Predicting Auckland's Exposure to Coastal Instability and Erosion

Technical Report 2020/021

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Cover picture: Stanmore Bay

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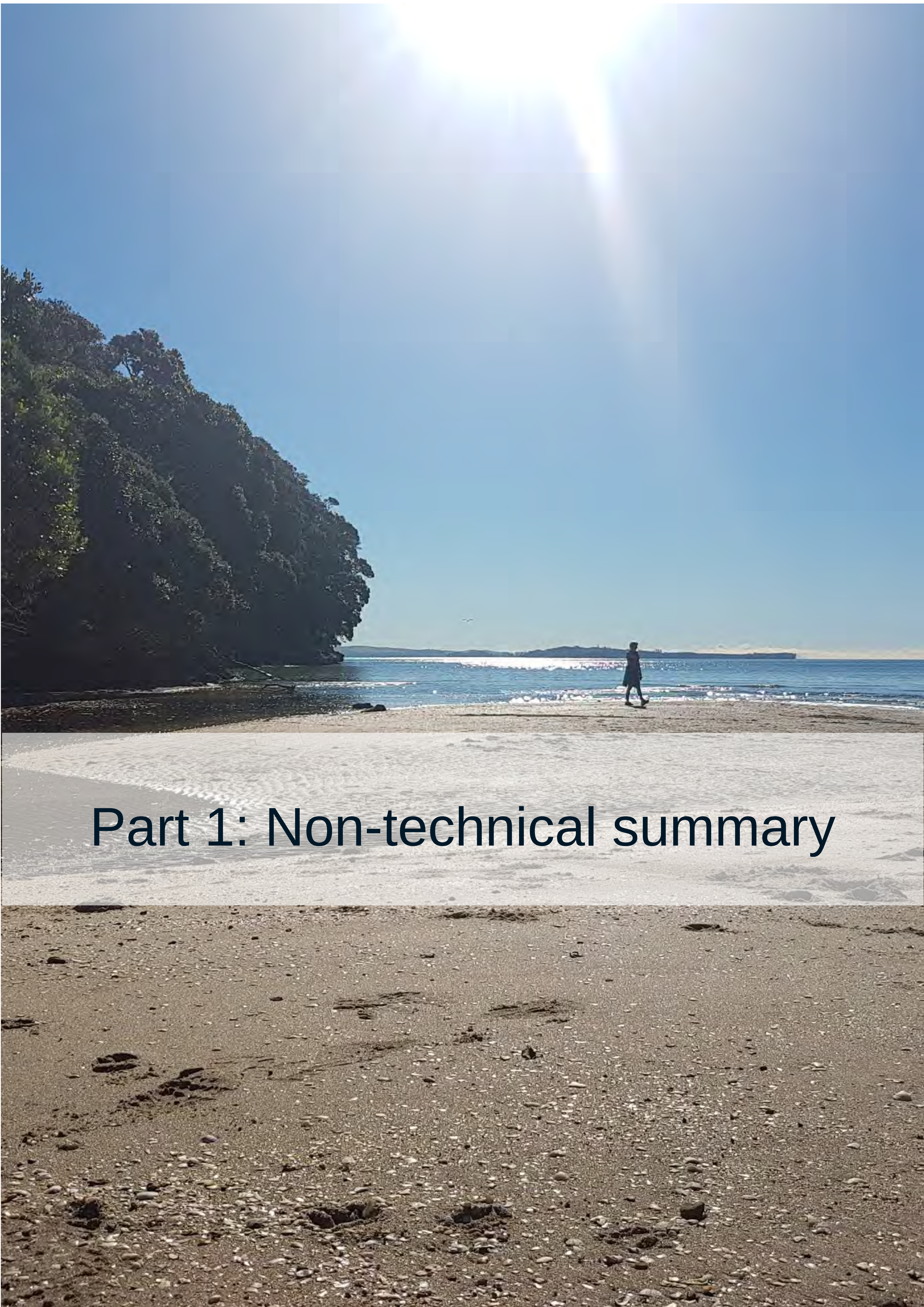

Part 1: Non-technical summary

Executive Summary

The Auckland region has over 3,200 km of coastline including three major harbours and a range of sandy beaches and dunes, rocky shores and cliffs, estuaries and offshore islands. As well as a long and diverse coastline, Auckland has the largest population density to coastline ratio in New Zealand. As a result, the city has a high exposure to coastal hazards including coastal instability and erosion. These hazards can present a safety risk, adversely affect property and infrastructure, and damage or destroy cultural and environmental sites.

A study undertaken in 2006 is the basis for the current coastal erosion rules within the Auckland Unitary Plan. No more up-to-date information related to the potential exposure of Auckland's coastline to erosion was available at the time of the plan's development.

To fill this knowledge gap, a programme of research has been undertaken to identify, at a regional level, the Area Susceptible to Coastal Instability and/or Erosion (ASCIE). ASCIE is the area landward of the current coastline that is at risk because of coastal erosion or instability caused by coastal erosion. Titled "*Regional Assessment of Areas Susceptible to Coastal Erosion and Instability*", this study was undertaken for Auckland Council by Tonkin + Taylor Ltd., with a peer review by the University of Auckland. The study forecasts the areas of Auckland's coastline that could be affected by coastal erosion and instability under a range of climate change (sea-level rise) scenarios and timeframes.

A non-technical overview of the study is given in Part 1 of this Technical Report while the detailed study as reported by Tonkin + Taylor is presented in Part 2. The intent of this separation is to provide a Council synopsis and interpretation for non-technical readers.

To assess the ASCIE, the coastline of Auckland was divided into 568 coastline 'cells', where the controlling factors are broadly consistent. The impact of sea level rise was modelled for each cell at 30, 50, and 100+ year timescales, and two climate change scenarios were used. A high emission scenario with little mitigation controls (RCP 8.5M), which matches the current track for global emissions, was used across all three timeframes. To get a full understanding of the worst-case scenario and check the sensitivity of the models, an extreme emissions scenario with no mitigation (RCP 8.5H+) was also modelled at the 100+ year timeframe.

The ASCIE has been calculated for each of these combinations, and the results for each cell presented as a distance in metres landward of the current coastline.

The ASCIE of cliffs and beaches are controlled by differing processes and were calculated separately using current best practice. The results are presented in tabular format and on a regional 'heat map'.

While the regional 'heat map' provides a high-level understanding of the potential erosion rates across Auckland's coastline, further work needs to be done to refine the model and provide more detailed mapping showing areas susceptible to coastal instability and erosion at a sub-regional level.

ASCIE was not calculated for reclaimed shorelines as it was assumed that structures reinforcing these shorelines will be maintained, supporting the planning definition in the Auckland Unitary Plan of reclaimed land as permanent.

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List of abbreviations

Abbreviation	Definition
ASCIE	Area susceptible to coastal instability and/or erosion
NZCPS	New Zealand Coastal Policy Statement, 2010
IPCC	Intergovernmental Panel on Climate Change
RCP	Resource concentration pathway
RMA	Resource Management ACT 1991

1.0 Introduction

1.1 Background

The Auckland region has over 3,200 km of coastline including three major harbours and a range of sandy beaches and dunes, rocky shores and cliffs, estuaries and offshore islands. As well as a long and diverse coastline, Auckland has the largest population density to coastline ratio in New Zealand, and as a result, we have a high exposure to coastal hazards. These hazards can present a safety risk, adversely affect property and infrastructure, and damage or destroy cultural and environmental sites.

Three critical coastal hazards are inundation, erosion and instability:

- Coastal inundation is the flooding of normally dry land by the sea, particularly during storms. This is often a temporary situation which reverses when the storm has passed, although rising sea levels will increase the frequency of flood events and cause some permanent inundation.
- Coastal erosion is the removal of the material forming the land due to natural processes, resulting in the coastline moving inland over time. It is a complex process caused by factors including wave energy, changes to sediment availability and land use, and sea-level rise. Although some types of shorelines (e.g. beaches) may undergo short term periods of erosion but then recover (i.e. build out again), other types of shorelines (e.g. cliffs) continuously erode with no cycle of recovery.
- Coastal instability is the movement of land (typically as a landslide) resulting from the loss of support caused by coastal erosion.

Coasts are naturally dynamic environments which are constantly changing in response to processes such as wave action. The response to these processes is controlled by natural characteristics such as the underlying geology. Changes to our coast are also caused by human modification and the ongoing effects of climate change induced sea-level rise.

1.2 Purpose

Due to its exposed location, Auckland is highly vulnerable to the potential impacts of both coastal erosion and inundation. While Auckland's exposure to coastal inundation is reasonably well understood and is documented elsewhere, the risk posed by coastal erosion (and consequential instability) is less well established. It is important that we understand the likely future evolution of our coast so that we can make sustainable, long-term decisions for its future management and any activities that occur within this zone.

In 2019, Auckland Council published a series of Climate Change Risk Assessments for the Auckland region. This data was used to inform the development of Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan which was adopted in July 2020. The supporting Climate Change Risk Assessment Programme included a regional inventory of Auckland's exposure to sea level rise. While this assessment specifically addressed Auckland's increasing risk of coastal inundation due to climate change, it did not cover coastal erosion. Up-to-date information related to the potential exposure of Auckland's coastline to erosion was not available at the time, and coastal erosion was therefore not considered.

To fill this knowledge gap, a programme of research was undertaken to identify, at a regional level, the areas of Auckland that are susceptible to coastal instability and erosion. Titled "*Regional Assessment of Areas Susceptible to Coastal Instability and Erosion*", this study was undertaken for Auckland Council by Tonkin + Taylor Ltd., with a peer review by the University of Auckland. It forecasts the areas of Auckland's coastline that could be affected by coastal erosion (and instability triggered by such erosion) under a range of climate change scenarios and timeframes. It builds upon an earlier 2006 study which formed the basis of the coastal erosion rules currently within the Auckland Unitary Plan.

A non-technical overview of the study is given here (Part 1 of this Technical Report), while the detailed study as reported by Tonkin + Taylor is presented in Part 2. Coastal inundation is not part of this research and is described in a separate report.

1.3 National and local policy context

The need to manage the long-term effects of natural hazards (including coastal hazards) is considered via a variety of policy documents including the Resource Management Act 1991 (RMA), the New Zealand Coastal Policy Statement 2010 (NZCPS), and the Ministry for the Environment's '*Coastal Hazards and Climate Change Guidance*' (2017). For full details on how these policies relate to coastal erosion, see Table 1.

To comply with national policy, all regions and districts must address the avoidance or mitigation of natural hazards in statutory planning processes. For Auckland this is achieved through a variety of both statutory and non-statutory documents, detailed in Table 1.

Table 1: Overview of statutory and non-statutory documents related to the management of coastal hazards

Scale	Requirement	Document title	Explanation
National	Statutory	Resource Management Act 1991 (RMA)	New Zealand's overarching document to promote the sustainable management of our natural environment
		New Zealand Coastal Policy Statement (2010)	Supports the RMA with a specific focus on the coastal environment. This includes Objective 5, which requires that coastal hazard risks (including for the impacts of climate change) are managed. The objective is supported by policies that require us to take a precautionary, long term (at least a 100-year) approach and to avoid increasing risk where practicable. Land that may be subject to natural hazards (including coastal erosion) within at least a 100-year timeframe, including for the potential effects of long-term climate change, must be identified and the risks managed.
	Non-statutory	MfE 'Coastal Hazards and Climate Change Guidance' (2017)	Sets out the most recent climate change and sea-level rise projections for New Zealand and endorses the need to understand long-term coastal hazard risk across this range of scenarios.
Regional	Statutory	Auckland Unitary Plan	Manages the effects of natural hazards through the 'Environmental Risk' chapter of the Regional Policy Statement (B10), Natural Hazards and Flooding Provisions (E.36), Subdivision Controls (E.38) and the Regional Coastal Plan (F). It includes definitions of the coastal hazard area. When subdivision/s, use or development requiring resource consent is proposed to be undertaken in this area, completion of a site-specific hazard assessment is required.
	Non-statutory	Coastal Management Framework for the Auckland Region (2017)	Highlights the need for a robust and consistent approach to coastal hazard management for Auckland, including identifying the need for updating coastal erosion and climate change impact information originally collected in 2006. Sets principles for coastal management.
		Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan (2020)	Outlines a series of key moves for climate action across Auckland, including the need to improve the resilience of our coastal communities. The development of long term, adaptive coastal management plans that are informed by up-to-date coastal hazards and climate change information is an important implementation action of the climate plan.
		Natural Hazard Risk Management Action Plan (In draft)	Summarises Auckland's risk from natural hazard (including coastal erosion) and identifies across-Council actions which need to be undertaken to mitigate these risks.

2.0 Method

2.1 Scale of assessment

The coastal erosion and instability technical report presented in Part 2 provides a regional scale assessment for the whole of Auckland. This study builds on and supersedes the earlier '*Regional Scale Assessment of Coastal Erosion*' (Tonkin + Taylor, 2006) by applying the latest erosion prediction methods and utilising updated datasets related to beach profiles, land elevations and sea-level rise projections taking climate change into account.

Regional scale assessments provide a valuable 'first pass' appraisal of the hazard. This high-level analysis provides a reasonably conservative assessment of the parts of Auckland's coastline potentially susceptible to coastal instability and erosion.

The results will guide any need for future, smaller scale or site-specific erosion assessments. These more detailed assessments would provide an opportunity to consider controlling factors and driving processes at a finer resolution to enable more detailed hazard management responses to be considered. This staged approach is in alignment with the Ministry for the Environment's *Coastal Hazards and Climate Change Assessment Guidance* (2017).

2.2 Areas susceptible to coastal instability and/or erosion (ASCIE)

While inundation due to sea level rise may be perceived as a major threat to coastal properties, long-term coastal erosion may also have significant impacts. As cliffs are eroded by wave action at the toe, the material above sea level will become unstable and episodic instability events (such as landslides) will cause the cliff to flatten to a slope under which it is 'stable'. Likewise, dunes have a natural angle at which they are stable, and when undermined at the toe will fail until they return to this angle.

To capture these landward areas at risk because of coastal erosion, the instability of the eroded land has been calculated as part of the assessment. The resulting Area Susceptible to Coastal Instability and/or Erosion (ASCIE) is reported as a distance in metres landward from the current coastline.

2.3 Division of the coastline into beaches, cliffs, and reclamation

Coastal erosion is a complex process defined by the permanent loss of coastal cliff areas or long-term regression of natural beaches and dunes. A distinction can be made between these two types of coast as they are driven by different processes. Reflecting this, the Part 2 technical report presents separate data and methodologies that are used to predict erosion of each system.

Beaches and dunes consist of uncemented or very weakly bound materials. They are dynamic environments that are subject to both erosion and accretion, controlled by the prevailing coastal processes (e.g. wave energy, water level) and the availability of sediment.

Figure 1: An East Coast beach with a small dune system
Small rises in sea level can cause rapid changes to these environments.

In contrast, coastal processes irreversibly erode cliff-faces. Several factors contribute to the erosion of cliffs including geology, topography, coastal processes and weathering. The interaction between these various processes is complex and cliff erosion rates can vary significantly between locations depending on the most dominant factors.

Figure 2: A typical Auckland East Coast cliff showing a recent repair to reinstate a footpath damaged by cliff instability
As the toe of these cliffs is eroded, instability higher up the cliffs will increase.

No ASCIE lines were generated for reclaimed shorelines as it was assumed that structures supporting these shorelines will be maintained, supporting the planning definition of reclaimed land as permanent.

2.4 Effects of climate change

Climate change is predicted to increase the current rates of erosion experienced around our coast, mainly because of sea-level rise. Increased storminess and changes in rainfall patterns may also change rates of erosion in Auckland. However, as these effects are expected to be small relative to sea level rise and the techniques for forecasting the impact of these changes are not yet developed, storminess and rainfall changes were not considered in this analysis.

Although sea level rise has been taken into consideration, the amount of sea level rise that we might experience over the next century is not precisely known, partially because it is a function of international emissions policy decisions that have not yet been made.

The Ministry for the Environment guidance outlines four potential scenarios of climate change based on the most recent Intergovernmental Panel on Climate Change (IPCC) Report (AR5). Known as Resource Concentration Pathways (RCPs), these scenarios represent potential trajectories of atmospheric concentrations of green-house gases over time, which correlate with expected levels of warming and sea level rise. RCPs described by the IPCC report are:

1) Low to eventual net-zero emission scenario (RCP2.6 M)
2) Intermediate-low emissions scenario (RCP4.5 M)
3) High-emissions scenario (RCP8.5 M)
4) Higher extreme scenario, with essentially no controls on emission by 2100 (RCP 8.5 H+).

The forecast sea level rise resulting from each RCP scenario is summarised in Figure 3. These have been extended to 2120, aligning with the minimum requirements to consider impacts over at least 100 years (NZCPS, 2010).

Because the primary purpose of this study is to identify the areas where more detailed studies are appropriate, the higher sea-level rise scenarios (RCP 8.5 M and RCP 8.5 H+) were used in the analysis. This approach follows recent guidance of Ministry for the Environment (2017). Global emissions are currently following the RCP 8.5 scenario.

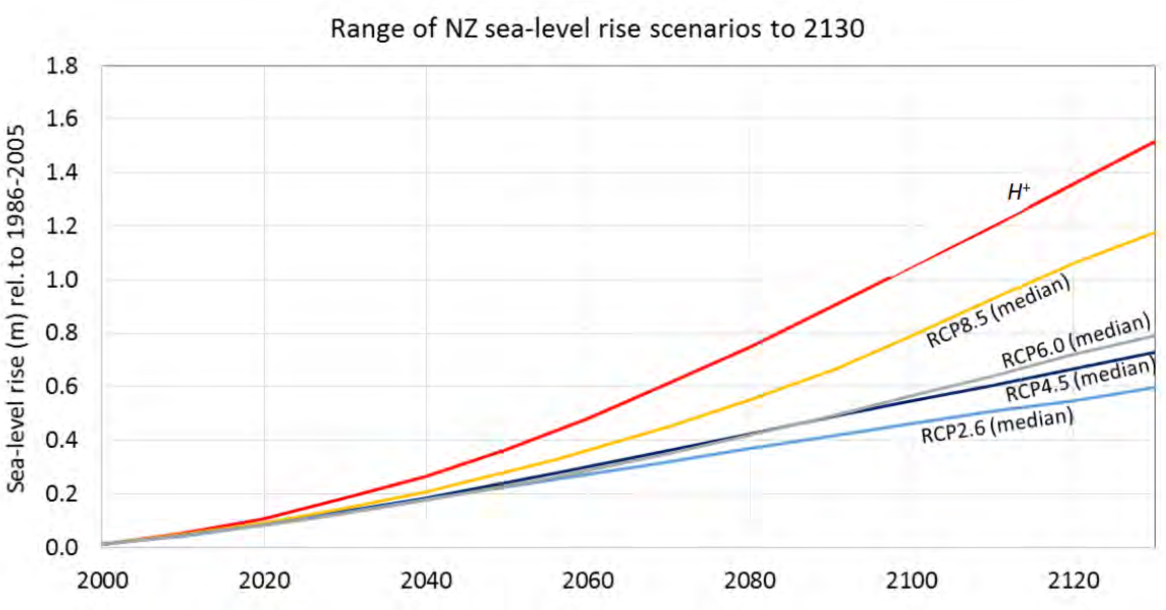


Figure 3: Four scenarios of New Zealand-wide regional sea-level rise projections
(Source, Ministry for the Environment, 2017)

2.5 Selection of timeframes

Erosion predictions have been made over three timeframes:

- ~30 years (to 2050)
- ~50 years (to 2080)
- 100+ years (to 2130).

The timeframes considered within the regional study are linked to Auckland Council's legislative requirements and the planning horizons commonly considered. For example, the NZCPS requires consideration of *'at least a 100-year timeframe'* for the identification of coastal hazards, which is further supported by the Auckland Unitary Plan. The shorter timeframe of 50 years aligns with the Building Act, while 30 years aligns with other regulatory requirements (e.g. coastal consents have a typical duration of 35 years).

2.6 Modelled scenarios

Four sea level rise scenarios have been considered, each reflecting a specific RCP climate change scenario and timeframe, as outlined in Table 2.

Table 2: Coastal erosion scenarios considered in the regional assessment

Scenario	Timeframe	Climate change scenario (RCP)	Associated relative sea-level rise projection (m)
1	2050 (~30years)	8.5 M	0.28
2	2080 (~50 years)	8.5 M	0.55
3	2130 (100+ years)	8.5 M	1.18
4		8.5 H+	1.52

2.7 Calculation of area susceptible to coastal instability and erosion

To calculate the ASCIE, the coastline of Auckland was divided into 568 coastline 'cells', where the controlling factors are broadly consistent. Each cell could be a beach or a cliff, but never both.

For each cell the controlling factors were defined, and then the likely coastal erosion modelled for each of the scenarios described above.

A sketch summarising the definition of the ASCIE for cliffs and beaches is given in Figure 4 and Figure 5.

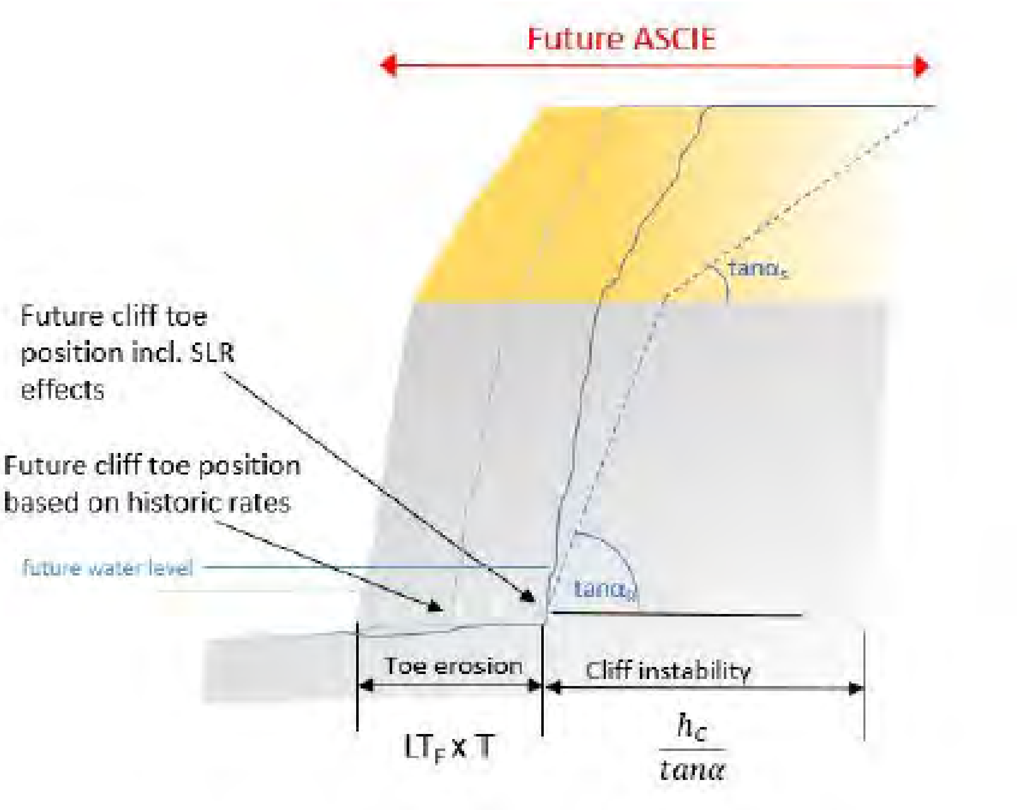


Figure 4: Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline.
Soil is shown in yellow, with rock below in grey.

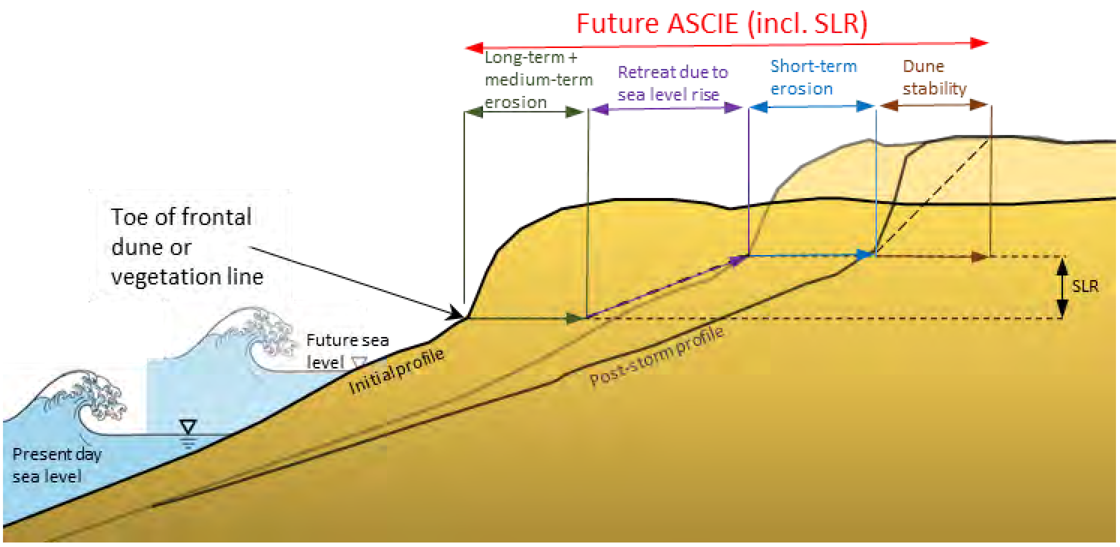


Figure 5: Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on open coast beach shoreline

The results for each cell are presented in Part 2 of this report in both tabular format and indicative, regional scale heat maps. There are separate maps for coastal cliffs and beaches.

