REPORT

Tonkin+Taylor

Coastal Hazards Assessment for Christchurch District

Methodology and Approach Summary

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1 Background

Christchurch City Council (CCC) has engaged Tonkin & Taylor Ltd. (T+T) to undertake a coastal hazard assessment (CHA) for the entire Christchurch district. The primary purpose of this assessment is to help inform the Council's Coastal Hazards Adaptation Planning (CHAP) programme.

This report provides a high-level overview of the scope, methodology and outputs for the analysis which will be undertaken. The scope of the assessment has been developed in conjunction with Council's CHAP project team and technical reviewer, who have confirmed that the finalised CHA scope described in this report is suitable for the intended purpose of helping to inform Council's adaptation planning.

For more information about the CHAP programme and how the outputs of this coastal hazard assessment will be used, refer to the cover letter "Coastal Hazards Assessment Methodology: Purpose and context" which accompanies this report on the CCC website.

2 Spatial extent and level of detail

2.1 Spatial extent

2.1.1 Spatial extent of the overall study area

The proposed spatial extent of the assessment is to cover the entire coastline of the Christchurch District extending from the Waimakariri River mouth in the north to the entrance to Te Waihora (Lake Ellesmere) in the south (Figure 2.1). The assessment includes open coast and pocket beaches, estuaries and lagoons and cliffs and banks. The assessment area within the estuary and lagoons is limited to the area directly attached to the Coastal Marine Area (CMA) boundary.

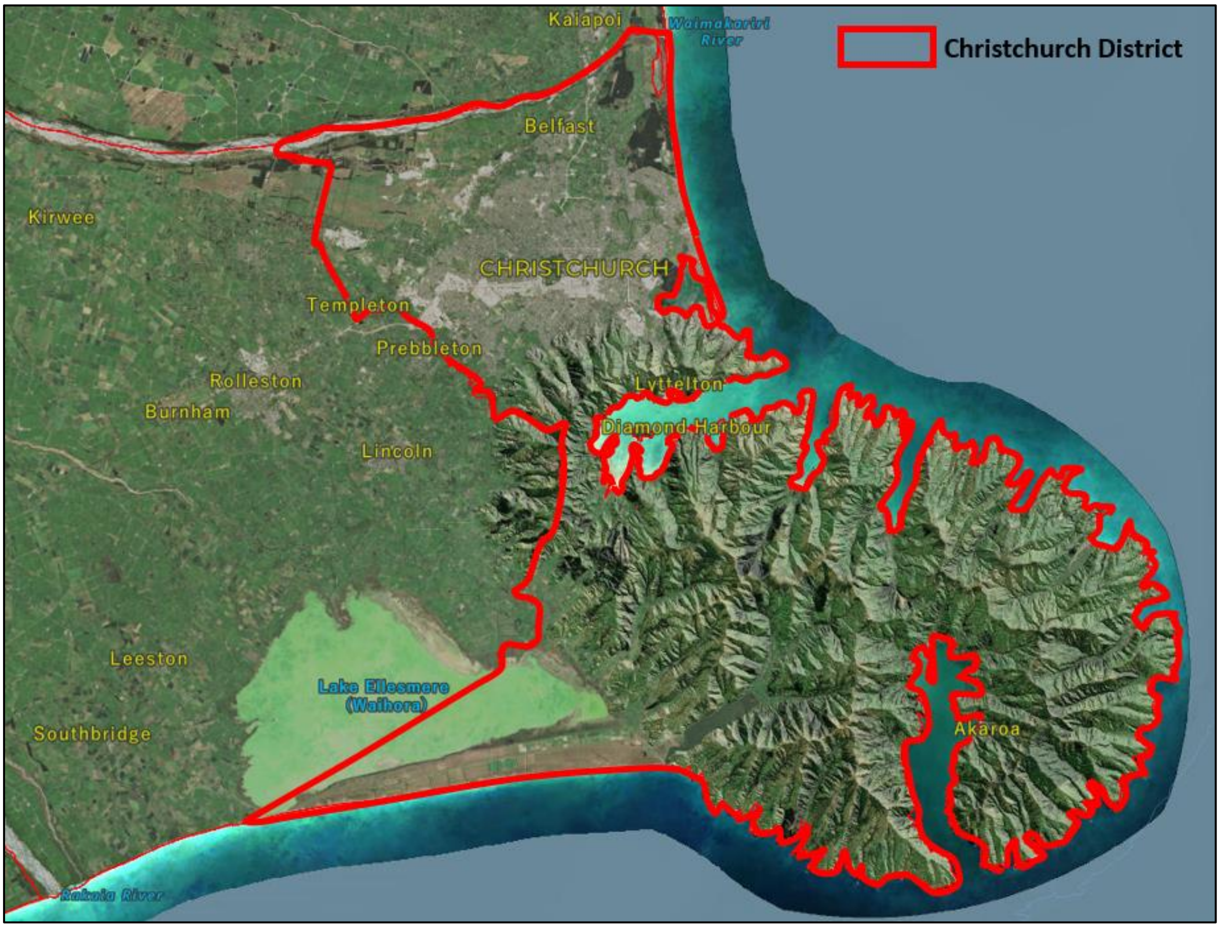

Figure 2.1: Study area extent (Christchurch District coastline)

2.1.2 Spatial extent of the coastal inundation hazard modelling

The inland boundary of the coastal inundation hazard modelling extent along the Christchurch open coast is shown in Figure 2.2, which has been determined based on a technical assessment of the interaction between sea level and floodplain hydraulics. To the west of this boundary there is increased uncertainty in the hydraulics, as flooding is controlled less by sea level and more by rainfall and rivers. This boundary doesn't suggest there will be no impact from sea level rise inland of this line, but rather that this flooding is better modelled using different methodologies than adopted for the coastal hazard assessment (e.g. using the citywide flood model used by Council to set minimum floor levels).

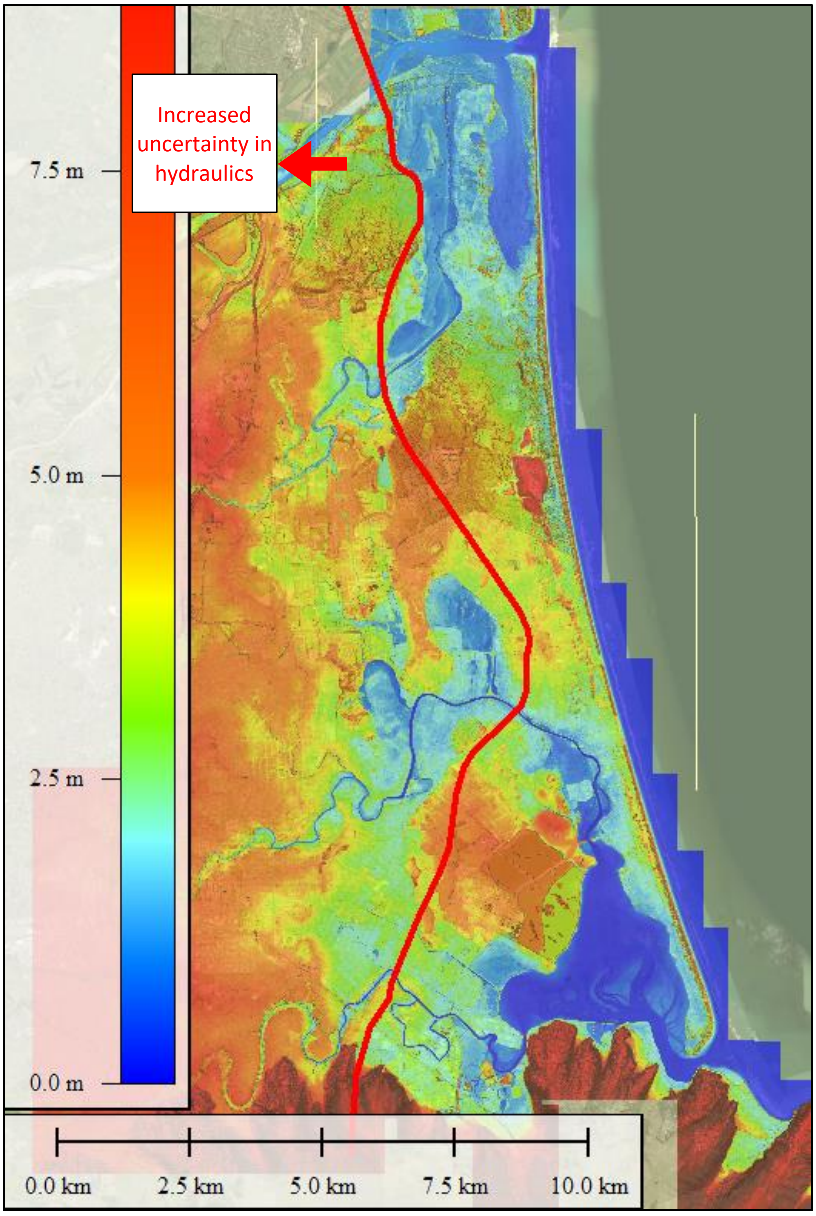

Figure 2.2: Inland boundary of the coastal inundation hazard modelling extent for the current study (red line). The shading shows the ground elevation above mean sea level (Lyttelton 1937 datum).

2.2 Level of detail

The level of detail in the analysis will vary along the coastline to suit the available information and the context. The methodology applied will depend on the hazard being assessed, the level of detail required and the coastal type. The “Coastal hazards and climate change” guidance issued by the Ministry for the Environment (MfE 2017) recommends the use of a two-level assessment for coastal hazard assessment:

1. A ***regional hazard screening*** that identifies areas that may potentially be subject to coastal hazard. This can help to identify high risk areas where more detailed assessment could be warranted in future. These may be undertaken in several ways including identifying existing problems, conversations with coastal communities, existing information and previous studies, GIS analysis and broad-scale hazard assessments using simple techniques.
2. A ***detailed hazard assessment*** that enables a more thorough understanding of the coastal processes, uncertainties and the effects of different future sea level rise scenarios, and thus the likelihood of hazard occurrence. This approach is recommended for areas of more intensive existing development, where there is a need for more information on how the hazard will change over time.

