REPORT

Coastal Hazard Assessment

Stage Two

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Executive summary

Christchurch City Council (Council) commissioned Tonkin & Taylor Ltd (T&T) to identify areas susceptible to coastal hazards (inundation and erosion) for the main coastal settlements selected by Council. The areas were termed coastal erosion hazard zones (CEHZ) and coastal inundation zones (CIHZ). The zones have been mapped over both a 50 year (2065) and 100 year (2115) planning timeframe for both the open and harbour coast to a standard suitable for inclusion in the District Plan. A peer review of the assessment methodology and reporting was undertaken by Hume Consultancy Ltd. All the suggested amendments documented in the peer review were included in this report (Version 2).

The New Zealand Coastal Policy Statement (NZCPS) is a national policy statement under the Resource Management Act 1991. The NZCPS states policies in order to achieve the purpose of the Act in relation to the coastal environments of New Zealand. Both the Environment Canterbury Regional Policy Statement (RPS) and the proposed Replacement District Plan will give effect to the NZCPS. The CEHZ methodology used for this project has been developed in accordance with the Objectives and Policies of the NZCPS directly relevant to the assessment of coastal erosion hazard.

The CEHZ methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters. This method has been refined for the open coast to include parameter bounds which are combined by stochastic simulation. The resulting distribution is a probabilistic forecast of potential hazard zone width, rather than including single values for each component and one overall factor for uncertainty.

This approach produces a range of hazard zones (probability distribution) corresponding to differing likelihoods which may be applied to risk-based assessments as advocated by the NZCPS and supported by best practice guidelines. Following consultation with Council, the $P_{66\%}$ CEHZ value at 2065 and the $P_{5\%}$ CEHZ value at 2115 are adopted as prudent likely and potential CEHZ values (termed CEHZ2065 and CEHZ2115 respectively).

We implemented separate methodologies to assess coastal hazards for the open coast and the harbour coast sites due to the different processes driving each of the two coastal environments. The harbour coast CEHZ methodologies combine two approaches to account for the low-lying morphology typical of these sites. Although we have not yet developed the harbour coast methodology to incorporate the probabilistic approach, the method is in accordance with best practice guidelines.

The CIHZ was mapped using two methods:

- Connected "bath-tub" method – maps the area of land below the inundation level based on LiDAR derived topography, where there is a connection pathway to the sea. This method was used for sites located within both the Lyttelton and Akaroa Harbours and the open coast.
- Dynamic model method (TUFLOW) – simulates the physics of the tide and inundation levels to dynamically map the inundation levels based on LiDAR derived topography and detailed bathymetry of the estuary. This method is beneficial for wide flat areas and was implemented for Avon-Heathcote Estuary and Brooklands Lagoon.

We recommend continuing to regularly monitor the shoreline position and inundation levels across the region to provide measured data, including continuing beach profile monitoring and digitising shorelines from aerial imagery or by GPS survey. We also recommend the adopted baselines and both the CEHZ and CIHZ values are reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

1 Introduction

Christchurch City Council (Council) commissioned Tonkin & Taylor Ltd (T&T) to identify areas susceptible to coastal hazards (inundation and erosion) for the main coastal settlements selected by Council. The areas were termed coastal erosion hazard zones (CEHZ) and coastal inundation zones (CIHZ). The zones have been mapped over both a 50 year (2065) and 100 year (2115) planning timeframe to a standard suitable for inclusion in the District Plan.

T&T completed an assessment of the effects of sea level rise for Christchurch City over a 100 year timeframe (T&T, 2013). The assessment included high level mapping of the areas susceptible to storm inundation and erosion due sea level rise over a 100 year timeframe for both the Avon-Heathcote Estuary and the Akaroa Harbour. The hazard mapping produced in the 2013 report needs to be refined for inclusion in the District Plan.

T&T have recently reviewed the existing coastal hazard zones (CHZ) as presented in the Canterbury Regional Coastal Environment Plan. The review was undertaken as Stage One study to check whether the existing CHZ should be re-assessed based on best practice guidelines and current scientific knowledge. The review recommended re-assessing the existing CHZ because they do not adequately incorporate the potential effects of sea level rise as required under the New Zealand Coastal Policy Statement (NZCPS, 2010). The CHZ also needed to be re-assessed to consider the coastal erosion hazard over a 50 year planning timeframe (2065). The coastal inundation hazard needs to be assessed for the open coast to identify low lying areas of land with coastal inundation pathways.

The extent of this study includes the coastal settlements located on non-consolidated sand or gravel shorelines within the Council jurisdictional boundaries (refer to Appendix A for site plan). The sites are listed below and are classified by their coastal environment as either open coast or Harbour/Estuary (harbour coast):

Open coast

- Southern Pegasus Bay from Waimairi Beach to Southshore including the South Brighton spit
- Sumner
- Taylors Mistake.

Harbour coast

- Avon-Heathcote Estuary
- Brooklands Lagoon
- Lyttelton Harbour
  - Allandale
  - Teddington
  - Charteris Bay
  - Purau.
- Akaroa Harbour
  - Akaroa Township
  - Takamatua
  - Duvauchelle
  - Wainui.

A peer review of the assessment methodology and reporting was undertaken by Dr Terry Hume of Hume Consultancy Ltd. All the suggested amendments documented in the peer review were included in this report (Version 2).

2 Background information

2.1 Statutory legislation

2.1.1 New Zealand Coastal Policy Statement

The New Zealand Coastal Policy Statement (NZCPS) is a national policy statement under the Resource Management Act 1991. The NZCPS states policies in order to achieve the purpose of the Act in relation to the coastal environments of New Zealand. Regional policy statements and regional and district plans must give effect to the NZCPS.

A number of the Objectives and Policies of the NZCPS are directly relevant to the assessment of coastal hazard. Relevant policies include:

- Policy 3 - requires a precautionary approach in the use and management of coastal resources potentially vulnerable to effects from climate change, so that avoidable social and economic loss and harm to communities does not occur.
- Policy 24 - identify areas in the coastal environment that are ***potentially*** affected by coastal hazards (including tsunami) and giving priority to the identification of areas at high risk of being affected. These should take into account national guidance and the best available information on the likely effects of climate change for each region.
- Policy 25 - promotes avoiding increasing the risk of social, environmental and economic values to erosion hazard in areas ***potentially*** affected by coastal hazards over at least the next 100 years.
- Policy 27 - promotes reducing hazard risk in areas of significant existing development ***likely*** to be affected by coastal hazards.

2.1.2 Canterbury Regional Policy Statement

The Canterbury Regional Policy Statement (CRPS) became operative on 15 January 2013. The CRPS provides an overview of the resource management issues in the Canterbury region and sets out a suite of objectives, policies and methods in order to achieve integrated management of the region's resources.

Chapters 8 and 11 are of particular relevance to the assessment of coastal hazards. These chapters deal with the Coastal Environment and Natural Hazards respectively.

The following objectives and policies are relevant to this report in regard to identifying coastal hazards in the Canterbury region:

- Issue 8.1.7 – Natural hazards in the coastal environment

  There is a need to assess the effects of climate change, and coastal hazards such as coastal erosion, on the coastal environment , and develop responses where human assets and natural values are threatened by such coastal hazards
- Objective 8.2.1 – Increasing knowledge of the coastal environment and its resources

  A programme of information gathering is undertaken on the natural processes, ecosystems and resources in the coastal environment; with the purpose of providing the basis for:

  (1) Development of a coastal strategy (ies) within five years to address the management of the coastal environment in Canterbury

  (2) Consequential changes to the Canterbury Regional Policy Statement, any relevant regional coastal plan(s) and district plans.

- Objective 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.

- Policy 11.3.5 – General risk management approach

  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, 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.

2.1.3 Regional Coastal Environment Plan

The Regional Coastal Environment Plan for the Canterbury Region (RCEP) was made operative in 2005. The RCEP manages the natural and physical resources of the Canterbury coastal environment.

Chapter 9 of the RCEP covers coastal hazards and section 9.2 details the following policies regarding management of coastal hazards for the Canterbury coast.

- 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.
  (e) Natural features that buffer the effects of coastal hazards should be protected.

2.2 Coastal processes

2.2.1 Water levels

Water levels play an important role in determining coastal erosion hazard both by controlling the amount of wave energy reaching the backshore causing erosion during storm events and by controlling the mean shoreline position on longer time scales.

Key components that determine water level are:

- Astronomical tides
- Barometric set-up and wind effects, generally referred to as storm surge
- Medium term fluctuations, including seasonal effects, El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) effects commonly called mean sea level anomaly (MSLA).
- Long-term changes in sea level due to climate change
- Wave transformation processes through wave set-up and run-up.

All levels presented in this report are reduced to Lyttelton Vertical Datum 1937 (RL m), unless stated otherwise.

2.2.1.1 Astronomical tide

The astronomical tides are caused by the gravitational attraction of solar-system bodies, primarily the Sun and Earth's moon. These forces result in ocean long waves interacting with the continental shelf in a complex way to produce a rise and fall in sea levels (tides). In New Zealand the astronomical tides have the largest influence on sea level.

Tidal levels for primary and secondary ports of New Zealand are provided by Land Information New Zealand (LINZ) based on the average predicted values over the 18.6 year tidal cycle. Values for Lyttelton in terms of Chart Datum, CCC Datum and Lyttelton Vertical Datum 1937 (RL m) are presented within Table 2-1. The spring tidal range is approximately 2.2 m and the mean sea level is around RL 0.2 m.

Table 2-1 Tidal levels at Lyttelton Harbour

Tide state	Lyttelton Chart Datum (m)	Lyttelton Vertical Datum 1937 (RL m)	CCC Datum (m)
Highest Astronomical Tide (HAT)	2.65	1.5	10.54
Mean High Water Springs (MHWS)	2.48	1.33	10.37
Mean Sea Level (MSL)	1.38	0.23	9.27
Mean Low Water Springs (MLWS)	0.27	-0.88	8.16
Lowest Astronomical Tide (LAT)	0.1	-1.05	7.99
Source: LINZ (2014) and Goring et al. (2009)			

2.2.1.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide (Figure 2-1). Storm surge applies to the general elevation of the sea above the predicted tide across a region but excludes nearshore effects of storm waves such as wave set-up and wave run-up at the shoreline.

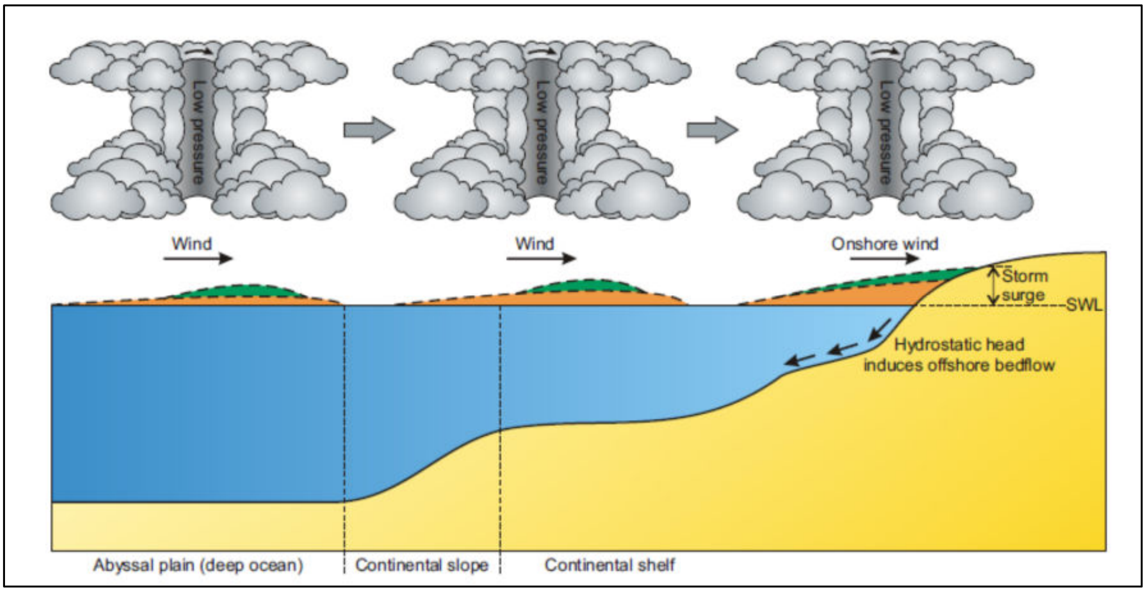

Figure 2-1 Processes causing storm surge (source: Shand, 2010)

2.2.1.3 Medium term fluctuations and cycles

Atmospheric factors such as season, El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) can all affect the mean level of the sea at a specific time (refer to Figure 2-2). The combined effect of these fluctuations may be up to 0.25 m according (Bell, 2012).

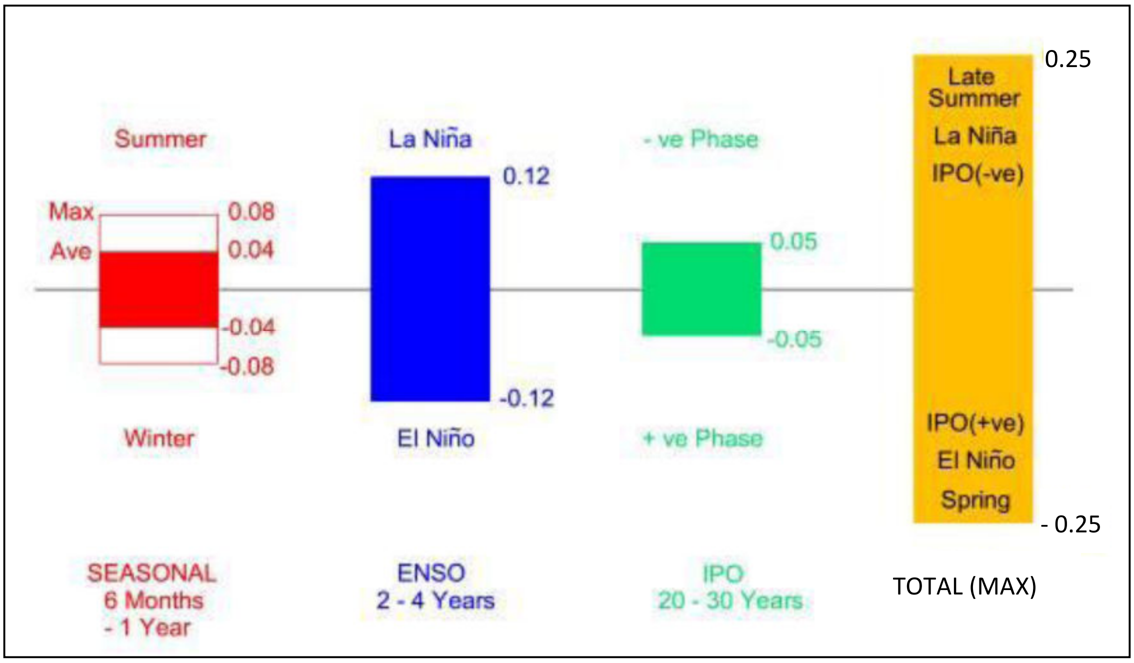

Figure 2-2 Components contributing to sea level variation over long term periods (source: Bell, 2012)

2.2.1.4 Storm tide levels

The combined elevation of the predicted tide, storm surge and medium term fluctuations is known as the storm tide. The 1% and 2% Annual Exceedance Probability (AEP) storm tide predicted by Goring et al. (2009) are RL 1.92 m and RL 1.87 m respectively. The storm tide calculated by Goring et al. (2009) was based on the Lyttelton tide gauge data (1998-2009) using the Empirical Simulation Technique (EST). The 1% and 2% AEP storm tide predicted for Sumner Head using the same techniques are RL 1.85 m and RL 1.8 m respectively (Goring, 2011).

No long term tide gauge data exists for Akaroa and this study assumes the storm tide levels presented in Table 2-2 for Lyttelton can be applied to the Akaroa Harbour sites. Additional wind set-up values have been calculated for the Akaroa Harbour, which increases the storm tide level for some sites at the head of the harbour.

Table 2-2 Extreme storm tide

Site	Storm tide level (RL m	
	1% AEP	2% AEP
Lyttelton	1.92	1.87
Sumner Head	1.85	1.8

2.2.1.5 Wave effects

Wave effects include wave set-up and wave run-up. Wave set-up is a local elevation in the mean water level on the foreshore, caused by the reduction in wave height through the surf-zone. Wave run-up is the sum of the wave set-up and the wave swash and is the maximum level that the waves reach on the beach relative to the still water level.

An indicator of wave run-up is recorded within the ECan beach profile dataset (i.e. storm debris line). Three significant storm events have occurred during the beach profile dataset period of 25 years in 1992, 2001 and 2014. Drift wood and storm debris line elevations were surveyed after these storm events, which ranged from RL 2.58 m to 2.8 m. The upper elevation relates to a wave run-up level range of approximately 1.1 m to 1.4 m, based on a tide level of RL 1.7 m (2% AEP Sumner Head) and RL 1.4 m (HAT Sumner Head) respectively.

2.2.1.6 Long-term sea levels

Historic sea level rise in New Zealand has averaged 1.7 ± 0.1 mm/year with Christchurch exhibiting a slightly higher rate of 1.9 ± 0.6 mm/year (Bell and Hannah, 2012). Climate change is predicted to accelerate this rate of sea level rise into the future. NZCPS (2010) requires that the identification of coastal hazards includes consideration of sea level rise over at least a 100 year planning period (i.e. 2115). Potential sea level rise over this time frame is likely to significantly alter the coastal erosion hazard.

