REPORT

Tonkin+Taylor

# Ōpōtiki Coastal Erosion Hazard Assessment - Stage 1 Waiotahe

**Prepared for**
Bay of Plenty Regional Council
**Prepared by**
Tonkin & Taylor Ltd
**Date**
February 2020
**Job Number**
1008669.v4

*Exceptional thinking together*
www.tonkintaylor.co.nz

# Document Control

| **Title:** **Ōpōtiki Coastal Erosion Hazard Assessment - Stage 1 Waiotahe** | | | | | |
|---|---|---|---|---|---|
| **Date** | **Version** | **Description** | **Prepared by:** | **Reviewed by:** | **Authorised by:** |
| Dec 2018 | V1 | Draft methodology and outputs for client review | Rebekah Haughey | Jon Clarke | |
| April 2019 | V2 | Draft report for client review | Rebekah Haughey | Jon Clarke, Tom Shand | Richard Reinen-Hamill |
| June 2019 | V3 | Final draft report with client comments addressed | Rebekah Haughey | | R. Reinen-Hamill |
| Feb 2020 | V4 | Final report | Rebekah Haughey | | R. Reinen-Hamill |

**Distribution:**

| | |
|---|---|
| Bay of Plenty Regional Council | 1 PDF copy |
| Tonkin & Taylor Ltd (FILE) | 1 PDF copy |

# Table of contents

## Executive summary

Waiotahe Beach is a 4 km stretch of north-facing, unconsolidated shoreline located in the Bay of Plenty, approximately 2 km west of Ōpōtiki Township. The beach is bound by the Waiotahe River mouth at the western end and the Waioeka River mouth at the eastern end. Tonkin + Taylor Ltd (T+T) were commissioned by Bay of Plenty Regional Council (BOPRC) to undertake a detailed assessment of coastal erosion hazard for the Waiotahe shoreline.

The coastal erosion hazard areas (CEHA) were defined using a probabilistic approach which combines standard and well-tested erosion models with a stochastic method for combining erosion parameter distributions to allow for inherent variance and uncertainty to be captured within the results. The open coast shoreline was assessed based on erosion hazard methodology for unconsolidated beaches. The shoreline in the vicinity of the Waioeka River mouth was assessed based on a geomorphological assessment taking into account short-term fluctuations and the long-term westward migration.

Results provide a range of potential erosion hazard distances for current and future timeframes (e.g. 2070 and 2130) including a range of sea level rise scenarios (Table E-1).

**Table E-1 Summary of timeframe and sea level rise scenarios used for the CEHA assessment**

| Timeframe in years | Sea level rise scenarios (m) |
|---|---|
| 2020 (current) | N/A |
| 2070 | 0.40 |
|  | 0.60 |
| 2130 | 0.8 |
|  | 1.25 |
|  | 1.60 |

Key conclusions from the assessment are:

- Most of the Waiotahe shoreline has shown long-term accretion trends. This is most likely due to the sediment supply from adjacent river mouths and the shoreline being a convergent point for net longshore sediment transport.
- Erosion hazard area is relatively consistent along the open coast shoreline.
- Westward migration of the Waioeka River mouth is the largest contributor to potential erosion hazard at the eastern end of the study area.

Based on the geomorphological assessment there is potential for the river mouth to continue to migrate over 800 m westward over the next 100 years. However migration to this full extent is unlikely as there is potential for the eastern spit to breach and for the river mouth to shift back eastward. There is uncertainty in how the river mouth will behave in the future, particularly with sea level rise and therefore we recommend annual monitoring of its position.

We recommend that this hazard assessment is updated at intervals of no more than 10 years or following significant changes in data availability, or best practice guidance or methods.

This study has assessed coastal erosion hazard areas at a local level and may be superseded by detailed site-specific assessment undertaken by a qualified and experienced practitioner using improved or higher resolution data than presented in this report.

# 1 Introduction

Waiotahe Beach is a 4 km stretch of north-facing shoreline located in the Bay of Plenty, approximately 2 km west of Ōpōtiki township (Figure 1-1). The beach is bound by the Waiotahe River mouth at the western end and the Waioeka River mouth at the eastern end.

Located at the eastern end of the beach is the Waiotahe Drifts subdivision, which is continuing to be developed with the eastern extent consented but not yet constructed.

Tonkin + Taylor Ltd (T+T) has been engaged by Bay of Plenty Regional Council (BOPRC) to undertake a detailed coastal erosion hazard assessment for the Waiotahe shoreline.

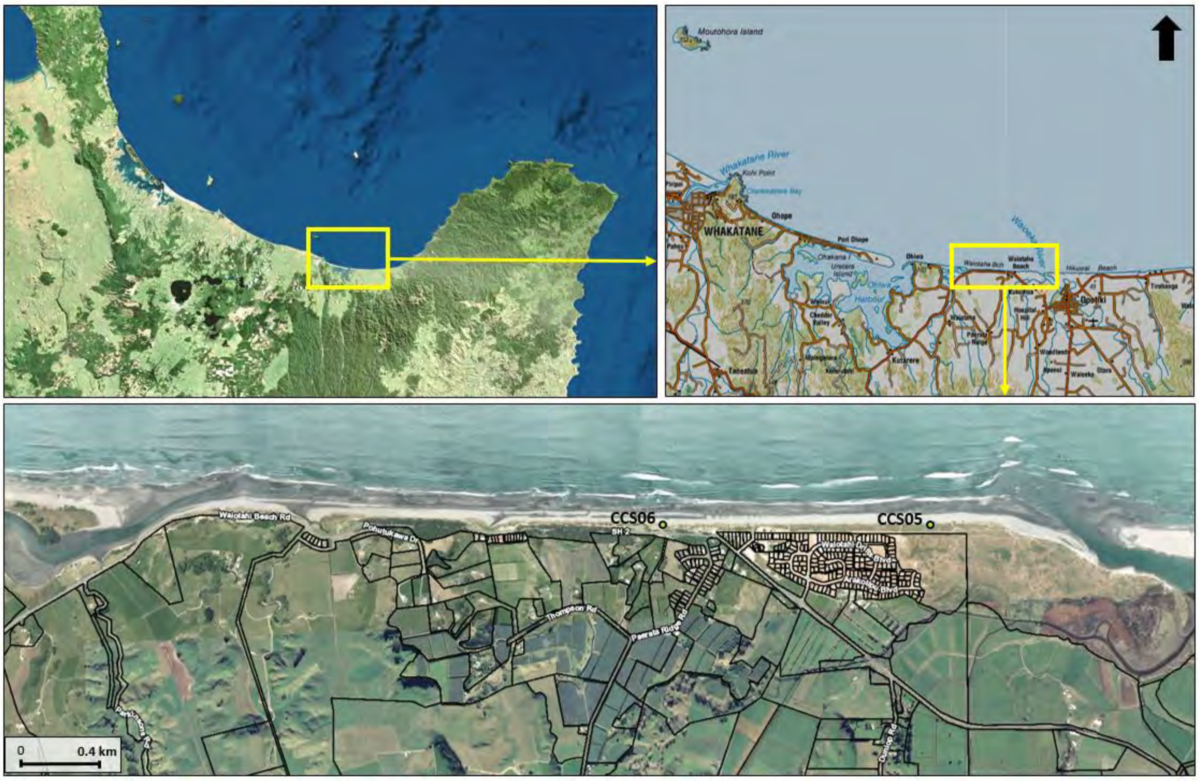


*Figure 1-1 Location of the Waiotahe shoreline and beach profile monitoring locations, CCS05 and CCS06*

## 1.1 Study scope

The purpose of the Waiotahe Coastal Erosion Hazard Assessment is to identify and map areas of land exposed to coastal erosion along the site of interest. The assessment is based on the following scope of works:

- Assess values of components contributing to coastal erosion along the Waiotahe shoreline
- Calculate probabilistic coastal erosion distances for Waiotahe using the T+T stochastic forecast methodology (Shand et al., 2015)
- Apply the coastal erosion methodology for current and future sea level scenarios in accordance with the requirements of:
  - New Zealand Coastal Policy Statement (NZCPS)
  - Natural hazard provisions of the Bay of Plenty Regional Policy Statement (RPS)
  - Proposed Regional Coastal Environment Plan (PRCEP)
  - Ministry for the Environment (MfE) Coastal Hazard Guidelines (2017)

- Map coastal erosion distances for present day, 50 year and 100 year timeframe for all SLR scenarios and for 66% and 5% exceedance probabilities
- Produce a technical report describing the methodology and a discussion of the results.

## 1.2 Report layout

The report is structured as follows:

- Background data outlined in Section 2
- Coastal processes described in Section 3
- Methodology for deriving coastal erosion hazard in Section 4
- Derivation of components for coastal erosion in Section 5
- Results and discussion of the erosion hazard assessment in  Section 6
- A summary of the assessment and recommendations are outlined in Section 7.

# 2 Background data

## 2.1 Previous studies

Previous coastal erosion hazard studies for the Waiotahe shoreline include Gibb (1994), Dahm and Kench (2007) and Eco Nomos Ltd (2016).

Gibb (1994) identified Areas Sensitive to Coastal Hazards (ASCH). The ASCH line was intended as a screening tool to identify areas where further coastal hazard analysis would be required. Based on Gibb (1994) the ASCH setback for the Waiotahe shoreline ranged from 100 to 130 m (Table 2-1).

As part of an Ōpōtiki District coastal erosion hazard assessment, Dahm and Kench (2007) divided the Waiotahe Beach into two sections (west and east) for analysing the erosion hazard. The erosion hazard setback was derived based on the combination of dynamic fluctuations and the shoreline response to projected sea level rise (up to 0.48 m SLR by 2100). A precautionary approach was used, with long term accretion trends excluded when assessing potential setbacks.

Dahm and Kench (2007) describe the western end of the Waiotahe shoreline as being subject to enhanced dynamic fluctuations due to the additional influence of river entrance effects. They also mention that the shoreline position fluctuates around the Waiwhakatoitoi Stream, however in general this section of the coast has been relatively stable over the past few decades.

The eastern end of the beach (Waiotahe Drifts) has undergone net accretion since 1945. Dahm and Kench (2007) identified the eastern extent in the vicinity of the Waioeka River mouth as having the greatest amount of shoreline change, with accretion up to 60 m. The dune toe position was measured to fluctuate up to 35 m.

Based on the dynamic shoreline fluctuations, projected changes in shoreline position in response to sea level rise and a dune stability factor, Dahm and Kench (2007) recommended an erosion setback of 70 m along Waiotahe Beach.

In 2016 Eco Nomos Ltd reviewed the coastal erosion hazard along Waiotahe Beach and assessed the worst likely coastal erosion for planning periods 50 years (2065), 100 years (2115) and also 200 and 500 years. The assessment also included the potential effects of SLR based on the RCP8.5M scenario. To account for the uncertainty around components contributing to coastal erosion, lower, modal and upper bound estimates were assessed for each erosion hazard scenario.

Erosion results from the review were generally similar to the 2007 study and also supported the ASCH lines being over precautionary. The 2065 erosion hazard area ranged from 35 to 50 m and the 2115 erosion hazard area ranged from 50 to 65 m (Table 2-1).

**Table 2-1 Summary of erosion hazard setbacks defined by previous studies**

| **Previous studies** | **Erosion hazard setbacks** | | |
|---|---|---|---|
| Gibb (1994) | 100 to 130 m (ASCH) | | |
| Dahm & Kench (2007) | 70 m | | |
| Eco Nomos Ltd (2016) | Current | 2065 | 2115 |
| | 23 to 38 m | 35 to 50 m | 50 to 65 m |

## 2.2 Site inspection

A site inspection was completed in early December 2018 by Rebekah Haughey (Coastal Scientist, T+T). The shoreline was checked for any evidence of recent shoreline erosion and any site characteristics that were not captured by the existing data sets. Photographs were also taken along each section of the shoreline.

## 2.3 Topography and bathymetry

Topography has been assessed using LiDAR (Light Detection and Ranging) data captured in 2015 (Figure 2-1). The LiDAR was sourced from the LINZ Data Service as a 1 m by 1 m DEM (digital elevation model). The DEM was used for determining both location and elevation of the dune toe and crest along the Waiotahe shoreline.

Bathymetry sources include the LINZ hydrographic chart (Chart NZ 542 Motiti Island to Pehitari Point). This bathymetric data was used in combination with beach profiles to derive cross-shore profiles for model input (see Section 5.6.1).

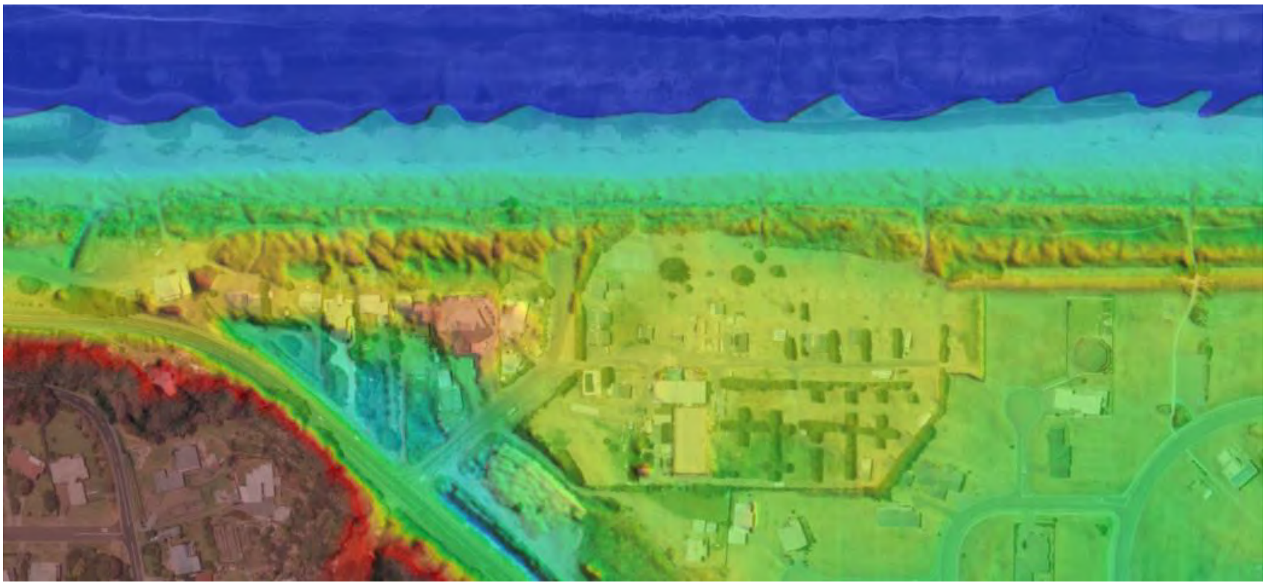


*Figure 2-1 Example of LiDAR DEM used for the Waiotahe shoreline.*

## 2.4 Beach profile data

BOPRC undertake beach profile surveys from the upper dune down to approximately the mean sea level contour. BOPRC have two profile locations along the Waiotahe shoreline (refer Figure 1-1) which have been surveyed annually since 1978 (BOPRC, 2011). A summary of the beach profile data for both sites is provided in Table 2-2.

**Table 2-2 Summary of beach profile data**

| Profile name | Surveys | | | |
|---|---|---|---|---|
| | No. of surveys | Start date | Latest survey date | Years |
| CCS05 | 45 | 27/01/1978 | 17/12/2018 | 40.8 |
| CCS06 | 45 | 05/04/1990 | 17/12/2018 | 28.6 |

## 2.5 Aerial photographs

The historical shoreline data was processed from aerial images using standard geo-referencing and digitising GIS methods using ArcGIS and Global Mapper software. Available aerial photographs were sourced from BOPRC (refer to Table 2-3 for a summary of the historic aerial photographs used for this study).

The seaward edge of the dune vegetation was digitised to represent the dune toe, which was taken as the shoreline proxy.

There are three main sources of potential error when estimating the shoreline position. These sources of error include:

1 Geo-referencing error (Er)
2 Shoreline proxy error (Es)
3 Digitising error (Ed).

The geo-referencing error is the potential offset of an image from a known point based on ground control points collected during the geo-referencing process. This potential error does not apply to GPS data and increases with the age of the photograph due to scale and lower number of suitable ground control points.

The shoreline proxy error is the estimated uncertainty in identifying the shoreline, which is more apparent 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.

The digitising error is the potential operator inconsistency in digitising a shoreline using ArcGIS software. For example, if the operator was to digitise the same shoreline on two separate occasions there is likely to be an offset between the two lines, which is the digitising error. The digitising error does not apply for the GPS data and remains constant for all historic shorelines based on aerial photographs.

The resultant potential error in shoreline position can be calculated using a sum of independent errors approach whereby:

$$E_{sum} = \sqrt{E_r^2 + E_s^2 + E_d^2} \qquad (2\text{-}1)$$

Based on the resolution of the aerial photographs the overall error associated with the shoreline position has been estimated and the overall error tends to be greatest for the oldest aerial photographs (refer Table 2-3).

**Table 2-3 Summary of historic aerial photographs used for shoreline analysis.**

| Year | Source | ID | Estimated error +/- (m) | Comments |
|---|---|---|---|---|
| 1940 | BOPRC | SN140 | 20 | Not included in long term analysis due to geo-referencing inaccuracy |
| 1966-1969 | BOPRC | SN1906 | 5 | |
| 1974 | BOPRC | SN3580 | 5 | |
| 1985 | BOPRC | SN8546 | 5 | |
| 2003 | BOPRC | - | 2 | |
| 2007 | BOPRC | - | 2 | |
| 2011 | BOPRC | - | 2 | |

| Year | Source | ID | Estimated error +/- (m) | Comments |
|---|---|---|---|---|
| 2014 | BOPRC | - | 2 | |

# 3 Coastal setting

The Waiotahe shoreline is an unconsolidated beach consisting of Holocene beach deposits (Figure 3-1). Sediment along the beach is mostly composed of sand-sized material. A dune system runs along the entire shoreline and is most expansive at the eastern extent near the Waioeka River mouth. The western end of the shoreline comprises a relatively narrow section of dunes backed by sandstone cliffs elevated up to 60 m RL.

Both ends of the beach are largely influenced by river dynamics, with the Waiotahe River mouth at the western end and the Waioeka River mouth at the eastern end. Two smaller streams emerge on to the beach at the western end, one of the streams being the Waiwhakatoitoi Stream.