2.2.1 Regional hazard screening

The MfE (2017) guidance notes that regional hazard screening may be undertaken in several ways, one of which is the use of broad-scale hazard assessments using simple techniques.

For erosion this may include making general assessment of typical storm erosion potential, long-term trends, stable angle of response for cliffs and potential climate change effects including a single, high-end sea level rise scenario. The MfE (2017) guidance suggests that for this level of assessment an RCP8.5H+ sea level rise scenario is utilised.

For inundation this would similarly assess a potential extreme water level under storm tide and wave conditions and a similar single, high-end sea level rise scenario.

Uncertainty would be incorporated into the derived values and these combined deterministically[1] to envelop the potential hazard. The spatial scale of this level of assessment is likely to be coarser, at ~1 – 10km resolution, with mapping to suit the level of detail and spatial scale.

2.2.2 Detailed hazard assessment

Detailed hazard assessments seek to ensure that the individual processes, likelihood of occurrence, uncertainty and inter-relationship are more thoroughly understood and combined in a robust manner. Multiple future scenarios should be considered including climate change and sediment supply scenarios.

For erosion this will include a thorough understanding of the storm erosion potential at individual sites, long-term trends and the potential for changes in the sediment budget in the future, the potential response of sand dunes and backshore slopes to being oversteepened and the potential for a range of climate change scenarios to modify these processes. The various components should be combined probabilistically[2] so that the resultant values are statistically robust.

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[1] A deterministic calculation assumes fixed values for the input parameters. Each individual parameter is usually selected conservatively (to give a less favourable outcome than average), which means that when these multiple unfavourable assumptions are combined it represents a near “worst case” scenario.

[2] A probabilistic calculation assumes a range of values for each input parameter. Values for each parameter are selected randomly based on the expected natural variability above and below average values, and the random selection and component combination calculation repeated a large number of times. This approach provides both a “best-estimate” and an understanding of the potential range of outcomes.

For inundation the various astronomical tide, storm surge and wave processes should be assessed and combined probabilistically. The potential for a range of climate change scenarios to modify these processes should be considered.

The spatial scale of this level of assessment is likely to be finer, at 0.1 to 1 km in resolution, with mapping enabling the various likelihoods and climate change scenarios to be considered. This level of assessment may be superseded by future site-specific assessment at a scale of 1 to 10 m and considering site-specific aspects such as the local processes and the effect of coastal engineering works.

To undertake a detailed probabilistic erosion assessment, sufficient data is required to define the parameter bounds:

- For erosion of beaches, beach profile data and historic shorelines are a key data source for understanding the long- and short-term parameter bounds.
- For erosion of cliff shorelines, a detailed assessment requires geologist input to assess the underlying cliff material and range of stable angles. However, detailed geological assessment of cliff material is not within the scope of this study and is more appropriate for site-specific analysis in locations where there is a particular need identified for more comprehensive information.
- While there is sufficient profile data and historic shorelines for the Christchurch open coast beaches, there is limited data around Banks Peninsula, including within Lyttelton and Akaroa Harbours. In many of the harbour locations there are protection structures which have been present since at least the 1970s (making estimation of long-term erosion rates difficult) and there is a lack of beach profile data. This means that a detailed erosion assessment along the harbour shorelines would require assumptions to be made around the parameter bounds.

To undertake a detailed probabilistic inundation assessment, sufficient data is required to define modelled water levels:

- Timeseries of water levels and wave heights are required, which are used to derive extreme values of total water level for different return periods.
- For the Christchurch open coast, water level data is available at the Sumner tide gauge and wave data is available from the MetOcean wave hindcast (1979 to 2019).
- Water level data is also available within the Avon-Heathcote Estuary, Brooklands Lagoon and Lyttelton Harbour. However, wave timeseries are not available in these locations.
- Wave timeseries are available at several locations along Banks Peninsula (MetOcean wave hindcast, 1979 to 2019), however these are situated offshore and have not been transformed to particular coastal locations. The NIWA coastal calculator provides joint-occurrence (water level and wave height) values along the coast, however there are no outputs between Taylors Mistake and Birdlings Flat and the data is limited as it has not considered storm events that occurred after 2000.

2.2.3 Adopted level of detail across the study area

For the current study, the preference is for detailed hazard assessment to be undertaken in all locations where it is appropriate, taking into account factors such as:

- Expected level of hazard (e.g. based on previous studies or ground elevation).
- The intensity of existing development in the area.
- Coastline type (e.g. for the types of cliffs present along the bays in Akaroa and Lyttelton harbours a regional assessment is expected to provide a good understanding of the hazard, and more detailed assessment would require intensive site-specific geological analysis).
- The technical information available (e.g. historic shoreline and beach profile data required to estimate long term erosion rates).
- Balancing the allocation of available time and budget resources to provide the suite of information most useful for current stages of adaptation planning.
- The ability to undertake detailed assessment in additional areas in future, if the initial regional assessment or adaptation discussions indicate that more detail is warranted (e.g. allowing highly detailed effort to be targeted where it can be of most use).

Based on these considerations we have assessed the appropriate level of detail for erosion and inundation assessment for the various parts of the shoreline, as illustrated in Figure 2.3 to Figure 2.5. The areas selected for detailed assessment within Lyttelton and Akaroa Harbours are selected as they are areas of existing higher-intensity development located on either harbour beach or bank shoreline (e.g. Cass Bay and Wainui). While there are other areas of development within these harbours (e.g. Governors Bay and Diamond Harbour), the majority of the shoreline is characterised by cliffs which are more appropriately assessed using a regional screening assessment in the first instance.

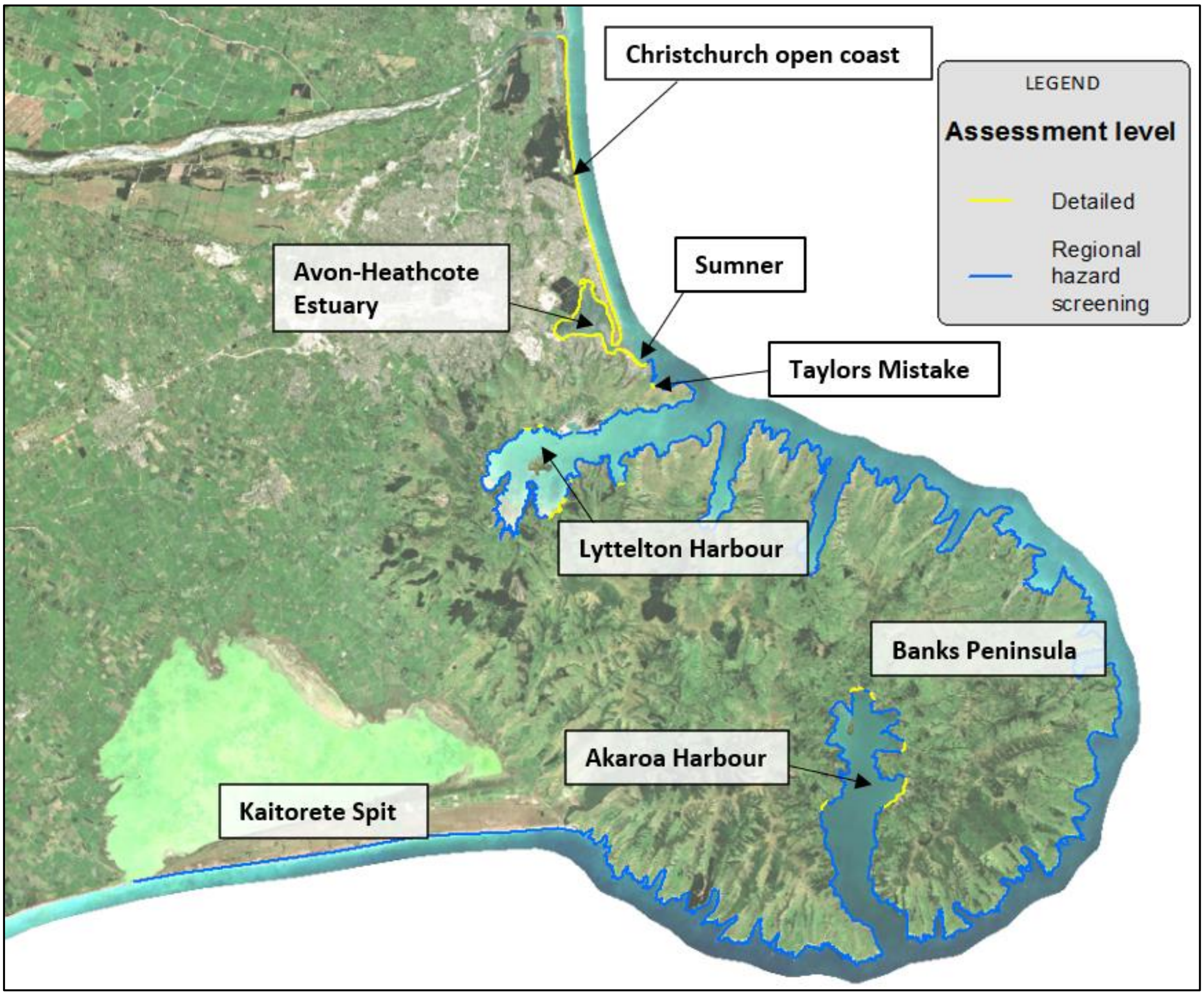

Figure 2.3 Christchurch district showing proposed extents and level of detail for the coastal erosion assessment.

