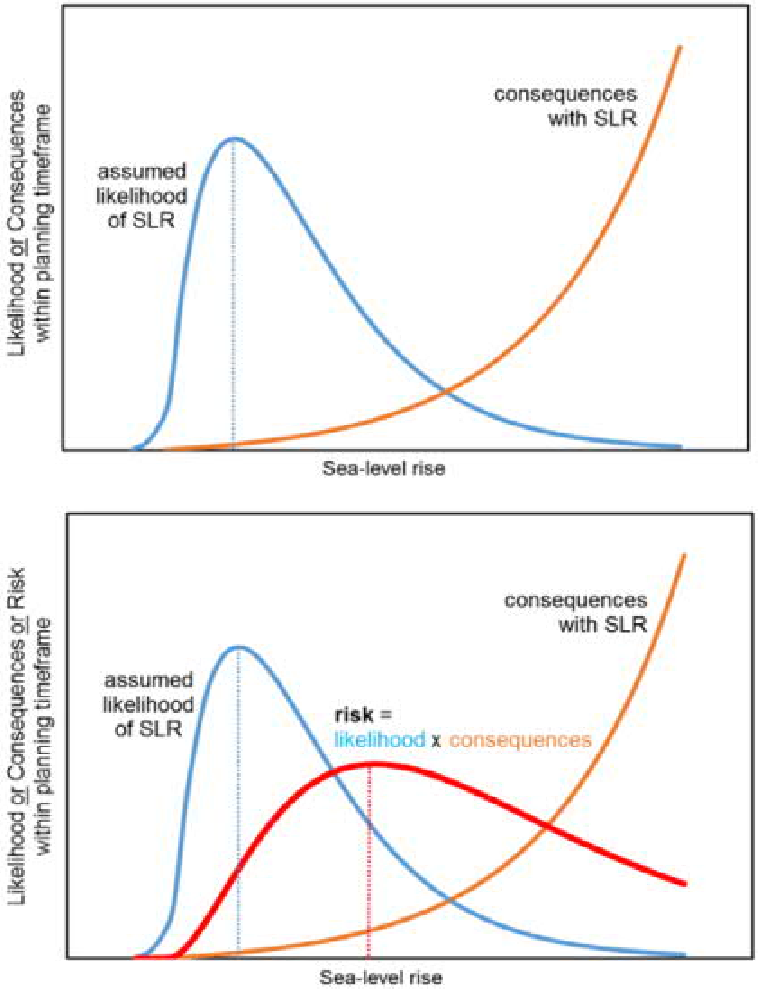

Figure 5.2: Generalised SLR probability and generic consequence curve (upper pane) resulting in the risk profile (lower pane). (From MfE, 2017).

Considering the above principles and discussion, it is recommended that the most appropriate T+T increments to use as SLR scenarios for a risk-based approach to land-use planning are:

- 0.6 m SLR by 2080, and
- 1.2 m SLR by 2130

As can be seen in Figure 5.1, both scenarios are located between the RCP 8.5 and 8.5H+ scenarios, and close or slightly above the SSP5-8.5 scenarios. The justifications for this recommendation include:

- Not taking the increments closest to lowest of the SSP-RCP scenarios is considered a precautionary approach to hazard planning, consistent with the principles of the RMA.
- Both scenarios are considered to be reasonable in terms of SSP-RCP scenarios, not taking the highest scenario (e.g RCP 8.5H+), but reflecting the slightly higher most recent SSP projections over the previous commonly used scenarios of planning (e.g. 1 m SLR in 100 years).and the recommends of the MfE (2017) coastal hazards guidance.

- Although it is recognised that globally there are likely to be more serious emission mitigation efforts in the future, both scenarios are not dependent on global political responses to reduce emissions.
- Both scenarios are unlikely to occur much before the specified time frame.
- We have a high degree of confidence that the lower magnitude of SLR (0.6 m) will occur at sometime within a reasonable planning timeframe, even if global emission reductions can be successfully implemented. From Figure 5.2., 0.6 m of SLR can be considered to be close to the likelihood peak of SLR over a 100 year timeframe.
- The use of a 60-year hazard time frame is not considered too conservative for restricting activities in high hazard area, while also being sufficient time for allowing other suitable activities with a degree of certainty around their occupancy and/or use,
- Although there is less certainly about the timing of the higher magnitude of SLR (1.2 m) and timing may be delayed beyond a beyond a reasonable planning timeframe if global emission reduction is successful, there is still a medium degree of confidence that this magnitude of rise will occur within the next 130 years. From Figure 5.2, this magnitude of SLR can be considered close to peak of risk of SLR over a 100-year timeframe and therefore some degree of planning controls is required for other activities that are most at risk.

The recommended scenarios are not available for the 48 deterministic erosion screening assessment cells for the bays and beaches of Banks Peninsula, Lyttleton and Akaroa Harbours. For these cells the scenario choices are limited to 0.4 m SLR by 2080, and 0.4 m or 1.5 m SLR by 2130. Being the upper and lower bounds of the scenario range these scenarios do not meet the above justifications or recommended scenarios. Therefore, it is recognised that the recommended scenarios would create an inconsistency in the hazard risk approach between the cells in Lyttelton and Akaroa Harbours where a probabilistic approach and those where a deterministic approach was taken. The effect of this different approach may be able to be negotiated using different thresholds for erosion risk categories in the different assessment cells and is considered further in Section 7.

In arriving at the above selections, we also considered several other SLR increments and timeframes from the T+T assessment in sensitivity testing with a range of thresholds to definite a risk-based approach to land use planning. Some of these increments are close to the RCP4.5 scenarios presented by MfE (2017), which in the absence of a NZ RCP6.0 scenario, are the next highest scenario to RCP8.5. The alternative increments considered included the following:

- 0.4 m SLR by 2050 – considered as a scenario for high erosion hazard areas. Discarded due to 30 year being considered too short a timeframe for land use activities having a certainty occupancy and/or use.
- 0.4 m SLR by 2080 (just above RCP4.5 scenario) – considered as it would allow consistency with the deterministic erosion assessment cells. Discarded due to high likelihood of being exceeded before 2080 therefore not providing the level of certainty in the protection to land-use afforded by the planning provisions.
- 0.8 m SLR by 2130 (approximately halfway between RCP 4.5 and RCP8.5) – considered as an alternative to a 1.2 SLR over the same period. Discarded due to high likelihood of being exceeded before 2130 therefore not providing the level of certainty in the protection to land-use afforded by the planning provisions.
- 1.0 m SLR by 2130 - considered as an alternative to a 1.2 SLR over the same period. Discarded as does not allow for recent increase in projections in IPCC AR6(2021), therefore could be considered to not reflect the most recently available science.
- 1.5 m SLR by 2130 – considered as would allow consistency with the deterministic erosion assessment cells. Discarded as being too conservative to be considered reasonable as is above the RCP 8.5+ magnitude but is suitable for use as an upper stress test for low erosion hazard categories.

- 2.0 m SLR y 2150 - as an upper stress test for low erosion hazard categories. Discarded as being too conservative and too uncertain that will occur even within this 130-year timeframe.

6. Coastal Inundation Hazard Thresholds

This section sets out our approach to developing appropriate thresholds for defining inundation hazards. Four flood risk categories are proposed: very low, low, medium and high. An overall summary of this recommended approach is provided in Section 6.1 followed by a discussion of the reasoning behind this recommendation and consideration of other thresholds and scenarios in Sections 6.3 to 6.5.

6.1 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 termed effects and outcomes based 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

i. are consistent with the RMA requirements to consider only risks which are “reasonably foreseeable” and “significant” in effect

ii. can be applied to the ‘bathtub’ outputs of the 2021 Coastal Hazard Assessment for Christchurch District (“the CHA”).

This approach takes 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 6.1. Four categories of flood risk defined by thresholds of water depth are proposed.

Table 6.1: Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 1% 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 < 0.5m)
Low	Low	(d < 0.5m)	Medium	(0.5m < d < 1.1m)
Medium	Medium	(0.5m < d < 1.1m)	High	(d > 1.1m)
High	High	(d > 1.1m)	High	(d > 1.7m)

The definitions in Table 6.1 were applied to the CHA inundation depth data to produce a map showing the four coastal flood risk areas for the entire district. Figure 6.1 below shows an example extract of the map in the area around the Avon-Heathcote estuary. Full inundation mapping outputs are available in the project webviewer.

Sections 6.2 to 6.5 discuss inundation factors and coastal inundation processes then describe and compare the flood mapping methods considered and present the basis for our recommended method in more detail. We also compare example results to the current District Plan and CCC flood layers.

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. We illustrate the difference between flood mapping using the CHA bathtub results and mapping using hydrodynamic model results.

In some locations there are gaps in the CHA data meaning the flood risk cannot be fully mapped using the available data. In Section 6.5 we discuss the implications of the limitations in the bathtub method, data uncertainties, application of freeboard and thresholds for ‘nuisance flooding’.

All maps produced for this assessment are available in a webviewer accessible to the project team. Maps of the preferred approach has been provided to CCC as a spatial layer.

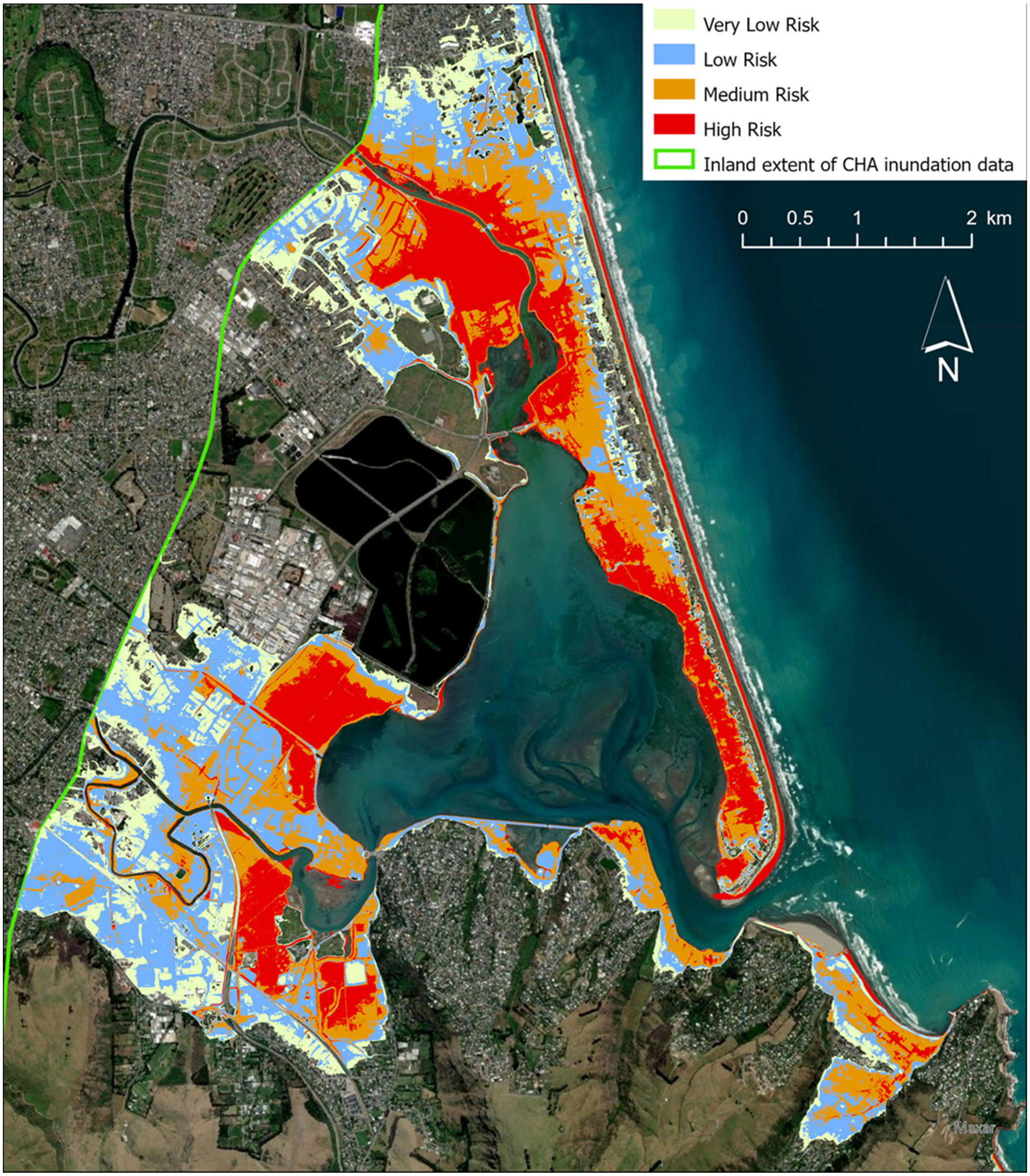

Figure 6.1: Coastal flood risk categories mapped using the CHA inundation data and recommended definitions of flood risk (example extract of mapping for the district)

6.2 Estimating the Extent and Depth of Coastal Inundation

Coastal inundation is usually understood to mean flooding from the sea caused by a ‘storm tide’. Storm tide is a combination of the astronomical high tide and ‘storm surge’ – the temporary rise in mean sea level during a storm caused by low atmospheric pressure, wind, and wave setup. The level of storm tides will increase in the future as the mean sea level rises in response to climate change.

A weather event that causes a storm tide can also result in heavy rainfall and high flow in rivers at the coast and coastal inundation is often a combination of flooding from different sources, arising from the same weather event. In any particular event, the individual probabilities of storm tide level and rainfall or river flow usually differ from each other and multiple combinations are possible for the same combined probability of occurrence. For example, the combined probability of a 1% AEP storm tide and 10% AEP river flow occurring together, or a 10% AEP storm tide and 1% AEP river flow occurring together may be 1% AEP in both cases. However, the maximum flood levels in each combination of events may be different. Nearer the coast, events with smaller probability storm tides are likely to result in higher flood levels. Further inland, flooding from events with a smaller probability fluvial flow is likely to be worse. Figure 6.2 illustrates conceptually how these sources of flooding usually combine in a coastal area for a given likelihood of occurrence.

To take account of combined sources of flooding, multiple combinations of storm tide and fluvial flow need to be considered so that a maximum “envelope” of flood extent can be produced. The relationship between the probability of storm tide and the probability of fluvial flow varies with location and depends on the correlation between the two conditions during a weather event. For example, the Flood Management Area in the current Christchurch District Plan is mapped as the maximum envelope of the 0.5% AEP storm tide combined with 5% AEP fluvial flow and the 5% AEP storm tide combined with 0.5% AEP fluvial flow.

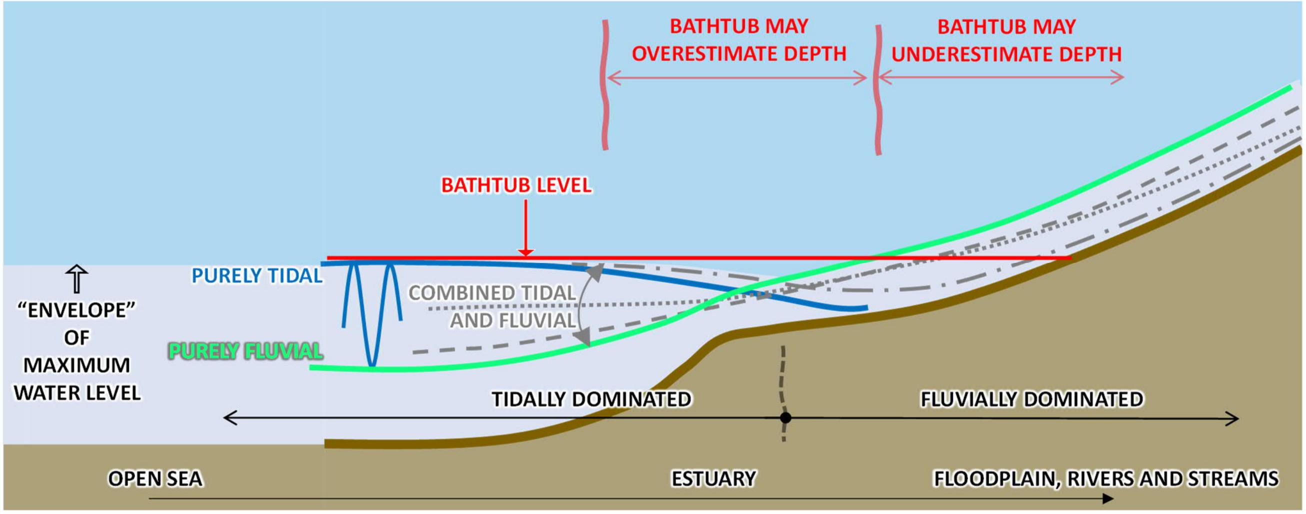

Figure 6.2: Conceptual cross-section of a coastal area comparing maximum flood levels for purely tidal events, purely fluvial events and a range of combined events, all of the same likelihoods of occurring. The bathtub level of maximum storm tide is shown for comparison.

Figure 6.2 also shows how the bathtub method compares to an envelope of maximum flood level derived from a range of combined events. In the bathtub method the storm tide level is projected across the entire coastal area to estimate the inundation depths. In the tidally dominated area, the flood level may fall inland, below the storm tide level, as water spreads out over the floodplain and up estuaries. The bathtub method tends to overestimate the flood level and depth in this area. Further inland, flood levels may be higher than the storm tide level due to the additional contribution to flooding from fluvial flow or rainfall and the bathtub method may underestimate the flood level and depth.

The coastal inundation processes and the interaction of the different sources of flooding during a storm event are naturally dynamic and accurate mapping of flood extents and depths usually requires hydrodynamic modelling of multiple combinations of events. However, the tendency of the storm tide to dominate flood level in areas closest to the coastline means that the difference between a simple bathtub approach and hydrodynamic modelling can be relatively small. In these areas the bathtub method also tends to be conservative and overestimates flood depth. In this way the method can be considered appropriate as a precautionary approach to defining flood risk for the purpose of land use planning at a district level. More detailed investigation of flooding may be appropriate for assessing individual developments or activities.

The uncertainty in flood depths using the bathtub method with a storm tide level generally increases the further inland it is applied. This is because in reality the storm tide level usually becomes increasingly attenuated as it travels inland due to frictional resistance and storage in the floodplain and river channels (although in some estuaries the tide level can increase due to "funnelling" of flow). Flooding from fluvial and pluvial events also starts to become more important than the tidal event of the same probability and these sources of flooding cannot be readily included in the bathtub method. The increase in uncertainty means there is a limit to how far inland the bathtub method is appropriate for planning purposes.

Figure 6.3 shows the difference between flood depths produced from a hydrodynamic model simulation of a storm tide event in the Avon-Heathcote estuary (Tonkin & Taylor, 2017: TUFLOW model simulation of 1% AEP storm tide and SLR to 2115, RCP8.5H+) and a bathtub projection of the peak storm tide level (inferred to be approximately 3.2m LVD37 inside the estuary mouth). The model simulation is for a purely tidal event, without any contribution from fluvial flow or rainfall. The map shows that inland from the main estuary the difference in depth between the two methods is generally negative in value i.e., the model depths are smaller than the bathtub depths– and the difference increases inland.

Figure 6.3 also shows the inland limit of the bathtub depth data produced for the CHA. The difference in depth at the bathtub data limit is around 0.3m, i.e., the bathtub depth is 0.3m greater than the hydrodynamic model for the same storm tide level at the mouth of the estuary, providing an indication of the likely range of uncertainty in the CHA inundation depth data for purely tidal events.

Since this dataset tends to be conservative within the area of coverage defined in the CHA, we consider it unnecessary to include an additional allowance for uncertainty in the depth data for mapping the inundation area or defining flood risk. However, in areas of higher flood risk, mitigation measures such as minimum floor level requirements should include an appropriate freeboard allowance above estimated flood level. More detailed assessment of flood level, including consideration of flooding from other sources, may be warranted for individual properties or developments to determine floor levels or other planning requirements.

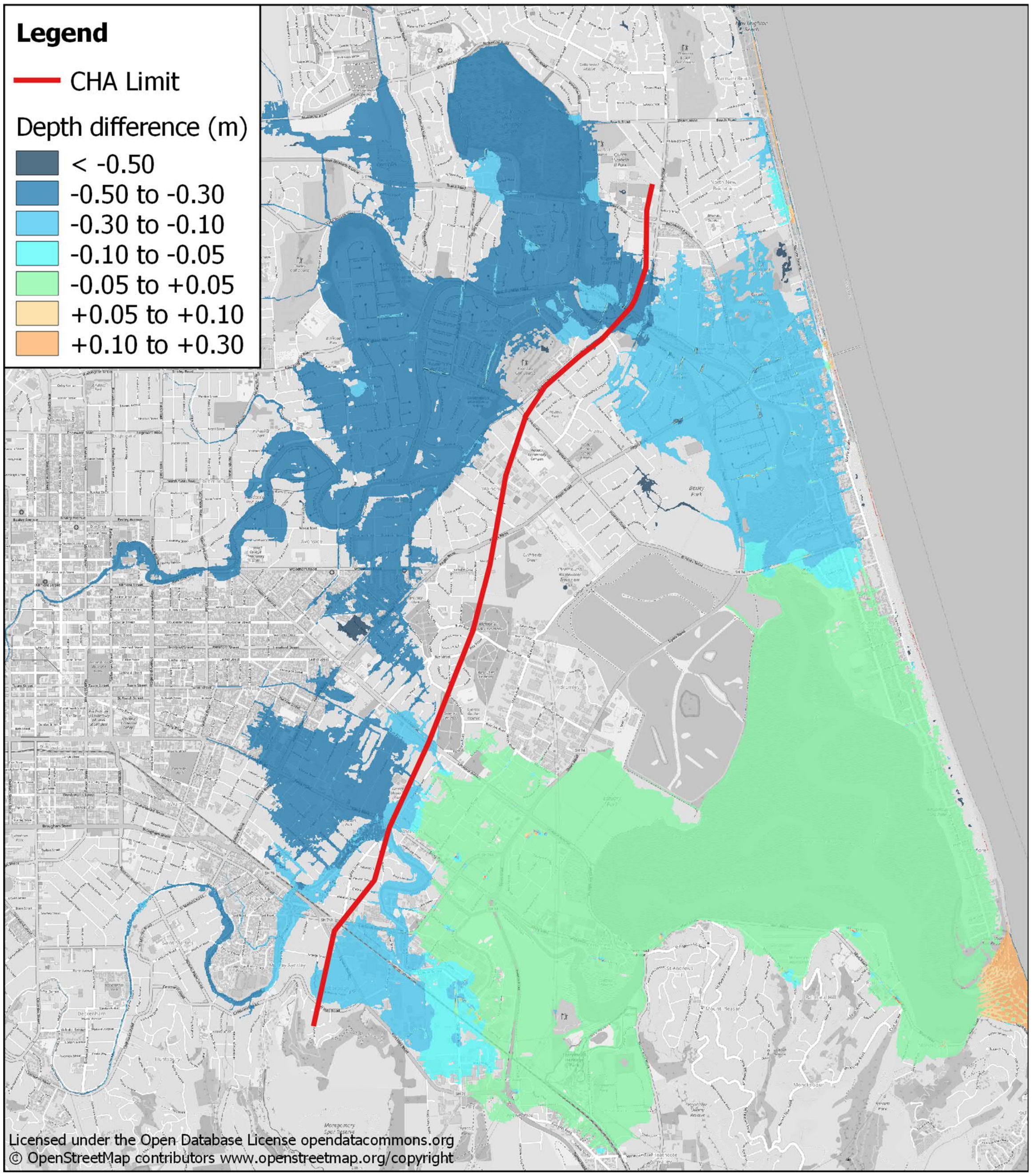

Figure 6.3: Map showing the difference between storm tide flood depths derived from a hydrodynamic model simulation and from a bathtub projection of the storm tide level (~3.2m LVD37). The difference is positive where the model depths are larger than the bathtub depths and vice versa. The maps also the limit of application of the bathtub method in the CHA.

6.3 Inundation Factors

6.3.1 Likelihood of Flooding

The likelihood of a given magnitude of flooding (water level or depth, for example) is usually measured by the Average Recurrence Interval (ARI) – how often, on average it occurs – or the Annual Exceedance Probability (AEP) – the chance it will happen in any one year.

The chance a given magnitude event will occur increases with the length of time considered, as summarised in Table 6.2.

Table 6.2: Likelihood of flooding over varying time periods

Flood magnitude	ARI	AEP	Chance an event will occur during a period of		
			30 years	60 years	100 years
"Small"	5 years	20%	100%	100%	100%
↓	10 years	10%	96%	100%	100%
↓	20 years	5%	79%	95%	99%
↓	50 years	2%	45%	70%	87%
↓	100 years	1%	26%	45%	63%
"Large"	200 years	0.5%	14%	26%	39%

The chance that a low probability event (such as the 1% or 0.5% AEP) will occur becomes relatively likely (a 40% to 50% chance) when considering a time period of 60 to 100 years. With reference to the requirements of Section 5 of the RMA, this chance of occurrence is considered to be consistent with being "reasonably foreseeable" and supports adopting a relatively low probability to define areas at risk of flooding. The smallest probability for which inundation data is provided in the CHA is the 1% AEP, which is considered a reasonably foreseeable event over the lifetime of a development.

Inundation mapping for planning and development control is often based on one or more likelihoods or probability of flooding. The Christchurch District Plan defines the Flood Management Area as the 0.5% AEP flood extent and the High Flood Hazard Management Area through the 0.2% AEP flood extent (with the inclusion of a water depth and velocity criterion). The Canterbury RPS defines areas subject to inundation as lying within the 0.5% AEP flood extent. By comparison, the UK Environment Agency's Flood Map for Planning (Rivers and Sea) defines four Flood Zones according to three likelihoods of flooding (from any source or combination of sources) as shown in Figure 6.4.[25]

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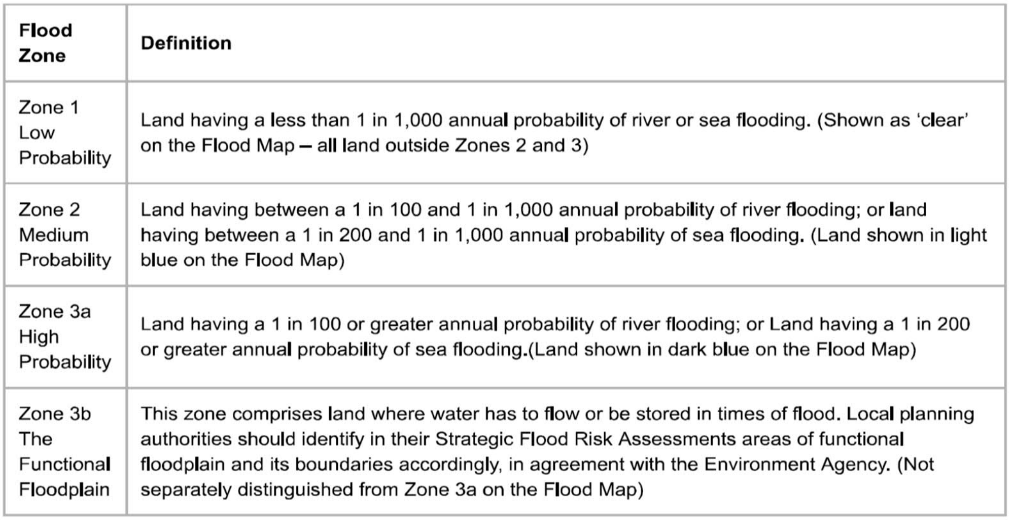
[25] Table 1 of Guidance - Flood risk and coastal change, Ministry of Housing, Communities & Local Government, www.gov.uk/guidance/flood-risk-and-coastal-change#flood-zone-and-flood-risk-tables



Flood Zone	Definition
Zone 1 Low Probability	Land having a less than 1 in 1,000 annual probability of river or sea flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding; or land having between a 1 in 200 and 1 in 1,000 annual probability of sea flooding. (Land shown in light blue on the Flood Map)
Zone 3a High Probability	Land having a 1 in 100 or greater annual probability of river flooding; or Land having a 1 in 200 or greater annual probability of sea flooding.(Land shown in dark blue on the Flood Map)
Zone 3b The Functional Floodplain	This zone comprises land where water has to flow or be stored in times of flood. Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and its boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)

Figure 6.4: Definition of Flood Zones in the UK Flood Map for Planning (Rivers and Sea)

6.3.2 Consequence of flooding

The consequence of flooding can be quantified in terms of financial costs for example, damages to property and assets, loss of possessions, disruption to services. This requires a detailed assessment of the value of properties and assets and calculation of damages for a range of flood probabilities and is usually applied to assessing protection of existing development rather than planning new development.

For planning purposes, the consequence is more usually quantified in terms of the 'flood hazard', a measure of the severity of the danger to people and vehicles and of damage to or failure of buildings during a flood. Methods for evaluating flood hazard, based on scientific research which includes full scale laboratory testing, are provided in Australian[26] ("the AR&R method") and UK[27] ("the DEFRA method") guidelines amongst others.

In these methods, flood hazard is generally defined as a function of the depth and velocity of the flood water. Additional factors such as the effects of debris in flood water are included in some methods. Figure 6.5 and Figure 6.6 show respectively the Combined Hazard Vulnerability Curves of the AR&R method and the Hazard to People Classification of the DEFRA method.