*Figure 3-1 Waiotahe shoreline.*

## 3.1 Water levels

Water levels play an important role in determining coastal erosion hazard by controlling the amount of wave energy reaching the backshore and 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 and wind effects, generally referred to as storm surge
- Medium term fluctuations, including El Niño–Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO) effects
- Long-term changes in sea level due to climate change
- Wave transformation processes through wave setup and run-up.

### 3.1.1 Astronomical tide

Tidal levels for primary and secondary ports of New Zealand are provided by LINZ based on the average predicted values over the 18.6 year tidal cycle. Tidal conditions within the Bay of Plenty are defined as low mesotidal to microtidal. Values for Ōpōtiki Wharf in terms of Chart Datum and Moturiki Vertical Datum 1953 (MVD-53 RL) are presented within Table 3-1. It is assumed that these are representative of the open coast tide levels of the project area.

**Table 3-1 Tidal levels given for the Ōpōtiki Wharf (LINZ, 2018)**

| Tide state | Chart datum (m) | (MVD-53 RL) |
|---|---|---|
| Highest Astronomical Tide (HAT) | 2.1 | 1.14 |
| Mean High Water Springs (MHWS) | 1.8 | 0.84 |
| Mean High Water Neaps (MHWN) | 1.5 | 0.54 |
| Mean Sea Level (MSL) | 1.0 | 0.04 |
| Mean Low Water Neaps (MLWN) | 0.4 | -0.56 |
| Mean Low Water Springs (MLWS) | 0.1 | -0.86 |
| Lowest Astronomical Tide (LAT) | 0.0 | -0.96 |

Source: LINZ New Zealand Nautical Almanac 2018-19

### 3.1.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind set up from winds blowing along or onshore which elevates the water level above the predicted tide (Figure 3-2). 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 setup and wave run-up at the shoreline.

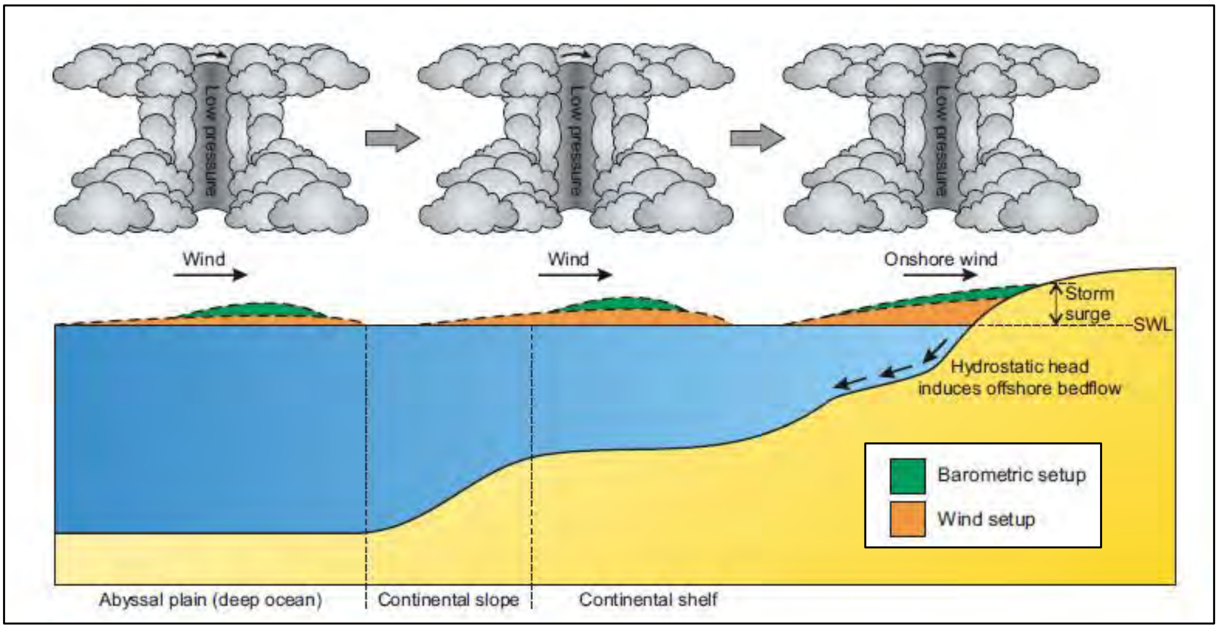


*Figure 3-2 Processes causing storm surge (source: Shand, 2010)*

### 3.1.3 Storm tide levels

The combined elevation of the predicted tide, storm surge and medium term fluctuations is known as the storm tide. The NIWA Coastal Calculator assesses the storm tide and wave hazard for 21 sites along the Bay of Plenty coastline. Extreme water levels predicted for the Waiotahe River mouth are shown in Table 3-2.

**Table 3-2 Extreme water level values for 2% and 1% Annual Exceedance Probability (AEP) events based on the NIWA Coastal Calculator (2018)**

| | 2% AEP | 1% AEP |
|---|---|---|
| **Storm tide (m MVD-53)** | 2.25 | 2.56 |
| **Storm tide + wave setup (m MVD-53)** | 2.62 | 2.99 |

### 3.1.4 Long-term sea levels

Historic sea level rise in New Zealand has averaged 1.7 ± 0.1 mm/yr with Bay of Plenty exhibiting a slightly higher rate of 1.9± 0.1 mm/yr (Bell and Hannah, 2012). Climate change is predicted to accelerate this rate of sea level rise into the future.

The Ministry for the Environment (2017) guideline recommends four sea level rise scenarios to cover a range of possible sea-level futures. The scenarios are based on the most recent IPCC report (IPCC, 2013) (Figure 3-3). Three of the scenarios (RCP2.6, RCP4.5, RCP8.5) are derived from the median projections of global sea-level rise for the RCPs presented by the IPCC in its Fifth Assessment Report (IPCC, 2013). The fourth scenario, NZRCP8.5H+ is at the upper end of the 'likely range' (83rd percentile) of SLR projections based on RCP8.5. This higher scenario is representative of a situation where more rapid rates of SLR could occur early next century due to dynamic ice sheet processes and instability thresholds that were not fully quantified in the IPCC AR5 projections (MfE, 2017).

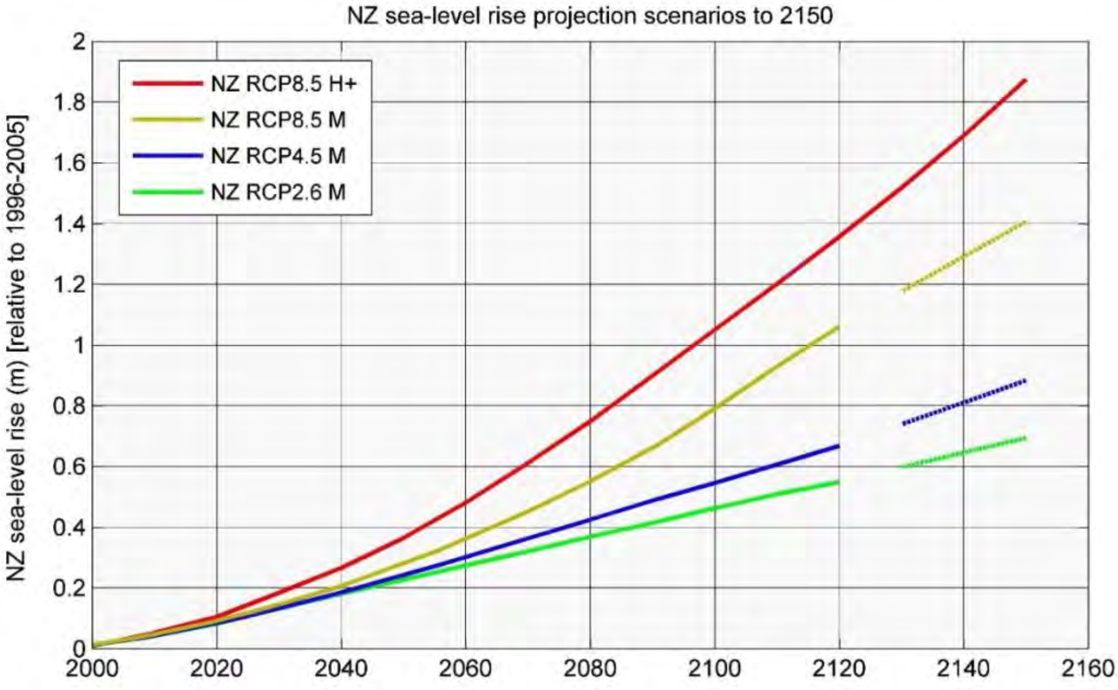


*Figure 3-3 Four scenarios of New Zealand-wide regional sea-level rise projections for use with the MfE 2017 guidance, with extensions to 2150 based on Kopp et al (2014) (Source: MfE, 2017)*

## 3.2 Waves

The Waiotahe shoreline is exposed to swell waves from the northwest around to the northeast, with the dominant swell direction from the north. Extreme significant wave heights based on the NIWA Coastal Calculator are summarised in Table 3-3.

**Table 3-3 Extreme offshore significant wave heights for 2% and 1% Annual Exceedance Probabilities (AEP) based on the NIWA Coastal Calculator (2018)**

| | 2% AEP | 1% AEP |
|---|---|---|
| **Offshore significant wave height (m)** | 7.23 | 7.79 |

## 3.3 Sediment sources

The Motu River, Waiaua River and Waioeka River are major sources of sand-size sediment to eastern Bay of Plenty beaches (Smith, 1986). Beach sediment characteristics adjacent to the Waiaua and Waioeka River mouths indicate a significant volume of sediment is being added to the beach deposits from the rivers. Based on the proximity of the river mouth, sediment loads from the Waioeka River are likely to have direct influence on the Waiotahe shoreline. The Waioeka River catchment is the second largest in the region, including some 1,130 km$^2$ which is largely steep and forested hill country (Smith, 1986). Depending of frequency of floods the sediment load from the Waioeka River is estimated to be 15,000 m$^3$/year (Dahm & Kench, 2002).

## 3.4 Sediment transport

Sediment transport is multi directional along the Ōpōtiki coastline. However, based on grain size data and wave conditions there is net longshore drift is to the south-west from the Motu River mouth (Smith, 1986).

The Waioeka river mouth has a large spit extending from the eastern bank, this implies net movement of sediment in a westerly direction. In contrast a spit has formed on the western bank of the Waiotahe River mouth, indicative of a west to east drift direction. This infers a change in net drift direction between the Waioeka River and the Waiotahi River, with Waiotahe Beach as a convergent point for sediment transport.

Modelling of the sediment transport rate around the Waioeka River mouth (T+T, 2017) indicates that net drift, from a 37 year dataset, is approximately 50,000 m$^3$/year in a westerly direction. However, there is huge variability and annual net transport of hundreds of thousands cubic metres is possible, in either direction, within a year. Modelling also indicates that variability in annual sediment transport direction and volume is influenced by longer term climatic trends (T+T, 2017).

The large ebb-tidal delta at the Waioeka River mouth is a major sediment sink which changes with wave conditions and river flows. The Waioeka River channel is typically on an oblique angle to the coast during mean and low river discharge but under extreme floods the channel changes to a more perpendicular orientation to the coast. This can result in a section of the delta being split, with some of the sediment deposited on the western shoreline. Dahm & Kench (2002) suggest that this cyclic channel migration and delta splitting provides the mechanism for westward alongshore sediment transfer to the Waiotahe shoreline.

## 3.5 Vertical land movement

Beavan and Litchfield (2012) have assessed vertical land movement (VLM) around New Zealand's coastline. They found the land around Ōpōtiki to be subsiding at an average rate of 1.2 mm/yr, measured over approximately 3 years. Due to the limited length of data we have assumed zero VLM.

# 4 Methodology

## 4.1 Statutory considerations

### 4.1.1 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 plans must give effect to (be consistent with) the NZCPS.

A number of the objectives and policies of the NZCPS are directly relevant to the assessment of coastal erosion 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 - requires identification of areas in the coastal environment that are potentially affected by coastal hazards (including Tsunami) giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, should be assessed having regard to:
  - physical drivers and processes that cause coastal change including sea level rise
  - short term and long term natural dynamic fluctuations of erosion and accretion
  - geomorphological character
  - cumulative effects of sea level rise, storm surge and wave height under storm conditions
  - anthropogenic influences
  - extent and permanence of built development
  - effects of climate change on the above matters, on storm frequency and intensity and on natural sediment dynamics.

  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 an increased risk of social, environmental and economic harm 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.

### 4.1.2 Regional Policy Statement

The Bay of Plenty Regional Policy Statement (RPS) outlines the Natural Hazard Policies for the region. The following Policy is relevant to this assessment:

- Policy NH 7A – Identify areas susceptible to natural hazards. Map hazard susceptibility areas (HSA) for the following natural hazards:
  - c) Coastal and marine processes
    - i) coastal erosion
    - ii) coastal inundation

- Policy NH 11B - Incorporates the effects of climate change in natural hazard risk assessment and use the following projections as minimum values when undertaking coastal hazard assessments:
  - a a 100 year timeframe
  - b a projection of a base sea level rise of at least 0.6 m (above the 1980–1999 average) for activities/developments which are relocatable
  - c a projection of a base sea level rise of 0.9 m (above 1980–1999 average) for activities where future adaptation options are limited, such as regionally significant infrastructure and developments which cannot be relocated
  - d an additional sea level rise of 10 mm/annum for activities with life spans beyond 2112.

### 4.1.3 Proposed Regional Coastal Environment Plan

The Bay of Plenty Regional Proposed Coastal Environment Plan (PRCEP) was publicly notified on 24 June 2014. The PRCEP manages the natural and physical resources of the Bay of Plenty coastal environment. This is a review of the operative Bay of Plenty Regional Coastal Environment Plan.

Chapter 5 of the PRCEP covers coastal hazards and section 5.1.3 specifically details the following policies on coastal hazard for sandy coasts and river mouth shorelines.

- Policy CH 11 - Identify and map erosion and inundation zones over a 100 year timeframe in high priority areas
- Policy CH 12 – apply an appropriate method to identify the erosion extent taking into account best practice guidelines, scientific guidance and relevant components including shoreline response to sea level rise.

This study maps erosion in accordance with the RRCEP policy above and also the RPS requirements for hazard susceptibility areas.

## 4.2 Risk-based approach

A risk-based approach to managing coastal hazard is advocated by the NZCPS and endorsed by BOPRC's RPS, with both the likelihood and consequence of hazard occurrence requiring consideration. For example, the NZCPS suggests consideration of areas both 'likely' to be affected by hazard and areas 'potentially' affected by hazard. The term likely may be related to a likelihood over a defined timeframe based on guidance provided by MfE (2017). This assessment aims to derive a range of hazard zones corresponding to differing likelihoods which may be applied to a risk assessment.

## 4.3 Stochastic forecast approach

The methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters (T+T, 2004; 2006; 2012) over a selected timeframe. However, rather than including single values for each component and a factor for uncertainty, parameter bounds are specified for each parameter and combined by stochastic simulation based on the methods described in Shand et al. (2015). The resulting distribution is a probabilistic forecast of potential hazard zone width over a selected timeframe.

The method is based on the premise that uncertainty is inherent in individual components due to an imprecise understanding of the natural processes and due to alongshore variability within individual study cells. Stochastic simulation allows the effect of these uncertainties to be explored simultaneously providing estimates of the combined hazard extent (i.e. the central tendency) and information on potential ranges and upper limit values. This contrasts with deterministic models where the combination of individual conservative parameters with additional factors for uncertainty often result in very conservative products and limited understanding of potential uncertainty range.

The stochastic method is described in Cowell et al. (2006). The methods used to define probability distribution functions (PDFs) for each parameter are described within the parameter descriptions below. Where PDFs are not defined empirically (i.e. based on data or model results), simple triangular distributions have been assumed with bounding (minimum and maximum) and modal parameters. These triangular distributions can be constructed with very little information yet approximate a normal distribution and permit flexibility in defining range and skewed asymmetry.

## 4.4 Coastal erosion hazard methodologies

### 4.4.1 Unconsolidated beaches

Coastal erosion hazard methodologies are different for unconsolidated beaches, cliffs, estuarine and river inlet shorelines. Most of the Waiotahe shoreline can be characterised as an unconsolidated beach. The method for unconsolidated beach shorelines is expressed in Equation 4-1, where the coastal erosion hazard area (CEHA) is established from the cumulative effect of five main parameters (Figure 4-1):

$$CEHA_{Beach} = ST + DS + \ (LT \ \times T) + SLR \qquad (4\text{-}1)$$

Where:

ST = Short-term changes in horizontal shoreline position related to storm erosion due to singular or a cluster of storms events or fluctuations in sediment supply and demand, beach rotation and cyclical changes in wave climate (m)

DS = Dune stability allowance. This is the horizontal distance from the base of the eroded dune to the dune crest at a stable angle of repose (m)

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

T = Timeframe (years)

SLR = Horizontal coastline retreat due to the effects of increased mean sea level (m).