The Ministry of Environment (MfE, 2008) guideline recommends a base value sea level rise of 0.5 m by 2090 (relative to the 1980-1999 average), with consideration of the consequences of sea level rise of at least 0.8 m by 2090 with an additional sea level rise of 10 mm per year beyond 2100. Bell (2013) and Tonkin & Taylor (2013) recommend that for planning to 2115, these values are increased to 0.7 and 1.0 m respectively. Bell (2013) also recommends that when planning for new activities or developments, that higher potential rises of 1.5 to 2 m above the present mean sea level should be considered to cover the foreseeable climate-change effects beyond a 100 year period.

Modelling presented within the most recent IPCC report (AR5; IPCC, 2014) show predicted global sea level rise values by 2100 to range from 0.27 m, which is slightly above the current rate of rise, to 1 m depending on the emission scenario adopted (Figure 2-3). The Representative Concentration Pathways (RCP) 8.5 scenario assumes emissions continue to rise in the 21st century on a "business as usual" rate. We consider assessing the effects of this scenario is prudent until evidence of emission stabilising justify use of a lower projection scenario. Extrapolating the RCP8.5 scenario to 2115 results in a potential sea level range from 0.62 to 1.27 m by 2115 (Figure 2-3). We note these figures do not include for the collapse of the marine-based sectors of the Antarctic ice sheet. However, this contribution is not likely to exceed several tenths of a meter of sea level rise during the 21st century (IPCC, 2015).

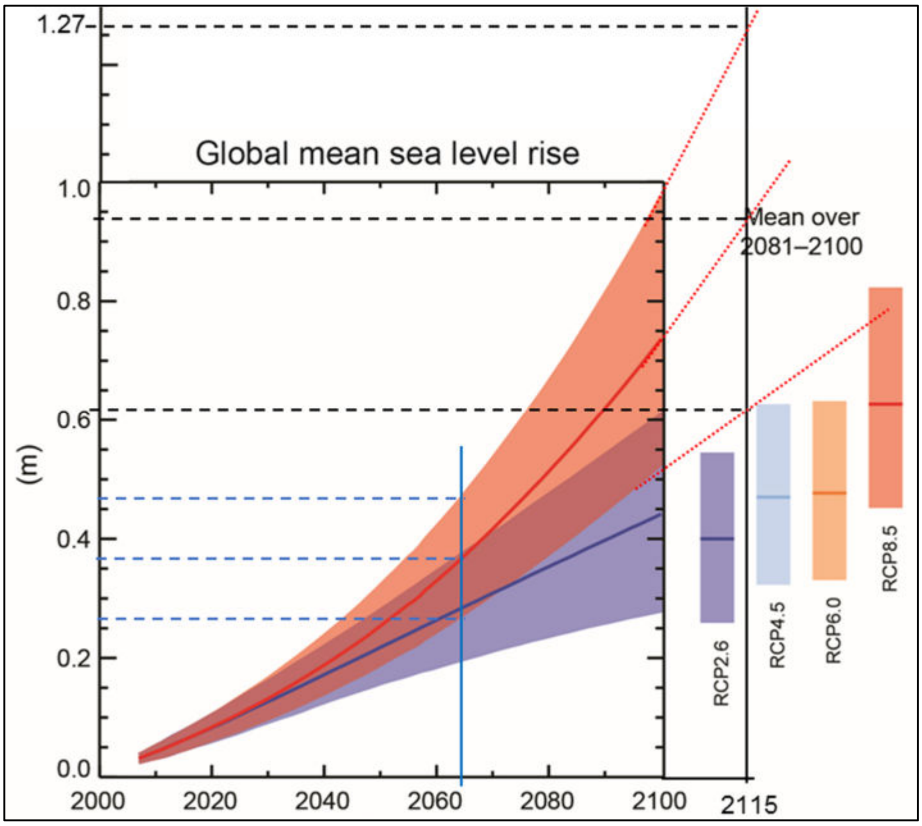

Figure 2-3 Projections of potential future sea level rise presented within IPCC AR5 (IPCC, 2014) with adopted values for this assessment extrapolated to 2115 (red dotted line) and 50 year projections (blue dashed line) based on the RCP8.5 scenario

2.2.2 Waimakariri River sediment supply

NIWA (1998) reviewed the sediment budgets for the Canterbury coast focusing on the influence of river sediment. The key conclusions of the report relevant to Southern Pegasus Bay are:

- The Pegasus Bay shoreline is a sandy shore which has prograded over the past 6-7,000 years (Holocene Period).
- The main sediment sources feeding the Holocene progradation of Southern Pegasus Bay were the Waimakariri River and the onshore movement of sand from the Banner Bank streaming north from the northern tip of Banks Peninsula.
- The supply from the Banner Bank is now considered to be exhausted and the Waimakariri River is now the only main sediment source.
- The beach sediment is fine sand and fine sand makes up approximately 20% of the Waimakariri River suspended sediment load, equating to around 360,000 m^3/year based on best current estimates.
- The longshore sediment transport system for Pegasus Bay is considered to be bidirectional centred on the Waimakariri River mouth. Therefore, the total amount of fine sand sediment transported south towards the Southern Pegasus Bay beaches is around 180,000 m^3/year (i.e. 0.5 x 360,000 m^3/year = 180,000 m^3/year).
- Based on a sediment budget compartment length of 16 km and an active beach profile height of 20 m (assumed by NIWA), the maximum rate of shoreline accretion is 0.56 m/year on average along the compartment (i.e. 180,000 m^3/year / 16 km / 20 m = 0.56 m/year). This estimated accretion rate of 0.56 m/year is sensitive to the input assumptions of suspended sediment load volume, the fine sand fraction percentage and the sediment budget compartment dimensions.

- This assessment is based on estimates of the existing situation and it is unknown how this may change as a result of climate change. Analysis of the potential effect of climate change on coastal sediment supply from rivers suggested the effects are likely to be minor in relation to existing short to medium term climate change responses associated with ENSO for example (NIWA, 2006).

2.3 New data collection

2.3.1 Shorelines

Digitised historic shorelines have been provided by ECan covering a time period between 1941 and 2011 (refer to Table 2-3). This set of shoreline information provides a total of five time-periods spaced approximately every 15 to 20 years for analysing long-term trends over a 70 year period (1941 – 2011).

The historic shorelines are based on digitising the shoreline proxy, taken to be the seaward edge of dune vegetation, from geo-referenced historic aerial photographs. The seaward edge of the dune vegetation was digitised to represent the dune toe, which was taken as the shoreline proxy. This shoreline proxy was chosen because the change in contrast from dune vegetation to beach sand can more accurately be identified on the historic black and white aerial photographs rather than the water line.

The GPS shoreline survey captured in 2014 for the Stage One assessment was limited to 3 relatively short sections. Therefore, the 2014 GPS shoreline was not included in this study because it does not extend over the entire open coast shoreline covered under the Stage Two assessment.

Table 2-3 Summary of aerial photographs input dataset

Date Captured	Run Number	Source	Scale
14/10/1941	SN 152	NZAM Aerial Photograph	1:16,000
10/05/1955	SN 872	NZAM Aerial Photograph	1:16,000
22/08/1979	SN 5468	NZAM Aerial Photograph	1:24,000
26/11/1994	SN 50038c	NZAM Aerial Photograph	1:24,000
24/02/2011	SN 521	NZAM Aerial Photograph	1:24,000

The shoreline data digitised from aerial photographs was verified against the source information by T&T. Verification and quality control focused on the accuracy of the shoreline proxy representation including the position and frequency of the polyline nodes. The geo-referencing of the historic aerial photographs was independently checked over a minimum of three ground control points (GCP) to verify the horizontal accuracy.

Three potential measurement errors have been estimated for the historic shoreline position:

- The geo-referencing error (Er) represents the potential offset of an image from a known point based on ground control points collected during the geo-referencing process.
- The digitising error (Ed) represents the potential operator inconsistency in digitising a shoreline using ArcGIS software.
- Shoreline proxy error (Es) is the estimated uncertainty in identifying the shoreline, which is more for black and white images. Example of features that cause shoreline proxy error

include scale, shadow, overhanging trees and the uncertainty in identifying the correct dune vegetation edge based on black and white contrast.

Refer to Table 2-4 for a summary of the estimated shoreline data error values. The resultant potential error in shoreline position can be calculated as between 2 and 4 m (0.025 and 0.05 m/year) using a sum of independent errors approach whereby:

$$E_{sum} = \sqrt{E_{\mathrm{r}}^2 + E_{\mathrm{d}}^2 + E_s^2} \qquad \text{(Equation 1)}$$

Table 2-4 Shoreline data error summary

	Data Type	
Potential Measurement Error (metres)	**A**	**B**
Geo-referencing error (Er)	1	2
Digitising error (Ed)	1	1
Shoreline proxy error (Es)	2	3
Total potential error (Et) (metres)	2.45	3.7
Rounded	***2m***	***4m***
Data Type A = post 2000 aerial source, B = pre 2000 aerial source		

2.3.2 Beach profiles

The natural cross-shore beach profile is expected to fluctuate in response to changes in the beach processes and sediment supply. ECan has undertaken regular beach profile surveys along southern Pegasus Bay between 1990 and 2014. The surveys are captured with a Leica TCA1100L total station in conjunction with a Sokkia prism survey pole. The vertical and horizontal accuracy is ±30 mm. The surveys are completed twice a year (summer & winter) and the cross-shore extent includes the backdune out to at least mean sea level. A summary of the beach profile data is presented in Table 2-5. Refer to Appendix D for a site plan for a location plan of beach profile positions.

Table 2-5 Summary of beach profile data for southern Pegasus Bay

Beach Profile Description					
Code	**Name**	**First survey date**	**Last survey date**	**Survey period (yrs)**	**Number of Surveys**
C1130	Waimairi Beach (Larnach Street)	9/05/1990	25/07/2014	24	38
C1111	Waimairi Beach (Beach Road)	7/08/2008	25/07/2014	6	20
C1100	North New Brighton (Pandora Street)	9/05/1990	25/07/2014	24	38
C1086	North New Brighton (Pacific Road)	9/05/1990	25/07/2014	24	38
C1065	North New Brighton (Effingham Street)	9/05/1990	25/07/2014	24	38
C1041	North New Brighton (Cygnet Street)	9/05/1990	25/07/2014	24	38
C1011	North New Brighton (Bowhill Road)	9/05/1990	25/07/2014	24	38

Beach Profile Description Code	 Name	First survey date	Last survey date	Survey period (yrs)	Number of Surveys
C0952	New Brighton (Rawhiti Street)	9/05/1990	25/07/2014	24	38
C0924	New Brighton (Lonsdale Street)	9/05/1990	25/07/2014	24	38
C0889	New Brighton (Hawke Street)	9/05/1990	25/07/2014	24	38
C0848	New Brighton (Hood Street)	9/05/1990	23/07/2014	24	38
C0815	New Brighton (Rodney Street)	9/05/1990	23/07/2014	24	38
C0781	New Brighton (Mountbatten Street)	9/05/1990	25/07/2014	24	38
C0748	South New Brighton (Jervois Street)	9/05/1990	23/07/2014	24	38
C0703	South New Brighton (Bridge Street)	9/05/1990	25/07/2014	24	38
C0650	South New Brighton (Beatty Street)	9/05/1990	25/07/2014	24	38
C0600	South New Brighton (Jellicoe Street)	9/05/1990	25/07/2014	24	38
C0531	South New Brighton (Halsey Street)	9/05/1990	21/07/2014	24	38
C0513	South New Brighton (Caspian Street)	9/05/1990	25/07/2014	24	38
C0471	South Shore (Heron Street)	9/05/1990	25/07/2014	24	38
C0431	Southshore (Penguin Street)	9/05/1990	17/07/2014	24	38
C0396	South Shore (Plover Street)	9/05/1990	25/07/2014	24	38
C0362	South Shore (Tern Street)	9/05/1990	17/07/2014	24	38
C0350	South Shore (Torea Street)	9/05/1990	25/07/2014	24	38
C0300	South Shore (South of Pukeko Place)	9/05/1990	25/07/2014	24	38
C0271	South Shore (End Rockinghorse Road)	9/05/1990	25/07/2014	24	38

2.3.3 LiDAR

Council sourced LiDAR data was processed in GIS using ArcGIS software (Spatial Analyst Licence) to form a digital elevation model (DTM). The LiDAR survey was undertaken in 2011 after the 2010-2011 Canterbury Earthquakes (Table 2-6). Metadata supplied with the source LiDAR indicates the survey equipment had a vertical accuracy ±0.07 m.The generated DTM has a grid cell size of 2 m by 2 m. Dune crest elevations were extracted from the DTM as a 3D polyline along the dune crest alignment using standard transect methods with a node spacing of 2 m. LiDAR was also used to establish the elevation of the dune toe for both sites. This information is required for the shoreline change analysis of the beach profile datasets.

Table 2-6 LiDAR source and commissioning agencies

DEM	Source LiDAR	Commissioning Agencies
Post-Sept 2010	NZAM, 5 Sep 2010	Ministry of Civil Defence and Emergency Management
Post-Feb 2011	NZAM, 8-10 Mar 2011 AAM, 20-30 May 2011	Ministry of Civil Defence and Emergency Management Christchurch City Council
Post-June 2011	NZAM, 18 & 20 Jul, 11 Aug, 25-27 Aug, and 2-3 Sep 2011	Earthquake Commission

DEM	Source LiDAR	Commissioning Agencies
Post-Dec 2011	NZAM 17-18 Feb, 2012	Earthquake Commission

3 Previous assessment methodology

Environment Canterbury Regional Council (ECan) have developed two CHZ's for the Canterbury region as set out in the Operative Regional Coastal Environment Plan (RCEP, 2005):

- Coastal Hazard Zone 1 (CHZ1) – landward limit of the active beach system including any long-term rates of erosion to **50 years**.
- Coastal Hazard Zone 2 (CHZ2) – landward limit of the active beach system including any long-term rates of erosion to **100 years**.

The southern Pegasus Bay shoreline was assessed to be an accreting shoreline and therefore only Coastal Hazard Zone 1 has been mapped as the landward limit of the active beach system in this area.

The delineation of the CHZ for Southern Pegasus Bay was completed prior to 2005 and there is now over 10 years of additional data that could be included in any new assessments. The New Zealand Coastal Policy Statement (NZCPS, 2010) has also been updated over this time, which provides further guidance on coastal hazard assessments. Furthermore, Envirolink published a best practice guideline to defining coastal hazard zones in 2012 (Ramsey, et al; 2012). Therefore, CCC require a review of the existing CHZ delineation to check it is in accordance with best practice guidelines and the current state of scientific knowledge.

Understanding the physical processes and drivers of change is a key process that must be carried out to enable a robust coastal hazard assessment and is a fundamental requirement of Policy 24 of the NZCPS. The Waimakariri River is a major source of sediment for the Southern Pegasus Bay shoreline, resulting in a historic trend of shoreline accretion. The existing CHZ assessment did not incorporate the potential effects of sea level rise as required under both the NZCPS (2010) and the Envirolink Guidelines (Ramsey, et al; 2012). Understanding how sea level rise could potentially interact with the coastal sediment budget is considered to be a key factor in the CHZ assessment.

4 Re-assessment methodology

We implemented separate methodologies to assess coastal hazards for the open coast and the harbour coast sites due to the different processes driving each of the two coastal environments. The Open Coast and Harbour Coast methodology are outlined in Sections 4.1 and 4.2 respectively.

4.1 Open coast

The re-assessment method for the open coast identifies areas susceptible to both coastal erosion (CEHZ) and inundation hazard (CIHZ). The mapping has been completed for both a 2065 and 2115 timeframe and will be suitable for inclusion in the District Plan.

4.1.1 Open coast coastal inundation hazard zone (CIHZ)

The coastal inundation hazard for the open coast has not previously been identified. Coastal inundation pathways were identified at three sites located along the open coast at New Brighton, Sumner and Taylors Mistake.

The coastal inundation level was based on the combination of the following components (refer to Section 2.2.1):

- Storm tide (Sumner Head tide gauge)
- Wave set-up (Coastal Engineering Manual method)
- Sea level rise (mid-range IPCC projections based on extrapolation of the RCP8.5 emission scenario).

Wave set-up was calculated based on the Coastal Engineering Manual method (CEM, ll-4-3). This method takes into account the wave climate and beach slope. Table 4-1 outlines the input wave climate and beach slope parameters used for this assessment.

Table 4-1 Input parameters used for the wave–set up calculations

Site	Deep water wave height (Ho)[1]		Deep water wave period (To)[1]		Beach slope (tanβ)[2]
	1% AEP	2% AEP	1% AEP	2% AEP	
New Brighton	5.98 m	5.75 m	14.45 sec	13.6 sec	0.01
Sumner	5.32 m	5.15 m	12.75 sec	12.75 sec	0.006
Taylors Mistake	5.32 m	5.15 m	12.75 sec	12.75 sec	0.01
Notes: [1]Wave climate data sourced from Tonkin & Taylor (1998) [2]Beach slope taken from the break point.					

Table 4-2 summarises the storm inundation component values used to calculate the CIHZ levels for the open coast. The total CIHZ level is calculated by summing the three inundation component values using a "building-block" approach. This approach represents a conservative upper bound of the inundation hazard. The maximum CIHZ level at the three sites for the 2065 and 2115 timeframes are RL 3.7 m and RL 4.4 m respectively. These levels are considered to be generally in line with previous reporting (T&T, 1998) although generally higher (i.e. 500 mm higher) than the observed upper levels of storm debris of approximately RL 2.8 m recorded since 1990 (refer to Section 2.2.1.5).