In the flood hazard curves in Figure 6.5, the thresholds for hazard to people are lower than for buildings, and the thresholds for hazard to vehicles are lower than for people. For lower velocities, less than 0.5 m/s, the hazard thresholds are independent of velocity and defined by water depth only. The hazard ratings in Figure 6.6 also depend on velocity for velocities below between 2.5 and 4.0 m/s, depending on water depth.

The CHA bathtub method does not determine velocity and so this data is not available for assessing hazard. From our experience of coastal inundation modelling using hydrodynamic models, for example in assessing coastal inundation hazards for Waimakariri District Council, velocities in floodplain areas are usually relatively low – below the 0.5 m/s value for inclusion in hazard definition in the AR&R method (Figure 6.5), for example. For these reasons we consider it appropriate to categorise flood hazard solely on depth and to use the "still water" depth thresholds from hazard guidelines to categorise flood hazard from the CHA bathtub depth data. We also note that the contribution of velocity to hazard was considered during the Christchurch Replacement District Plan

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[26] Australian Rainfall and Runoff: A Guide to Flood Estimation, Book 6, Chapter 7 (Smith and Cox, 2019)

[27] Framework and Guidance for Assessing and Managing Flood Risk for New Development, UK Defra/Environment Agency Flood and Coastal Defence R&D Programme FD2320/TR22

review process[28] in relation to the definition of the High Flood Hazard Management Area. This area was found to be largely defined by the water depth criterion rather than the combined depth and velocity criterion since, away from the main river channels, velocity was generally low.

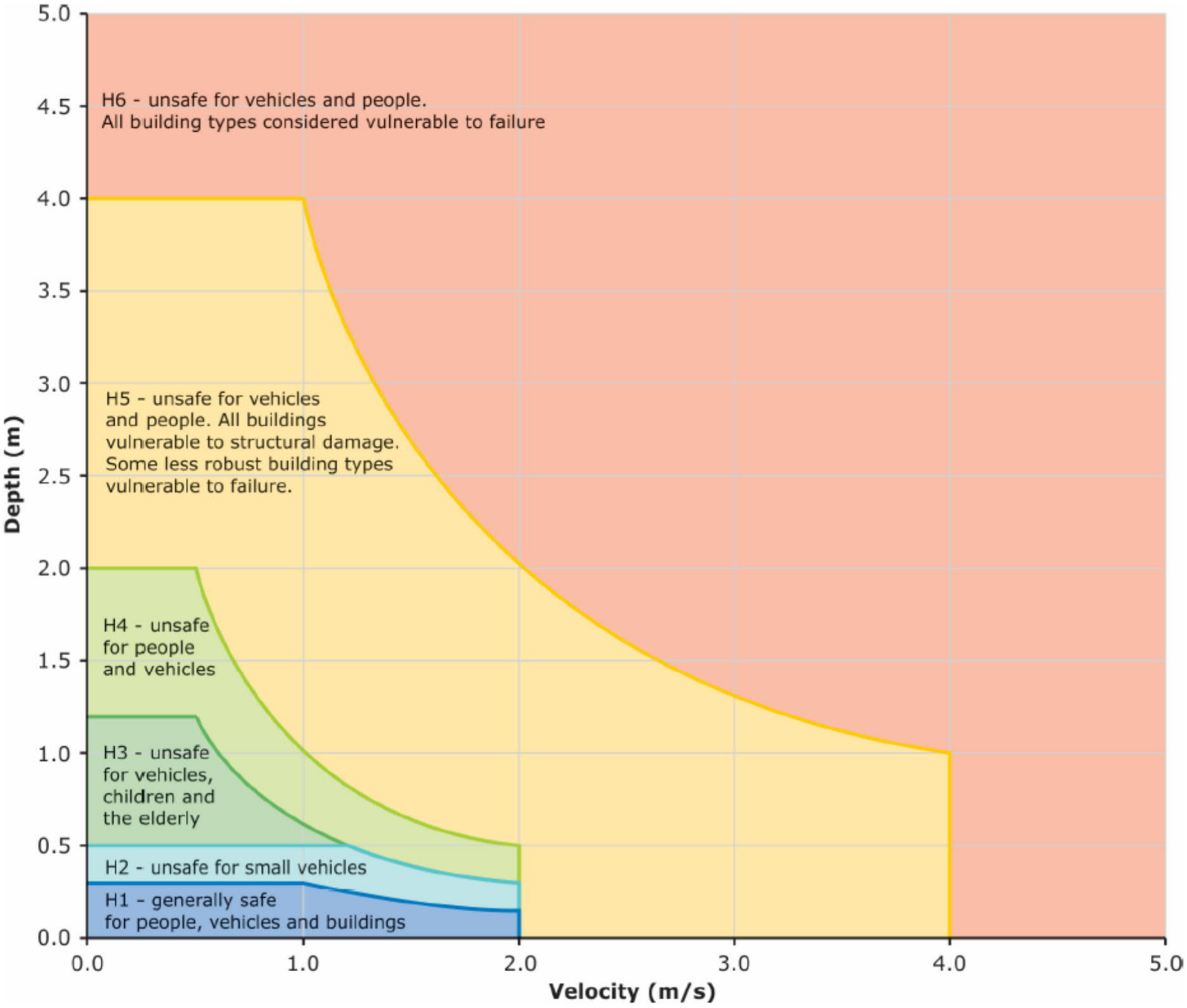

Figure 6.5: Combined flood hazard curves (Figure 6.7.9 of Australian Rainfall and Runoff: A Guide to Flood Estimation, Book 6, Chapter 7)

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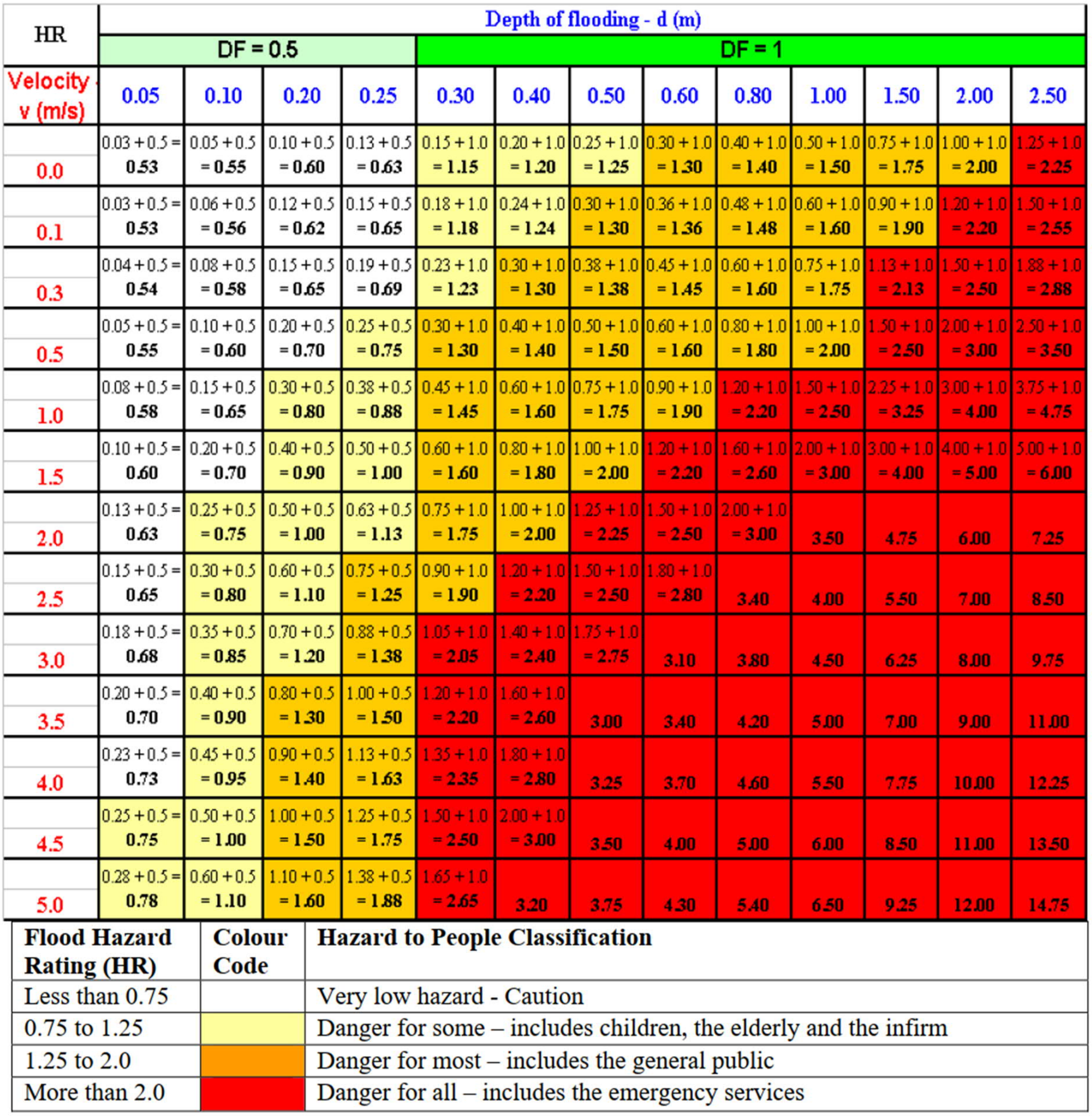
[28] Independent Hearings Panel, Christchurch Replacement District Plan, Decision 53, Chapter 5: Natural Hazards – Stage 3, 2016



HR	Depth of flooding - d (m)												
	DF = 0.5				DF = 1								
Velocity v (m/s)	0.05	0.10	0.20	0.25	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	2.50
0.0	0.03 + 0.5 = 0.53	0.05 + 0.5 = 0.55	0.10 + 0.5 = 0.60	0.13 + 0.5 = 0.63	0.15 + 1.0 = 1.15	0.20 + 1.0 = 1.20	0.25 + 1.0 = 1.25	0.30 + 1.0 = 1.30	0.40 + 1.0 = 1.40	0.50 + 1.0 = 1.50	0.75 + 1.0 = 1.75	1.00 + 1.0 = 2.00	1.25 + 1.0 = 2.25
0.1	0.03 + 0.5 = 0.53	0.06 + 0.5 = 0.56	0.12 + 0.5 = 0.62	0.15 + 0.5 = 0.65	0.18 + 1.0 = 1.18	0.24 + 1.0 = 1.24	0.30 + 1.0 = 1.30	0.36 + 1.0 = 1.36	0.48 + 1.0 = 1.48	0.60 + 1.0 = 1.60	0.90 + 1.0 = 1.90	1.20 + 1.0 = 2.20	1.50 + 1.0 = 2.55
0.3	0.04 + 0.5 = 0.54	0.08 + 0.5 = 0.58	0.15 + 0.5 = 0.65	0.19 + 0.5 = 0.69	0.23 + 1.0 = 1.23	0.30 + 1.0 = 1.30	0.38 + 1.0 = 1.38	0.45 + 1.0 = 1.45	0.60 + 1.0 = 1.60	0.75 + 1.0 = 1.75	1.13 + 1.0 = 2.13	1.50 + 1.0 = 2.50	1.88 + 1.0 = 2.88
0.5	0.05 + 0.5 = 0.55	0.10 + 0.5 = 0.60	0.20 + 0.5 = 0.70	0.25 + 0.5 = 0.75	0.30 + 1.0 = 1.30	0.40 + 1.0 = 1.40	0.50 + 1.0 = 1.50	0.60 + 1.0 = 1.60	0.80 + 1.0 = 1.80	1.00 + 1.0 = 2.00	1.50 + 1.0 = 2.50	2.00 + 1.0 = 3.00	2.50 + 1.0 = 3.50
1.0	0.08 + 0.5 = 0.58	0.15 + 0.5 = 0.65	0.30 + 0.5 = 0.80	0.38 + 0.5 = 0.88	0.45 + 1.0 = 1.45	0.60 + 1.0 = 1.60	0.75 + 1.0 = 1.75	0.90 + 1.0 = 1.90	1.20 + 1.0 = 2.20	1.50 + 1.0 = 2.50	2.25 + 1.0 = 3.25	3.00 + 1.0 = 4.00	3.75 + 1.0 = 4.75
1.5	0.10 + 0.5 = 0.60	0.20 + 0.5 = 0.70	0.40 + 0.5 = 0.90	0.50 + 0.5 = 1.00	0.60 + 1.0 = 1.60	0.80 + 1.0 = 1.80	1.00 + 1.0 = 2.00	1.20 + 1.0 = 2.20	1.60 + 1.0 = 2.60	2.00 + 1.0 = 3.00	3.00 + 1.0 = 4.00	4.00 + 1.0 = 5.00	5.00 + 1.0 = 6.00
2.0	0.13 + 0.5 = 0.63	0.25 + 0.5 = 0.75	0.50 + 0.5 = 1.00	0.63 + 0.5 = 1.13	0.75 + 1.0 = 1.75	1.00 + 1.0 = 2.00	1.25 + 1.0 = 2.25	1.50 + 1.0 = 2.50	2.00 + 1.0 = 3.00	3.50	4.75	6.00	7.25
2.5	0.15 + 0.5 = 0.65	0.30 + 0.5 = 0.80	0.60 + 0.5 = 1.10	0.75 + 0.5 = 1.25	0.90 + 1.0 = 1.90	1.20 + 1.0 = 2.20	1.50 + 1.0 = 2.50	1.80 + 1.0 = 2.80	3.40	4.00	5.50	7.00	8.50
3.0	0.18 + 0.5 = 0.68	0.35 + 0.5 = 0.85	0.70 + 0.5 = 1.20	0.88 + 0.5 = 1.38	1.05 + 1.0 = 2.05	1.40 + 1.0 = 2.40	1.75 + 1.0 = 2.75	3.10	3.80	4.50	6.25	8.00	9.75
3.5	0.20 + 0.5 = 0.70	0.40 + 0.5 = 0.90	0.80 + 0.5 = 1.30	1.00 + 0.5 = 1.50	1.20 + 1.0 = 2.20	1.60 + 1.0 = 2.60	3.00	3.40	4.20	5.00	7.00	9.00	11.00
4.0	0.23 + 0.5 = 0.73	0.45 + 0.5 = 0.95	0.90 + 0.5 = 1.40	1.13 + 0.5 = 1.63	1.35 + 1.0 = 2.35	1.80 + 1.0 = 2.80	3.25	3.70	4.60	5.50	7.75	10.00	12.25
4.5	0.25 + 0.5 = 0.75	0.50 + 0.5 = 1.00	1.00 + 0.5 = 1.50	1.25 + 0.5 = 1.75	1.50 + 1.0 = 2.50	2.00 + 1.0 = 3.00	3.50	4.00	5.00	6.00	8.50	11.00	13.50
5.0	0.28 + 0.5 = 0.78	0.60 + 0.5 = 1.10	1.10 + 0.5 = 1.60	1.38 + 0.5 = 1.88	1.65 + 1.0 = 2.65	3.20	3.75	4.30	5.40	6.50	9.25	12.00	14.75

Flood Hazard Rating (HR)	**Colour Code**	**Hazard to People Classification**
Less than 0.75		Very low hazard - Caution
0.75 to 1.25	🟨	Danger for some – includes children, the elderly and the infirm
1.25 to 2.0	🟧	Danger for most – includes the general public
More than 2.0	🟥	Danger for all – includes the emergency services

Figure 6.6: Hazard to People Classification using Hazard Rating (Table 13.1 from Framework and Guidance for Assessing and Managing Flood Risk for New Development, UK Defra/Environment Agency Flood and Coastal Defence R&D Programme FD2320/TR22– Extended version) – Hazard Rating (HR) = d x (v+0.5) + DF (d is water depth, v is velocity and DF is the Debris Factor)

The DEFRA method specifically considers the hazards to people while the AR&R method considers hazards to people, vehicles, and buildings. However, the lower flood depth thresholds in the AR&R method reflect hazard to people rather than hazard to buildings. The District Plan primarily controls the development of buildings and infrastructure, for which the depth of water for a given severity of hazard is higher than that for people. Although buildings and other infrastructure can be designed and constructed to perform safely in areas of relatively deep flooding, most development will be occupied or used by people who will need to access or egress buildings during a flood. The depth thresholds for the same category of hazard are lower for people than for buildings. We therefore consider it appropriate, and consistent with the requirements of Section 6(h) of the RMA to consider “significant risks”, to define flood hazard depth thresholds based on hazards to people, considering the AR&R and DEFRA thresholds.

6.3.3 Change in Likelihood and Consequences in the Future

The likelihood and consequences of coastal inundation in the district will increase in the future due to sea level rise resulting from climate change, which will increase storm tide levels. Figure 6.7 shows how the frequency of the present day 100-year and 10-year storm tides in the Avon-Heathcote estuary, as defined in the CHA, will increase in the future based on MfE (2017) projections of sea level rise for the RCP8.5H+ scenario.

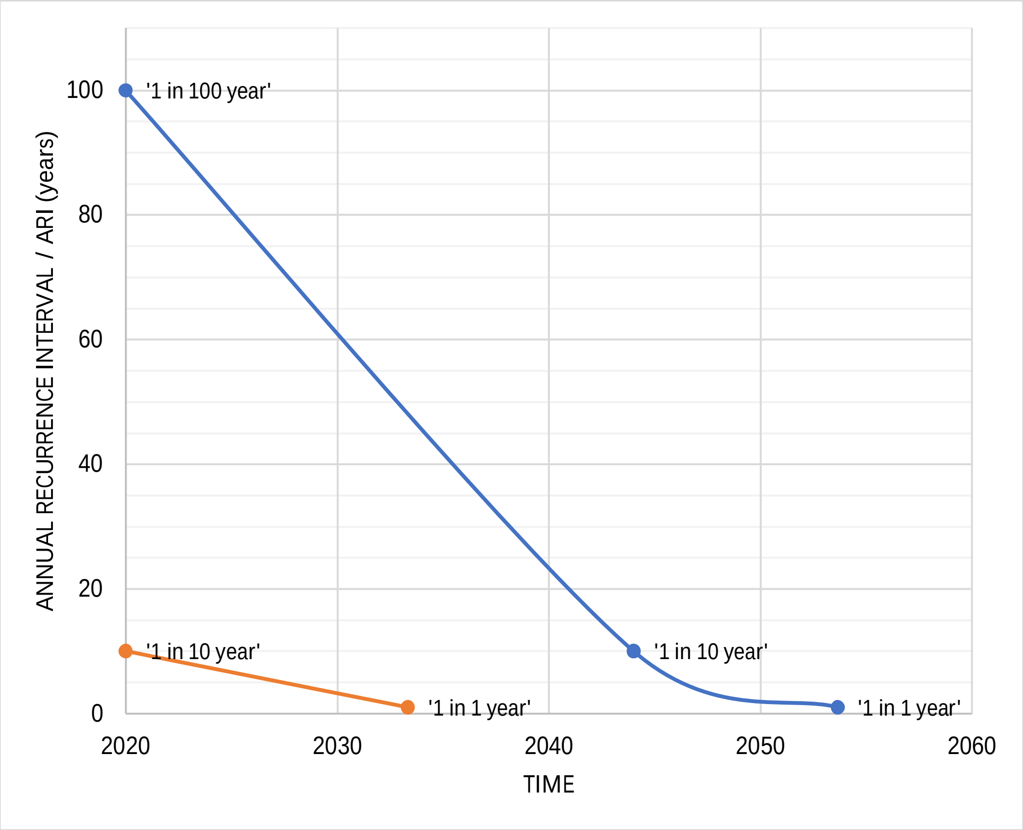


Figure 6.7: Change in Annual Recurrence Interval of present-day 100-year and 10-year ARI storm tides in the Avon-Heathcote estuary (RCP8.5H+ scenario of MfE 2017)

Land use planning should take account of reasonably foreseeable amounts of SLR in considering coastal inundation hazard. Figure 6.7 shows that based on current projections, the frequency of present-day extreme tides will increase rapidly over the next 20 to 40 years. The effect of SLR on inundation can be included by mapping inundation for representative scenarios of SLR values combined with the present-day storm tide level. We have selected SLR values of 0.6m and 1.2m as “lower” and “higher” SLR scenarios for inundation mapping as set out in Section 5 of this report.

The lower value SLR scenario is more likely to occur within the planning timeframe (it will occur sooner) than the higher value. There is less confidence in the timing of the higher value SLR scenario (it will occur later) but it can reasonably be expected to occur at some point in the future.

6.4 Mapping Methods

6.4.1 Methods

Two main methods for categorising and mapping coastal inundation for the district have been assessed as summarised below.

Method 1: Inundation categorised according to the likelihood or frequency of flooding, regardless of the depth of flood water. In this method we have used the CHA bathtub flood extent for the 10-year ARI and 100-year ARI (10% and 1% AEP) flood events as thresholds to define three inundation categories. Although the 1-year ARI (63% AEP) flood extent is also available from the T+T bathtub assessment, these areas are generally well known to be regularly inundated and there is little need for additional planning controls.

Method 2: Inundation categorised by hazard severity, defined by the maximum depth of flood water during a low frequency event. In this method we have used the CHA bathtub water depths for the 100-year ARI (1% AEP) storm tide event – the smallest probability considered in the CHA – to categorize flood hazard. Two different hazard classification systems were also tested:

> Method 2a: Water depth bands based on the AR&R method (Combined Hazard Vulnerability Curves of “Australian Rainfall and Runoff: A Guide to Flood Estimation”, Book 6).
>
> Method 2b: Water depth thresholds based on the DEFRA method (Hazard to People Classification of “Framework and Guidance for Assessing and Managing Flood Risk for New Development”, UK DEFRA R&D Technical Report FD2320/TR2).

Both the classification systems consider flood water velocity as a factor in categorising hazard. Since the bathtub method does not determine velocity, we have categorised hazard using the “still water” depth criteria, or zero velocity.

For both methods, we have produced separate maps for each of the two representative values of SLR selected – a lower value scenario of 0.6m and a higher value scenario of 1.2m – for mapping coastal inundation. Table 6.3 to Table 6.5 summarise the definitions of the inundation categories and SLR scenarios for each method.

Table 6.3: Definition of categories and scenarios for coastal inundation - Method 1 (likelihood)

Scenario		Probability of flooding	Rating	Likelihood description	Overall likelihood category
SLR	Timescale				
0.6 m	Likely to occur soon	Less than 1% AEP	Low	Less likely to flood (<39% chance over 50 years)	Low in the near future
		Between 1% AEP and 10% AEP	Medium	Likely to flood (39% to 99% chance over 50 years)	Medium in the near future
		10% AEP or greater	High	Very likely to flood (more than 99% chance over 50 years)	High in the near future
1.2m	Unlikely to occur soon, likely to occur later	Less than 1% AEP	Low	Less likely to flood (<39% chance over 50 years)	Low further in the future
		Between 1% AEP and 10% AEP	Medium	Likely to flood (39% to 99% chance over 50 years)	Medium further in the future
		10% AEP or greater	High	Very likely to flood (more than 99% chance over 50 years)	High further in the future

Table 6.4: Definition of categories and scenarios for coastal inundation - Method 2a (hazard/flood depth)

Scenario		"Bathtub" water depth (1% AEP)	Rating	Hazard description	Overall hazard Category
SLR	Timescale				
0.6 m	Likely to occur soon	0 m to 0.5 m	Low	Generally safe for people	Low in the near future
		0.5 m to 1.2 m	Medium	Unsafe for children and the elderly and for vehicles	Medium in the near future
		Over 1.2 m	High	Unsafe for people and vehicles	High in the near future
1.2m	Unlikely to occur soon, likely to occur later	0 m to 0.5 m	Low	Safe for people	Low further in the future
		0.5 m to 1.2 m	Medium	Unsafe for children and the elderly and for vehicles	Medium further in the future
		Over 1.2 m	High	Unsafe for people and vehicles	High further in the future

Table 6.5: Definition of categories and scenarios for coastal inundation - Method 2a (hazard/flood depth)

Scenario		"Bathtub" water depth (1% AEP)	Rating	Hazard description	Overall hazard Category
SLR	Timescale				
0.6 m	Likely to occur soon	0 m to 0.3 m	Low	Very low hazard	Low in the near future
		0.3 m to 0.5 m	Medium	Danger for some (children, elderly, infirm)	Medium in the near future
		Over 0.5 m	High	Danger for most (general public)	High in the near future
1.2m	Unlikely to occur soon, likely to occur later	0 m to 0.3 m	Low	Very low hazard	Low further in the future
		0.3 m to 0.5 m	Medium	Danger for some (children, elderly, infirm)	Medium further in the future
		Over 0.5 m	High	Danger for most (generalpublic)	High further in the future

6.4.2 Results

The overall inundation extent for the district, categorised by likelihood of inundation (Method 1) is presented in Figure 6.8.

The mapping shows that over most of Banks Peninsula the extent of inundation is generally small and the additional area inundated in the "medium" likelihood category is very small. This is because the ground level generally rises rapidly from the coastlines and the areas of lower ground are bounded by steeper slopes. The largest area of inundation is in the coastal plain between the mouth of the Avon-Heathcote estuary and the Waimakariri River.

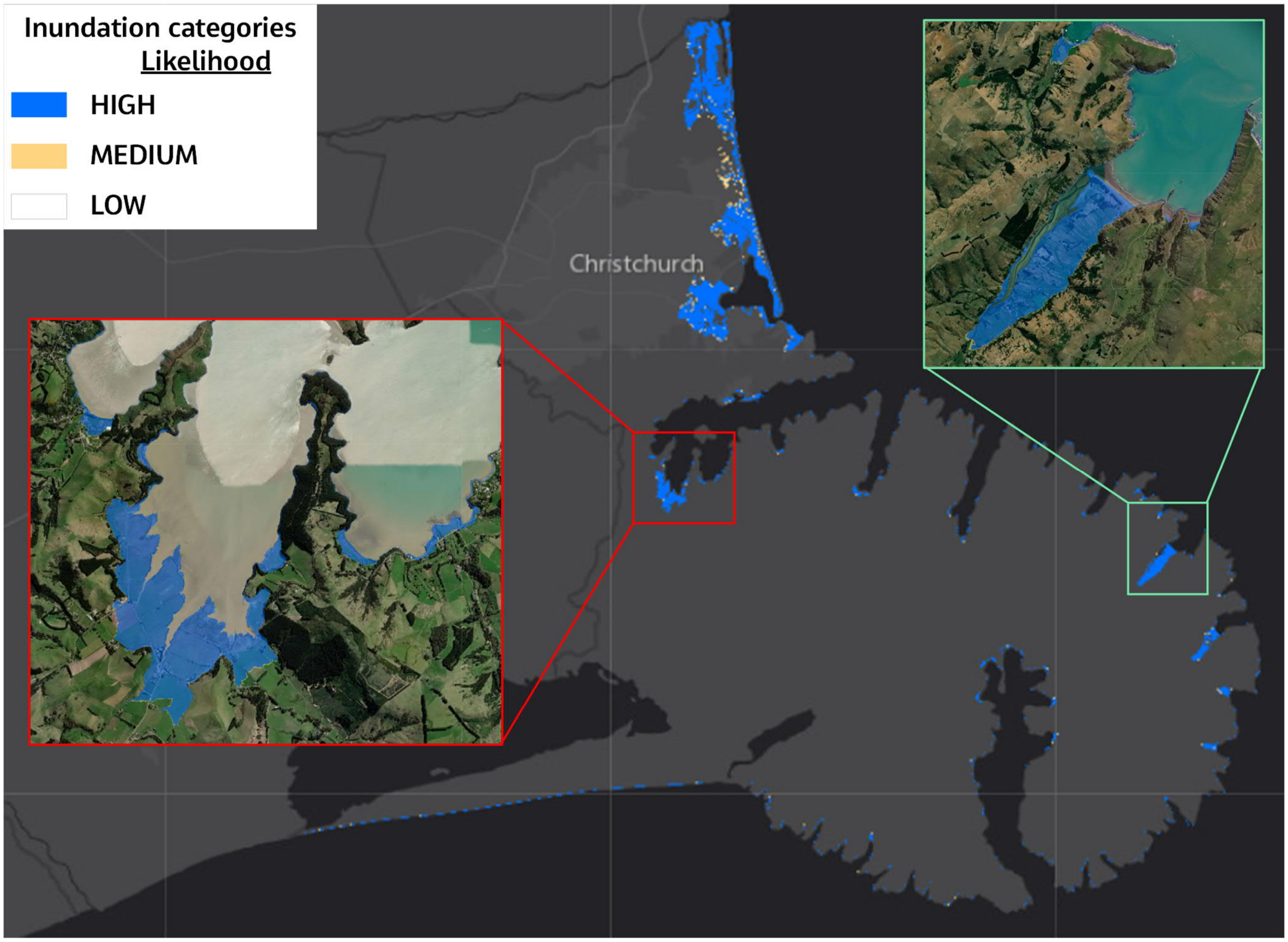


Figure 6.8: Inundation map for Method 1 (flood likelihood) – note that, for clarity, "low" likelihood has not been shaded on the map – it is defined as all land outside of "medium" and "low" likelihood.