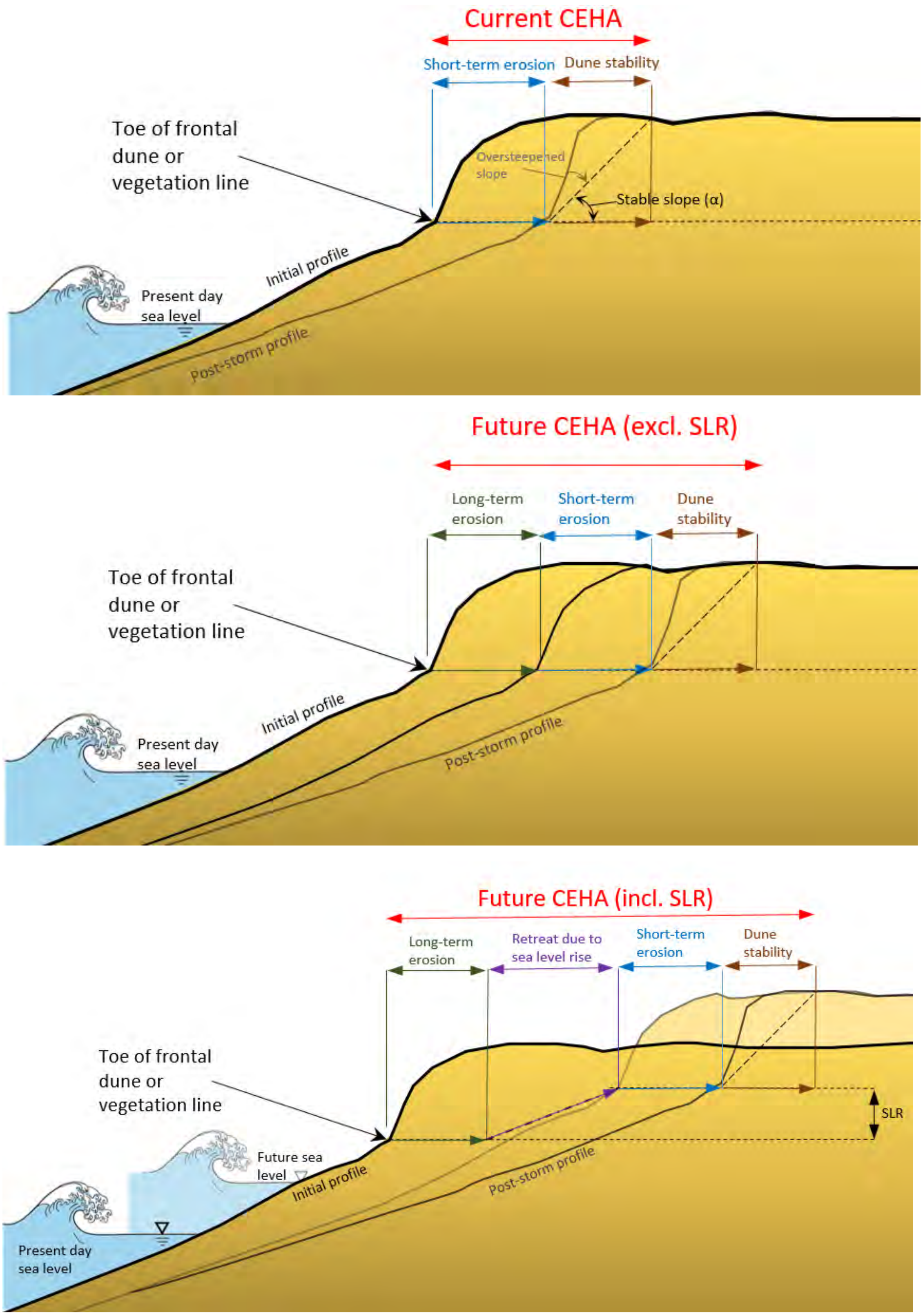


*Figure 4-1 Definition sketch for coastal erosion hazard area on open coast beach shoreline*

The CEHA$_{Beach}$ baseline to which values are referenced is the most recent dune toe derived from site survey data or LiDAR.

### 4.4.2 River/stream mouths

Shoreline movement around river/stream mouths is typically complex and highly variable in both space and time. There can be multiple factors influencing the shoreline position around river and stream mouths, including:

- Alongshore migration of river mouths and stream channels
- Changes in river flows which can either cause
  - enlargement of river mouths during flood events; or
  - contraction of river mouths during periods of sustained low flows
- Upstream channel modifications and changes in sediment loads; and
- Shifts in ebb tidal delta positions due to changes in wave conditions.

The Waiotahe shoreline has 4 river/stream mouths. At the western end of Waiotahe Beach there are 2 small streams which flow from culverts out through the dune system. These stream mouths are in a fixed position due to the restriction through the culverts and therefore the extent over which the stream channel and mouth can migrate is limited.

Similarly, the Waiotahe River mouth at the western extent of the beach is also partly restricted. The presence of the road and associated protection works along the eastern bank acts to limit any eastward migration of the river mouth. As the structure is protecting State Highway 2, it is assumed that the structure will be maintained and upgraded as required in the future. Therefore, any potential erosion hazard associated with movement of the Waiotahe River mouth is not included in this assessment.

In contrast, the Waioeka River mouth at the eastern extent of the beach, is not restricted and has historically been very dynamic with changes in river flows and sediment dynamics. While the size of the Waioeka River mouth has increased and decreased in varying conditions, the position of the river mouth has historically been migrating westward.

For this assessment the shoreline around the two small streams and the Waiotahe River mouth have been assessed based on the erosion hazard in the adjacent open coast cells. However, for the Waioeka River mouth a geomorphological assessment has been completed by Shand (2019), taking into account three specific geomorphological aspects:

1. Longer-term behaviour of the river channel, banks and the (inlet throat) approach channel;
2. The seaward basin shape in which earlier Holocene inlet behaviour may be preserved, and
3. Shorter-term entrance behaviour.

Each of these aspects are discussed in more detailed in Appendix A.

# 5 Component derivation

## 5.1 Coastal cells

The Waiotahe shoreline has been divided into eight coastal cells based on shoreline behaviour which can influence the resultant hazard (Figure 5-1). Factors which may influence the behaviour of a cell include:

- Historical shoreline trends
- Cell morphology and lithology
- Profile geometry
- Backshore elevation.

Table 5-1 shows the chainage for each individual cell as a spatial reference point. Chainage is the distance measurement from a fixed point taken at the western end of the site. The shoreline from chainage 0 to 300 m is protected by revetment which protects SH2. With agreement from the client that this revetment is likely to be maintained in the future, the coastal erosion hazard has not been assessed for this section.

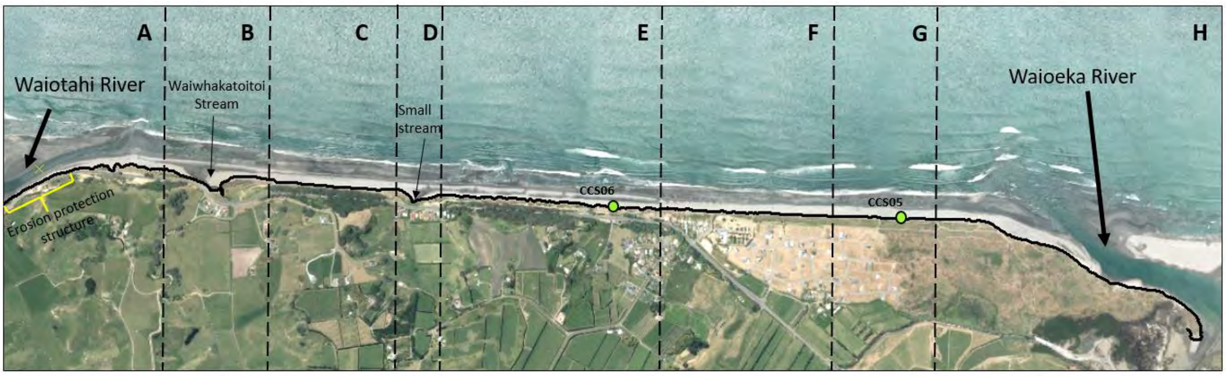


*Figure 5-1 Overview of cell divisions along the Waiotahe shoreline*

**Table 5-1 Cell divisions for the Waiotahe shoreline**

| Cell | Cell type | Chainage (m from western end of revetment) |
|---|---|---|
| A | Unconsolidated beach | 300 to 650 |
| B | Unconsolidated beach | 650 to 1,100 |
| C | Unconsolidated beach | 1,100 to 1,560 |
| D | Unconsolidated beach | 1,720 to 1,970 |
| E | Unconsolidated beach | 1,970 to 2,900 |
| F | Unconsolidated beach | 2,900 to 3,630 |
| G | Unconsolidated beach | 3,630 to 4,110 |
| H | River inlet | 4,110 to 4,300 |

*Figure 5-2 Site photos for the Waiotahe shoreline.*

## 5.2 Planning timeframe

Three different planning timeframes have been applied to provide information on current hazards and information at sufficient time scales for planning and accommodating future development:

- Present Day (2020)
- 50 years (2070)
- 110 years (2130).

## 5.3 Short-term

Short-term (ST) effects apply to non-consolidated beach and estuary coastlines where rebuilding follows periods of erosion. These effects include changes in horizontal shoreline position due to storm erosion caused by singular or clusters of storms events, or seasonal fluctuations in wave climate or sediment supply and demand.

The short-term coastline movements can be assessed from analysis of:

- Statistical analysis of shoreline position obtained from aerial photographs or beach profile analysis
- Numerical assessment of storm erosion potential.

### 5.3.1 Statistical methods

Based on visual inspection of the beach profile data the dune toe level was estimated to be around 2 m RL. The horizontal movement of the dune toe was used to assess the storm cut distance using inter-survey storm cut distances.

The inter-survey storm cut is the landward horizontal retreat distance measured between two consecutive surveys (i.e. distance between excursion distances). Figure 5-3 shows measured excursion distances over time for profile CCS06. We note that due to the relatively long period between surveys these distances may not represent the largest excursion that may have occurred between these time periods. However, the data set provides the best source of information to analyse.

The beach profile analysis results for both profiles CCS05 and CCS06 are shown in Table 5-2. Figure 5-3 shows that while the beach has experienced net accretion, the shoreline fluctuates over time. The largest inter-survey storm cut measured at profile CCS05 was 27 m in early 2015. The largest inter-survey storm cut measured at profile CCS06 occurred during 2013 and also measured 27 m.

**Table 5-2 Mean and maximum inter-survey storm cut**

| Beach profile | Mean inter-survey storm cut (m) | Largest inter-survey storm cut (m) |
|---|---|---|
| CCS05 | -12 | -27 |
| CCS06 | -13 | -27 |

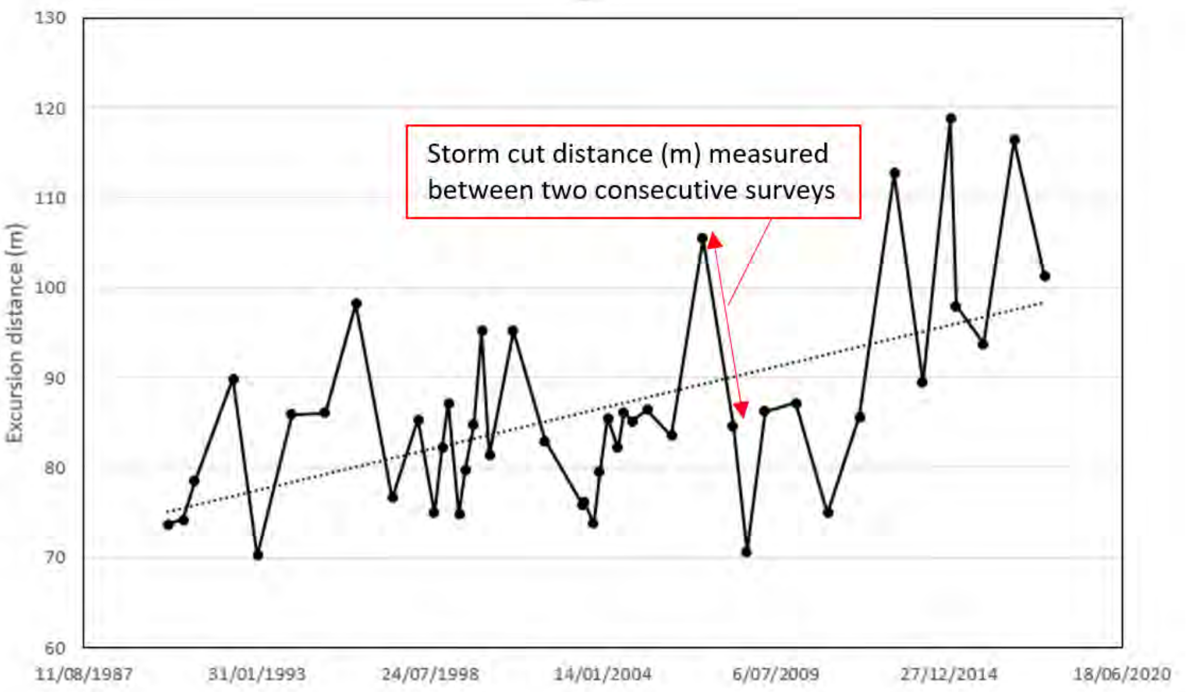


*Figure 5-3 Example of dune toe linear regression plot for CCS06 Waiotahe*

The analysed storm cut distances are based on a 28 year dataset. In order to extrapolate extreme values derived from a limited number of observations (i.e. 28 years of 6 to 12-monthly surveys), extreme value analyses have been undertaken. These have been carried out adopting the following distances:

1 Alongshore-mean
2 Alongshore-maximum.

The extreme value analysis was completed based on the Weibull distribution (Figure 5-4).

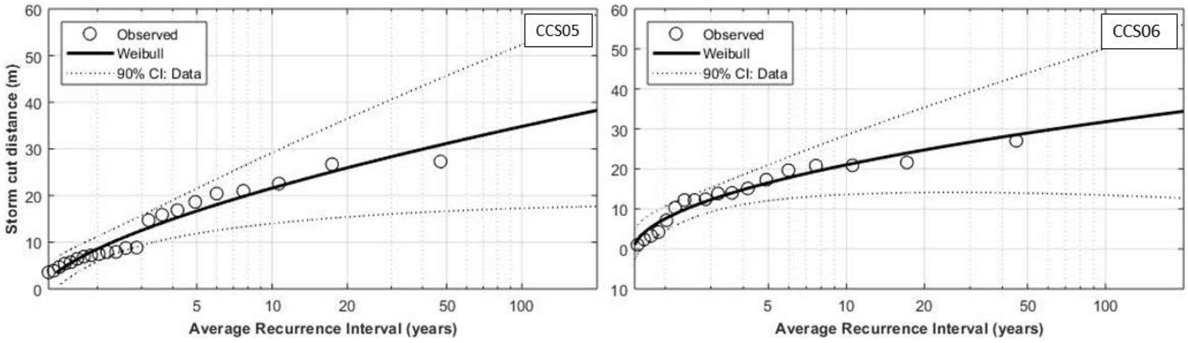


*Figure 5-4 Extreme storm cut distances for profiles CC05 and CC06 based on the Weibull distribution*

**Table 5-3 Short term storm cut values adopted based on the extreme value analysis of the beach profiles**

| Beach profile | Min (m) | Mode (m) | Max (m) |
|---|---|---|---|
| | 2 year ARI storm cut | 20 year ARI storm cut | 100 year ARI storm cut |
| CCS05 | 10 | 25 | 35 |
| CCS06 | 10 | 25 | 30 |

## 5.4 Dune stability

The dune stability (DS) 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:

$$DS = \frac{H_{dune}}{2(\tan \alpha_{sand})} \qquad (5\text{-}1)$$

Where $H_{dune}$ is the dune height from the eroded base to the crest and $\alpha_{sand}$ is the stable angle of repose for beach sand (ranging from 30 to 34 deg). In reality, dune scarps will stand at steeper slopes due to the presence 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.

Based on the 2015 LiDAR the range of dune crest heights for each cell are summarized in Table 5-4.

**Table 5-4 Adopted dune height ranges for each of the cells along Waiotahe Beach**

| Cell | Dune heights (m) | | |
|---|---|---|---|
| | Minimum | Mode | Maximum |
| A | 2.5 | 3.0 | 3.5 |
| B | 3.0 | 4.0 | 5.0 |
| C | 1.2 | 1.3 | 1.5 |
| D | 3.0 | 4.0 | 5.0 |
| E | 1.5 | 2.5 | 4.0 |
| F | 2.0 | 2.7 | 3.0 |
| G | 2.4 | 2.7 | 2.8 |
| H | 3.0 | 4.0 | 5.0 |

## 5.5 Long-term trends

### 5.5.1 Unconsolidated beach

The long-term rate of horizontal coastline movement (LT) 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 along Waiotahe Beach. These have been derived from geo-referenced historic aerial photographs.

Software developed by T+T has then be used to measure the distance to each shoreline from an assumed baseline at 5 m increments. A weighted linear regression analysis is then undertaken on each set of shoreline measurements to estimate long-term retreat rates. In a weighted linear regression, more reliable data (lower error values) are given greater emphasis or weight towards determining a best-fit line. By calculating trends along the entire shoreline, rather than at a low number of discrete points, alongshore variation in trends can be determined and either used to inform parameter bounds or separated into separate coastal behaviour cells.

Overall, the historic shorelines show a trend of long term accretion along the Waiotahe Beach shoreline (Table 5-5 & Figure 5-7). The accretion rates increase from west to east and are up to 0.71 m/yr within Cell G, approximately 500 m west of the Waioeka River mouth (Table 5-5). The high accretion rates within cell G are likely to be linked with the dynamics and position of the Waioeka River mouth and associated delta.

**Table 5-5 Adopted long term accretion rates for unconsolidated beach cells based on regression analysis**

| Cell | Long term accretion rates adopted for each cell based on the regression analysis (m/year) | | |
|---|---|---|---|
| | Min (lower 95% CI) | Mode (average regression) | Max (upper 95% CI) |
| A | 0.02 | 0.32 | 0.61 |
| B | 0.02 | 0.32 | 0.61 |
| C | 0.02 | 0.32 | 0.61 |
| D | 0.02 | 0.32 | 0.61 |
| E | 0.27 | 0.46 | 0.64 |
| F | 0.29 | 0.41 | 0.53 |
| G | 0.45 | 0.58 | 0.71 |

Accretion rates derived from the historic shorelines were also compared with the rates measured from the beach profile datasets. The beach profile datasets extend back to 1976 and 1990 at locations CCS05 (Cell G) and CCS06 (Cell E), respectively. Based on horizontal movement of the dune toe (2 m contour) there has been an average long-term accretion trend of 0.88 m/yr at CCS05 and 0.73 m/yr at CCS06 (Figure 5-5). These accretion rates are slightly higher than the rates measured from historic shorelines. The regression plots for the historic shoreline data at each beach profile location (Figure 5-6) show that there has been a relatively consistent accretion rate since 1966, with a slight increase in more recent years and hence why the accretion rate from the beach profile datasets is slightly higher. The beach profiles show that the shoreline can undergo periods (several years) of erosion or accretion but overall the profiles have gradually been accreting.