Table 4-2 Coastal Inundation Hazard components values

Site	Timeframe	Storm Tide (m)	Wave set-up (m)	Sea level rise (m)	Total CIHZ level (RL m)
New Brighton	2065	1.8	1.49	0.4	3.7
	2115	1.85	1.53	1.0	4.4
Sumner	2065	1.8	1.27	0.4	3.5
	2115	1.85	1.31	1.0	4.2
Taylors Mistake	2065	1.8	1.29	0.4	3.5
	2115	1.85	1.33	1.0	4.2
All levels reduced to Lyttelton Datum 1937 (LVD-1937)					

The inundation zones (CIHZ) were mapped for both Taylors Mistake and Sumner by extrapolating the total inundation level inland where pathways exist based on a digital elevation model (DEM) derived from LiDAR surveyed post the 2010-2011 Canterbury Earthquakes. The CIHZ maps are presented in Appendix E.

The elevation of the foredunes located along the open coast shoreline from Waimairi to the Avon-Heathcote Estuary mouth are generally sufficient to mitigate the coastal inundation hazard. However, there are two sites at New Brighton where the foredunes have been modified and inundation pathways exist through the foredunes:

- New Brighton Library
- North New Brighton Community Centre and North Beach Surf Lifesaving Club.

The inundation pathways at both sites are relatively narrow and the quantity of inundation will be affected by tide levels and friction. Therefore the volume of water able to propagate inland will be restricted. It is expected that the inundation level will decrease inland further away from the shoreline due to the limited volume of seawater able to pass through the pathway within the time period of a typical storm event. Therefore, the inundation levels for New Brighton are more likely controlled by the storm-tide level within the harbour. Further analysis is required to accurately identify the open coast inundation extent for New Brighton. An alternative option is to remove the hazard risk by restoring the foredune to eliminate these open coast inundation pathways.

4.1.2 Open coast coastal erosion hazard zone (CEHZ)

The CEHZ's were established from the cumulative effect of four main components, which includes an allowance for uncertainty/likelihood:

$$CEHZ = ST + DS + (LT \times T) + SL \qquad \text{(Equation 2)}$$

Where:

ST = Short term /horizontal coastline fluctuations including storm cut (m).

DS = Dune slope is characterized by the horizontal distance from the base of the eroded dune to the crest of a stable angle of repose (m).

LT = Long term rate of horizontal coastline movement (m/yr).

T = Timeframe (years). In this instance a period of 50 and 100 years will be used for CEHZ2065 and CEHZ2115 respectively (i.e. 2065 and 2115).

SL = Horizontal coastline retreat due to possible accelerated sea level rise (m).

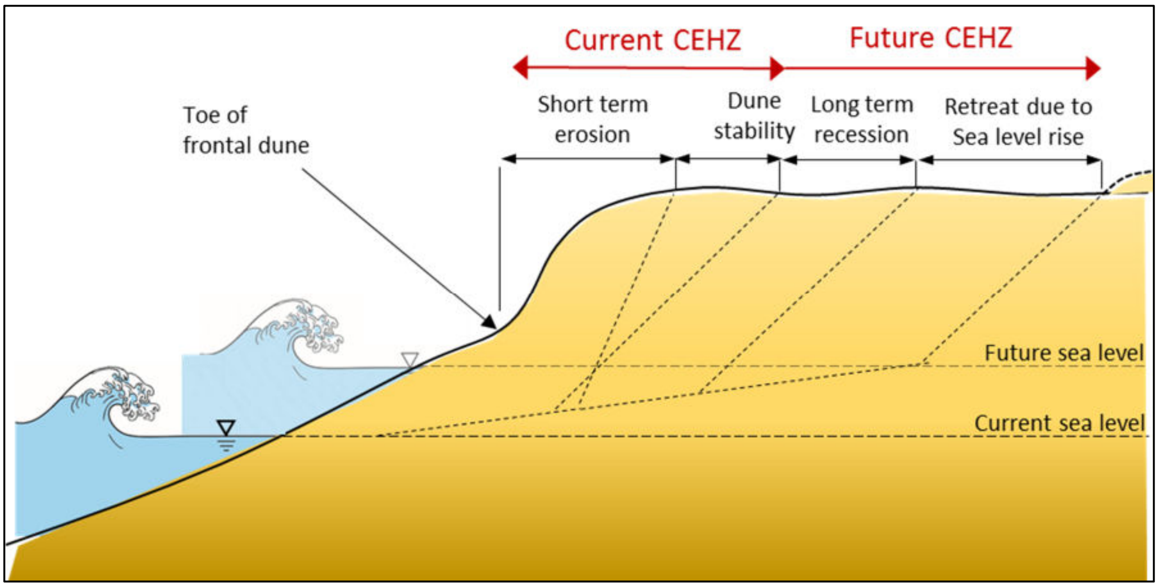

Figure 4-1 Definition sketch for open coast CEHZ

The CEHZ baseline to which values are referenced is the most recent dune toe derived from aerial photographs captured in 2011, except where the dynamic spit shoreline begins to fluctuate south of Tern Street. In the dynamic spit area the baseline was taken as the most inland extent of fluctuation (envelope) (i.e. Shand, 2012).

The Envirolink guide to good practice[1] recommends moving from deterministic predictions to probabilistic projections, and that the recognition and treatment of uncertainty is a key source of variance between CHZ predictions by practitioners. We have adopted a probabilistic approach which is consistent with the Envirolink guide, and includes the following steps:

- Use probability distribution function to contain the best estimate (mode), lower and upper bounds of the four components (excludes T which is fixed) based on either available data or heuristic reasoning based on experience.
- Probability distributions constructed for each components are randomly sampled and the extracted values used to define a potential CEHZ distance. This process is repeated 10,000 times using a Monte Carlo technique and an example of a probability distribution of the resultant CHZ width is forecast (Figure 4-2) for a specific location.
- Utilise the probabilistic distributions to map the range of CEHZ distances for each time frame and assign a pragmatic probability or likelihood for each CEHZ.

The probabilistic approach recognises there will always be inherent uncertainties associated with projections and provides a much more transparent way of capturing and presenting such uncertainty. We note that this method results in a range of potential hazard zone distances and that the selection of the appropriate probabilistic value will be based on discussions with Council. The probabilistic method also aligns with risk assessment approach where the results can be aligned with a range of likelihood scenarios if required.

[1] http://www.envirolink.govt.nz/Envirolink-tools/

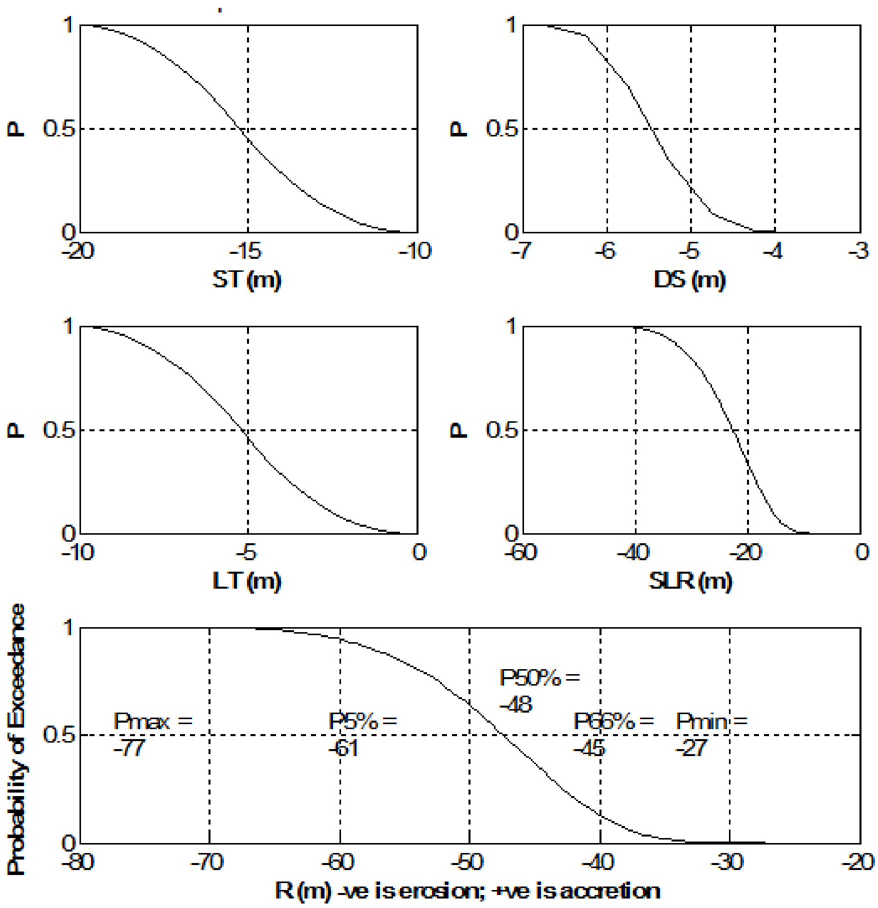

Figure 4-2 Example of cumulative distribution functions of parameter samples and the resultant CHZ distances

4.1.3 Defining coastal behaviour cells

The open coast CEHZ assessment was limited to the Pegasus Bay shoreline located between Waimairi Beach in the north and the mouth of the Avon-Heathcote Estuary in the south. The open coast has been divided into seven coastal cells (A-F) based on shoreline composition and behaviour which can influence the resultant hazard. Factors which may influence the behaviour of a cell include:

- cell morphology
- profile geometry
- backshore elevation
- historic shoreline trends.

All the open coast cells have a similar morphology with a dune backshore and a relatively flat fine sand beach. Cell G represents the distal end of the New Brighton spit where the shoreline has historically fluctuated and the morphology is relatively low lying. The main influence on the cell division along the open coast is the historic shoreline trends. Refer to Table 4-3 for a summary of the cell divisions and Appendix C for the spatial extent of each cell.

All cells have experienced accretion over the long-term with the highest rates occurring at the north and south extents of the open coast site (i.e. cells A, F and G). The lowest rates of accretion have occurred at cell B where the backshore has been modified and carparks, structures and other public access routes have altered the dune morphology. Some areas along cell B have minimal established dune vegetation, which reduces the dune capacity to trap wind-blown sand and accrete seaward. Refer to Section 4.1.5 for a full description of the components values adopted for each cell.

Table 4-3 Summary of the behaviour cell characteristics for the open coast

Site	Christchurch open coast						
Cell	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Chainage[1], (m)	0-1900	1900-3500	3500-5100	5100-6200	6200-7400	7400-8600	8600-9600
ECan beach profiles within each cell	C1130 C1111 C1100 C1086 C1065 C1041	C1011 C0952 C0924 C0889	C0848 C0815 C0781 C0748	C0703 C0650 C0600	C0531 C0513 C0471	C0431 C0396 C0362	C0350 C0300 C0271
Morphology	Unmodified dune backshore	Modified dune backshore	Unmodified dune backshore	Unmodified dune backshore	Unmodified dune backshore	Unmodified dune backshore	Low lying distal spit backshore
Historic shoreline movement	Accretion (high)	Accretion (low)	Accretion (average)	Accretion (average)	Accretion (average)	Accretion (high)	Fluctuates
Note[1]: Chainage is a distance measure from the origin taken as the start of cell A at E1577557m N5186179m (NZTM)							

4.1.4 Component derivation

The CEHZ components identified in Section 4.1.2 and Equation 1 have been assessed for each behaviour cell and are described in the following sections below.

4.1.4.1 Planning timeframe (T)

Two planning time frames were applied to provide information on current hazards and information at sufficient time scales for planning and accommodating future development:

- 2065 Coastal Erosion Hazard Zone (50 years): CEHZ2065
- 2115 Coastal Erosion Hazard Zone (100 years): CEHZ2115.

4.1.4.2 Short-term (ST)

Short-term effects apply to non-consolidated sandy beach systems where rebuilding follows periods of erosion. These effects include changes in horizontal shoreline position, due to storm erosion caused by singular or clusters of storm events, or seasonal fluctuations in wave climate or sediment supply and demand. The short-term shoreline movements have been assessed from analysis of:

1. statistical analysis of dune toe position obtained from aerial photographs or beach profile analysis
2. numerical assessment of storm erosion potential.

Statistical methods

The horizontal position of the dune toe derived from the ECan beach profile analysis was used to assess short-term fluctuation. The beach profile analysis was undertaken by ECan and checked and reported on by T&T.

Linear regression analysis was undertaken on the ECan profile data based on the cross-shore position of the dune toe relative to the benchmark. The linear regression technique fits a straight line to the full set of data points using a least squares routine. The linear model is represented by Equation 1 below:

$$Y = a + bX + e \qquad \text{(Equation 3)}$$

Where:

Y is the dependant variable (cross-shore distance to the dune toe)

X is the independent variable (time)

a is the intercept on the Y axis

b is the slope coefficient (rate of shoreline change)

e is the fitting error.

The model outputs provide values for rate of shoreline change over time, and the strength of the rate or trend is calculated as the correlation coefficient (r^2). The closer the r^2 value is to 1.0 the stronger the linear fit around the trend. Figure 4-3 shows an example of the linear regression results for the Hood Street beach profile site (C0848).

Although the beach has experienced net accretion, the shoreline fluctuates over time. The ongoing accretion is likely to be periodic, responding to pulses of sediment supplied from the Waimakiriri River. This periodic short-term trend is apparent between 1993 and 1995, where the shoreline built out approximately 14 m over a 2 year period (Figure 4-3). This response may have also been a result of beach recovery from a series of prior coastal storms during the winter of 1992, which cumulatively caused significant erosion.

Periods of erosion caused by southerly storm events and tropical cyclone events are also apparent within the dataset, with erosion of up to 10 m occuring over a 2 year time period at profile C0848. Of note the dune toe experienced a much lower rate of accretion during the period between 2000 and 2010, with the some beach profile sites recording net erosion over this 10 year period.

While this analysis provides information on short-term trends, the data sets are generally too short to inform the long-term components. The data is therefore de-trended to remove any long-term effects leaving residual excursion distances (Figure 4-4). A negative residual represents an erosion event measured landward from the de-trended (projected) shoreline position. The maximum negative residual is -5.8 m for the C0848 profile site.

A full set of the linear regression and residual plots for all profiles are presented in Appendix B. The beach profile analysis results for all profiles are displayed in

Table 4-4. Table 4-4 displays the linear regression rate of shoreline movement including the correlation coffecient (r^2) and the standard deviation (SD). Table 4-4 also shows three indicators of short-term shoreline movement including the 3 x SD value, the maximum negative residual value and the maximum cumulative erosion. Table 4-4 provides summary statistics of these three short-term shoreline movement indicators.

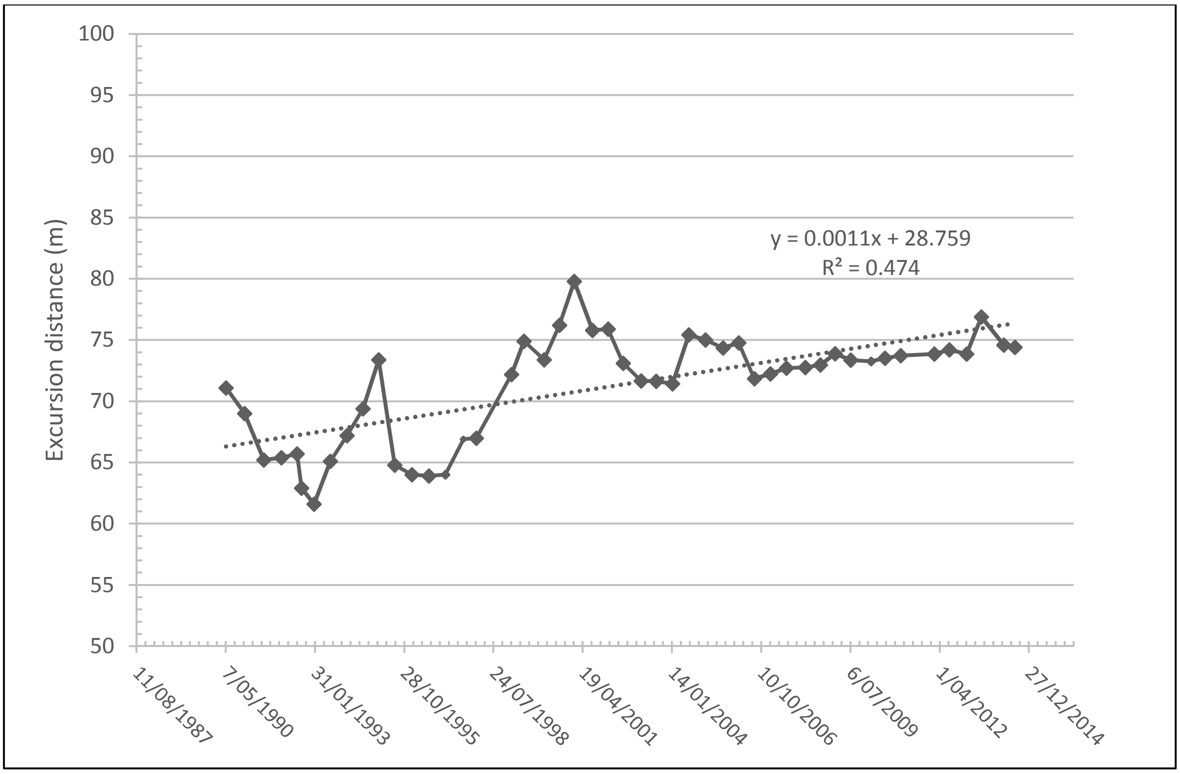

Figure 4-3 Example of dune toe linear regression plot for C0848 Hood Street (New Brighton)