3.0 Results

Full results are presented in Part 2 of this report (the *"Areas Susceptible to Coastal Erosion and Instability in the Auckland Region*").

3.1 Cliffs

For the 2130 RCP 8.5 M scenario, ASCIE distances across Auckland cliffs vary, particularly with geological type, exposure and cliff height. For example, distances range from less than 20 m for low Tauranga Group cliffs in sheltered harbour environments, to more than 200 m for high cliffs along the open and exposed coast of Great Barrier Island (see Figure 6).

For low cliffs, toe erosion is generally the dominant factor, particularly in more recent, weak geology. In higher cliffs, the toe erosion is generally a relatively small component, while potential slope instability triggered by the toe erosion is responsible for the majority of the reported distances. The cliff toe regression component becomes more important over longer timeframes (i.e. 2080-2130).

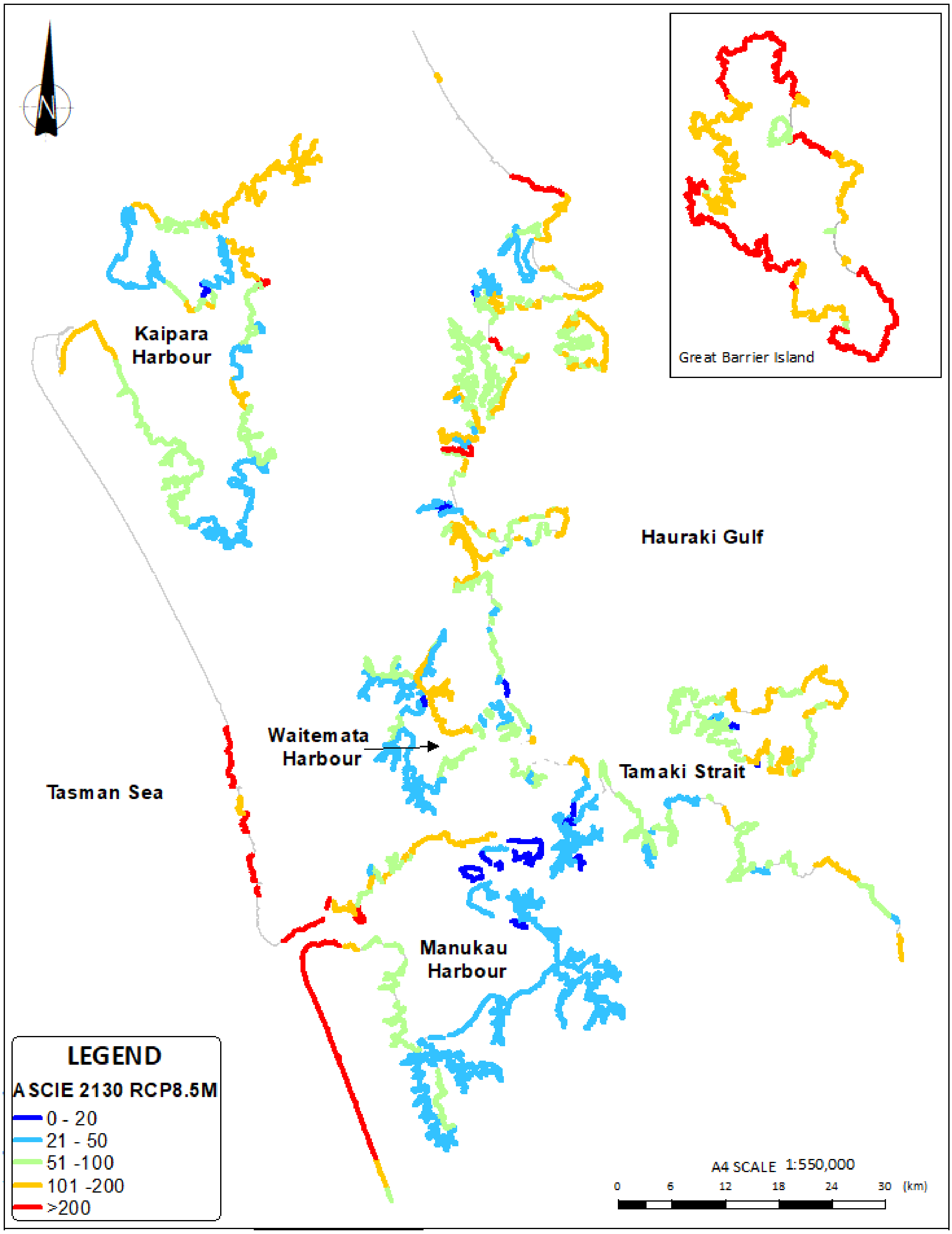


Figure 6: Colour map of the banded ASCIE distances for cliffs at 2130 adopting the RCP8.5M

3.2 Beaches

The range of total ASCIE distances for each environment reflects the effect of site-specific factors on the final erosion rate, such as historic long-term changes in shoreline position and dune height.

The resulting ASCIE for beaches is a combination of five parameters of which the short-term component (e.g. erosion due to storms) typically dominates for timeframes between 2030 and 2050, while the sea level rise response and historic long-term component dominates for the longer timeframes (i.e. 2080-2130).

Under the 2130 RCP 8.5 M scenario, predicted erosion values for beaches across Auckland vary from less than 20 m in sheltered harbour coast beaches to more than 190 m along the highly exposed shorelines of the Outer Hauraki Gulf and West Coast (see Figure 7). Sea level rise is a major contributor to the high ASCIE values, in some cases adding more than 90 m to expected values.

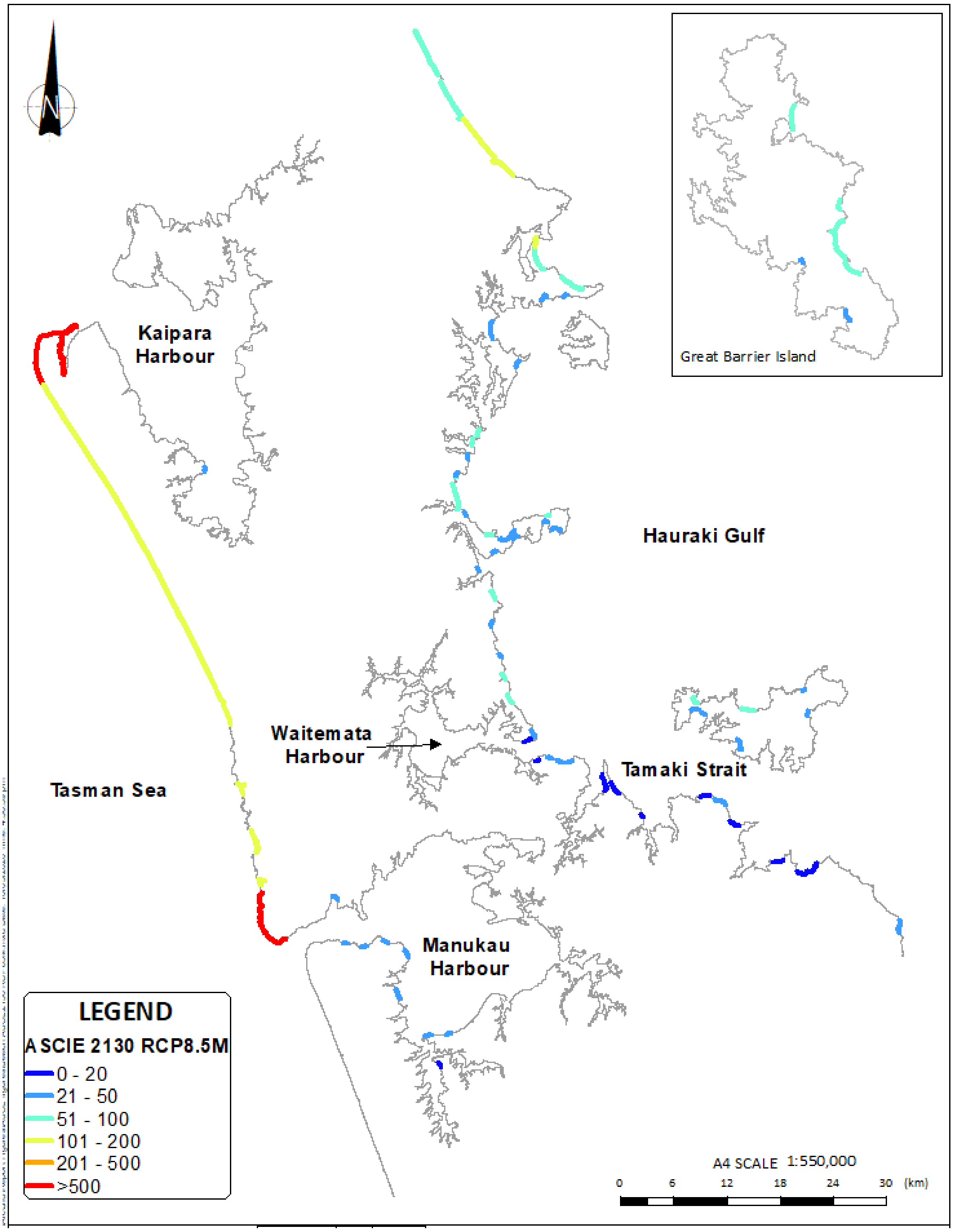
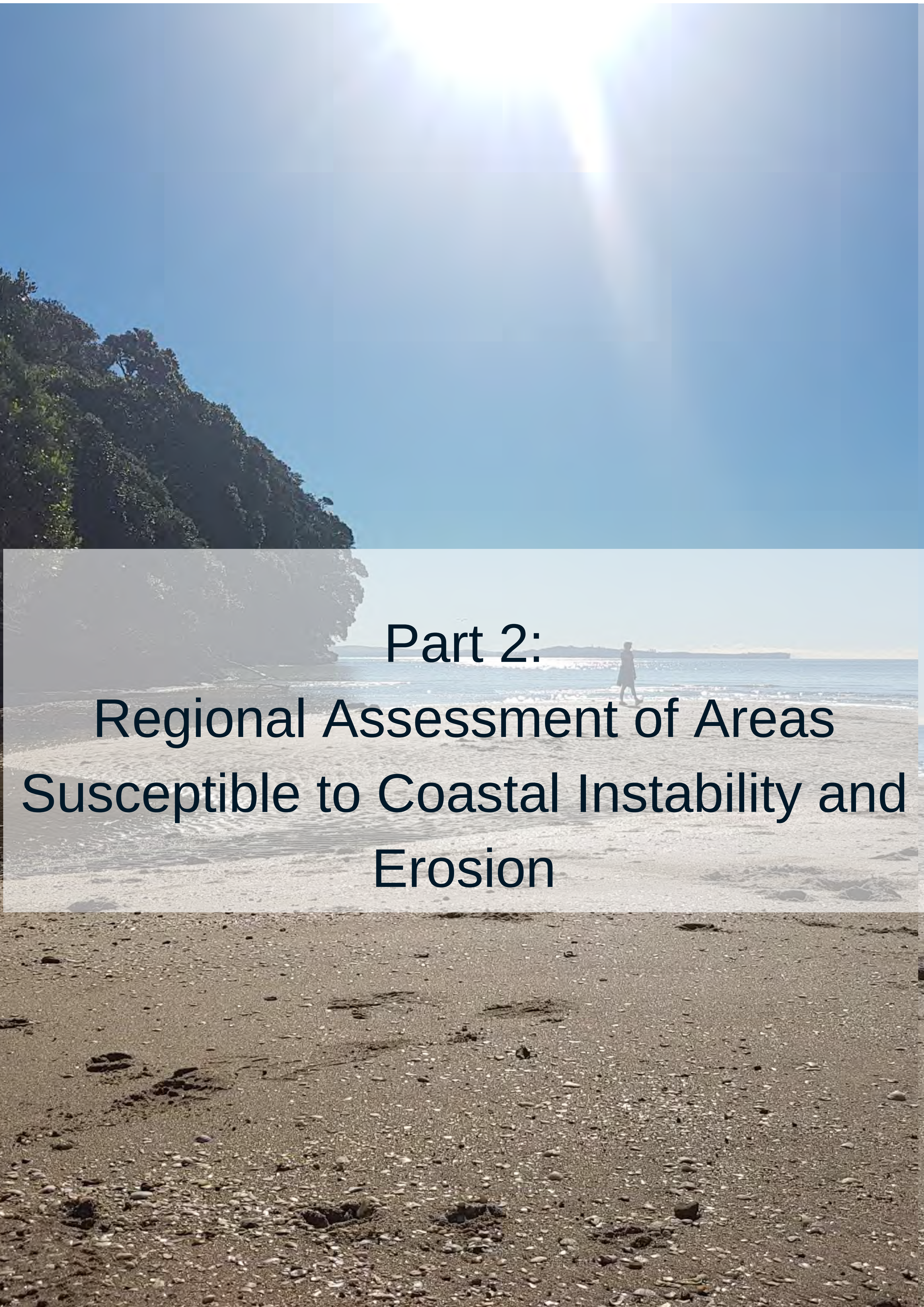


Figure 7: Colour map of the banded ASCIE distances for beaches at 2130 adopting the RCP8.5M

4.0 Next steps

While the regional 'heat map' provides a high-level understanding of the potential erosion rates across Auckland's coastline, further work needs to be done to refine the model and provide more detailed mapping showing areas susceptible to coastal instability and erosion at a sub-regional level. To achieve this, cliff heights will be sampled at more regular intervals (e.g. 20 m) to increase accuracy of the erosion assessment, and areas where cliffs meet beaches will be individually assessed to ensure any large changes in erosions between nearby areas are realistic. Detailed lines showing the potential areas of Auckland's coast that may be at risk within the 100-year study period will be generated and released on Auckland Council's online GeoMaps portal after review.

Maps showing the more detailed lines are not intended for site-specific use (e.g. when making decisions about building design). Rather, they indicate the areas within which more detailed studies should be considered to define the risk. The mapping will enable Aucklanders to review and engage with our current understanding of long-term coastal change and climate change impacts and will inform future sustainable hazard management approaches for the region.



Part 2:
Regional Assessment of Areas Susceptible to Coastal Instability and Erosion

REPORT

Tonkin+Taylor

Regional Assessment of Areas Susceptible to Coastal Instability and Erosion

Regional Assessment

Prepared for
Auckland Council
Prepared by
Tonkin & Taylor Ltd
Date
January 2021
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January 2021	6	Final report including errata	P.Knook	R.Reinen-Hamill	R.Reinen-Hamill

Errata:

- Changed Equation 4.2 by removing LT_H (page 27)
- Changed Equation 4.4 by removing LT_H (page 28)
- Updated text in Section 4.3.1 to reflect changes in Equation 4.2 and Equation 4.4 (page 27)
- Updated Figure 4.6 to reflect changes in Equation 4.2 and Equation 4.4 (page 28)
- Updated Equation 5.3 by replacing R with LT_F (page 47)
- Updated Appendix F to include footnote regarding variable resulting cliff ASCIE distances.

Distribution:

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Regional Assessment

Glossary of terms

Term	Description
Active translation profile	Cross-shore beach profile across which sediment can be transported in onshore or offshore direction
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ASCIE	Area Susceptible to Coastal Instability and/or Erosion
ASCE2006	Areas susceptible to coastal erosion derived by Reinen-Hamill et al. (2006)
AUP	Auckland Unitary Plan
AVD-46	Auckland Vertical Datum 1946
Bruun Rule	A simple mathematical relationship that states: as sea-level rises, the shoreface profile moves up and back while maintaining its original shape
CMP	Coastal Management Plan
CD	Chart Datum
CDF	Cumulative distribution function
CI	Confidence interval
Coastal accretion	A long-term trend of shoreline advance and/or gain of beach sediment volume
Coastal erosion	Landward movement of the shoreline which may include both long-term retreat over several years or decades and short-term loss of sediment due to storms
Coastal hazard	Where coastal processes adversely impact on something of value resulting in a hazard
CS	Cliff stability component
DEM	Digital Elevation Model
DS	Dune stability component
ECBF	East Coast Bay Formation. Type of cliff geology.
ENSO	El Nino Southern Oscillation
GSI	Geological Strength Index from Marinos and Hoek (2001) and Hoek et al., (2013) and subsequent development
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
LiDAR	Light Detection and Ranging – a method of remotely deriving land elevation, generally from an aeroplane
LT	Long-term erosion component
LT_H	Historical long-term erosion component
LT_F	Future long-term erosion component
m	Sea level rise response factor for cliffs
MfE	Ministry for Environment
MHWS	Mean high water springs – a measure of high tide based on a statistical exceedance of high tides in a month
MHWS-10	Water level exceeded by 10% of the MHWSs
MLWS	Mean low water spring – a measure of low tide based on a statistical exceedance of low tides in a month

Term	Description
MSL	Mean sea level. Sea level averaged over a long (multi-year) period
MT	Medium-term erosion component
NZCPS	New Zealand Coastal Policy Statement
NZGD	New Zealand Geology Department
NZVD2016	New Zealand Vertical Datum 2016
OSA	Overall stable angle
PDF	Probability distribution function
PTM	Profile translation method
RCP Scenario	Representative Concentration Pathways (RCPs) are four greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014
RL	Reduced Level (Auckland Vertical Datum 1946)
RMA	Resource Management Act
SD	Standard Deviation
SLR	Sea level rise. Trend of annual mean sea level over timescales of at least three or more decades. Must be tied to one of the following two types: global – overall rise in absolute sea level in the world's oceans; or relative – net rise relative to the local landmass (that may be subsiding or being uplifted)
SL	SLR component
ST	Short-term erosion component
Cliff instability distance	Horizontal distance between the cliff toe and cliff crest
T+T	Tonkin + Taylor (Tonkin & Taylor Ltd.)
VLM	Vertical land movements

1 Introduction

1.1 Background and purpose

Auckland Council previously commissioned Tonkin & Taylor Ltd (T+T) to provide a regional assessment of Areas Susceptible to Coastal Erosion (ASCE). The report, delivered in 2006 (Reinen-Hamill et al., 2006) used a combination of available information and additional site-specific data to derive likely, possible, unlikely and rare areas susceptible to coastal erosion for the entire Auckland region coastline. These areas were not mapped at that time as a robust definition of the coastal edge was not available.

Auckland Council now requires a revised erosion study for the Auckland region including an updated technical report to spatially identify areas susceptible to coastal instability and/or erosion. The requirement is to consider a range of planning horizons out to at least 100 years, consider a range of sea-level rise (SLR) scenarios aligned with national guidance and use best practice approaches. The results are intended for use by Auckland Council in understanding the potential extent of the hazard and the long-term implications of climate change, contributing to future natural hazards education and decision making. The intended use and limitations of this study (see Section 1.4) should be considered and understood before the results of this study are used.

A Stage 1 scoping assessment was undertaken prior to this Stage 2 assessment and includes a review of the previous assessment (Reinen-Hamill et al., 2006), as well as of more recent literature, policy, guidance and data. This was used to identify knowledge and information gaps in the previous assessment, which require updating. Appropriate methodologies were developed to allow quantification of coastal erosion for the different coastal types in the Auckland region.

This study (Stage 2) includes a regional-scale assessment to identify and map the areas of land potentially susceptible to coastal erosion and/or land instability associated with this erosion. Two more detailed, local-scale assessments have been undertaken in parallel, one for an unconsolidated beach shoreline (Omaha Beach; T+T, in prep. a) and one for a consolidated cliff shoreline (Stanmore Bay; T+T, in prep. b). The detailed assessments have been used to verify the methodologies adopted for the region-wide assessment and confirm results are applicable on a regional scale.

1.2 Study scope

Areas susceptible to coastal instability and erosion (ASCIE) have been assessed for the entire Auckland coastline including Auckland mainland, Great Barrier Island, Waiheke Island and Kawau Island. The remaining islands within the Auckland region are outside of the scope of this study. The assessment is based on the following scope of works:

- review background data to ascertain key processes, historical changes, split up the shoreline in coastal cells and to select the most appropriate conceptual model of erosion for each coastal cell.
- assess values of the components contributing to coastal erosion and associated instability along the Auckland shoreline according to the adopted model.
- calculate erosion distances deterministically for the regional-scale assessment considering uncertainty in values.
- apply the coastal erosion methodology for current and future sea level scenarios aligned with national guidance and best practice approaches.
- produce a technical report describing the models and methodology utilised and a discussion of the results.

- produce maps of ASCIE lines for selected timeframes, SLR scenarios and likelihoods separately in GIS format following the publication of this report.

The following scenarios (timeframe + SLR scenario) have been assessed and mapped for this study as requested by Auckland Council:

- 2050 RCP8.5M.
- 2080 RCP8.5M.
- 2130 RCP8.5M.
- 2130 RCP8.5H+.

These scenarios have been selected to inform ASCIE information mapping, planning and long-term implications of climate change. The short-term ASCIE (i.e. 2030 timeframe) has been considered in this report but was not requested to be mapped.

1.3 Adopted level of detail

In relation to a coastal hazard assessment, MfE (2017) advocates the use of a two-level assessment:

1. A first-pass assessment that takes into account the various hazard drivers as outlined in the NZCPS Policy 24 (1) (a) – (h).
2. A more detailed, second-pass or low-level assessment that enables a more thorough understanding of the coastal processes, uncertainties and the effects of different future SLR scenarios, and thus the likelihood of hazard occurrence.

This is essentially a technical risk assessment process (Kenderdine et al., 2016). It comprises a two-level assessment. A "*first-pass"* assessment should take into account the various hazard drivers as outlined in the NZCPS Policy 24. A more detailed 'second' assessment could then be undertaken on a local to site-specific scale for areas that have been identified as high-risk areas in the 'first-pass' assessment.

This approach is supported by Carpenter et al. (2017). The hierarchy of spatial assessment scales included by Carpenter et al. (2017), indicate that a regional-scale assessment should be undertaken first/before to inform lower scale assessments (e.g., for asset management planning or localised hotspot management.

In line with the NZCPS (2010), MfE (2017) and Carpenter et al. (2017), levels of details for coastal erosion hazard assessments have been derived and are shown in Table 1.1 including the alongshore spatial scale. This report sets out a regional-scale assessment for the whole Auckland shoreline (level A), with local-scale assessments undertaken for Stanmore Bay and Omaha Beach (level B).

Table 1.1: Levels of detail for coastal erosion hazard studies

Level	Adopted levels of detail	Adopted alongshore scale/length
A	Regional-scale	0.5-5 km
B	Local-scale	10-100 m
C	Site-specific scale	1-10 m

1.4 Intended use and limitations

The purpose of the ASCIE identified within this 'first-pass' assessment is that they represent land potentially susceptible to coastal erosion and/or land instability associated with this erosion at a regional scale for present day conditions and a range of possible future climate change states. This means the areas outside of the identified ASCIE may be considered unlikely to be susceptible. It should be noted that this 'first-pass' assessment has been undertaken at a high level (regional scale) and may be superseded by local and site-specific scale assessment by a suitably qualified and experienced practitioner. The two local-scale assessments undertaken in parallel with this 'first-pass' assessment report (refer to T+T, in prep. a and T+T, in prep. b) show examples of how the regional-scale assessment can be scaled down to a higher level of detail.

The regional-scale assessment of ASCIE is based on available data and tools and understanding of coastal processes. Uncertainty may be introduced to the assessment by:

- an incomplete understanding of the parameters influencing the areas susceptible to coastal instability and/or erosion.
- an imprecise description of the natural processes affecting, and the subsequent quantification of each individual parameter.
- errors introduced in the collection and processing of data.
- scale of assessment and variance in the processes occurring within individual coastal cells.
- other hazards such as land based geotechnical instability, or planning and landscape impacts, etc. that are not accounted for within the ASCIE.
- adopted methodologies.
- the scale of the mapping – regional heat maps.

Of these uncertainties, the alongshore variance of individual coastal cells may be reduced by splitting the coast into continually smaller cells. However, available data, such as beach profiles, are often available only at discrete intervals, meaning increasing cell resolution may not necessarily increase data resolution and subsequent accuracy. Computational and resource limitations also restrict the practical number of cell divisions. The cells have been refined as far as practical for a regional-scale assessment based on factors which could significantly affect results. Residual uncertainty may be allowed for by including the uncertainty in the total ASCIE value.

Uncertainty in individual parameters is incorporated into the present assessment by adopting typical upper bound values and considering uncertainty values for each component. Uncertainties in individual parameter components will reduce as better and longer local data is acquired, particularly around rates of short- and long-term shoreline movement and shoreline response to SLR. Data collection programmes such as beach profiling are essential to reducing this uncertainty and should be continued and starting cliff laser scanning programmes would be recommended. In the interim, typical upper bound values have been adopted which is in line with a *regional screening* assessment as recommended by MfE (2017). For future updates uncertainties may be reduced based on longer and more detailed datasets available.