Method 1 Likelihood thresholds

A sample extract of the inundation map for both SLR scenarios for Method 1 at the southern end of the Avon-Heathcote estuary is provided in Figure 6.9. All maps produced for this assessment are available in a webviewer accessible to the project team. Maps of the preferred approach has been provided to CCC as a spatial layer.

For both SLR scenarios the map shows that the extent of the "high" likelihood category (>10% AEP) is large and the extent of the "medium" likelihood category (1% to 10% AEP) is very small in comparison. This is because the variation in storm tide level for different likelihoods is relatively small (e.g. 0.2m between the 10% and 1% AEP for the southern Avon-Heathcote estuary) and the land is relatively flat and bounded by steeper ground. The difference in flood depth between the two likelihoods is also relatively small compared to typical hazard classification thresholds. Most of the inundated area is categorised as a "high" likelihood of flooding but the actual flood hazard will vary within it.

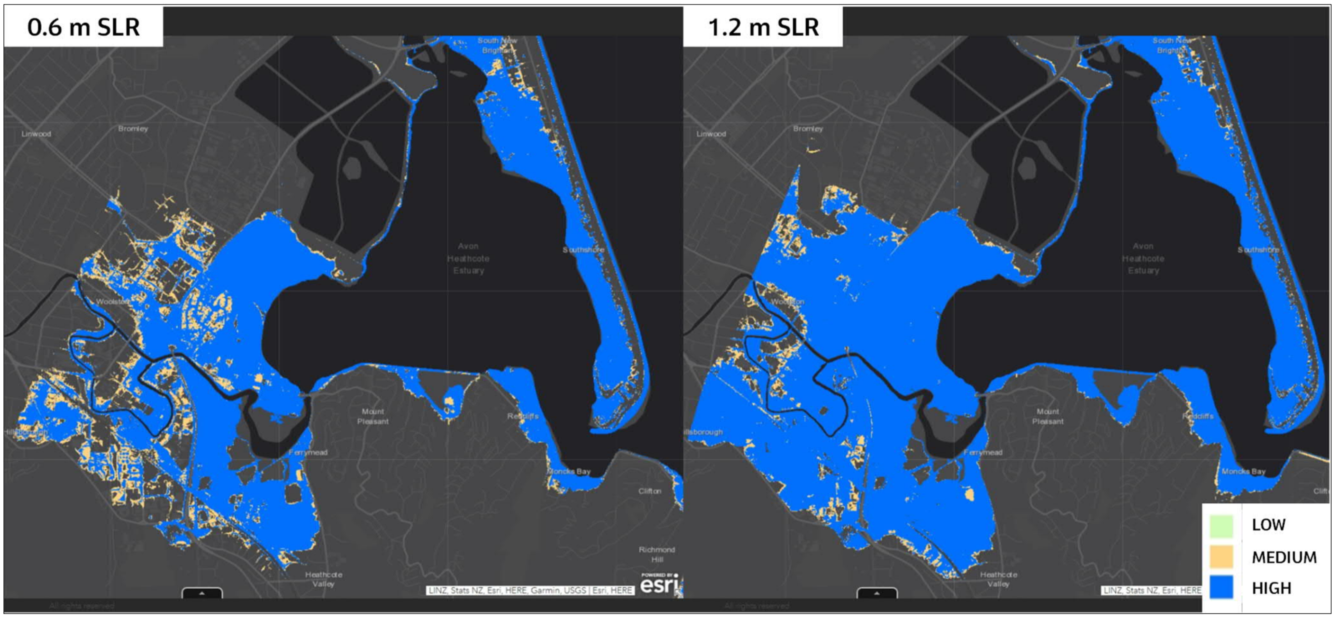


Figure 6.9: Inundation map for Method 1 (flood likelihood) – note that, for clarity, “low” likelihood has not been shaded in the map. It is defined as all land outside of “medium” and “low” likelihood.

Because the difference in inundation extent for different likelihoods is small and the method does not adequately differentiate between areas of higher and lower hazard, this method of categorising inundation is not recommended for planning purposes.

Given the small difference in extents, use of a single likelihood for mapping is appropriate and we recommend using the1% AEP, the smallest for which CHA data is available, for inundation mapping.

Method 2a Hazard thresholds (AR&R categories)

A sample extract of the inundation map for both SLR scenarios for Method 2a in show in Figure 6.10.

The map shows clear differentiation between the three categories of hazard for both SLR scenarios when using the AR&R hazard thresholds method applied to the 1% AEP flood depths. The likelihood of inundation is not explicitly taken into account in this method. However, the difference in depths between the 1% AEP and 10%AEP depths (generally between 0.1m and 0.3m) means that when the inundation thresholds are applied to the less likely 1% AEP water depth, they are equivalent to a lower depth threshold for the more likely 10% AEP depths. For example in the south of the Avon-Heathcote estuary the “medium” hazard depth threshold of 0.5m for the 1% AEP corresponds to a depth of 0.3m (similar to the more conservative DEFRA method threshold) for the 10% AEP. In this way the hazard thresholds reflect a lower depth threshold for more frequent events and a higher depth threshold for less frequent events. This is shown in Figure 6.11.

For these reasons this hazard threshold method is recommended as the basis for mapping inundation. However, to avoid the need for separate flood maps for each SLR scenario, it would be preferable to incorporate the effect of SLR on hazard within an overall method.

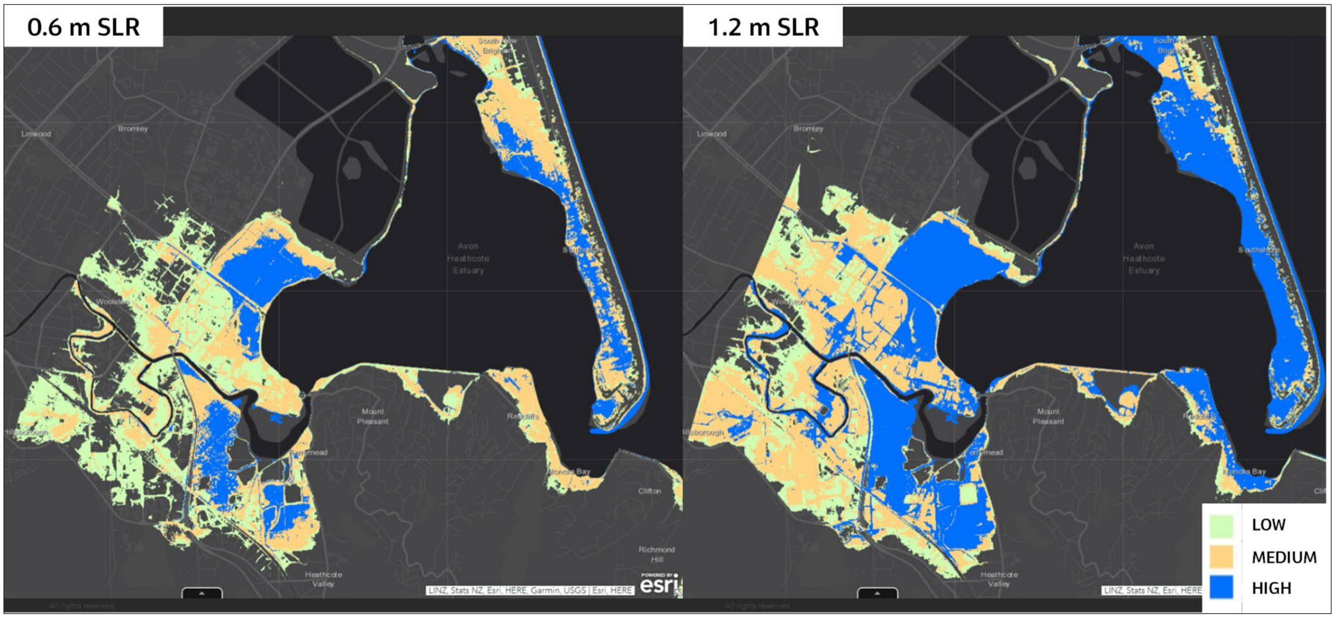


Figure 6.10: Inundation map for Method 2a (flood hazard – AR&R method)

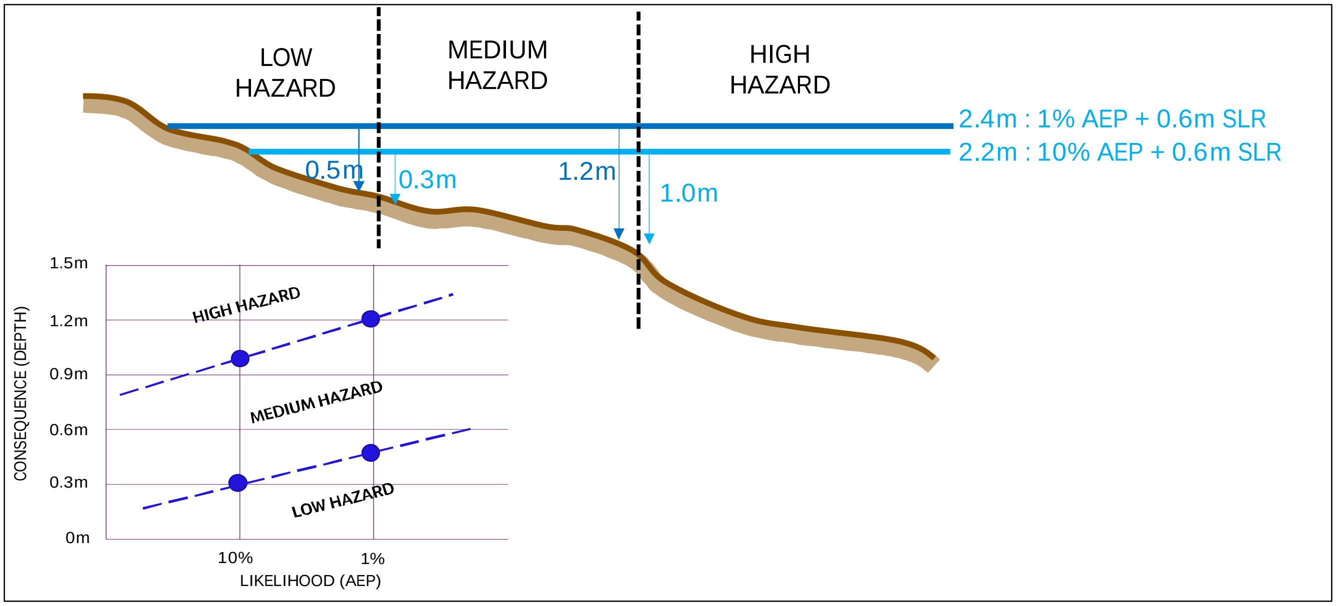


Figure 6.11: Example of the relationship between threshold values for 1% and 10% AEP flood depths using the AR&R method (Avon-Heathcote estuary south)

Method 2b Hazard thresholds (DEFRA categories)

A sample extract of the inundation map for both SLR scenarios for Method 2b is provided in Figure 6.12.

The map shows less differentiation between the three categories of hazard for both SLR scenarios when applied to the 1% AEP flood depths than when using the AR&R hazard thresholds method (Method 2a). This is because of the relatively small difference between the “medium” and “high” depth thresholds (0.3m and 0.5m respectively). The “medium” hazard depth threshold of 0.3m applied to the 1% AEP depths equates to a 0.1m or lower threshold when applied to the 10% AEP depths which is less appropriate than the equivalent depths using the AR&R thresholds.

For these reasons we recommend Method 2a (AR&R hazard thresholds) instead of Method 2b (DEFRA hazard thresholds) as the basis for inundation mapping.

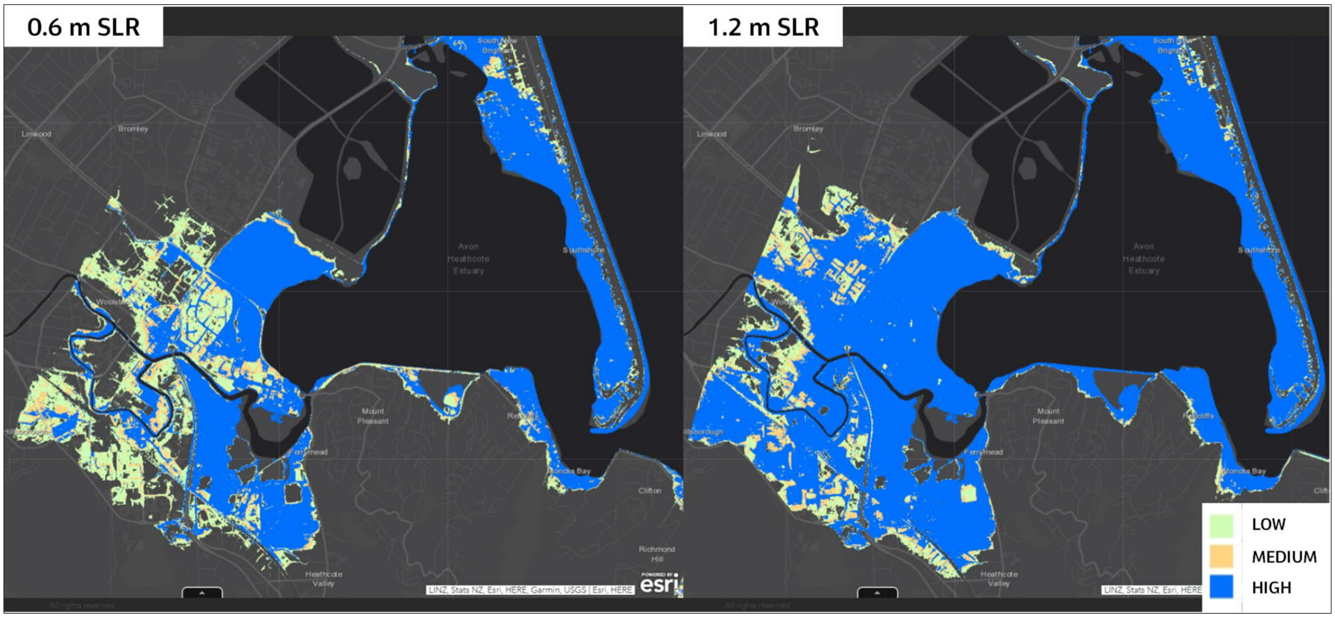


Figure 6.12: Inundation map for Method 2b (flood hazard – DEFRA method)

6.4.3 Comparison of Hazard Mapping from Bathtub and Hydrodynamic Model Data

Figure 6.13 compares hazard maps for the recommended thresholds of Method 2b, the AR&R method, using the CHA bathtub data and the hydrodynamic model results presented in Section 6.2.[29]. The storm tide in the model simulations is estimated to be approximately 3.2m LVD37, or around 2.84m NZVD2016, inside the estuary mouth. Figure 6.13 (a) shows the flood hazard categorised from the CHA bathtub data for a water level of 2.8m NZVD2016 (the closest value available in the dataset). Figure 6.13 (b) shows the flood hazard categorised from the TUFLOW model results.

The results show that there is generally little difference in the extents of the hazard categories mapped from the two datasets. This provides confidence in using the bathtub data for this purpose. Most of the differences are close to the inland boundary of the CHA dataset. This reflects the generally small differences in water depths produced by the two methods relative to the hazard category depth ranges and the tendency for larger differences close to the inland limit of the CHA dataset. The results suggest that, for hazard mapping, a minor adjustment of the inland limit of the bathtub mapping could reduce potential inconsistencies with flood mapping for inland areas derived from models.

The area in Aranui, between Pages Road and Breezes Road (circled in red) is connected via a drainage channel to the estuary. The capacity of the drain and the local stormwater network could limit the extent and depth of flooding in this area, as suggested in the TUFLOW model results. However, the model representation of this flow

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[29] Tonkin & Taylor, 2017: TUFLOW model simulation of 1% AEP storm tide and SLR to 2115, RCP8.5H+

path may not be sufficiently detailed to accurately simulate inundation through this pathway. In such “disconnected” areas, further assessment of inundation pathways may be needed to reduce uncertainty in the mapped hazard.

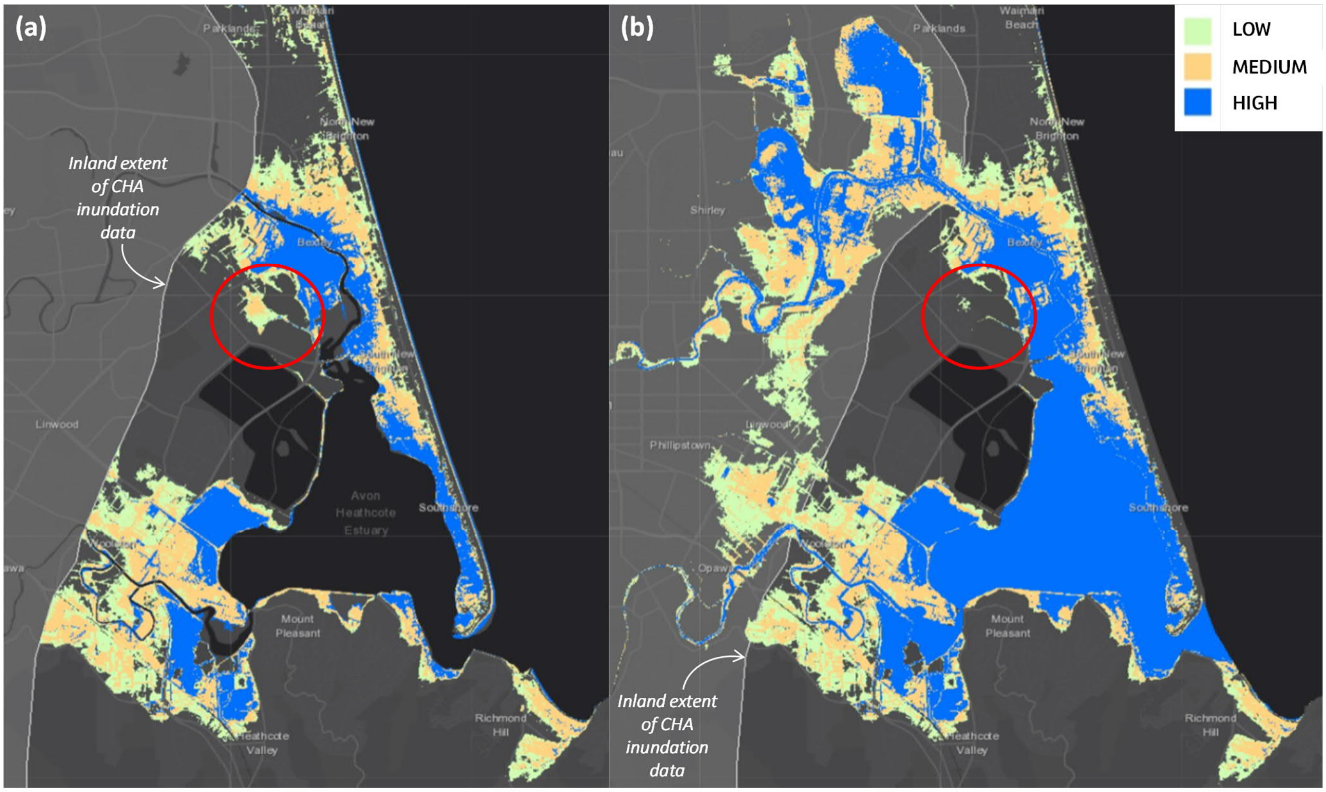

Figure 6.13: Comparison of hazard zones defined using Method 2a (AR&R hazard thresholds) and (a) CHA bathtub data for a water level of 2.8m NZVD201; and (b) T+T TUFLOW model simulations results for a storm tide of ~2.84 mNZVD2016. (Note that land within the estuary, below MHWS, is not mapped in the CHA data). Differences in Aranui circled in red.

6.5 Recommended Method and Thresholds

6.5.1 Method

From the results of our tests of applying alternative methods and thresholds to the CHA bathtub depth data, we recommend a mapping method which:

- uses a single likelihood of flooding,
- categorises hazard using still water depth thresholds informed by published scientific guidelines,
- includes the effect of SLR for two representative climate change scenarios.

The SLR value can be used as a measure of likelihood instead of the probability of flooding because:

i. it reflects both the degree of certainty of occurrence and the time period in which it is likely to occur

ii. the depth of flooding varies more with SLR than with AEP for a range of “reasonably foreseeable” and “significant” occurrences.

By combining measures of both likelihood and hazard our method defines thresholds and categories of flood risk.

6.5.2 Thresholds and Scenarios

We recommend categorising the inundation hazard using the 1% AEP depth data. This is the smallest AEP for which CHA data is available and we consider it is consistent with the purpose of the RMA to promote sustainable management of natural and physical resources, ensures that the District Planning framework considers intergenerational needs, and a precautionary approach is applied.

We recommend the H3 (“unsafe for vehicles, children and the elderly”) and H4 (“unsafe for vehicles and people”) hazard classification thresholds of the Australian Rainfall and Runoff guidelines as upper bounds to defining hazard threshold depths. This reflects the fact that most development will be occupied or used by people who will need to access and egress buildings during a flood and for whom the depth thresholds for the same category of hazard are lower than for buildings. We therefore consider it appropriate, and consistent with the requirements of Section 6(h) of the RMA to consider “significant risks”, to define flood hazard depth thresholds based primarily on hazards to people.

As indicated, our hazard categories we have incorporated SLR values of:

0.6m – a lower value, more certain to occur within the planning timescale and will occur sooner, and

1.2m – a higher value, less certain to occur within the planning timescale and will occur later, but can reasonably be expected to occur at some point in the future

We recommend that the inundation area is mapped using the 1% AEP depths with a SLR value of 1.2m (the higher value). This ensures that areas that may become at risk of flooding in the future are included in planning considerations.

Figure 6.14 shows our recommended values of depth thresholds applied to the 1% AEP flood depths with SLR of 1.2m. The corresponding depths for the 0.6m SLR scenario are shown for comparison. We have used the recommended H3 threshold value of 0.5m as the threshold for “medium hazard”. For the “high” hazard threshold we have used a value of 1.1m applied to the 1% AEP depth. This is slightly lower than the recommended H4 threshold value (1.2m) but corresponds to a depth of 0.5m in the lower SLR scenario, in line with the recommended H3 threshold value.

Table 6.6 presents the threshold values and Figure 6.15 illustrates the depths of water in each flood risk category for the two SLR scenarios.

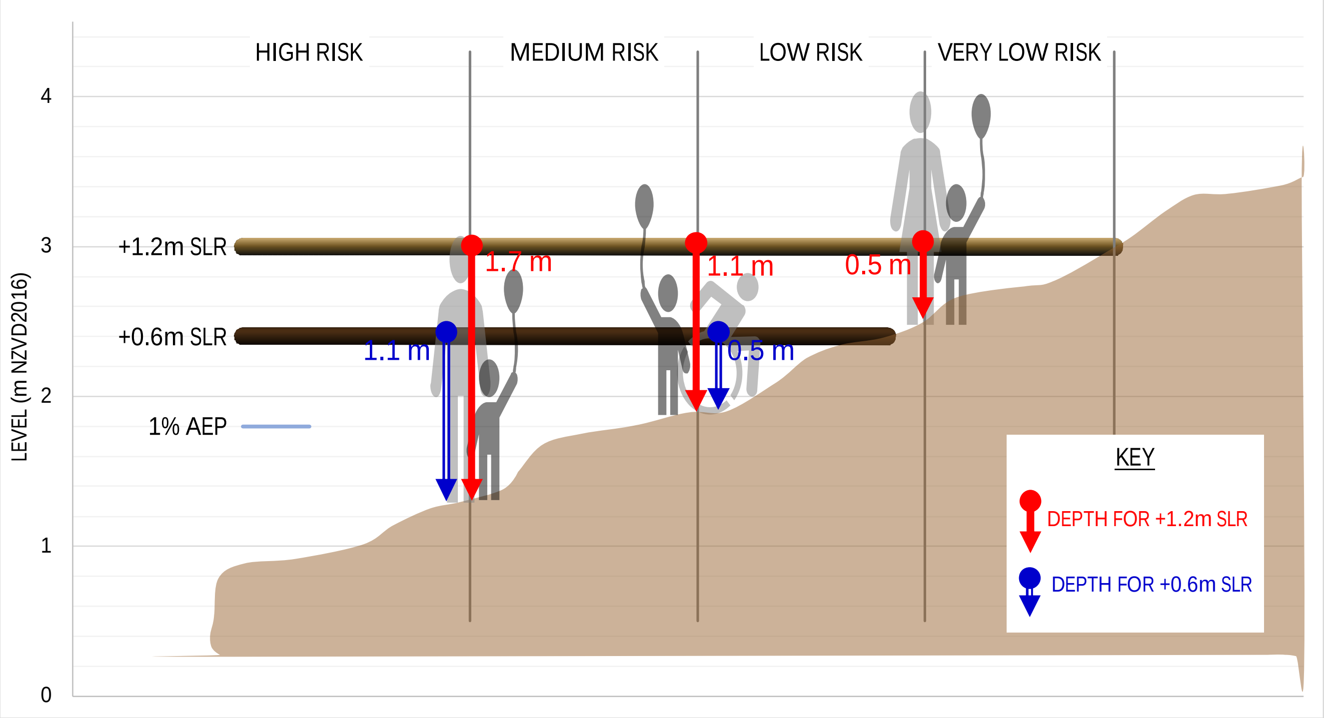

Figure 6.14: Recommended depth thresholds for defining flood risk based on the 1% AEP flood level and 1.2m SLR

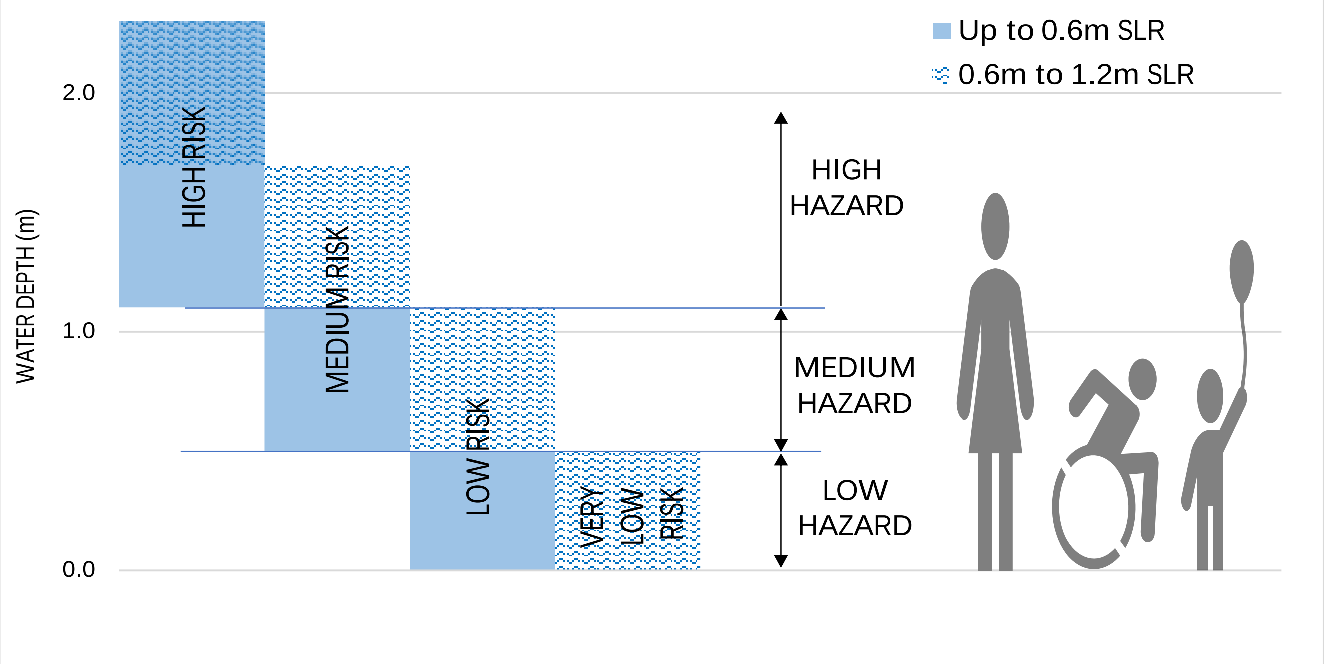

Figure 6.15: Flood risk categories based on the thresholds defined in Figure 6.14

Table 6.6: Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 1% AEP)

Coastal flood risk category	Flood hazard with 0.6m SLR		Flood hazard with 1.2m SLR	
Very low	None	(dry)	Low	(d < 0.5m)
Low	Low	(d < 0.5m)	Medium	(0.5m < d < 1.1m)
Medium	Medium	(0.5m < d < 1.1m)	High	(d > 1.1m)
High	High	(d > 1.1m)	High	(d > 1.7m)

6.5.3 Comparison of Hazard Mapping with Current Flood Maps

The flood risk categories mapped using the CHA bathtub depth data at two sample locations – the Avon-Heathcote estuary and the Waimakariri River and Brooklands Lagoon area. These areas are shown in Figure 6.16, Figure 6.17 and Figure 6.18. The current District Plan mapping of the High Flood Hazard Management Area, the CCC 0.5% AEP flood extent and the current District Plan Flood Management Area are overlaid for comparison. The 0.5% AEP flood extent is similar to the Flood Management Area overlay of the Christchurch District Plan. However, that overlay also includes land where ground levels are within a height of 250mm above the 0.5% AEP flood level. These were derived from models considered appropriate for use at the time of development of the District Plan (around 2014) and tend to be more extensive than a modelled extent or a bathtub map for a similar storm tide level.