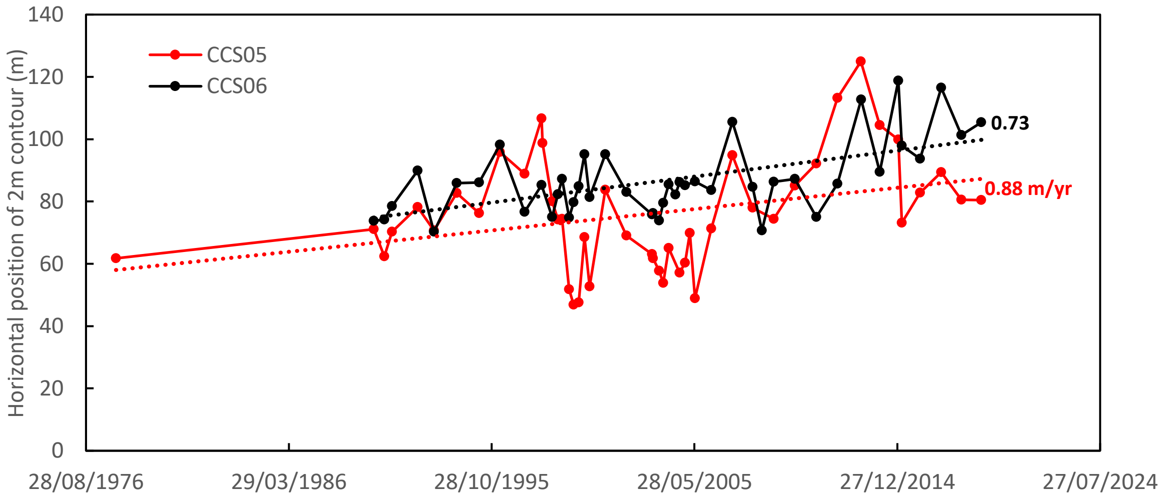


*Figure 5-5 Dune toe (2m contour) movement for beach profiles CCS05 and CCS06*

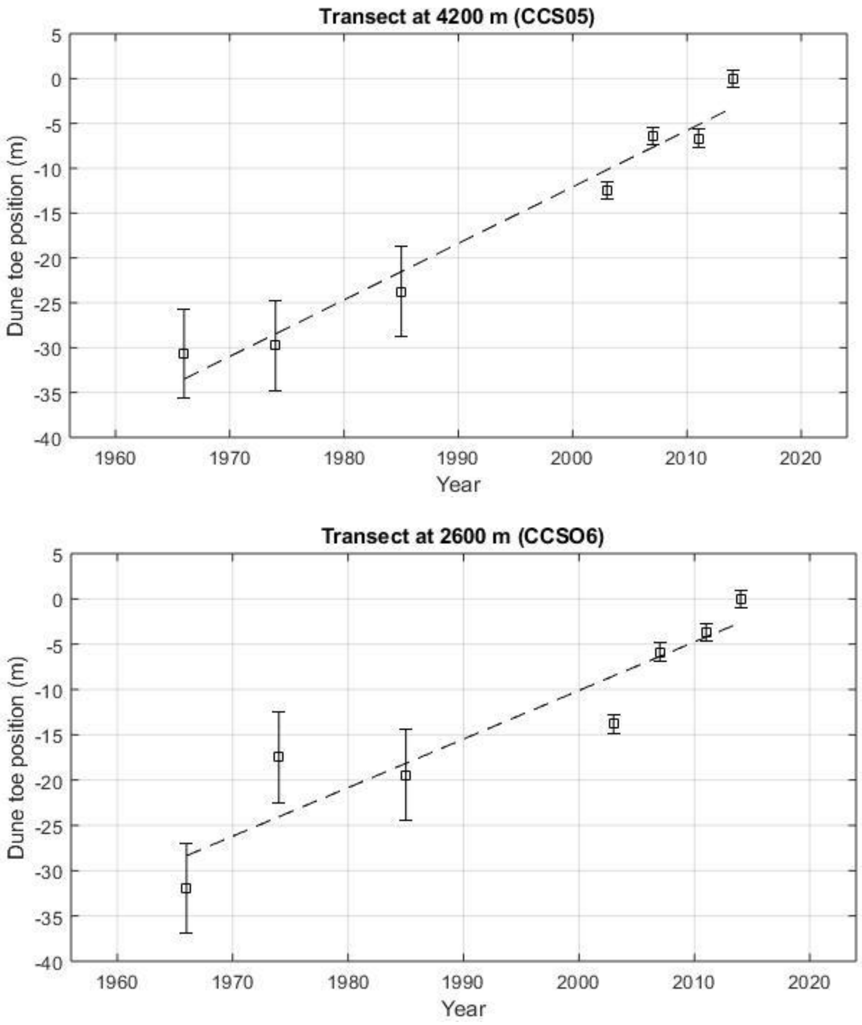
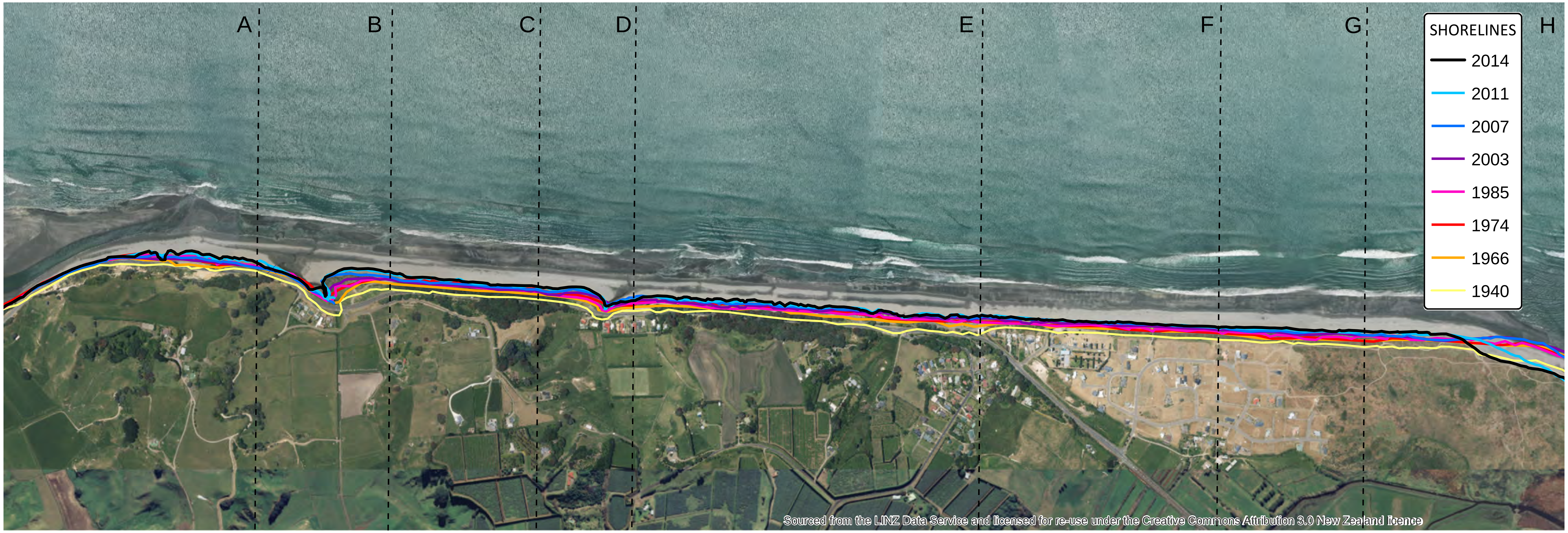
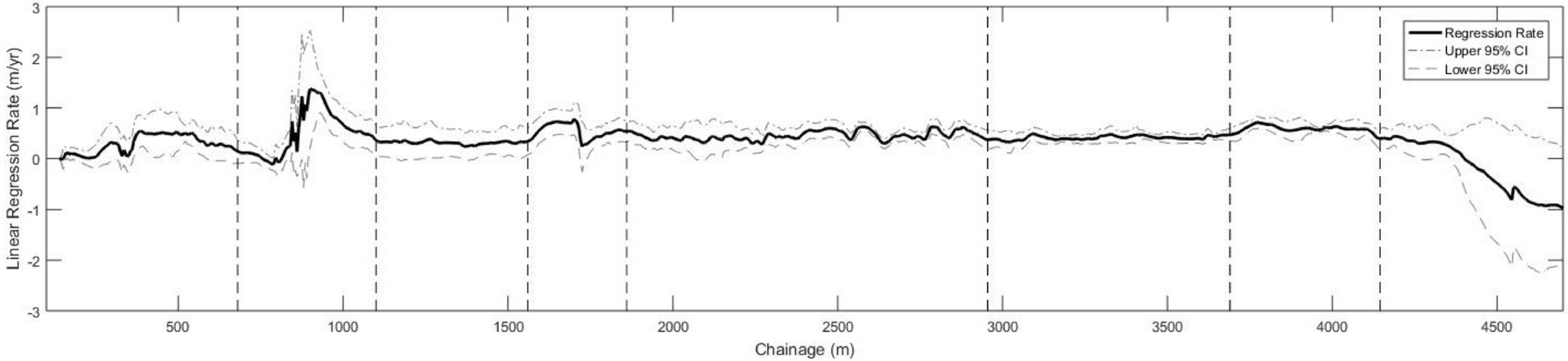


*Figure 5-6 Regression plots for historic shoreline data at locations CCS05 and CCS06*

Based on previous studies and geomorphic evidence the key component contributing to the long-term accretion along the Waiotahe shoreline is the sediment supply from the rivers and dominant westward longshore drift, driven by the dominant northeast wave climate. Historically the relevant river catchments have been forested with native vegetation and had relatively minor modification. If catchment landuse remains the same in the future, the sediment supply to the coast is also likely to be similar. Therefore, the historic long-term rates are likely to be representative of future rates.

A sensitivity analysis has, however, been undertaken assuming the sediment supply has been reduced. The long term accretion rates have been assumed to reduce to zero for each coastal cell. The sensitivity analysis gives an indication of the shoreline response in a scenario where future sediment supply is reduced.





Notes: Aerial photograph sourced from LINZ Data Service 2014 -2015

Long term regression analysis is based on the shorelines from 1966 to 2014

A3 SCALE 1:12,500

0 0.1 0.2 0.3 0.4 0.5 (km)

**Tonkin+Taylor**

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

| | | |
|---|---|---|
| DRAWN | RHAU | Dec.18 |
| CHECKED | | |
| APPROVED | | |
| ARCFILE<br>Waiotahe_LT.mxd | | |
| SCALE (AT A3 SIZE)<br>1:12,500 | | |
| PROJECT No.<br>1008669 | | |

# Waiotahe Beach

## Long term shoreline analysis

Regression analysis with 95% Confidence Intervals (CI)

FIGURE No. Figure 5-7

Rev. 0

Path: P:\1008669\WorkingMaterial\Shoreline analysis\Confidence intervals\Waiotahe_LT.mxd Date: 20/12/2018 Time: 11:10:13 AM

## 5.6 Effects of sea level rise

We have adopted a range of sea level rise (SLR) values over the two required future timeframes of 2070 and 2130 (i.e. 50 and 110 years respectively). The range of SLR values for each timeframe are based on three RCP scenarios consistent with the guidance provided within MfE (2017). Table 5-6 presents the SLR values used in this present assessment. The 2130 RCP8.5 value of 1.25m SLR is in accordance with the RPS (Policy NH11B).

An average historic rate of SLR of 1.9 mm/year for Tauranga Harbour was subtracted from the adopted SLR values for use in assessment. This approach is required because the existing long term trends and processes already incorporate the response to the historic SLR. Therefore the historic rate must be subtracted to avoid double counting.

**Table 5-6 Sea level rise values (m) utilised in assessment**

| Year | Timeframe (years) | SLR (m) | RCP Scenario |
|---|---|---|---|
| 2020 | 0 | 0 | N/A |
| 2070 | 50 | 0.4 | RCP4.5 (approx.) |
| 2070 | 50 | 0.6 | RCP8.5 |
| 2130 | 110 | 0.8 | RCP4.5 |
| 2130 | 110 | 1.25 | RCP8.5 |
| 2130 | 110 | 1.6 | RCP8.5H+ |

### 5.6.1 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 5-8). 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 may be defined by the following equation:

$$SL = \frac{L_*}{B + d_*} S \tag{5-2}$$

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

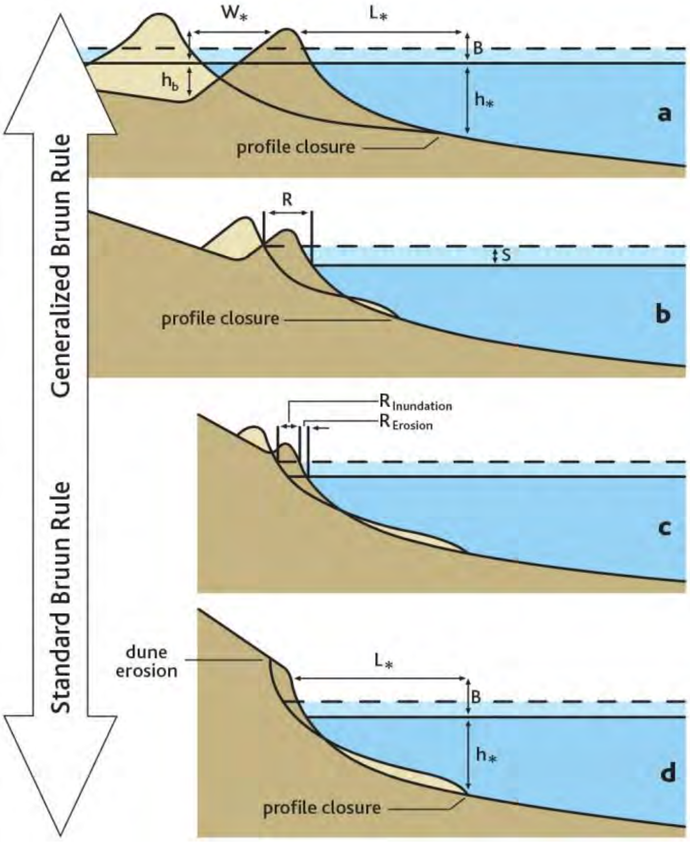


*Figure 5-8 Schematic diagrams of the Bruun model modes of shoreline response (after Cowell and Kench, 2001).*

The rule is governed by simple, two-dimensional conservation of mass principles and assumes no offshore or onshore losses or gains and an instantaneous profile response following sea level change. 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). Losses or gains to the system and changes to the equilibrium profile are likely accounted for within the long-term change parameter (LT) (Section 5.5) and therefore are not likely to introduce additional uncertainty. The definition of a closure depth (maximum seaward extent of sediment exchange) and the lag in response of natural systems have been cited as significant limitations in the method (Hands, 1983).

The inner parts of the profile exposed to higher wave energy are likely to respond more rapidly to changes in sea level. For example, Komar (1999) proposes that the beach face slope is used to predict coastal erosion due to individual storms. Deeper definitions of closure including extreme wave height-based definitions (Hallermeier, 1983), sediment characteristics and profile adjustment records (Nicholls et al., 1998) are only affected during infrequent large-wave events and therefore may exhibit response-lag.

Shand et al. (2013) argue that as sea level rise is expected to be ongoing, then the outer limit of profile adjustment is likely to be ‘left behind’ before it can reach equilibrium. 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. Shand et al. (2013) tested a range of closure depth definitions against a non-equilibrium model calibrated using 30 years of beach data (Ranasinghe et al., 2011). Results show the various definitions of closure to predict Recession/SLR values straddling the entire probabilistic (2 – 99%) range predicted by the Ranasinghe’s probabalistic model.

To define parameter distributions, the Bruun rule estimates using the outer Hallermeier closure depth definition (di) have been adopted as upper bound values, estimates using the inner Hallermeier closure definition (dl) 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 the average mean low water spring position and average beach crest height. The Hallermeier closure definitions are defined as follows (Nicholls et al., 1998):

$$d_l = 2.28H_{s,t} - 68.5(H_{s,t}^2 / gT_s^2) \cong 2 \times H_{s,t} \quad (5\text{-}3)$$

$$d_i = 1.5 \times d_l \quad (5\text{-}4)$$

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 the $H_S$ and $T_P$ were based on the MetOcean View wave hindcast. The resulting $H_S$ and $T_P$ parameters are 3 m and 10.5 s respectively. Based on these wave climate parameters the inner closure depth is calculated as 6.3 m below mean low water spring using the Hallermeier method defined in Equation 6-3 (equivalent to 7 m below mean sea level. The outer closure depth is calculated as 9.8 m (equivalent to 10.6 m below mean sea level). The average dune crest is approximately 6 m above mean sea level. This results in a total active profile height of between 13 to 16.6 m (6 m dune height and 7 m to 10.6 m closure depth).

## 5.7 River/stream mouths

Historic aerial photographs show limited shoreline movement around the Waiotahe River mouth (Cell A). This is likely to be due to the road and protection works on the eastern bank restricting any further migration eastward. Historic aerial photographs also show the long term movement of the stream mouths within cells B and D are restricted by culverts.

In contrast to the other river/stream cells, cell H (Waioeka River mouth) has shown gradual westward movement over the last 152 years (1867 to 2019). Shand (2019) found that the inlet throat systematically migrated westward between 1867 and 2015 at an average rate of approximately 8 m/yr, with the rate substantially increasing during recent years. Shand (2019) suggests that the migrational process is related to changes in the upstream channel configuration, including changes from natural river processes and possibly river control structures, which will potentially continue to effect the inlet morphology.

Based on the findings from Shand (2019) the erosion hazard within Cell H has been assessed based on the combined effect of long-term trends and short-term fluctuations (see Appendix A). The rates adopted for long-term westward migration and short-term fluctuation of this cell are outlined in Table 5-7.

The long-term trends are based on the inlet approach channel alignments measured by Shand (2019). The maximum rate of westward migration (8 m/yr) is based on the end point regression from 1867 to 2015. Shand (2019) indicates that future migration continuing at this rate is possible but very unlikely. The minimum migration value (0 m/yr) is based on the spit on the eastern side of the river mouth potentially breaching within the next 10 years. As a result the river mouth would shift back eastward and the process of westward migration would repeat until the eastern spit breaches again. The modal value lies between these extremes but cannot be predicted with more accuracy.

The adopted short-term values have been derived from regression analysis of shoreline positions along a lateral sampling transect at the river entrance (Figure 5-9). The short-term values have been assessed based on the standard error (SE) of the residuals where the minimum, modal and maximum values are equal to 1 x SE, 2 x SE and 3 x SE, respectively.