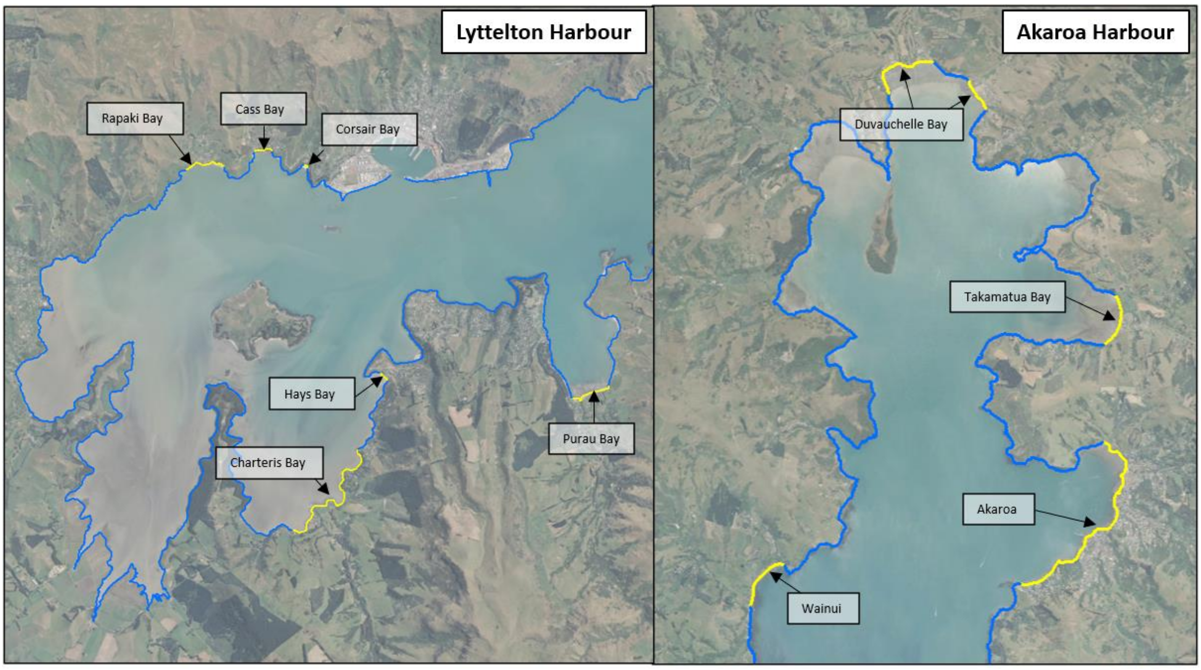

Figure 2.4: Location of detailed (yellow) and regional hazard screening (blue) assessments proposed for the coastal erosion assessment within Lyttelton and Akaroa Harbours.

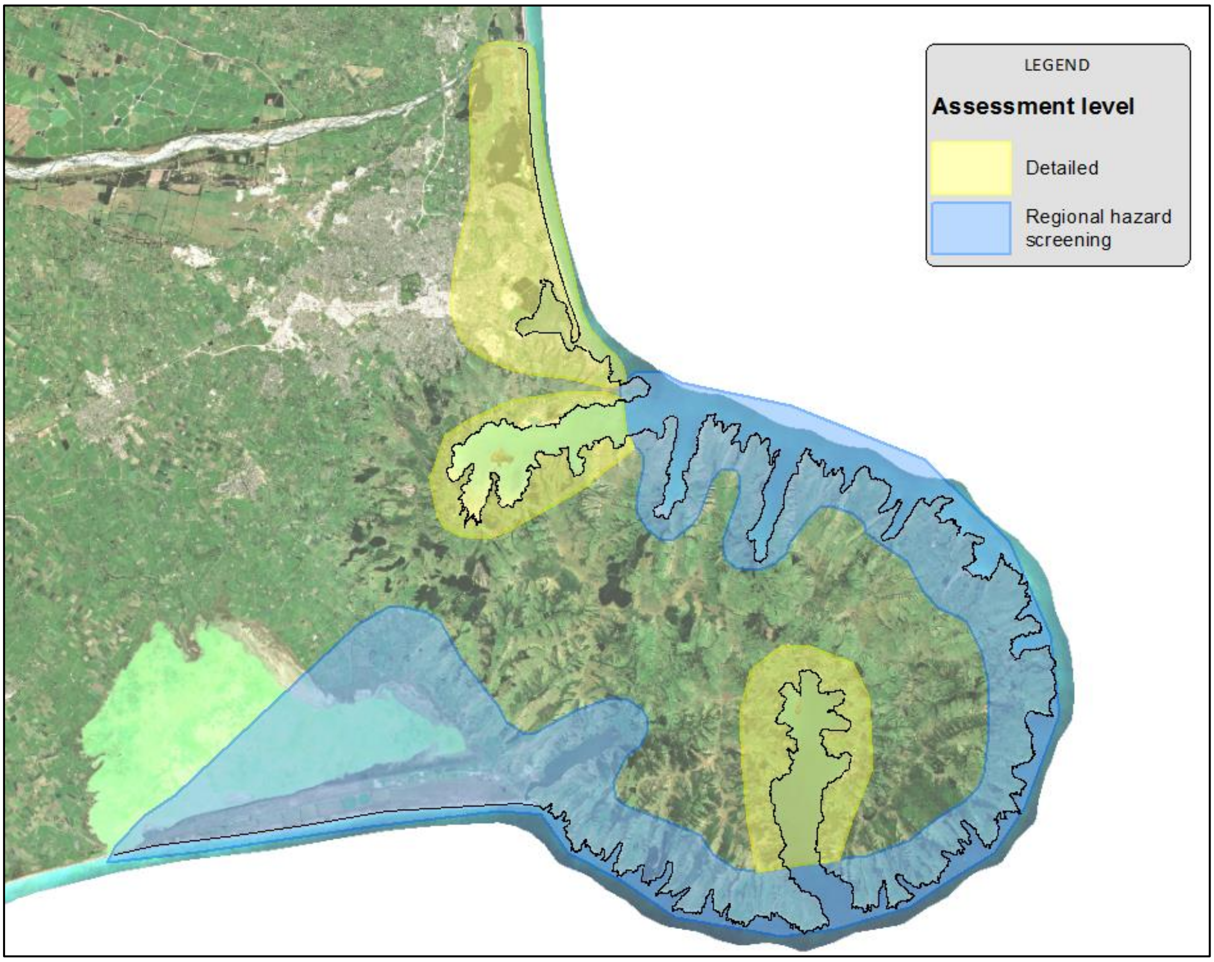

Figure 2.5: Christchurch district showing proposed extents and level of detail for the coastal inundation assessment.

3 Hazard assessment methodology

3.1 Available environmental data and assessments

3.1.1 Existing information

There is a substantial amount of existing information which can help to inform the current Christchurch CHA study. This includes information such as:

- Topography (the shape and elevation of the land)
- Bathymetry (the shape and depth of rivers, estuaries and sea beds)
- Aerial imagery showing the current coastal environment and changes over time
- Beach cross section profiles
- Water levels from measured from gauges and inferred from models and analyses
- Wave data (measured and inferred from models)
- River flow measurements
- Wind measurements
- Rainfall measurements
- Geomorphology (how landforms evolve through natural erosion and deposition processes)
- Ground movements due to earthquakes and long-term creep processes (refer Section 3.1.2)
- Sediment supply from rivers and drift along the coast
- Build-up of sediment in estuaries and harbours
- Observations of water levels and extent of inundation/erosion in notable storm events
- Anthropogenic influences such as dredging, gravel extraction, dune restoration and lake opening

3.1.2 Vertical land movement

MfE (2017) recommend consideration of vertical land movement (VLM), such as uplift or subsidence caused by creeping tectonic plates, because changes in land level can accelerate or decelerate the local effects of a rise in absolute sea level. It is recommended that any significant long-term VLM (>10 years) should be factored into local predictions of future relative sea level[3].

Long-term records of VLM are limited for Christchurch region. The recent work completed by Pearson et al (2019) shows notable subsidence on the eastern side of Christchurch (-0.2 to -0.7 mm/yr). However, as the ground level monitoring covers only a short period after the Canterbury earthquakes (2015 to 2019) and has limited spatial coverage across the city, this data does not provide a reliable basis for extrapolating VLM for decades into the future or defining a pattern of movement across the district.

Therefore, rather than “locking in” a specific VLM rate and spatial pattern in the assessment, land movement will be treated as another source of uncertainty in the prediction of future relative sea level at a particular location. This means that different combinations of absolute sea level rise and local land subsidence can be explored, to give a better understanding of the range of possible future conditions.

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[3] Relative sea level is measured relative to a fixed surface point on land (e.g. a tide gauge), whereas absolute sea level is measured relative to the centre of the earth. Any changes in relative sea level at a particular location represent the combined effect of vertical land movement and changes in absolute sea level. It is this relative sea level rise which is most relevant for community adaptation planning.

3.2 Analysis scenarios and technical input assumptions

3.2.1 Summary of current practice

When selecting scenarios for analysis and making assumptions about technical inputs, it is useful to check for consistency with analysis undertaken previously for Christchurch and elsewhere. This helps to reduce the potential for conflicting results where different models overlap (e.g. the CCC city-wide flood model) or intersect (e.g. neighbouring districts in the region). It is also important to check at this time that the scenarios cover the range of potential future conditions likely to be relevant for adaptation planning.

A summary of current practice and MfE guidance for erosion and inundation scenarios is outlined in Table 3.1.