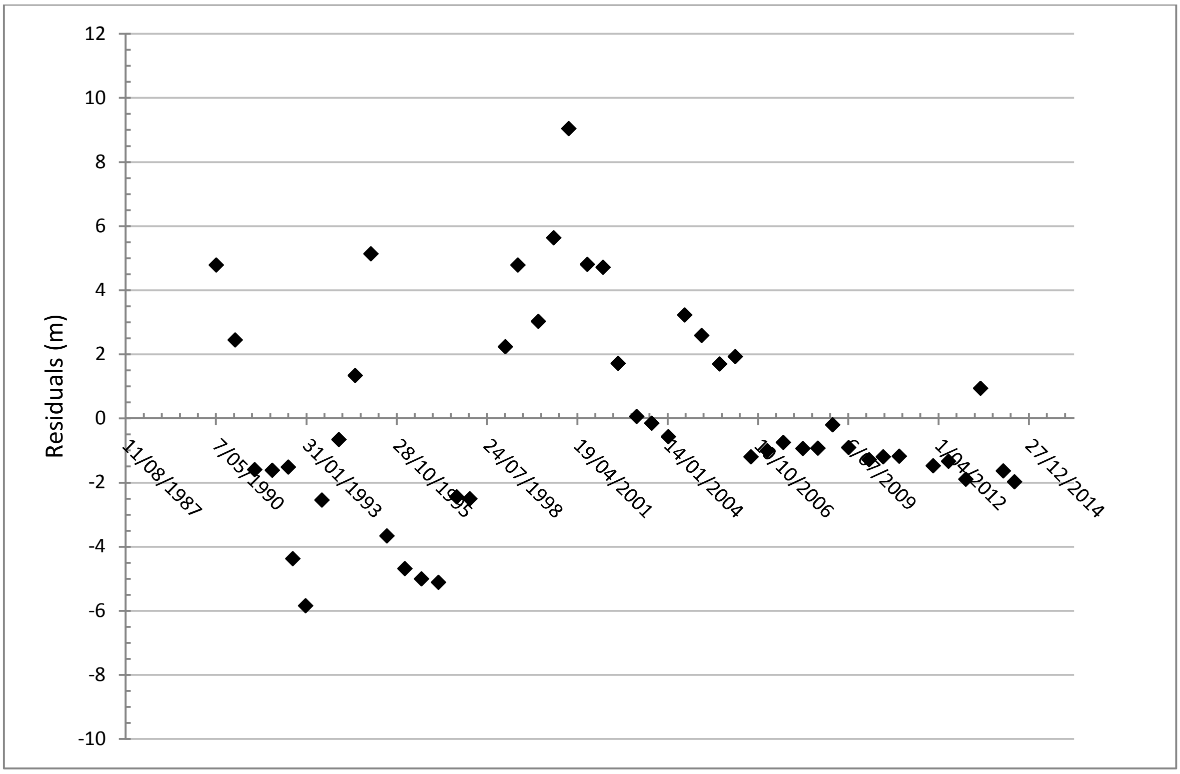

Figure 4-4 Example dune toe excursion residuals (de-trended) for C0848 Hood Street (New Brighton)

The standard deviation of residual values describes the spread of the de-trended excursion distances. Previous work by Tonkin & Taylor (T&T, 2004; T&T 2006) found that the distribution of annual residual shoreline movement could be considered to be approximately normally distributed. The values at 1 standard deviation (SD), 2 x SD and 3 x SD from the mean will have corresponding annual probabilities of occurrence of 16%, 2.5%, and 0.5% respectively.

The maximum negative residual indicator represents the largest erosion event measured inland from the projected shoreline position. The maximum cumulative erosion indicator is the total landward distance the shoreline retreated over a number of consecutive surveys where erosion occurred. For the C0848 profile example illustrated in Figure 4-3, the maximum cumulative erosion distance is -9.5 m surveyed between 1990 and 1993.

Table 4-4 Statistical measures of dune toe excursion

	Linear regression statistics			Short-term shoreline movement indicators		
Profile	**Rate of Shoreline Change (m/year)**	**Regression Coefficient (r^2)**	**Standard Deviation (SD) (m)**	**3 x SD (m)**	**Maximum Negative Residual (m)**	**Maximum Cumulative Erosion (m)**
C1130	-0.02	0.00	2.37	-7.10	-4.32	-6.7
C1111	0.47	0.37	1.25	-3.75	-2.06	-3.4
C1100	0.23	0.24	2.94	-8.81	-5.79	-7.2
C1086	0.08	0.02	3.71	-11.12	-7.69	-12.3
C1065	0.38	0.43	3.16	-9.48	-8.03	-12.9
C1041	0.25	0.34	2.58	-7.74	-3.97	-8
C1011	0.00	0.00	0.06	-0.18	-0.13	-0.2
C0952	0.15	0.09	3.41	-10.24	-4.33	-8.7
C0924	0.36	0.47	2.75	-8.24	-4.12	-6.8
C0889	-0.01	0.08	0.25	-0.74	-0.73	-0.6
C0863	0.12	0.11	1.39	-4.17	-5.74	-3.4
C0848	0.42	0.47	3.17	-9.50	-5.84	-9.5
C0815	0.37	0.45	2.84	-8.51	-5.14	-5.5
C0781	0.23	0.35	2.30	-6.90	-5.88	-8.2
C0748	0.58	0.72	2.53	-7.58	-3.65	-3.7
C0703	0.27	0.22	3.66	-10.97	-7.96	-5.8
C0650	0.74	0.66	3.84	-11.51	-4.41	-9
C0600	0.46	0.37	4.33	-12.98	-7.56	-9.8
C0531	0.16	0.13	2.96	-8.87	-3.50	-4.9
C0513	0.87	0.67	4.39	-13.17	-6.03	-7.6
C0471	0.64	0.74	2.73	-8.20	-4.37	-6.9
C0431	0.26	0.21	3.46	-10.39	-6.90	-8.9
C0396	0.85	0.65	4.45	-13.34	-5.92	-14.6
C0362	1.24	0.79	4.64	-13.91	-15.03	-12.1
C0350	0.47	0.45	3.74	-11.23	-8.87	-15.7

Profile	Linear regression statistics			Short-term shoreline movement indicators		
	Rate of Shoreline Change (m/year)	Regression Coefficient (r^2)	Standard Deviation (SD) (m)	3 x SD (m)	Maximum Negative Residual (m)	Maximum Cumulative Erosion (m)
C0300	0.86	0.48	6.50	-19.49	-8.39	-16.8
C0271	1.28	0.30	14.08	-42.23	-14.58	-28.9

Table 4-4 shows the short-term shoreline movement indicator values vary considerably along the coastline with a relatively wide range and no apparent longshore trend. Table 4-5 summarises the three short-term indicator values by listing the minimum, average and maximum values across all sites. The southernmost profile (C0271) has been excluded from the summary statistics due to the influence of the estuary delta causing relatively large fluctuations in shoreline position along the distal end of the New Brighton spit. The relatively large fluctuation in shoreline position is taken into consideration for this cell (Cell G) by implementing the inlet migration curve (IMC) method. The IMC method accounts for the large shoreline fluctuations and an additional allowance for this within the SF component (i.e. larger SF values) would be considered too conservative.

Table 4-5 Summary of short-term shoreline movement indicators

Summary statistic	Short-term shoreline movement indicator		
	3 x SD (m)	Maximum Negative Residual (m)	Maximum Cumulative Erosion (m)
Minimum value	-0.2	-0.1	-0.2
Average value	-9.2	-5.6	-8.0
Maximum value	-19.5	-15.0	-16.8

Numerical model assessment of storm erosion potential

Erosion of the upper beach is dependent on the energy able to reach the backshore, the duration of exposure to that energy and the erodibility of the upper beach material. The energy able to reach the backshore is dependent on water level and the offshore profile which controls wave breaking and energy dissipation. Both of these parameters change over the duration of a storm event.

The numerical cross-shore sediment transport and profile change model SBEACH (Storm Induced BEAch CHange) (Larson and Kraus, 1989) has been used to define storm cut volumes and horizontal movement of the dune toe. SBEACH considers sand grain size, the pre-storm beach profile and dune height, plus time series of wave height, wave period, water level in calculating a post-storm beach profile. Model development involved extensive calibration against both large scale wave tank laboratory data and field data. SBEACH has been verified for measured storm erosion on the Australian east coast (Carley, 1992; Carley et al. 1998). Southern Pegasus Bay is subject to similar wave climate and storm events as the Australian east coast and the model is therefore considered applicable for these environments.

Model input

A representative cross-shore profile from the dune crest to the RL -10 m contour was assessed for the open coast based on average profile surveys information. Design storm nearshore time series including wave height, period and water level are applied at the outer profile boundary (i.e. Figure 4-5). Design storms for 10 yr, 100 yr and 2x100 yr events are simulated with the later allowing for potential clustering of storms. Such clustering may result in greater erosion as the first event lowers the beach height and relatively greater wave energy may reach the backshore in subsequent events.

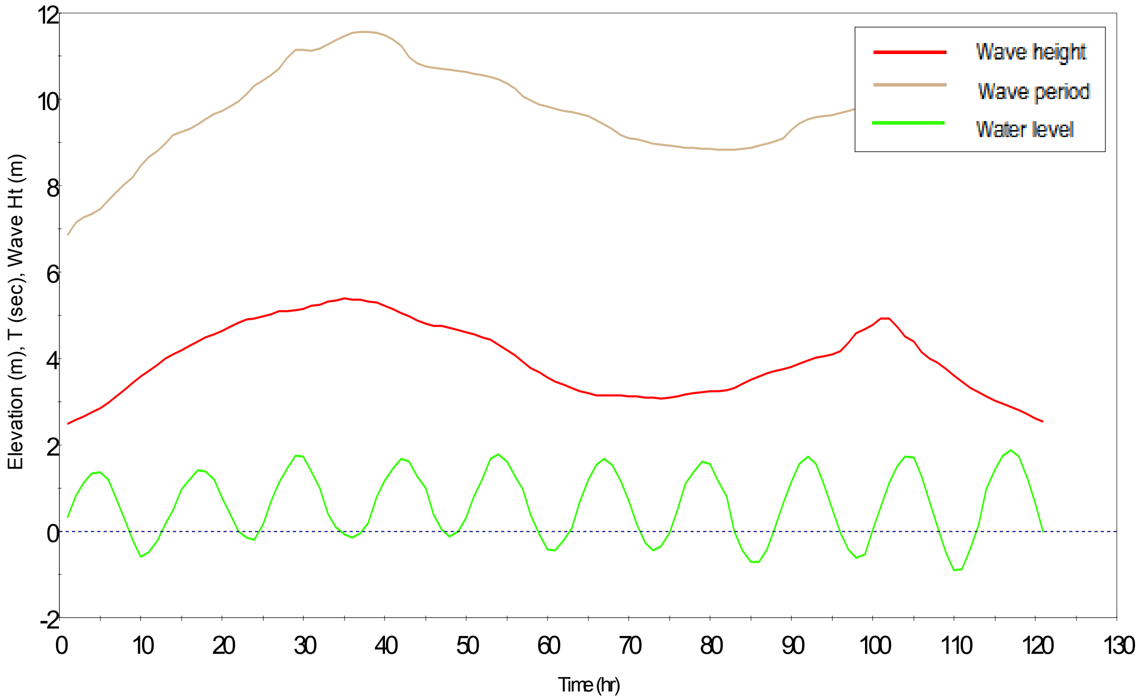

Figure 4-5 Synthetic 100yr design storm input for Pegasus Bay

Model results

Figure 4-6 shows the initial and equilibrium profiles formed due to 10, 100 and 2x100 year storms. Changes in horizontal shoreline position at a predefined contour (i.e. the dune toe) provide information on short-term erosion distances.

The model results are presented for both the highest astronomical tide (HAT) contour (RL 1.5 m) and a typical dune toe contour (RL 2.5 m). The range of shoreline excursion distances calculated by SBEACH for the open coast is shown in Table 4-6.

Table 4-6 Storm excursion distances calculated by SBEACH

Storm	Contour	10 year (m)	100 year (m)	2 x 100 year (m)
Rodney Street	1.5m	-5	-7.5	-10
	2.5m	-0.5	-3	-4
Tern Street	1.5m	-3	-5	-8
	2.5m	-0	-2	-5

Numerical storm cut distances of 8 to 10 m were found for the HAT tide contour and 4 to 5 m for the dune toe contour for the 2 x 100 year storm. However, based on observations of similar beach systems we consider that this model likely underestimates storm cut on relatively flat dissipative beaches, as it does not include the effects of infra-gravity waves which dominate swash motions and sediment transport on dissipative beaches. Therefore, the SBEACH results for the HAT tide level were considered a minimum value for the short-term component lower bound.

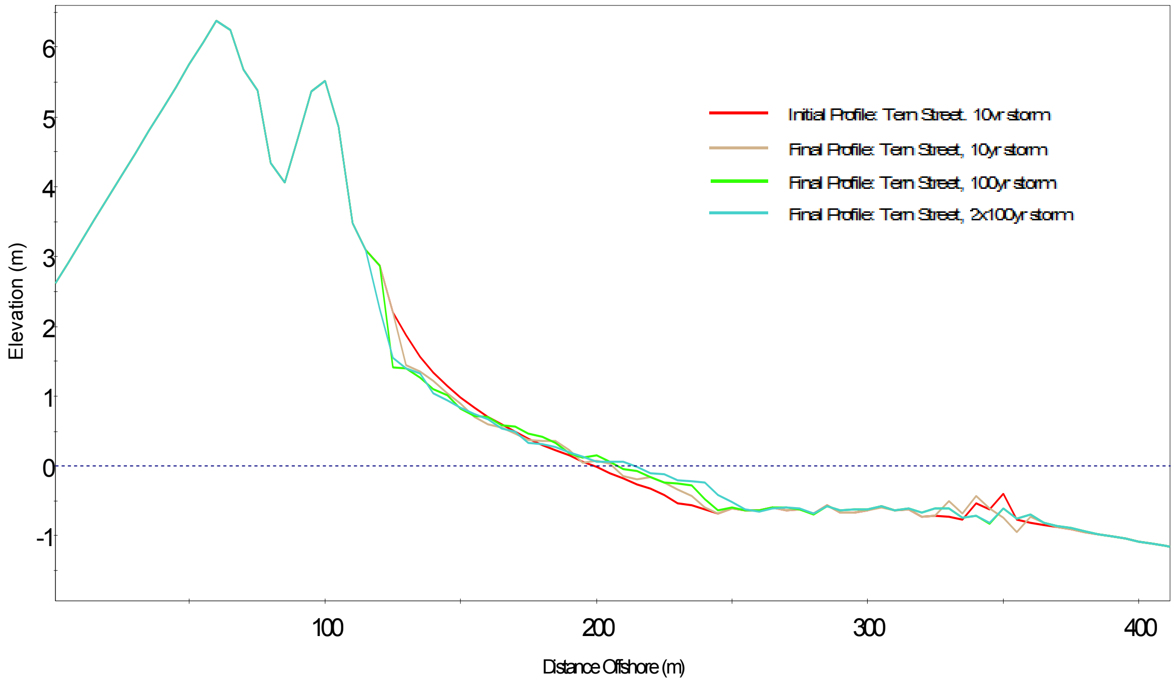

Figure 4-6 SBEACH results for Tern Street beach profile site (C0362)

Adopted values

The assessment of the short-term fluctuation component (SF) was based on consideration of both statistical and numerical methods. The ECan beach profile datasets provides adequate information for statistical analysis to derive the modal and upper bounds for the short-term component.

The maximum 3 x SD value of -19.5 m (rounded to 20 m) was interpreted as the upper bound value for the short-term fluctuation component (Figure 4-4). We consider that both the maximum negative residual and the maximum cumulative erosion distance of approximately -15 m are representative of modal value for the short-term fluctuation component (Figure 4-4). The results from the numerical SBEACH model at HAT were used to set the lower bounds. The maximum 2 x 100 year storm retreat value of -10 m modelled for the Rodney Street Profile was adopted as the lower bound for the short-term fluctuation component for all sites (Figure 4-5). Table 4-7 summarises the upper, mode and lower values adopted for the short-term fluctuation component.

The value bounds were applied to all cells as no longshore trends were apparent in the beach profile dataset. It was considered prudent to use the maximum value for each indicator within the full dataset as we considered there was no morphological reason why that maximum value could not occur within any cell. We consider the most likely reason for the variability in the indicator values across sites is due to temporary hydrodynamic features such as traveling rips and bar formations and the direction of the individual storm events.

Table 4-7 Short-term erosion component values

		Short-term component value bounds		
Site	**Cell**	**Lower (m)**	**Mode (m)**	**Upper (m)**
Open coast	A-G	10	15	20

4.1.4.3 Dune stability (DS)

The dune stability factor delineates the area of potential risk landward of the erosion scarp by buildings and their foundations. The parameter assumes that storm erosion results in an over-steepened scarp which must adjust to a stable angle of repose for loose dune sand. The dune stability width is dependent on the height of the existing backshore and the angle of repose for loose dune sand. This has been obtained from an examination of historic reports, a review of the beach profile data and our assessment of the beach sediments obtained in this study. The dune stability factor is outlined below:

$$DS = \frac{H_{dune}}{2(\tan\alpha_{sand})} \qquad \text{(Equation 4)}$$

Where H_{dune} is the dune height from the eroded base to the crest and α_{sand} is the stable angle of repose for beach sand (ranging from 30 to 34 degrees). In reality, dune scarps will stand at steeper slopes due to the present of binding vegetation and formation of talus slope at the toe, however, these have been ignored for the present assessment as any development immediately landward of the scarp and within the area defined by the formula may still be vulnerable. Parameter bounds are defined based on the variation in dune height along the coastal behaviour cell and potential range in stable angle of repose (Table 4-8).