Due to the large scale of the assessment (i.e., 0.5-5 km resolution) errors are inherently introduced due to the variance within a coastal cell. To identify areas that could potentially be susceptible to coastal instability and/or erosion typical upper bound values have been adopted for each coastal cell. This means that in some areas the ASCIE may be overpredicted (i.e., shown further landward). However, this also means that in ASCIE may be underpredicted in areas where values are larger than the typical upper bound value (i.e., the largest or maximum values). Therefore, this assessment is recommended to be used as a preliminary tool. The regional-scale ASCIE can be refined by undertaking an assessment on a more detailed scale (see framework for refinement of ASCIE in Section 8).

The ASCIE values assessed for this study identify areas susceptible to processes related to coastal erosion only, including instability of the land above. Other hazards and requirements such as, but not limited to, land based geotechnical instability, planning, amenity, and landscape matters, are not accounted for within the ASCIE. If these ASCIE derived in this report are used for residential development or subdivision purposes, these more refined assessments may alter the zones generated from the regional assessment approach. The appropriate assessments should consider issues associated with visual effects, amenity, recreation, effect of non-residential buildings such as in ground or above ground utilities, fences, and paths etc.

The methodologies adopted in this report are based on best practice. These methods are typically based on theoretical understanding of coastal processes and are simplified such that they are appropriate for most of the shorelines. However, there may be shorelines that behave differently and cannot be described by one of the adopted methods. For instance, if the cliff crest and cliff toe become physically disconnected (e.g., due to cliff top erosion or land sliding), the adopted method for cliffs may not be entirely appropriate. Furthermore, in this regional-scale assessment a distinction between true cliffs (actively eroding) and coastal hill slopes (formed over millenniums) could not be made, with both types considered as coastal cliffs. Likewise, if a beach contains a rocky substrate or is backed by a cliff then the methodology used to assess hazard for beach environments may not be appropriate in the future if the beach is completely removed. Nonetheless, for these shorelines, the most representative method is adopted to predict the area potentially susceptible to coastal erosion.

1.5 Report layout

The report is structured as follows:

- the coastal setting and historical context are described in Section 2.
- data sources are outlined in Section 3.
- methodology for deriving ASCIE in Section 4.
- derivation of components for coastal erosion in Section 5.
- results and discussion of erosion susceptibility assessment in Section 6.
- framework for refinement of ASCIE in Section 8.
- a summary of the assessment and recommendations are outlined in Section 9.

2 Auckland coastal environment

2.1 Regional setting

The Auckland region lies between the Tasman Sea to the west and the Hauraki Gulf to the east. The region includes three major harbours and several large islands within the Hauraki Gulf. The Auckland region including major islands (i.e., Great Barrier Island, Waiheke Island and Kawau Island) includes some 3,200 km of shoreline consisting of:

- Consolidated shorelines, which can be subdivided in:
  - Estuarine banks, which are typically low-lying, and
  - Hard and soft cliffs, which can be over 100 m high and highly exposed.
- Unconsolidated beaches, including large open coast beaches and small headland-bound, pocket beaches.
- Reclaimed shorelines, which are typically comprised of land fill and protected by coastal structures.
- Protected shorelines. These are consolidated, unconsolidated or reclaimed shorelines protected by a coastal protection structure such as vertical walls, sloping revetments, etc.

Based on the coastal setting, the Auckland shoreline can be broadly classified into five different areas (see Figure 2.1 for extent of different areas). Note that smaller embayments that are sheltered within larger, more active environments have not been split up for this regional-scale assessment.

Open West Coast

The open west coast shoreline extends from Kariotahi to the southern head of Kaipara Harbour. The shoreline is typically a high energy environment, comprising large exposed coastal cliffs and dissipative beaches.

Outer Hauraki Gulf

The outer Hauraki Gulf includes the open east coast shoreline between Takatū Point and Mangawhai as well as Great Barrier Island. The outer Hauraki Gulf shoreline is exposed to the open ocean storms from north to east.

Inner Hauraki Gulf

The inner Hauraki Gulf includes the open east coast shoreline between Takatū Point and Takapuna as well as Kawau Island and the northern side of Waiheke Island. The inner Hauraki Gulf is bound by the Coromandel Peninsular to the east and has multiple islands. In general, the inner Hauraki Gulf is typically a more sheltered environment compared with the outer Hauraki Gulf.

Tamaki Strait

Tamaki Strait separates the mainland from Waiheke Island along the southern edge of the Hauraki Gulf. The Strait is approximately 6 to 12 km wide with relatively sheltered cliff and beach shorelines, including the southern side of Waiheke Island and the south eastern side of Auckland.

Harbour environments

The Auckland region includes three harbours, the Kaipara Harbour and the Manukau Harbour on the west coast and the Waitematā Harbour on the east coast. The Kaipara Harbour is the largest of the harbours and is located north of Auckland City with mostly rural harbour margin. The Manukau Harbour is located south west of Auckland City and is characterised by urban development along the eastern margin, with small settlements and rural land around the northern and southern margins.

The Waitematā Harbour is located close to the Auckland City centre, with urban development around majority of the harbour margin. The harbour shorelines are relatively sheltered environments.

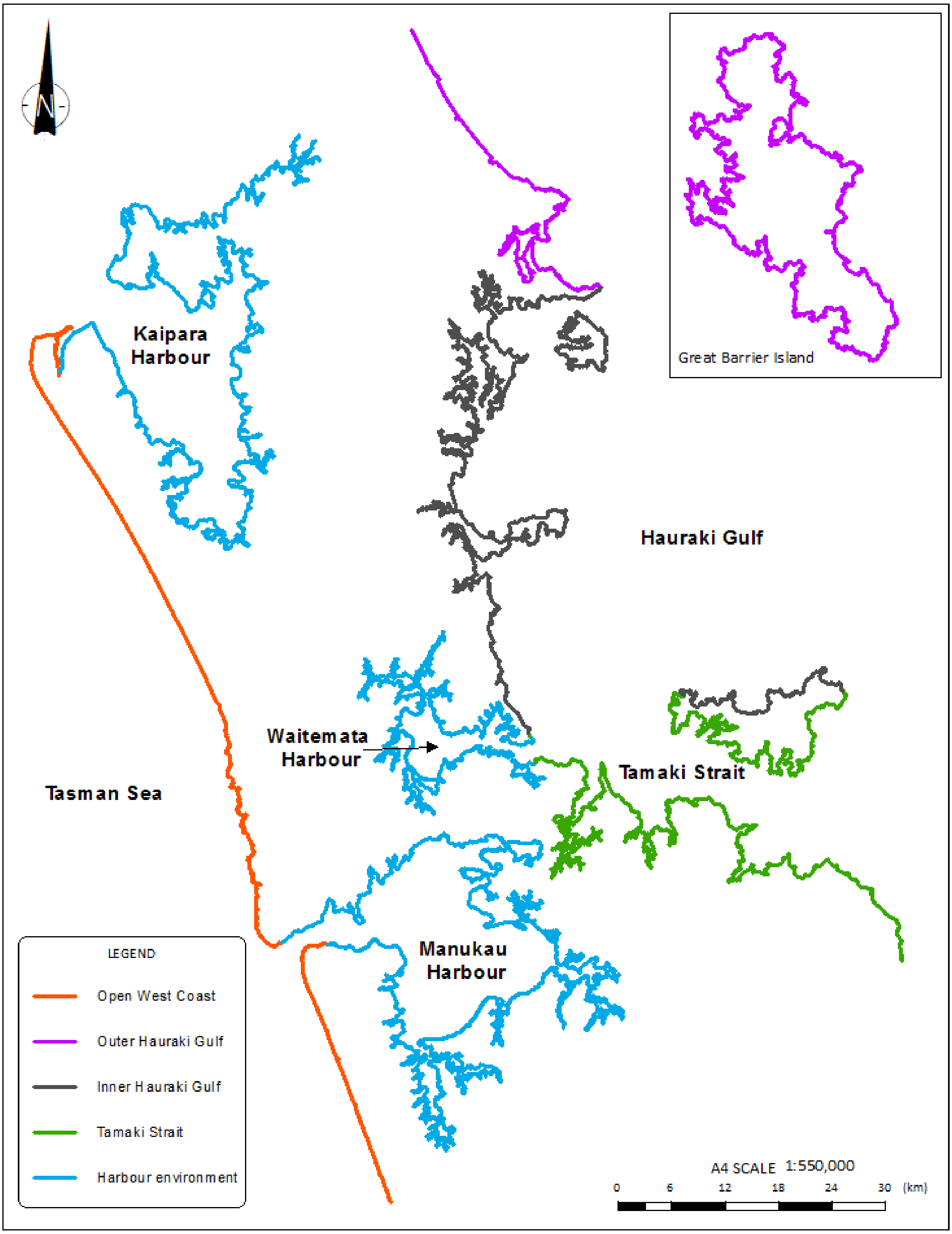

Figure 2.1: Five main coastal areas in Auckland

2.2 Vertical land movement

Beavan and Litchfield (2012) have assessed vertical land movement (VLM) around New Zealand's shoreline. Figure 2.2 shows the estimated vertical land changes (mm/year) for the North Island. They found that at the Auckland measurement gauge the VLM was relatively stable based on a 10-year measurement duration. At the Warkworth site a subsidence rate of 0.7 mm/year was estimated based on a 3-year record. Overall, the measurement gauges at Whāngārei, Coromandel and Auckland show a relatively stable VLM based on a measurement period around 10 years.

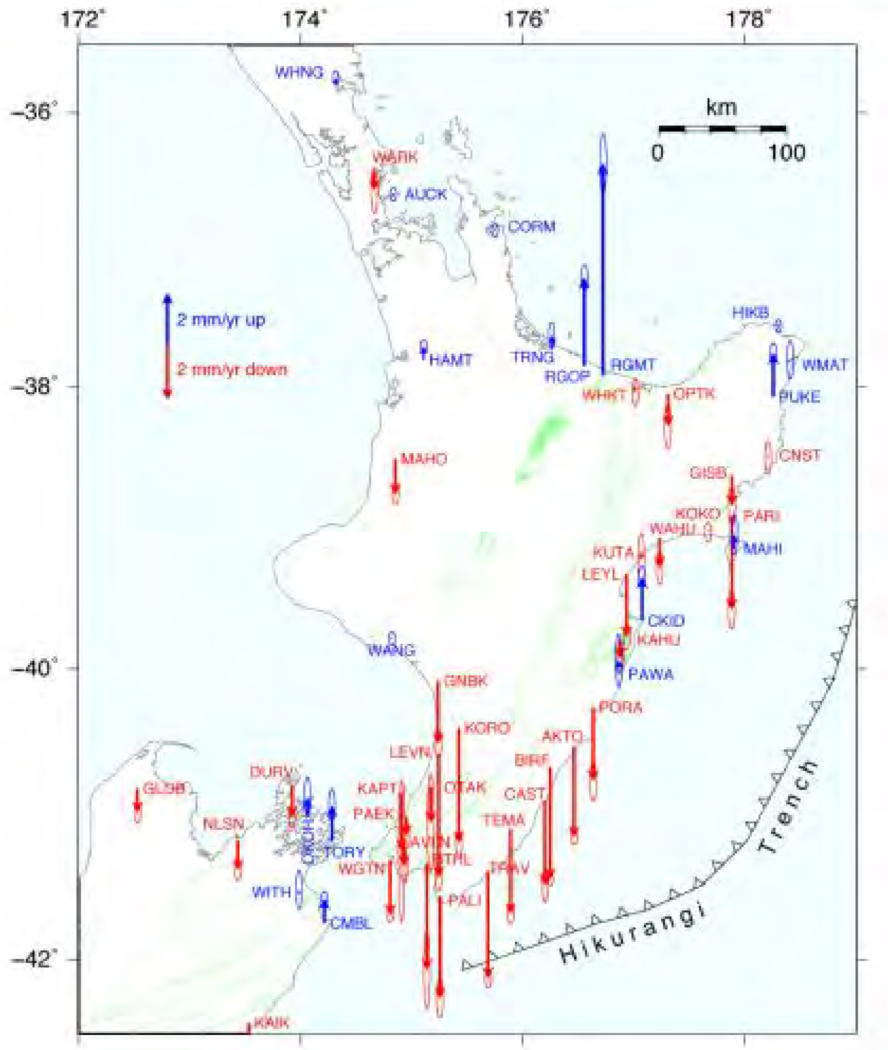

Figure 2.2: Estimated vertical land changes for North Island by Beavan and Litchfield (2012)

2.3 Geology

The geology of the Auckland region can be divided into a range of lithologies based on series or age, stage and formation, and composition, as shown on the geological maps (Edbrooke, 2001 - Figure 2.3; Kemode, 1992) and in Appendix D. The geology of the coastal slopes can then be divided into two types based on their shear strength:

1 Soils (generally less than 1MPa).

2 Rock (greater than 1MPa).

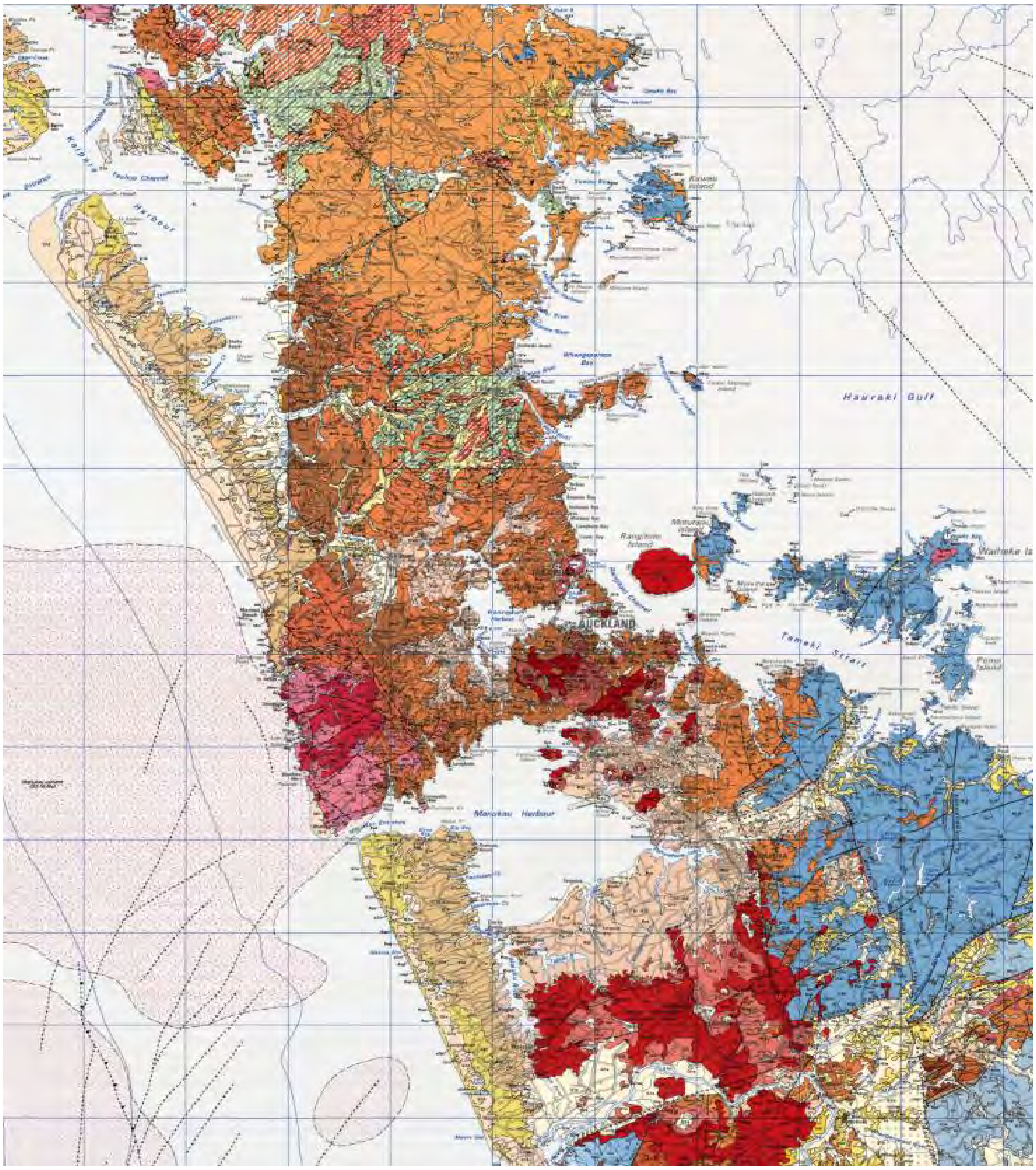

Figure 2.3: Simplified geological map for Auckland region (Edbrooke, 2001)

2.3.1 Soil

Soil cliffs or coastal slopes were defined as generally lightly cemented, cohesive soils consisting of marine, alluvial and organic materials, generally within the Tauranga Group, or residual soils derived from the parent material. These materials are typically youngest within each area and are often derived from the erosion of older formations. Soil shorelines are typically characterised by a low inter-tidal flat backed by a bank or cliff up to 10 to 15 m high. These inter-tidal flats are typically submerged at high tide and generally consist of material eroded off the bank. Soil-shores primarily exist in estuarine environments such as the Waitematā, Manukau and Kaipara Harbours, but can also be located on exposed shorelines with a shore platform.

Material strengths for soils are generally firm to hard clays and silts (25 to 500 kPa) and loose to dense sands and gravels, occasionally entering into the lower end of extremely weak rocks (at 500 kPa) when lithified or cemented. The instability mechanism within these materials are dependent on the cohesive and frictional properties on the type of material (clays, silts, sands and gravels, with/without organics), with coastal instability mechanisms through rotational and translational slides or high angle topples and brittle toe buckles. The instability mechanisms of these soils appear to be primarily a result of toe erosion and homogeneous collapse of over-steepened material.

The location of the soil cliffs, which are highly variable in composition throughout the Auckland region, were determined directly from geological maps, experience and knowledge of the project team. These are mainly contained within four groups:

1. Residual soil: highly to completely weathered parent rock with the removal of structure and fabric.
2. Coastal sediments, Karioitahi: dunes, weakly cemented dune and inter-dune facies.
3. Alluvial sediments, Tauranga Group: soft sediments ranging from clays to sand with gravels and peat.
4. Āwhitu Group: moderately consolidated dune sands south of Awhitu Peninsula, Manukau Heads to the west of the region which appear to be spatially uniform.

2.3.2 Rock

Rock cliffs were defined based on their geological units from Edbrooke (2001). However, each geological unit is unique within its coastal location, with variations in strength, weathering and the tectonics history of the material, all that having an influence on the rock mass structure and discontinuity networks. The two most influential material properties for coastal instability are strength and structure. As the intact rock strength increases the instability mechanism alters from material strength dominated (rotational, semi rotational slides) to structurally controlled instability (high angle falls/topples along planes or wedges) due to the rocks' structures having a lower strength than the rock material.

To domain a rock mass, the lithology and weathering needs to include the unique structures (joints, beds, faults, folds). The structures divide the rock up into a series of interlocking blocks of varying sizes and shapes that are used in qualitative or quantitative classification of the rock mass strength. The individual discontinuity properties then have the most significant effect on the rock mass strength and are fundamental in the understanding of the coastal slopes' global stability. The rock slope shorelines were divided into the following domains:

1. Auckland Volcanic Field and Coromandel Volcanic Zone, with lava / lava-breccia, andesite, dacite, tuff, ash, lapilli and scoria. The lavas range from moderately strong, to very strong (20 to 250 MPa)
2. Akarana Supergroup, split into:

a Waitematā Group rocks, while more uniform in their weathering profile, differed markedly in geological structure. Some were horizontally and uniformly layered, with little apparent defects, while other areas were intensely deformed and faulted. These rocks appeared to be of lower heights, flatter slopes and undergoing more recent erosion. They are extremely weak to very weak mudstones, siltstones and sandstones, particularly the East Coast Bays Formation (ECBF); 500 kPa to 5 MPa, to the weak to moderately strong Pākiri Formation (10-25 MPa), which has a higher volcanic content.

b Waitakere Group rocks more complex that the Waitemata Group with the inclusion of andesite tuff breccias, pillow lava flows, intrusions, volcaniclastic sandstones and siltstones. This increases the material strength ranging from very weak to strong (2 to 100 MPa).

3 Northland Allochthon, sheared mudstones, siltstone and limestones, that was emplaced into the Waitemata Group in the north of the region. Material strength is highly variable.

4 Waipapa Group greywacke (sandstones and siltstones) that vary from extremely weathered, low strength cliffs in the Firth of Thames to much fresher, more competent material on the more exposed Tawharanui Peninsula. The unit is generally weak to moderately strong (5 to 25 MPa).

2.3.3 Coastal slope domains

The coastal slopes have been divided into two types, soil or rock, then into eight domains based on their Group or Formation name, as shown in Table 2.1.

Table 2.1: Adopted geological domains for this study

Type	Domain name	Comment
Soil	Tauranga Group	Soft sediments ranging from clays to sand with gravels and peat (incl. Tauranga Group, Puketoka Formation)
Soil	Āwhitu Group	This includes the Kariotahi Group and Awhitu Group comprised of dunes, weakly cemented dune and inter-dune facies
Rock	Auckland Volcanic Field and Coromandel Volcanic Zone (termed AVF/CVZ)	Mixed domain which is not able to be separated based on individual units due to the regional scale. This includes lavas, scoria, tuffs, ash
Rock	ECBF	Waitematā Group - East Coast Bay Formation, and a low volcanic content
Rock	Pakiri Formation	Other Waitematā Group Formations with a higher volcanic content, which increases the strength and generally decreases number of structures
Rock	Waitakere Group	This predominately silts and sands with varying volcanic content, either as intrusions, lavas, breccias or volcaniclastics
Rock	Northland Allochthon	Emplaced/thrusted into the Waitemata and Waitakere Groups
Rock	Waipapa Group	Greywackes, argillites

2.4 Sediments

Beach sediment properties around the Auckland region are described by Reinen-Hamill et al. (2006). Sediment characteristics are broadly consistent within each area.

Open west coast

Sediment on the open west coast is typically black sands containing a significant amount of heavy minerals such as iron ores, lighter quartz and feldspar (Hamill and Balance, 1985; Blue & Kench, 2018). Most of the sediments originate from andesitic volcanic rocks of Taranaki and historically from the Taupō Volcanic Zone via the Waikato River (Hamill and Balance, 1985). However, due to construction of several dams on the Waikato River the sediment supply from the river has reduced (King et al., 2006).

Outer Hauraki Gulf

Sediments in the outer Hauraki Gulf are typically clean, well sorted, fine to medium sands. Sandy sediments tend to extend offshore to depths of 60 m before being covered by a layer of mud. Schofield (1985) suggests the sand is derived predominately from rock formations in central North Island and is sourced from when the Waikato River flowed into the Firth of Thames during the last glaciation.

Inner Hauraki Gulf

Sediments within the inner Hauraki Gulf are a combination of mud/silt tidal flats in the sheltered regions and sandy beaches on the slightly more exposed areas, particularly in the north. However, the sandy beaches tend to be perched on top of tidal flats. It is understood that the main source of sediment along the inner Hauraki Gulf shorelines is broken shell from nearshore shellfish beds and erosion from local cliff and streamed catchments.

Harbour environments

Sediments within the harbours tend to vary with fine silts and mud occurring in the low energy areas and medium to coarse sands accumulating in the higher energy areas. This general pattern is consistent across the three harbours (Manukau, Waitematā and Kaipara) and is predominately due to the high and low energy regimes driven by wave and/or tidal currents.

2.5 Topography and bathymetry

Topography has been assessed using the Digital Elevation Model (DEM) derived from LiDAR (Light Detection and Ranging) data captured in 2016-2018 for the entire Auckland region (refer to Section 3.3). The DEM was used for determining cliff/dune crest and toe elevations and cliff/dune/beach slopes. An example of the DEM at Omaha Beach is shown in Figure 2.4.

Offshore bathymetry was sourced from LINZ hydrographic charts (see example for Omaha Bay in Figure 2.4). The bathymetry was used to derive cross-shore profiles for numerical model input (see example in T+T, in prep. a) and to derive closure slopes for the SLR component (see Section 5.5.3).