In both sample areas the mapped “high” flood risk area generally aligns with the existing High Flood Hazard Management Area. In the area along the Styx River (Figure 6.17) there are areas within the High Flood Hazard Management Area for which there are no depth values in the CHA bathtub data. These areas are generally bounded by “high” flood risk areas. These areas were masked out of the bathtub data in the CHA methodology because the ground levels are below the Mean High Water Springs (MHWS) tide level. All land below MHWS is excluded from the CHA data for presentation purposes at is regularly inundated without storm tide effects. Lower lying land, beyond the estuaries and shorelines is also excluded. This masking should be removed when applying the data for planning maps so that all land below storm tide level is mapped.

In the area around the Avon-Heathcote estuary, the existing 0.5% AEP flood extent is similar to the extent of the low flood risk area closer to estuary. Further inland the area of low flood risk outside the 0.5% AEP extent increases. The very low flood risk area generally lies beyond the 0.5% AEP extent. These differences are due to the different values of SLR adopted in the two maps (1.2m and 1m), differences in storm tide levels and the increasingly conservative nature of the bathtub map further inland. South of Brooklands lagoon, the bathtub hazard extent is significantly greater than the 0.5% AEP extent. This could be due to attenuation of storm tide in the lagoon and floodplain in the hydrodynamic model used to map the 0.5% AEP extent, or could be due to differences in the tidal boundary water level adopted in the two methods.

The existing Flood Management Area is generally very similar in overall extent to the flood risk area mapped from the CHA bathtub data around the Avon-Heathcote estuary, with generally only the “very low” risk area extending beyond the Flood Management Area.

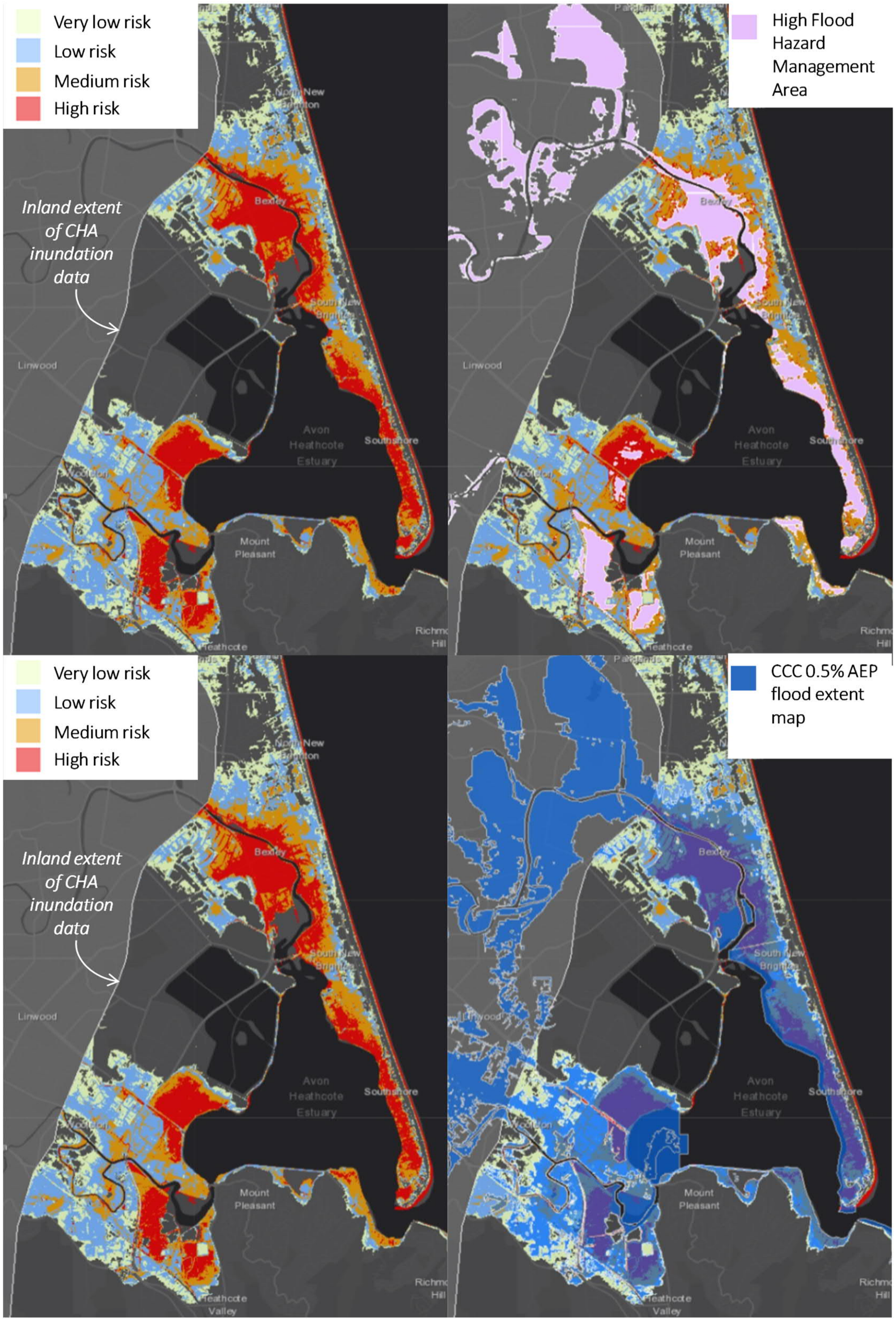

Figure 6.16: Recommended flood risk mapping of coastal inundation compared to current High Flood Hazard Management Area and CCC 0.5% AEP flood extent in the Avon-Heathcote estuary

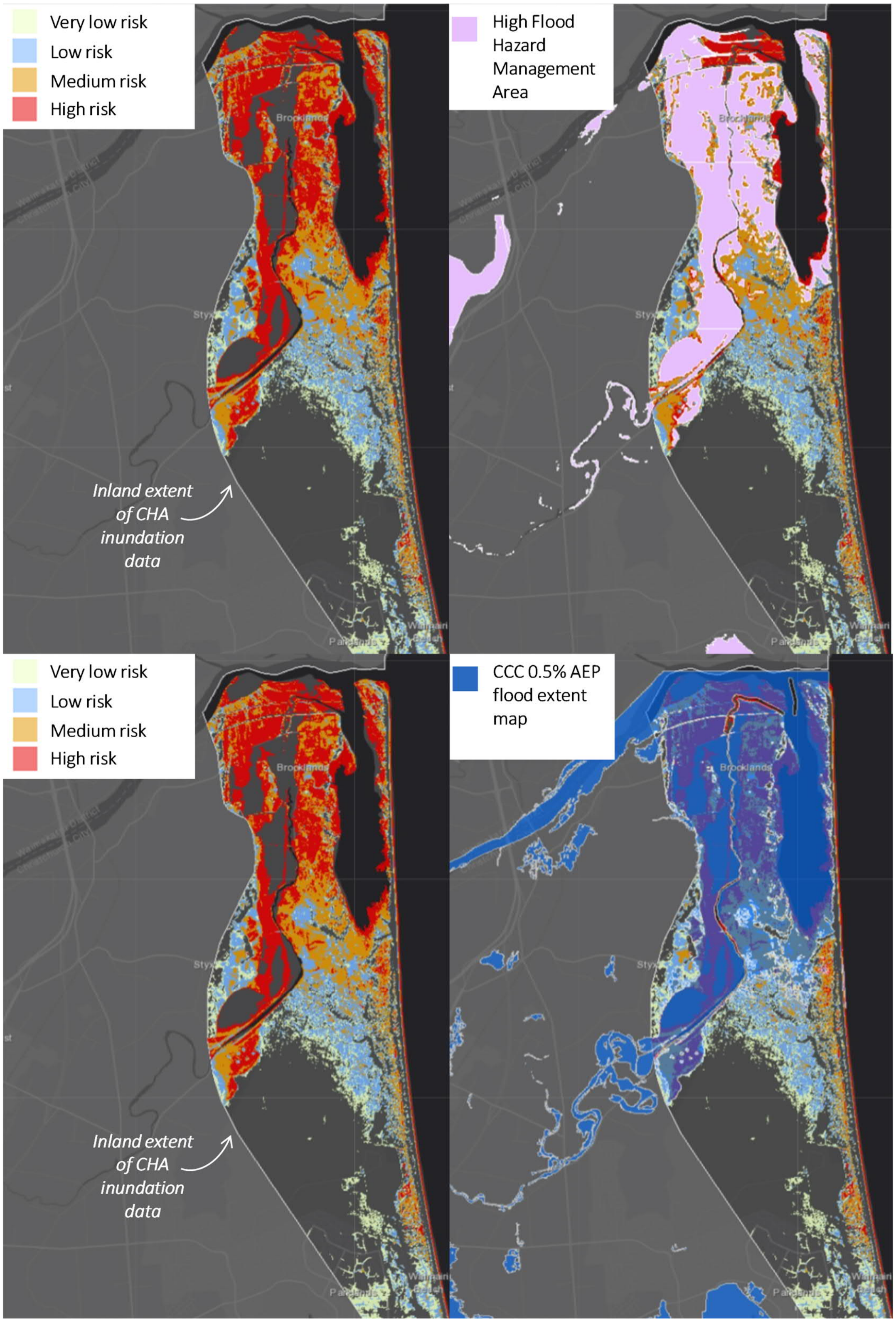

Figure 6.17: Recommended flood risk mapping of coastal inundation compared to current High Flood Hazard Management Area and CCC 0.5% flood extent at the Waimakariri River and Brooklands Lagoon

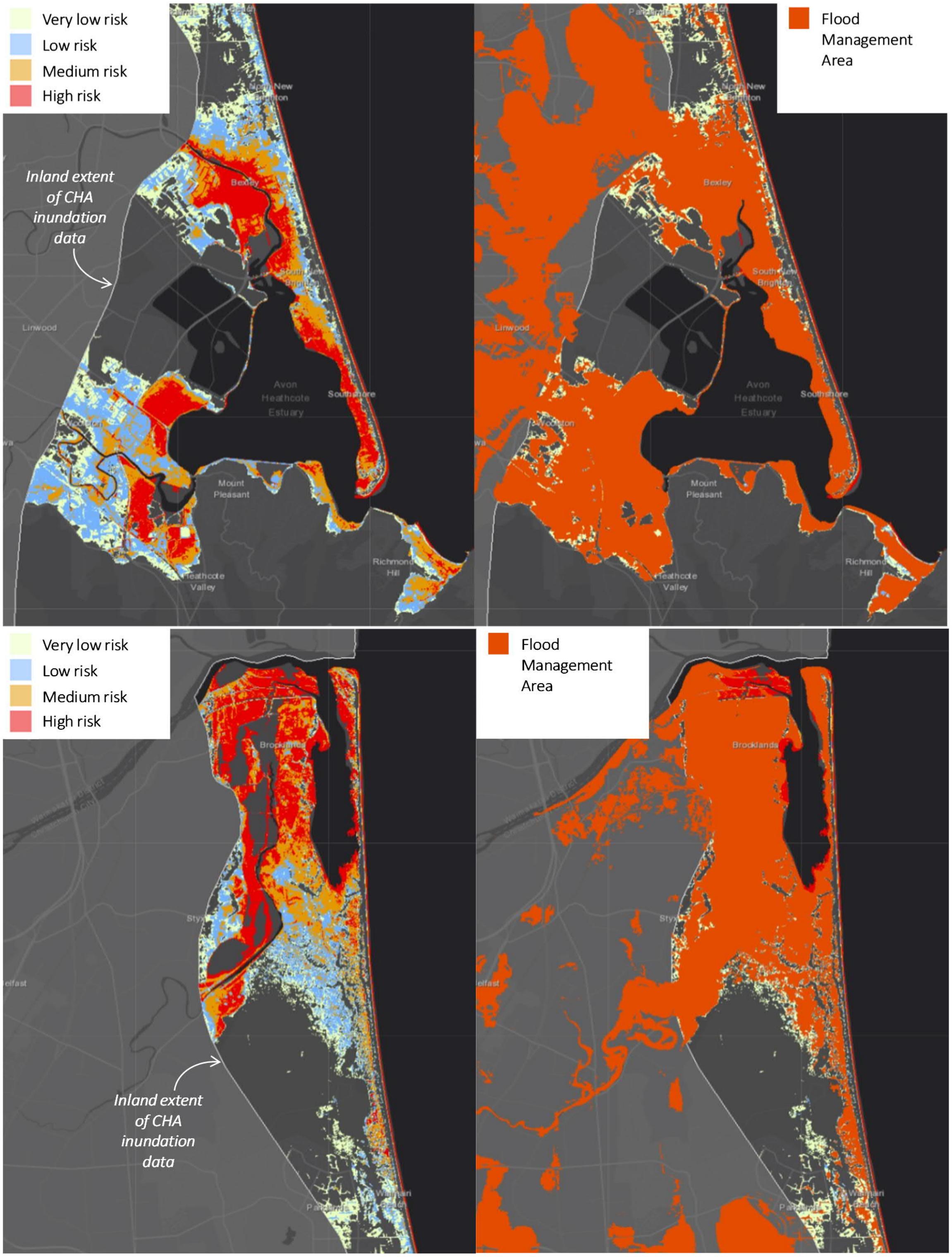

Figure 6.18: Recommended flood risk mapping of coastal inundation compared to current Flood Management Area in the Avon-Heathcote estuary and at the Waimakariri River and Brooklands Lagoon

6.5.4 Relationship to Tsunami Inundation

The Scope of Works included the requirement to cross reference the inundation hazard thresholds to tsunami inundation data, to advise on areas of hazard overlap or gaps, and to consider whether an integrated multi hazard approach should influence the risk categories. A number of hydrodynamic tsunami inundation modelling studies for the Christchurch district has been undertaken since 2011 primarily for Civil Defence purposes. The majority of these have involved worst case tsunami scenarios with return periods in the order of 2500 years and are not relevant for comparison with the coastal flood inundation data for this study. However, a 2018 model study[30] for the CCC LDRP multi-hazards study includes a 500 year tsunami scenario, which can be used for comparative assessment. This study involved modelling tsunami inundation depths for Christchurch city area from a South American earthquake source, which previous studies had shown to be the worst-case scenario for Christchurch. As well as present day sea levels, the modelling also included tsunami inundation with 1.06 m SLR by 2120. The modelling did not include Lyttelton or Akaroa Harbours.

The modelling results showed the inundation extent within the city to be 39 km2 for a 500 -year tsunami arriving at current mean sea level, with maximum depth of 5.4 m near the Waimakariri River mouth. The resulting inundation map is presented in Appendix C and shows the main inundation locations with depths in the range 1-5 to 2 m around Brooklands Lagoon, and the low-lying areas around the Avon-Heathcote Estuary and lower river channels. Some inundation was also predicted around the dune openings at New and North Brighton. Extremely high flow velocities (7- 8 m/s) were predicted at the mouth of the Estuary and the Waimakariri River, with high velocities (3-4 m/s) near the dune openings, Sumner and mouths of the Avon and Heathcote Rivers

The inundation maps for the same tsunami scenario arriving with 1.06 m SLR is also presented in Appendix C. The inundation extent is nearly doubled to 70 km^2 and reaches a maximum depth of 5.8 m. Depths in many areas around the Styx, Lower Avon and Lower Heathcote and the Estuary are predicted to be greater than 2m. The dunes along the coastal strip are overtopped at numerous locations causing nearly continuous inundation of the land along Marine Parade. Although flow velocities are similar to the current day scenario, the overtopping is likely to erode dunes and causing an increase in inundation that is not captured by the model.

The extent and depth of flooding for (a) the 500 year (0.2%) tsunami with 1.06m SLR and (b) the coastal inundation risk map is compared in Figure 6.19. This was developed using the recommended depth thresholds and the CHA bathtub data for the 1% AEP event with 1.2m SLR for a sample area around the Avon-Heathcote estuary. The maps show that inland from the estuary the overall area at risk from tsunami inundation aligns fairly closely to the CHA flood risk areas and the areas of highest water depth tending to lie within the “medium” and “high” risk areas for coastal inundation. However, tsunami flooding is more extensive and deeper due to the greater height and much greater duration and velocity of water arriving at the shore in a tsunami event.

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[30] Passarella C., Arnold J., Lane E.; Land Drainage Recovery Programme: Tsunami Study. NIWA report 2018039CH Prepared for CCC.

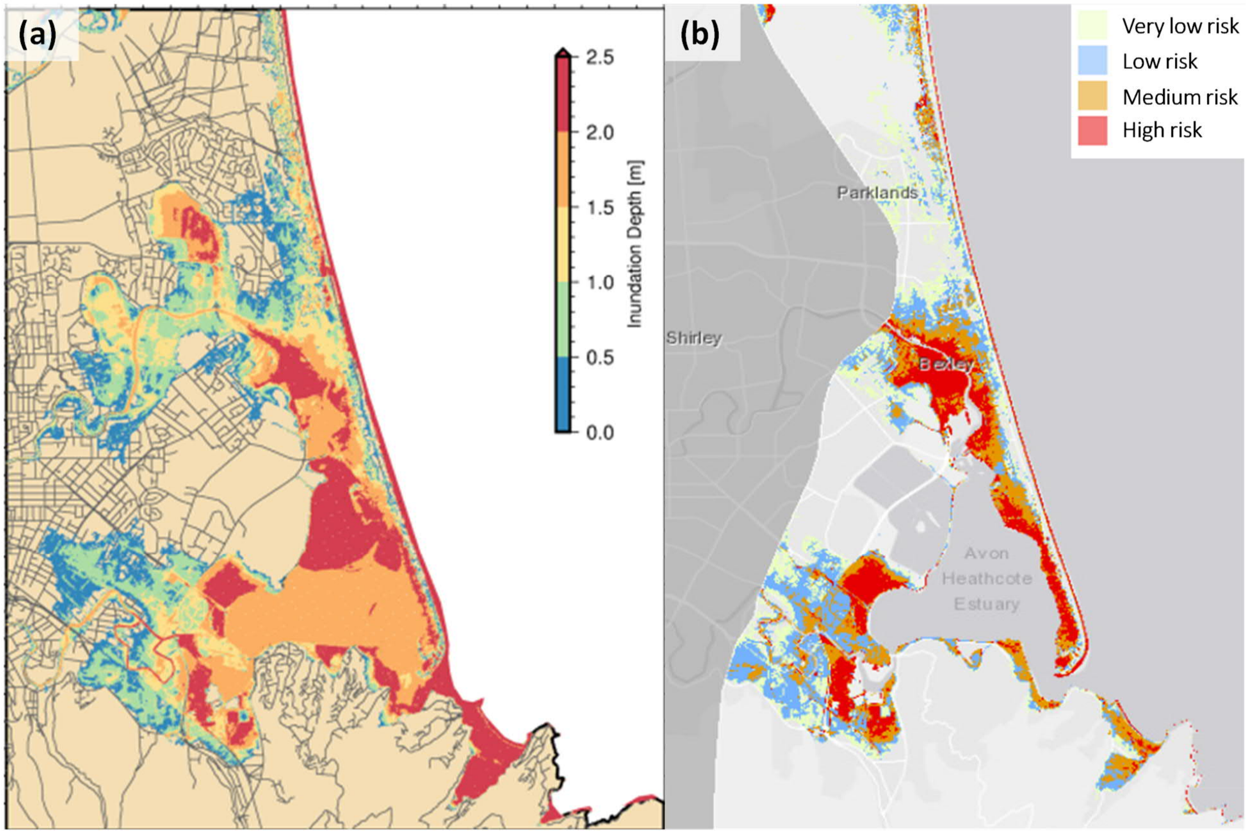

Figure 6.19: Comparison of (a) tsunami inundation map (500 year with 1.06m SLR) and (b) flood risk category map derived using recommended thresholds and the 1% AEP flood depths with 1.2m SLR from the CHA in the Avon-Heathcote estuary.

For the Banks Peninsula and Kaitorete coastline, Environment Canterbury commissioned GNS Science to undertake multiple tsunami source and magnitude modelling over 2019[31] and 2020,[32] which included scenarios from up to 20 Pacific sources that give wave heights in the order 3 m to 5 m along the Peninsula and Kaitorete coast. Although the probabilities of these tsunami events are not given, they are considered to be much more comparative to the flood probabilities than the 2500-year events used in other tsunami modelling. Although the maps presented from this modelling (reproduced in Appendix C) are small scale covering the whole peninsula, they indicate that maximum tsunami water depths in the head of Lyttelton Harbour and the north to NE facing bays could be up to 6 m for a 3 m tsunami wave, and up to 8 m for a 5 m tsunami wave. As such these tsunami water depths are considerably greater than the flood inundation depths therefore the proposed flood thresholds from this analysis are not appropriate for tsunami risk.

Any planning provisions and restrictions applied to the areas at risk from coastal inundation will also be of benefit in reducing the impacts of tsunamis. However, due to the very low probability of tsunami events, and the availability to have sufficient time for evacuation in the largest and potentially most damaging events (e.g. 12-16 hrs for South American tsunami source) the Civil Defence management response to them rather than a planning response is appropriate.

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[31] Mueller, C., Wang, X., Power, W.L., Lukovic, B., 2019, Multiple scenario tsunami modelling for Canterbury. Report prepared for Environment Canterbury. GNS Science consultancy report; 2018/198, GNS Science, Lower Hutt, New Zealand.

[32] Mueller, C., Wang, X., Lukovic, B., 2020. Multiple scenario tsunami modelling for the Selwyn coastline, Kaitorete Barrier and Akaroa Harbour. Report prepared for Environment Canterbury. GNS Science consultancy report 2020/47, GNS Science, Lower Hutt, New Zealand.

6.5.5 Considerations in Applying the Risk Thresholds

Uncertainties

We have developed our recommended method for flood risk mapping for use with the CHA bathtub depth outputs. For inundation from purely tidal events, this dataset tends to be conservative within the area of coverage defined in the CHA. For this reason, we consider it unnecessary to include an additional allowance for uncertainty in the depth data for mapping the inundation area or defining flood risk. In areas of higher flood risk, mitigation measures such as minimum floor level requirements should include an appropriate freeboard allowance above estimated flood level. More detailed assessment of flood level, including consideration of flooding from other sources, may be warranted for individual developments to determine floor levels or other measures.

The bathtub method maps all land below the flood level without taking account of connectivity with the source of flooding or the hydraulic capacity of pathways connecting flooded areas. Some flood risk areas may be separated by higher ground from the source of flooding, which could prevent flooding in the “unconnected area”. In common with the CHA, we have included both “connected” and “potentially unconnected” areas when mapping flood risk using the proposed depth thresholds. In the CHA maps, potentially unconnected areas are highlighted through different colouring to help guide adaptation responses. These could include more detailed, case by case assessments to determine if pathways, such as culverts or sub-surface stormwater drains which are not represented in the terrain data, would connect such areas and if their capacity would allow significant inundation. Including all land which is below the source flood level in the inundation area also allows the residual risk from breaches of stopbanks or impedance of stormwater drainage in low-lying areas to be included in both sets of maps.

Negligible risk

The flood risk maps show all depths of water. Flood maps often exclude areas of very shallow water on the basis that the flooding constitutes a “nuisance” rather than a danger and additional controls are not needed. If a minimum depth of flooding is used to define the inundation area and the applicability of planning rules, such as minimum floor level, then this should be consistent with other development controls. For example, for housing outside of secondary flow paths the minimum floor height required under the Building Code is 150mm above the adjacent ground level. To avoid the risk of flooding above floor level, additional freeboard would be required where flood depths exceed 150mm as a minimum. We recommend that the minimum depth applied to inundation mapping should be no greater than 50mm. A negligible depth threshold could be included in the “very low risk” threshold of Table 6.6, i.e., as “$0.05m < d < 0.5m$”, for mapping the same CHA bathtub depth data.

Data limitations

As discussed in Section 6.4.3, the CHA depth data is masked so that any land below the MHWS tide level is excluded e.g. along the River Styx. This limits the coverage of the flood risk map since these areas are generally at risk. The bathtub method is simple to apply, and the flood levels used in the CHA could be readily applied to the same LiDAR ground level data to remove gaps in the coverage for preparation of planning maps.

The raster data used to produce the flood risk map results in a very complex topology due to the small grid size used. For planning purposes this should be simplified and smoothed. This could include removal of any areas at “indirect” risk of flooding if these are confirmed to be unconnected.

7. Coastal Erosion Hazard Thresholds

This section first presents the recommended coastal erosion thresholds and similarly to the inundation section then provides the discussion and reasoning behind this recommendation and the other approaches that were considered.

7.1 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 whole current beach-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 healthy beach factors”.
2) For the Avon-Heathcote Estuary; two erosion zones comprising of
    a) A High-Medium Hazard Coastal Erosion Zone to a landward limit defined by the 66% probability erosion distance with 0.6 m SLR by 2080, with consideration of a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell under this scenario/threshold option, and
    b) A Low Hazard Coastal Erosion Zone to a landward limit defined by the 10% probability erosion distance with 1.2 m SLR by 2130 with consideration of a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell under this scenario/threshold option
3) For the beaches and bays of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single 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 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.

The following discussion provides the discussion and justifications behind these recommendations.

7.2 Critical Thinking

In applying a risk-based approach to land-use planning for coastal erosion hazards, the key determination is likelihood as the consequence is always high, for example land is eroded and therefore will be unusable after a certain time.

To define appropriate erosion likelihoods for different coastal erosion risk categories for land-use planning a combination of SLR scenario, time frames and probability of occurrence needs to be considered so risk can be expressed as:

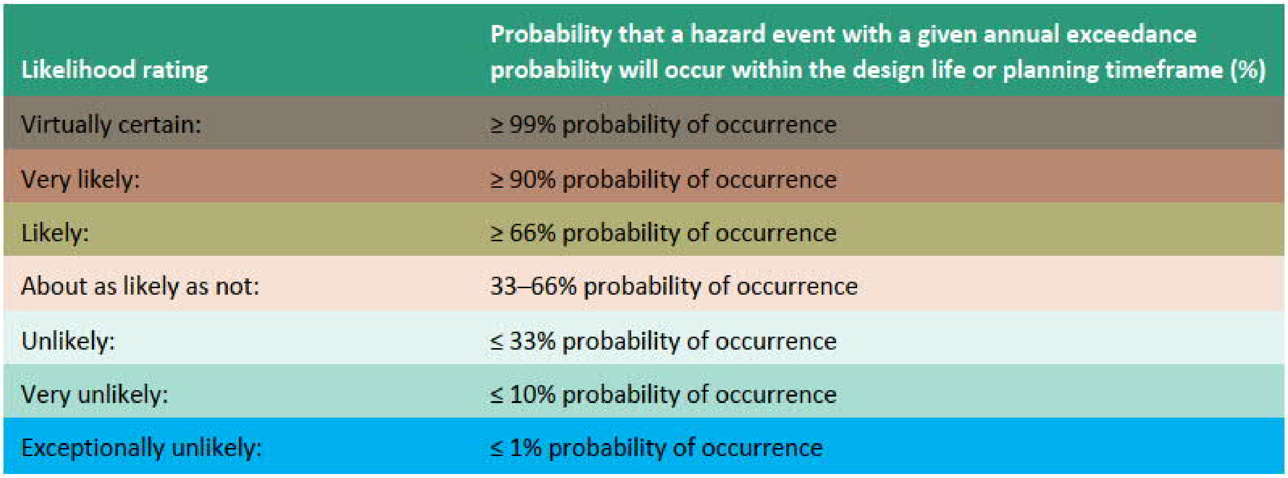
"xxx probability that erosion will occur within yyy time frame under zzz SLR scenario".

As per Section 5, we have defined the most appropriate SLR scenarios and timeframes as being 0.6 m SLR by 2080, and 1.2 m SLR by 2130. So, the probabilities that a certain erosion distance will occur within these scenarios and timeframes can be used to define the thresholds for determining different categories of hazard risk. The critical thinking behind the selection of these thresholds includes:

1. The probabilities are a measure of the "Statistical Uncertainty" of resulting erosion distance based on distribution of certainty in the input data used for the erosion models and calculations. Most of the distributions applied are normal, triangular, or extreme event depending on the data availability. This has not addressed the "modelling uncertainty" covering how well the models and methods used can predict future erosion, or the "Scenario uncertainty", which is addressed in the choice of scenarios in Section 4.

   In the T+T assessment the probabilities are expressed as the likelihood that the erosion will reach or be greater than the calculated ASCE to that location. Therefore, the probabilities decrease with distance from the current shoreline position, as there is decreasing likelihood that erosion will reach or exceed this position with the specified magnitude of SLR within the specified timeframe. Hence for the same SLR magnitude and timeframe, we can be more certain that erosion will reach the positions with higher probabilities, and less certain it will reach the positions with lower probabilities.