Table 4-8 Dune stability component values

		Dune stability component value bounds		
Site	**Cell**	**Lower (degrees)**	**Mode (degrees)**	**Upper (degrees)**
Open coast	A-G	30	32	34

4.1.4.4 Long –term (LT)

The long-term rate of horizontal coastline movement includes both ongoing trends and long-term cyclical fluctuations. These may be due to changes in sea level, fluctuations in coastal sediment supply or associated with long-term climatic cycles such as IPO.

Long-term trends have been evaluated by the analysis of the historic shoreline positions. These have been derived from geo-referenced historic aerial photographs. The historic shoreline data was analysed using the GIS-based Digital Shoreline Analysis System (DSAS) model to evaluate long term trends. DSAS processes the shoreline data and calculates shoreline change statistics at 10 m intervals along the entire site. Rates of long-term shoreline movement are derived using linear regression analysis (refer to Section 4.1.4.2). By calculating trends along the entire shoreline, rather than at a low number of discrete points (i.e. beach profile surveys), alongshore variation in long-term trends can be determined more accurately and either be used to inform parameter bounds or to separate the site into coastal behaviour cells.

Maps displaying the DSAS rate of shoreline change output results at 10 m intervals along the shoreline are presented in Appendix C. All areas of Southern Pegasus Bay have experienced net accretion over the last 70 years. Figure 4-7 displays a graph of the DSAS results with the historic shoreline movement rate plotted along the open coast from cell A to F (chainage 0 to 8,600 m). The graph plots both the linear regression rate (LRR) and the end point rate (EPR), which calculated the rate between the earliest and latest record only (i.e. 1941 and 2001). The LRR method was chosen to represent the long-term component value bounds because it accounts for all available data and the rate is adjusted to a trend that best fits all data points. The EPR results are displayed in Figure 4-7 for comparison purposes only. The long-term shoreline movement rates used in the assessment are presented in Table 4-9.

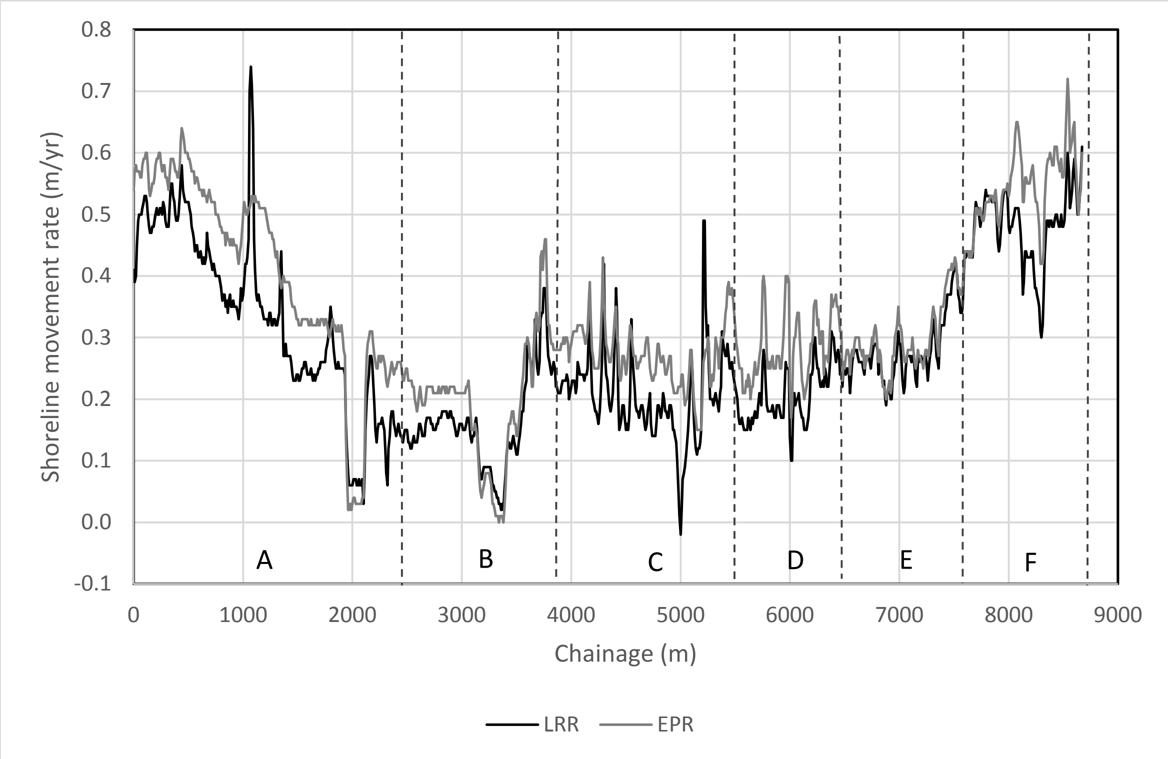

Figure 4-7 Summary of DSAS results for the open coast

The greatest rate of accretion along Southern Pegasus Bay was recorded in the Southshore area, which is consistent with the beach profile analysis results. The lowest rate of accretion was recorded at New Brighton. This result is expected as the New Brighton area has the greatest amount of man made changes within the dunes along the Southern Pegasus Bay shoreline. The dune area located adjacent to the New Brighton Library and pier fronting Marine Parade has little or no sand binding dune vegetation. This is mainly due to the area having high public use and structures have been constructed in the active dune area (e.g. New Brighton Library and Marine Parade car park).

The 2010 – 2011 Canterbury earthquakes caused minor subsidence along the Northern New Brighton shoreline and minor uplift along the southern shoreline in the order of 0.1 to 0.2 m. This adjustment may modify littoral transport processes, potentially reducing the dominant southerly longshore drift rates. However, ECan have not noted any indication of a response in the beach profile record to date.

Table 4-9 long-term erosion component values

Open coast site	Long-term component value bounds		
Cell	**Lower (m)**	**Mode (m)**	**Upper (m)**
A	+0.5	+0.4	+0.25
B	+0.18	+0.15	+0.1
C	+0.35	+0.25	+0.15
D	+0.3	+0.2	+0.15
E	+0.3	+0.25	+0.2
F	+0.55	+0.45	+0.35

4.1.4.5 Effects of sea level rise (SL)

Adopted sea level values

We have adopted a range of sea level rise values over the 100 year timeframe (i.e. 2115) which conform to guidance provided within MfE (2008) but also take into account new model results presented in the IPCC 5th Assessment Report (AR5;IPCC, 2014).

Utilising the most recent projections (IPCC, 2014) and adopting a precautionary approach required by NZCPS (2010) and in keeping with recommendations in MfE (2008), this assessment has adopted sea level rise values projected for the *RCP8.5 scenario - emissions continue to rise in the 21st century* ("business as usual"). This is considered prudent until evidence of emission stabilising justify use of a lower projection scenario. These sea levels range from 0.27 to 0.47 m by 2065 and 0.62 to 1.27 m by 2115 (refer to Section 2.2.1.5).

An average historic rate of sea level rise of 1.9 mm/year has been deducted from the adopted sea level rise values for use in this assessment on the basis that the existing long-term trends and processes already incorporate the response to the historic situation. The base year for the projections to 2115 is 2015. Table 4-10 presents the sea level rise values used in this coastal hazard assessment.

Table 4-10 Sea level rise values utilised in assessment

Time frame	Lower (m)	Mode (m)	Upper (m)
Projected 2065	0.27	0.37	0.47
Adjusted 2065	0.18	0.28	0.38
Projected 2115	0.62	1.0	1.27
Adjusted 2115	0.43	0.81	1.08
Note: the adjusted values include a discount of 1.9 mm/year based on average historical trends			

Beach response

Geometric response models propose that as sea level is raised, the equilibrium profile is moved upward and landward conserving mass and original shape Figure 4-8. The most well-known of these geometric response models is that of Bruun (Bruun, 1962, 1988) which proposes that with increased sea level, material is eroded from the upper beach and deposited offshore to a maximum depth, termed closure depth. The increase in sea bed level is equivalent to the rise in sea level and results in landward recession of the shoreline. The model can be defined by the following equation:

$$SL = \frac{L_*}{B + h_*} S \qquad \text{(Equation 5)}$$

Where SL is the landward retreat, h_* defines the maximum depth of sediment exchange taken as the closure depth, L_* is the horizontal distance from the shoreline to the offshore position of h_*, B is the height of the berm/dune crest within the eroded backshore and S is the sea level rise.

The EnviroLink best practice guidelines for defining coastal hazard zones in New Zealand states the Bruun Rule is applicable to open coast sandy beaches (Ramsey *et, al*; 2012). The Bruun Rule has also been tested in the Environment Court and was accepted as a suitable precautionary approach to predict the beach response to sea level rise for the purposes of coastal hazard planning *(Skinner v Tauranga District Council A 163/02).*

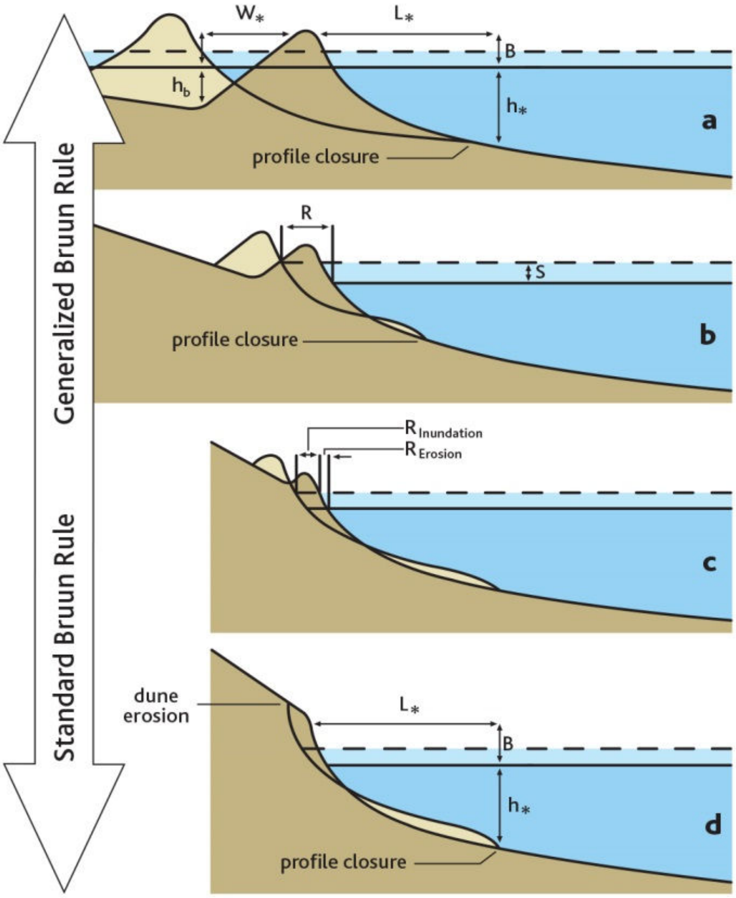

Figure 4-8 Schematic diagrams of the Bruun model modes of shoreline response (after Cowell and Kench, 2001)

The Bruun Rule is considered to provide an acceptable "order of magnitude" estimate of shoreline retreat distance due to a rise in sea level (Ramsey et al, 2012). However, it is governed by simple, two-dimensional conservation of mass principles and is limited in its application in the following aspects:

- The rule assumes that there is an offshore limit of sediment exchange or a 'closure depth' beyond which the seabed does not raise with sea level

- The rule assumes no offshore or onshore losses or gains
- The rule assumes an equilibrium beach profile where the beach may fluctuate under seasonal and storm influences but returns to a statistically average profile (i.e. the profile is not undergoing long term steepening or flattening)
- The rule does not accommodate variations in sediment properties across the profile or profile control by hard structures such as substrate geology or adjacent headlands.

While some have questioned the actual existence of a closure depth (Cooper and Pilkey, 2004), the Bruun Rule is not necessarily reliant on its physical existence. While long-term sediment exchange may occur to very deep water depths (i.e. the 'pinch-out' point), this "ultimate limit" profile adjustment extent is only valid if either the profile response is instantaneous or if sea level changes and then stabilises with the profile 'catching up'. As sea level rise is expected to be ongoing and a lag in profile response is apparent, the outer limit of profile adjustment is likely to be left behind. The closure depth can therefore be more realistically defined as the point at which the profile adjustment can keep up with sea-level change and becomes a calibration parameter in lieu of an adequate depth dependent lag parameter.

To define SL component distributions, the Bruun rule estimates using the outer Hallermeier closure depth definition (d_i) have been adopted as upper bound values, estimates using the inner Hallermeier closure definition (d_l) provides the modal (most likely) values and results using the beach face slope (Komar, 1999) provide the lower (almost certain) bounds. The beach face is defined by average mean low water spring position and average beach crest height. The Hallermeier closure definitions are defined as follows (Nicholls et al., 1998):

$$d_l = 2.28H_{s,t} - 68.5(H_{s,t}^2 / gT_s^2) \cong 2 \times H_{s,t}$$ (Equation 6)

$$d_i = 1.5 \times d_l$$ (Equation 7)

Where d_l is the closure depth below *mean low water spring,* $H_{s,t}$ is non-breaking significant wave height exceeded for 12 hours in a defined time period, nominally one year, and T_s is the associated period.

For this study the deep water (non-breaking) wave climate parameters of H_e and T_e were based on the ECan wave buoy data recorded over a 14 year period between 1999 and 2013. The wave buoy is located in deep water east of Banks Peninsula. The resulting H_e and T_e parameters are 4.2 m and 10.8 s respectively. Based on these wave climate parameters the inner closure depth is calculated as 8.5 m below mean low water spring using the Hallermeier method defined in Equation 6 (equivalent to 9.5 m below mean sea level). The outer closure depth is calculated as 13 m (equivalent to 14 m below mean sea level) using the Hallermeier method defined in Equation 7. The average dune crest is approximately 8.5 m above mean sea level. This results in a total active profile height of between 18 m to 23 m (8.5 m dune height and 9.5 m to 14 m closure depth), similar to the 20 m identified by NIWA in previous studies (refer to Section 2.2.2).

4.1.5 Combination of parameters

For each coastal cell, the relevant theoretical hazard component bounds influencing the CEHZ have been defined according to the methods described above and as summarised in Table 4-11. The input value bounds for each CEHZ component is presented in Table 4-12 for all six cells along the open coast. The values presented in Table 4-12 are taken as the input for the stochastic simulation.

Table 4-11 Theoretical erosion hazard parameter bounds

Parameter	Lower bound	Mode	Upper Bound	Reference Table
ST (m)	2 x 1% AEP storm cut at the HAT contour	Maximum cumulative erosion or maximum residual	3 x standard deviation (SD)	Table 4-6
DS (m)	H_{max} & α_{min}	H_{mean} & α_{mean}	H_{min} & α_{max}	Table 4-7
LT (m/yr)	-90% CI of smallest trend in cell	Mean regression trend	+90% CI of largest trend in cell	Table 4-8
SLR (m)[1]	lower 95% SLR value for RCP8.5 scenario minus historic trend	50% SLR value for RCP8.5 scenario minus historic trend	upper 95% SLR value for RCP8.5 scenario minus historic trend	Table 4-9
Closure slope[1]	Slope across active beach face to typical swash excursion	Slope from dune crest to inner Hallermeier closure depth	Slope from dune crest to outer Hallermeier closure depth	n/a

Table 4-12 Input bound for each CEHZ components within each cell

Site		**Christchurch open coast**					
Cell		**1A**	**1B**	**1C**	**1D**	**1E**	**1F**
Chainage, m (from N/W)		0-1900	1900-3500	3500-5100	5100-6200	6200-7400	7400-8600
Morphology		Dune	Dune	Dune	Dune	Dune	Dune
Short-term (m)	**Min**	10	10	10	10	10	10
	Mode	15	15	15	15	15	15
	Max	20	20	20	20	20	20
Dune elevation (m RL)	**Min**	6.5	7.0	7.5	7.0	6.5	6.0
	Mode	8.0	8.0	8.5	8.5	8.0	7.5
	Max	9.5	9.0	10.0	9.5	9.5	8.5
Stable angle (deg)	**Min**	30	30	30	30	30	30
	Mode	32	32	32	32	32	32
	Max	34	34	34	34	34	34
Long-term (m) -ve erosion +ve accretion	**Min**	0.5	0.18	0.35	0.3	0.3	0.55
	Mode	0.4	0.15	0.25	0.2	0.25	0.45
	Max	0.25	0.1	0.15	0.15	0.2	0.35
Closure slope	**Min**	0.035	0.026	0.038	0.041	0.027	0.029

Site		Christchurch open coast					
Cell		1A	1B	1C	1D	1E	1F
	Mode	0.018	0.016	0.014	0.013	0.012	0.012
	Max	0.006	0.006	0.006	0.005	0.005	0.005
SLR 2065 (m)	Min	0.18	0.18	0.18	0.18	0.18	0.18
	Mode	0.28	0.28	0.28	0.28	0.28	0.28
	Max	0.38	0.38	0.38	0.38	0.38	0.38
SLR 2100 (m)	Min	0.43	0.43	0.43	0.43	0.43	0.43
	Mode	0.81	0.81	0.81	0.81	0.81	0.81
	Max	1.08	1.08	1.08	1.08	1.08	1.08
Note[1]: Chainage is a distance measure from the origin taken as the start of cell A at E1577557m N5186179m (NZTM)							

Probability distributions constructed for each component are randomly sampled and the extracted values used to define a potential CEHZ distance. This process is repeated 10,000 times using a Monte Carlo technique and the probability distribution of the resultant CEHZ2 width is forecast. Figure 4-9 presents an example of the results for each CEHZ component and the resultant CEHZ distance for Cell A at 2115. The example shows both the histogram and the cumulative distribution frequency graphs. Results show the possible CEHZ2 to range from 12 to -140 m, with a $P_{50\%}$ (50% probability of exceedance) value of -22 m. This result can be interpreted as a 50 % chance of coastal erosion exceeding 22 m by 2115. The $P_{5\%}$ is -60 m, which is substantially below the maximum extent of -140 m.