Table 3.1: Summary of current practice for coastal erosion and inundation assessment

	Timeframes	**RCP scenarios[1]**	**Erosion likelihoods[2]**	**Return periods**
CCC 2017 CHA[3]	2065, 2120	2.6, 4.5, 8.5, 8.5H+	66% (likely), 5% (potential)	1% AEP (100 year storm tide event)[4]
Other Canterbury studies	A range of regional and detailed assessments Either single high-end scenario RCP 8.5H+, 100yr OR a range of sea level rise values based on MfE guidance			1% AEP (100 year) OR 2% (50 year)
Other NZ studies	2030, 2050, 2080, 2130	4 RCP scenarios as above OR increments of SLR	66%, 50%, 5%	Mostly 1% AEP (100 year) using NIWA coastal calculator
MfE (2017) guidance	Minimum timeframe of at least 100yrs Need to understand current hazard	4 RCP scenarios as above OR increments of SLR that broadly relate to these	Supports probabilistic erosion techniques but suggests modifying to more clearly separate statistical uncertainty from natural variability from uncertainty in future sea level	For all areas 1% AEP (100 year) with SLR For communities already exposed (i.e. present-day risk) – need to understand impact of smaller and more frequent events to understand triggers

[1] Aligning with IPCC projections and MfE recommendations

[2] The probability distributions provided in erosion assessments are not quantitatively exact but rather provide an indication of the central tendency and range.

[3] Note these scenarios only for open coast, for other sites single (upper end) scenario and likelihood used for two timeframes.

[4] Combined with 1% AEP wave height on the open coast and wind speed within the harbours to derive a single extreme water level.

3.2.2 Coastal erosion

For the current Christchurch CHA study, it is proposed to use increments of relative sea level rise which can be aligned with timeframes and a range of future conditions, as summarised in Table 3.2. For the detailed erosion hazard assessment five timeframes are proposed including present day (to 2030), 2050, 2080, 2130 and 2150. The proposed relative sea level rise increments approximately align with the RCP scenarios recommended by MfE (2017), with the inclusion of an additional high-end increment to model the upper range of potential combined effects of absolute sea level rise and land subsidence (refer Section 3.1.2). This incremental approach is preferred over selection of a specific combination of timeframe, sea level and vertical land movement as it provides a more nuanced understanding of potential effects over a range of future conditions, which is more useful for adaptation planning purposes.

The probability distributions provided in erosion assessments are not quantitatively exact but rather provide an indication of the central tendency and range. Therefore, a range of erosion likelihoods would be produced for the detailed assessments ranging from $P_{95\%}$ (almost certain to occur) to $P_{5\%}$ (highly unlikely). In our experience the outliers are highly unlikely to occur as the distributions have long tails as a result of the combination of multiple events. For the detailed erosion hazard assessment these probability distributions will be mapped as a gradient shading (refer Section 4.2.1) rather than as a series of lines at different probability levels as was mapped for the 2017 study. This new mapping approach is expected to be a more effective way to convey the range of uncertainty in the information used for community engagement and adaptation planning.

The detailed erosion assessment will primarily focus on scenarios where the sediment supply[4] reaching the Christchurch open coast beaches remains unchanged from the current-day situation. This level of sediment supply is currently sufficient to maintain a long-term trend of accretion[5], however this could switch to a trend of erosion as a result of future changes in sea level and sediment transport along the coast. Sensitivity checks (“stress tests”) will also be undertaken, examining the effect of changes in the future sediment supply reaching the Christchurch open coast beaches. This will consider both reduced and increased supply scenarios, as presented in the NIWA 2018 coastal sand budget report.

In line with recommendations in MfE (2017) guidance and regional practice, the regional screening assessment would use three scenarios: present day, 2080 with 0.8 m sea level rise, 2130 with 1.5 m sea level rise (high-end sea level rise), with maximum erosion distances based on deterministic combination of components. This is found to be generally equivalent to between the $P_{5\%}$ and $P_{1\%}$ values when assessed probabilistically.

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[4] The primary source of sediment discharged into Southern Pegasus Bay is the Waimakariri River. Some of this sediment is then transported southwards to the Christchurch open coast beaches.

[5] Accretion is a natural process where beaches grow due to deposition of sediment, but even if a beach has a general longer-term trend of accretion it can still experience shorter-term erosion in storm events.

Table 3.2: Proposed coastal erosion assessment scenarios

Assessment	Timeframe	Relative sea level increment[2] (m)	Likelihood scenarios[3]	Sediment supply reaching beaches[4]
Detailed[1]	Current – 2030	0	The following range of likelihoods mapped as a gradient: Pmin P99% P95% P85% P66% P50% P33% P15% P5% P1% Pmax	N/A
	2050	+0.2		Scenario 1 No change to sediment supply
		+0.4		
		+0.6		
	2080	+0.4		
		+0.6		
		+0.8		
		+1.2		
	2130	+0.6		
		+0.8		
		+1.0		
		+1.2		
		+1.5		
	2150	+2.0		
	2130	+1.5		Scenario 2 Reduced supply (11% reduction)
	2130	+1.5		Scenario 3 (Increased supply 28% increase)
Regional screening assessment	Current – 2030	0	Upper bound (assumed)	-
	2080	+0.4		
	2080	+0.8		
	2130	+1.5		

[1] Both full probabilistic and quasi-probabilistic.

[2] Relative sea level combines the effect of both rising sea level and vertical land movement. Increments are specified relative to current-day sea level.

[3] This provides an indication of the probability of a modelled erosion extent occurring for a particular storm event. For example, land mapped within the P95% extent is highly likely to be eroded in the type of event being modelled, whereas erosion of land within the P5% extent is highly unlikely (but not impossible) in that type of event.

[4] The sediment supply reaching the beaches depends on both the amount of sediment discharged by the Waimakariri River, and the amount of this sediment which is transported southwards along the coast. This will be assessed for Christchurch open coast beaches only, as it is not relevant for other beaches.

3.2.3 Coastal inundation

For the current Christchurch CHA study, it is proposed to use the same relative sea level rise increments as proposed for erosion (with approximate alignment with timeframes and RCP scenarios), as summarised in Table 3.3. Assessment of a range of return period events is proposed for detailed assessment sites, to provide an indication of the potential range of effects and their frequency. Understanding this relationship between frequency and severity of effects can be important for adaptation planning. For example, lower water levels might occur relatively often but only cause “nuisance” effects, whereas higher water levels might occur only rarely but have more destructive effects. 1, 10 and 100 year ARI events have been adopted because they provide good coverage of this range of effects, and there would be little additional value in analysing intermediate ARI events (e.g. for the purposes of adaptation planning the effects of a 50 year event would be similar to that of a 100 year event as the difference in water level is less than 0.1m).

Individual components making up the extreme water level will be combined probabilistically where possible (i.e. wave set up and run up), or by sensitivity where not (i.e. wave effects within the Avon-Heathcote/Ihutai estuary).

Future erosion may affect inundation extents on the open coast, particularly wave run up effects (magnitude and extent of flow), where breaches in the dune may allow flows to propagate further inland. The New Zealand Coastal Policy Statement requires that cumulative effects such as these are considered. This combined effect of erosion and inundation is proposed to be assessed initially as a sensitivity check (“stress-test”) for a single timeframe (2130) and high-end sea level rise scenario (1.5 m). Based on these results, additional scenarios can be considered if required.

Table 3.3: Proposed coastal inundation assessment scenarios

Assessment	Relative sea level increment[1] (m)	Return period event[2]	Effect of erosion[3]
Detailed assessment[4]	0 +0.2 +0.4 +0.6 +0.8 +1.0 +1.2 +1.4 +1.5 +2.0	1 year ARI 10 year ARI 100 year ARI	-
	+1.5	100 year	Future P5% and P50% erosion for same scenario[2]
Regional screening assessment	0 +0.4 +0.8 +1.5	1 year 10 year 100 year	-

[1] Relative sea level combines the effect of both rising sea level and vertical land movement. Increments are specified relative to current-day sea level.

[2] Return period events describe the Average Recurrence Interval (ARI) of an extreme water level (e.g. a 10 year ARI water level is a water level that occurs on average once every 10 years). Smaller ARI values represent lower water levels that occur more often, and larger ARI values represent higher water levels that occur less often.

[3] Christchurch open coast only.

[4] Both full probabilistic and quasi-probabilistic.

3.3 Protection structures

3.3.1 Erosion protection structures

Various types and conditions of coastal erosion protection structures exist around the Christchurch coastline, including the open coast, Avon-Heathcote/Ihutai Estuary and Lyttleton and Akaroa Harbours. For the current Christchurch CHA study, an agreed approach is required for assessing the erosion hazard along the currently protected shorelines.

3.3.1.1 Available information

There are three key sources of collated information regarding the locations and extents of coastal structures across Christchurch:

- The 2017 Christchurch coastal hazard assessment collated information from Council's asset management system and supplemented this with mapping of other significant structures visible in the 2015 aerial photography. The resulting GIS database does not include every coastal protection structure across Christchurch City, covering only the specific 2017 study areas. Structures that were not visible in the 2015 aerial photography or appeared in very poor condition were not digitised. The structures around Lyttleton Port reclamation are also excluded from the database.
- The 2019 condition assessment of the eastern edge of the Avon-Heathcote/Ihutai Estuary presents information on the current location, extent and condition of built structures, soft barriers and natural shorelines along the estuary edge from Evans Ave to the southern tip of Southshore Spit.
- The 2008 Akaroa Harbour Basin Settlements Study included an inventory of the coastal protection works at each settlement in Akaroa Harbour. This includes information on the location, type, length, height, age and condition of the mapped coastal protection structures.

All three of these sources provide good information regarding the spatial extent of mapped structures, however there is less comprehensive data regarding other details such as the type, geometry, condition and legal/consent status of each structure. An initial review of this data also indicates that not all significant structures along the Christchurch coast have been mapped in these databases. Discussions with CCC are ongoing regarding gap-filling options for collating a more comprehensive inventory of coastal structures.

3.3.1.2 Structure types

Coastal erosion protection structures around Christchurch City region can be broadly classified into three different categories:

Class 1 – Significantly modified shorelines

There are three locations where the shoreline has been significantly modified with land reclamation and hard protection structures: the southern shore of the Avon-Heathcote estuary (Figure 3.1), Lyttelton Port (Figure 3.1) and Akaroa township (Figure 3.1).