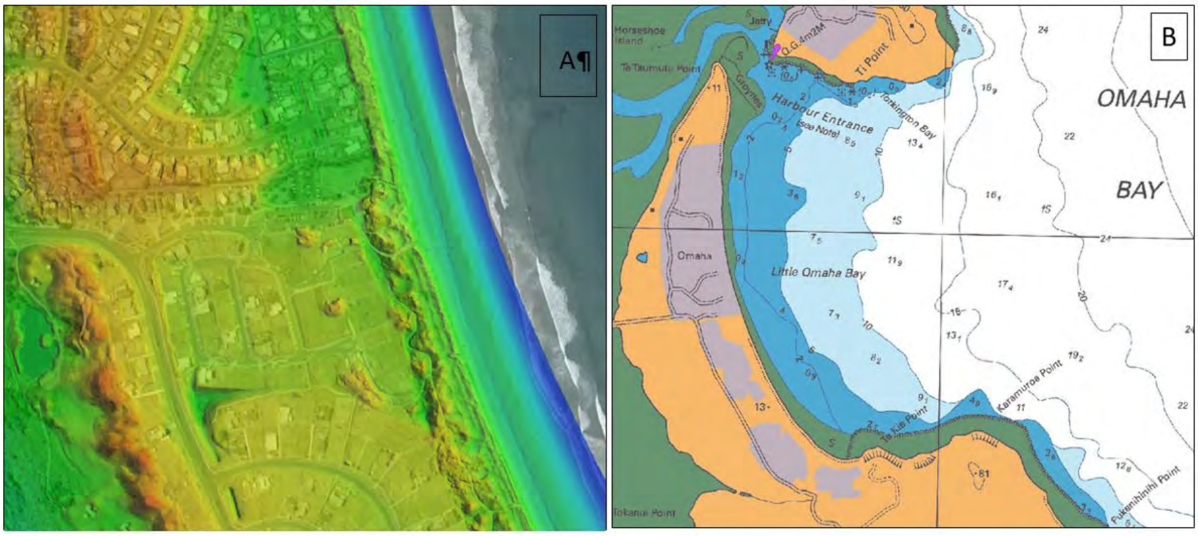

Figure 2.4: Examples of the 2016-2018 LiDAR-derived DEM at Omaha Beach (A) and LINZ hydrographic chart NZ5212 at Omaha Bay

2.6 Reclaimed land

The majority of Auckland's shoreline is comprised of natural beaches, cliffs and embankments. However, there are sections of shoreline along which land has been reclaimed. Examples of this are ports, harbours, marinas and for other major infrastructure works such as the state highways. The largest reclaimed land area in Auckland is the Port of Auckland (see example in Figure 2.5 showing the historical shoreline position in 1840 and the present-day outline of the shoreline on a recent aerial photograph). Reclaimed areas/shorelines are typically comprised of fill material and are protected by coastal protection structures. These coastal protection structures are typically maintained as they typically protect major infrastructure works, such as state highways and ports.

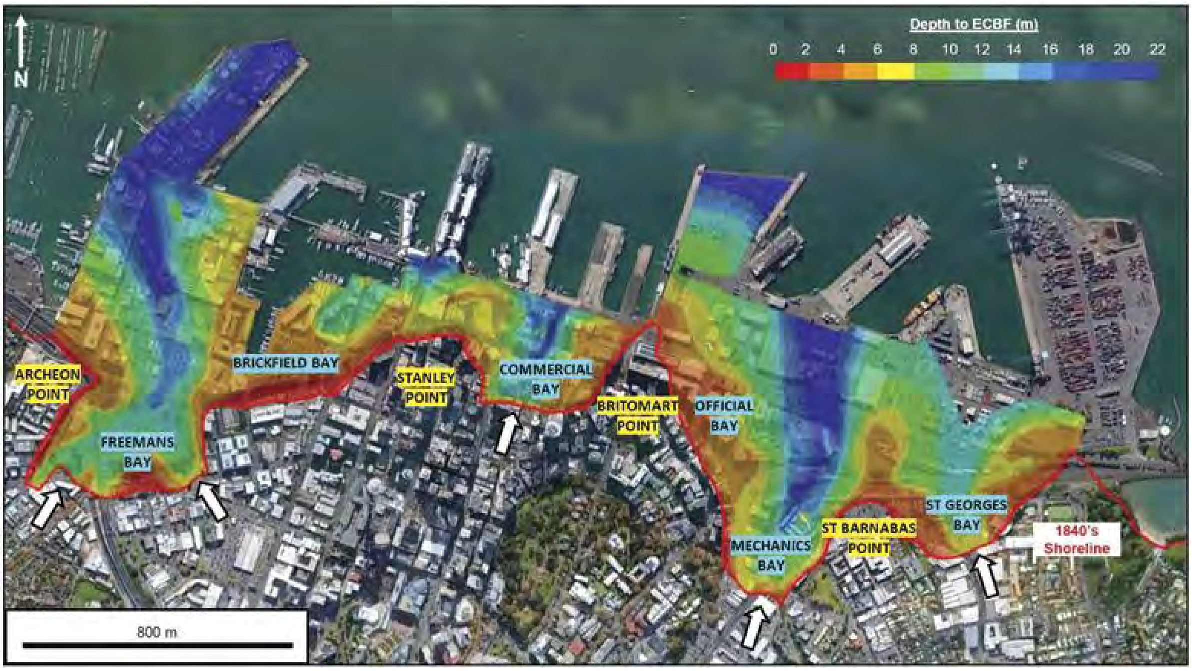

Figure 2.5: Auckland CBD's historical (1840s) shoreline shown as a red line, the coloured area shows the depth to ECBF (Source: Lee and Wotherspoon, 2016)

2.7 Coastal water levels

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

Key components that determine water level are:

- Astronomical tides.
- Barometric and wind effects, generally referred to as storm surge.
- Medium term fluctuations, including ENSO (El Niño–Southern Oscillation) and IPO (Interdecadal Pacific Oscillation) effects.
- Long-term changes in sea level.
- Wave transformation processes through wave setup and run-up.

2.7.1 Astronomical tide

Tidal levels for primary and secondary ports around Auckland are provided by LINZ (2019) based on the average predicted values over the 18.6-year tidal cycle. The spring tidal levels and mean sea levels for the different open coast areas and harbours are presented within Table 2.2. Tidal levels are based on the primary or secondary ports and are shown in terms of Auckland Vertical Datum 1946 (AVD-46), hereafter referred to as Reduced Level (RL).

Table 2.2: Astronomical tide around Auckland region (LINZ, 2019)

Location (primary/secondary port)	Tidal level (RL m)		
	Mean High Water Springs (MHWS)	Mean Sea Level (MSL)	Mean Low Water Springs (MLWS)
Outer Hauraki Gulf (Leigh)[1]	0.86	-0.35	-1.45
Inner Hauraki Gulf (Tiritiri Matangi Island)[1]	1.16	-0.05	-1.45
Waitematā Harbour and Tamaki Straight (Port of Auckland)[1]	1.56	0.16	-1.55
Open west coast (Anawhata)[2]	1.0	-0.5	-1.9
Manukau Harbour (Onehunga)[2]	2.0	0.2	-1.7
Kaipara Harbour (Shelly Beach)[2]	1.6	-0.2	-2.1

[1]Based on conversion of CD = -1.745 m AVD-46 at the Port of Auckland tide gauge
[2]Based on conversion of CD = -2.204 m AVD-46 at Onehunga tide gauge

2.7.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide. The combined elevation of the predicted tide and storm surge is known as the storm tide. Stephens et al. (2016) derived storm tide estimates for the Hauraki Gulf and Waitematā Harbours by probabilistically combining the *astronomical tide*, with *storm surge* and the *monthly mean sea level anomaly*. A summary of storm tide elevations excluding wave set-up for the Auckland region is presented in Table 2.3.

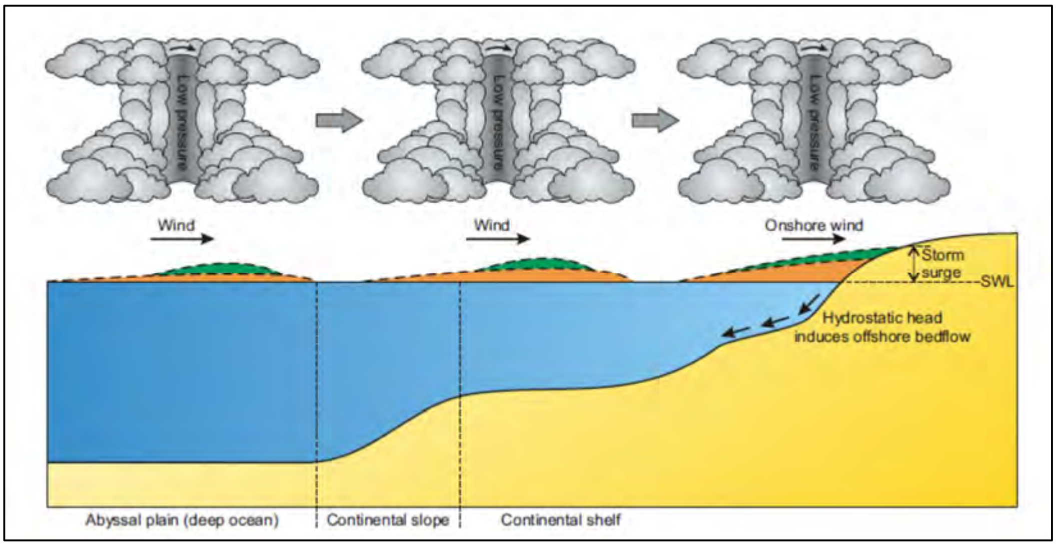

Figure 2.6: Processes causing storm surge (source: Shand et al., 2010)

Table 2.3: Summary of storm tide elevations for Auckland (Stephens et al., 2016)

Location	100-year ARI Storm tide level (RL m)
Outer Hauraki Gulf	1.8 to 1.9
Inner Hauraki Gulf	1.9 to 2.3
Tamaki Strait	2.1 to 2.2
Waitematā Harbour	2.3 to 2.6
Open west coast	2.2 to 2.3
Manukau Harbour	2.4 to 3.5
Kaipara Harbour	2.5 to 3.3

[1]Relative to AVD-46 including +0.15 m offset for baseline mean sea level (present-day estimate)

2.7.3 Long term sea levels

Historical SLR (i.e., 1916-2004) for the Auckland region and wider New Zealand has averaged 1.7 ± 0.1 mm/year (Hannah and Bell, 2012). Climate change is predicted to accelerate this rate of SLR into the future.

The MfE (2017) guideline recommends four SLR scenarios to cover a range of possible sea-level futures. The scenarios are based on the most recent IPCC report (IPCC, 2013) (Figure 2.7).

1. Low to eventual net-zero emission scenario (RCP2.6 median projection).
2. Intermediate-low scenario (RCP4.5 median projection).
3. High-emissions scenario (RCP8.5 median projection).
4. Higher extreme H+ scenario, based on the RCP8.5 83rd percentile projection from Kopp et al. (2014).

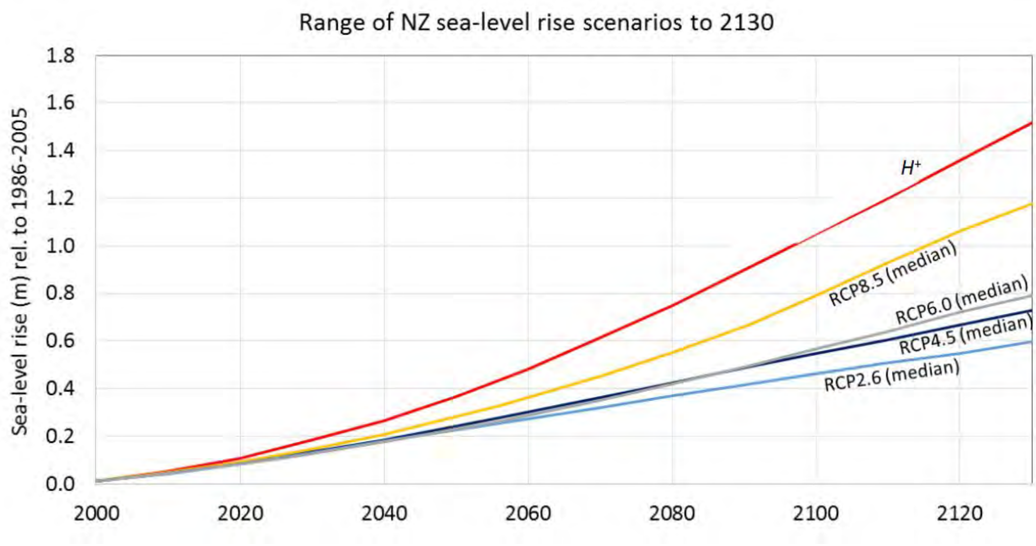

Figure 2.7: Range of SLR scenarios to 2130 (Stephens, 2017)

2.8 Waves

The open west coast is exposed to both short period wind waves from the south to the northwest and longer period swell waves, generally associated with intense low-pressure systems generated within the Southern Ocean and southern Tasman Sea. The open east coast shoreline is more sheltered from the prevailing winds and swell than the west coast, however, it is exposed to locally generated seas and extratropical cyclone swells from the north to southeast. The outer Hauraki Gulf shorelines are typically exposed to higher wave energy compared with the inner Hauraki Gulf shorelines, which are partially sheltered by islands and headlands. The main source of waves within the harbours and estuaries is locally generated wind-waves. Local morphology strongly influences the wave heights, with wind-waves throughout the harbours and estuaries generally being fetch and depth-limited.

Stephens et al. (2016) used WASP wave hindcasts for the years 1970 to 2000 to derive extreme significant wave heights around Auckland open coast. Extreme significant offshore wave heights for the open coast shorelines within the Auckland region extracted from roughly at the -15 m depth contours are presented in Table 2.4. The extreme wave heights within the harbour environments shown in Table 2.4 have been derived using the fetch-limited equations by Goda (2003) and using the 100 year ARI wind speed from ANZS1170:2011.

Table 2.4: Extreme significant wave heights for Auckland region

Location	100-year ARI significant wave heights (m)
Open west coast[1]	8.3 to 8.4
Outer Hauraki Gulf[1]	5.5 to 7
Inner Hauraki Gulf[1]	2.2 to 6
Tamaki Strait[1]	0.7 to 3
Waitematā Harbour[2]	up to 1.2
Manukau Harbour[2]	up to 1.5
Kaipara Harbour[2]	up to 1.5

[1] Extreme offshore significant wave height based on Stephens et al. (2016).

[2] Fetch-limited waves heights based on 100-year ARI wind speeds.

3 Data sources

3.1 Previous coastal erosion studies

The regional-scale assessment for the Auckland region by Reinen-Hamill et al. (2006) includes background data, analyses of available beach profiles, short and long-term shoreline changes, delineation and classification of the cliffs and beaches. This dataset forms a useful basis for this study.

Reinen-Hamill et al. (2006) includes a table of coastal erosion related projects undertaken by T+T up to 2004. A similar review was undertaken for this assessment, with coastal erosion related projects undertaken by T+T between 2004 and 2018 that include assessed beach or cliff erosion rates listed in Appendix A. Other studies that have been considered formed part of a literature review undertaken for Stage 1.

An international study of shoreline trends around the world was recently undertaken by Luijendijk et al. (2018). This study assessed beach shoreline changes based on analyses of satellite images, which included the shorelines of Auckland. However, the course spatial scale and relatively short temporal duration of this study is not enough to be used for this regional-scale assessment. It is understood that the technique used for the study is proposed to be applied onto a national or regional scale in New Zealand and could potentially be used when higher resolution analysed data becomes available.

3.2 Aerial survey

An aerial survey of the Auckland shoreline was undertaken in December 2018. The purpose of this survey was to obtain high resolution oblique photographs of the beach and cliff shoreline. The aeroplane was flown at an elevation of roughly 500 ft (~150 m) and typical offshore distance of 300-500 m. The oblique aerial photographs have been processed and geo-tagged so that a clean dataset of photographs including their GPS coordinates is available.

The obliqueness of the photographs is particularly useful for interpretation of shoreline slopes, heights and relief, and validation of geological type, lithology and susceptibility to landslides. This data is intended to be used in combination with available 2016-2018 LiDAR DEM information and right-angle photographs. Figure 3.1 shows examples of oblique aerial photographs along the Auckland shoreline captured during the aerial survey. Refer to Appendix B for details on the aerial survey.

3.3 LiDAR data

A LiDAR survey of the entire Auckland region was undertaken by AAM NZ Limited (AAM) between 6 May 2016 and 9 August 2018. Tidal areas identified by Auckland Council were flown within 1.5 hours either side of the predicted low tide based on LINZ tide predictions. The data was supplied in the form of point clouds and was post-processed by AAM and supplied to Auckland Council in the form of 1 m x 1 m digital surface and elevation models (DSM and DEM). These data sets were provided by Auckland Council, with the generated DEM being used for this assessment and is referred to as 2016-2018 LiDAR DEM.

The coordinate system of the LiDAR data is in NZGD 2000 New Zealand Transverse Mercator (NZTM) and the vertical datums are New Zealand Vertical Datum 2016 (NZVD2016) and Auckland Vertical Datum 1946 (AVD-46), with the AVD-46 used for this study. The stated vertical accuracy of the LiDAR data is ± 0.1 m and horizontal accuracy is ± 0.3 m. It is noted that the definition of the ground under trees and low dense vegetation (e.g. long grasses on dunes) may be less accurate.

Figure 3.1: Examples of oblique aerial survey photographs taken at Stanmore Bay (top left), Omaha Beach (top right), Whatipu (middle left), Orere Point (middle right), Kawakawa Bay (bottom left) and Āwhitu open coast (bottom right)

3.4 Historical aerial photographs

Historical aerial photographs are available from both Auckland Council GeoMaps and from Retrolens, which were reproduced from the New Zealand Crown Aerial Photograph Archive. The historical aerial photographs included on the Auckland Council GeoMaps are georeferenced (accuracy unknown) for photographic runs captured between 1940 and 2017 (i.e., 1940, 1959, 1996, etc.). The extents of these photographs are different for each survey date. The earliest photographs typically only include the urban area and do not cover the entire Auckland region until 2010/2011.

The historical aerial photographs included on Retrolens are not georeferenced and are from photographic runs captured between the late 1930s to the early 2000s. These historical photographs cover most of the Auckland region. However, the scales of these photographs vary across the region and between dates.

3.5 Beach profile data

Auckland Council has collected beach profile data at 36 different beach sites within the Auckland region. They first started surveying the beach profile at five locations along the beach at Omaha in 1965. Since then, another 35 beach sites have been added, which have been surveyed bi-annually. An overview map of where beaches have been surveyed within the Auckland region is shown in Figure 3.2.

A summary table including the number of profiles along each beach location, start and end dates, and length of survey periods is included in Appendix C. This table shows that the longest survey period is 53 years, but with a note that there is a 10-year gap. For the west coast the typical survey period is 13-25 years, with 33 years as the longest period at Muriwai. For the exposed east coast (Pākiri and Omaha) the survey period is typically 20+ years, with Omaha Beach surveyed the longest. The east coast south of the Whangaparāoa peninsula has a typical survey length of 15-17 years, with a note that for some locations survey data does not extend beyond 2015. There are also a number of profiles within the Auckland region that have been added in the last five years.

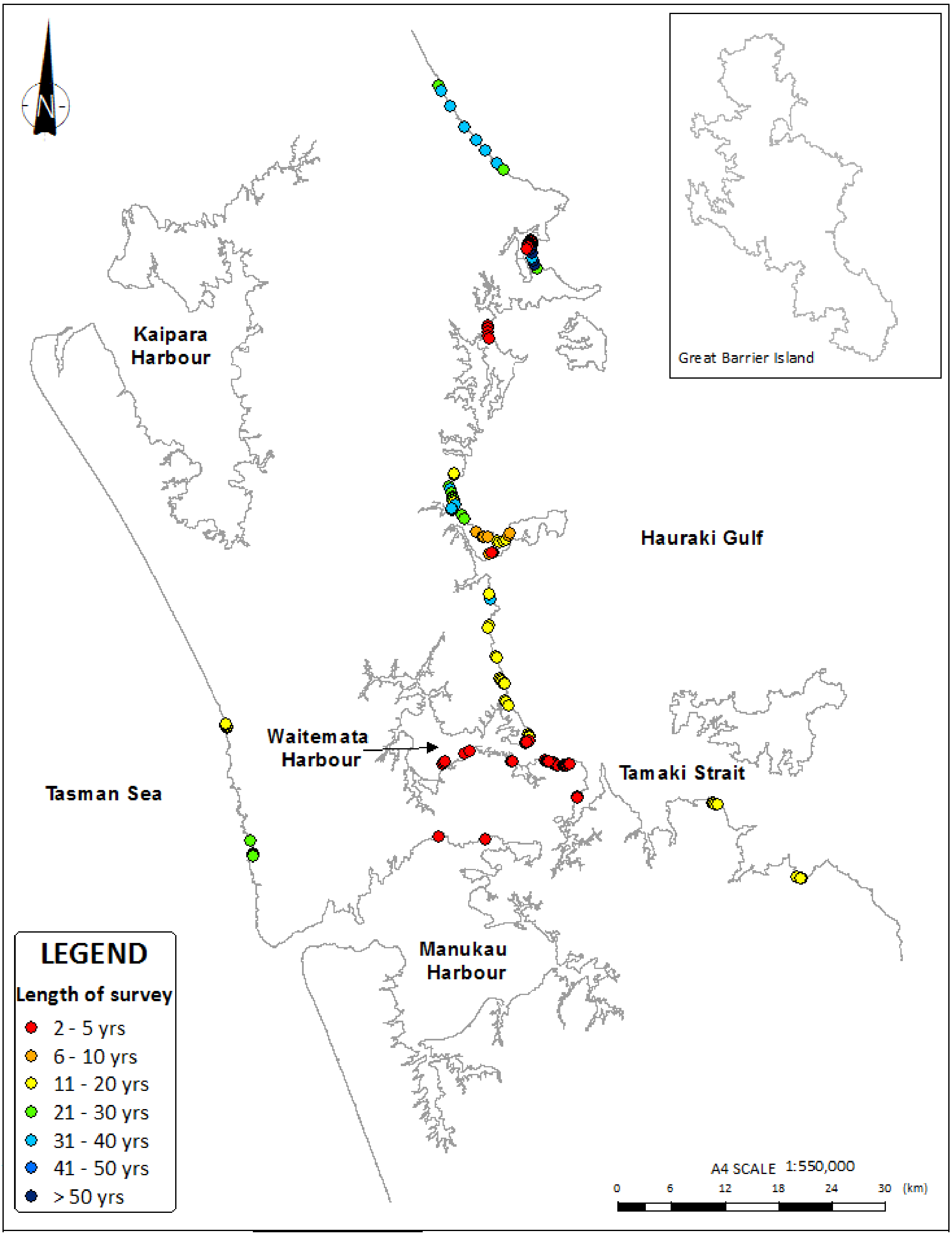

Figure 3.2: Locations where beach profile data is available (including length of survey period)

4 Methodology

4.1 Baseline derivation

The ASCIE distances are assessed with respect to a base shoreline (i.e., baseline) and is the first step in assessing the landward extent of ASCIE. The ASCIE baseline is based on the most recent shoreline (taken to be 2016) to which coastal erosion distances are referenced and represents the toe of the coastal edge for different coastal types:

- Beach: dune toe
- Cliff: cliff toe
- Coastal structure: toe of structure.

Figure 4.1 shows examples of the coastal edge for the above coastal types. The baseline has been digitised using GIS software (Global Mapper and ArcGIS), a drawing tablet and spatial data sourced from Auckland Council. The following spatial datasets were used in the below hierarchic order to digitise the baseline:

1. 2016-2018 LiDAR DEM for entire Auckland region
2. Aerial photographs
    - 2016 aerial photographs
    - 2010-2011 aerial photographs (where 2016 aerial photographs are missing)
    - 2006-2008 aerial photographs (where 2010-2011 and 2016 aerial photographs are missing)
3. Oblique aerial photographs.

The toe of the coastal edge was identified primarily using the 2016-2018 LiDAR DEM where available, with the (oblique) aerial photographs used where the coastal edge toe could not be identified from the DEM (e.g., at low-lying shorelines or where a change in slope could not be identified). This approach was taken because the vegetation line does not necessarily follow the dune or cliff toe and following the coastal edge toe identified from the DEM provides a more consistent approach. It should be noted that while the baseline represents the 2016 shoreline, it also represents any current erosion or accretionary phases beaches are in at the time the LiDAR was captured.

Elevation data was used as a transparent layer on top of the aerial imagery throughout the digitising process using a scale of 1:500 to 1:1000. Regular profile checks were made during the digitising process to ensure the digitised shoreline was located at the toe position, according to elevation data. In areas where no marked topographic feature or coastal structure was available to define the shoreline, the edge of vegetation was used.

The baseline has been digitised along the entire Auckland shoreline and extends into estuaries and streams typically up to the MHWS-10 line mapped by NIWA (2012). However, streams that interrupt the shoreline, but are less than 10 m wide, were typically excluded. Protruding structures such as breakwaters or groynes have also been excluded from the baseline. The mean high water level was not used to define the shoreline in any location. The total length of the baseline created is 2,520 km.

Due to the resolution of the DEM and the complexity of the entire shoreline in some locations along the Auckland shoreline, the accuracy of the baseline along the open coast is estimated at ±2.5 m and within estuaries at ±5 m (see Table 4.1). Low-lying shorelines are typically comprised of shallow and flat (<1:100) foreshore slopes with subtle changes in grades and are typically covered by vegetation. This makes it more difficult to accurately digitise the shoreline, with the digitising/shoreline proxy error estimated at ±5 m.