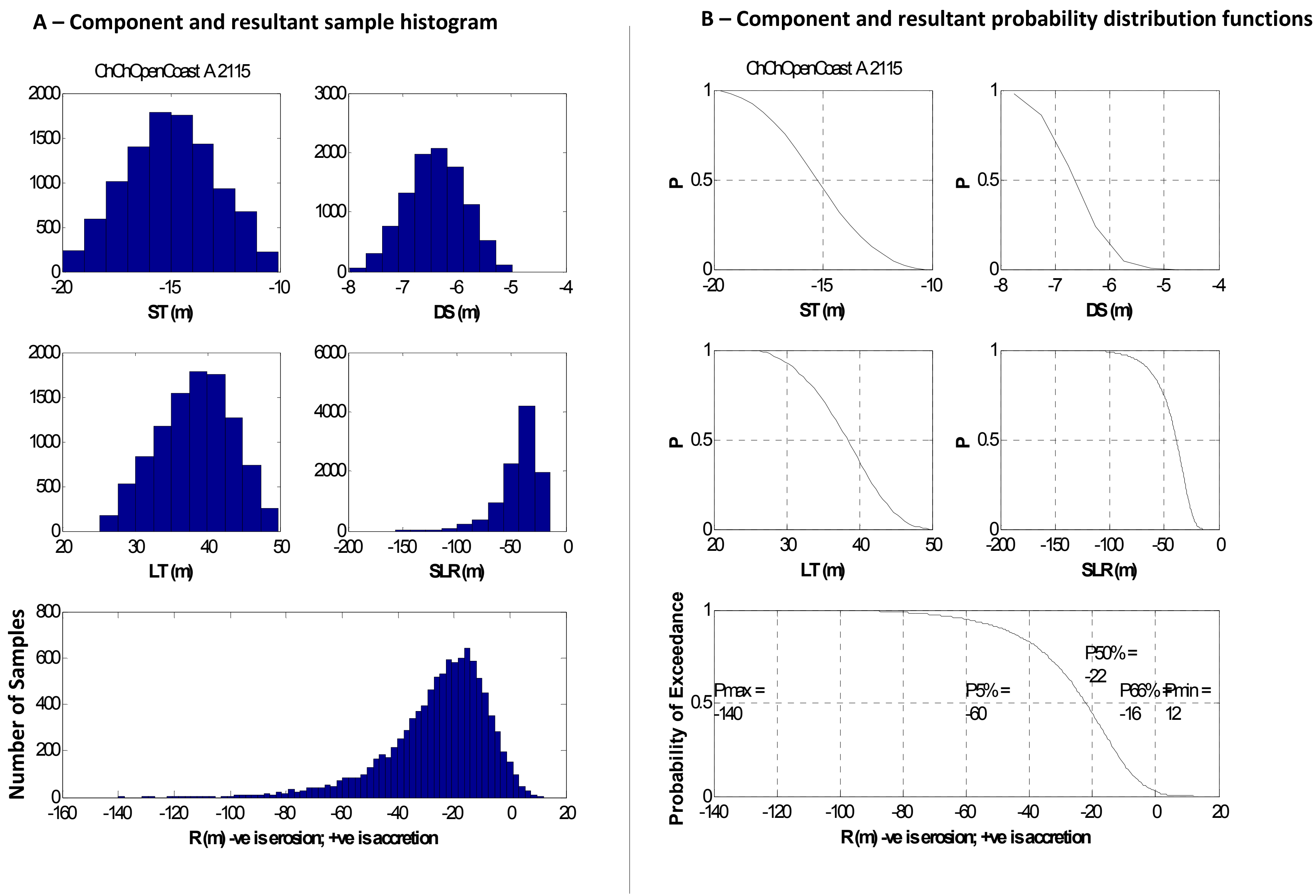

Figure 4-9 Example histogram (A) and cumulative distribution functions (B) of component samples (ST, DS, LT and SLR) and the resultant CEHZ distances (R) for cell A at 2115. Refer to Figure 4-1 and Section 4.1.1 for explanation of the components.

4.1.6 Risk-based approach

A risk-based approach to managing coastal hazard is advocated by both the NZCPS (2010) and the CRPS (2013) with both the likelihood and consequence of hazard occurrence requiring consideration. For example, the NZCPS (2010) suggests consideration of areas both ‘likely’ to be affected by hazard and areas ‘potentially’ affected by hazard (refer to Section 2.1.1). While the term ‘likely’ may be related to a likelihood over a defined timeframe based on guidance provided by MfE (2008), i.e. a probability greater than 66% as shown in Table 4-13, the term potential is less well defined. This assessment therefore aims to derive a range of hazard zones corresponding to differing likelihoods which may be applied to risk assessment.

Table 4-13 Likelihood of scenario occurring within the selected planning horizon

Designation	Frequency	Description	IPCC definition
			Virtually certain (> 99% chance that a result is true)
A	Almost certain	Is expected to happen, perhaps more than once	Very likely (90–99%)
B	Likely	Will probably happen	Likely (66–90%)
C	Possible	Might occur; 50/50 chance	Medium (33–66%)
D	Unlikely	Unlikely to occur, but possible	Unlikely (10–33%)
E	Rare	Highly unlikely, but conceivable	Very unlikely (1–10%)
			Exceptionally unlikely (< 1%)

4.1.7 Mapping the CEHZ

Coastal erosion hazard zone distances are mapped as offsets to the existing baseline of the 2011 dune toe (refer to Appendix D for the coastal erosion hazard zone maps). The CEHZ2065 and CEHZ2115 for the South Brighton Spit zone (Cell G) will be offset from the Inlet Migration Curve (IMC) baseline, due to the shoreline fluctuation in this area. The IMC is defined as the most inland shoreline position over the fluctuating spit area (i.e. Shand, 2012). The assessment will include the changes that have occurred since the Canterbury earthquakes due to changes in land level and assess potential effect of future sea level rise. Refer to Figure 4-10 for an illustration of the IMC delineation for cell G. Figure 4-10 shows the historic shorelines fluctuate within cell G and the IMC represents the landward edge of the shoreline fluctuation and is used as the baseline for offsetting the CEHZ distance.

Where the hazard values differ between adjacent coastal cells, the mapped CEHZ is merged over a distance of at least 10 x the difference between values providing smooth transitions or along contours or material discontinuities where these are present.

Notes: Aerial photograph taken in 2011

A3 SCALE 1:4,000

0 50 100 150 Meters

LEGEND

Inlet Migration Curve

Shoreline (dune toe position)

1941 1994

1955 2011

Location Plan

Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Auckland
www.tonkin.co.nz

DRAWN	PPK	Mar.15
CHECKED		
APPROVED		
ARCFILE 851857.001_F4-10.mxd		
SCALE (AT A3 SIZE) 1:4,000		
PROJECT No. 851857.001		

CHRISTCHURCH CITY COUNCIL
Coastal Hazard Assessment
Inlet Migration Curve

FIGURE No. Figure 4-10

Rev. 0

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4.1.8 Uncertainties and limitations

Uncertainty may be introduced to the assessment by:

- an incomplete understanding of the components influencing the coastal erosion hazard zone
- an imprecise description of the natural processes affecting, and the subsequent quantification of each individual parameter
- errors introduced in the collection and processing of data
- variance in the processes occurring within individual coastal cells.

Of these uncertainties, the alongshore variance of individual coastal cells may be reduced by splitting the coast into continually smaller cells. However, data such as beach profiles are often available only at discrete intervals, meaning increasing cell resolution may not necessarily increase data resolution and subsequent accuracy. We believe we have refined the cells as far as practical based on factors which could significantly affect results. Residual uncertainty may be allowed for by selecting a lower probability CEHZ value.

The first two uncertainty items listed above are being continually developed within coastal research fields. However, there is generally a lag time between scientific developments, and their use in practical assessment as they are refined, tested and made generically applicable. This assessment has used relatively new techniques by incorporating probabilistic assessment of components.

Similarly, numerical models are beginning to better resolve the physical processes responsible for coastal erosion although as noted above the inability to consider infra-gravity waves does affect SBEACH's ability to represent erosion for flat dissipative beaches. However, complex coupled models are computationally expensive and heavily reliant on quality, long-term data. Without such data, complex model results are largely meaningless. We have attempted to balance the use of numerical modelling where useful (wave and beach response) with analytical and empirical assessment to ensure results are robust and sensible.

The re-assessment methodology developed by T&T incorporates the uncertainty in the individual components within the individual parameter bounds. Greater uncertainty utilises wider parameter bounds while less uncertainty utilises narrower bounds. This allows independent uncertainty terms to be combined within the probabilistic framework rather than utilising a single factor or adding uncertainty to each term as has been done previously.

Uncertainties in individual components will reduce as better and longer local data is acquired, particularly around rates of short- and long-term shoreline movement and shoreline response to sea level rise. Data collection programmes such as beach profiling are essential to reducing this uncertainty and should be continued. Our approach can also allow for uncertainties and data limitations by the user defined selection of the P value output. We recommend that conservative, lower probability CEHZ values are selected for implementation.

4.1.9 Anthropogenic effects

The human influences can affect the coastal erosion hazard. Erosion protection works have been installed along portions of the New Brighton shoreline to protect public assets (e.g. car parks and the New Brighton Library). The dune height along these types of areas are also reduced which can increase the inundation hazard.

While properly designed coastal protection works along beach can reduce erosion rates while in place, the shoreline position is generally returned to its long-term equilibrium position rapidly once the structure fails or is removed. We have therefore evaluated the hazard extent excluding the effects of any structures. This identifies the potential land area that could be affected, or the area that is benefitting with the structure. Informed decision around the future maintenance or re-consenting of structures can then be made.

Dune planting and fencing has been undertaken along sections of New Brighton. If this strategy is not maintained over the timeframe of the CEHZ period, then we could expect a greater area of land to be susceptible to coastal erosion hazard in this area.

The open coast assessment for the Sumner site is limited to the inundation hazard only. Council considers that the Sumner rock revetment protects a strategic asset (The Esplanade) and will continue to be maintained to protect the land from coastal erosion. Therefore, the coastal erosion hazard was not assessed for the Sumner site.

4.2 Harbour coast

Coastal hazard zones for the harbour coast have not previously been mapped. The assessment method for the harbour coast identifies areas susceptible to both coastal erosion (CEHZ) and inundation hazard (CIHZ). The mapping has been completed for both a 2065 and 2115 timeframe and will be suitable for inclusion in the District Plan.

4.2.1 Harbour coast coastal inundation hazard zone (CIHZ)

The coastal inundation level was mapped by combining the following components (refer to Section 2.2.1 for more background information):

- Storm tide
- Wave set-up
- Wind set-up
- Sea level rise.

4.2.1.1 Storm tide

The combined elevation of the predicted tide, storm surge and medium term fluctuations is known as the storm tide (refer to Section 2.2.1.4). Goring et. al (2009, 2011) has calculated the 1% and 2 % AEP storm tide levels for both Sumner Head and Port Lyttelton.

The Sumner Head storm tide results was adopted for the Avon-Heathcote Estuary and the Port Lyttelton storm tide results were adopted for sites within Lyttelton Harbour. No long term tide gauge data exists for Akaroa and this study assumes the storm tide levels presented in Table 4-10 for Lyttelton can be applied to the Akaroa Harbour sites. Additional wind set-up values have been calculated for the Akaroa Harbour, which increases the storm tide level for some sites at the head of the harbour. The 1% AEP was adopted for the 2115 planning timeframe and the 2% AEP was adopted for the 2065 planning timeframe (refer to Table 4-14).

Table 4-14 Extreme storm tide

Site	Storm tide level (RL m)	
	1% AEP	2% AEP
Port Lyttelton	1.92	1.87
Sumner Head	1.85	1.8

4.2.1.2 Wave set-up

Waves can super-elevate the mean water level during the breaking process (termed wave set-up). Wave set-up represents a constant flow of water over a coastal barrier above the storm tide level and is generally included in static flood assessments for the purposes of hazard mapping. The additional wave run-up is not considered in the inundation calculation because it attenuates inland and is unlikely to cause widespread inundation over areas several tens of meters from the coast (Ramsey et.al, 2012). However, wave run-up may be an important consideration for assets located close to the existing shoreline (e.g. port and road infrastructure).

The wave climate for Akaroa Harbour has been previously assessed by Todd et al (2008) considering both wind waves and refracted swell waves. The largest source was used for this assessment which was generally the wind wave source.

The wave climate for Lyttelton Harbour has been calculated for each site individually based on fetch, wind stress and water depth to assess wave set-up (T&T, 2015). Fetch and depth limited wave height prediction methods by Young and Verhagen (1996), Goda (2003) and CRESS (Coastal and River Engineering Support System) have been evaluated and compared using the hourly wind speeds converted from 3 second gusts (AS/NZS 1170.2:2011). The methods by Young and Verhagen (1996) and Goda (2003) incorporate an average depth and beach slope, where the method by CRESS allows multiple sections with variable water depth and beach slope. Due to tidal channels and flats present at Lyttelton Harbour we have adopted the method by CRESS to incorporate depth variations.

Offshore swell waves entering Lyttelton Harbour are not expected to be greater than the wind wave climate and have not been modelled separately. Swell waves are considered to be depth limited and also reduced by refraction as they curve into the sites and shoal over the shallow intertidal flats.

Wave set-up is predicted by using the method as described in the Coastal Engineering Manual (CEM, section ll-4-3) (USACE, 2002). This method takes into account the wave height and length and beach slope. Beach slopes between MHWS and LAT, using depth contours from LINZ charts, have been adopted to calculate wave set-up. Wave set-up ranged from 0.15 m to 0.28 m within the Akaroa and Lyttelton Harbour sites (refer to Table 4-11). The wave set-up calculation for each site was based on the direction of the longest fetch distance.

4.2.1.3 Wind set-up

In basins or semi-enclosed basins onshore wind stresses causing wind setup at the shoreline can become important and should be taken into account for static flood assessments. Wind set-up is included in the storm tide calculated by Goring et al. (2009, 2011) for Lyttelton Harbour and Sumner Head. However, further wind set-up is expected at the head of the harbours due to the additional fetch distance to the site.

The wind set-up has been assessed by comparing formulations by CIRIA (2007) (Construction Industry Research and Information Association) and CRESS. Both methods include wind speed, water depth and fetch length. However, CRESS allows multiple sections with variable depth where CIRIA assumes an average water depth. Wind set-up predictions by CIRIA and CRESS show similar results and range between 0.08 and 0.25 m (refer to Table 4-11). Note two sites within Lyttelton Harbour (Purau and Charteris Bay) do not incur additional wind set up due to being located relatively close to the Port tide gauge location.

4.2.1.4 Sea level rise

Long-term changes in mean sea level should be considered in assessing future inundation levels. Historic sea level rise in Christchurch over the last 100 years is estimated at around 1.9 mm/year

(Bell and Hannah, 2012). Climate change is predicted to accelerate this rate of sea level rise into the future. Section 2.2.1.6 outlines the current state of scientific knowledge and best practice guidance on sea level rise projections. We have adopted a sea level rise of 1.0 m by 2115 and 0.4 m by 2065 for this assessment, based on the mid-range IPCC projections for the RCP8.5 emission scenario.

Since tidal characteristics are expected to remain unchanged by future sea level rise, storm tide characteristics are expected to remain similar (MfE, 2008). Therefore, to predict future extreme inundation levels, sea level rise can simply be added to the present day storm tide levels.

4.2.1.5 Coastal inundation values

The 2115 coastal inundation levels for both the Lyttelton Harbour and Akaroa Harbour sites are presented in Table 4-15, and displayed as maps in Appendix E (levels reduced to Lyttelton Vertical Datum 1937). The corresponding coastal inundation levels for the 2065 planning timeframe are presented in Table 4-16, and are also mapped in Appendix E. The total inundation levels are based on combining the four components described above. The main difference in the total level between the two timeframes is the sea level rise component. We note that the wave set-up and wind set-up component values are the same for both timeframes. This is because the relatively small difference in wind velocity between the 1% and 2% AEP extreme events does not result in a change to the values used.