These structures have been present since at least the 1940s, and significant development has since occurred which relies upon the protection provided. Failure of these structures would likely cause significant disruption to the wider community or city. In light of these wider implications the New Zealand Coastal Policy Statement recognises that hard protection structures may be the only practical means to protect existing infrastructure of national and regional importance, increasing the likelihood that these may be maintained or immediately repaired if damaged.

Figure 3.1: Extent of significantly modified shorelines

Figure 3.2: Example of significantly modified shoreline in Akaroa

Class 2 – Functional private and public structures

These include functional, consented private structures and functional public structures. The consent status has been chosen as a key factor for the private structures as it relates to the legal ability to undertake repair if damaged and often reflects on the degree of engineering involved in their design and construction. If they fail or are damaged, these may be able to be repaired during the consent term. However, it is unknown if they will be re-consented at the end of consent term so the degree of protection in the long term is uncertain. For public structures, the consent status is a less relevant classification factor because many of these structures pre-date the Resource Management Act and so will not have resource consent for their construction.

Another relevant consideration could be the condition of the structure, however this may be more difficult to consistently determine and incorporate into the assessment. For example, there are consented private structures along the eastern margin of Avon-Heathcote estuary which have been damaged and may no longer be functional.

Figure 3.3: Example of functional public structures (left) Corsair bay (right) French Farm Bay.

Class 3 - Informal, non-consented structures

These include all non-consented and/or informal structures. They may have limited effectiveness at reducing erosion and are less likely to be repaired if damaged. This means the long-term erosion (and effects of sea level rise) could be similar to the adjacent unprotected coast (i.e. as if the structure was not present).

Figure 3.4: Example of informal, non-consented structures along the Avon-Heathcote Estuary

3.3.1.3 Proposed approach to coastal structures

The proposed approach for incorporating coastal protection structures within the erosion hazard assessment is outlined below, with the approach differing depending on the structure class. This is broadly consistent with the range of approaches previously taken for previous hazard studies elsewhere around New Zealand. It is also recognised that as the primary intended use of the hazard assessment is to help inform adaptation planning, it is important (where technically possible) to limit assumptions regarding future management approaches.

Class 1 – Significantly modified shorelines

For the coastal erosion assessment we will map the current (short-term) hazard area based on the height of structure and an assumed stable angle of repose of fill material. Because these shoreline modifications are so extensive and have been in place for so long, it is not feasible to use past observations of erosion rates to estimate what the long-term erosion rates would be in the absence of structures. Therefore the future (long-term) hazard area will be set equivalent to the current hazard area, which would be the case if the structure was promptly repaired if damaged (Figure 3.5). However, if the protection structure fails and is not promptly repaired then it is likely the fill material will rapidly erode, and the shoreline will eventually move back towards its 'original' natural position (this scenario has not been modelled in this study, but could be assessed in future as part of adaptation planning if relevant).

Class 2 (Functional private and public structures) and Class 3 (Informal, non-consented structures)

It is not possible to reliably distinguish between Class 2 and Class 3 structures using the currently-available information, and it would be difficult even if more detailed information was collated. Long-term erosion effects may also be similar for both classes. It is therefore proposed that Class 2 and Class 3 structures are treated in the same way for the current Christchurch CHA study.

Known structures would be shown on the hazard map for context. However, the impact of these structures on future erosion will not be considered in the assessment and the mapped erosion hazard will be based on the characteristics of the adjacent unprotected shoreline (i.e. as if the structure was not present). This allows the long-term importance of these structures to be considered as part of adaptation planning, acknowledging they may provide some degree of protection against erosion now and into the future but also showing what could be at risk if they were to fail.

The current (short-term) hazard area will represent the immediate hazard if the structure were to fail, considering the structure height and characteristic stable angle of 2(H):1(V), and assuming that scour of debris and toe erosion is not significant for the harbour shorelines where these structures are located. The future (long-term) hazard area will include long-term trends and shoreline response to SLR without the structure present (based on the adjacent non-protected shoreline). In some locations the adjacent unprotected shoreline is up to 1 km away and may have different characteristics, so generic assumptions on long term rates will be adopted.

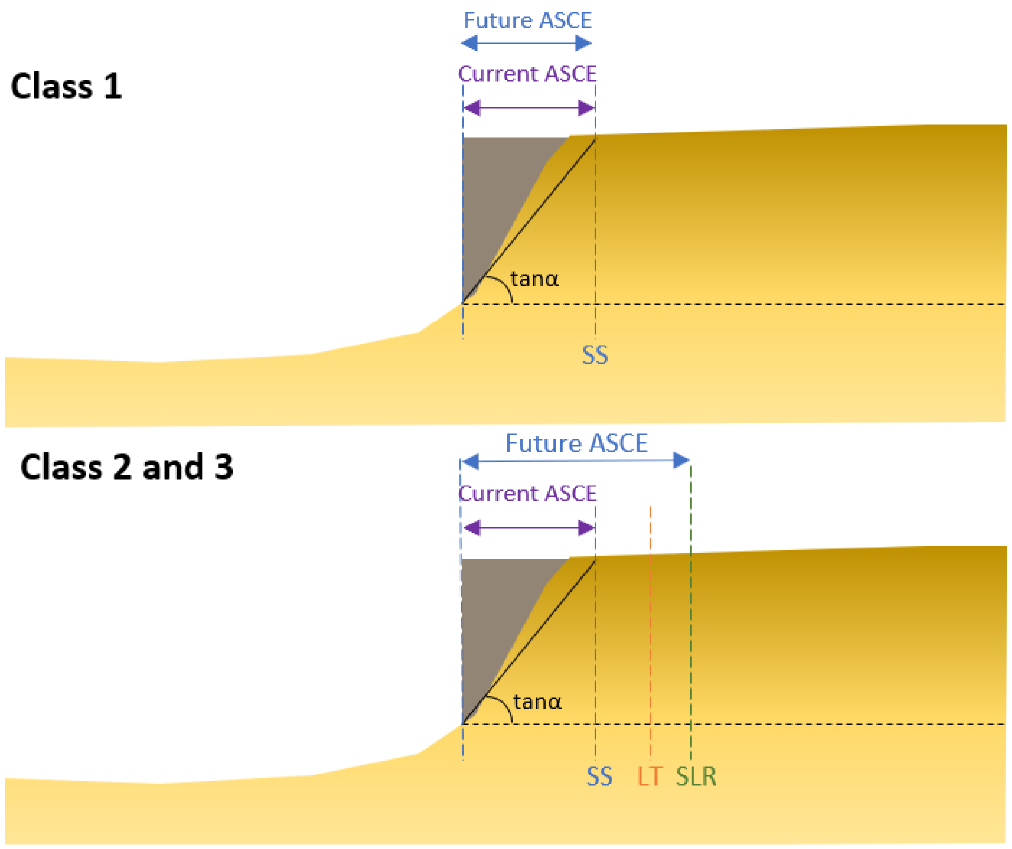


Figure 3.5: Schematic of area susceptible to coastal erosion (ASCE) for different protection structure classes (SS = slope stability, LT = long-term erosion, SLR = response to sea level rise)

3.3.2 Inundation protection structures

Stopbanks are present at various locations along rivers and streams throughout Christchurch, providing a degree of protection against inundation during storms (i.e. short-term events). The inundation analysis identifies land below the modelled water level which is “connected” directly to the sea, so stopbanks act to “disconnect” areas which are protected.

Existing stopbanks are already represented in the LiDAR ground elevation survey information which is used for the inundation analysis. Surveyed stopbank levels provided by CCC have been compared against the digital elevation model from the 2018 LiDAR survey to ensure all existing stopbanks are accurately captured. This showed that the LiDAR and survey levels are typically within 0.1 m, with the LiDAR typically being higher than surveyed levels (which is as expected, because the survey levels do not capture landscaping elements such as paths). As the differences are within the derived water level accuracy, the LiDAR elevation model can be adopted directly without the need to “burn in” specified stopbank crest levels. Current and planned stopbanks will be identified on the maps.

However, stopbanks are less effective at protecting against long-term increases in sea level, because a high water level on one side of the stopbank can cause groundwater to rise on the other side. This means that land can be inundated from below via groundwater even if the stopbank is higher than the water level. There are also various drainage outlets which pass through the stopbanks to drain the land behind. These outlets may result in back-flow during storm events (e.g. if a one-way flap-gate becomes stuck open) or may no longer be able to drain if there is a permanent increase in the water level on the river side. To identify areas where these kinds of indirect inundation could occur, the analysis maps “disconnected inundation” areas where land is lower than the modelled water level but not directly connected to the sea.

3.4 Analysis methodology

3.4.1 Coastal erosion

The regional hazard screening erosion assessment includes a deterministic approach where the upper bound parameters are adopted for each cell. This regional assessment will be undertaken for all hard cliffs, beaches/banks within Lyttelton and Akaroa harbours away from major settlements and around outer Banks Peninsula, and Kaitorete Spit.

For the detailed assessments, due to different data availability, slightly different levels of probabilistic erosion assessment are proposed for different parts of the study area:

Full probabilistic:	Where there is sufficient data including historic shorelines and beach profile datasets, it is proposed to undertake full probabilistic analysis, including statistical analysis of shoreline position and profiles. The full probabilistic approach will be adopted for the Christchurch open coast beaches.
Quasi-probabilistic:	Where there are data limitations (e.g. no beach profile history), a more detailed assessment is still feasible, however it requires some generic assumptions to be made around parameter bounds, including short term and long term components. This approach will be adopted for the Avon-Heathcote estuary and beach/bank shorelines along existing major settlements within Lyttelton and Akaroa harbours.

The key analysis steps for the erosion analysis are:

1 Define coastal behaviour cells, based on the shoreline composition and other factors which may influence the resultant hazard (e.g. morphology and lithology, exposure to waves, profile geometry, backshore elevation and historical shoreline trends).

2 Derive the baseline, which is the shoreline position to which erosion distances will be referenced and mapped from. This will correspond to the dune toe or seaward edge of vegetation for beach shorelines and the cliff/bank toe for consolidated shorelines.