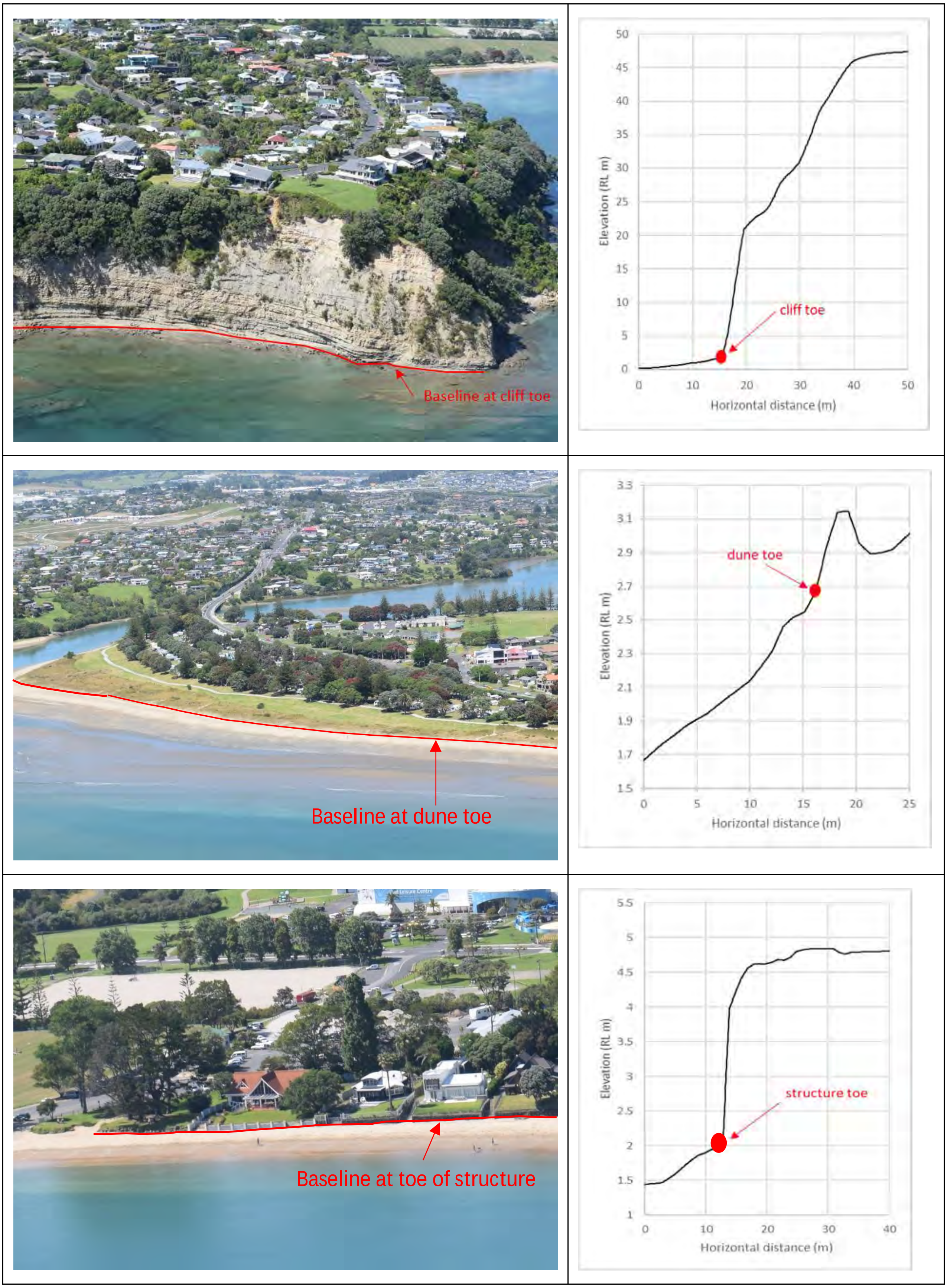

Figure 4.1: Example of baseline for cliff shoreline (upper panel), beach shoreline (middle panel) and coastal structure (lower panel)

Table 4.1: Potential measurement error of the baseline

Potential measurement error	Beaches and cliff shoreline	Low-lying estuarine shoreline
Geo-referencing error[1]	0.3 m	0.3 m
Resolution of DEM	1 m	1 m
Digitising/shoreline proxy error	2 m	5 m
Root-sum-square (RSS) error	*2.23 m*	*5.11 m*
Rounded	*2.5 m*	*5 m*

[1]Source: AAM (2018)

4.1.1 Coastal structures

Coastal protection structures have been identified for the entire Auckland shoreline based on the 2016, 2010-2011 and 2006-2008 aerial photographs and the oblique aerial photographs from the 2018 survey (see examples in Figure 4.2). The baseline was used as a basis to create the coastal structures GIS line which runs along the toe of the structures. The coastal structures have been classified as follows:

- Rock revetment (sloping).
- Seawall (vertical).
- Marina.
- Wharf.
- Groynes.
- Informal.

Where possible the coastal protection structures have been classified as a sloping rock revetment or vertical seawall. Marinas and wharfs have been classified separately as these are types of major infrastructure. Groynes have been classified where multiple groynes are situated along a coastal cell. Where it was not possible to identify the type of structure or where multiple coastal structures are situated along a coastal cell (e.g. various structure types built by property owners), the coastal structure has been classified ‘informal’. An approximate shoreline length of 145 km was identified as being protected by coastal structures, with an additional total length of 5 km identified as shore normal structures (i.e. not along the length of the shoreline). Figure 4.5 shows the locations and extents of the identified coastal protection structures, with a more detailed example shown in Figure 4.3.

Both consented and non-consented structures are included. However, it should be noted that not all coastal structures along the Auckland shoreline have been identified.

For this assessment, no allowance for the protective effects of identified structures has been included. This is generally due either their limited extent (less than the cell size) or due to uncertainty in the structure conditions and its remaining design life, which is likely to be less than the study time frames (100 years). Assessment of ASCIE for shorelines protected by coastal structures should be undertaken on a local-scale or site-specific scale.

Figure 4.2: Examples of aerial survey photographs used to identify coastal structures such as vertical seawalls and revetments (top panel), marinas (bottom left) and wharfs (bottom right)

Figure 4.3: Example of extents of protected shorelines (black solid line)

4.2 Coastal types and cells

The shoreline has been split into cells based on the following variables:

- Coastal type:
  - unconsolidated beaches.
  - cliffs and consolidated banks.
  - reclaimed land.
- Cell morphology.

- Shoreline exposure.
- Historical shoreline trends.
- Profile geometry.
- Backshore elevation.
- Coastal structure controlled.

The shoreline has been split into the coastal types of unconsolidated beaches, and cliff and consolidated banks based on geology using available QMAPs (Edbrooke, 2001) and into coastal cells that represent reclaimed land. The oblique aerial photographs and the 2016-2018 LiDAR DEM were used to identify the extent of the coastal cells taking into account the remaining variables. This was undertaken following a stepwise process by considering the above variables, which can influence the behaviour of a coastal cell, in hierarchic order.

Where beaches are backed by cliffs, such as perched or pocket beaches, or where coastal erosion is controlled by adjacent headlands, the coastal cell is classified as a cliff shoreline. This approach is consistent with Reinen-Hamill et al. (2006) and is considered appropriate for a regional-scale assessment. A minimum shoreline length of 0.5 km per coastal cell was adopted for unconsolidated beach and consolidated cliff shorelines (excluding reclaimed shorelines) with the prerequisite that it is composed of at least 70% of the dominant geological type.

The shoreline for the Auckland region including splits in coastal type is shown in Figure 4.4, with the locations of the identified coastal structures shown in Figure 4.5. A summary table of the shoreline length, number of cells for different coastal types and percentage fronted by identified coastal structures is shown in Table 4.2.

Table 4.2: Summary of shoreline length and number of cells for different coastal types

Coastal types	Number of cells	Total length (km)	% of total shoreline	% fronted by coastal structure
Cliffs and consolidated banks	427	2,250	90%	2.6%
Unconsolidated beaches	79	186	7%	8.6%
Reclaimed	62	84	3%	83%
Total Auckland shoreline	568	2,520	100%	5.7%

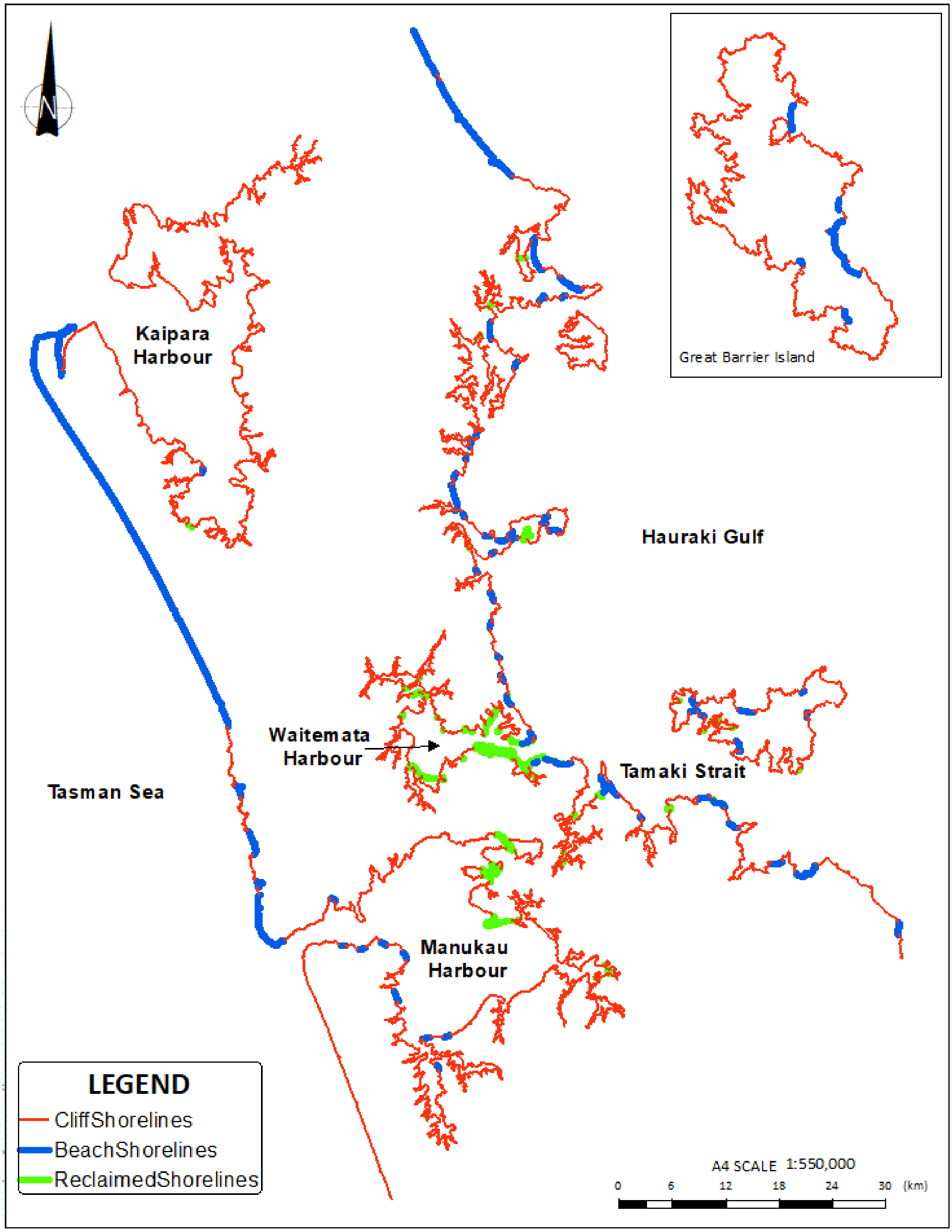

Figure 4.4: Auckland region baseline including splits in coastal type

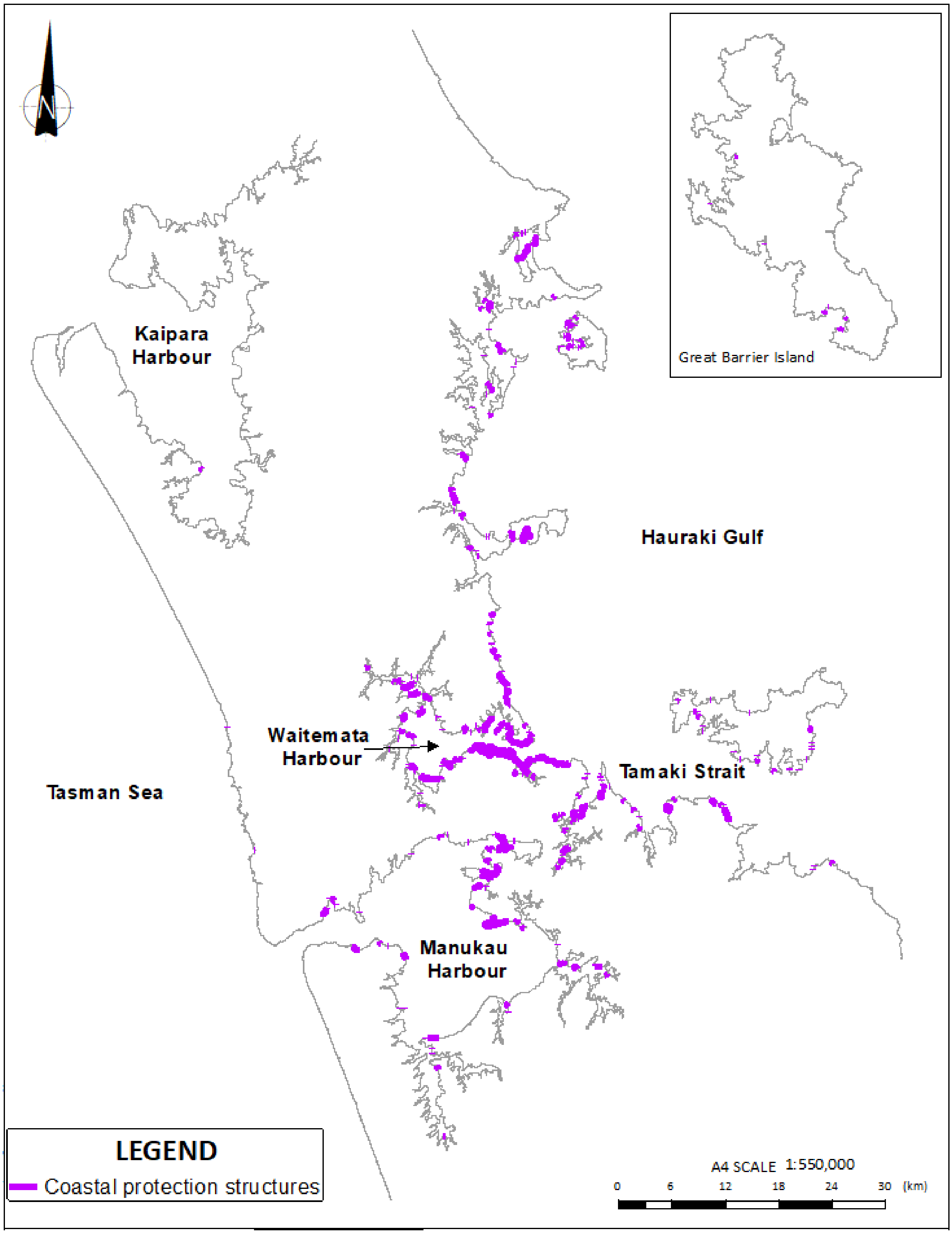

Figure 4.5: Auckland region baseline including locations and extents of identified coastal protection structures

4.3 Conceptual models of coastal instability and erosion

4.3.1 Cliff shorelines

Consolidated shorelines, which include soil and rock cliffs, are not able to rebuild following periods of erosion but rather are subject to a one-way process of degradation. Areas susceptible to coastal erosion and coastal land instability along cliff (consolidated) shorelines typically have two components:

- Toe Erosion

  A gradual retreat of the cliff toe caused by weathering, marine and bio-erosion processes. This retreat will be affected by global process such as SLR and potentially increased soil moisture. Future cliff toe position based on historical erosion rates with a factor applied to allow for the effect of future SLR.

- Cliff Instability

  Episodic instability events are predominately due to a change in loading or material properties of the cliff or yielding along a geological structure. In soft cliffs, instability causes the cliff slope to flatten to a slope under which it is 'stable'. Soil cliff slope instabilities are influenced by processes that erode and destabilise the cliff toe, including marine processes, weathering and biological erosion or change the stress within the cliff slope. Most of the hard cliffs are stable at very steep angles. Instability events may range from small-scale instabilities (block or rock falls) or discontinuities, to cliff slope instability cause by large-scale and deep-seated mass movement. The latter mode of failure in hard cliffs is rare.

These types of instability events cannot be predicted with certainty. They can only be monitored once signs of movement are observed. To generate a rate from episodic events the time period needs to be long enough to enable the cliffs to undergo a full cycle of regression; toe erosion, over steepening, instability, removal of failed material, toe erosion.

If erosion of the cliff toe is halted through either natural (i.e., establishment of a beach) or artificial (i.e., through rock protection) processes, then the above cliff will continue to adjust until a stable profile is reached. After which time vegetation often becomes established as there is no further removal of material.

The conceptual models for the toe erosion component and cliff instability component are as follows:

$$\textit{Cliff Instability} = (h_{Cr}/\tan\alpha_r) + (h_{Cs}/\tan\alpha_s) \qquad \text{(Equation 4.1)}$$

$$\textit{Cliff Toe Erosion} = (LT_F \times T) \qquad \text{(Equation 4.2)}$$

Where:

h_{Cr} = Height (m) of the rock layer of the cliff

h_{Cs} = Height (m) of the soil layer of the cliff

α_r = The slope angle (degrees) of the rock layer

α_s = The slope angle (degrees) of the soil layer

LT_H = Historical long-term retreat (regression rate), (m/year)

LT_F = Potential future cliff toe retreat due to SLR effects.

T = Timeframe over which erosion occurs (years).

These can then be combined into the models for consolidated shoreline for the present day ASCIE and future ASCIE. The present day ASCIE is a function of the cliff instability component only as regression of the cliff toe is a long-term process. The future ASCIE is a function of both cliff instability and cliff toe regression, with the latter likely being affected by increased SLR rate effects.

The models for consolidated shorelines are expressed in Equation 4.3 (current ASCIE) and Equation 4.4 (future ASCIE), where the ASCIE is established from the cumulative effect of the components (Figure 4.6):

$$Current\ ASCIE = (h_{Cr}/tan\alpha_r) + (h_{Cs}/tan\alpha_s) \quad \text{(Equation 4.3)}$$

$$Future\ ASCIE = (LT_F \times T) + (h_{Cr}/tan\alpha_r) + (h_{Cs}/tan\alpha_s) \quad \text{(Equation 4.4)}$$

Note that coastal cliffs may be comprised of more than one geological type with different characteristics. If the cliff slope is comprised of two geotechnical domains, soil and rock, they will have different observed field angles. If a cliff is composed of only one geotechnical domain, only the relevant component (i.e., either rock or soil) should be used in the equations. The height and slope for each domain are assessed separately where applicable (see definition sketch Figure 4.6). For those cliffs where the cliff height (h_c) and the slope angle (α) are subdivided in an upper "soil" (h_{cs} and α_s) and lower "rock" (h_{cr} and α_r) section, the composite slope profile (i.e., combination of rock and soil slopes) is used to derive the horizontal cliff instability distance.

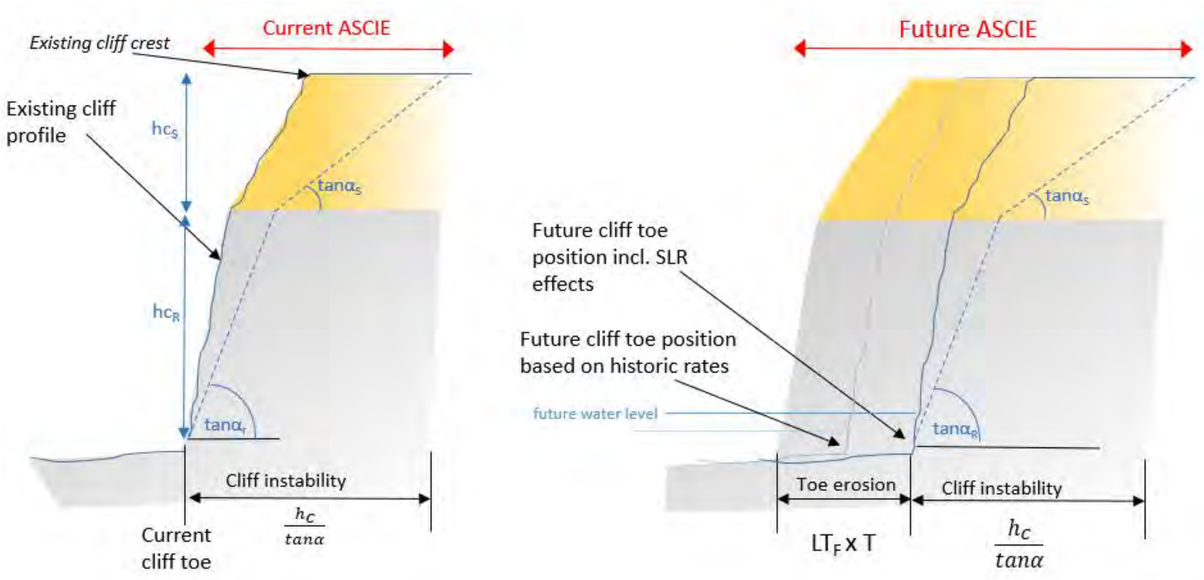

Figure 4.6 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

A short-term component (ST) has not been included in deriving ASCIE for cliffs and unconsolidated shorelines as these shorelines are unable to rebuild after storm events. The purpose of ST is to allow for the dynamic shoreline movements over a short-term period, including erosion following storms and accretion during calm periods.

4.3.1.1 Groundwater

Coastal slopes within the Auckland region were generally observed having a groundwater table at, or near, the toe of the slope profile. This research was undertaken through the NZGS database search and cross-referencing coastal ground investigation data in or on the coastal slopes. It was considered that higher groundwater levels could be very would be localised (perched). This is spatially difficult to locate with certainty and then represent statistically in a model, as such, this process has been discounted from the conceptual coastal cliff stability model.

4.3.2 Beaches

Conceptual models for coastal erosion of unconsolidated beaches differ slightly in comparison to those of cliffs and estuarine shorelines. The model for unconsolidated beach shorelines is expressed in Equation 4.5 (Current ASCIE) and Equation 4.6 (Future ASCIE), where the ASCIE is established from the cumulative effect of six main components (Figure 4.7):

$$Current\ ASCIE_{Beach} = ST + DS \qquad \textit{(Equation 4.5)}$$

$$Future\ ASCIE_{Beach} = (LT\ \times T) + SL + ST + DS + MT \qquad \textit{(Equation 4.6)}$$

Where:

ST = Short-term changes in horizontal shoreline position related to storm erosion due to singular or a cluster of storm 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).

MT = Medium-term erosion fluctuation of the shoreline (m). This allows for shoreline fluctuations on a decadal timeframe due to ENSO or IPO effects, or changes in sediment budget, which are not included in the long-term changes. Note that this parameter may not be included for beaches that do not experience significant medium-term fluctuations and will be omitted for those sites.

LT = Long-term erosion rate of horizontal shoreline movement (m/year), excluding medium-term fluctuations.

T = Timeframe (years)

SL = Horizontal shoreline retreat because of increased mean sea level (m).

4.3.3 Reclamations

Reclaimed shorelines are typically comprised of ‘hard’ coastal protection structures that protect reclaimed fill areas. Typical examples of reclaimed shorelines are found around ports and within the Auckland downtown area. Figure 2.5 in Section 2.6 shows an example of the Auckland CBD shoreline in the 1840s and the reclaimed area. For these types of shoreline, the long-term shoreline movement is equal to zero as the land has been protected since its creation. If the protection structure fails it is likely that the fill material will erode, and the shoreline will eventually move back towards its ‘original’ natural position.

For the reclaimed areas identified in our assessment it is assumed that the current shoreline position will be maintained by the reclamation owners and is considered permanent in line with Auckland Unitary Plan. Therefore, the ASCIE for reclaimed shorelines is assumed to remain at the baseline.