Table 4-15 Coastal Inundation levels for the 2115 planning timeframe

Site	1% AEP storm tide (m)[1]	Wave set-up (m)	Additional Wind set-up (m)	Sea level rise to 2115(m)	Total 2115 Inundation Level (m)[2]
Alandale	1.92	0.23	0.16	1.0	3.3
Teddington	1.92	0.21	0.25	1.0	3.4
Charteris Bay	1.92	0.24	n/a	1.0	3.2
Purau	1.92	0.26	n/a	1.0	3.2
Wainui	1.92	0.24	0.02	1.0	3.2
Duvauchelle	1.92	0.28	0.08	1.0	3.3
Takamatua	1.92	0.15	n/a	1.0	3.1
Akaroa North	1.92	0.18	n/a	1.0	3.1
[1] Lyttelton Vertical Datum 1937 (LVD-37) [2] Rounded to 1 decimal place.					

Table 4-16 Coastal Inundation levels for the 2065 planning timeframe

Site	2% AEP storm tide (m)[1]	Wave set-up (m)	Additional Wind set-up (m)	Sea level rise to 2115(m)	Total 2065 Inundation Level (m)[2]
Alandale	1.87	0.23	0.16	0.4	2.7
Teddington	1.87	0.21	0.25	0.4	2.7
Charteris Bay	1.87	0.24	n/a	0.4	2.5
Purau	1.87	0.26	n/a	0.4	2.5

Site	2% AEP storm tide (m)[1]	Wave set-up (m)	Additional Wind set-up (m)	Sea level rise to 2115(m)	Total 2065 Inundation Level (m)[2]
Wainui	1.87	0.24	0.02	0.4	2.5
Duvauchelle	1.87	0.28	0.08	0.4	2.6
Takamatua	1.87	0.15	n/a	0.4	2.4
Akaroa	1.87	0.18	n/a	0.4	2.5
[1] Lyttelton Vertical Datum 1937 (LVD-37) [2] Rounded to 1 decimal place.					

4.2.1.6 Coastal inundation mapping

The coastal inundation was mapped for the Akaroa and Lyttelton Harbour sites using the "bath tub" method. The "bath tub" method extrapolates the storm inundation level inland where pathways exist based on a digital elevation model (DEM) derived from LiDAR surveyed post the 2010-2011 Canterbury Earthquakes. A GIS script has been used to discount pools or depressions that are not connected to the sea. The "bath tub" method results in a mapped inland extent of flooding inundation from the sea.

The "bath tub' mapping approach described above assumes that if an inland area is connected to the open coast via a drain/river then this area will be inundated to the equivalent level as the adjacent open coast. This assumption is based on there being no time lags or diminished volumes in flooding the inland areas. Since the sites within both Lyttelton and Akaroa Harbour have relatively steep backshore topography, the "bath tub" approach can be considered a suitable method.

The situation is different for the wide low-lying areas inland of the Avon-Heathcote Estuary and Brooklands Lagoon, where friction will reduce the volume of water that can inundate an area over the peak of the tidal cycle. Therefore, the "bath tub" method which assumes instantaneous inundation of the entire area is not suitable for this site. We have adopted a different method for the Avon-Heacote Estuary, Brooklands Lagoon and Sumner sites and applied a hydrodynamic model (i.e. TUFLOW) to assess the plausible inland extent of coastal inundation. The model uses LiDAR derived topography and detailed bathymetry of the estuary and simulates the physics of the tide and inundation levels to dynamically map the land susceptible to coastal inundation hazard.

The TUFLOW model used to assess the effects of sea level rise in Christchurch was based on the model derived by Tonkin & Taylor for the Earthquake Commission (EQC). The details of the model are outlined in the Increased Flooding Vulnerability: Overland Flow Model Build Report; Volume 3 (T&T, 2014b). A summary of the relevant model parameters and calibration testing is provided in Appendix F.

The TUFLOW model was run for both the 2065 and 2115 CIHZ scenarios for a peak tide level of 2.6 m RL and 3.3 m RL respectively (refer to Table 4-17). Due to the uncertainty of wave effects over the wide flat flood plains a freeboard[2] allowance of 0.4 m was included to allow for some localised wave effects and other uncertainties. The freeboard allowance of 0.4 m was selected to be consistent with the existing freeboard set out in the operative Christchurch City Plan for minimum

[2] Freeboard refers to a safety factor expressed as a vertical measurement above the predicted flood level. Freeboard should allow for unknown factors such as wave action, hydrological effects and errors in topographic survey. For comparison the Federal Emergency Management Agency (FEMA) recommend a freeboard allowance of 1 foot (0.3 m) for the purposes of planning for flood management.

floor levels in areas vulnerable to flooding. The 0.4 m freeboard allowance is a substitute for both the wave set-up and additional wind set-up components included in the CIHZ assessment for the other harbour coast sites located within Lyttelton and Akaroa Harbour.

Table 4-17 Summary of coastal inundation level input components for TUFLOW

Component	2065 CIHZ (m)	2115 CIHZ (m)
1% AEP inundation level	n/a	1.85
2% AEP inundation level	1.8	n/a
Sea level rise projection	0.4	1.0
Freeboard	0.4	0.4
Total (rounded to 1 significant figures)	**2.6**	**3.3**
Note: [1]Vertical Datum taken as Lyttelton Vertical Datum 1937 (LVD).		

4.2.2 Harbour coast coastal erosion hazard zone (CEHZ)

The majority of the shoreline around Akaroa Harbour and Lyttelton Harbour are hard cliff shorelines which are not expected to retreat from coastal erosion. However the settlements located at the head of the bays are located on soft shorelines with narrow beaches and relatively low lying backshores and are affected by storm induced erosion. The sites within Lyttelton Harbour and also Duvauchelle and Takamatua located in Akaroa Harbour consist of silty sand or fine sand beaches with wide, shallow intertidal nearshore zones. Akaroa and Wainui both have relatively steep nearshore zones with mixed sand and gravel beaches.

The CEHZ methodology for harbour coasts is based on the same Equation 2 set out for open coasts first described in Section 4.2.1.

$$CEHZ = ST + DS + (LT \times T) + SL \qquad \text{(Equation 2)}$$

Where:

ST = Short-term erosion due to storm cut (m)

DS = Dune stability is characterized by the horizontal distance from the base of the eroded scarp to the backshore crest of a stable angle of repose (m)

LT = Long term rate of horizontal coastline movement (m/yr)

T = Timeframe (years). In this instance a period of 50 and 100 years will be used for CEHZ1 and CEHZ2 respectively (i.e. 2065 and 2115)

SL = Horizontal coastline retreat due to possible accelerated sea level rise (m).

The components have been derived in a similar way for harbour coasts with a modified term for shoreline retreat due to the effects of sea level rise. The dune stability (DS) and planning timeframe (T) components were assessed using the same method as open coasts outlined in Section 4.1.4.3 and Section 4.1.4.1 respectively. The derivation of the other three components is explained below:

4.2.2.1 Component derivation

Short term (ST)

The short term erosion due to potential storm cut for all harbour coast sites was assessed as – 5 m. This is based on visual observations from site visits and previous coastal hazard assessments for harbour coast environments (Todd et al, 2008; T&T, 2014a).

Long-term (LT)

The shorelines along the harbour sites are considered to be relatively stable with little horizontal movement evident from historical aerials available from ECan and shoreline analysis provided in previous reporting (Todd et al, 2008). The long term component has been set at zero for all harbour coast sites.

Sea level rise (SL)

The harbour coast beaches consist of either silty sand, fine sand or mixed sand and gravel and have a wide intertidal zone with no extensive dune system. Therefore they are expected to behave differently to sandy beaches in response to a rise in mean sea level. The effect of sea level rise on estuarine type shorelines can be highly variable and complex and will depend on the interrelationship between:

- backshore topography and geology
- sediment supply and storage.

Although sedimentation is apparent at some sites, it is expected that the acceleration in sea level rise is likely to exceed sedimentation rates (MfE, 2008).

The dynamics of coastal estuarine harbour processes and multi-year cycles of sand exchange between the intertidal flats, deltas and the adjacent coastline are complex. Therefore, any reliable statement about how individual inlet systems may respond to climate change effects is difficult to make. However, it is probable that there would be some shoreline retreat under accelerated sea level rise conditions.

Although the traditional Bruun Rule (Bruun, 1962, 1988) developed for open coast sandy beaches does not directly apply for estuarine and gravel type shores, one approach is to assume that the sediment supply and active beach width remains constant during a change in sea level (i.e. equilibrium profile method). The beach profile is likely to respond to these conditions with an upward and landward translation over time (Komar, 1999). The landward translation of the beach profile (**X**) can be defined as a function of sea level rise (**Δs**) and the active beach slope (**tanα**). The active beach slope above the intersection of the beach and the fronting intertidal flats was adopted. The equilibrium profile method relationship is given in Equation 1 and displayed in Figure 4-11 (equilibrium profile method).

$$SL = \frac{\Delta s}{\tan \alpha} \qquad \text{(Equation 8)}$$

Where:

SL = the landward translation of the beach profile due to sea level rise (m)

Δs = increase in sea level rise (m)

tanα = average slope of the active beach (HAT to beach toe).

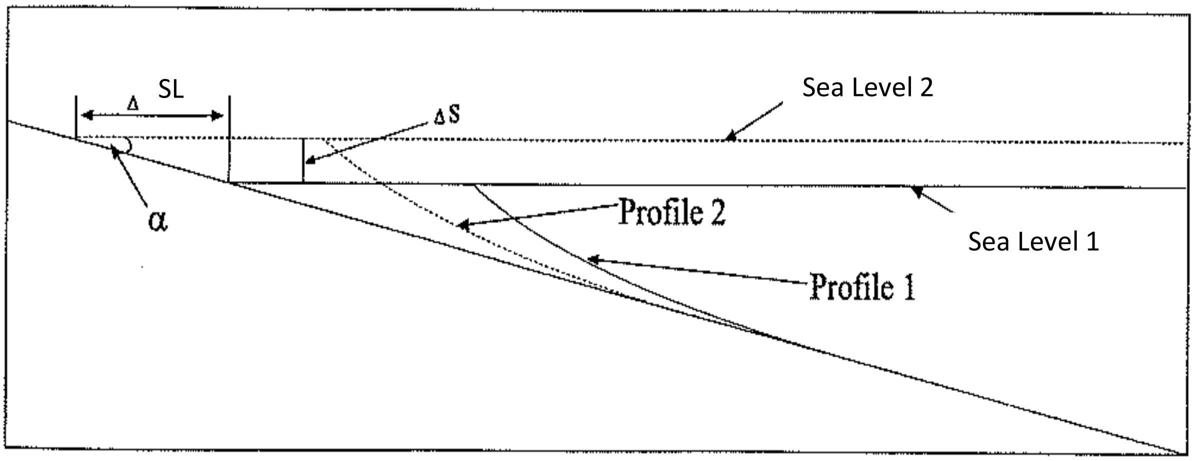


Figure 4-11 Horizontal translation distance of the beach profile under sea level rise (source: adopted from Hennecke and Cowell, 2000)

An average historic rate of sea level rise of 1.9 mm/year has been deducted from the adopted sea level rise values for use in this assessment on the basis that the existing long-term trends and processes already incorporate the response to the historic situation (2.2.1.6). The base year for the projections to 2115 is 2015. Table 4-10 presents the sea level rise values used in this coastal hazard assessment.

The calculated retreat values due to sea level rise based on the equilibrium profile method are presented in Table 4-18 and 4-19 for the 2065 and 2115 timeframes respectively.

Table 4-18 Summary of the estimated shoreline retreat due to potential sea level rise to 2065 using the equilibrium profile method

Settlement	**Sea level rise (m)[1]**	**Slope (Vertical:Horizontal)[2]**	**Equilibrium Profile Shoreline Retreat (m)[3]**
Wainui	0.27	0.10	3
Duvauchelle	0.27	0.06	5
Takamatua	0.27	0.04	6
Akaroa	0.27	0.09	3
Allandale	0.27	0.03	9
Teddington	0.27	0.01	22
Charteris Bay	0.27	0.08	4
Purau	0.27	0.10	3

Note: [1]Sea level rise projected to 2115 reduced by the historic rate of 1.9mm/yr
[2]The vertical and horizontal distances were measured from LiDAR and site measurements.
[3]The shoreline retreat distance is rounded to the nearest whole number.

Table 4-19 Summary of the estimated shoreline retreat due to potential sea level rise to 2115 using the equilibrium profile method

Settlement	Sea level rise (m)[1]	Slope (Vertical:Horizontal)[2]	Equilibrium Profile Shoreline Retreat (m)[3]
Wainui	0.81	0.10	8
Duvauchelle	0.81	0.06	14
Takamatua	0.81	0.04	19
Akaroa	0.81	0.09	9
Allandale	0.81	0.03	28
Teddington	0.81	0.01	65
Charteris Bay	0.81	0.08	11
Purau	0.81	0.10	8

Note: [1]Sea level rise projected to 2115 reduced by the historic rate of 1.9mm/yr
[2]The vertical and horizontal distances were measured from LiDAR and site measurements.
[3]The shoreline retreat distance is rounded to the nearest whole number.

We consider that the equilibrium profile method is suitable to estimate the shoreline retreat due to sea level rise for the silty sand and mixed sand and gravel beaches of the harbour coast sites. Estimating the shoreline response to sea level rise using the equilibrium profile based method is limited to the existing backshore geology and topography, which varies considerably within each of the settlements. Therefore, the equilibrium profile method is expected to over predict the shoreline retreat in some areas where the sites backshore morphology changes from a narrow width of unconsolidated sediments to steep erosion resistant geology. The inland extent of the CEHZ has been limited based on expert opinion when considering the backshore topography and geology.

A second method was also applied to harbour coast sites to identify the shoreline retreat due to sea level rise. This method is referred to as passive inundation or the high tide translation method, and is consistent with the principles described in the eShorance estuary shoreline response model (Stephens and Giles, 2010). The high tide translation method is defined as the landward translation of the high water line due to increased future sea level. Note that this method is applicable only if the future mean high water exceeds the estuary bank crest height. The method is used to identify areas of land potentially susceptible to erosion due to sea level rise. While this is not technically erosion (loss of material), the net result is the same with the mean shoreline position being translated inland (i.e. identifies land likely to become intertidal wetland over the planning timeframe).

The landward extent of shoreline retreat using the high tide translation method is taken as the intersect position between the sea level rise projection elevation above HAT and the existing cross shore profile (Figure 4-12). For the purposes of this study, we have used HAT as the high tide level because this is often the level of the seaward edge of vegetation or bank toe, which delineates the shoreline along the harbour coast sites. Based on the HAT level of RL 1.5 m above Lyttelton Vertical Datum 1937 (LVD) and the sea level rise projection of 1.0 m, the adopted high tide translation level for 2115 is RL 2.5 m (LVD). The 2065 passive inundation level was taken as RL 1.9 m (i.e. RL 1.5 m + 0.4m).

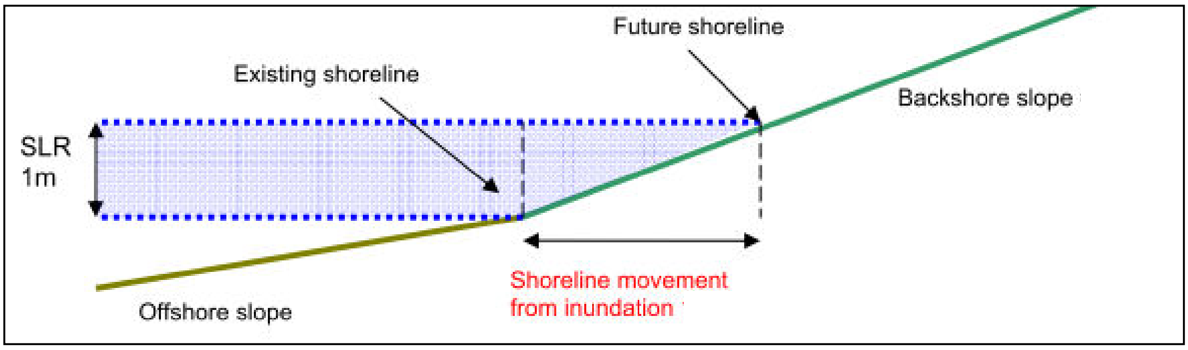


Figure 4-12 Example of calculating shoreline retreat based on passive inundation (source: eShorance, Stephens and Giles, 2010)

The CEHZ for harbour coast sites was mapped separately for both of the following methods:

- Equilibrium profile method – CEHZ distance mapped inland from the seaward edge of vegetation (2010 aerial photograph) baseline based deriving the SL component from Equation 8 and combining all components based on Equation 2.
- High tide translation method – CEHZ distance mapped inland of the translated high tide level based on Equation 2 excluding the SL component. The following translated high tide contours were adopted:
  - 2115 (HAT + 1.0 m sea level rise)
  - 2065 (HAT + 0.4 m sea level rise).

  The HAT level of RL 1.5 m for Lyttelton Harbour was applied to the Lyttelton Harbour and Akaroa Harbour sites. The HAT level of RL 1.4 m for Sumner Head was applied to the Avon-Heathcote, Brooklands and Sumner sites. Table 4-20 outlines the resulting contours adopted as the baseline for the high tide translation method. The CEHZ distance based on Equation 2 (excluding the SL component) was offset from these contours.

Table 4-20 High tide translation method contours adopted for the 2065 and 2115 timeframes

Sites	2065 (RL m)	2115 (RL m)
Lyttelton and Akaroa Harbours	1.9	2.5
Avon-Heathcote Estuary and Brooklands	1.8	2.4

The two resulting CEHZ were then overlayed for each site and the most landward alignment was adopted. Generally the equilibrium profile method produced the most landward CEHZ extent for the 2065 timeframe because the RL 1.9 m level did not always exceed the estuary bank crest height. Conversely, the high tide translation method generally produced the most landward extent for the 2115 timeframe because the RL 2.5 m level exceeded the estuary bank crest level in most cases. The CEHZ mapping extent was finally checked against backshore topography and geology and restricted to the low lying areas comprising unconsolidated sediments.