   The probabilities used in the thresholds link to the quantitative likelihood ratings presented in MfE guidance) as shown in Figure 7.1. The most expected likelihood ratings to be used as thresholds include; very likely (⩾ 90%), likely (⩾66%), unlikely (⩽33%), and very unlikely (⩽10%). It is noted that T+T assessment presents results of a 5% probability, as the middle of the 'very unlikely' range (0-10%). The ASCE distance to this probability level is slightly greater than to the 10% probability (in the order of 5 m along the Christchurch open coast and 1-2 m in the Avon-Heathcote Estuary) and is less likely to occur. However, for consistency of approach of using the probability limit of each likelihood rating so that all of the proposed zone has a likelihood greater than 'very unlikely', we have used the 10% probability position for defining 'very unlikely' occurrence rather than the 5% middle position presented by T+T.



Likelihood rating	Probability that a hazard event with a given annual exceedance probability will occur within the design life or planning timeframe (%)
Virtually certain:	≥ 99% probability of occurrence
Very likely:	≥ 90% probability of occurrence
Likely:	≥ 66% probability of occurrence
About as likely as not:	33–66% probability of occurrence
Unlikely:	≤ 33% probability of occurrence
Very unlikely:	≤ 10% probability of occurrence
Exceptionally unlikely:	≤ 1% probability of occurrence

Figure 7.1: Relationship between quantitative likelihood ratings and probabilities. (From MfE, 2017; Table F-3)

An example of how these likelihood ratings convert to a probability distribution of erosion distance is shown in Figure 7.2.

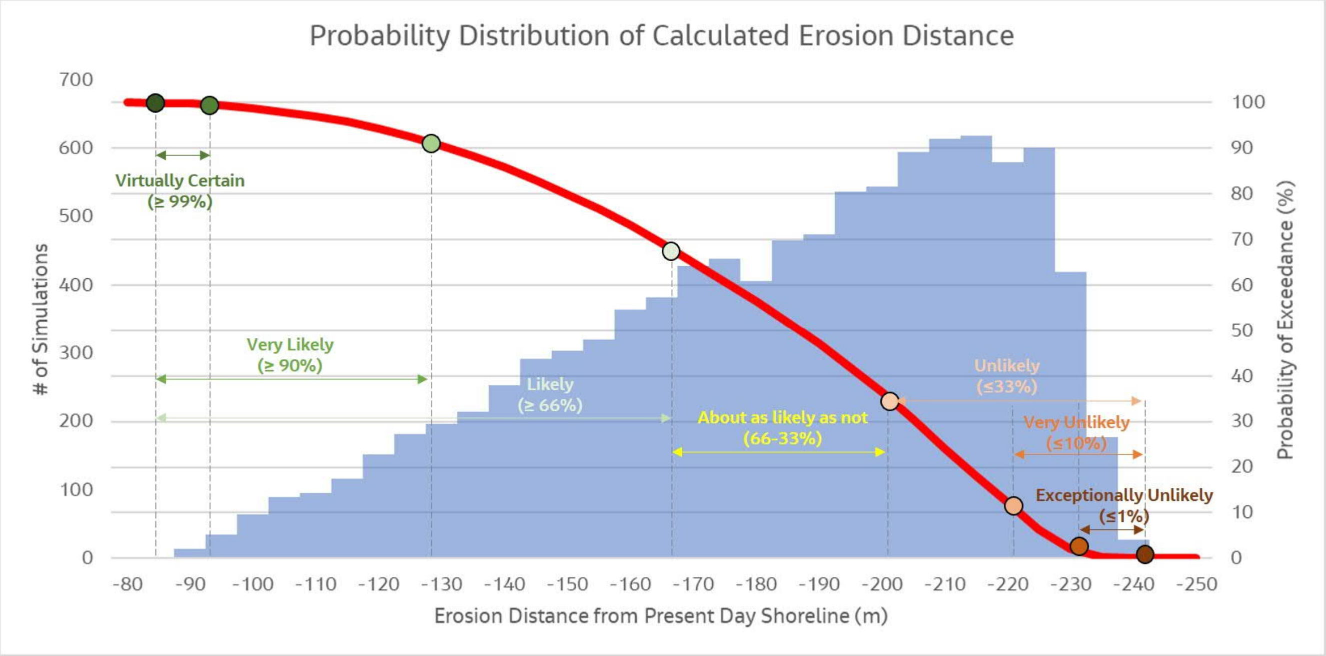


Figure 7.2: Example of probability distribution of erosion distances

2. For consistency of risk assessment, there needs to be a degree of consistency between the thresholds applied across the different assessment types: probabilistic, deterministic, cliffs and protection structures. While the above consideration of probabilities can be applied to the beach, bay and estuary cells where a probabilistic assessment was undertaken, it cannot be applied to cells and areas covered by the other assessment methods as the full range of probabilities is not available for these cells. Ways of addressing this inconsistency are considered in the testing of different threshold options under each of the assessment methods.

3. The distance between the thresholds defining different hazard risk categories needs to be sufficient for likely land-use activity to be reasonably able to be carried out in the zone between the thresholds. For example, it is considered that the use of thresholds which only produce 5 m wide hazard zones are not going to be acceptable. This raises the following two questions:

   I. Where the distance between thresholds is too narrow for an acceptable planning zone width, should the position be shown just for information that there are hazards in the area (e.g. low risk of erosion for sea level rise over a100 year time frame) without associated planning provisions, or should a generic acceptance zone width be applied even though some (and possibly most) of the zone doesn't meet the risk threshold?

   II. Whether the number of erosion hazard categories required can be reduced for some environments from the three originally envisaged for this study to one or two to provide suitable widths for land-use planning purposes.

4. For beach and bay environments, due to the ASCE distances being from the position of the dune/beach ridge/bank toe, the thresholds for planning set-backs need to also allow for natural backshore environments (e.g. dunes and beach ridges) within the set back distance. Therefore, the whole of the beach environment is considered to be in a high hazard category so that the full natural protection ability of the beach against coastal hazards is not compromised. This is consistent with NZCPS Policy 26 (natural defences against coastal hazards) as well as having a number of ecological, nature character, and landscape

reasons for being protected from inappropriate development which are consistent with objectives 1 and 2 of NZCPS. The inclusion of the whole active beach and dune environment with Coastal Erosion Hazard Zones is consistent with the approach taken in both the RPS and the RCEP.

5. In additional to the need to protect the current beach environment, there may also be a need to provide an additional width within erosion set-back zones for "future healthy beach factors". 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 healthy 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 may be predicted to reach by the chosen scenario/threshold combination, but also allowing for the beach and dune systems to 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. It is not possible in the timeframe of this analysis to recommend possible widths required for "future healthy beach factors".

6. The T+T approach of mapping ASCE's in cells creates a number of discontinuities in mapping of the potential thresholds across the cell boundaries, which creates difficulties for District Plan Erosion Hazard Zone mapping. It is possible to develop a process for smoothing these discontinuities across other cells involving consideration of the representativeness and certainty of the data used in the ASCE calculation as the cell boundary is approached from both longshore directions. Such a process would need to be well justified and documented as the largely subjective movement of the hazard zone is likely to be subject to challenge. This smoothing will be required to be done before the threshold mapping can be used for consultation on potential erosion hazard planning zones, however it is beyond the scope of this analysis to develop the details of the process to undertake this task.

7.3 Hazard Threshold Options

7.3.1 For Detailed Probabilistic Assessment Cells

As described in Section 4.2, detailed probabilistic assessments were undertaken for 52 cells covering the Christchurch City open coast, parts of the Avon-Heathcote Estuary, and beach or bank shorelines along the existing larger settlements within Lyttelton and Akaroa Harbours.

The analysis for these probabilistic assessment cells involved trialling two approaches to defining thresholds for erosion hazard categories. The preferred and alternative approach are discussed in turn below.

From the analysis, the Preferred approach involved reducing the probabilities and/or increase the SLR scenarios through time while descending the hazard categories from high to low to recognise different levels of certainty in the erosion calculations and that different land-uses may be appropriate over different timeframes. While there are multiple combinations of timeframes, scenarios and thresholds possible, the best two options chosen to be tested for sensitivity of resulting erosion distances are presented in Table 7.1. Note that although the 0.4 m SLR by 2050 and 2.0 m SLR by 2150 scenarios do not fit the recommended SLR scenarios from section 5 (e.g. 0.6 m by 2080 and 1.2 m by 2130), they are included in the sensitivity test for completeness of options.

Table 7.1: Threshold options for recommended probabilistic assessment approach to defining hazard categories

Hazard Category	Option	Time Frame	SLR since 2020	T+T Probability	Likelihood description (Statistical uncertainty)
High	(a)	2050	0.4 m	10%	Greater erosion is very unlikely, so very certain this erosion distance will occur in this short timeframe
	(b)	2080	0.6 m	66%	Erosion up to this distance is likely within this medium timeframe, so less certain than option (a) High Hazard
Medium	(a)	2080	0.6 m	33%	Greater erosion than this position is unlikely within this medium timeframe
	(b)	2130	1.2 m	66%	Erosion up to this distance is likely within this longer timeframe, but less certainty that SLR to this magnitude will occur within the timeframe
Low	(a or b)	2130	1.2 m	33%	Greater erosion than this position is unlikely within this longer timeframe, but less certainty that SLR to this magnitude will occur within the timeframe
	(a or b)			10%	Greater erosion is very unlikely within this longer timeframe, but less certainty that SLR to this magnitude will occur within the timeframe
	(a or b)	2150	2.0 m	33%	Greater erosion than this position is unlikely within this much longer timeframe, but also much less certainty that SLR to this magnitude will occur within the timeframe

The Alternative Approach involved applying a consistent time frame and SLR scenario across all hazard categories, with the decreasing probabilities being used to define the thresholds between hazard categories. From the T+T increments, the chosen SLR scenario to test was the 1.2 m by 2130, with the threshold options being as shown in Table 7.2. A second option under this approach of applying the 2.0 m SLR by 2150 scenario as the low hazard threshold was also included in the sensitivity testing.

Table 7.2: Threshold options for alternative probabilistic assessment approach to defining hazard categories

Hazard Category	Option	Time Frame	SLR since 2020	Probability	Likelihood description (Statistical uncertainty)
High	(a)	2130	1.2 m	90%	Erosion very likely up to this distance over this long timeframe.
	(b)			66%	Erosion likely up to this distance over this long timeframe, so less certain than option (a) High Hazard
Medium	(a)	2130	1.2 m	66%	Erosion likely up to this distance over this long timeframe,
	(b)			33%	Greater erosion than this position is unlikely within this longer timeframe.
Low (1a)	(a)	2130	1.2 m	33%	Greater erosion than this position is unlikely within this longer timeframe.

	(b)			10%	Greater erosion than this position is very unlikely within this longer timeframe.
Low (1b)	(a or b)	2150	2.0 m	33%	Greater erosion is unlikely within this much longer timeframe, but also less certainty that SLR to this magnitude will occur within the timeframe

Sensitivity testing of the erosion distances from each of the threshold options and consideration of the points raised above in section 7.2 around zone widths and relationship to whole beach widths are discussed below for each of coastal environments where T+T applied a probabilistic assessment approach.

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

Figure 7.3 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 Table 7.1. All maps produced for this assessment are available in a webviewer accessible to the project team. Maps of the preferred approach has been provided to CCC as a spatial layer.

As can be seen from Figure 7.3, the options for high and medium hazard categories are largely within the existing beach 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 recommended that to ensure that the full natural protection ability of the dune system against coastal hazards is not compromised, the whole beach-dune width be treated as a High Hazard zone. The position of this zone is shown in Figure 7.4 for the same areas as presented in Figure 7.3 (e.g. North Brighton and Southshore). Note that the width of dune in Figure 7.4has subjectively been applied by the Jacobs team for the purpose of this mapping from vegetation patterns on aerial imagery and smoothed along Marine Parade. These dune positions would need to be confirmed before being used in District Planning Erosion Hazard Zoning.

This approach of including the whole beach-dune environment in the High-Hazard category is consistent with NZCPS Policy 26 and with the approach taken in defining Coastal Erosion Hazard Zone 1 in both the RPS and the RCEP. The position of Coastal Erosion Hazard Zone 1 is shown in Figure 7.4. As per section 7.2, there are also a number of ecological, nature character, and landscape reasons for protecting the whole beach/dune environment from inappropriate development.

It is noted that this whole beach/dune width approach to the High Hazard zone removes the issue with inconsistency zone boundaries across the assessment cell boundaries as shown at South Brighton Spit in the right pane for Figure 7.3. However, it is also noted that the width of the current dune system is variable due to spatial differences in width of the beach-dune buffer applied to past developments. Further work is required to define an optimum width required for healthy dune systems within the High Hazard Zone, as it is likely that in some places current width will be too narrow (e.g. North and New Brighton due to Marine Parade), and in others may be wider that required (e.g. South Brighton & Southshore).

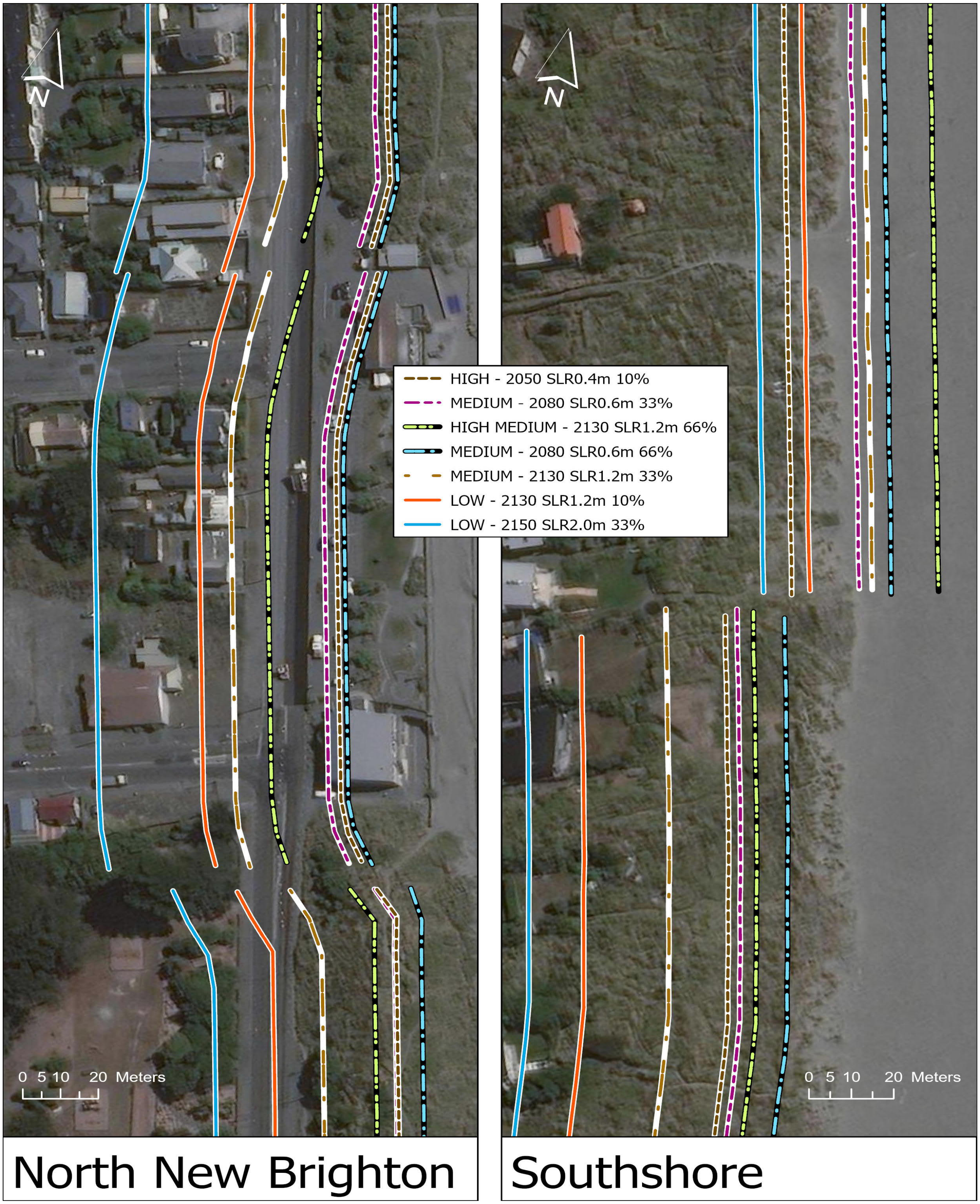


Figure 7.3: Possible options for High, Medium and Low Coastal Erosion Hazard Categories at North Brighton (left) and Southshore (right). Not recommended due to High and Medium zones being within the beach system

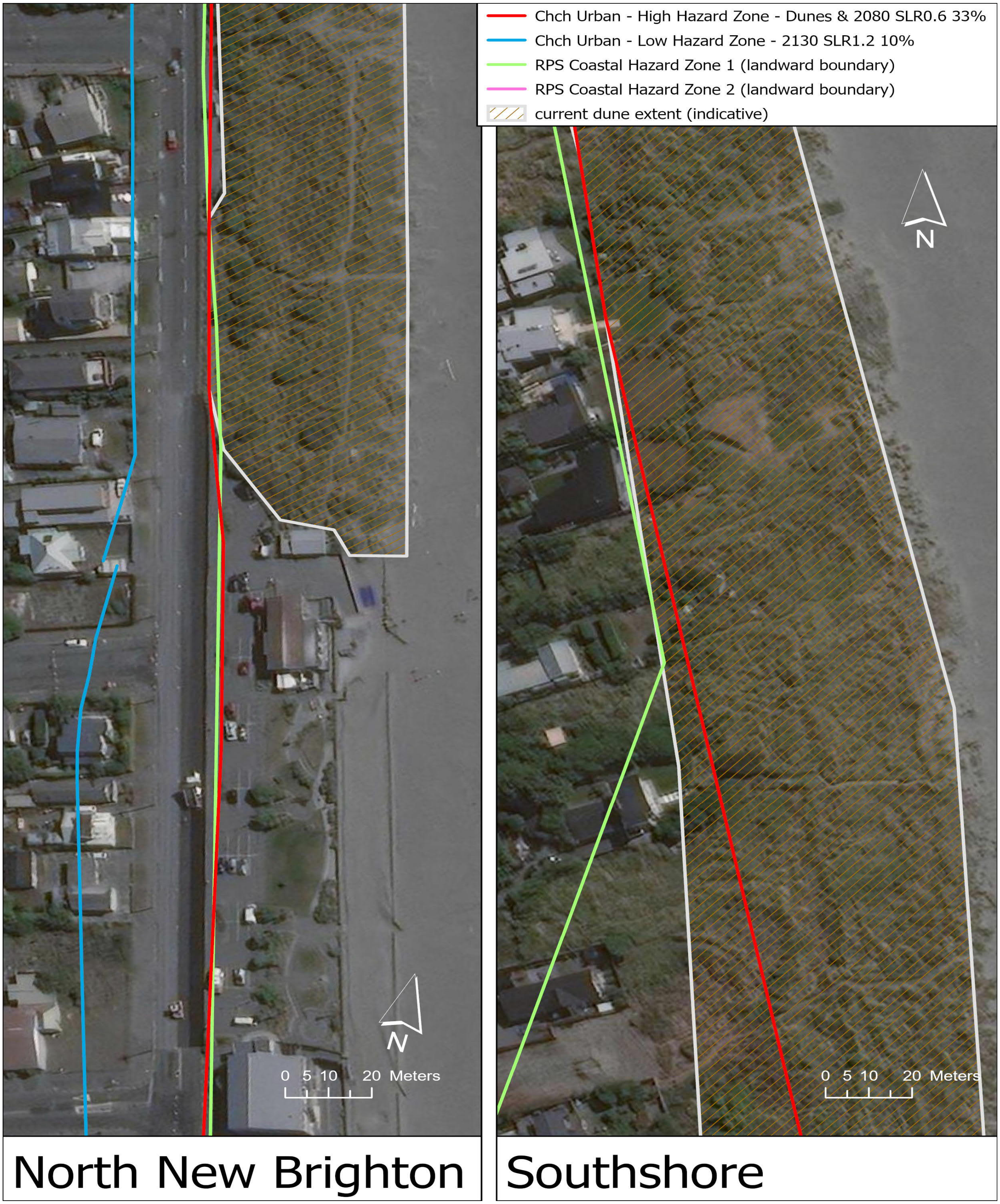


Figure 7.4: Recommended High Coastal Erosion Zone covering whole of the dune environment compared to the RPS/RCEP Hazard Zone 1 and recommended Low Coastal Erosion Hazard Category based directly from the T+T data at the same locations as shown in Figure 7.3 - North Brighton (left) and South Brighton Spit (right).

For the Low Hazard zone, Figure 7.3suggests 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 5.2 this scenario is conservative and it is more uncertain whether this magnitude of SLR will occur within a reasonable time frame for land-use planning. Therefore the 10% probability with 1.2 m SLR by 2130 is considered more appropriate landward boundary for the low Hazard zone and has a higher degree of consistency with the maximum scenario from the deterministic assessment. However, as also noted in Section 7.2, further work is required to define the additional width required in the Low Hazard Coastal Erosion Zone for ‘future healthy beach factors’. This could result in the Low Hazard boundary being close to the position of the 33% probability with 1.5 m SLR by 2150.

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 7.4. As can be seem from the right pane in Figure 7.4(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.

An overview of where Low Hazard zones would be required based directly on the position of the 10% probability with 1.2 m SLR by 1230 from the T+T data (e.g. no consideration of ‘future healthy beach factors’ or minimum width) are shown in Figure 7.5, with fuller spatial details being available on the webviewer.

Figure 7.5: Locations where recommended Low Coastal Erosion Hazard Category based directly from the T+T data would be required along the Christchurch open coast - Brooklands Lagoon (left), North New Brighton (centre) and New Brighton (right).

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

Figure 7.6 shows examples on how the high, medium, and low hazard zones would look at two locations in the Avon-Heathcote Estuary from applying the possible threshold options in Table 7.1 under the preferred approach.

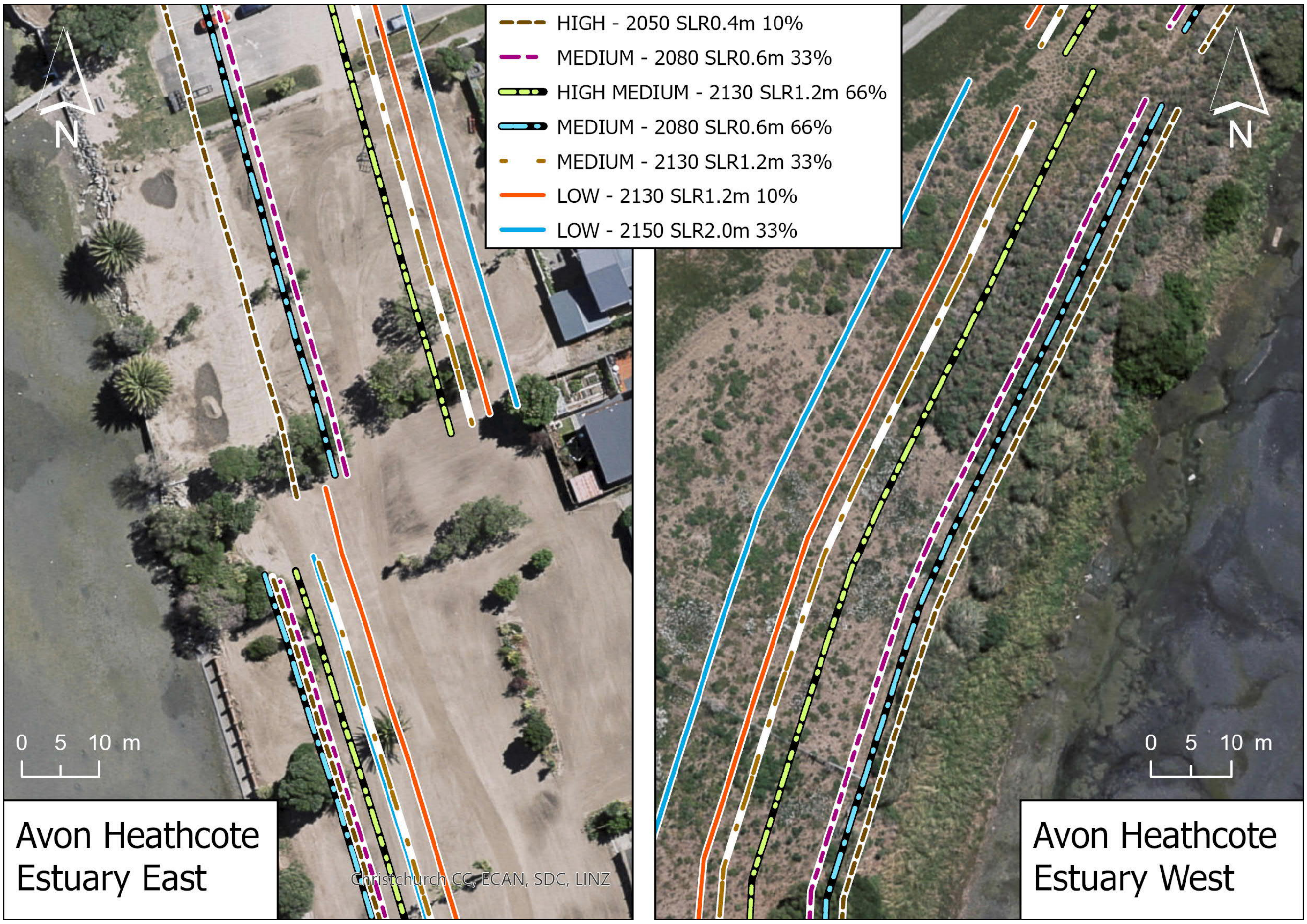


Figure 7.6: Possible options for High, Medium and Low Coastal Erosion Hazard Categories at Southshore (left) and Oxidation ponds (right) around the Avon-Heathcote Estuary. Not recommended due to zones being too narrow.

As can be seen from Figure 7.6, 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 7.6 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. It is therefore further recommended that consideration should be given to applying consistent erosion hazard widths 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. Under this approach, the width of both the High-Medium and Low Coastal Erosion Hazard Zones being 20 m. The position of the recommended Coastal Erosion Hazard Zone boundaries under this approach for selected locations around the estuary is shown in Figure 7.7. More detailed spatial details of these recommended positions are available on the webviewer.

Figure 7.7: Recommended High-Medium and Low Coastal Erosion Hazard Categories at Southshore (left) and Oxidation ponds (right) around the Avon-Heathcote Estuary.

Bays of Banks Peninsula

The recommended threshold options for the Avon-Heathcote Estuary were applied to Charteris Bay and Wainui to see how the resulting zones would look for the bays in Lyttelton and Akaroa Harbours where the probabilistic approach was used. The resulting hazard zones at 10-20 m for the High-Medium hazard category and an additional 10 m for the Low Hazard category were considered too narrow to be practical for land-use planning zones.

It is therefore considered that there only be one hazard zone of these bays in the Harbours having the threshold boundary of:

- 10% probability of erosion with 1.2 m SLR by 2130. The zone has a width 20 -30 m depending on location, as shown in Figure 7.8for Charteris Bay and Wainui.

However, for consistency, this hazard zone also needs to be tested for compatibility with the those calculated in other bays of Lyttelton and Akaroa Harbours and outer Peninsula calculated by the deterministic approach. The results of this comparative testing are presented in the following section.

Figure 7.8: Possible single Coastal Erosion Hazard Zones for Charteris Bay, Lyttelton Harbour (left Pane) and Wainui, Akaroa Harbour (Right Pane), where probabilistic assessments were undertaken. Requires comparative testing against Deterministic assessments.

7.3.2 For Deterministic Screening Assessment Cells

There are 48 cells in the bays and beaches of Lyttelton and Akaroa Harbours and the outer bays of the Peninsula where the deterministic screening approach was used due to lack of data to undertake a probabilistic approach. For these cells different SLR scenarios were used and due to the conservativeness of the method, the statistical probability of erosion occurrence to the resulting ASCE distances are assumed to be 1-5%. However, for a risk based approach to land-use, it is considered important that for similar environments, the resulting risk categories and zone widths are similar regardless of method. Although this would best be achieved by re-running the deterministic assessment for a SLR of 1.2 m by 2130, the comparative testing of the following available thresholds was undertaken:

- Deterministic assumed 1-5% probability for 1.5 m SLR by 2130
- Probabilistic 5% probability for 1.5 m SLR by 2130 (for comparison to similar threshold/scenario as deterministic approach)
- Probabilistic 10% probability for 1.2 m SLR by 2130 (for comparison to best probabilistic single zone option from above)

The results of this comparative testing for Wainui, where there are adjoining probabilistic and deterministic assessment cells are shown in Figure 7.9, which shows the following important results:

1) There is very little difference in the width of a single hazard zone from using the different probabilistic thresholds (max 5 m), and
2) The position of the probabilistic and deterministic low hazard thresholds are very similar.

Therefore, based on this result, it recommended that a single coastal erosion hazard zone for Banks Peninsula bays and beaches is appropriate, and can be based on the following thresholds:

1) For Probabilistic assessment cells the 10% probability of erosion occurrence for 1.2 m SLR by 2130 to be consistent with the Low Hazard zones along the Christchurch Open Coast and the Avon-Heathcote Estuary.
2) For deterministic assessment cells the boundary of the ASCE from the 1.5 m SLR by 2130 scenario, which has an assumed probability of 1-5%.