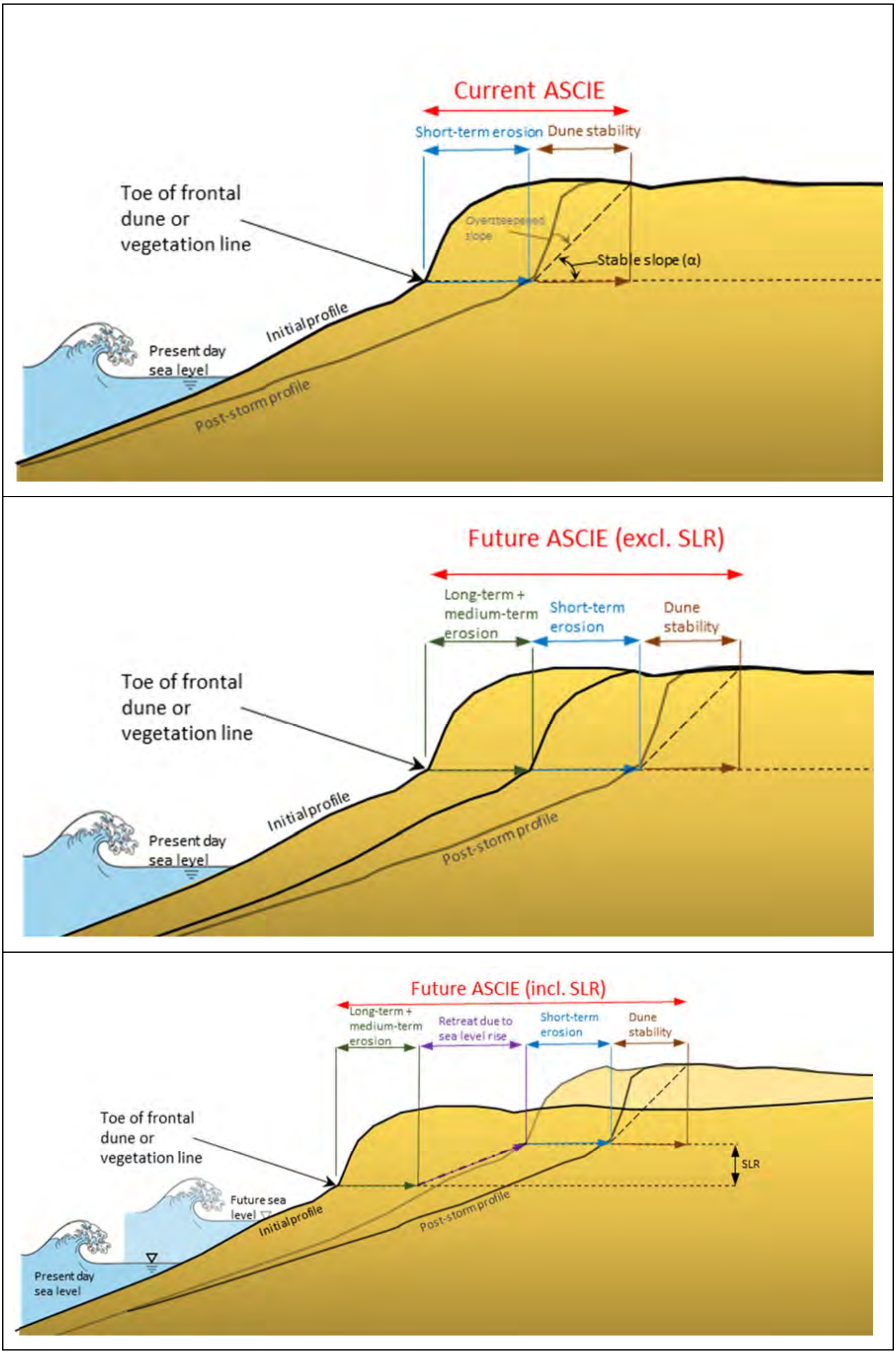

Figure 4.7 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on open coast beach shoreline for present day (A), future timeframe excl. SLR effects (B) and future timeframe incl. SLR effects (C)

4.4 Parameter combination

For the regional-scale assessment, a deterministic approach has been adopted using single values for each component for each coastal cell. Upper bound values that are applicable across the entire cell (therefore conservative for parts) have been used. The upper bound values typically have a likelihood of 1-10% probability of exceedance. This 'building-block' approach (i.e., combination of individual conservative parameters) is expected to produce upper bound results, which is in line with suggestions included in MfE (2017) for first-pass 'high level' assessments to identify areas potentially exposed to coastal erosion.

As potential limitations in available data (e.g., infrequent and short time period of beach surveys or obscured historical aerial photographs) may affect the accuracy of this data, residual uncertainty values for each parameter are estimated and included in the results tables (refer to Appendix E). The uncertainty is typically estimated by Standard Deviation (SD) of the data or 95% Confidence Intervals (CI) of derived trends but may be estimated based on expert judgement. The resulting residual uncertainty value is derived by taking the root-sum-square of the uncertainty values of each individual component as shown in the equation below:

$$Residual\ uncertainty = \sqrt{x_1^2 + x_2^2 + x_3^2 + \cdots} \qquad \textit{(Equation 4.7)}$$

Where X_1, X_2 and X_3 are uncertainty values for individual components.

That residual uncertainty may then be added to the resulting ASCIE distances if required.

4.4.1 Probabilistic approach

The Envirolink guide to good practice (Ramsey et al., 2012) recommends moving from deterministic predictions to probabilistic projections, and that the recognition and treatment of uncertainty is a key source of variance between coastal hazard predictions by practitioners. This approach is supported by MfE (2017) which recommends using probability distributions for detailed assessment.

For a regional-scale assessment it is not possible to adopt a probabilistic approach due to the large scale of individual cells, total length of the shoreline and lack of site-specific data to build probability distributions around each parameter. It is more appropriate to undertake a probabilistic assessment on a local-scale or site-specific scale, with the regional assessment identifying these areas that are at high risk for more detailed assessment. Two more detailed, local-scale assessments have been undertaken in parallel using a probabilistic approach, at Omaha Beach and Stanmore Bay (refer to T+T, in prep. a and T+T, in prep. b), consistent with both the Envirolink guide and MfE (2017).

4.5 Coastal cells with limited data

Data from previous studies (refer to Section 3 for available data sources) and methodologies described in Section 5 have been used to derive component values. However, it may not be possible to derive ASCIE distances for each coastal cell based on cell-specific data due to limited availability in some areas (refer to Section 3 for available data sources). Therefore, for coastal cells with limited data, parameter values from adjacent cells or cells exhibiting similar coastal geomorphology (see Section 5.2, coastal type) have been adopted, where available. Alternatively, Reinen-Hamill et al. (2006) data was used applying expert judgement (refer to Appendix E and Appendix F). This was undertaken by characterising each coastal cell (as described below) and adopting parameter values from coastal cells with similar characteristics. In the case that values from adjacent, similar coastal cells are adopted, the maximum of these values has been adopted to allow for potential differences between coastal cells. Figure 4.8 shows a flow chart of how values for components were derived based on data available.

The beach shorelines have been characterised based on exposure, tidal range, and material (refer to Appendix E). The exposure is based on 12-hour exceedance annual wave height for open coast beaches, derived from MetOceanView (MSNZL, 2019), and the fetch distance for harbour or estuary beaches. The tidal ranges have been derived from LINZ (2019) and the beach material from sediment sample data (refer to Section 2.4) or from inspection of oblique aerial photographs. Appendix E shows the data sources for the short, medium and long-term components.

The consolidated cliff shorelines have been characterised based on geology type, existing face slope angle and cliff height (refer to Appendix F). The geology type has been based on Edbrooke (2001), and the cliff height and slope derived from the LiDAR data. Appendix F shows the data sources for the LT component. Where limited or no data is available for a consolidated cliff cell, data from adjacent cells with similar geology, existing face slope angle and cliff height is used.

It should be noted that the ASCIE distances for cells with limited data may potentially be under- or overestimated by following the above approach. However, this approach provides the best source of information to derive ASCIE distances.

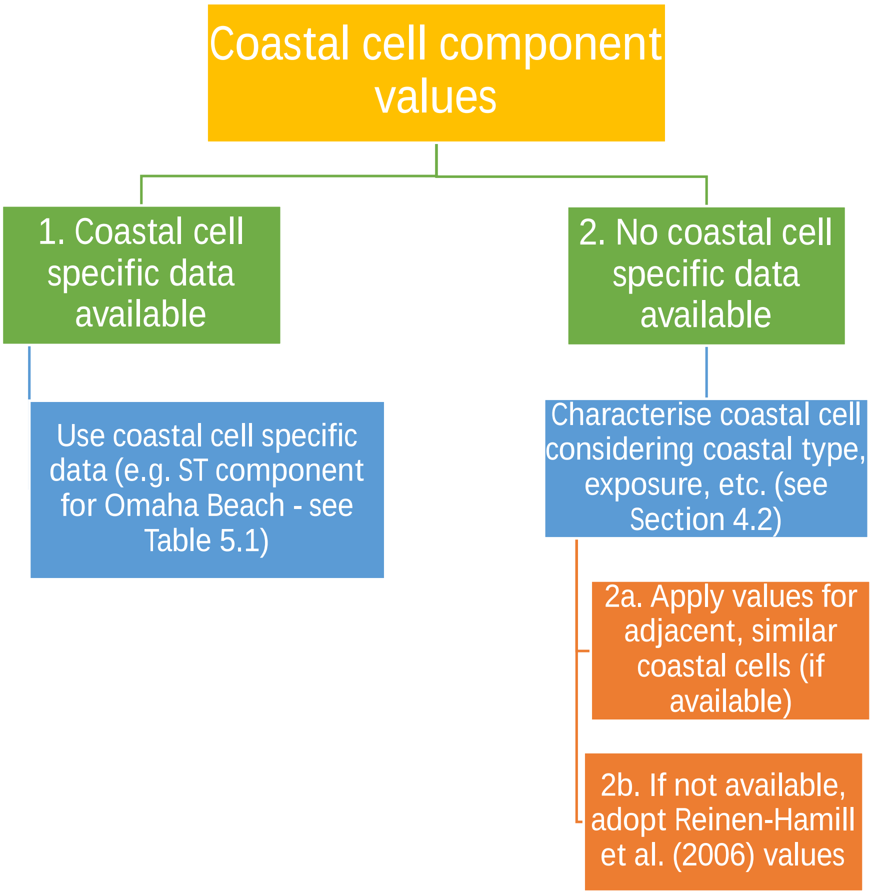

Figure 4.8: Flow chart of component value derivation

5 Component derivation

5.1 Planning timeframe (T)

Four different timeframes have been applied to provide information on the coastal erosion and instability hazard. These represent a range of time scales considered appropriate to inform hazard information mapping, planning and long-term implications of climate change:

- Short-term (applicable to 2030).
- 30 years (2050).
- at least 50 years (taken to be 2080).
- at least 100 years (taken to be 2130).

These timeframes have been selected by Auckland Council to ensure the results are relevant and align with the NZCPS requirements to consider at least a 100 year time frame. Note that for the short-term timeframe no medium- or long-term effects (i.e., ENSO and SLR effects) have been considered. The future timeframes 2050, 2080 and 2130 have been adopted for respectively 30 year, at least 50 year and at least a 100-year timeframe for this assessment.

5.2 Short-term erosion (ST)

Unconsolidated shorelines exposed to wave energy typically undergo short-term cycles of storm-induced erosion (i.e., storm cut) due to single or clusters of storm events, followed by periods of re-building. These short-term fluctuations are not predictable and can occur during any year and so need to be considered for both present day and future hazard assessment. Medium-term fluctuations, generally associated with sediment supply or climatic changes, and long-term trends are accounted for within other components (refer to Section 5.3.2 and 6.4).

The short-term shoreline movements have been assessed using statistical analysis of shoreline positions obtained from beach profile analysis. The methodology is set out in Section 5.2.1, including a sample of results, and adopted values presented in Section 5.2.2.

5.2.1 Methodology

The horizontal movement of the shoreline (i.e., dune toe) based on the Auckland Council beach profile analysis was used to assess the short-term erosion (ST) distances using inter-survey erosion distances.

The inter-survey erosion distance is the landward horizontal retreat distance measured between two consecutive surveys (i.e., distance between excursion distances). Figure 5.1 shows an example of the measured excursion distances over time for profile P2 at Omaha Beach, which is a beach profile surveyed biannually situated near Inanga Lane (refer to Appendix C for graphs for all beaches). It is noted that due to the relatively long periods between surveys (i.e., typically 6 months across the Auckland region) these distances may not represent the largest excursion that may have occurred between these time periods, but on the other hand could be a result of multiple storms that occurred within the survey period. However, the data set provides the best source of information to analyse.

In order to estimate the ST distances for larger return periods, which may not be captured within the profile dataset, extreme value analyses were undertaken for each profile location separately by including all the inter-survey erosion distances. Analyses were undertaken using the methods described in (Mariani et al., 2012) using toolboxes provided in WAFO (2012). The extreme value curve using the Weibull method was found to reasonably fit the observed datasets and was therefore adopted. Figure 5.2 shows an example of the extreme value curve for P2 at Omaha Beach, with extreme value curve figures for each beach included in Appendix C.

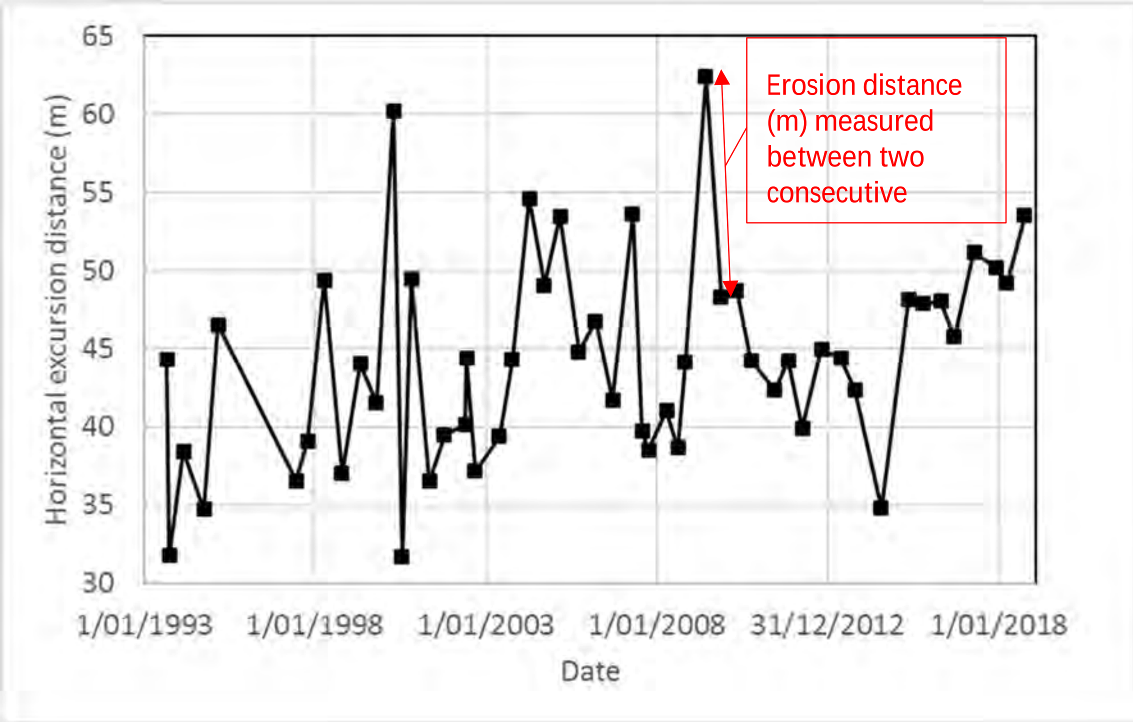

Figure 5.1: Example of excursion distance of dune toe (RL 3 m) over time for profile P2 at Omaha Beach (indicated with block squares, artificial connecting lines are included for visual purposes)

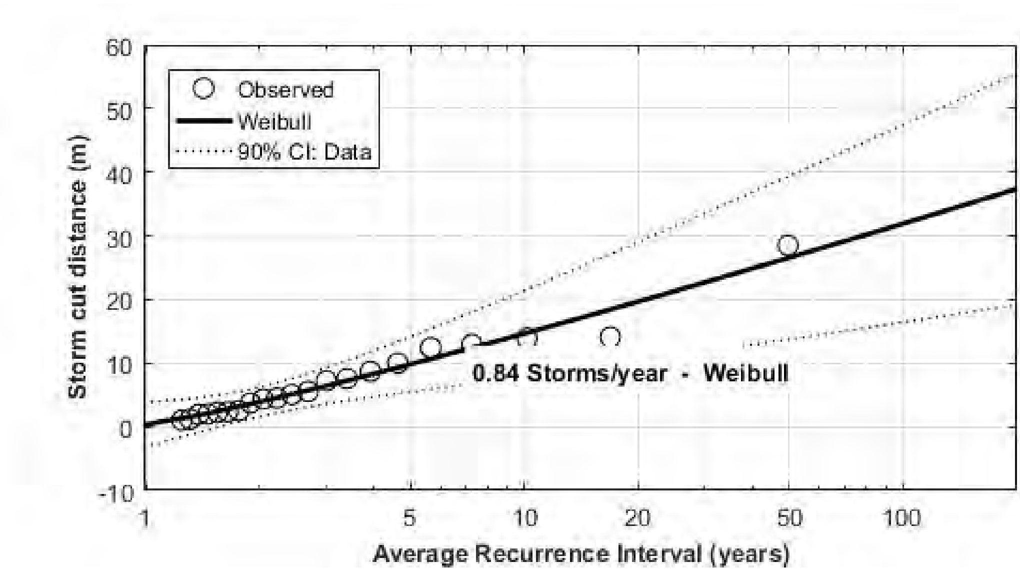

Figure 5.2: Example of extreme value analysis curve based on inter-survey distances from P2 at Omaha Beach

The resulting 10-year ARI and 100-year ARI ST distances for each beach are included in Appendix C. An example of the resulting ST distances for Omaha north and south is shown in Table 5.1.

Table 5.1: Short-term erosion (ST) distances for Omaha beach

Beach	Profile	Initial Survey Year	End survey year	Survey length (years)	Short-term erosion distance (m)	
					10-year ARI	100-year ARI
Omaha South	P1	1993	2018	25	15	27
	P2	1965	2018	53	15	32
	P3	1965	2018	53	12	25
	P4	1978	2018	40	20	52
	P5	1965	2018	53	16	30
	P6	1965	2018	53	15	30
Omaha North	P7	1965	2018	53	17	41
	P8	1993	2018	25	10	18
	P9	1993	2018	25	9	17

Table 5.1 shows that the 10 year ARI ST distance ranges from 9 to 20 m. The 100 year ARI ST distance ranges from 17 to 52 m. However, as described in T+T (in prep. a) the values for P4 and P7 are likely influenced by human activity. Therefore, the 100 year ARI ST is up to 32 m, which is similar to the value derived by Reinen-Hamill et al. (2006).

5.2.2 Adopted values

The 100-year ARI short-term erosion values have been adopted for the regional-scale assessment. For each coastal cell the adopted ST values are rationalised based on the derived 100-year ARI short-term erosion distances considering all available beach profiles. For instance, for Omaha south 30 m was adopted and for Omaha north 20 m was adopted. These values were adopted as both profiles P4 and P7 were found not representative (refer to T+T, in prep. a). The uncertainty is based on the standard deviation of the inter-survey erosion distance residuals.

Table 5.2 shows a summary of the adopted ST values excluding and including uncertainty for each area. This shows the smallest ST distances were found for the harbour coast beaches (3-10 m excluding uncertainty), while the largest ST values were found along the Outer Hauraki Gulf beaches (15-30 m excluding uncertainty). The Outer Hauraki Gulf beaches (e.g., Omaha) tend to have higher ST values than the more energetic west coast beaches due to their morphology (Wright and Short, 1984). West coast beaches are frequently exposed to high wave energy and therefore tend to remain in a dissipative beach state, with even very large wave events being dissipated offshore. By comparison, beaches on the east coast are subject to lower background wave energy, particularly during summer and often are in accreted, reflective beach states and highly susceptible to erosion when large storms occur (typically late summer through to early winter). The west coast beaches of Great Barrier Island are less exposed compared to the east facing shoreline, and ST values of the Inner Hauraki Gulf have been adopted for these beaches. Figure 5.3 shows the spatial variability of the adopted ST values across the Auckland region.

Table 5.2: Summary of ST excluding and including uncertainty for each area

Area	ST excluding uncertainty (m)	ST including uncertainty (m)
Harbour coasts (incl. Tamaki Strait)	3 to 10 m	5 to 15m
Inner Hauraki Gulf	5 to 15 m	8 to 20m
Outer Hauraki Gulf	15 to 30 m	20 to 38m
West Coast	15 to 20 m	20 to 30m

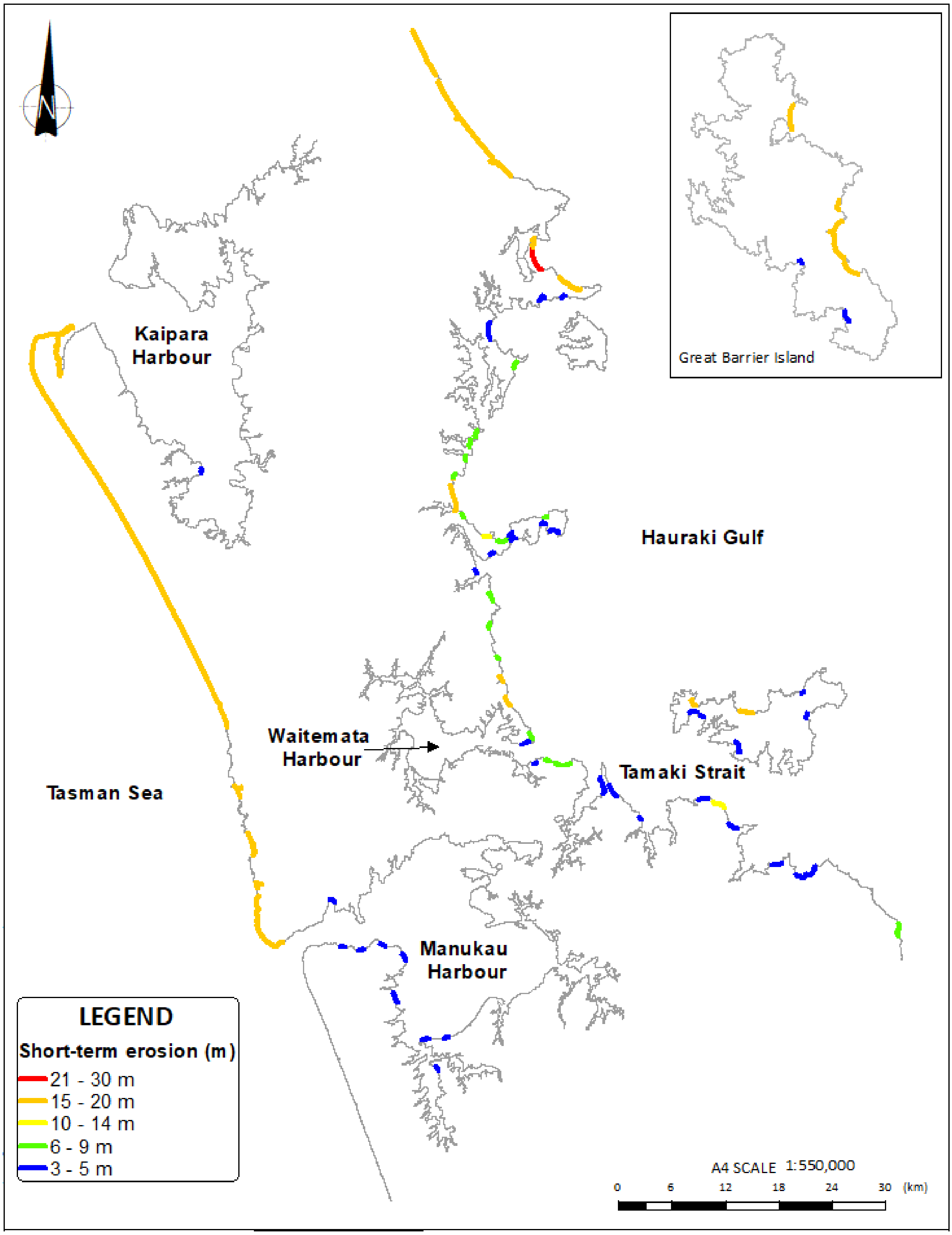

Figure 5.3: Adopted short-term erosion distances for beaches

5.3 Long-term trend (LT)

5.3.1 Cliffs

The long-term trend for cliff shorelines is defined by the average shoreline retreat at the toe of the cliff. This retreat may be caused by weathering (wet-drying or biological) or mechanical (wave-induced) processes.

A commonly used method for evaluating long-term trends is to digitise historical shoreline positions using geo-referenced historical aerials (refer to Section 3.4). Long-term trends using this method were attempted at several discrete locations along the East Coast (e.g., Stanmore Bay, Rothesay Bay), West Coast (between beaches), Manukau Harbour (e.g., Pararekau Island), Tamaki Strait (e.g., Bucklands Beach) and Kaipara Harbour. However, a limitation in using the historical aerial photographs for digitising shorelines is the visibility of the shoreline, in particular for cliff shorelines. For most of the cliff shorelines in the Auckland region the shoreline (i.e., cliff toe) is obscured by vegetation.

Figure 5.4 shows an example of vegetation situated along the cliff top hanging over the cliff face and toe and obscuring the shoreline south of Castor Bay at both the 1959 and 2017 aerial photographs. In such cases digitising the shoreline based on aerial photographs alone is not possible. Furthermore, geo-referencing historical aerial photographs can be difficult where no distinct and consistent features exist, such as buildings, roads or other topographical features.

Figure 5.4: Aerial photograph from 1959 (left) and 2017 (right) south of Castor Bay (source: Auckland Council Geomaps)

Therefore, the distance of cliff toe retreat between aerial surveys was measured along transects at discrete locations. Regression analysis was then used to estimate the average retreat rate (refer to example of regression analysis at Stanmore Bay; T+T, in prep. b). Where it was not possible to either geo-reference historical aerial photographs or digitise the cliff toe, long-term erosion rates were based on Reinen-Hamill et al. (2006).