3 Develop conceptual models for the various coastal types present, which reflect the key drivers of erosion (e.g. sea level, short and long-term erosion and slope instability). The coastal types present across Christchurch district include unconsolidated sandy beaches and gravel barriers, consolidated banks and harder cliffs. The potential erosion distance is assessed individually for each of the key drivers, and these components are then added together (either probabilistically or deterministically depending on the approach adopted for a location) to define the overall area susceptible to coastal erosion (ASCE).

4 Two ASCE extents are mapped. The “Current ASCE” reflects present-day sea level and short-term erosion/instability drivers only. The “Future ASCE” additionally includes sea level rise and long-term erosion.

3.4.2 Coastal inundation

A regional hazard screening inundation assessment will be undertaken where water level timeseries may be available, but nearshore wave timeseries is not available so an empirical formula will be used to assess the wave effects component. This regional assessment will be undertaken for outer Banks Peninsula, Kaitorete Spit, Wairewa (Lake Forsyth) and Te Waihora (Lake Ellesmere).

For the detailed assessments, due to different data availability, slightly different levels of probabilistic inundation assessment are proposed for different parts of the study area:

Full probabilistic:	This approach will be adopted where both water level and modelled wave timeseries are available. These timeseries will be used to undertake extreme value analyses to derive return period water levels. The full probabilistic approach will be adopted for the Christchurch open coast.
Quasi-probabilistic:	This approach will be adopted where water level timeseries are available but wave timeseries are not available, for major harbours and estuaries that may be subject to super-elevation of water levels due to wave effects. For these locations numerical wave models will be set up (for the defined scenarios only), which will use extreme wind speeds to model wind-generated waves to assess wave effects. Therefore, this approach is a combination of probabilistically derived water levels with modelled wave effects added deterministically. A quasi-probabilistic approach is proposed for Brooklands Lagoon, Avon-Heathcote Estuary, Lyttelton Harbour and Akaroa Harbour.

The focus of the current CHA technical assessment is to produce “base” hazard information that can then feed into community engagement, risk evaluation and risk mitigation and adaptation planning undertaken by CCC in the future. Given the intent of the data usage for high-level public engagement and adaptation planning, and the large number of scenarios to be considered, a “bathtub” modelling approach has been adopted to assess the approximate potential coastal inundation extents around Christchurch City. This approach is simpler than the alternative hydrodynamic modelling approach that was applied in the 2017 coastal hazard study, but the flexibility and responsiveness that it offers means that is considered more suitable for the specific intended purpose of this study (i.e. the initial engagement and risk evaluation stages of adaptation planning).

The bathtub inundation model identifies all land that is below a defined water level and maps the depth at these locations. The analysis distinguishes between land where floodwater is directly “connected” to the coast, and “non-connected” areas below the defined water level (typically low-lying areas which may be susceptible to indirect flooding via groundwater or drainage outlets). The model is driven by a water level which is representative of the inundated areas, based on analysis of data from water level gauges at Bridge St, Ferrymead Bridge, the Styx tide gates and Sumner Head. Levels measured at the gauges will already include components driving water levels such as tide, storm surge, river flows, rainfall, local wind effects and wave breaking over the Sumner and Waimakariri Bars. Statistical analysis undertaken on these water levels implicitly includes these components without them having to be separated out and analysed separately in terms of their magnitude and joint likelihood of occurrence.

There are some limitations with this modelling approach (as with any analysis method), for example:

- It assumes a uniform water surface level
- Hydraulics landward of the water level gauges are not included
- The accuracy of the ground elevation model can influence the ‘connected’ and ‘non-connected’ inundation extents
- No pipes or buried infrastructure are included to convey any tidal inflow.

However, these limitations will be identified to users of the information and measures implemented to limit any additional uncertainty introduced (e.g. the inland boundary of the model as discussed in Section 2.1).

A conceptual outline of the coastal inundation analysis is set out in Figure 3.6. This takes a two-part approach:

1 Assessing extreme water levels for representative locations along the open coast and within estuaries, lagoons, harbours and lakes resulting in a look up table of extreme levels for various scenario combinations.

2 Mapping inundation at 0.1 m depth increments around the entire coast (where covered by the ground elevation model), using a “bathtub” mapping approach.

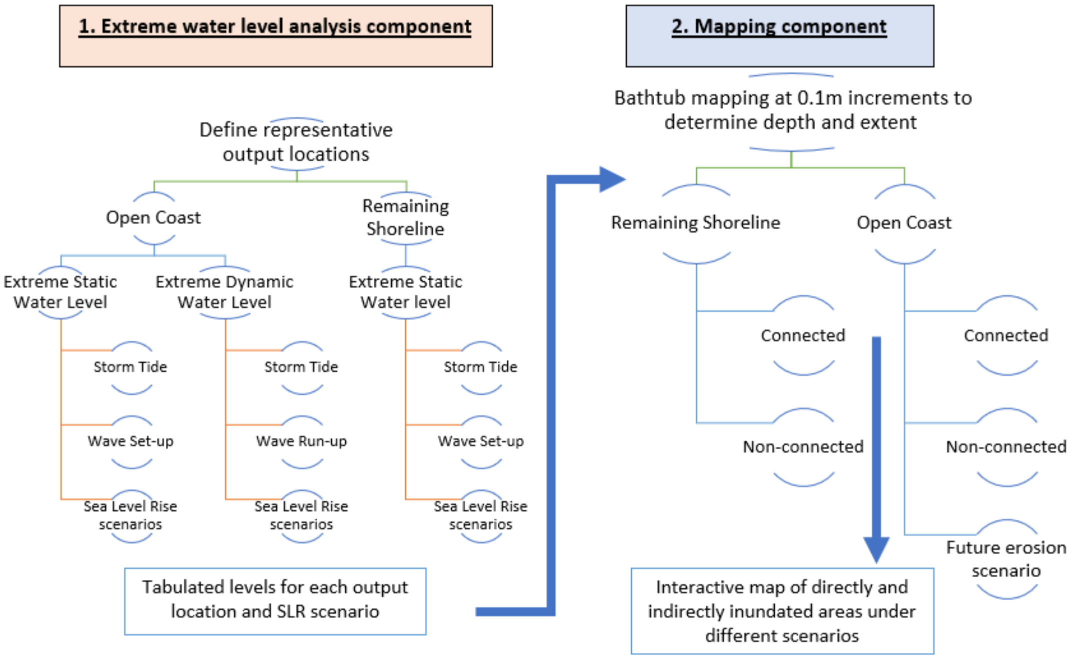


Figure 3.6 Conceptual approach for inundation assessment and mapping

3.4.3 Groundwater

As discussed in Section 3.3.2, areas mapped as “disconnected” coastal inundation may reflect potential for groundwater flooding driven by increasing sea level. However, detailed groundwater modelling will not be undertaken as part of the current coastal hazard study, as a comprehensive city-wide model of present-day and potential future groundwater levels has recently been developed as part of the CCC Land Drainage Recovery Programme (LDRP).

The LDRP study will likely be the most appropriate source of groundwater information for many purposes. However, in some cases for adaptation planning it may be useful to also refer to the bathtub inundation model developed as part of the current coastal hazard assessment (e.g. when considering scenarios not included in the LDRP study, or cumulative effects of different types of hazards). To assist the CHAP project team with interpretation of this groundwater information and determine the preferred approach for adaptation planning, a mapping overlay exercise will be undertaken to compare the results from the LDRP and coastal hazard studies.

4 Hazard assessment outputs

4.1 Example outputs from previous hazard studies around New Zealand

To understand options for presenting results from the Christchurch coastal hazard assessment it is useful to understand how this type of information has been presented previously elsewhere.

Areas susceptible to coastal erosion hazard are typically mapped as lines or areas for selected timeframes and scenarios. For probabilistic assessments, specific likelihoods are typically selected for mapping. An example of mapping of lines is shown in Figure 4.1 for Waipu Cove, and an example of zones mapped for Tauranga Harbour is shown in Figure 4.2.

Figure 4.1: Example of mapped coastal erosion hazard lines for Waipu Cove, Northland.

Figure 4.2 Example of coastal erosion hazard mapping for Tauranga Harbour.

Areas susceptible to coastal inundation are typically mapped as polygons showing the inundation extents. However, there are several variations in visualising the inundation extents depending on the assessed scenarios. For example, Figure 4.3 and Figure 4.4 demonstrate the interactive websites developed by Waikato Regional Council and Tauranga City Council.

Figure 4.3 shows the inundation extent, with water depth shown as a shade of blue. Low-lying areas which are not directly connected to the sea but may be inundated indirectly (e.g. from groundwater) are shown as green. Users can adjust the slider to select the sea level rise value of interest.

Figure 4.4 shows a similar tool, but with depth ranges shown as different colours and only for pre-defined scenarios (timeframes, return period events and sea level rise values).