Figure 7.9: Comparative testing of Probabilistic and deterministic thresholds at Wainui, Akaroa Harbour

7.3.3 For Cliff Assessment Cells

As outlined in Section 4.2.1, the ASCE along the cliff shorelines of the Banks Peninsula is defined as a generic setback distance between 20-30 m. Examples of the comparative widths of these generic cliff hazard zones to the Banks Peninsula single hazard zone in adjoining bays are shown in Figure 7.10 (Charteris Bay) and Figure 7.11 (Wainui). As can be seen from these Figures, the widths of the respective zones are not dissimilar, hence it is considered that there is no significant inconsistency in using these generic cliff erosion setbacks as the boundary for a single erosion zone for land-use planning along the cliff environments of Banks Peninsula.

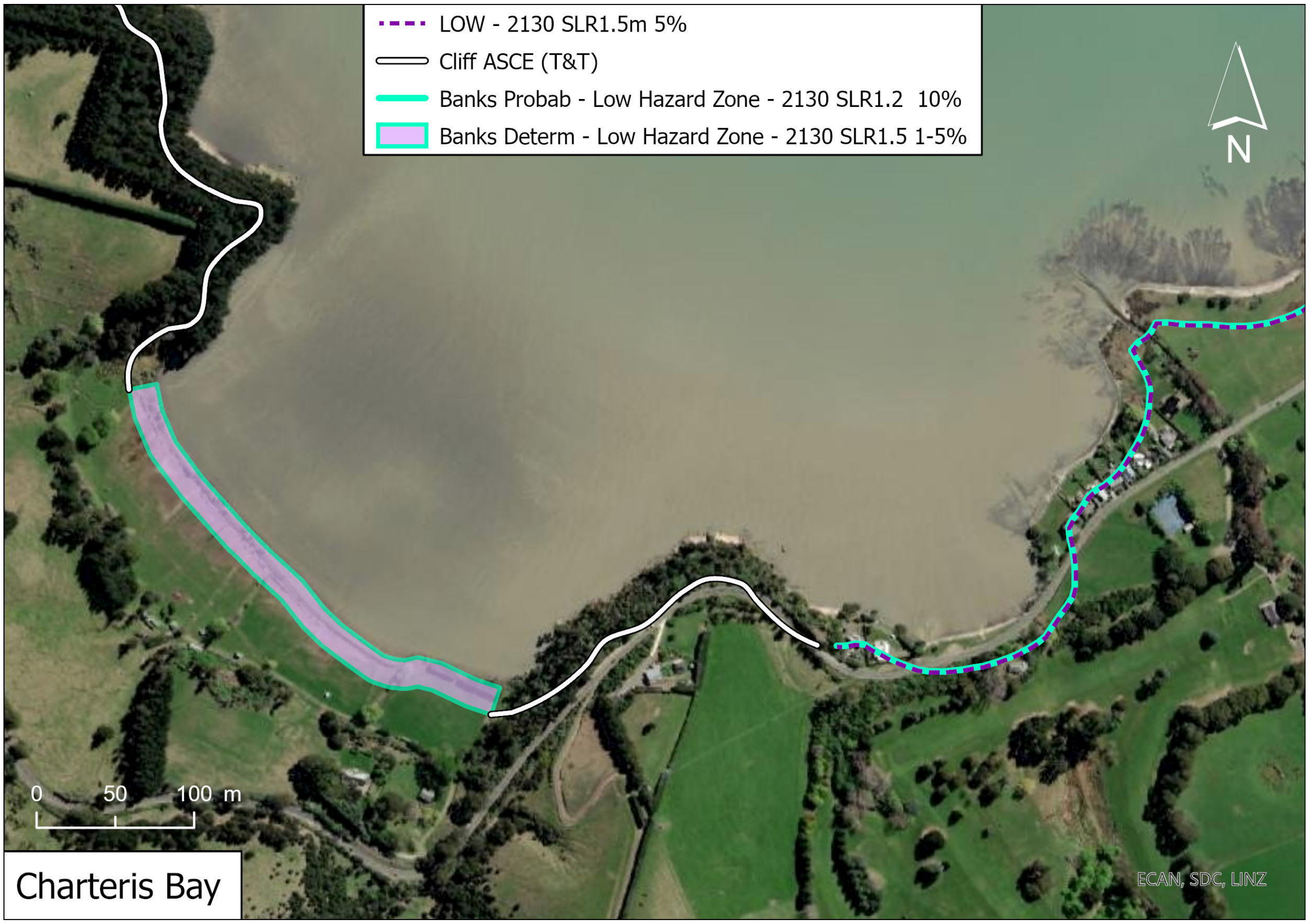


Figure 7.10: Comparative width of generic cliff erosion zone to adjoining probabilistic and deterministic single hazard zones at Charteris Bay, Lyttleton Harbour.

Figure 7.11: Comparative width of generic cliff erosion zone to adjoining probabilistic and deterministic single hazard zones at Wainui, Akaroa Harbour.

7.3.4 For Erosion Protection Cells

As indicated in Section 4.2 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.

It is recognised that inconsistencies in the erosion zone positions at the boundaries of these protection cells with the detailed assessment cells, will need to be addressed.

7.3.5 Considerations in Applying the Risk Thresholds

Uncertainties

Although the SLR scenarios have been chosen with regard to the uncertainties in the magnitude of rise, and the timeframes over which they will occur, and we have developed our recommended erosion thresholds based on the statistical uncertainty of the erosion occurring under these scenarios, there are other sources of uncertainty in the data used to create the thresholds. These include

- The modelling uncertainty, in that how well do the models used estimate future erosion? This is particularly relevant to;
    1) the extrapolation of past historical rates of shoreline movement, which is dependent on sand supply from the Waimakariri River and longshore transport by waves. The T+T assessment presents erosion data for both reductions and increases in sediment supply, and
    2) the accuracy of the Bruun Rule to calculate the erosional effects of SLR.

    There is nothing that can be done to reduce modelling uncertainty.
- The uncertainty in the appropriate erosion across the cell boundaries where the position of the same threshold values do not align. The recommended whole beach/dune environment approach to High Hazard Coastal Erosion Zones for all cells on the Christchurch open coast and the consideration of generic erosion hazard zone widths for Avon-Heathcote Estuary cells, will reduce the significance of this limitation. It is possible to develop a process for smoothing these discontinuities across other cells involving consideration of the representativeness and certainty of the data used in the ASCE calculation as the cell boundary is approached from both longshore directions.
- Uncertainty about the future effectiveness and lifetimes of current protection structures and any future erosion mitigation measures. This is addressed by the recommendation of a standard generic 20 m High Coastal Erosion Hazard zone in these areas.
- Uncertainty about the spatial footprint of the current dune and backshore environments, and how much width is required so that the full natural protection ability of the beach against coastal hazards is not compromised. This can be addressed with further analysis of dune responses to past storm events and modelling of potential future storm scenarios.
- Uncertainty around how dune environments will naturally grow and develop in the future, particularly once they begin to migrate beyond their current footprint, and how much additional area is required for “future healthy beach factors”. This can be addressed with further investigations into dune migration processes.

Data limitations

The analysis of possible scenario and threshold combinations is limited to the data provided from the T+T hazards assessment. These limitations include:

- Data common to all assessment methods being limited to only two timeframes (2080 and 2130). Our consideration of scenarios is therefore limited to these timeframes.
- Data in the deterministic assessment cells not being provided for the preferred scenarios (0.6 m by 2080 and 1.2 m by 2130), therefore limiting the ability for direct comparison with the probabilistic assessment cells.
- The deterministic data being limited to the upper probability bound, therefore potentially raising questions on whether this is a reasonable hazard likelihood over the timeframe to 2130.

8. 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 to the direct project team in a webviewer and the preferred approach will be mapped as pdf's in the final version of this report. 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:

Inundation Table 8.1 provides the recommended definitions for coastal flood risk mapping and Figure 8.1 and Figure 8.2 provide graphical examples of these four flood risk categories.

Table 8.1: Recommended definitions for coastal flood risk mapping using the CHA inundation depth data (d = water depth from the CHA for 1% AEP)

Coastal flood risk category	Flood hazard with 0.6m SLR	Flood hazard with 1.2m SLR
Very low	None (dry)	Low (d < 0.5m)
Low	Low (d < 0.5m)	Medium (0.5m < d < 1.1m)
Medium	Medium (0.5m < d < 1.1m)	High (d > 1.1m)
High	High (d > 1.1m)	High (d > 1.7m)

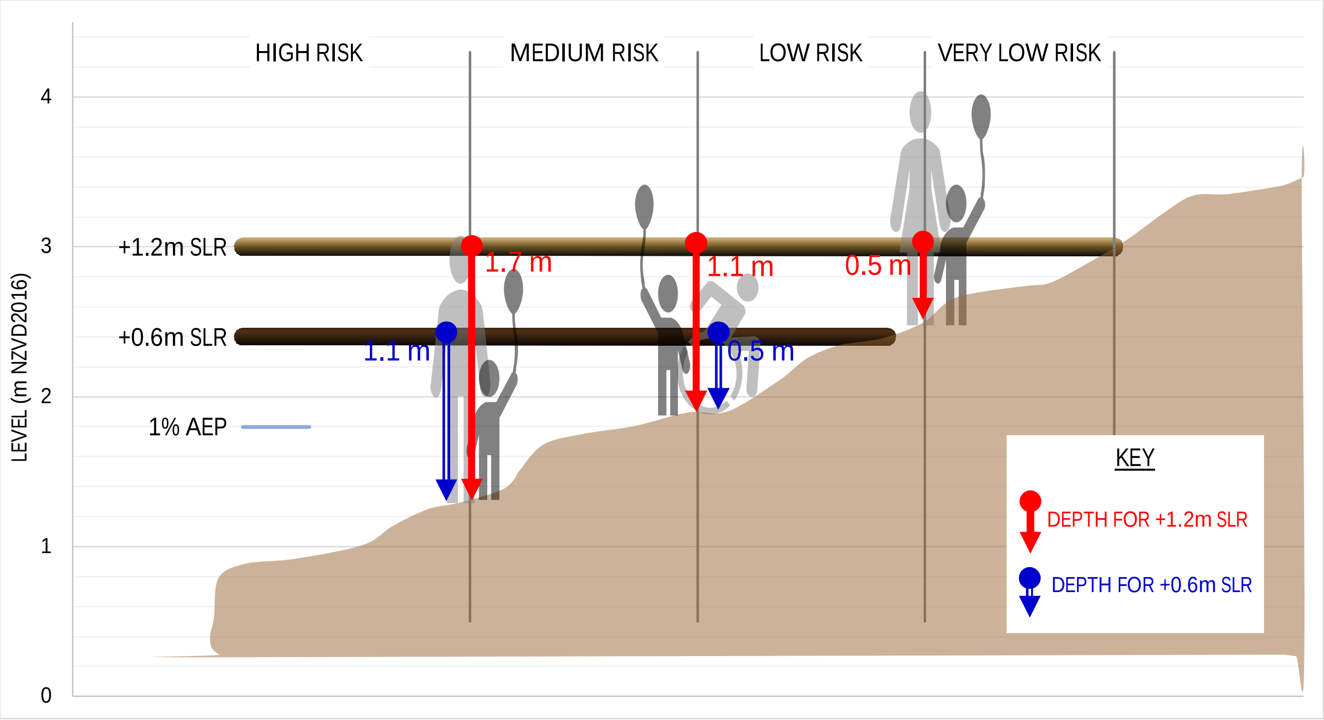


Figure 8.1: Recommended depth thresholds for defining flood risk based on the 1% AEP flood level and 1.2m SLR

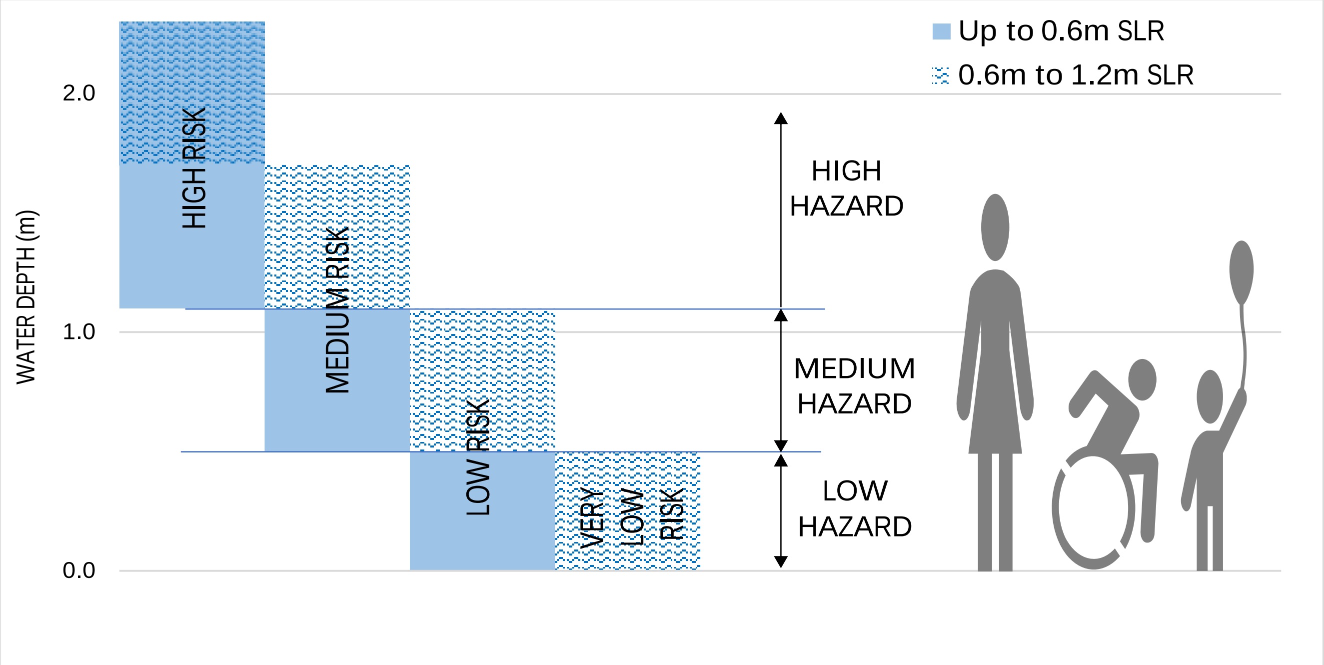


Figure 8.2: Flood risk categories based on the thresholds defined in Figure 8.1

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 whole current beach-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 healthy beach factors”.
2) For the Avon-Heathcote Estuary; two erosion zones comprising of
    a) A High-Medium Hazard Coastal Erosion Zone to a landward limit defined by the 66% probability erosion distance with 0.6 m SLR by 2080, with consideration of a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell under this scenario/threshold option, and
    b) A Low Hazard Coastal Erosion Zone to a landward limit defined by the 10% probability erosion distance with 1.2 m SLR by 2130 with consideration of a consistent generic width of 20 m across all cells to be equal to the largest ASCE in any cell under this scenario/threshold option
3) For the beaches and bays of the Banks Peninsula, Lyttelton Harbour and Akaroa Harbour; a single 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 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 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.

Recommendations

It is recommended that CCC discuss the draft plan change policies and other methods that are developed for these hazard areas with the author of this report to identify whether they are broadly consistent with the reasoning behind the definition of thresholds and choice of scenarios.

Appendix A. Literature Review Summary Information

Table A.1: Summary of hazard categorising methodologies and associated thresholds in multiple documents

Document	Flood hazard	Erosion hazard
Auckland Council: Natural Hazard Risk Communication Toolbox Natural Hazard Risk Management Action Plan, 2014 https://www.civildefence.govt.nz/assets/Uploads/NHRCToolbox/NHRCToolbox-Auckland-Council.pdf	- Depth - velocity - Likelihood - Consequence	
Auckland Unitary Plan, update 9 July 2021 https://unitaryplan.aucklandcouncil.govt.nz/pages/plan/Book.aspx?exhibit=AucklandUnitaryPlan_Print	- Depth - Likelihood - Consequence	- Likelihood - Magnitude - Consequence
Dunedin City Council 2020, 2nd Generation District Plan (2GP) https://www.dunedin.govt.nz/council/district-plan/2nd-generation-district-plan	- Likelihood - Velocity - Consequence[33] - Sensitivity[34] Figure A.1 and Figure A.2	
Waikato Regional Council: General info on website: Flood Hazard Information Questions and Answers https://www.hamilton.govt.nz/our-council/council-publications/districtplans/flood/Pages/Flood-FAQ.aspx	- Depth (for both inside and outside the River zone Figure A.3) - Velocity (just for OUTSIDE the	

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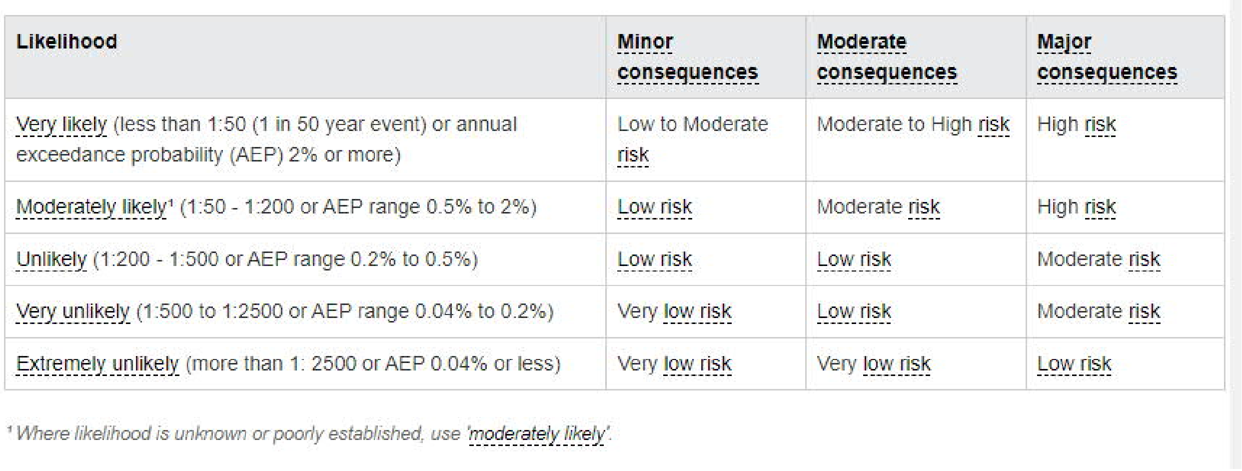
[33] The consequences of a natural hazard event occurring are considered in the context of health and safety, costs of damage to the built environment, and social and economic impacts on the wider community

[34] the sensitivity of land use activities is classified according to the health and safety implications of the land use. This helps to manage the consequences that may occur as a result of a natural hazard event. This sensitivity classification draws from, and broadly corresponds to, the building importance levels defined in the Building Regulations 1992 (Schedule 1: The building code).

Document	Flood hazard	Erosion hazard
	River zone Figure A.4)	
Hamilton City council (2012 information) https://www.hamilton.govt.nz/our-council/council-publications/districtplans/flood/Documents/GIS%20-%20Metadata%20for%20Flood%20Hazard%20Modelling%20(FHM)%20Data%20-%20City%20Waters.pdf	- Depth - Velocity Figure A.5	
Waimakariri District Council https://waimakariri.maps.arcgis.com/apps/MapSeries/index.html?appid=16d97d92a45f4b3081ffa3930b534553	- Velocity - Depth: (High Hazard depth >1 m, Medium Hazard – 0.3m <Depth< 1m, Low – Depth less than 0.3m)	
Thames Coromandel District Plan	- Depth - Velocity Figure A.6	
Christchurch District Plan https://districtplan.ccc.govt.nz/pages/plan/book.aspx?exhibit=DistrictPlan (based on Canterbury RPS Canterbury Regional Policy Statement | Environment Canterbury (ecan.govt.nz)	- Depth - Velocity - Likelihood	-likelihood
Wellington city council https://gis.wcc.govt.nz/LocalMaps/Viewer/?map=5c3d903dc4c043e0953410033c5c0b3e	- Depth Figure A.7	

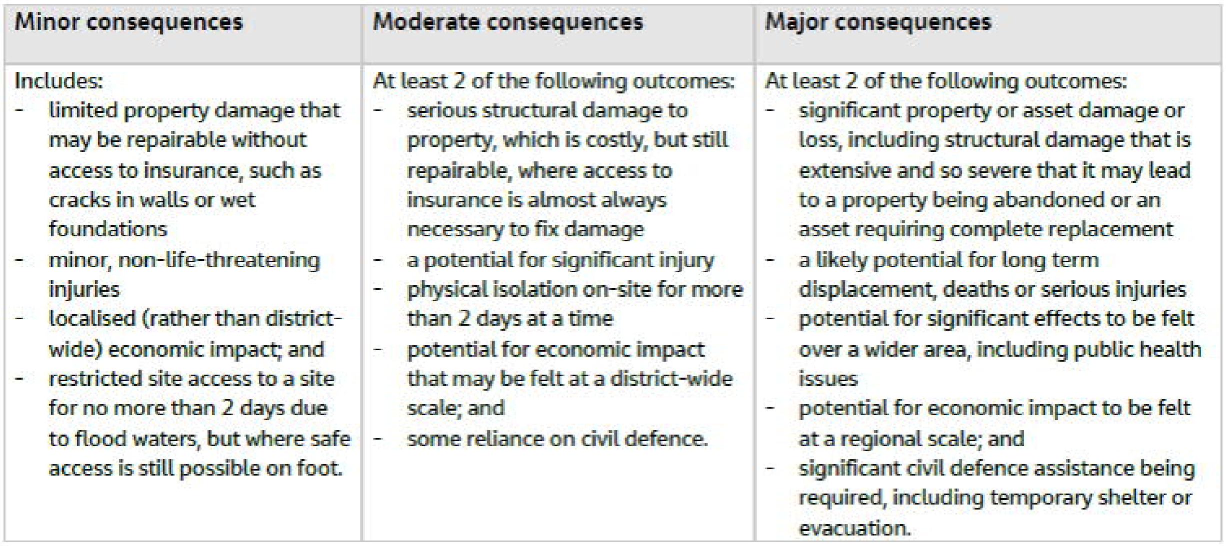
Document	Flood hazard	Erosion hazard
Technical flood risk management guideline: Flood hazard Australian Disaster Resilience Handbook Collection 2012 https://knowledge.aidr.org.au/media/1891/guideline-7-3-technical-flood-risk-management.pdf	- Depth - Velocity Figure A.8 and Figure A.9	
Department for Environment, Food & Rural Affairs (Defra) Flood Risks to People-Phase 2, 2006	- Depth - Velocity Figure A.10	
Managing natural hazard risk in New Zealand – towards more resilient communities 2014 https://www.lgnz.co.nz/assets/Publications/de504aaea2/Managing-natural-hazards-LGNZ-think-piece.pdf	- Likelihood - Consequence	
The National Flood Risk Analysis for the Netherlands FINAL REPORT, 2017? https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/programma-projecten/veiligheid-nederland/english/flood-risk-the/	- Likelihood - Consequence	
World Meteorological Organization https://public.wmo.int/en/resources/bulletin/chinas-implementation-of-impact-and-risk-based-early-warning	- Depth Figure A.11 and Figure A.12	



Likelihood	Minor consequences	Moderate consequences	Major consequences
Very likely (less than 1:50 (1 in 50 year event) or annual exceedance probability (AEP) 2% or more)	Low to Moderate risk	Moderate to High risk	High risk
Moderately likely[1] (1:50 - 1:200 or AEP range 0.5% to 2%)	Low risk	Moderate risk	High risk
Unlikely (1:200 - 1:500 or AEP range 0.2% to 0.5%)	Low risk	Low risk	Moderate risk
Very unlikely (1:500 to 1:2500 or AEP range 0.04% to 0.2%)	Very low risk	Low risk	Moderate risk
Extremely unlikely (more than 1: 2500 or AEP 0.04% or less)	Very low risk	Very low risk	Low risk

[1] Where likelihood is unknown or poorly established, use 'moderately likely'.

Figure A.1: Dunedin Council



Minor consequences	Moderate consequences	Major consequences
Includes: - limited property damage that may be repairable without access to insurance, such as cracks in walls or wet foundations - minor, non-life-threatening injuries - localised (rather than district-wide) economic impact; and - restricted site access to a site for no more than 2 days due to flood waters, but where safe access is still possible on foot.	At least 2 of the following outcomes: - serious structural damage to property, which is costly, but still repairable, where access to insurance is almost always necessary to fix damage - a potential for significant injury - physical isolation on-site for more than 2 days at a time - potential for economic impact that may be felt at a district-wide scale; and - some reliance on civil defence.	At least 2 of the following outcomes: - significant property or asset damage or loss, including structural damage that is extensive and so severe that it may lead to a property being abandoned or an asset requiring complete replacement - a likely potential for long term displacement, deaths or serious injuries - potential for significant effects to be felt over a wider area, including public health issues - potential for economic impact to be felt at a regional scale; and - significant civil defence assistance being required, including temporary shelter or evacuation.