Reinen-Hamill et al. (2006) evaluated a range of methods to derive long-term trends, including the use of aerial photographs or cadastral surveys, or using structures or geological markers (e.g., shore platforms) as proxies. They concluded that aerial surveys typically give upper bound values, while shore platform widths typically give values at the lower end. The other two methods tend to fall in between those two. An example of this on Auckland's North Shore is provided where a range of erosion rates have been determined using various methods, which are presented below for background purposes:

- Aerial Surveys: Brodnax (1991) compared aerial photographs since 1940 and found rates of erosion to vary between 50 and about 300 mm/year. Average rates were found to be ~150mm/year.
- Cadastral Surveys (1920 – 1980): Brickell Moss Raines & Stevens Ltd. in Riley (2001) found rates of 50 – 100 mm/year, averaging 75 mm/year.
- Man-made structures: Riley (2001), Brodnax (1991) and Glassey (2003) analysed a variety of structures dating back to 1926 and found rates varying between 0 and 82 mm/year. Their average rate was around 40 mm/year.
- Geological markers: Moon and de Lange (2003) used 7,400 years as their available time for shore platform development. Platform widths between Waiake Beach and Browns Bay were measured at 10 – 100 m giving erosion rates of 4 – 20 mm/year. Although this area is slightly out-side the area of the cadastral and man-made structure surveys it gives a general indication of lower rates of erosion with more specific observation at the toe of the cliff.

The method using geological markers was then further explored by evaluating shore platform widths based on a combination of GSI and exposure. It was found that the dominant factor affecting long-term retreat in cliffs is the structure and surface condition of the rock mass, rather than exposure or strength. Based on this, the long-term retreat rates were based on the analysis of shore platform widths, adopted from available literature, and expert judgement.

5.3.1.1 Adopted values

For the regional-scale assessment the long-term erosion rates have been based on analysis of historical aerial photographs for locations where possible and T+T site specific studies between 2006 and 2018 where available. For the remaining cliff coastal cells, Reinen-Hamill et al. (2006) values were used due to difficulties of geo-referencing historical aerial photographs and digitising shorelines as a result of vegetation obscuring cliff toe and crest positions. Refer to Appendix F for source of adopted LT rate for each cliff coastal cell. The most recent available upper bound values are used where multiple studies including long-term rates are available. Engineering judgement was used to determine the uncertainty for LT, with an upper bound uncertainty of -0.05 m/year (i.e., 5 m over 100 years) adopted, as it was not possible to estimate the uncertainty for each coastal cell based on available data. An exception for adopting an upper bound uncertainty value is for sites where more detailed assessments have been undertaken (e.g., Stanmore Bay; T+T, in prep. b).

No accretion is possible for cliff shorelines, except where landslide material temporarily occupies the shoreline in front of the cliff face (before being removed by action).

Table 5.3 shows a summary of the adopted LT values per century (excluding uncertainty) per lithology. This shows that the smallest LT values are found for Waitakere Group and the largest LT values for ECBF and Tauranga Group. Note that the upper bound LT value for ECBF was derived from the Stanmore Bay assessment (T+T, in prep. b), which was assessed in more detail.

Table 5.3: Summary of adopted LT values (excluding uncertainty) per lithology

Lithology	LT (m/century) excluding uncertainty
Puketoka Formation	2 to 15
Awhitu Group	3
AVF/CVZ	2 to 10
Waitakere Group	1 to 2
ECBF	1 to 15 (typically 3-6)
Pākiri Formation	1 to 10
Northland Allochthon	4 to 10
Waipapa Group	3 to 5

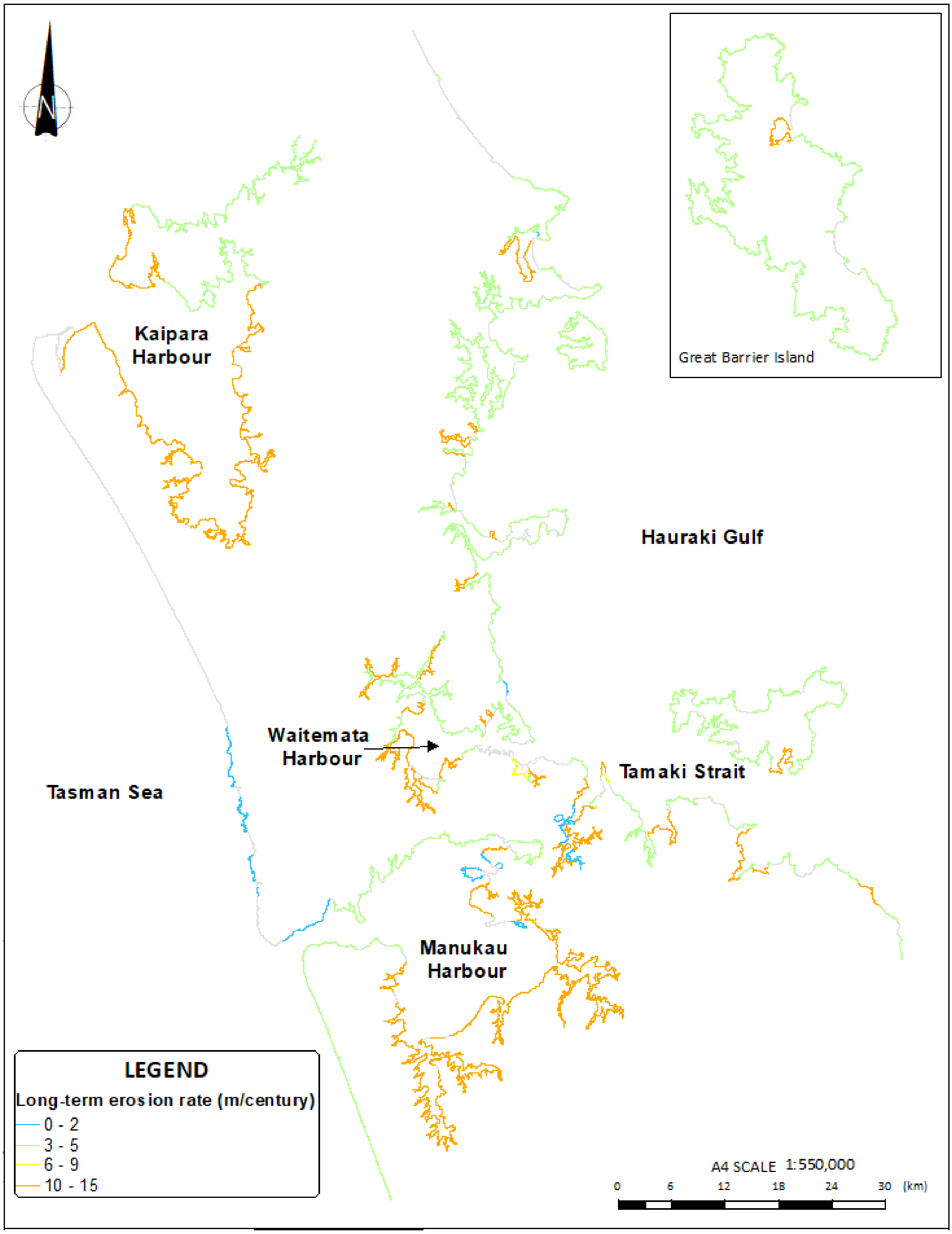

Figure 5.5: Long-term erosion rates (m/century) for cliffs excluding uncertainty

5.3.2 Beaches

Long-term shoreline trends for beaches are typically derived from surveyed beach profile datasets or digitised shorelines from historical aerial photographs. As an extensive beach profile dataset is available for the Auckland region including 25 beaches, this dataset was used to assess long-term shoreline trends.

The horizontal position of shorelines (i.e., dune toe) extracted from beach profile analysis can be used where available to assess long-term trends. These may be due to changes in sea level, fluctuations in coastal sediment supply or associated with long-term climatic cycles such as IPO.

The long-term trend has been derived by extracting the horizontal position of the dune toe at each beach profile location and plotting over time to derive the linear regression rates. Figure 5.6 shows an example of the surveyed beach profiles at Omaha Beach P1 (beach profile, which is surveyed bi-annually and situated at southern end of shoreline) including the dune toe elevation. Figure 5.7 shows an example of the horizontal position of the dune toe (i.e., excursion distance) over time including the derived linear regression rate and 95% Confidence Intervals (CIs) at Omaha Beach P1. Both the linear regression rates and CIs have been derived for each beach profile location and were used if trends seemed reasonable. For instance, if only a small number of survey points was available for a given profile location from which a linear regression rate was derived which seemed unrealistic, this rate was not used. Appendix C shows the beach profile trends for each available profile location.

It should be noted that the linear regression rate is sensitive to the position of the dune toe at the start of the survey period (i.e., the survey period started after several storms or after a period of accretion). Engineering judgement was used to assess whether long-term trends seemed reasonable.

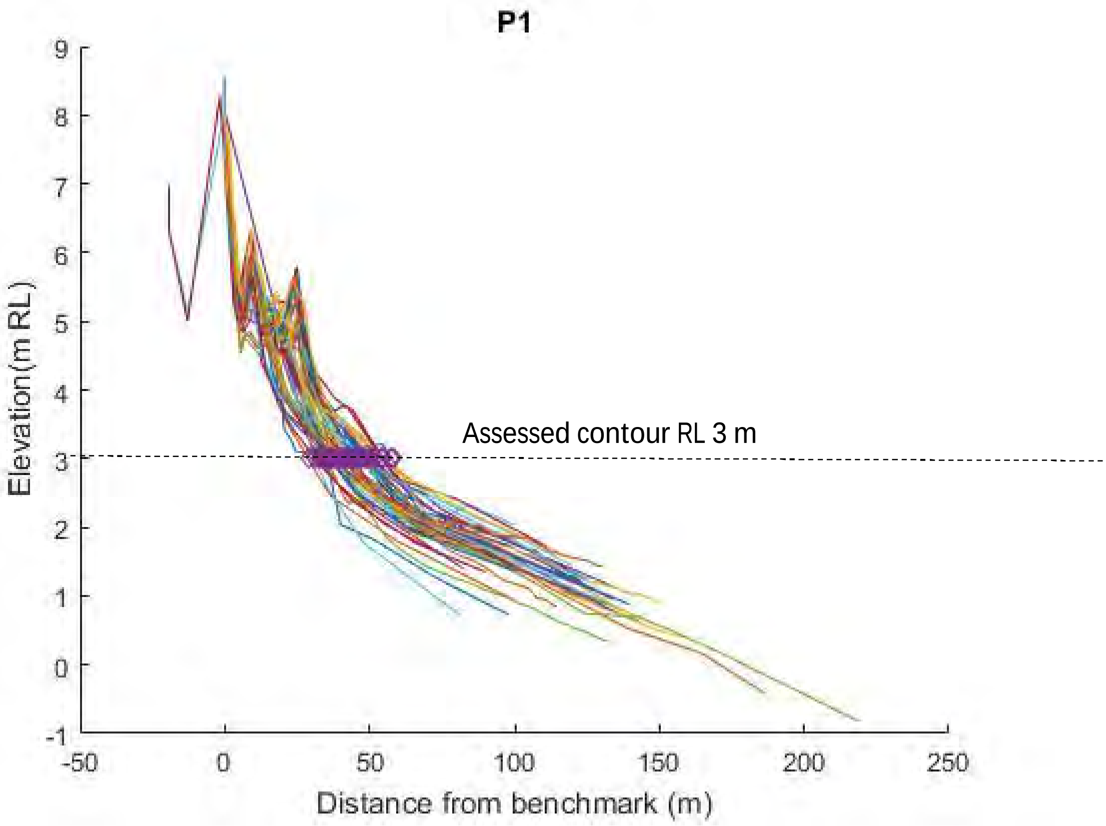

Figure 5.6: Example of beach profiles for Omaha Beach P1

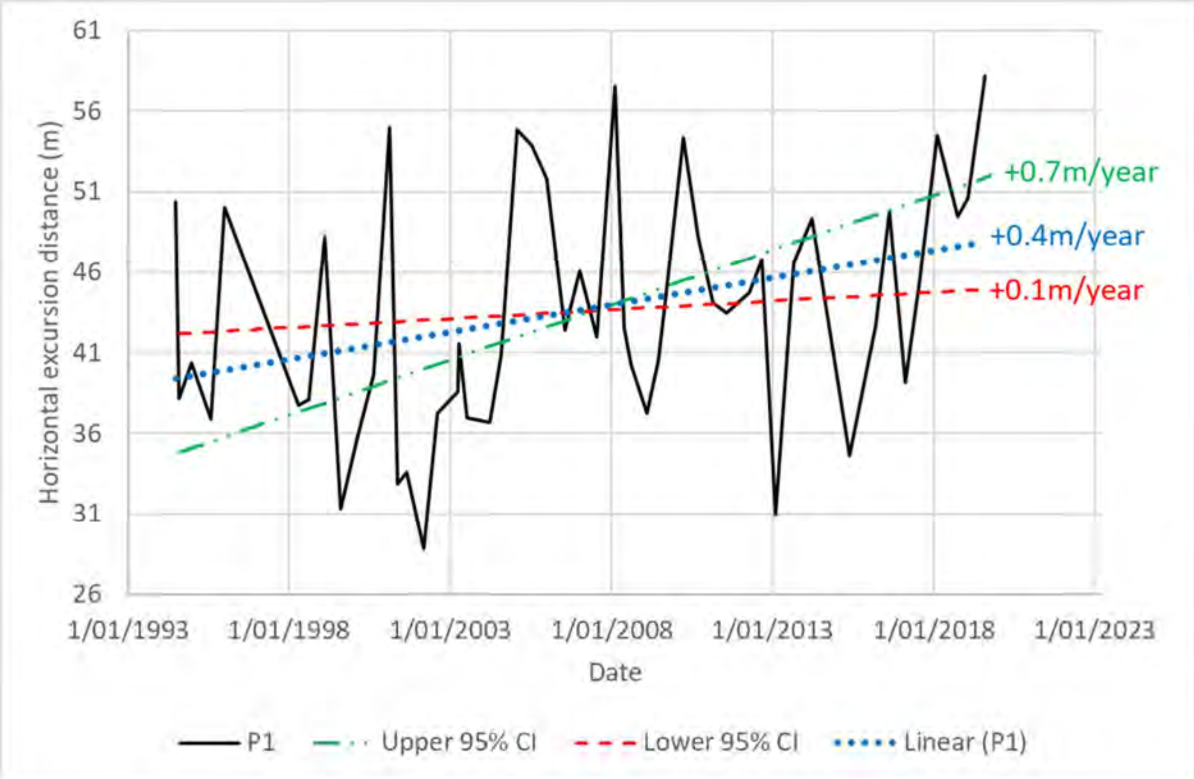

Figure 5.7: Example of the dune toe excursion distance over time including derived linear trend (0.4 m/year) and 95% CIs at Omaha Beach P1

5.3.2.1 Adopted values

For the regional-scale assessment the long-term erosion rates were rationalised based both on the beach profile analysis and Reinen-Hamill et al. (2006) values, with upper bound values (applicable for the entire coastal cell) adopted where multiple beach profiles are available. Figure 5.8 shows the adopted long-term rates for the beach cells within the Auckland region. The uncertainty has been based on the lower 95% CI of the adopted long-term rate.

For beaches where the beach profile datasets are limited, LT values are adopted from adjacent nearby beaches with similar wave exposure. For beaches where no data was available, with different wave exposure and settings to adjacent nearby beaches, a long-term rate of -0.03 m/year (3 m per 100 years) with an uncertainty of -0.02 m/year (2 m per century) was adopted. This was adopted in line with Reinen-Hamill et al. (2006) as the long-term rate for the majority of beaches in Auckland is controlled by adjacent headlands, which were found to retreat approximately -0.03 m/year (refer to Reinen-Hamill et al., 2006). For this regional-scale assessment LT has been set to zero for accreting shorelines. This is due to uncertainty in future sediment supply and whether the accretion trend is likely to be consistent over 100 years. Appendix E shows the adopted LT rates for each coastal cell including the source from which the rates are derived.

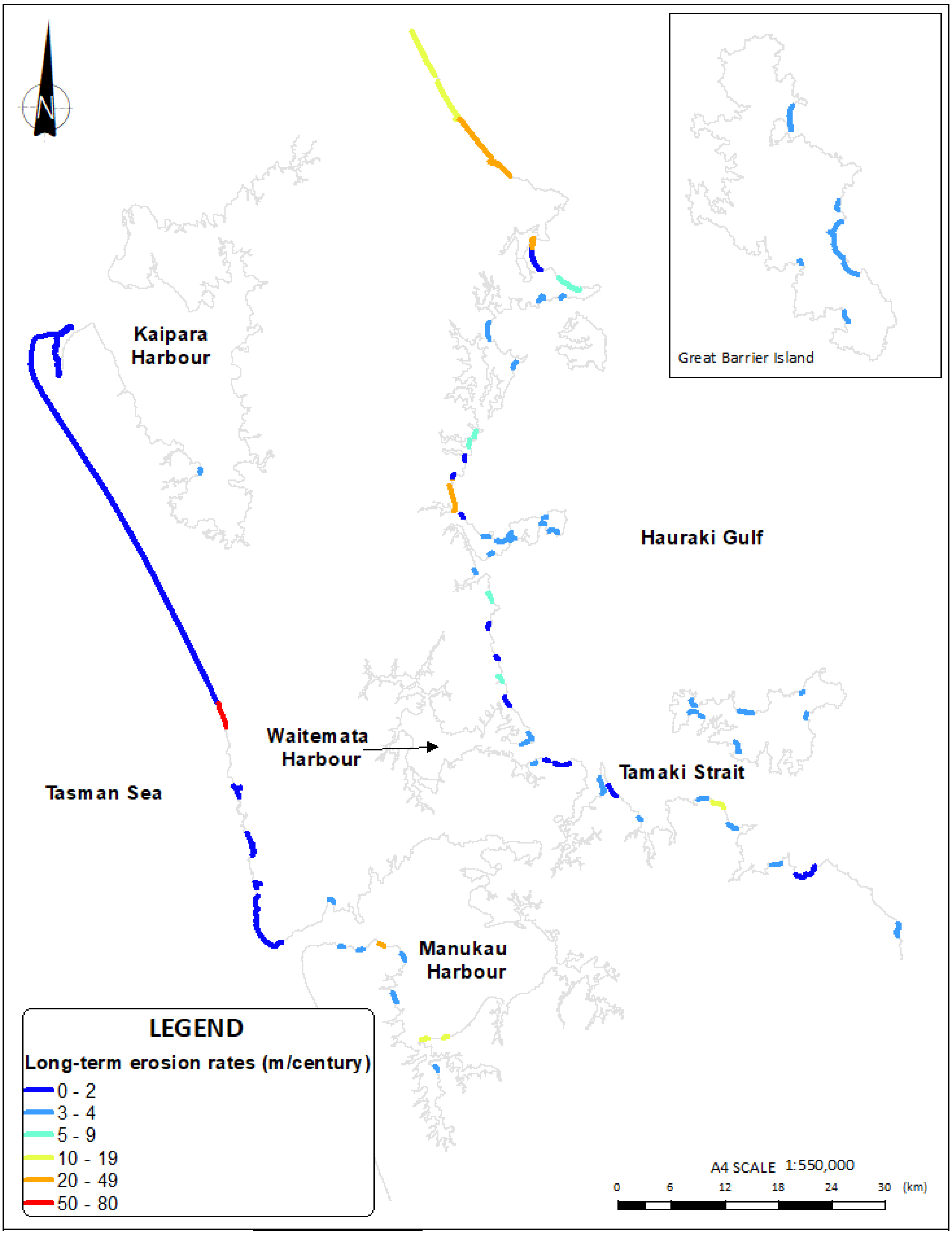

Figure 5.8: Long-term rates for beaches (m/century) excluding uncertainty

5.4 Medium-term fluctuation (MT)

Following the assessment of long-term shoreline trends, it was found that for some beaches, in particular the West Coast beaches and the beach at Pākiri, show evidence of medium-term fluctuations. Figure 5.9 shows examples of long-term trends at Piha and Pākiri, indicating the presence of medium-term fluctuations. These may be due to long-term changes in sea level and coastal sediment budget (i.e., typically in the order of 50-100 years). Fluctuations in sediment supply or climate cycles over shorter periods (i.e., 10-25 years) are considered medium-term fluctuations if they fluctuate around a mean (see example in Figure 5.9). These medium-term fluctuations are potentially related to medium-term climatic cycles (i.e., as reported by de Lange (2000) and Wood (2010) for Coromandel beaches). Other examples of where this medium-term component might be required is where there are longer-term fluctuations in sediment supply or sand-spit migration. Therefore, a medium-term fluctuation distance is included where appropriate.

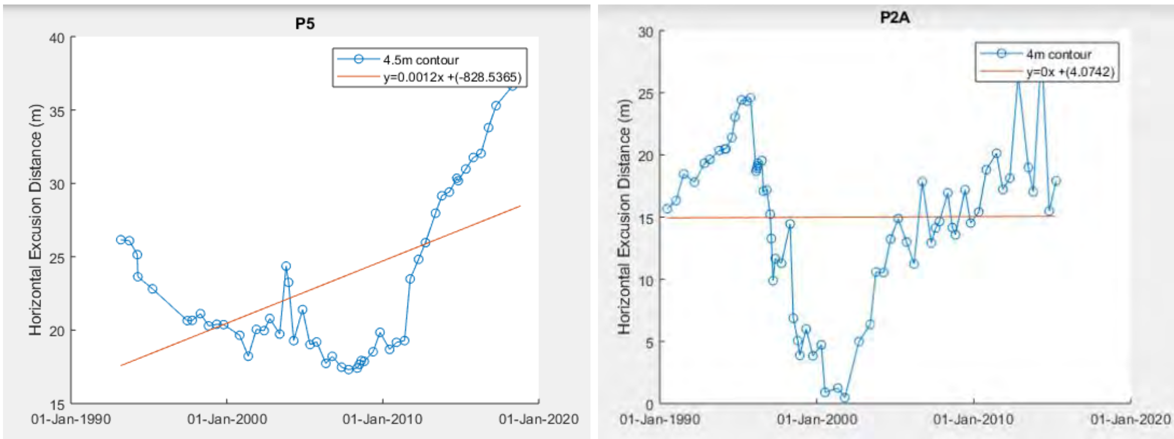

Figure 5.9: Examples of variable long-term trends at Piha P5 (left) and at Pākiri P2A (right)

For the West Coast beaches, profile analysis at Piha (up to a 30-year record length) typically shows an accretion trend (refer to Appendix C), but at various rates, with periods of limited change and periods of erosion also present. Blue & Kench (2017) use historical aerial photographs back to the 1940s to assess multi-decadal shoreline changes at Whatipu, Karekare, Piha and Te Hēnga (see example for Karekare Beach in Figure 5.10). They found that these west coast beaches are accreting, albeit at different rates and at different times. Their conclusion appears to be that the variations in sediment supply from the Manukau bar have resulted in differing trends along the different beaches. Based on this, and as all trends seem to be slowing, it is considered that these observed trends are not necessarily 'long term' (i.e., they will continue at the derived rate over at least 100 years) and would be prudent to consider them part of medium-term cycles or fluctuations.

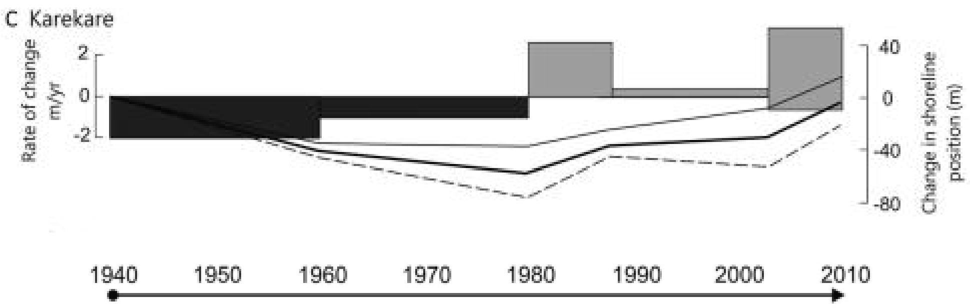

Figure 5.10: Block diagrams showing annual rates of shoreline change for Karekare (source: Blue & Kench, 2017)

5.4.1 Adopted values

An MT component have been utilised for West Coast beaches (Whatipu to Muriwai), which allows for fluctuations on a decadal timeframe. In these instances, the long-term trend is also set to zero (i.e., 0 m/year) as this could not be derived with certainty from the available data period. However, it should be noted that both a long-term trend and medium-term fluctuation may be present. SLR

Table 5.4 shows ST, MT and LT for the West Coast beaches including uncertainty. The MT distances have been based on Blue & Kench (2017), with the LT set to zero (assumed dynamically stable in the long-term) at Whatipu, Karekare, Piha and Te Hēnga. At Muriwai, processes seem to be slightly different, potentially as effects of the fluctuations in sediment supply from the Manukau Bar are reducing with distance further north, with a more consistent erosion trend evident. Figure 5.11 shows a relatively stable long-term trend north of the Okiritoto Stream (left panel) and a consistent erosion trend south of the stream, which has been slowing down over the last 10-20 years. This indicates that a medium-term fluctuation may be evident. Therefore, both MT distances and LT rates have been adopted for Muriwai, with LT rates based on beach profile analyses. The LT rate of 0 m/year for Muriwai North and relatively large LT rate for Muriwai South was supported by a review of historical aerial photographs (1940s, 1960s and 2017) showing a relatively unchanged shoreline at Muriwai north, and a consistent large erosion rate at Muriwai south of Okiritoto Stream.