5 Coastal erosion hazard assessment results

Components have been assessed for each coastal cell based on the data and methodologies described in the preceding sections. The open and harbour coast CEHZ results are presented in Section 5.1 and Section 5.2 respectively.

5.1 Open coast CEHZ values

For each coastal cell a range of CEHZ probabilistic values are calculated and presented within Table 5-1. Following consultation with Council, the $P_{66\%}$ value for 2065 (value with a 66% likelihood of being exceeded by 2065) and the $P_{5\%}$ value for 2115 (5% likelihood of being exceeded by 2115) were adopted as prudent ***likely*** and ***potential*** coastal erosion hazard zones values termed the CEHZ2065 and CEHZ2115 respectively.

The results of the probabilistic assessment are presented in Table 5-1 for both the current (2015) and future (2065 and 2115) timeframes. The full set of both the histogram and cumulative distribution function graphs from the probabilistic assessment output are presented in Appendix G for each site. The current 2015 coastal erosion hazard assessment is based on the short-term fluctuation (SF) and dune stability (DS) components only.

We note that the current 2015 results show a greater distance than the future 2065 timeframe results for some cells (i.e. cell A and G). This is due to the long-term accretion trend in these locations being greater than the potential retreat due to sea level rise over the 2065 timeframe. When selecting the CEHZ2065 value, the largest distance calculated for the 66% probability of exceedance at both the 2015 and 2065 timeframes was chosen. This is because the minimum CEHZ2065 distance must account for the potential short-term fluctuations for the purposes of hazard mapping.

The CEHZ2065 distances range from -20 m to -30 m across all cells with an average of -23 m. The CEHZ2115 distances range from -60 m to -98 m with an average of -83 m. The CEHZ values have been mapped with respect to the adopted baseline and are presented in Appendix D.

The South New Brighton spit is expected to be susceptible to erosion from both the open coast and the harbour coast edges. Due to the relatively low lying land on the harbour side of the spit, erosion is expected to potentially effect the full width of the spit along the southern 2.5 km (i.e. south of Caspian Street) over the 2115 timeframe. Figure D 7 located in Appendix D shows the land susceptible to erosion over both a 2065 and 2115 timeframe.

Table 5-1 Probability of CEHZ exceedance results for Southern Pegasus Bay for both the 2065 and 2115 timeframe

Cell		A			B			C			D			E			F		
Timeframe		2015	2065	2115	2015	2065	2115	2015	2065	2115	2015	2065	2115	2015	2065	2115	2015	2065	2115
Probability of CEHZ (m) Exceedance	Min	-16	-1	12	-16	-16	-22	-16	-9	-4	-16	-10	-6	-15	-11	-10	-15	1	15
	99%	-17	-6	3	-17	-22	-31	-17	-13	-11	-17	-15	-14	-17	-16	-20	-16	-4	4
	95%	-18	-9	-3	-18	-24	-35	-18	-16	-17	-18	-17	-19	-18	-19	-26	-17	-8	-2
	90%	-19	-10	-7	-19	-26	-39	-19	-17	-20	-19	-19	-22	-19	-21	-30	-18	-9	-6
	80%	-19	-12	-12	-20	-28	-43	-20	-20	-25	-20	-21	-27	-19	-23	-35	-19	-12	-12
	70%	-20	-14	-15	-20	-29	-47	-21	-21	-29	-21	-23	-31	-20	-25	-40	-20	-14	-17
	66%	-20	-15	-16	-20	-30	-48	-21	-22	-31	-21	-23	-33	-20	-25	-41	-20	-14	-19
	60%	-21	-16	-19	-21	-31	-51	-21	-23	-33	-21	-24	-36	-21	-27	-45	-20	-16	-22
	50%	-21	-17	-22	-21	-32	-54	-22	-25	-38	-22	-26	-40	-21	-28	-49	-21	-17	-27
	40%	-22	-19	-27	-22	-33	-58	-23	-27	-42	-22	-28	-46	-22	-30	-55	-21	-20	-33
	33%	-22	-20	-30	-22	-35	-62	-23	-28	-46	-23	-30	-50	-22	-32	-59	-22	-21	-37
	30%	-23	-21	-31	-23	-35	-63	-23	-29	-48	-23	-31	-52	-23	-33	-61	-22	-22	-39
	20%	-23	-23	-38	-23	-38	-70	-24	-32	-56	-24	-34	-61	-23	-36	-70	-23	-25	-48
	10%	-24	-28	-49	-24	-42	-82	-25	-36	-67	-24	-39	-75	-24	-41	-84	-24	-30	-62
	5%	-25	-32	-60	-25	-46	-93	-25	-40	-79	-25	-44	-89	-25	-46	-98	-24	-35	-76
	1%	-26	-40	-85	-26	-55	-119	-26	-49	-104	-26	-55	-121	-26	-57	-126	-25	-46	-105
	Max	-27	-62	-140	-27	-72	-157	-28	-67	-162	-27	-80	-179	-27	-76	-185	-27	-69	-155
	CEHZ2065	-20			-30			-22			-23			-25			-20		
	CEHZ2115	-60			-93			-79			-89			-98			-76		

5.2 Harbour coast CEHZ values

The land susceptible to coastal erosion hazard was identified for both the 2065 and 2115 timeframes as CEHZ2065 and CEHZ2115 respectively. The CEHZ were assessed for the harbour coast sites utilising the following two methods for deriving the future shoreline retreat due to sea level rise:

- Equilibrium profile method
- High tide translation method.

The CEHZ distances based on the equilibrium profile method are displayed in Table 5-2 and are measured landward of the seaward edge of vegetation based on the 2011 aerial photographs. The CEHZ distances based on the high tide translation method vary within each site due to the existing topography and therefore cannot be listed in a table. The final CEHZ delineation for the harbour coasts was assessed based on combining both methods listed above. The assessment results in the minimum CEHZ being set to the distance derived using the equilibrium method (refer to Table 5-2). The CEHZ alignment is extended inland where the high tide translation method exceeds beyond this minimum distance. The final CEHZ alignment is then restricted to the low-lying areas comprising unconsolidated sediments. Refer to Appendix D for a full set of the CEHZ for the harbour coasts.

Table 5-2 Summary of CEHZ component and resultant values based on the equilibrium profile method

	Components (m)					**CEHZ values (m)**	
	SL						
Site	**2065**	**2115**	**LT**	**SF**	**DS**	**CEHZ2065**	**CEHZ2115**
Wainui	3	8	0	5	2.3	10	15
Duvauchelle	5	14	0	5	2.2	12	21
Takamatua	6	19	0	5	1.9	13	25
Akaroa	3	9	0	5	1.9	9	16
Allandale	9	28	0	5	1.8	16	34
Teddington	22	65	0	5	1.4	28	71
Charteris Bay	4	11	0	5	1.4	10	17
Purau	3	8	0	5	1.9	10	15

6 Coastal inundation hazard assessment results

6.1 Open coast CIHZ values

The open coast inundation zones (CIHZ) were mapped for both Taylors Mistake and Sumner by extrapolating the total inundation level inland where pathways exist based on a digital elevation model (DEM) derived from LiDAR surveyed post the 2010-2011 Canterbury Earthquakes. The CIHZ levels for the 2065 and 2115 timeframes are RL 3.5 and 4.2 m respectively. The CIHZ maps showing land situated below these elevations are presented in Appendix E.

The elevation of the foredunes located along the open coast shoreline from Waimairi to the Avon-Heathcote Estuary mouth are generally sufficient to mitigate the coastal inundation hazard over a 100 year timeframe. However, there are two sites at New Brighton where the foredunes have been modified and inundation pathways exist through the foredunes:

- New Brighton Library
- North New Brighton Community Centre and North Beach Surf Lifesaving Club.

Inundation of land behind the dunes is expected at these two locations during a 1% AEP storm event including an allowance for sea level rise over the 2065 and 2115 timeframes. The inundation pathways at both sites are relatively narrow and the quantity of inundation will be affected by tide levels and friction. Therefore the volume of water able to propagate inland will be restricted and the inundation levels for New Brighton are more likely controlled by the storm-tide level within the harbour. Further analysis is required to accurately identify the open coast inundation extent for New Brighton. An alternative option is to remove the hazard risk by restoring the foredune at the two sites to eliminate these open coast inundation pathways.

We note that wave run-up effects may effect land and public assets located close to the shoreline. However, wave run-up has not been assessed for the purpose of mapping inundation hazard because the elevated water levels attenuate over a relatively short distance inland. Wave run-up is not commonly included in the coastal inundation still water level for the purposes of mapping hazard zones (Ramsey et. al; 2012).

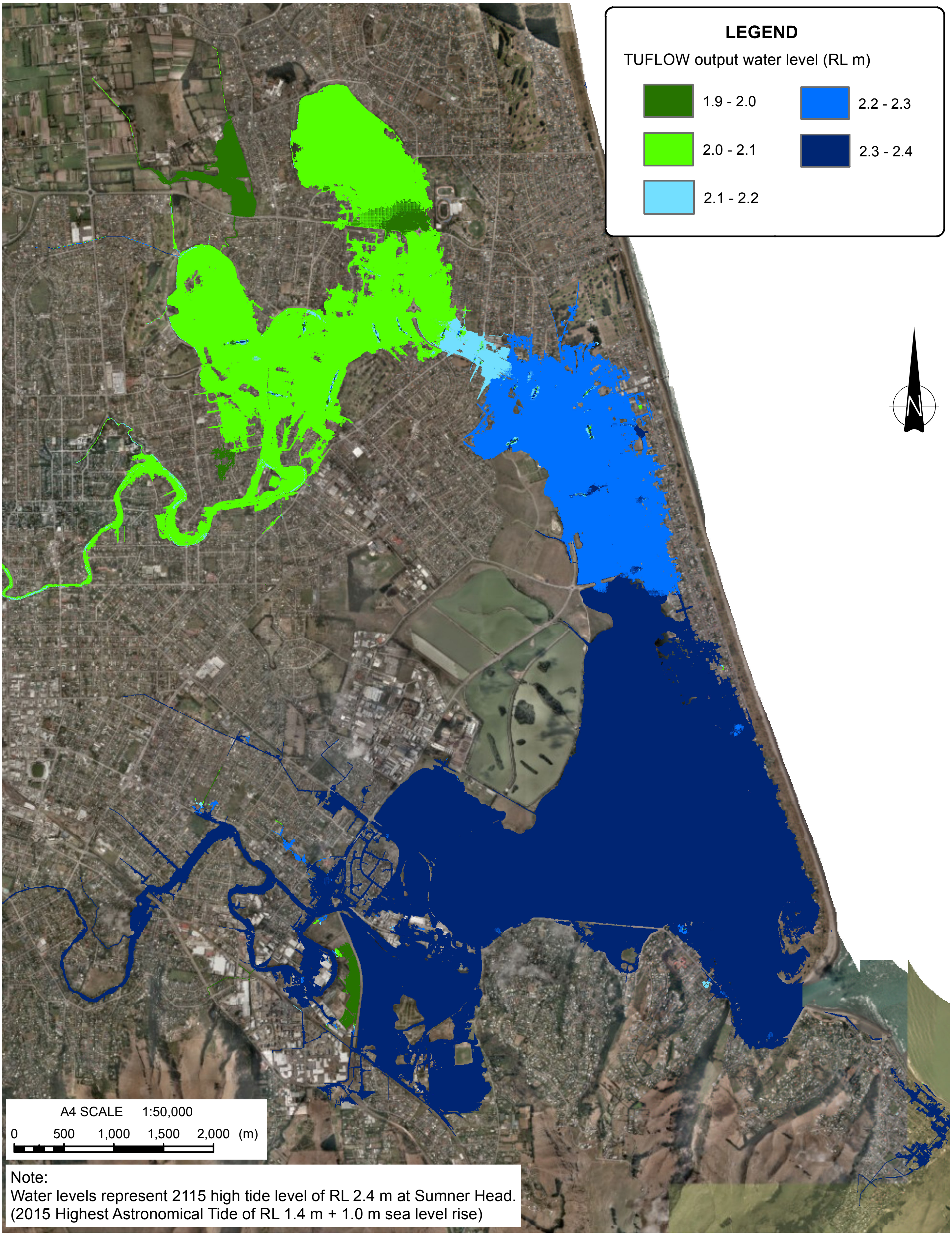
6.2 Harbour coast CIHZ values

The land susceptible to coastal inundation hazard was identified for both the 2065 and 2115 timeframe as coastal inundation hazard zones (CIHZ). The inundation levels are presented in Section 4.2.1.5 and in Table 4-15 and Table 4-16. The CIHZ for the harbour coast was mapped using two methods:

- Connected “bath-tub” method – maps the area of land below the inundation level based on LiDAR derived topography, where there is a connection pathway to the sea. This method was used for sites located within both the Lyttelton and Akaroa Harbours.
- Dynamic model method – simulates the physics of the tide and inundation levels to dynamically map the inundation levels based on LiDAR derived topography and detailed bathymetry of the estuary. This method is beneficial for wide flat areas and was implemented for Avon-Heathcote Estuary, Brooklands Lagoon and Sumner.

The results of the CIHZ assessments for the harbour coasts were mapped for both the 2065 and 2115 timeframe and are presented in Appendix E.

Figure 6-1 shows the TUFLOW output results for the Avon-Heathcote Estuary with a boundary water level of RL 2.4 m. This water level comprises the HAT of RL 1.4 m and an allowance of 1.0 m for sea level rise to 2115. The results of the TUFLOW dynamic modelling show the inundation levels reduce over the model domain due to frictional, infiltration and tidal time lag effects. The inundation level in the upper reaches of the Avon River was reduced by over 400 mm.



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Coastal Hazard Assessment
TUFLOW Example Results
Avon-Heathcote Estuary

FIGURE No. Figure 6-1. Rev. 0

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7 Discussion

Coastal processes and future shoreline positions are difficult to accurately forecast over a 100 year timeframe due to the potential for morphological feedbacks to slow or increase the rates of historic trends. These forecasts become more uncertain when considering the effect of potential sea level rise and interrelationships with other systems (i.e. spit and estuary inlets).

Some areas of the open coast have areas of relatively narrow dune vegetation where backshore areas comprise revetment, grass reserve or private development. We expect dune recovery to be negatively affected where native dune vegetation has been removed. Removal of dune vegetation could result in a greater erosion response in both the long-term and short-term than historically experienced.

The probabilistic method used for the open coast includes the uncertainty within each component to produce a range of CEHZ distances. The results of this assessment allow Council to consider this uncertainty when selecting a probability of exceedance output in accordance with risk-based guidance provided in the NZCPS.

The harbour coast CEHZ assessment combines two building-block methods to identify land susceptible to coastal erosion hazard. Although we have not yet developed the harbour coast methodology to incorporate the probabilistic approach, the methods are commonly applied and are still in accordance with best practice guidelines.

We recommend continuing to monitor the shoreline position at both sites by mapping shoreline positions from aerial photographs or GPS surveys along with continuing the traditional beach profile dataset. The shoreline monitoring will provide measured data to help resolve these uncertainties for future re-assessments.

8 Summary and conclusions

The areas susceptible to coastal hazards (inundation and erosion) over both a 50 year (2065) and 100 year (2115) planning timeframe have been identified within the main coastal settlements selected by Council. The areas were termed coastal erosion hazard zones (CEHZ) and coastal inundation zones (CIHZ) and have been mapped for both the open and harbour coast to a standard suitable for inclusion in the District Plan.

The CEHZ methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters. This method has been refined for the open coast to include parameter bounds which are combined by stochastic simulation. The resulting distribution is a probabilistic forecast of potential hazard zone width, rather than including single values for each component and one overall factor for uncertainty.

This approach produces a range of hazard zones (probability distribution) corresponding to differing likelihoods which may be applied to risk-based assessments as advocated by the NZCPS and supported by best practice guidelines. Following consultation with Council, the $P_{66\%}$ CEHZ value at 2065 and the $P_{5\%}$ CEHZ value at 2115 are adopted as prudent likely and potential CEHZ values (termed CEHZ1 and CEHZ2 respectively).

We implemented separate methodologies to assess coastal hazards for the open coast and the harbour coast sites due to the different processes driving each of the two coastal environments. The harbour coast CEHZ methodologies combine two approaches to account for the low-lying morphology typical of these sites. Although we have not yet developed the harbour coast methodology to incorporate the probabilistic approach, the method is in accordance with best practice guidelines

The CIHZ was mapped using two methods:

- Connected “bath-tub” method – maps the area of land below the inundation level based on LiDAR derived topography, where there is a connection pathway to the sea. This method was used for sites located within both the Lyttelton and Akaroa Harbours and the open coast.
- Dynamic model method (TUFLOW) – simulates the physics of the tide and inundation levels to dynamically map the inundation levels based on LiDAR derived topography and detailed bathymetry of the estuary. This method is beneficial for wide flat areas and was implemented for Avon-Heathcote Estuary, Brooklands Lagoon.

We recommend continuing to regularly monitor the shoreline position and inundation levels across the region to provide background data, including continuing beach profile monitoring and digitising shorelines from aerial imagery or by GPS survey. We also recommend the adopted baselines and both the CEHZ and CIHZ values are reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

9 Applicability

This report has been prepared for the benefit of 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 without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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