Figure A.2: Dunedin Council

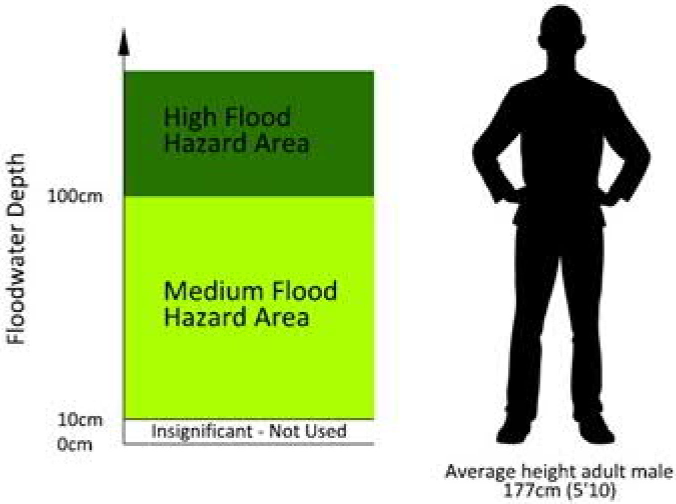


Figure A.3: Waikato River zone

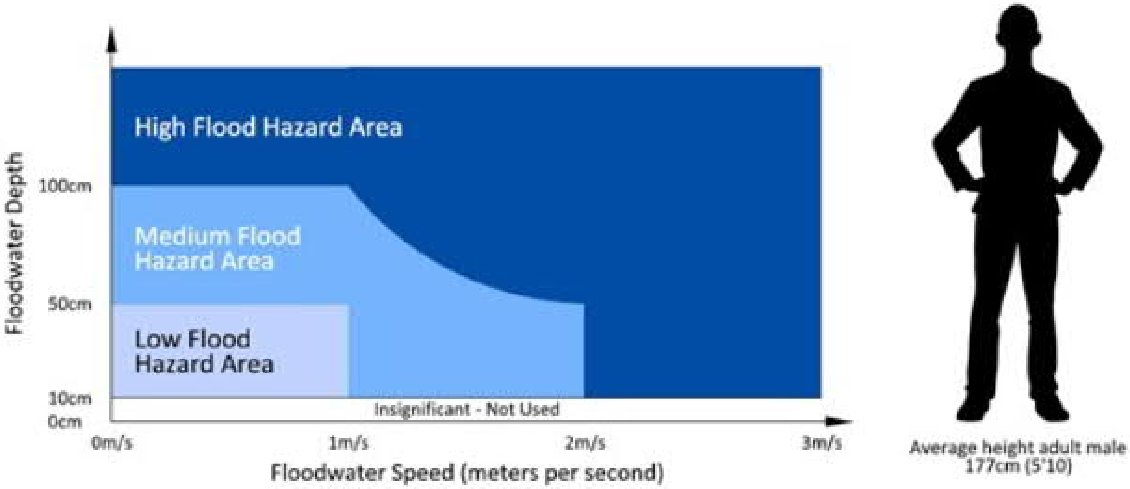


Figure A.4: Outside Waikato River zone

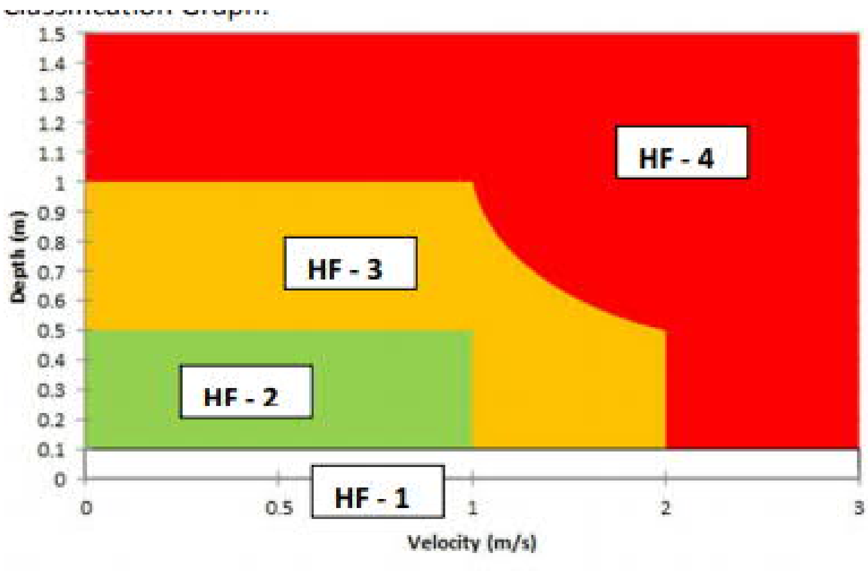


Figure A.5: Hamilton City Council

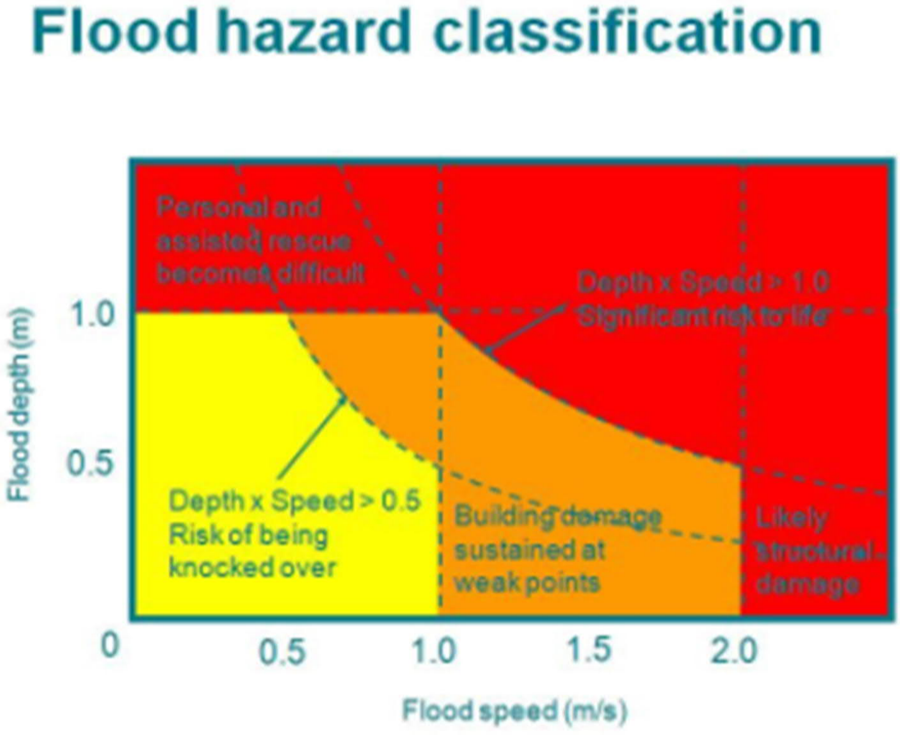
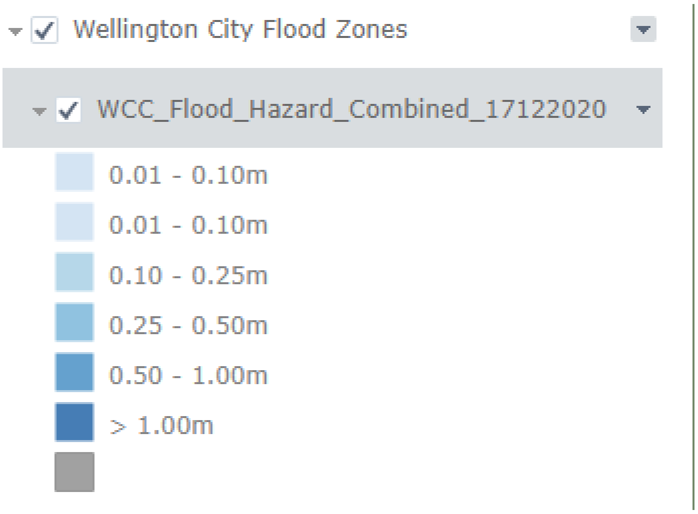


Figure A.6: Thames Coromandel

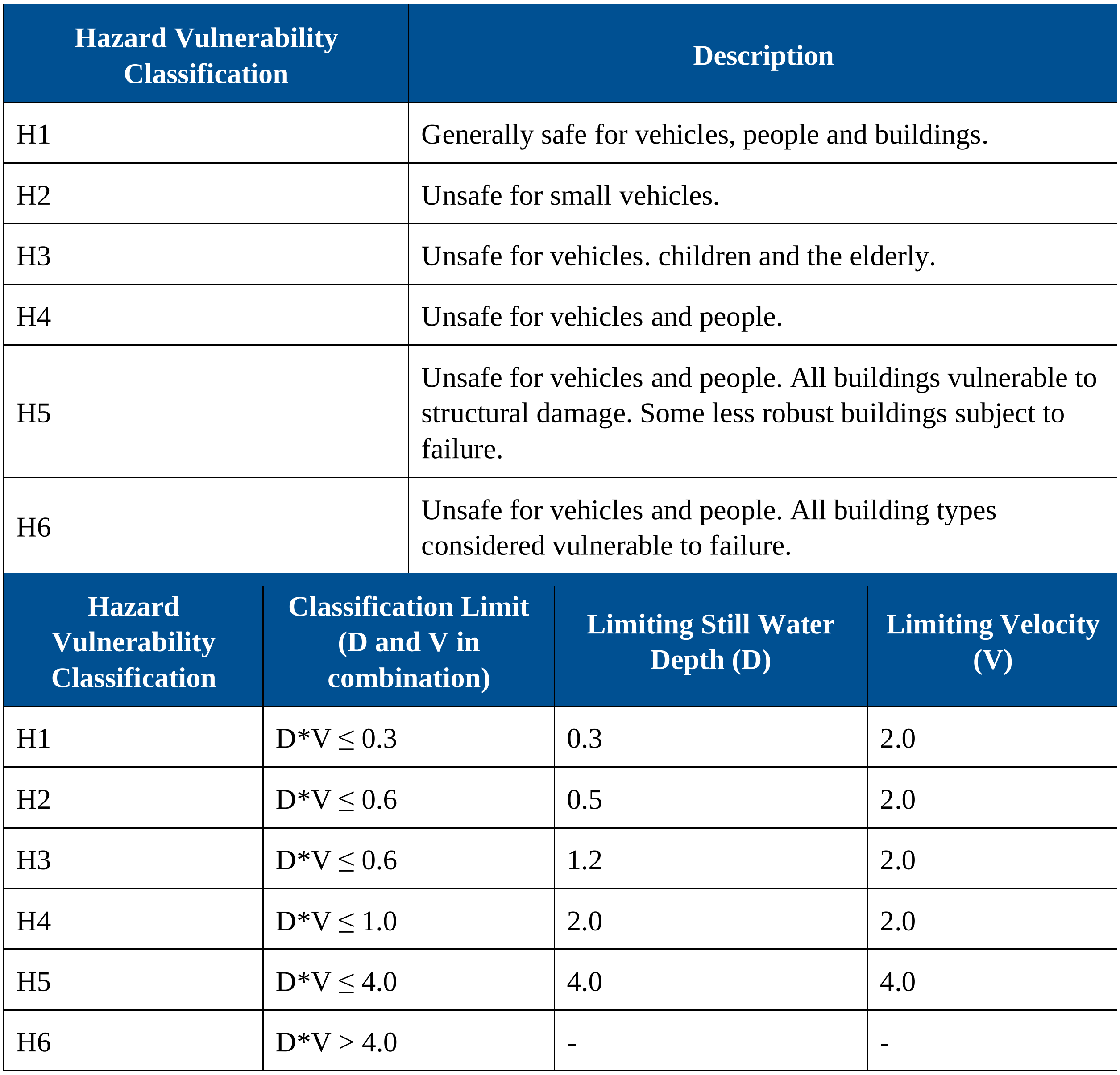


☑ Wellington City Flood Zones

☑ WCC_Flood_Hazard_Combined_17122020

- 🟦 0.01 - 0.10m
- 🟦 0.01 - 0.10m
- 🟦 0.10 - 0.25m
- 🟦 0.25 - 0.50m
- 🟦 0.50 - 1.00m
- 🟦 > 1.00m
- ⬛

Figure A.7: Wellington City Flood Hazard



Hazard Vulnerability Classification	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles. children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

Hazard Vulnerability Classification	Classification Limit (D and V in combination)	Limiting Still Water Depth (D)	Limiting Velocity (V)
H1	D*V ≤ 0.3	0.3	2.0
H2	D*V ≤ 0.6	0.5	2.0
H3	D*V ≤ 0.6	1.2	2.0
H4	D*V ≤ 1.0	2.0	2.0
H5	D*V ≤ 4.0	4.0	4.0
H6	D*V > 4.0	-	-

Figure A.8: Australian Disaster Resilience Handbook (thresholds)

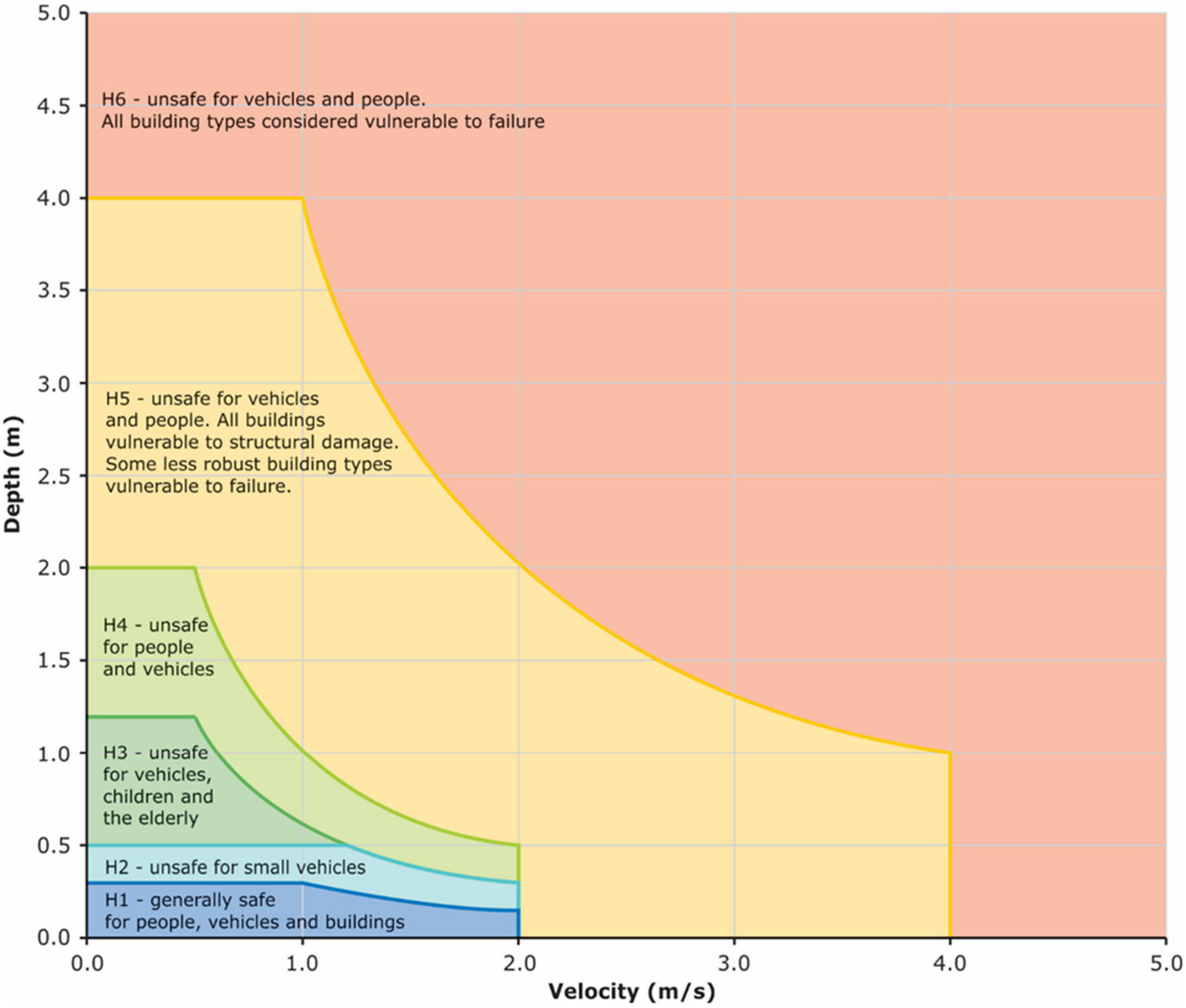


Figure A.9: Australian Disaster Resilience Handbook (categories)

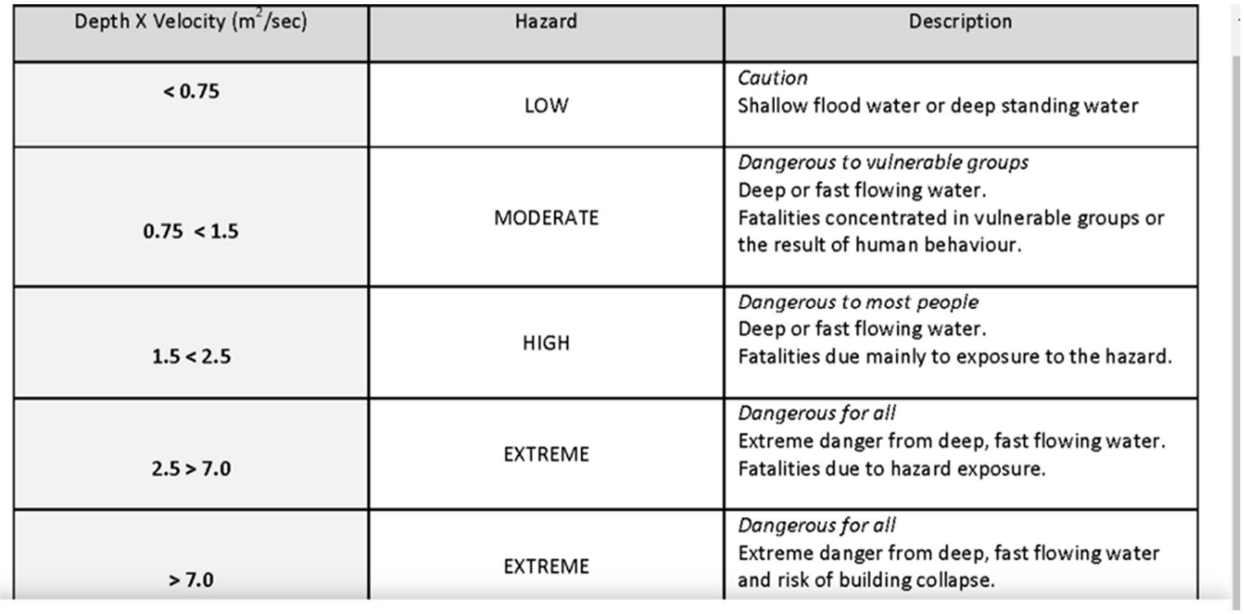
Velocity Coefficient C 0.5

(V+C) * D

	Depth									
Velocity	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**
0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25
0.50	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
1.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
1.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
2.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
2.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
3.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
3.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
4.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
4.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
5.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75

	From	To	
Class 1	0.75	1.25	Danger for some
Class 2	1.25	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

Figure A.10: Defra hazard matrix



Depth X Velocity (m^2/sec)	Hazard	Description
< 0.75	LOW	*Caution* Shallow flood water or deep standing water
0.75 < 1.5	MODERATE	*Dangerous to vulnerable groups* Deep or fast flowing water. Fatalities concentrated in vulnerable groups or the result of human behaviour.
1.5 < 2.5	HIGH	*Dangerous to most people* Deep or fast flowing water. Fatalities due mainly to exposure to the hazard.
2.5 > 7.0	EXTREME	*Dangerous for all* Extreme danger from deep, fast flowing water. Fatalities due to hazard exposure.
> 7.0	EXTREME	*Dangerous for all* Extreme danger from deep, fast flowing water and risk of building collapse.

Figure A.11: World Meteorological Organization

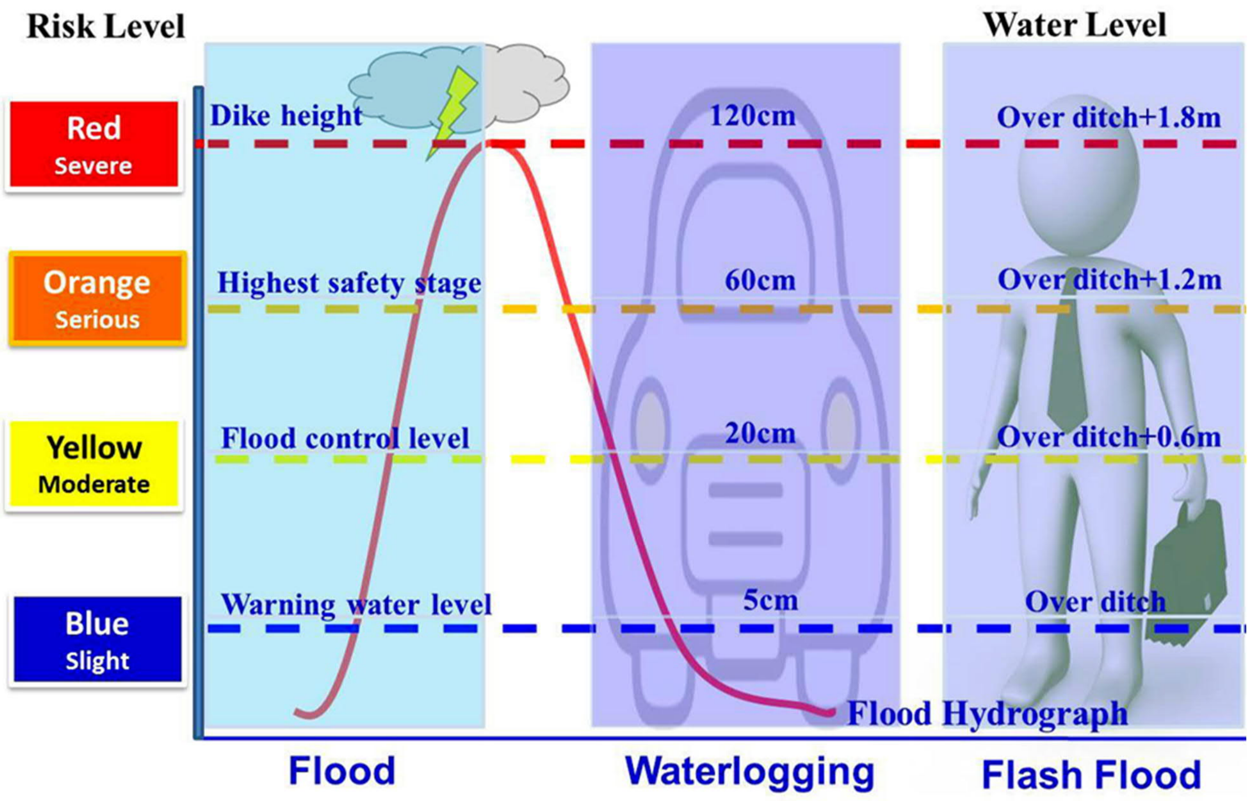


Figure A.12: World Meteorological Organization

Appendix B. Detailed Planning Context

B.1 New Zealand Coastal Policy Statement (NZCPS)

NZCPS provides national direction for the management of, and adaption to coastal hazards. Objective 5 of the NZCPS provides an overarching guidance regarding hazards and land uses:

To ensure that coastal hazard risks taking account of climate change, are managed by:

- locating new development away from areas prone to such risks;
- considering responses, including managed retreat, for existing development in this situation; and
- protecting or restoring natural defences to coastal hazards.

Policy 3: Precautionary approach:

(1) Adopt a precautionary approach towards proposed activities whose effects on the coastal environment are uncertain, unknown, or little understood, but potentially significantly adverse.

(2) In particular, adopt a precautionary approach to use and management of coastal resources potentially vulnerable to effects from climate change, so that:

> *(a) avoidable social and economic loss and harm to communities does not occur;*
>
> *(b) natural adjustments for coastal processes, natural defences, ecosystems, habitat and species are allowed to occur; and*
>
> *(c) the natural character, public access, amenity and other values of the coastal environment meet the needs of future generations.*

The means by which to identify coastal hazard risks is described by Policy 24:

(1) Identify areas in the coastal environment that are potentially affected by coastal hazards (including tsunami), giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, are to be assessed having regard to:

(a) physical drivers and processes that cause coastal change including sea level rise;

(b) short-term and long-term natural dynamic fluctuations of erosion and accretion;

(c) geomorphological character;

(d) the potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent;

(e) cumulative effects of sea level rise, storm surge and wave height under storm conditions;

(f) influences that humans have had or are having on the coast;

(g) the extent and permanence of built development; and (h) the effects of climate change on:

(i) matters (a) to (g) above;

(ii) storm frequency, intensity and surges; and

(iii) coastal sediment dynamics; taking into account national guidance and the best available information on the likely effects of climate change on the region or district.

These matters have been addressed by T+T in preparing the Coastal Hazard Assessment, which is the base data for the analysis of thresholds for defining the boundaries of coastal hazard categories in this report.

The NZCPS requires councils to utilise the information developed in Policy 24 to manage the risks, and wider effects of hazards on land uses. This approach is elaborated on by Policy 25:

- In areas potentially affected by coastal hazards over at least the next 100 years:
- avoid increasing the risk of social, environmental and economic harm from coastal hazards.
- avoid redevelopment, or change in land use, that would increase the risk of adverse effects from coastal hazards;
- encourage redevelopment, or change in land use, where that would reduce the risk of adverse effects from coastal hazards, including managed retreat by relocation or removal of existing structures or their abandonment in extreme circumstances, and designing for relocatability or recoverability from hazard events;
- encourage the location of infrastructure away from areas of hazard risk where practicable;
- discourage hard protection structures and promote the use of alternatives to them, including natural defences; and
- consider the potential effects of tsunami and how to avoid or mitigate them.

It should be noted that the language used in this policy is directive with the use of “avoid” in the first two sub-parts to the policy. RMA case law have established that avoiding or avoidance is of the highest order of responses, only surpassed by prohibiting. In Environmental Defence Society Inc v The New Zealand King Salmon Co Ltd [2014] NZSC 38, the New Zealand Supreme Court found that the use of the word avoid in the NZCPS means “not allowing" and "inappropriateness". As such, Policy 25 provides a clear direction as to the importance of preventing an increase in coastal hazard risks, as well as the potential for more restrictive controls on existing land uses. Policy 25 also provides clear direction as the duration that coastal hazard risks should be considered, that being 100 years.[35]

While this report does not recommend specific responses to coastal hazard, it is recognised that this analysis will be used in concert with other analysis and community engagement to confirm preferred regulatory responses to these risks. This process will also include the reporting required under s32 of the RMA, with the s32 reporting needing to address Policy 27 of the NZCPS:

1 In areas of significant existing development likely to be affected by coastal hazards, the range of options for reducing coastal hazard risk that should be assessed includes:

---

[35] The NZCPS describes risk as:

“Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence (AS/NZS ISO 31000:2009 Risk management – Principles and guidelines, November 2009).”

It should be noted that exercises to identify and assess risks are not limited by the above description, given that it is only a description rather than a binding definition.

a) promoting and identifying long-term sustainable risk reduction approaches including the relocation or removal of existing development or structures at risk;

b) identifying the consequences of potential strategic options relative to the option of "do-nothing";

c) recognising that hard protection structures may be the only practical means to protect existing infrastructure of national or regional importance, to sustain the potential of built physical resources to meet the reasonably foreseeable needs of future generations;

d) recognising and considering the environmental and social costs of permitting hard protection structures to protect private property; and

e) identifying and planning for transition mechanisms and timeframes for moving to more sustainable approaches.

2. In evaluating options under (1):

a) focus on approaches to risk management that reduce the need for hard protection structures and similar engineering interventions;

b) take into account the nature of the coastal hazard risk and how it might change over at least a 100-year timeframe, including the expected effects of climate change; and

c) evaluate the likely costs and benefits of any proposed coastal hazard risk reduction options.

B.2 Canterbury Regional Policy Statement (the RPS)

RPS Chapter 11 "Natural Hazards" policies provides some direction for assessing coastal hazards. The two relevant objectives of this chapter are:

11.2.1 - Avoid new subdivision, use and development of land that increases risks associated with natural hazards.

New subdivision, use and development of land which increases the risk of natural hazards to people, property and infrastructure is avoided or, where avoidance is not possible, mitigation measures minimise such risks.

11.2.3 – Climate change and natural hazards

The effects of climate change, and its influence on sea levels and the frequency and severity of natural hazards, are recognised and provided for.

These objectives are then detailed further by the following policies:

11.3.1 - Avoidance of inappropriate development in high hazard areas

To avoid new subdivision, use and development (except as provided for in Policy 11.3.4) of land in high hazard areas, unless the subdivision, use or development:

1. is not likely to result in loss of life or serious injuries in the event of a natural hazard occurrence; and
2. is not likely to suffer significant damage or loss in the event of a natural hazard occurrence; and

3. is not likely to require new or upgraded hazard mitigation works to mitigate or avoid the natural hazard; and

4. is not likely to exacerbate the effects of the natural hazard; or

5. Outside of greater Christchurch, is proposed to be located in an area zoned or identified in a district plan for urban residential, industrial or commercial use, at the date of notification of the CRPS, in which case the effects of the natural hazard must be mitigated; or

6. Within greater Christchurch, is proposed to be located in an area zoned in a district plan for urban residential, industrial or commercial use, or identified as a "Greenfield Priority Area" on Map A of Chapter 6, both at the date the Land Use Recovery Plan was notified in the Gazette, in which the effect of the natural hazard must be avoided or appropriately mitigated; or

7. Within greater Christchurch, relates to the maintenance and/or upgrading of existing critical or significance infrastructure.

11.3.2 - Avoid development in areas subject to inundation

In areas not subject to Policy 11.3.1 that are subject to inundation by a 0.5% AEP flood event; any new subdivision, use and development (excluding critical infrastructure) shall be avoided unless there is no increased risk to life, and the subdivision, use or development:

1. is of a type that is not likely to suffer material damage in an inundation event; or

2. is ancillary or incidental to the main development; or 3. meets all of the following criteria:

    a. new buildings have an appropriate floor level above the 0.5% AEP design flood level; and

    b. hazardous substances will not be inundated during a 0.5% AEP flood event; provided that a higher standard of management of inundation hazard events may be adopted where local catchment conditions warrant (as determined by a cost/benefit assessment). When determining areas subject to inundation, climate change projections including sea level rise are to be taken into account.

11.3.4 - Critical infrastructure

New critical infrastructure will be located outside high hazard areas unless there is no reasonable alternative. In relation to all areas, critical infrastructure must be designed to maintain, as far as practicable, its integrity and function during natural hazard events.

11.3.5 - General risk management approach

For natural hazards and/or areas not addressed by policies 11.3.1, 11.3.2, and 11.3.3, subdivision, use or development of land shall be avoided if the risk from natural hazards is unacceptable. When determining whether risk is unacceptable, the following matters will be considered:

1. the likelihood of the natural hazard event; and

2. the potential consequence of the natural hazard event for: people and communities, property and infrastructure and the environment, and the emergency response organisations. Where there is uncertainty in the likelihood or consequences of a natural hazard event, the local authority shall adopt a precautionary *approach. Formal risk management techniques should be used, such as the Risk Management Standard (AS/NZS ISO 31000:2009) or the Structural Design Action Standard (AS/NZS 1170.0:2002).*

11.3.6 - Role of natural features

The role of natural topographic (or geographic) and vegetation features which assist in avoiding or mitigating natural hazards should be recognised and the features maintained, protected and restored, where appropriate.

11.3.9 - Integrated management of, and preparedness for, natural hazards

To undertake natural hazard management and preparedness for natural hazard events in a coordinated and integrated manner by ensuring that the lead agencies have particular regard to:

1. the investigation and identification of natural hazards;

2. the analysis and mapping of the consequential effects of the natural hazards identified;

3. the effects of climate change and resulting sea level rise;

6. any other matters necessary to ensure the integrated management of natural hazards in the Canterbury region

These objectives and policies are consistent with the direction set by the NZCPS, in that decision making associated with land use activities should avoid increasing natural hazard risks. They also recognise and provide for the projected increases in sea levels and associated hazards and detail the types of risks to be considered, principally loss of life or significant damage to property. They also acknowledge the importance of critical infrastructure and its locational requirements (i.e. some infrastructure must be located within/through hazardous areas.

It is also noted that these policies are directive, in that they detail specific requirements for building in inundation areas and this direction has been incorporated into this study's identification of risks. The policy framework also set out the requirement for district and city councils to investigate, map and address natural hazards, with specific regard given to the effects of sea level rise and climate change.