**Table 5-7 Long-term and short-term components accounted for in the erosion hazard around the Waioeka River mouth**

| | Long-term westward migration (m/yr) | Short-term fluctuations (m) |
|---|---|---|
| **Max** | 8 | 60 |
| **Mode** | 4 | 40 |
| **Min** | 0 | 20 |

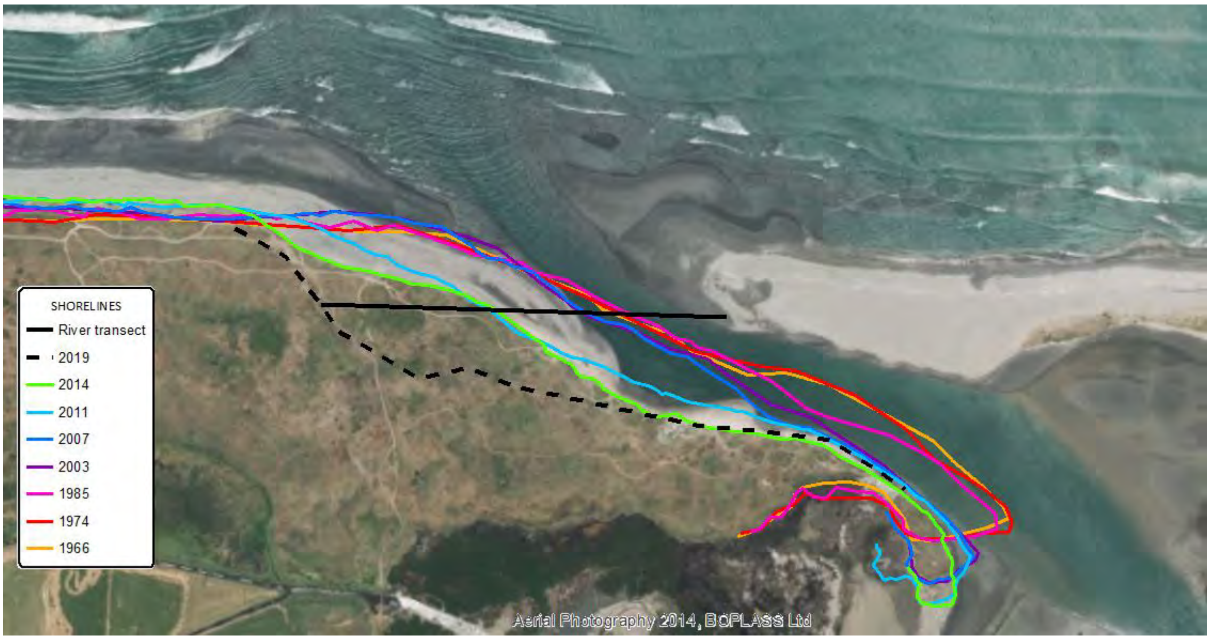


*Figure 5-9 Historic shorelines used to assess the short-term fluctuation around the Waioeka River mouth*

Due to high uncertainty in how the river mouth dynamics will respond with future sea level rise, any additional potential sea level rise effects have not been accounted for within Cell H but will likely be captured by the landward movement of the adjacent open coast cell (Cell G). Furthermore, SLR-induced erosion of the westward migrating spit may induce breaching, halting the westward migration of the river mouth.

## 5.8 Combination of parameter components to derive CEHA

For each coastal cell, the relevant parameters influencing the CEHA and parameter bounds have been defined according to the methods described above as summarised in Table 5-8. Probability distributions constructed for each parameter are randomly sampled and the extracted values used to define a potential CEHA distance. This process is repeated 10,000 times using a Monte Carlo technique and probability distribution of the resultant CEHA width is forecasted. Figure 5-10 presents an example component and CEHA histogram cumulative distribution functions for Waiotahe Cell C at 2130. The curved lines represent probability of exceedance by 2130, measured on the right-hand axis.

### Table 5-8 Summary of theoretical erosion hazard parameter bounds

| **Parameter** | **Lower bound** | **Mode** | **Upper bound** |
|---|---|---|---|
| ST (m) | 2 year ARI inter-survey storm cut | 20 year ARI inter-survey storm cut | 100 year ARI inter-survey storm cut |
| SS (m) | Hmax & αmin | Hmean & αmean | Hmin & αmax |
| LT (m/yr) | 0 (assume no accretion) | Mean regression trend | +95% CI of largest trend in cell |
| Closure slope | Slope across active beach face to swash excursion | Slope from dune crest to inner Hallermeier depth | Slope from dune crest to outer Hallermeier closure depth |

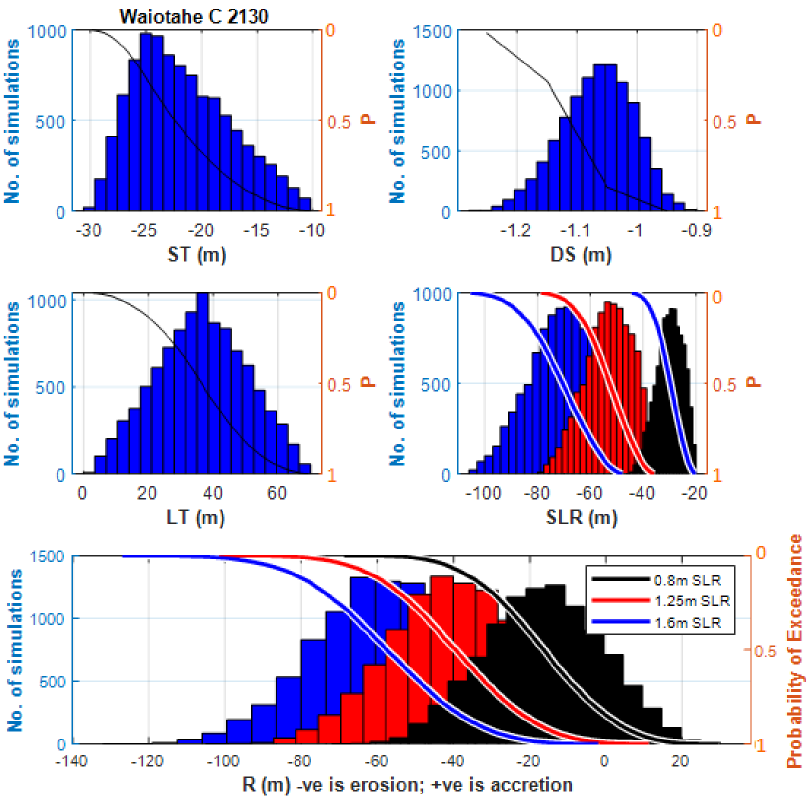


*Figure 5-10 presents an example component and CEHA histogram cumulative distribution functions for Waiotahe Cell C in 2130*

# 6 Erosion hazard assessment

## 6.1 Component values

Components have been assessed for each coastal cell based on the data and methodologies described in the preceding sections. Adopted components are presented for each cell within Table 6-1.

**Table 6-1 Adopted component values for the Waiotahe coastal erosion hazard assessment**

| **Cell** | | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|
| **Cell centre (NZTM)** | E | 1969862 | 1970383 | 1970830 | 1971327 | 1971945 | 1972780 | 1973383 | 1974348 |
| | N | 5786818 | 5786744 | 5786738 | 5786679 | 5786659 | 5786609 | 5786588 | 5786326 |
| **Chainage, m (from W)** | | 300 to 650 | 650 to 1,100 | 1,100 to 1,560 | 1,560 to 1,990 | 1,990 to 2,900 | 2,900 to 3,630 | 3,630 to 4,110 | 4,110 to 4,300 |
| **Morphology** | | Dune | Dune | Dune | Dune | Dune | Dune | Dune | Inlet |
| **Short-term (m)** | Min | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 20 |
| | Mode | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 40 |
| | Max | 30 | 30 | 30 | 30 | 30 | 35 | 35 | 60 |
| **Dune (m above toe)** | Min | 2.5 | 2.5 | 1.2 | 1.5 | 1.5 | 2.0 | 2.4 | 3.0 |
| | Mode | 3.0 | 3.0 | 1.3 | 2.5 | 2.5 | 2.7 | 2.7 | 4.0 |
| | Max | 3.5 | 3.5 | 1.5 | 4.0 | 4.0 | 3.0 | 2.8 | 5.0 |
| **Stable angle (deg)** | Min | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | Mode | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| | Max | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| **Long-term (m) -ve erosion +ve accretion** | Min | 0.02 | 0.02 | 0.02 | 0.02 | 0.27 | 0.29 | 0.45 | 8.0 (west) |
| | Mode | 0.3 | 0.3 | 0.3 | 0.3 | 0.5 | 0.4 | 0.6 | 4.0 (west) |
| | Max | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.7 | 0.0 |
| **Closure slope (beaches)** | Min | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | N/A |
| | Mode | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | |
| | Max | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | |

## 6.2 Results

Erosion hazard distances based on the cumulative distribution functions for all cells along the Waiotahe shoreline are outlined in Table 6-2. $P_{50\%}$ means there is a 50% chance of an erosion distance being exceeded within that timeframe. $P_{66\%}$ can be considered a likely scenario and $P_{5\%}$ can be considered a very unlikely scenario.

Both the current and future CEHA are relatively similar along the section of open coast. The current $P_{66\%}$ and $P_{5\%}$ are on average -20 m and -30 m, respectively. The future CEHA at 2130 based on the 1.6 m SLR scenario, ranges from -42 to -57 m for the $P_{66\%}$ and is up to -99 m for the $P_{5\%}$. The slight variations between cells is driven mostly be the differences in accretion rates and dune heights. Due to the large long term accretion rates, there are several scenarios where the future CEHA is further seaward than the current CEHA. Although the future CEHA also take into account SLR, for the lower SLR scenarios, the impact from long term accretion is likely to counteract any potential recession due to SLR. For these scenarios the CEHA has been mapped equivalent to the current CEHA.

While it is assumed that the historic long term accretion rates will continue in the future, the $P_{5\%}$ from the sensitivity analysis, assuming zero accretion, is presented in Table 6-2. Based on the sensitivity analysis the future $P_{5\%}$ CEHA could shift between 11 to 65 m further landward.

The largest potential hazard is in the vicinity of the Waioeka River mouth (Cell H). The current hazard ranges from -58 m for the $P_{66\%}$ to -82 m for the $P_{5\%}$. These erosion distances are offset westward (shore parallel) from the current western river bank position. This current hazard is based on the potential short-term fluctuations described in Shand (2019; Appendix A). The erosion hazard for the 2130 timeframe is up to 820 m westward for the $P_{5\%}$. This distance is based on the high rates of continued westward migration and short-term dynamic fluctuations. It is important to note that the future erosion hazard associated with river migration not only dominates the hazard within Cell H but potentially influences Cell G, and for the 100 year $P_{5\%}$ some of Cell F (Appendix B).

The initial ASCH setback defined by Gibb (1994) was intended as a conservative approach and is consistent with the maximum erosion (very unlikely) erosion extends calculated in the current study. The 70 m setback defined by Dahm & Kench (2007) was based on 0.48 m SLR by 2100 but did not account for any long term accretion.

The erosion hazard distances calculated by Eco Nomos Ltd (2016) were based on the RCP8.5 SLR scenario and are comparable with $P_{66\%}$ values calculated in the present study for the 1.25 m SLR. The current study accounts for potential erosion distances based on a range of lower SLR scenarios and the upper limit, RCP8.5H+ scenario. Alongshore variations have also been accounted for within the present study and therefore there are slight variations between coastal cells.

**Table 6-2 Coastal erosion hazard distances for the Waiotahe shoreline**

| Site | Cell | Timeframe | SLR (m) | Probability of Exceedance | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | P66% | P50% | P5% | Max | P5% LT = 0 |
| Waiotahe | A | Current (2020) | 0.03 | -10 | -20 | -23 | -28 | -31 | -28 |
| | | 50yr (2070) | 0.4 | 4 | -18 | -22 | -35 | -49 | -47 |
| | | | 0.6 | -5 | -28 | -32 | -47 | -63 | -59 |
| | | 110yr (2130) | 0.8 | 31 | -11 | -17 | -43 | -63 | -65 |
| | | | 1.25 | 14 | -33 | -40 | -70 | -95 | -94 |
| | | | 1.6 | 1 | -50 | -58 | -91 | -121 | -117 |

| Site | Cell | Timeframe | SLR (m) | Probability of Exceedance | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | P66% | P50% | P5% | Max | P5% LT = 0 |
| | B | Current (2020) | 0.03 | -10 | -20 | -22 | -28 | -31 | -28 |
| | | 50yr (2070) | 0.4 | 5 | -18 | -22 | -36 | -48 | -47 |
| | | | 0.6 | -2 | -28 | -32 | -47 | -61 | -59 |
| | | 110yr (2130) | 0.8 | 30 | -11 | -17 | -43 | -66 | -65 |
| | | | 1.25 | 13 | -33 | -41 | -69 | -98 | -94 |
| | | | 1.6 | 0 | -50 | -59 | -90 | -124 | -117 |
| | C | Current (2020) | 0.03 | -8 | -19 | -21 | -27 | -30 | -27 |
| | | 50yr (2070) | 0.4 | 6 | -17 | -21 | -34 | -47 | -46 |
| | | | 0.6 | -3 | -27 | -31 | -45 | -61 | -58 |
| | | 110yr (2130) | 0.8 | 30 | -10 | -16 | -42 | -69 | -64 |
| | | | 1.25 | 11 | -32 | -39 | -68 | -102 | -93 |
| | | | 1.6 | -2 | -49 | -57 | -89 | -127 | -116 |
| | D | Current (2020) | 0.03 | -11 | -22 | -24 | -29 | -32 | -29 |
| | | 50yr (2070) | 0.4 | 5 | -18 | -22 | -36 | -49 | -47 |
| | | | 0.6 | -3 | -28 | -32 | -47 | -63 | -59 |
| | | 110yr (2130) | 0.8 | 31 | -11 | -17 | -43 | -65 | -65 |
| | | | 1.25 | 13 | -33 | -41 | -69 | -97 | -94 |
| | | | 1.6 | -1 | -50 | -58 | -90 | -122 | -117 |
| | E | Current (2020) | 0.03 | -9 | -19 | -22 | -27 | -30 | -27 |
| | | 50yr (2070) | 0.4 | 9 | -11 | -14 | -24 | -35 | -47 |
| | | | 0.6 | 0 | -21 | -24 | -36 | -50 | -59 |
| | | 110yr (2130) | 0.8 | 36 | 4 | -1 | -19 | -39 | -65 |
| | | | 1.25 | 20 | -19 | -24 | -46 | -71 | -93 |
| | | | 1.6 | 8 | -35 | -42 | -68 | -96 | -116 |
| | F | Current (2020) | 0.03 | -10 | -21 | -23 | -31 | -35 | -31 |
| | | 50yr (2070) | 0.4 | 3 | -16 | -18 | -28 | -39 | -50 |
| | | | 0.6 | -4 | -25 | -28 | -40 | -54 | -62 |
| | | 110yr (2130) | 0.8 | 24 | -4 | -8 | -23 | -38 | -67 |
| | | | 1.25 | 8 | -26 | -31 | -51 | -70 | -96 |
| | | | 1.6 | -5 | -43 | -49 | -73 | -96 | -119 |
| | G | Current (2020) | 0.03 | -9 | -20 | -22 | -30 | -34 | -30 |
| | | 50yr (2070) | 0.4 | 11 | -6 | -9 | -19 | -29 | -50 |
| | | | 0.6 | 3 | -16 | -19 | -31 | -43 | -62 |

| Site | Cell | Timeframe | SLR (m) | Probability of Exceedance | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | P66% | P50% | P5% | Max | P5%<br>LT = 0 |
| | | 110yr (2130) | 0.8 | 41 | 15 | 11 | -4 | -21 | -67 |
| | | | 1.25 | 24 | -6 | -11 | -32 | -53 | -96 |
| | | | 1.6 | 12 | -23 | -29 | -54 | -78 | -119 |
| | H (inlet) | Current (2020) | N/A | -28 | -58 | -63 | -82 | -100 | -82 |
| | | 50yr (2070) | N/A | -33 | -226 | -265 | -417 | -492 | -417 |
| | | 100yr (2130) | N/A | -58 | -418 | -499 | -820 | -962 | -820 |

For Cells A-G, -ve values are landward of the baseline and +ve values are seaward

For Cell H, -ve values are west of the of the baseline and +ve values are east

# 7 Summary

Waiotahe Beach is a 4 km stretch of north-facing, unconsolidated shoreline located in the Bay of Plenty, approximately 2 km west of Ōpōtiki Township. The beach is bound by the Waiotahe River mouth at the western end and the Waioeka River mouth at the eastern end.

Tonkin + Taylor Ltd were commissioned by Bay of Plenty Regional Council to undertake a detailed coastal erosion hazard assessment for the Waiotahe shoreline.

The coastal erosion hazard areas were defined using a probabilistic approach which combines standard and well-tested methods. The approach is based on a stochastic method of combining erosion parameter distributions to allow for inherent variance and uncertainty. Results provide a range of potential erosion hazard distances for current and future timeframes (e.g. 2070 and 2130) including different sea level rise scenarios.

Along the open coast the current CEHA averages -20 m and -30 m ($P_{66\%}$ and $P_{5\%}$). The future 100 year CEHA based on the 1.6 m SLR scenario, ranges from -23 to -50 m for the $P_{66\%}$ and is up to -91 m for the $P_{5\%}$. Overall, the updated erosion hazard distances are comparable with the setbacks defined in previous studies, but provide a probabilistic understanding of the impacts of different sea rise scenarios. Key conclusions are as follows:

- Most of the Waiotahe shoreline has historically shown long-term accretion trends. This is most likely a result of sediment supply from adjacent river mouths and the shoreline being the convergent point for longshore sediment transport.
- The current erosion hazard is dominated by short-term erosion processes and is relatively consistent along the open coast shoreline.
- The future erosion hazard along the open coast is determined by the effects of sea level rise balanced by long-term accretion with the larger future sea level rise values causing larger erosion hazard.
- An additional source of potential hazard at end eastern end of the site is from westward migration of the Waioeka River mouth.

Based on the geomorphological assessment there is potential for the river mouth to continue to migrate up to 1 km westward over the next 100 years with an average likelihood of around 500 m. Migration to the full extent predicted is unlikely as there is potential for the eastern spit to breach and for the river mouth to shift back eastward. However, there is uncertainty in how the river mouth will behave in the future, particularly with sea level rise and therefore we recommend annual monitoring of its position.

We also recommend that this hazard assessment is updated at intervals of no more than 10 years or following significant changes in data availability, or best practice guidance or methods.

This study has assessed coastal erosion hazard areas at a local scale and may be superseded by detailed site-specific assessment undertaken by qualified and experienced practitioner using improved or higher resolution data than presented in this report.

# 8 Applicability

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

Tonkin & Taylor Ltd

Report prepared by: Report reviewed by:

........................................................ ........................................................

Rebekah Haughey
Coastal Scientist

Jonathan Clarke
Senior Coastal Engineer

Dr Roger Shand
Coastal Geomorphologist

Authorised for Tonkin & Taylor Ltd by:

…………………………………………………..