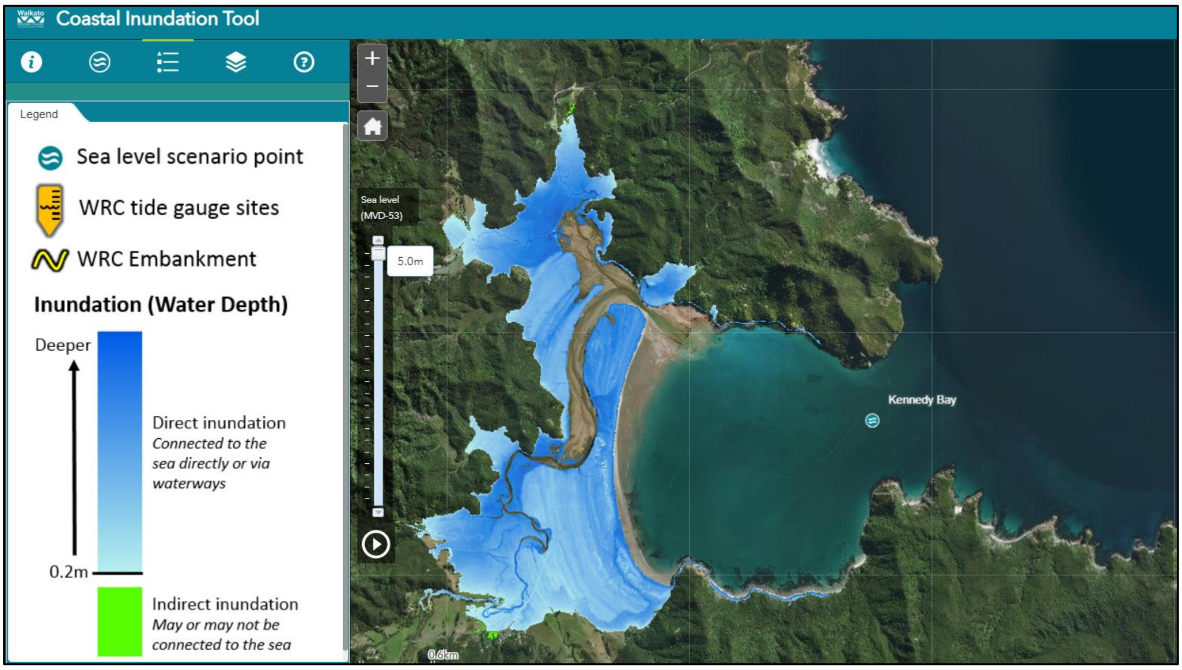


Figure 4.3: Inundation extents mapped at 0.1 m increments for Waikato region, with direct inundation depth indicated as graduated blue colours and indirect (disconnected) inundation areas indicated in green.

This tool allows you to view a range of harbour inundation scenarios generated by various extreme storm events and potential sea level rise through to 2130. You can find a specific property, view a general area, or see the entire city.

Step 1: Select Hazard Timeframe

Step 2: Select Sea Level Rise Scenario (metres above Moturiki Datum)

Step 3: Select Likelihood of Storm Event (Annual Exceedance Probability)

Contour layer

○ Show Contours ● Hide Contours

Current | 2070/2080 | **2130**

Sea level rise
○ 0.8 metres
● 1.25 metres
○ 1.6 metres

Storm Event Likelihood
● None
● 2% AEP
○ 1% AEP

Current

This group of data presents the extent of inundation based on the current sea level, and the impact of three extreme storm events with present day annual exceedance probability (AEP) likelihoods of 2%, 1% and 0.2 %. Note: A 1% AEP event has a 1% chance of occurring in any year.

Year 2070/2080

This group of data presents the extent of inundation based on two SLR scenarios out to 2070/2080 – 0.4m and 0.6m. The impacts of one storm event, with 1% AEP is provided based on the chosen SLR.

Year 2130

This group of data presents the extent of inundation based on three SLR scenarios out to 2130 – 0.8 m, 1.25m and 1.6m. The impacts of three storm events with 2%, 1% and 0.2% AEPs are provided based on the chosen SLR. Note: The 1.25m SLR scenario combined with a storm event with a 1% AEP is utilised for consideration of any new building and subdivision proposals located within the extent of this scenario.

Depth (metres above existing ground level)
● 0.1 to 0.25m
● 0.25 to 0.5m
● 0.5 to 1.00m
● Above 1m

Figure 4.4: Inundation extents for selected scenarios for Tauranga Harbour, with depth ranges shown as different colours.

4.2 Options for presenting results of the Christchurch hazard assessment

The details of how the hazard assessment results are presented can be adjusted in future to meet the needs of the adaptation planning team as they progress through community engagement, so it is not necessary to “lock in” decisions about outputs at the current time. However, it is useful to start developing an initial understanding of options for how the information could be presented.

4.2.1 Coastal erosion results

For the areas where a detailed hazard assessment is undertaken, one option would be to map the areas susceptible to coastal erosion (ASCE) showing the full range of probabilities of exceedance in a combined manner (rather than as multiple lines for different probabilities, which can be confusing). An example of this approach for a selected timeframe and SLR scenario is shown in Figure 4.5. The graduated shading shows the decreasing/increasing probability of exceedance, which aligns with the histograms and probability of exceedance shown in the graph below the map. The shaded map can be used to find a probability of exceedance for a selected scenario for a particular location of interest (e.g. house or road). Separate shadings are created for each timeframe and SLR scenario, which could be integrated in a web-based tool using a slider to select the scenario of interest.

For areas where a regional hazard screening is undertaken, one option would be to map the areas susceptible to coastal erosion (ASCE) as polygons corresponding to the two assessed timeframes and high-end scenarios, as shown by the example in Figure 4.6. These provide a useful upper envelope of potential hazard and can be further refined in the future by local scale assessments.

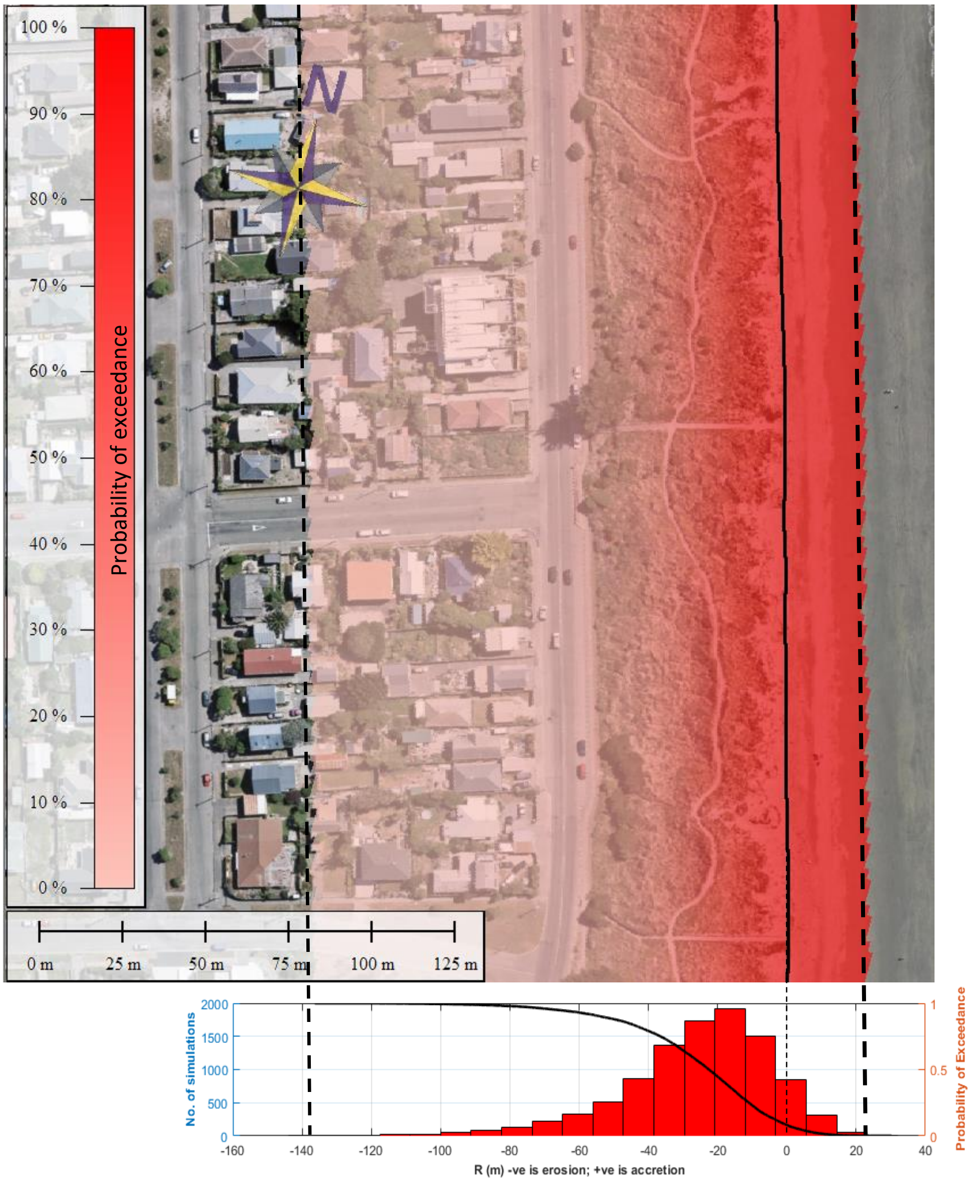


Figure 4.5: Example of erosion mapping using probabilistic output for detailed hazard assessment sites.

Figure 4.6: Example of simplified erosion mapping for regional hazard screening sites.

4.2.2 Coastal inundation results

It is proposed that the analysis would quantify inundation extent and depth for 0.1m elevation increments. Look-up tables would provide extreme water level elevations relevant to various locations around the coast. For areas where a detailed assessment was undertaken the look-up table would cover various combinations of return-period event, timeframe and sea level rise scenario. For areas where a regional screening assessment was undertaken the look-up table would present a single return-period event and sea level rise scenario. Figure 4.7 shows how the locations of these look up tables could be distributed around the coast.

Areas connected to the coastline that would be subject to direct inundation can be shown separately from areas which are not connected but could be susceptible to inundation by piped connections and/or raised groundwater. These layers could then be presented in an interactive form with sliders for event, timeframe and sea level rise scenario or for specific water levels.