Lastly, Policy 11.3.1 helpfully provides a definition of high hazard areas, which includes land subject to sea water inundation and coastal erosion:

"*High hazard areas*" are:

1. *flood hazard areas subject to inundation events where the water depth (metres) x velocity (metres per second) is greater than or equal to 1, or where depths are greater than 1 metre, in a 0.2% AEP flood event;*

2. *land outside of greater Christchurch subject to coastal erosion over the next 100 years; and*

3. *land within greater Christchurch likely to be subject to coastal erosion including the cumulative effects of sea level rise over the next 100 This includes (but is not limited to) the land located within Hazard Zones 1 and 2 shown on Maps in Appendix 5 of this Regional Policy Statement that have been determined in accordance with Appendix 6; and*

4. *land subject to sea water inundation (excluding tsunami) over the next 100 years. This includes (but is not limited to) the land located within the sea water inundation zone boundary shown on Maps in Appendix 5 of this Regional Policy Statement.*

B.3 Regional Coastal Environment Plan for the Canterbury Region (RCEP)

The RCEP recognises the dynamic and connected nature of the coastal environment and therefore includes objectives, policies and rules for coastal hazards on the landward of the Mean High Water Spring boundary of mandatory Regional Coastal Plans. The following objective and related policies are considered relevant:

Objective 9.	*a. To minimise the need for hazard protection works, and avoid or mitigate the actual or potential effects of coastal hazards by locating use and development away.*
Policy 9.1	*a. New habitable buildings should be located away from areas of the coastal environment that are, or have the potential to be, subject to sea water inundation or coastal erosion.* *b. Any new development in the coastal environment should be designed or located in such a way that the need for coastal protection works, now and in the future, is minimised.* *c. The continued use and protection of essential infrastructure and services should be provided for, where no reasonable alternative exists, in areas subject to coastal hazards, provided adverse effects on the coastal environment are avoided, remedied or mitigated.*

The RCEP pre-dates both the NZCPS and RPS, and its language is less restrictive than the NZCPS (i.e. should rather than avoid), there is never-the-less the same clear guidance as to the importance of identifying, mapping and assessing coastal hazards. This includes the mapping of coastal erosion hazard zones along the majority of the region's coastline which form the areas for implementation of the rules under the above hazard objectives and policies.

These erosion hazard zones are defined as being:

- Erosion Hazard Zone 1:

  (a) For stable or accretionary shorelines: Where there is no evidence of shoreline erosion, the width of Hazard Zone 1 is the area landward of the Coastal Marine Area boundary to the landward limit of the active beach system. This position is determined either by ground survey, or from aerial photography.

  (b) For most eroding shorelines: The width of Hazard Zone 1 includes the active beach system and the area landward of this, which is likely to be part of the active beach system if contemporary erosion processes continue unaltered for the next 50 years. Hence, the landward limit of Hazard Zone 1 corresponds to the projected position of the landward toes of the active beach system.

  The width of hazard zones has been determined by interpolating the rate of shoreline retreat between fixed determination points. For all determination points, except for some special situations listed below, there was no evidence of a change in the long term rate of shoreline retreat. Therefore, the longest term historical erosion rates have been used. These will include short term fluctuations.

- Erosion Hazard Zone 2:

  No Hazard Zone 2 is defined for stable or accreting shorelines.

  For eroding shorelines, Hazard Zone 2 is landward of Hazard Zone 1, and covers areas that could become part of the active beach system within 50 to 100 years if the erosion rates used to calculate Hazard Zone 1 were to continue unaltered for 100 years.

The RCEP also maps a sea water inundation zone, covering areas known to have been affected by coastal inundation the past, but does not include any policies or rules around this hazard.

B.4 The Christchurch District Plan

The Christchurch District Plan currently includes a number of objectives and policies relevant to coastal hazards. These would likely be reviewed and amended or replaced by a potential CHPC. Current objectives and policies include:

Objective 3.6 – Natural Hazards

(a)New subdivision, use and development (other than new critical infrastructure or strategic infrastructure to which paragraph b. applies):

(i) is to be avoided in areas where the risks from natural hazards to people, property and infrastructure are assessed as being unacceptable; and

(ii) in all other areas, is undertaken in a manner that ensures the risks of natural hazards to people, property and infrastructure are appropriately mitigated.

(b) New critical infrastructure or strategic infrastructure may be located in areas where the risks of natural hazards to people, property and infrastructure are otherwise assessed as being unacceptable, but only where:

(i) there is no reasonable alternative; and

(ii) the strategic infrastructure or critical infrastructure has been designed to maintain, as far as practicable, its integrity and form during natural hazard events; and the natural hazard risks to people, property and infrastructure are appropriately mitigated.

(iii) There is increased public awareness of the range and scale of natural hazard events that can affect Christchurch District.

(iv) The repair of earthquake damaged land is facilitated as part of the recovery.

5.2.2.1.1 Policy - Avoid new development where there is unacceptable risk

(a) Avoid new subdivision, use and development, including new urban zonings, where the risk from a natural hazard is assessed as being unacceptable.

5.2.2.1.2 Policy -- Manage activities to address natural hazard risks

(a) Manage activities in all areas subject to natural hazards in a manner that is commensurate with the likelihood and consequences of a natural hazard event on life and property.

5.2.2.1.3 Policy -- Infrastructure

(a) Avoid locating new critical infrastructure where it is at risk of being significantly affected by a natural hazard unless, considering functional and operational requirements, there is no reasonable alternative location or method.

(b) Enable critical infrastructure to be designed, maintained and managed to function to the extent practicable during and after natural hazard events.

(c) Recognise the benefits of infrastructure and the need for its repair, maintenance and ongoing use in areas affected by natural hazards.

5.2.2.2 Policy for managing risk from flooding

(a)Map hazard risk for the Flood Management Area based on:

(i) a modelled 0.5% AEP (1 in 200-year) rainfall event plus a 5% AEP (1 in 20-year) tide event plus 250mm freeboard; OR a modelled 5% AEP (1 in 20-year flood event) plus a 0.5% AEP (1 in 200-year) tide event plus 250mm freeboard; OR 11.9m above Christchurch City Council Datum (the maximum 200-year tidal contour) plus 250mm freeboard; whichever is the greater; and

(ii)allowance for 1 metre of sea level rise and an increase in rainfall intensity by 16% through to 2115 as a result of climate change; and

(iii) a maximum buffer extension of the modelled rainfall event areas by 60 metres in a north/south and east/west direction.

(b) In the High Flood Hazard Management Area:

(i) provide for development of a residential unit on residentially zoned land where the flooding risk is predominantly influenced by sea-level rise and where appropriate mitigation can be provided that protects people's safety, well-being and property from unacceptable risk; and

(iii) in all other cases, avoid subdivision, use or development where it will increase the potential risk to people's safety, well-being and property.

(e)Except for filling required to meet minimum floor levels, ensure that filling in urban areas at risk of flooding in a major flood event does not transfer flooding risk to other people, property, infrastructure or the natural environment.

(f) Reduce potential flood damage by ensuring floor levels for new buildings or additions to buildings, except those unlikely to suffer material damage, are above flooding predicted to occur in a major flood event, including an allowance for appropriate freeboard.

The above objective and policies provide a context regarding hazard identification and assessment, including specific guidance regarding flooding and sea level rise. In particular, the District Plan replicates the language of higher order RMA documents, in that hazards should be avoided where the risks generated by these hazards is unacceptable. This study has employed this policy approach and incorporates the concept of unacceptable risk into its methodology.

The District Plan also recognises the functional need for activities in hazard locations, principally infrastructure. Again, consideration of the risks to critical infrastructure has been incorporated into this study. Lastly, the District Plan also incorporates a set sea level rise figure as it relates to inundation risks. This current District Plan approach is acknowledged by this study and it is noted that the current sea level rise horizon and level will likely be replaced by any future plan change.

B.5 The Banks Peninsula District Plan

The Banks Peninsula District Plan currently includes a number of objectives and policies relevant to coastal hazards. These would likely be reviewed and amended or replaced by a potential CHPC. Current objectives and policies include:

Chapter 38 – Objective 1

To avoid or mitigate the costs resulting from natural hazards in terms of loss of life and loss or damage to property and the environment.

Policy 1A

New subdivision and development shall take into account any potential risks from natural hazards. The minimum protection aimed for is that there should be no damage:

- *To new dwellings or their contents from flood events with a 1:500 probability of occurrence, or from events arising from slope instability.*
- *To existing dwellings or their contents from flood events with a 1:200 probability of occurrence, or from events arising from slope instability.*

Policy 1C

Risk reduction measures shall be promoted where existing activities are located in areas of high existing or potential risk.

Policy 1E

Council data on natural hazard events will be updated progressively, and consideration given to any need for a review of natural hazards provisions in the Plan.

Policy 1F

No measure intended to remedy or mitigate a natural hazard should have a significant adverse effect on the environment.

Policy 1G

In flood-prone areas earthworks should only be undertaken in such a way that they do not cause or worsen flood risk elsewhere

B.6 Coastal Hazards and Climate Change: guidance for local Government

Provides non-statutory guidance to assist local governments for effective climate change adaptation planning in the face of increasing coastal hazard risks form climate change. The document adopts, and recommends, a 10-step decision cycle for-long term strategic planning and decision-making[36]. It also explains the relationship for coastal hazard management under RMA, policy and plans.[37] The guidance provide some useful recommendations in using climate change hazards information such as sea level rise (SLR) scenarios in the local planning context, discussed in Section 5 of this report.

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[36] See page 14 of the document here https://environment.govt.nz/assets/Publications/Files/coastal-hazards-guide-final.pdf

[37] See page 218 of the document here https://environment.govt.nz/assets/Publications/Files/coastal-hazards-guide-final.pdf

Appendix C. 500 year Return Period Tsunami Inundation Depths

From Bosserelle C., Arnold J., Lane E.; Land Drainage Recovery Programme: Tsunami Study. NIWA report 2018039CH Prepared for CCC.

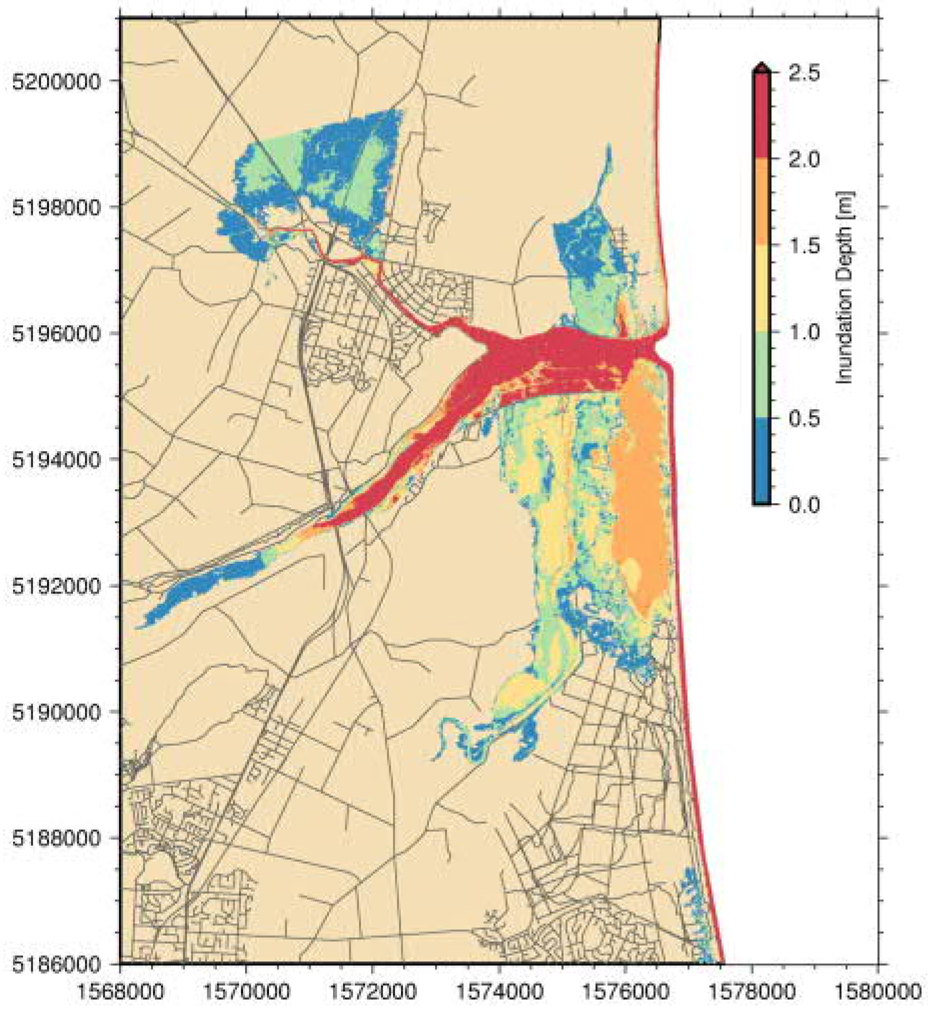

Figure 3-21: Maximum inundation depth (i.e., height above ground) for 1:500-year return period event Current Sea Level - Northern Section. Note that for the river channels the value given is the height above the pre-tsunami water level.

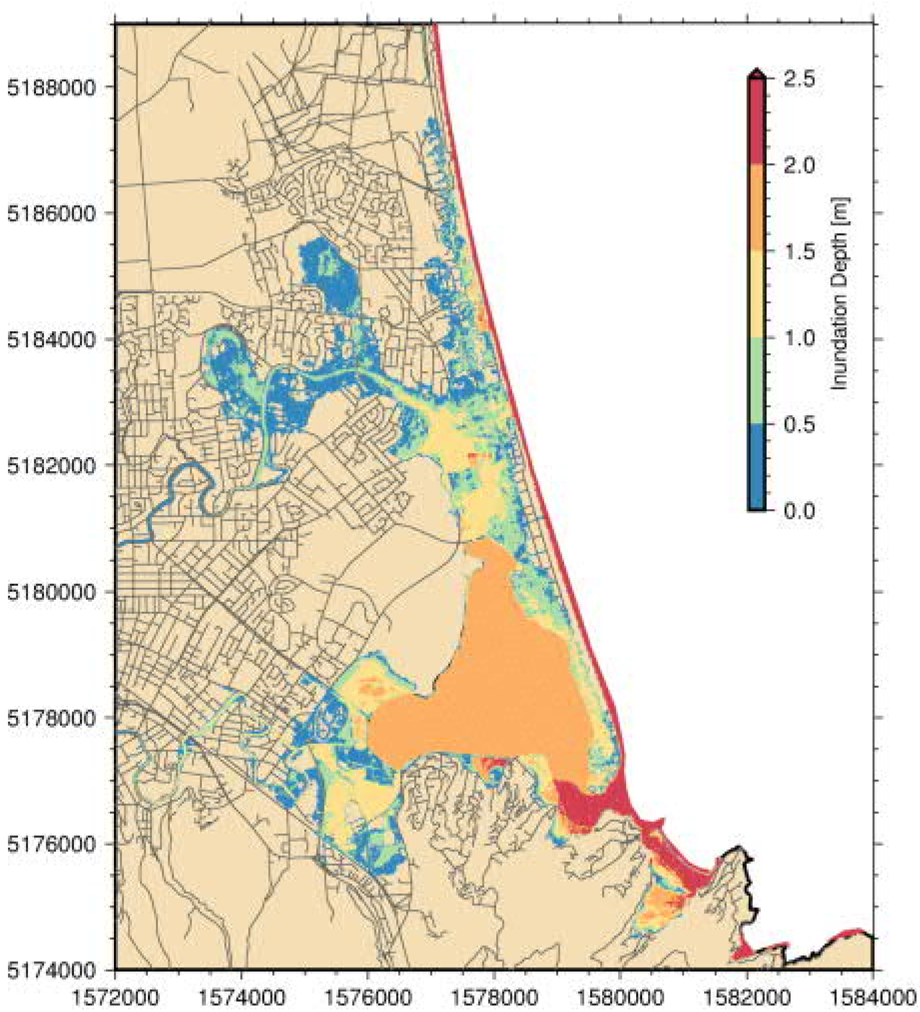

Figure 3-23: Maximum inundation depth (i.e., height above ground) for 1:500-year return period event Current Sea Level - Southern Section. Note that for the river channels the value given is the height above the pre-tsunami water level.

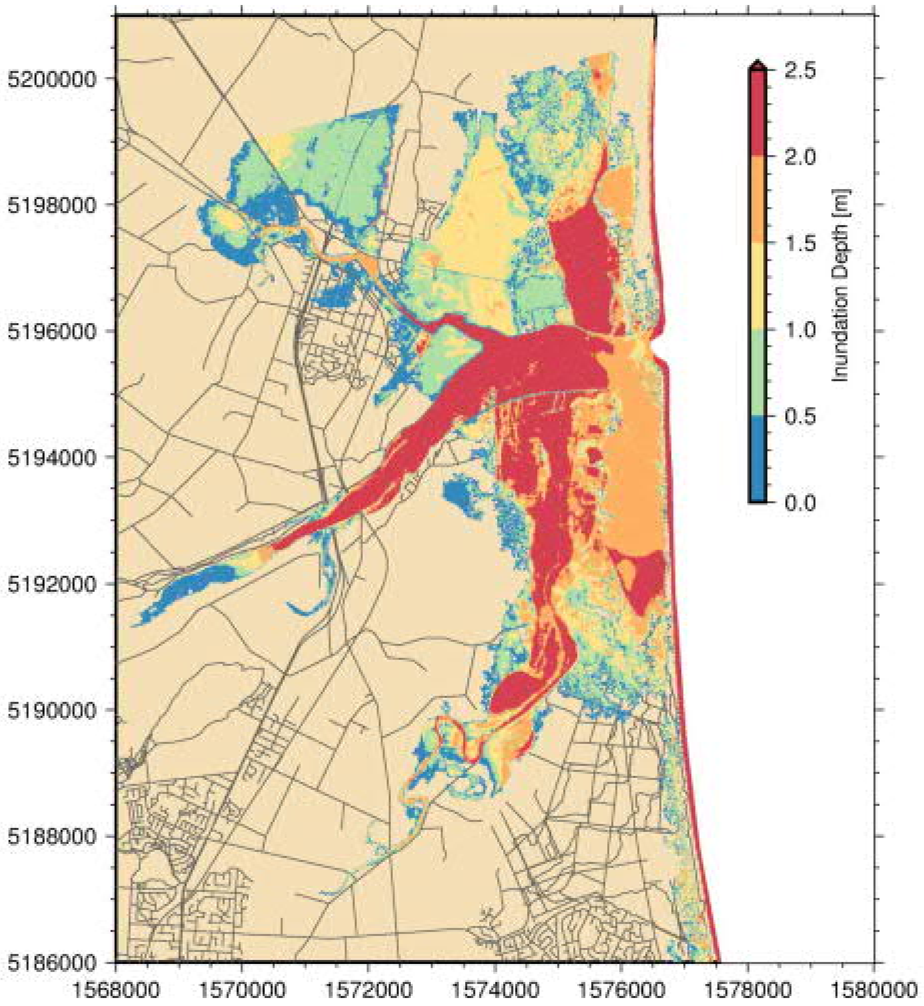

Figure 3-33: Maximum inundation depth (i.e., height above ground) for 1:500-year return period event 2120 Sea Level Scenario – 1.06 m Sea Level Rise - Northern Section. Note that for the river channels the value given is the height above the pre-tsunami water level.

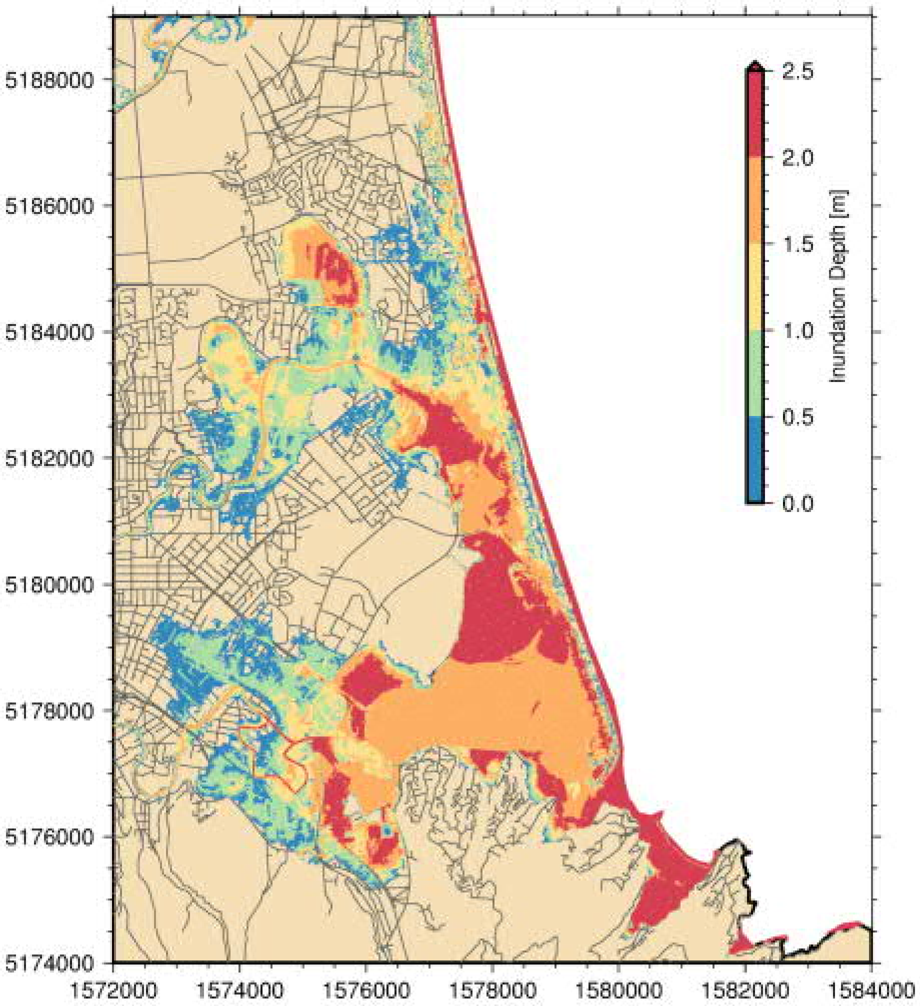

Figure 3-35: Maximum inundation depth (i.e., height above ground) for 1:500-year return period event 2120 Sea Level Scenario – 1.06 m Sea Level Rise - Southern Section. Note that for the river channels the value given is the height above the pre-tsunami water level.

From GNS Science 2019 & 2020 (as presented in ECan 2020 – Review of tsunami evacuation zones for Banks Peninsula and the Kaitorete coast)

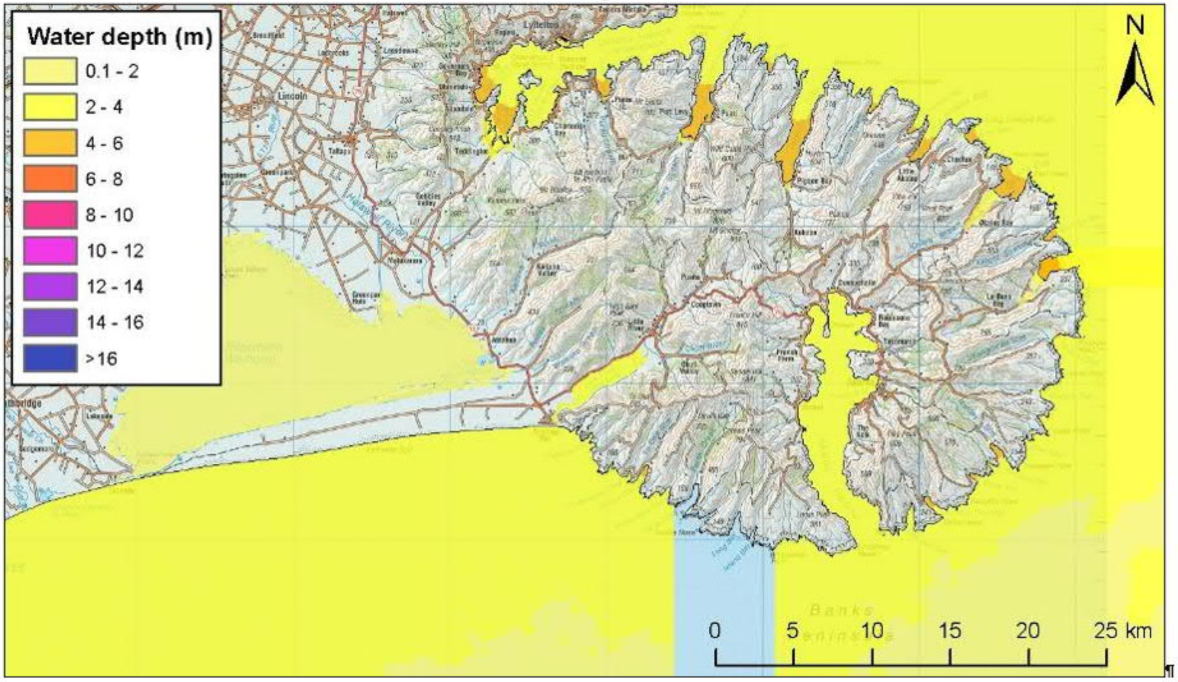

Figure 3-2: Maximum modelled inundation water depths for eighteen different tsunami sources around the Pacific Ocean that generate an ~ 3 metre wave height at coast. Note that each separate scenario inundates very slightly different areas within the total modelled inundation extent. Water depths in the ocean and coastal lakes are water height above mean sea level (the coastal lakes are is assumed to be full at the time of the tsunami). Water depths on land are water height above ground. From Mueller *et al,* 2020 and Roger *et al,* 2020.

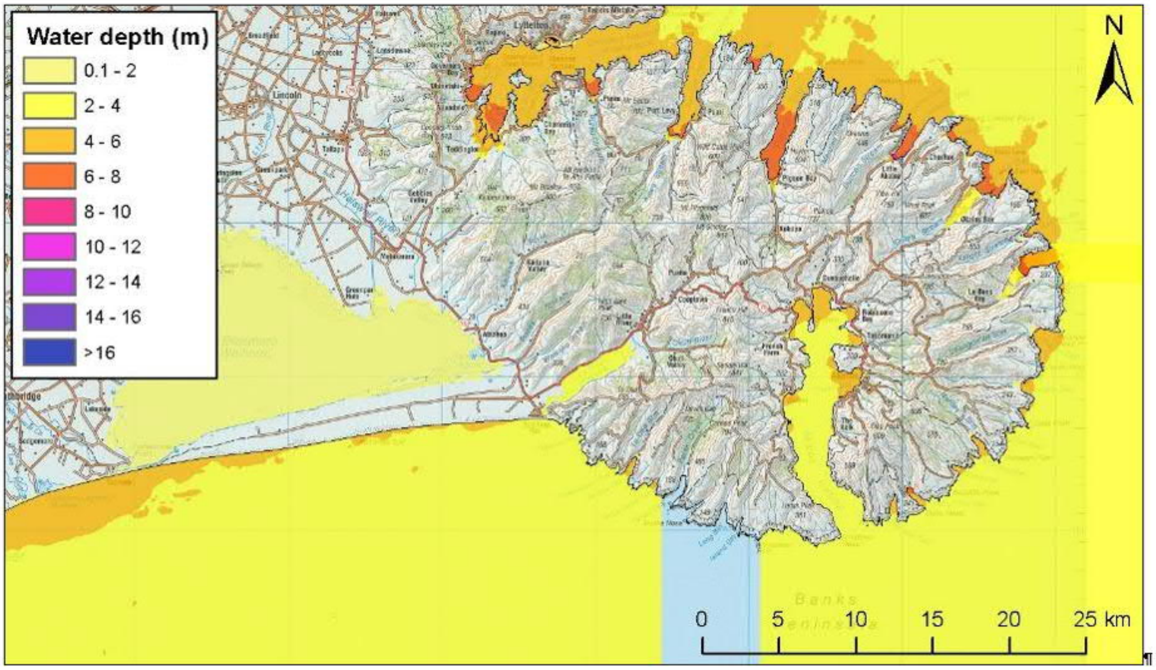

Figure 3-3: Maximum modelled inundation water depths for twenty different tsunami sources around the Pacific Ocean that generate an ~ 5 metre wave height at coast. Note that each separate scenario inundates very slightly different areas within the total modelled inundation extent. Water depths in the ocean and coastal lakes are water height above mean sea level (the coastal lakes are is assumed to be full at the time of the tsunami). Water depths on land are water height above ground. From Mueller *et al,* 2020 and Roger *et al,* 2020.

Appendix D. Glossary

Risk-related terminologies	Definitions
Hazard	Severity and magnitude of a natural or human-induced event or trend that causes harmful impacts (consequences) on natural, built environment, or social systems (MfE 2020).
Exposure	The lack of systems (i.e., properties, infrastructures, human) protection against adversity (adverse hazard factors) in a hazard prone area, that could cause negative impacts.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt
Risk	The interaction between the hazard, exposure of things to that hazard and the vulnerability of the things that are exposed.
Scenarios	The range of SLR curves under various RCP emission scenarios, timeframes and event return periods that were considered most suitable for use for District Planning purposes.
Threshold	was conceptually to be used in this work as a method of categorising between areas of differing level of risk. So, it was the method by which some characteristic of the hazard was to be used to determine between high, medium and low risk
Representative Concentration Pathway (RCP)	A future assumptions of greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change
Shared Socioeconomic Pathways (SSPs)	Shared Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies.
Scenarios	The combination of a future timeframe and climate change Representative Concentration Pathways (RCP), which together determine a projected SLR and consequent increase in hazard exposure,