Richard Reinen-Hamill

Project Director

RHAU
p:\1008669\issueddocuments\r20200211.waiotaheerosionhazardassessment.final.docx

# 9 References

Beavan R.J. and Litchfield, N.J. (2012) Vertical land movement around the New Zealand coastline: implications for sea-level rise, GNS Science Report 2012/29. 41p.

BOPRC (2011). NERM beach profile monitoring 2011.Bay of Plenty Regional Council.

Bruun P (1962) Sea-level rise as a cause of shore erosion. J. Waterways Harbors Div 88:117–130.

Bruun, P., (1988) The Bruun Rule of erosion by sea level rise: a discussion on large-scale two- and three-dimensional usages. JCR, 4, 627–648.

Carley J T (1992), "Analysis of SBEACH Numerical Beach Erosion Model", MEngSc Thesis*,* University of New South Wales.

Carley, J.T., Couriel, E.D. and Cox, D.R., 1998. Numerical modelling sand nourishment profiles/quantities and beach erosion due to storms and sea level rise. WRL Tech. Rep. 98/04. University of New South Wales. Australia.

Cooper, J. A. G., & Pilkey, O. H. (2004). Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global and planetary change*, *43*(3-4), 157-171.

Cowell, P.J., Thom, B.G., Jones, R.A., Everts, C.H. and Simanovic, D. (2006) Management of Uncertainty in Predicting Climate-Change Impacts on Beaches. JCR 22(1)232-245.

Gorman, R. (2016). Ōpōtiki Wave Climate and Forecasting. Report prepared for Ōpōtiki District Council. NIWA, Hamilton.

Hallermeier, R.J. (1983) Sand transport limits in coastal structure designs. Proc. of Conf. on Design,Construction, Maintenance and Performance of Coastal Structures. ASCE, Arlington, pp 703–716.

Hands, E.B., 1983. The Great Lakes as a test model for profile response to SL changes. In: Komar, P.D. (ed.), Handbook of Coastal Processes and Erosion.

Hannah, J. and Bell, R.G. (2012) Regional sea level trends in New Zealand. Journal of Geophysical Research 117: C01004.

IPCC (2013). Working Group I contribution to the IPCC 5th Assessment Report "Climate Change 2013: The Physical Science Basis". DRAFT report by Intergovernmental Panel on Climate Change. June, 2013.

Komar, P.D., McDougal, W.G., Marra, J.J. and Ruggiero, P. (1999). The Rational Analysis of Setback Distances: Application to the Oregon Coast. Shore and Beach Vol. 67 (1) 41-49.

Kopp RE, Horton RM, Little CM, Mitrovica JX, Oppenheimer M, Rasmussen DJ, Strauss BH, Tebaldi C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth’s Future 2(8): 383–406.

Larson, M and Kraus, N C (1989), “SBEACH: Numerical Model for Simulating Storm-Induced Beach Change, Report 1: Theory and Model Foundation”. *Technical Report CERC-89-9*, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg USA.

Ministry for the Environment (2017). Coastal hazards and climate change: guidance for local government.

Nicholls, R.J., Laron, M., Capobianco, M. and Birkemeier, W.A. (1998) Depth of Closure: Improving Understanding and Prediction. ICCE 1998.

Ranasinghe, R., Callaghan, C. and Stive, M.J.F (2011) Estimating coastal recession due to sea level rise: beyond the Bruun rule. Climate change June 2010.

Shand, T D, Goodwin, I D, Mole, M A, Carley, J T, Harley, M D and Peirson, W L (2010), NSW Coastal Inundation Hazard Study: Coastal Storms and Extreme Waves, WRL TR2010/16.

Shand, T.D., C Wasko, S Westra, G Smith, J T Carley and W L Peirson (2012) Joint Probability Assessment of NSW Extreme Waves and Water Levels. WRL Technical Report 2011/29. April 2012

Shand, R.D., (2012), Kapiti Coast erosion hazard assessment, 2012 Update report prepared for the Kapiti Coast District Council by Coastal Systems Ltd. Client report No. 2012-8 CRep, August 2012.

Shand, T. D., Shand, R.D., Reinen-Hamill, R., Carley, J.T. and Cos, R.J. (2013). A Review of Shoreline Response Models to Changes in Sea Level. Australasian Coasts and Ports Conference, Sept 2013.

Shand, R.D., (2019). Geomorphological Assessment of the Waioeka inlet. A report prepared for Tonkin and Taylor Ltd on behalf of the Bay of Plenty Regional Council. Coastal Systems Ltd.

Smith, R.K. (1986) Motu river sediments: A source of eastern Bay of Plenty beach material. In Motu River: A description of its catchment, channel, waters and sediments. Miscellaneous Publication 92, Water and Soil Directorate, Ministry of Works and Development, Wellington

Stevens, H. and Giles, G. (2010) eShorance: an online methodology for estimating the response of estuarine shores from SLR. 19th NSW Coast Conf.

Tonkin + Taylor (2004) Hawkes Bay Regional Coastal Hazard Assessment. Report prepared for Hawkes Bay Regional Council.

Tonkin + Taylor (2006) Regional assessment of areas susceptible to coastal erosion. Technical report prepared for Auckland Regional Council.

Tonkin + Taylor (2012) Coastal Hazard Assessment: Waikawa to Waitarere. Technical report prepared for Horizons Regional Council.

Tonkin + Taylor (2017) Coastal Hazard Assessment for Christchurch and Banks Peninsula (2017). Technical report prepared for Christchurch City Council.

Tonkin + Taylor (2018) Te Tumu Natural Hazard Assessment – Coastal Hazard. Technical report prepared for Tauranga City Council.

# Appendix A Geomorphological assessment of the Waioeka inlet

.

# Geomorphological Assessment of the Waioeka inlet

A report prepared for Tonkin and Taylor Ltd on behalf of the Bay of Plenty Regional Council

**By Dr Roger D Shand**

**COASTAL SYSTEMS Ltd**

**Research, Education and**
**Management Consultancy**

70 Karaka Street.
Wanganui, New Zealand.

Phone: +64 634 44214 Mobile: +64 21 057 4189

rshand@coastalsystems.co.nz
www.coastalsystems.co.nz

| | |
|---|---|
| Reference | 2019-01 CRep |
| Version | V2 FINAL |
| Status | For Release |
| Date | 15 March, 2019 |

# CONTENTS

# 1 INTRODUCTION

Tonkin and Taylor are carrying out an erosion hazard assessment for the Bay of Plenty Regional Council (BOPRC) between the Waiotahi and Waioeka Rivers (Figure 1). Tonkin and Taylor have commissioned Coastal Systems Ltd to prepare a "Geomorphological Assessment regarding the behaviour of the Waioeka Inlet, with particular focus on how far westward it might migrate before the spit is breached based on historical evidence. And/or how the inlets future behaviour could be incorporated within an erosion hazard assessment given that historic data shows the mouth migrating westward and speeding up".

The physical characteristics of the inlet and coast have been described by Dahm and Kench 2002, 2004 as follows. The catchment is some 1130 km$^2$ which is largely steep and forested hill country with two main tributaries, the Waioeka and Otara Rivers. The confluence is 1.5 km upstream of the throat (this straight reach forming the approach channel to the inlet throat). The annual mean flow in this reach is 43 m$^3$/s with combined spring tide discharge of 60 to 70 m$^3$/s, while the annual flood flow is about 1000 m3/y and combined spring tide discharge of 100 to 150 m3/s. River sediments are medium sand with increasing silt/clay on the margins and gravel within the main channel and western side of the inlet. The annual volume supplied to the inlet by the river is considered to be less than 15,000 m$^3$. Fine to medium sand occurs on the coast beyond the inlet. Net longshore drift is estimated to be in balance with a flux of some 10,000 m$^3$/y. The coast is backed by Holocene sand dunes and swamp. In addition, a relic sea cliff made of volcanic sediments lies some 1.75 km westward of the present Waioeka mouth (see Figure 1).

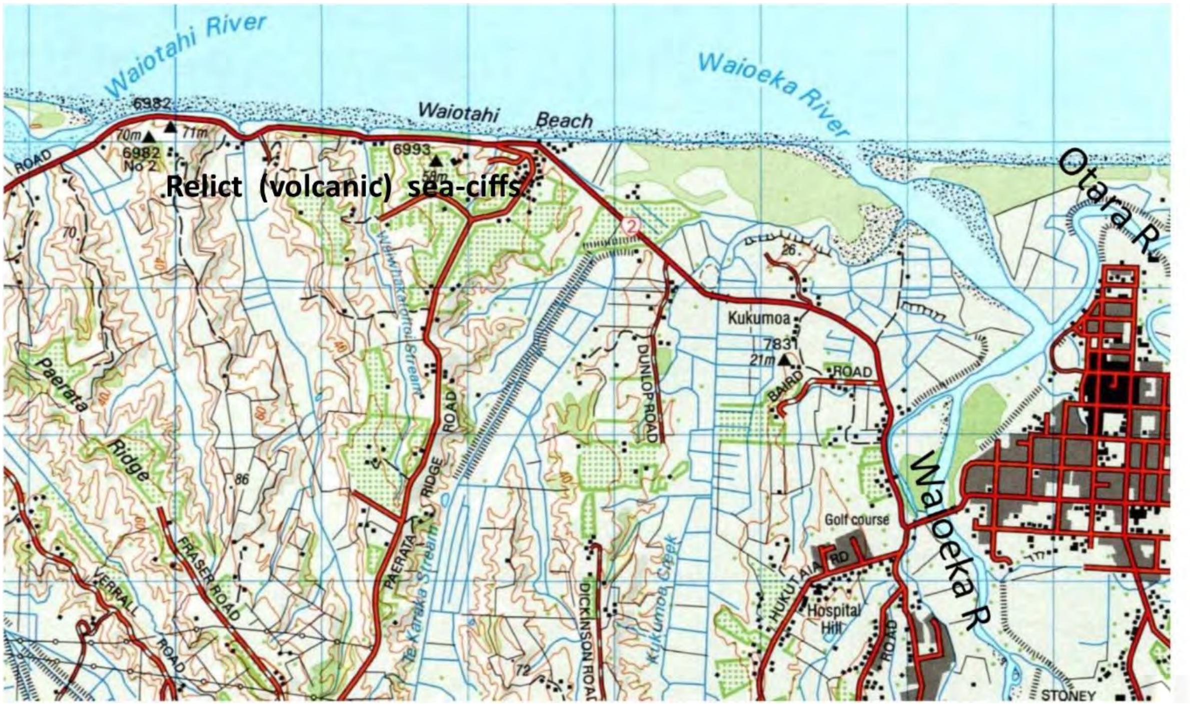


*Figure 1* *Location diagram. Grid lines are 1 km apart*

Gibb (1994) found the open coast shoreline to be accreting to each side of the Waioeka Rivermouth: averaging 0.2 m/y to the east and 0.6 m/yr to the west. Dahm and Kench (2002, 2004) found the Waieoka entrance had migrated westward some 900 to 1100 m in the past 140 years (averaging 7.5 to 9.5 m/yr), but had slowed to 2.8 m/y between 1940 and 2000. BOPRC ground surveys of the western bank of the Waioeka River collected in 2017 and 2018, show an increased westward migration rate of 10 to 15 m/yr. These results demonstrate a net westward movement of the inlet, and indicate considerable shorter-term variation occurs with an episode of enhanced migration presently underway.

Three specific geomorphological aspects are investigated in the present study:

1. Longer-term behaviour of the river channel, banks, and the (inlet throat) approach channel;
2. The seaward basin shape in which earlier Holocene inlet behaviour may be preserved, and
3. Shorter-term entrance behaviour.

The present study analyses morphological data obtained from cadastral plans (1866, SO 2810, 1867, SO 2809), aerial photographs (1940, 1944, 1945, 1954, 1964, 1966, 1970, 1971, 1976, 1981, 1985, 1987, 2014-15), satellite imagery (2003, 2007, 2011, 2012, 2015, 2019), NWASCO coastal resource maps ec 3967 Sheets 3 and 4, and BOPRC ground survey data 1994, 2017, 2018). These data were abstracted after georeferencing to NZTM using LINZ spatial data and 2014-15 orthophotos downloaded from the LINZ web site https://www.linz.govt.nz/land/maps/aerial-imagery-and-orthophotography

## 2 LONGER-TERM (HISTORICAL) BEHAVIOUR

Channel orientation as it approaches the inlet throat can be a first order control of inlet configuration and behaviour where there are no structural (natural or artificial) controls and can over-ride net littoral drift direction (Shand and Shepherd, 2016). Consequently, a line was fitted to perturbations along the left bank of the approach channel for the 1867, 1945, and 2015 samples – these being approximately equally spaced and the western bank was chosen as it is evident in all images and is of particular interest to this study. The resulting alignments are depicted by straight lines in Figure 2 and define an average westward migration rate at the coast of 8.05 m per year with 8.2 m/yr for the 1867 to 1945 period and 7.9 m/y for the 1945 to 2015 period.

What is of initial interest is the increasing westerly offset of the approach channel as the associated ebb flow is a primary driver of morphological change. Indeed, this association suggests that continued westward migration of the entrance can be expected. However, to define a causal relationship, channel behaviour had to be investigated in more detail. In particular, river control structures were superimposed and riverbank change at 6 key locations were identified and vectorised (marked in Figure 2).

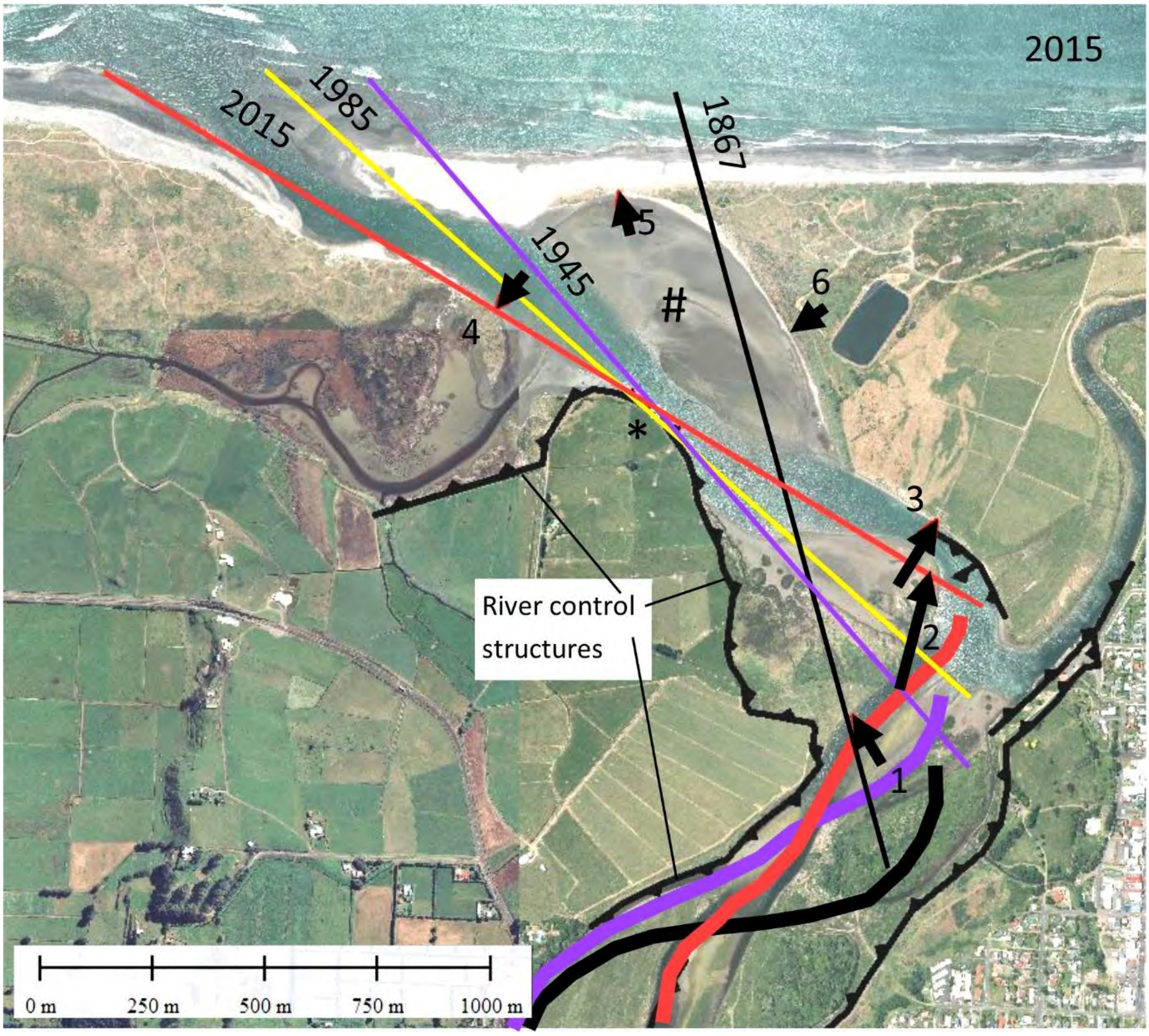


***Figure 2*** *Inlet approach channel alignments (straight lines) for 1867, 1945, 1985 and 2015. Upstream river channels (bold curved lines at base of image) for 1867, 1945 and 2015 are also shown. Shoreline change vectors (1945 to 2015) are depicted for key sites, and river control structures (stop banks and riprap protection works) are also marked.*

The first result is the control apparently exerted by the left bank control structure mid-way along the approach channel (marked by the asterisk in Figure 2), a location where the 1942, 1985 and 2015 alignments all intersect and pivot anti-clockwise. This (1960s?) structure appears to have arrested what had been westward bank migration since 1878.

Now considering the vectorised locations of bank change beginning at the upstream end. The main river channel immediately upstream of Vector 1 has changed from a west to east orientation (see 1867 channel marked by the thick black line) to the current more south to north orientation (2015 bold red line). This has resulted in the bank at Vector 1, which is immediately downstream of the control structure, eroding some 120 m and the depositing sediment in the vicinity of Vector 2 where a point bar some 260 m long has formed since 1945. This point bar has subsequently directed flow against the right bank in the vicinity of Vector 3 where the back has retreated some 165 m since 1945. The BOPRC placed protective rock rip rap at this location in 2013 but according to council staff little of this structure remains after recent flood events. These channel and bank behaviours would result in the alignment axes rotating around the mid approach channel structure (marked by the * ) and thence drive the approach channel against the western bank in the vicinity of Vector 4 which has sustained 90 m of erosion since 1945. These mechanisms are likely to have contributed to the historical westward migration of the inlet mouth and this behaviour could continue into the future - all things being equal.