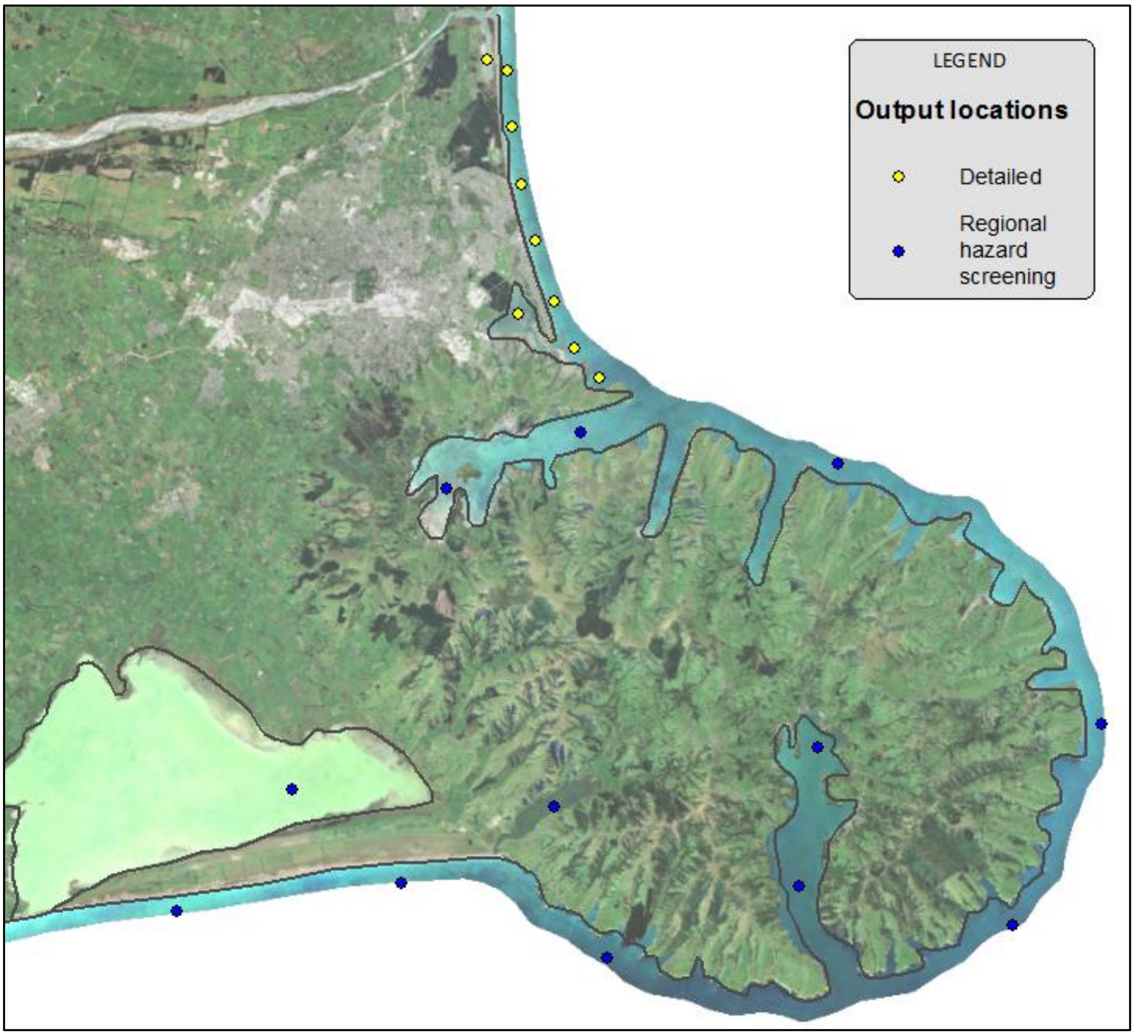
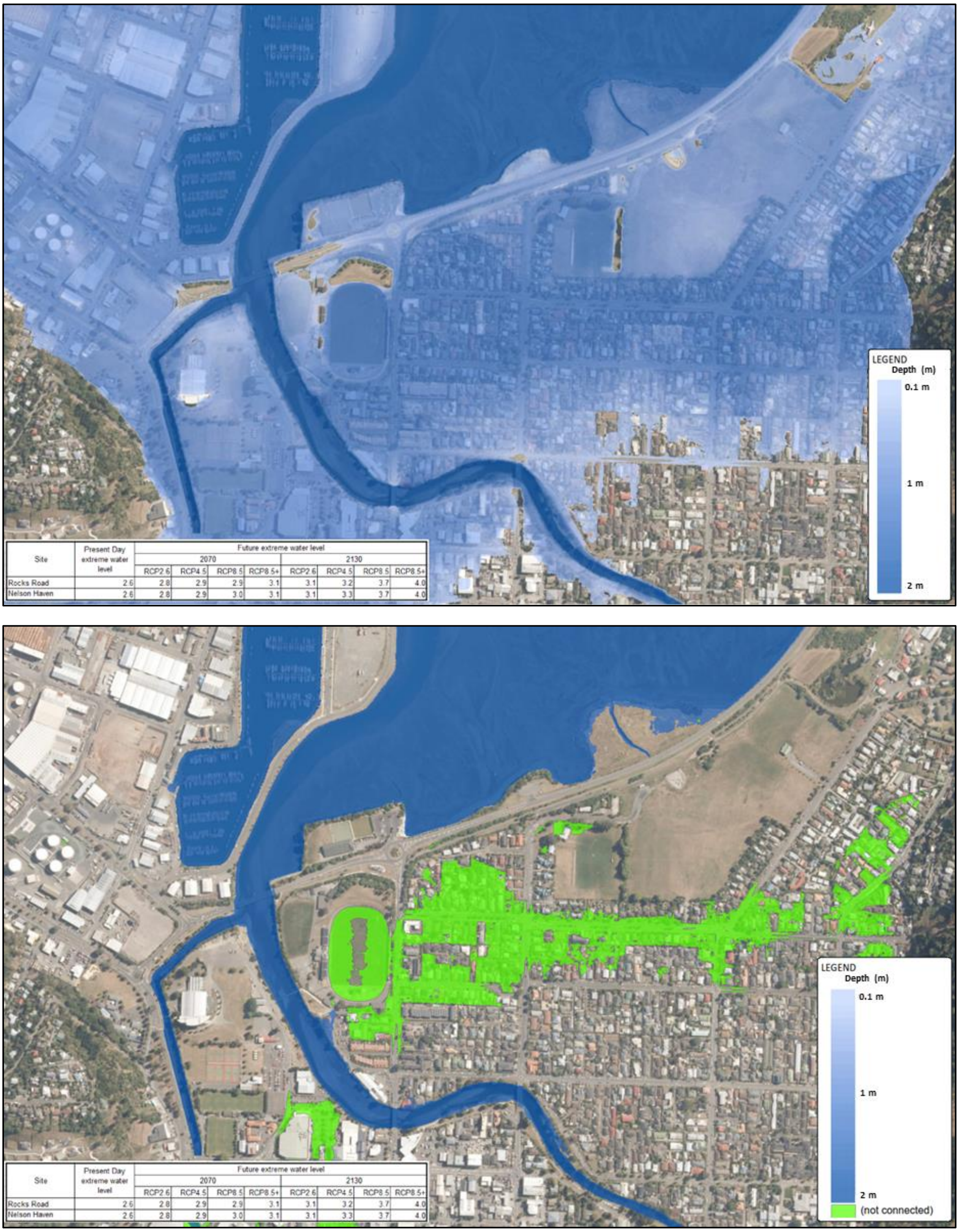


Figure 4.7: Proposed output locations for inundation level lookup tables.



Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Rocks Road	2.6	2.8	2.9	2.9	3.1	3.1	3.2	3.7	4.0
Nelson Haven	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0

Site	Present Day extreme water level	Future extreme water level							
		2070				2130			
		RCP2.6	RCP4.5	RCP8.5	RCP8.5+	RCP2.6	RCP4.5	RCP8.5	RCP8.5+
Rocks Road	2.6	2.8	2.9	2.9	3.1	3.1	3.2	3.7	4.0
Nelson Haven	2.6	2.8	2.9	3.0	3.1	3.1	3.3	3.7	4.0

Figure 4.8: Example of lookup table and inundation extent and depth (blue shading in top map) with areas below but not connected to the coast (green shading in bottom map).

5 Feedback and agreement on scope

The proposed scope was tested with the technical peer reviewer, Environment Canterbury staff and The CHAP project team to ensure it is technically robust and is suitable for the intended purpose of helping to inform adaptation planning. Options agreed to and changes made through this process include:

- Increasing the scope of the detailed hazard screening to include Akaroa and Lyttelton Harbour, and determining an approach for detailed assessment to be undertaken for other communities if regional screening indicates that more detail is warranted.
- Adapting the erosion methodologies to suit the specific local conditions for the gravel beach along Kaitorete Spit.
- Including the inland extent boundary to limit the coastal inundation model to the area where flooding is controlled more by sea level and less by rainfall and rivers.
- Mapping of areas of disconnected inundation to identify indirect effects such as groundwater flooding.
- Included a 2150 scenario to reflect New Zealand Coastal Policy Statement guidance to identify coastal hazards risk over *at least* the next 100 years.
- Included an erosion scenario with an increased sediment supply to the Christchurch open coast beaches.
- Included an intermediate sea level increment for the regional hazard screening, to provide more graduated information for adaptation planning.
- Included additional high-end relative sea level rise increments (0.6 m at 2050, 1.2 m at 2080, 1.5 m at 2130) to account for potential combined effect of future land subsidence and a rise in absolute sea level.
- Adapted the approach to coastal protection structures for erosion to reduce the assumptions made in advance of adaptation planning and better understand risk of failure for critical structures, and the approach for all other structures to reflect the limitations in currently available information.

6 Applicability

This report has been prepared for the exclusive use of our client Christchurch City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

The coastal hazard assessment described in this report will be undertaken at a broad scale across the entire Christchurch City district, and is intended to approximately describe the magnitude and extent of present day and future hazards across neighbourhood-sized areas. It is not intended to describe hazards at an individual-property level, and in many cases there will be other sources of information which provide more relevant site-specific details (such as District Plan controls for Resource Consent and minimum floor levels for Building Consent). The coastal hazard assessment will consider a range of potential likelihoods, sea level rise scenarios and effects, reflecting uncertainty both due to data limitations and incomplete understanding of the processes.

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