It is noted that should the rock control at point * not have existed then the bank would have likely continued to erode at this location and an anti-clockwise meander develop which would have returned the channel to a more shore-normal orientation. Indeed, the Holocene morphology considered in the following section suggests that the present approach channel may has a more extreme westward offset than occurred previously.

However, our bank analysis at Vector 5 shows that the inside of the spit has migrated (eroded) seaward some 95 m since the 1940s. By contrast the spit's seaward shoreline has been relatively stable so the spit is narrowing - from about 75 m in 1985 to 20 m in 2014-15 or (1.8 m/yr), with the rate increasing to over 2.2 m/yr since 2003. The reason for this narrowing appears to be related the eastern (right) bank adjacent to the inter-tidal flat (# in Figure 2) migrating westward (up to 80 m at Vector 6 since the 1940s) and then focusing and deflecting flow westward along the spit (at Vector 5) toward the mouth. If this erosion (at Vector 5) continues, the spit could breach in about 10 years' time. However, given that the breach will be the result of a constrained floodway rather than driven by erosion induced by the main approach channel, the persistence of such a breech and its impact on the western shoreline, the problematic area of interest for the present study, is uncertain.

## 3 HOLOCENCE MORPHOLOGY

Figure 3 provides a 3D view as State Highway 2 approaches Waiotahi Beach. The Waioeka Rivermouth lies approximately 1 km downcoast. The road can be seen to run along the base of the relict (Holocene) seacliff. The orientation of the sea-cliff is interpreted as the westernmost margin of the Waioeka River and preserves an extreme orientation. Also marked in Figure 3 are yellow and red straight lines – these being parallel to the 1985 river alignment and the 2015 river alignments respectively as depicted earlier in Figure 2. The 1985 alignment is approximately parallel to the road (base of relict sea-cliff), while the red 2015 alignment has a greater westward offset than the relict cliff-line. These orientations at least suggest the present offset is greater than that experienced by this river in the past. However, as discussed in Section 2, the present offset may be unduly influenced by river control structures, while the Holocene orientation would relate to a natural system. This evidence and argument are therefore perhaps more of interest than assistance in answering the question relating to westward migration potential of the inlet system.

***Figure 3*** *State Highway 2 approaching Waiotahi Beach with old sea-cliff on the left (inland) side of the road. The Waioeka Rivermouth is to lower right off photo (1 km distant). The red line is parallel to the present channel approach alignment (red line in Figure 2), while the yellow line is parallel to the 1985 approach channel alignment in Figure 2. See text for discussion.*

## 4 SHORTER-TERM BEHAVIOUR

The more recent imagery and survey data show the erosion of the (vegetation-defined) western shoreline in the vicinity of the throat has increased. This raises the issues of if, and if so then how, such change should be incorporated when calculating the longer-term migration rate for an erosion hazard assessment.

Shorter-term inlet behaviour is a product of several variables and inter-related processes which invariably result in sediment moving from one side of the inlet throat to the other (inlet bypassing). A primary mechanism (evident in the Waioeka historical imagery) involves growth of the tip of the spit (by marine and fluvial processes during periods of lower energy) followed by “trimming” or shortening of the spit tip during higher energy – especially extreme river flood events. Sediment swept seaward is subsequently returned, typically as a coherent sand-body, through the surfzone to weld onto the western (in the Waioeka situation) inter-tidal beach or platform. This material can prograde the shoreline with a portion being transported inland through the throat and form recurved spits (for example see the western shoreline immediately landward of Vector 4 in Figure 2).

In situations where the spit has a longer low-lying end section, flood flows may “cut” through the spit with the truncated portion welding onto the previously offset side of the inlet. Artificial cutting is often used as part of inlet management regimes.

Where this process involves a greater length of spit (typically wider and higher), the process is referred to as spit “breeching” and this tends to occur over a longer time period. This latter process is what may occur at Vector 5 during the next decade or so.

Trimming processes are evident in the Waioeka image series as occurring every few years. However, the most recent episode appears to involve a longer section of spit with more significant morphological impacts. Key images which summarise this process between 2011 and 2019 are depicted in Figure 4.

The 2011 image shows the inlet with a strong westerly asymmetry and well-defined spit. The spit outline has been superimposed upon the 2012 image and his shows a recently shortened (flood trimmed) subaerial spit along with a more shore-normal channel orientation across the ebb delta , and a coherent sand body or “slug” (marked by the asterisk) on the western inlet platform – presumably composed of the truncated spit sediment.

The November 2015 image, which has the 2012 high and low water lines superimposed, shows the subaerial spit has extended westward some 450 metres which is substantially greater than for any other inter-survey period in the historical record back to 1940. On the offset (western) side of the inlet, the 2012 slug appears to have migrated onshore and the high tide shoreline has subsequently prograded seaward some 50 m adjacent and seaward of the throat. Inside the throat the high tide shoreline had eroded by a similar amount. Such erosion is commonly observed when waves and or current cross a sand body/area of deposition. Also of note, the channel approaching the throat in the 2015 image has a more westward orientation (see the white arrow in Figure 4) than in any earlier image.

The 2019 image, which has 2015 features superimposed, shows a slightly shortened spit and a slug in the western surf zone – both indicative of a previous flood event trimming the spit tip, followed by some recovery. Of particular significance, however, is erosion to the western high water shoreline adjacent to the throat and even greater erosion (marked by the #) of the accompanying vegetation front defining the dune-line. This dune erosion is consistent with the channel’s antecedent (2015) westward approach direction forcing flow into the western side of the throat. The BOPRC vegetation-front surveys from June 2017 and May 2018 (the latter co-incides with the 2019 image vegetation line), show 80% of this erosion had occurred prior to the 2017 survey. And a comparison of the 2015 HWM superimposed upon the 2019 image shows this shoreline has recovered some 70 %.

This type of more extreme short-term inlet behaviour appears to have not occurred before and may result either from random processes or as a product of the increasing westerly offset of the approach channel in which case such behaviour can be expected to occur again and perhaps dominate in the future. While substantial HWM recovery has occurred (which leads vegetation/dune recovery) perhaps indicating a random process, this may be premature as the 2019 image shows persistence of the westerly channel approach immediately upstream of the throat (see the white approach arrow on the 2019 image in Figure 4).

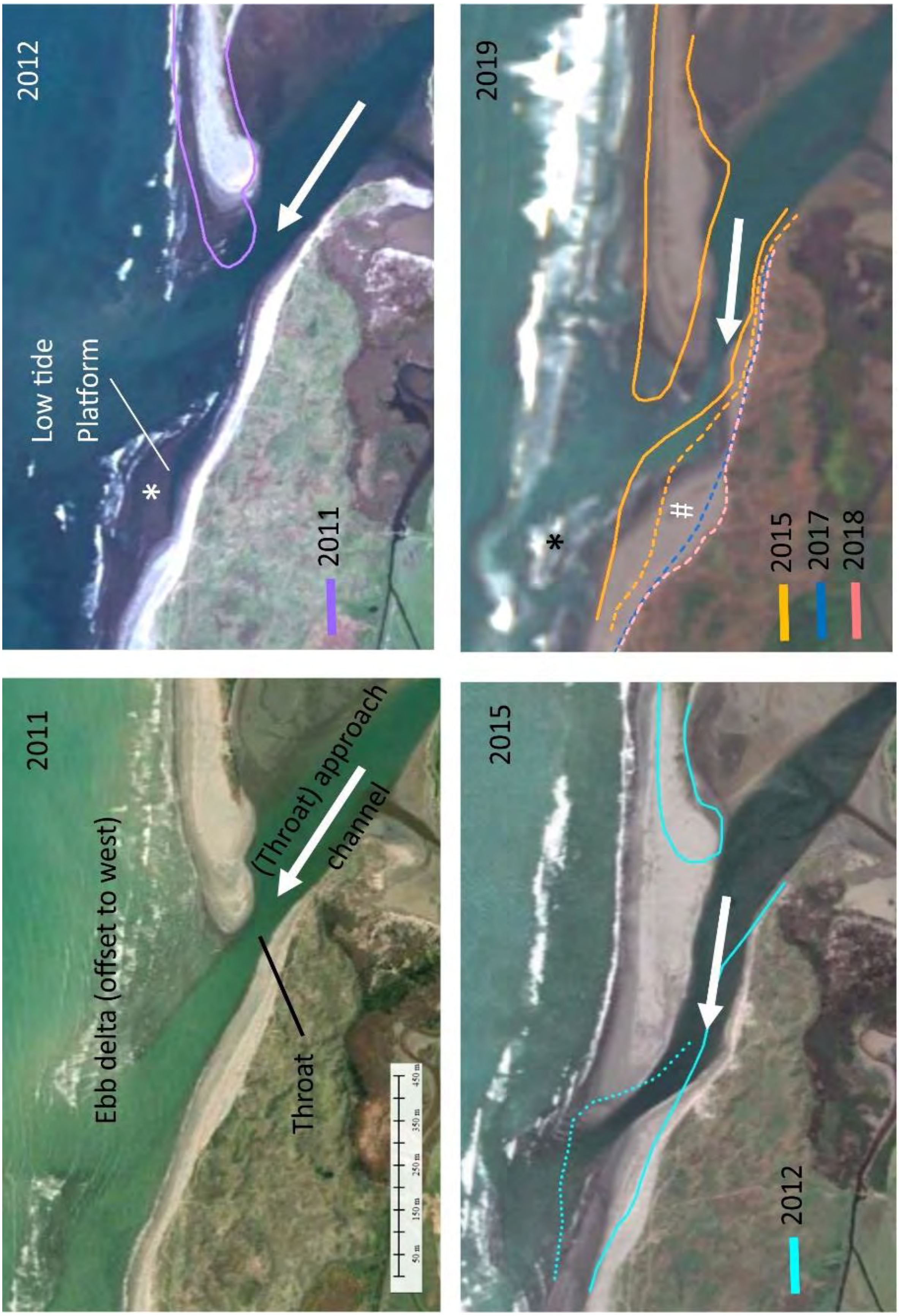


***Figure 4*** *Recent inlet configuration changes. Dotted line marks low tide platform, solid lines denote high water mark (HWM) and the dashed lines denote vegetation front/dune toe, all from the previous image. The 2017 and 2018 shorelines are BOPRC dune vegetation surveys. White arrows depict the inlet throat approach channel, asterisks mark recent sediment accumulations (slugs) and the hash marks recent erosion/recovery.*

# 5 SUMMARY/CONCLUSIONS

This somewhat high-level geomorphological assessment of the Waioeka Inlet found that the inlet throat has systematically migrated westward between 1867 and 2015 at an average rate of about 8 m/yr with this rate substantially increasing more recently.

This migrational process is related to changes in the upstream channel configuration – changes which have been affected by both natural river processes and also influenced by river control structures. Such upriver changes will potentially continue their effect inlet morphology.

However, continues extrapolation is potentially problematic for the following reasons:

1) The approach channel's (high-end) westerly offset captured during the Holocene by western cliff alignment is less than the present offset;
2) Upriver processes have also been narrowing the spit several hundred metres east of the typical throat location and breeching within the next 10 years appears to be plausible, and
3) Recent accelerated erosion is associated with a unique short-term behaviour that may result from a random process, i.e. it is unlikely to be repeated.

Each of the above reasons have caveats; however, because of their potential validity and the excessive high-end predictors derived from analysis and extrapolation the full data set with its recent extreme values, I suggest that an erosion hazard assessment for this area could be based on a long-term erosion component determined by regression analysis which excludes the more recent extreme period of erosion (i.e. use 1940 to 2012 data). In addition, a short-term component should be included to account for the more recent increase in erosion. This approach should provide adequate protection until future inlet behaviour becomes more certain.

## CONSULTANT DISCLAIMER

Coastal Systems Ltd (CSL) have prepared this document for exclusive use by the Client and agents in the described project. CSL accepts no responsibility for consequences of usage of this document's materials for alternative uses or by third parties.

CSL have exercised due and customary care in preparing this document, but has not, save as specifically stated, independently verified information from stipulated outside sources. CSL assumes no liability for any loss resulting from errors, omissions or misrepresentations made by others.

Any recommendations, opinions or findings are based on circumstances and facts as they existed at the time CSL performed this work. Subsequent changes in such circumstances and facts may adversely affect any of the recommendations, opinions or findings, and CSL assumes no consequential responsibility.

COASTAL SYSTEMS LTD

R D Shand

……….…………………………….

Dr Roger Shand

Senior Coastal Scientist

# References

Gibb, J.G., 1994. Initial assessment of areas susceptible to coastal hazards for selected parts of the Bay of Plenty. A report prepared for the Bay of Plenty Regional Council, 34p.

Gibb, J.G., 1998. Coastal hazard zone assessment for part of Waiotahi Beach, Opotiki District, Bay of Plenty. A report for Walton Mountain Ltd. 19p.

Gibb, J.G., 1999. Review of selected factors for assessment of areas susceptible to coastal hazards, Bay of Plenty Region. A report prepared for the Bay of Plenty Regional Council, 16p.

Dahm, J. and Kench, P., 2002. Feasibility Study: Opotiki Entrance navigation improvements. A report prepared for the Opotiki District Council. 72p.

Dahm, J. and Kench, P., 2004. Opotiki Entrance: navigation improvements phase 2, Feasibility Study. A report prepared for the Opotiki District Council. 69p.

Shand, R.D. and Shepherd, M.J. 2016. Geomorphological Assessment relating to natural character of the Manawatu Coast. A report prepared for the Manawatu District Council. 52p.

# Appendix B Coastal erosion hazard maps

Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 3.0 New Zealand licence

Notes: Aerial photograph sourced from LINZ Data Service 2015-2019

A3 SCALE 1:7,000

0 0.15 0.3 (km)

N

**Tonkin+Taylor**

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

| | | |
|---|---|---|
| DRAWN | RHAU | Jun.19 |
| CHECKED | | |
| APPROVED | | |

ARCFILE
working.mxd
SCALE (AT A3 SIZE)
1:7,000
PROJECT No.
1008669

# Opotiki Coast Erosion Hazard Assessment

Stage 1 Waiotahe
Final Draft
Sheet 1

FIGURE No.

Rev.
0

Path: P:\1008669\WorkingMaterial\Mapping\working.mxd Date: 7/06/2019 Time: 4:21:27 PM

Notes: Aerial photograph sourced from LINZ Data Service 2015-2019

A3 SCALE 1:7,000

0 0.15 0.3 (km)

**Tonkin+Taylor**

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

| | | |
|---|---|---|
| DRAWN | RHAU | Jun.19 |
| CHECKED | | |
| APPROVED | | |

ARCFILE
working.mxd

SCALE (AT A3 SIZE)
1:7,000

PROJECT No.
1008669

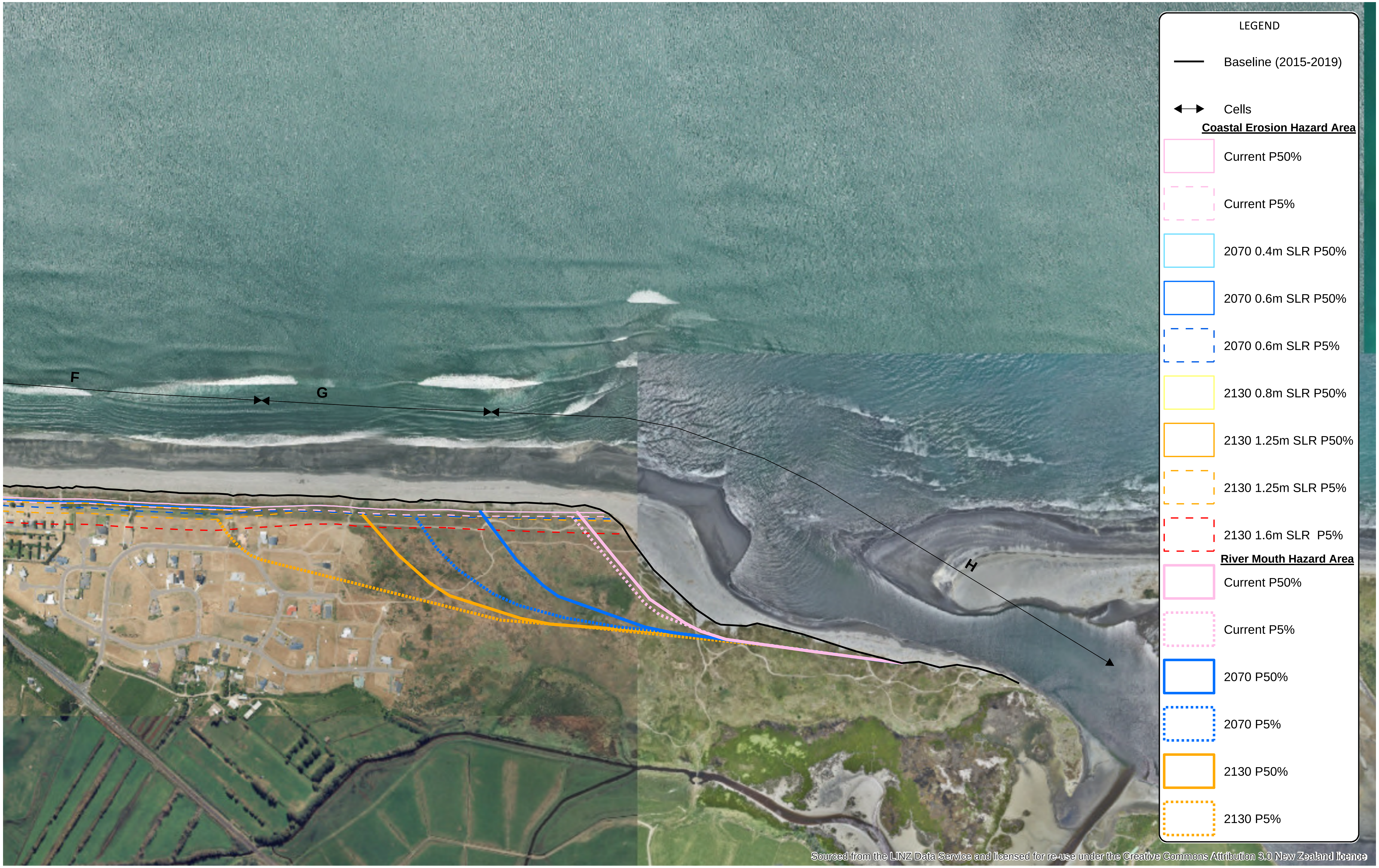
# Opotiki Coast Erosion Hazard Assessment

Stage 1 Waiotahe
Final Draft
Sheet 2

FIGURE No.

Rev.
0

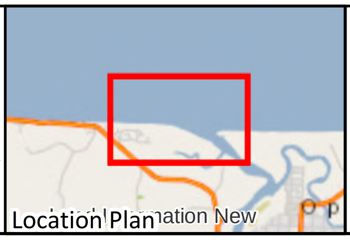
Path: P:\1008669\WorkingMaterial\Mapping\working.mxd Date: 7/06/2019 Time: 4:37:19 PM



Notes: Aerial photograph sourced from LINZ Data Service 2015-2019

A3 SCALE 1:7,000

0 0.15 0.3 (km)


Location Plan

**Tonkin+Taylor**

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

| | | |
|---|---|---|
| DRAWN | RHAU | Jun.19 |
| CHECKED | | |
| APPROVED | | |
| ARCFILE<br>working.mxd | | |
| SCALE (AT A3 SIZE)<br>1:7,000 | | |
| PROJECT No.<br>1008669 | | |

# Opotiki Coast Erosion Hazard Assessment

Stage 1 Waiotahe
Final Draft
Sheet 3

FIGURE No.

Rev.
0

Path: P:\1008669\WorkingMaterial\Mapping\working.mxd Date: 6/06/2019 Time: 4:49:44 PM

# Appendix C CEHA probabilistic model outputs

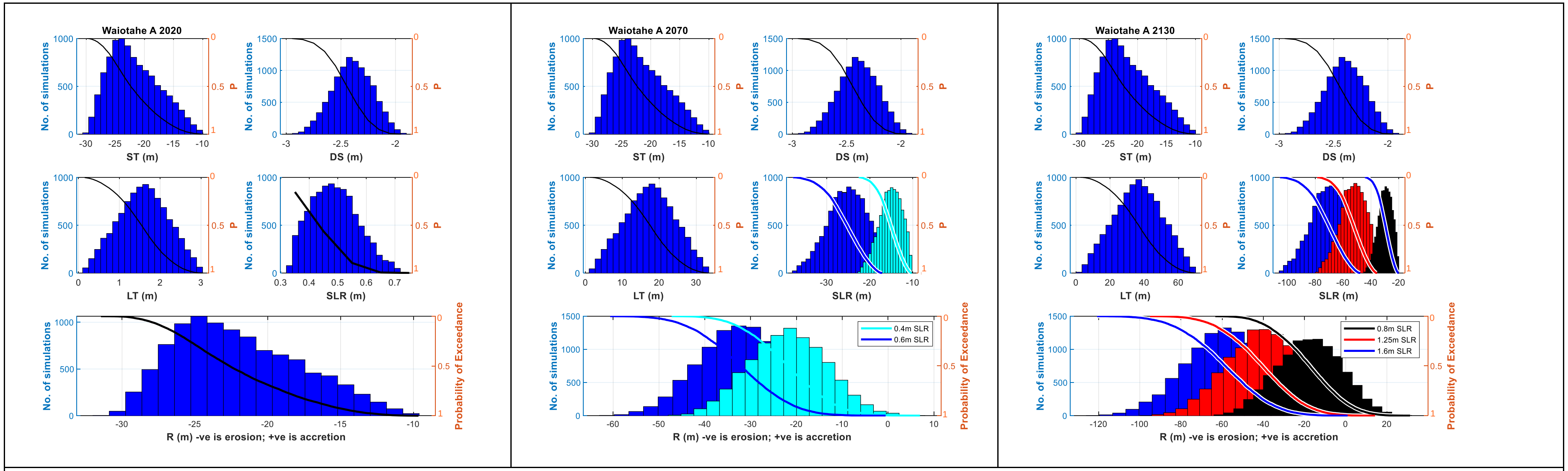


*Figure C -1 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell A in 2020 (left), 2070 (centre), 2130 (right).*

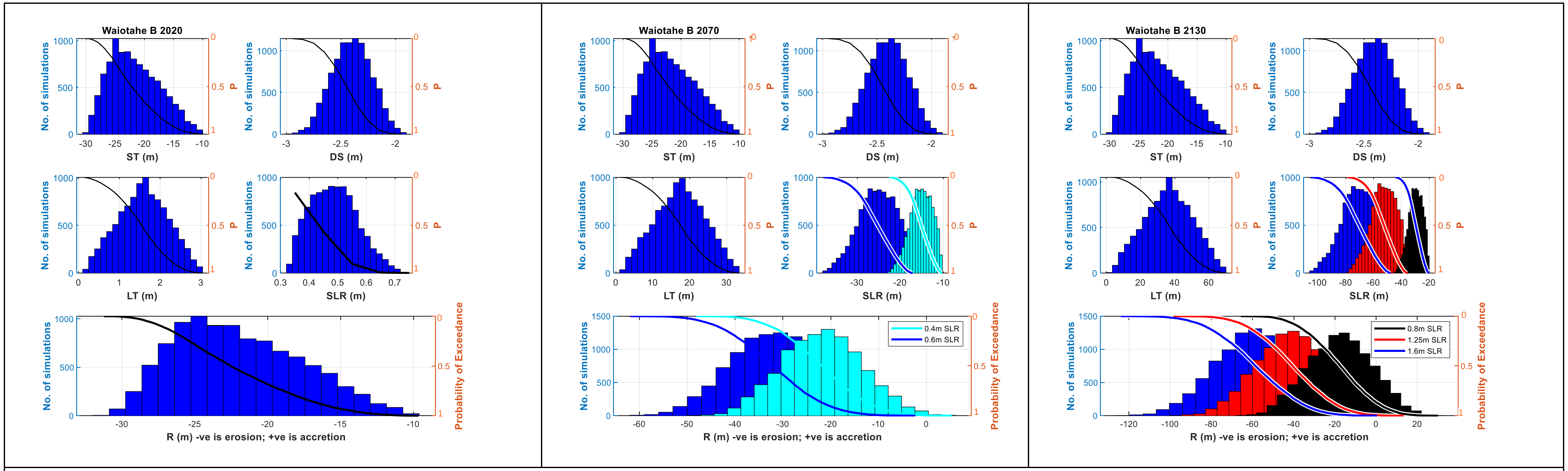


*Figure C -2 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell B in 2020 (left), 2070 (centre), 2130 (right).*

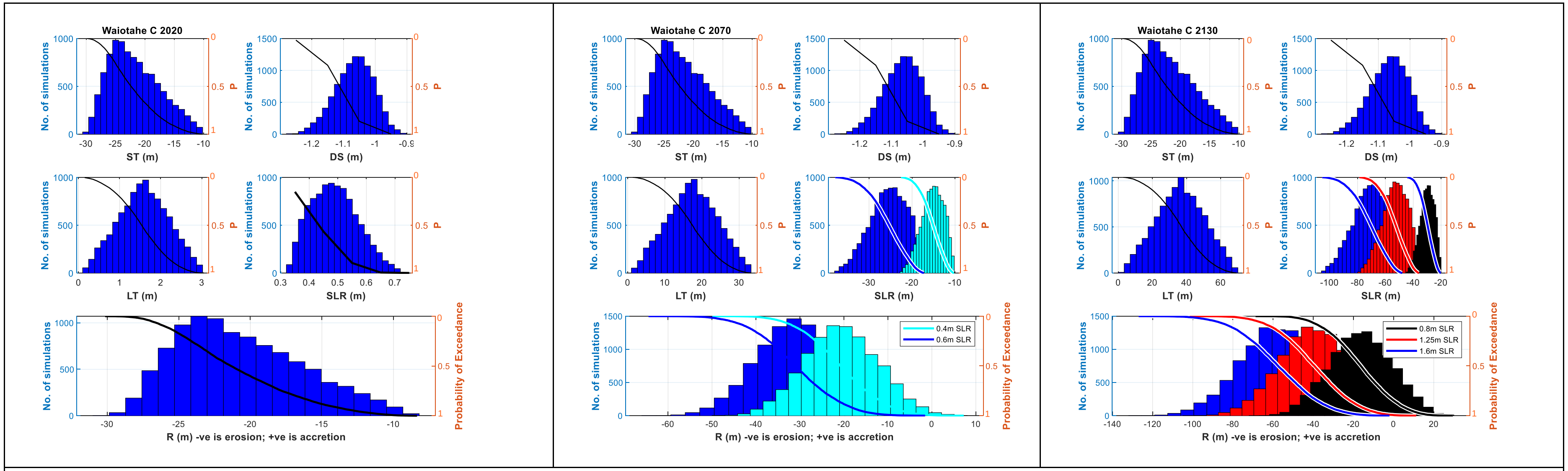


*Figure C -3 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell C in 2020 (left), 2070 (centre), 2130 (right).*

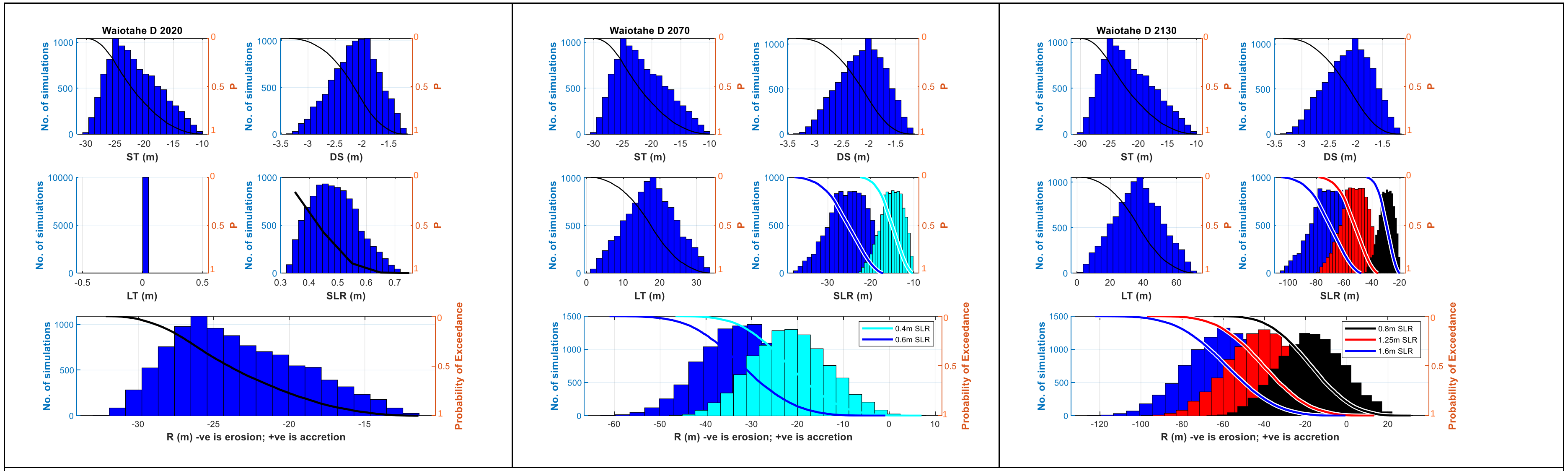


*Figure C -4 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell D in 2020 (left), 2070 (centre), 2130 (right).*

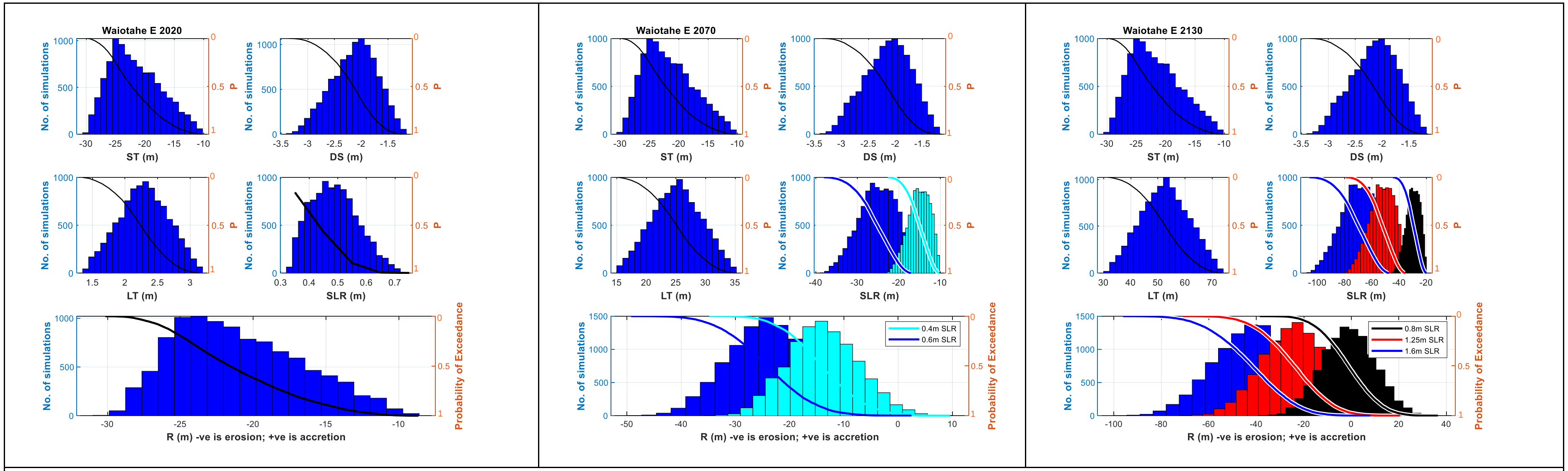


*Figure C -5 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell E in 2020 (left), 2070 (centre), 2130 (right).*

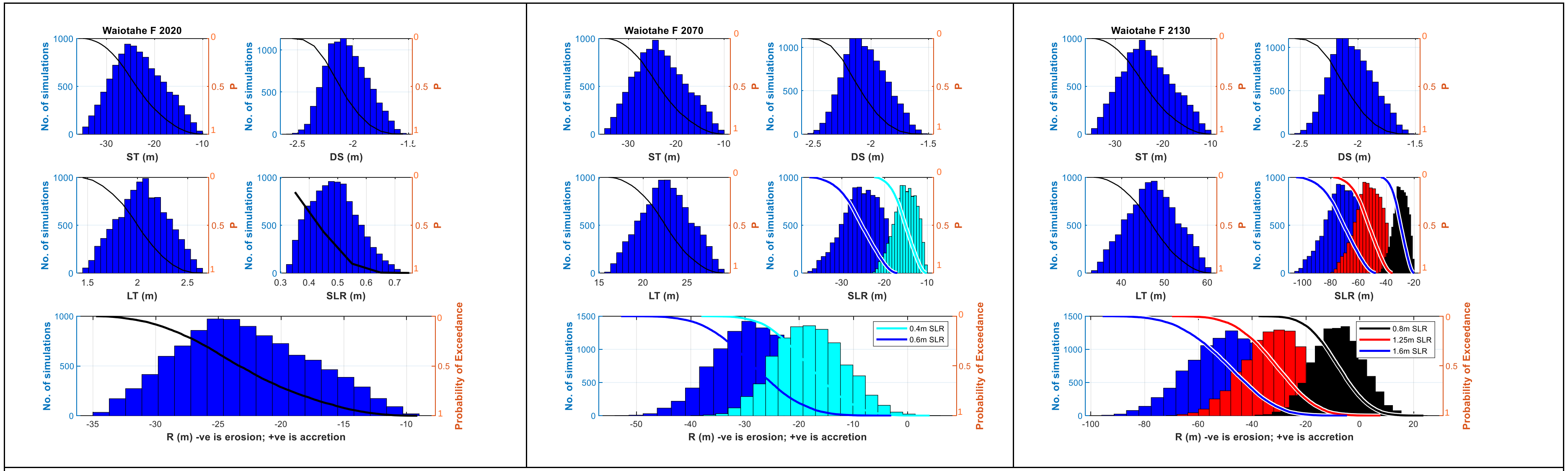


*Figure C -6 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell F in 2020 (left), 2070 (centre), 2130 (right).*

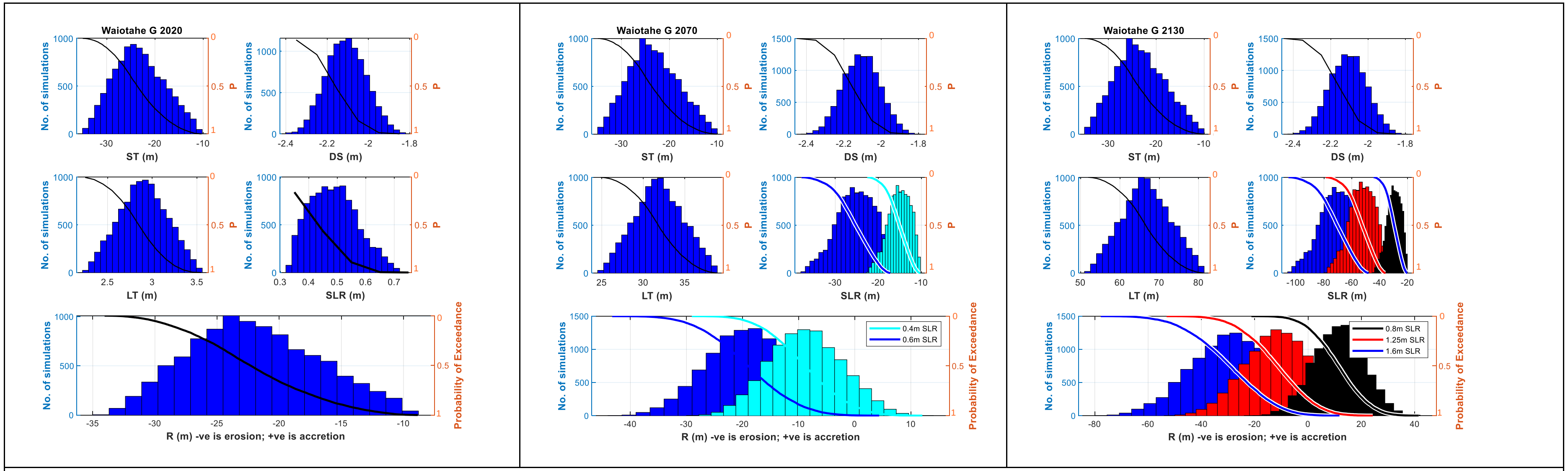


*Figure C -7 Histograms and cumulative distribution functions of parameter samples and resultant CEHA distances for Cell G in 2020 (left), 2070 (centre), 2130 (right).*

www.tonkintaylor.co.nz