At Pākiri, on Auckland's north east coast, a medium-term erosion distance of 10 m was adopted based on beach profile analysis, see Figure 5.9 right panel roughly showing ±10 m fluctuation. For the remaining beach cell shorelines, apart from Kawakawa Beach (MT = 5 m incl. uncertainty), a medium-term value could not be derived based on the available beach profile data and therefore no MT value was adopted for the remaining beach cells.

The adopted MT values shown in Table 5.4 have been adopted for the at least 100 year timeframe, with 30% and 50% of the values adopted for the 30 year and at least 50 year timeframes respectively.

Table 5.4: Summary of adopted ST, MT and LT values including uncertainty (±) for West Coast beaches for the 100 year timeframe

Beach	ST (m)	MT (m)	LT (m/year)
Whatipu	20±10	750±250	0±0.05
Karekare	20±10	35±15	0±0.05
Piha south	15±5	12±3	0±0.05
Piha north	20±10	30±10	0±0.05
Te Hēnga south	20±10	50±25	0±0.05
Te Hēnga north	15±5	12±3	0±0.05
Muriwai south	15±5	15±5	-0.8±0.2
Muriwai north	20±10	15±5	0±0.1

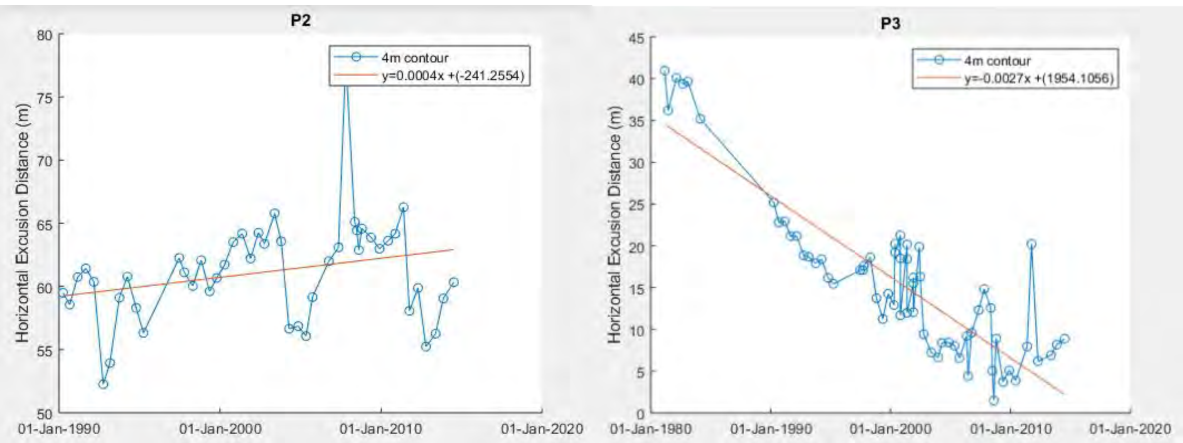

Figure 5.11: Long-term trend at Muriwai north P2 (left) and Muriwai south P3 (right)

5.5 Effects of SLR

5.5.1 Adopted SLR values

The SLR values for the 2050, 2080 and 2130 timeframes based on the guidance from MfE (2017) are shown in Table 5.5. The SLR values have been adjusted from a 1986-2005 baseline as presented in MfE (2017) to the present-day baseline, which is 2016 as the LiDAR DEM was captured between 2016 and 2018. For consolidated cliff and embankment shorelines these '*adjusted'* SLR values are used to assess the effect of SLR (refer to Section 5.5.3). For unconsolidated beach shorelines an average historical rate of SLR of 1.7 mm/year has been deducted from the projected SLR value to provide an *'effective'* SLR for use in this assessment on the basis that the existing long-term trends and processes already incorporate the response to the historical situation (see Table 5.5). The SLR values have not been adjusted to vertical land level changes as these have been assumed to be zero (refer to Section 2.2).

Four timeframe/SLR scenarios were selected by Auckland Council for mapping purposes (see shaded cells in Table 5.5):

- 2050 RCP8.5M.
- 2080 RCP8.5M.
- 2130 RCP8.5M.
- 2130 RCP8.5H+.

ASCIE distances have been assessed for these scenarios (refer to Section 6).

Table 5.5: Adopted SLR values as shaded in grey (m)

Timeframe	SLR scenario	Projected SLR relative to 1985-2005 baseline[1]	'Adjusted' SLR from present day baseline[2,3]	'Effective' SLR from present day baseline[2,4,5]
2050	RCP2.6	0.23	0.16	0.10
	RCP4.5	0.24	0.17	0.11
	RCP8.5	0.28	0.20	0.14
	RCP8.5H+	0.37	0.27	0.22
2080	RCP2.6	0.37	0.30	0.19
	RCP4.5	0.42	0.35	0.24
	RCP8.5	0.55	0.47	0.36
	RCP8.5H+	0.75	0.65	0.55
2130	RCP2.6	0.6	0.53	0.34
	RCP4.5	0.74	0.67	0.48
	RCP8.5	1.18	1.10	0.91
	RCP8.5H+	1.52	1.42	1.23

[1] Source: Projected SLR from MfE (2017) referencing IPCC (2013) Assessment Report 5

[2] Correction applied to adjust from 1986-2005 (taken to be 1995) to 2016 (baseline derived from 2016-2018 LiDAR DEM)

[3] Utilised for consolidated cliff and embankment shorelines

[4] Subtracts assumed historical rate of 1.7 mm/year (Hannah & Bell, 2012) to avoid double-counting erosion response

[5] Used for unconsolidated beach shorelines

5.5.2 Cliff response to SLR (LT_F)

Erosion of a consolidated shoreline is a one-way process of material removal, which typically can be divided into components. Gradual recession is caused by weathering and coastal processes along with episodic failures due to changes in loading, daylighting of geological structures or extreme events (e.g., storms, rainfall, leaking utilities).

This section describes the method for assessing gradual recession because of rising sea levels. Marine hydraulic processes affect cliffs either by wave action causing erosion at the toe, or by removing slope debris deposited at the toe following cliff-face collapse. SLR increases the amount of wave energy able to propagate over a fronting platform or beach to reach a cliff toe, removing talus more effectively and increasing the potential for hydraulic processes to affect erosion and recession. However, in some locations, the existence of a talus will provide self-armouring, and may slow cliff recession due to waves.

Reinen-Hamill et al. (2006) used the method by DEFRA (2002), who propose a simple method to evaluate recession in soft-cliff environments by assuming that future regression (LT_F) will be proportional to historical rates (LT_H) multiplied by the ratio of future (S_F) to historical sea-level rise (S_H). The model shown in Equation 5.1 below assumes, however, that the profile will respond instantaneously and that all recession that has occurred historically was a function of historical sea-level rise (i.e., marine processes).

$$LT_F = LT_H \times \frac{S_F}{S_H} \qquad \textit{(Equation 5.1)}$$

Walkden and Dickson (2006) use process-based mathematical models to simulate the sensitivity of shore profile response to SLR over timescales of decades to centuries incorporating factors for rock strength, cliff height, wave and tide characteristics, beach volume at the cliff toe, the distribution of erosion under a breaking wave field, profile slope and variation of tidal elevation. They found that regression rates become independent of beach volume below approximately 20 m^3/m (i.e., below this volume the beach does not influence cliff toe recession rates but above it the beach offers some protection). In the absence of beach protection, they find that for the soft cliffs tested (historical rates of recession of 0.8 to 1 m/year), an equilibrium recession rate could be described by the following equation.

$$LT_F = LT_H \sqrt{\frac{S_F}{S_H}} \qquad \textit{(Equation 5.2)}$$

It was noted, however, that equilibrium conditions take some time to develop, with the case tested taking nearly 1000 years to adjust from a past SLR rate of 2 mm/year to a future rate of 6 mm/year, although the majority of the increase occurred in the first century.

Ashton et al. (2011) proposed a generalised expression for future recession rates of cliff shorelines (shown in Equation 5.3 and Figure 5.12), where *m* is the coefficient, determined by the response system (SLR response factor). The future rate of SLR *(S_F)* is based on the adjusted SLR values as set out in Table 5.5 divided by the relevant timeframes. The historical rate of SLR (*S_H)* is based on Hannah and Bell (2012).

$$LT_F = LT_H \left(\frac{S_F}{S_H}\right)^m \qquad \textit{(Equation 5.3)}$$

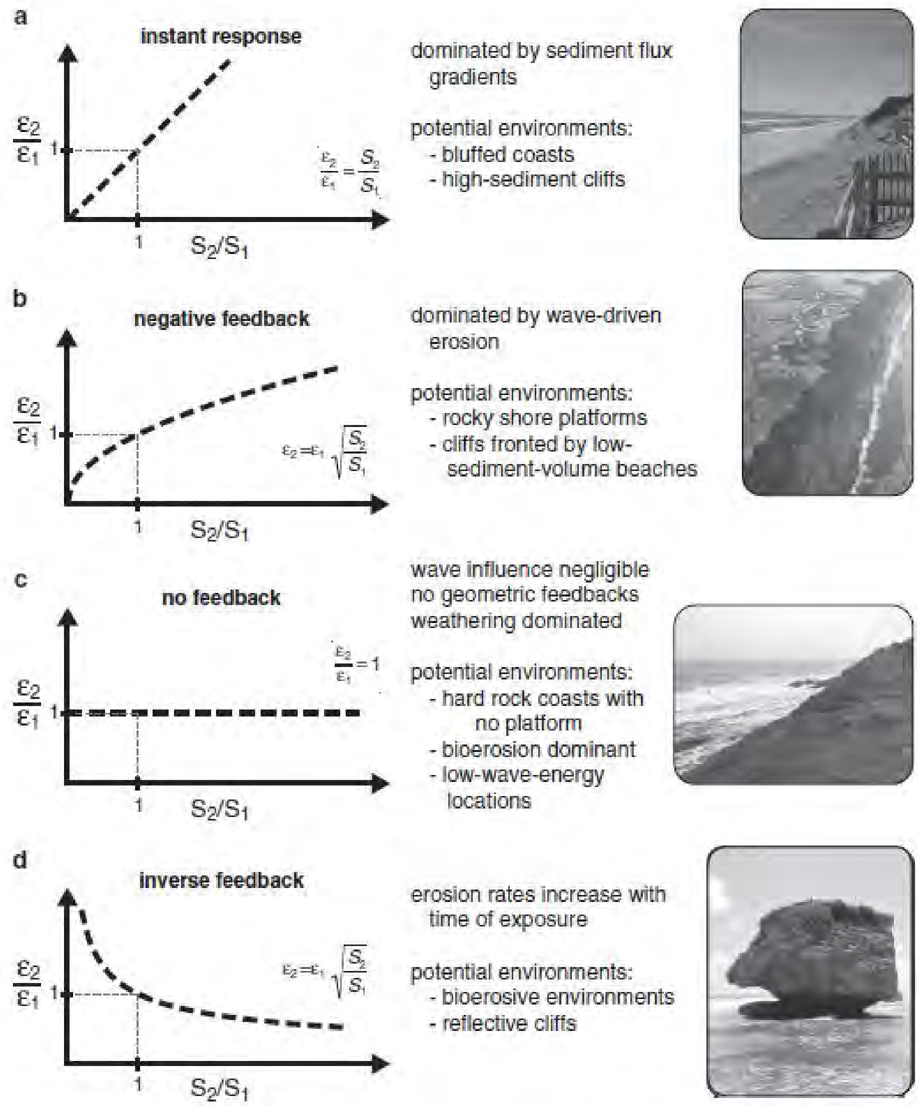

Figure 5.12 Possible modes of cliff response to SLR (adapted from Ashton et al., 2011), with E_1 = historical long-term rate, E_2 = future long-term rate, S_1 = historical SLR and S_2 = future SLR

An instantaneous response (*m* = 1) is where the rate of future recession is directly proportional to the increase in SLR. An instant response is typical of unconsolidated or weakly consolidated shorelines. No feedback (*m* = 0) indicates that wave influence is negligible, and weathering dominates. The most likely response of consolidated soft-rock shorelines is a negative/damped feedback system (*m* = 0.5), where rates of recession are slowed by development of a shore platform (see Figure 5.12). Ashton et al. (2011) also suggested an additional case of inverse feedback when *m* < 0 indicating a reduction in recession with increasing sea levels. They suggest this could occur when erosion is influenced by factors such as bio-erosion is controlled by bio-erosion or the wave-impact regime, which could be modified by additional submergence. The approach suggested by Ashton et al. (2011) is conceptually plausible and has the potential to predict recession rates on a wide variety of rock types with further analysis. The Ashton et al. (2011) formula has therefore been adopted for this study.

5.5.2.1 Adopted values

Given the uncertainties in deriving response type without detailed site-specific modelling, analysis and calibration data, a range of response types have been adopted as parameter bounds. Material erosion susceptibility (i.e., hardness) and wave exposure are the two main factors which contribute to cliff shoreline response and have therefore been used to derive the SLR response factor. The negative/damped feedback system (m = 0.5) have been used as an upper bound value as higher m values would realistically not be expected to occur in the Auckland coastal cliffs. Table 5.6 outlines the range of response factors (m) for high, medium and low wave exposures applicable for the adopted main geological types in Auckland including the relative material susceptibility.

The Tauranga Group was considered the weakest material and therefore a mean of m = 0.5 has been adopted in locations of high wave exposure. For medium and low wave exposure the m value was reduced by 0.1 and 0.2 respectively, with a mean of respectively m =0.4 and m =0.3. The upper and lower bound values were based on the uncertainty in m value, which was estimated at ±0.1. The upper bound m value for the high wave exposure is 0.5 as this is considered the upper limit. The m values for the other geological units were then scaled based on the estimated material susceptibility. The m values for the medium to highly susceptible materials have been estimated to be 0.1 less than the highly susceptible materials and the medium susceptible materials estimated to be 0.2 less (see Table 5.6). The Auckland volcanic units were considered to have no feedback (i.e., no increased long-term cliff toe erosion due to increased SLR rates), however, an upper bound m value of 0.1 was adopted to allow for any uncertainties.

Table 5.6: Adopted consolidated shoreline response factors to SLR for Auckland geological units and exposures (m)

Geological unit	Material susceptibility	Exposure	Min	Mode	Max
• AVF/CVZ • Waitakere Group	Low	Any	0	0.05	0.1
• Pākiri Formation • Waipapa Group	Med	Low	0	0.1	0.2
		Med	0.1	0.2	0.3
		High	0.2	0.3	0.4
• ECBF • Āwhitu Group • Northland Allochthon	Med-High	Low	0.1	0.2	0.3
		Med	0.2	0.3	0.4
		High	0.3	0.4	0.5
• Tauranga Group	High	Low	0.2	0.3	0.4
		Med	0.3	0.4	0.5
		High	0.4	0.5	0.5

For the regional-scale assessment the modal (i.e., mode) values have been adopted. The uncertainty is based on the upper bound (i.e., max) values. Figure 5.13 shows the adopted m values for the entire Auckland region.

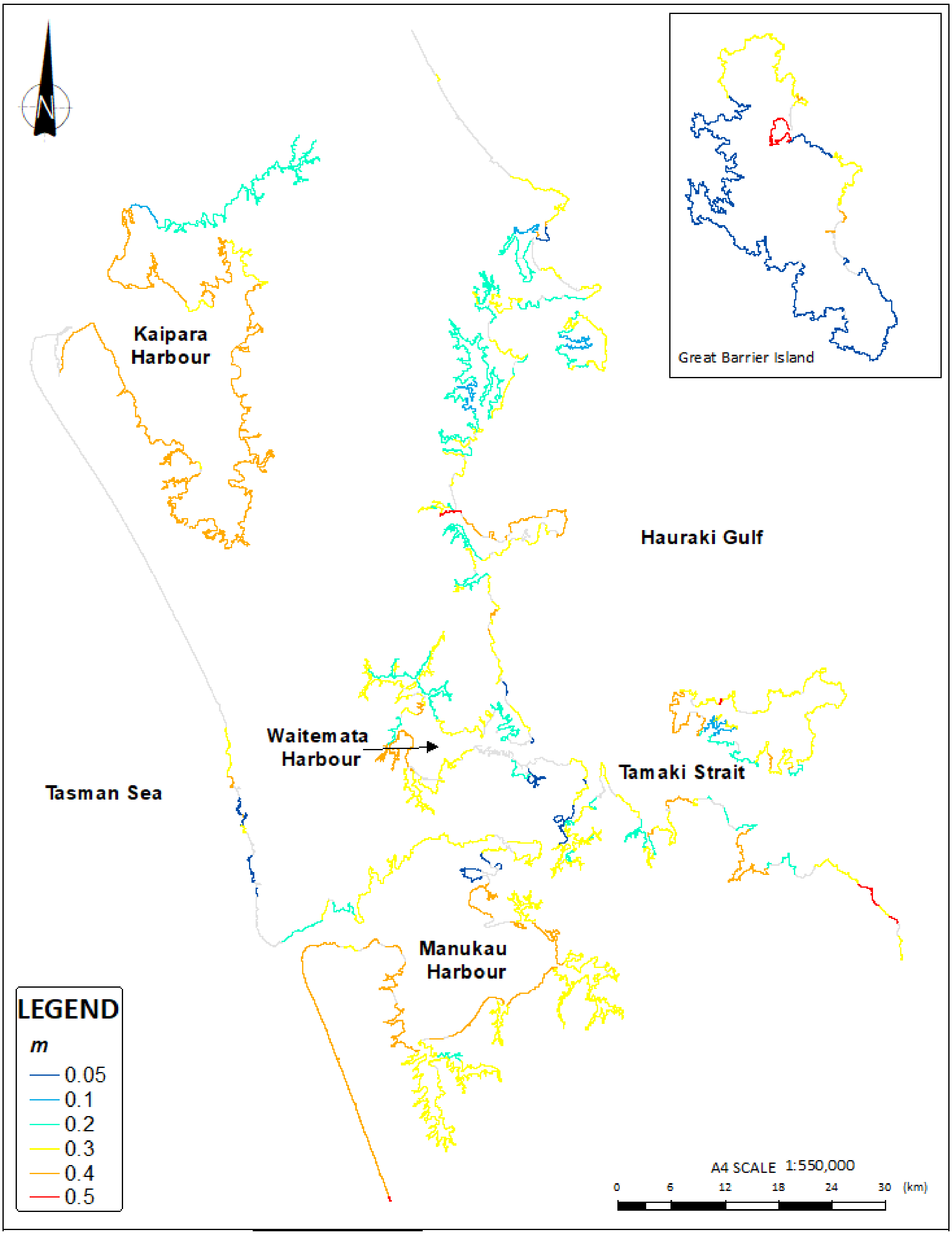

Figure 5.13: Adopted m values for Auckland region

5.5.3 Beach response to SLR (SL)

Geometric response models propose that as sea level is raised, the equilibrium profile is moved upward and landward conserving mass and original shape (see Figure 5.14). The most well-known of these geometric response models is the Bruun Rule (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 seabed 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:

$$SL = \frac{L_*}{B + d_*} S \qquad \textit{(Equation 5.4)}$$

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 SLR. Figure 5.14 shows the schematic diagrams of the Bruun models, with the Standard Bruun rule used for this assessment.

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.

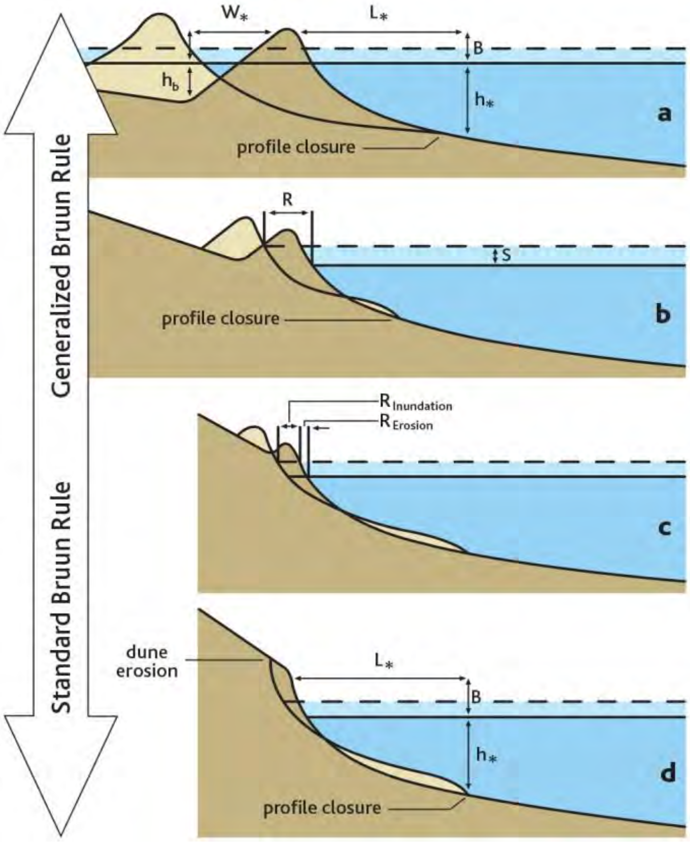

Figure 5.14: Schematic diagrams of the Bruun model modes of shoreline response (after Cowell and Kench, 2001)

To define parameter distributions, three different active translation slopes (refer to L_*/B+D component in Equation 5.4) have been derived, which include:

1 Active beach face, average dune toe position to low water mark (lower bound).

2 Inner closure slope, average dune crest to inner Hallermeier closure depth (modal value).

3 Outer closure slope, average dune crest to outer Hallermeier closure depth (upper bound).

The Hallermeier closure definitions are defined as follows (Nicholls et al., 1998):

$$d_l = 2.28H_{s,t} - 68.5\left(\frac{H_{s,t}^2}{gT_s^2}\right) \cong 2\ x\ H_{s,t} \qquad \textit{(Equation 5.5)}$$

$$d_i = 1.5\ x\ d_l \qquad \textit{(Equation 5.6)}$$

Where d_l is the inner closure depth below mean low water spring, $H_{s,t}$ is the non-breaking significant wave height exceeded for 12 hours in a defined time period, nominally 1 year, and T_s is the associated period. $d_i$is the outer closure depth below mean low water springs. For this study the deep water (non-breaking) wave climate parameters of $H_{s,t}$ and T_s were based on the MetOceanView hindcast data (MSNZL, 2019) extracted roughly at the -10 m contour. The inner and outer closure slopes have been assessed for all open coast beaches.

At harbour coast beaches (i.e., Waitematā, Manukau and Kaipara Harbours and Tamaki Strait) the MSNZL (2019) derived wave data was not available. Furthermore, harbour coast beaches typically have wide intertidal zones with no extensive dune system, with the inner and outer closure depths not necessarily being applicable. Most of the terrestrial sediments supplied to the beach areas are from the catchment via the streams that discharge to the coast and from erosion from the cliff coasts adjacent. Therefore, harbour coast beaches are expected to behave differently to sandy open coast beaches in response to a rise in mean sea level. For harbour coast beaches the active beach face slope was used for the active translation slope.

5.5.3.1 Adopted values

Following an assessment of inner and outer closure slopes for the open coast beaches and the active beach face slopes for the harbour coast beaches, the active translation slopes have been rationalised for each area as shown in Table 5.7. The rationalised active translation slopes for the open coast beaches have been based on the assessed inner closure slopes, with the uncertainty based on the difference between the outer and inner closure slopes.

Table 5.7: Adopted rationalised translation slopes for each region

Area	Active translation slope excluding uncertainty (-)	Active translation slope including uncertainty (-)	Adopted closure depth (m)
Outer Hauraki Gulf	0.02	0.015	10
Inner Hauraki Gulf	0.025	0.02	7.5
West Coast	0.013	0.01	15
Harbours (incl. Tamaki Strait)	0.08	0.05	5

For the regional-scale assessment the beach response to SLR is based on the active translation slopes, derived using the adopted closure depths, as set out in Table 5.7 and using the Bruun method to calculate the horizontal retreat distance. Single SLR values are adopted as set out in Section 5.5.1. The active translation slopes including uncertainty for the regional-scale assessment is set out in Table 5.7.

5.6 Coastal slope height

The coastal slope height for beach and cliff cells has been derived from the 2016-2018 LiDAR DEM. Cross-shore profiles were generated at typically 100-500 m alongshore intervals for beaches from which dune heights were derived. For cliffs the projection method as set out in Section 7.3.1 has been used to derive slope heights at 20 m alongshore intervals. However, cliff heights are not required to be derived to calculate the ASCIE distance as this is done within the cliff projection mapping process (refer to Section 7.3.1).

5.6.1 Adopted values

For the regional-scale assessment single typical upper bound dune heights have been adopted that are representative for each coastal cell. The calculated typical upper bound heights have been compared with the Reinen-Hamill et al. (2006) adopted values and visual checks of the 2016-2018 LiDAR DEM were undertaken to review the calculated dune heights, with heights modified where required. The uncertainty in dune is determined based on the uncertainty in the data rather than the statistical uncertainty (i.e., variance in height within a cell). The uncertainty in data has been estimated at ±2 m based on the accuracy of the LiDAR data and rounding the heights up to the nearest one.

Figure 5.15 shows a map of the dune and cliff heights for the Auckland region. For cliffs the typical upper bound values have been based on the 95th % from individual profiles within a cell. This means there is a probability of approximately 5% the cliff height is higher within a coastal cell.

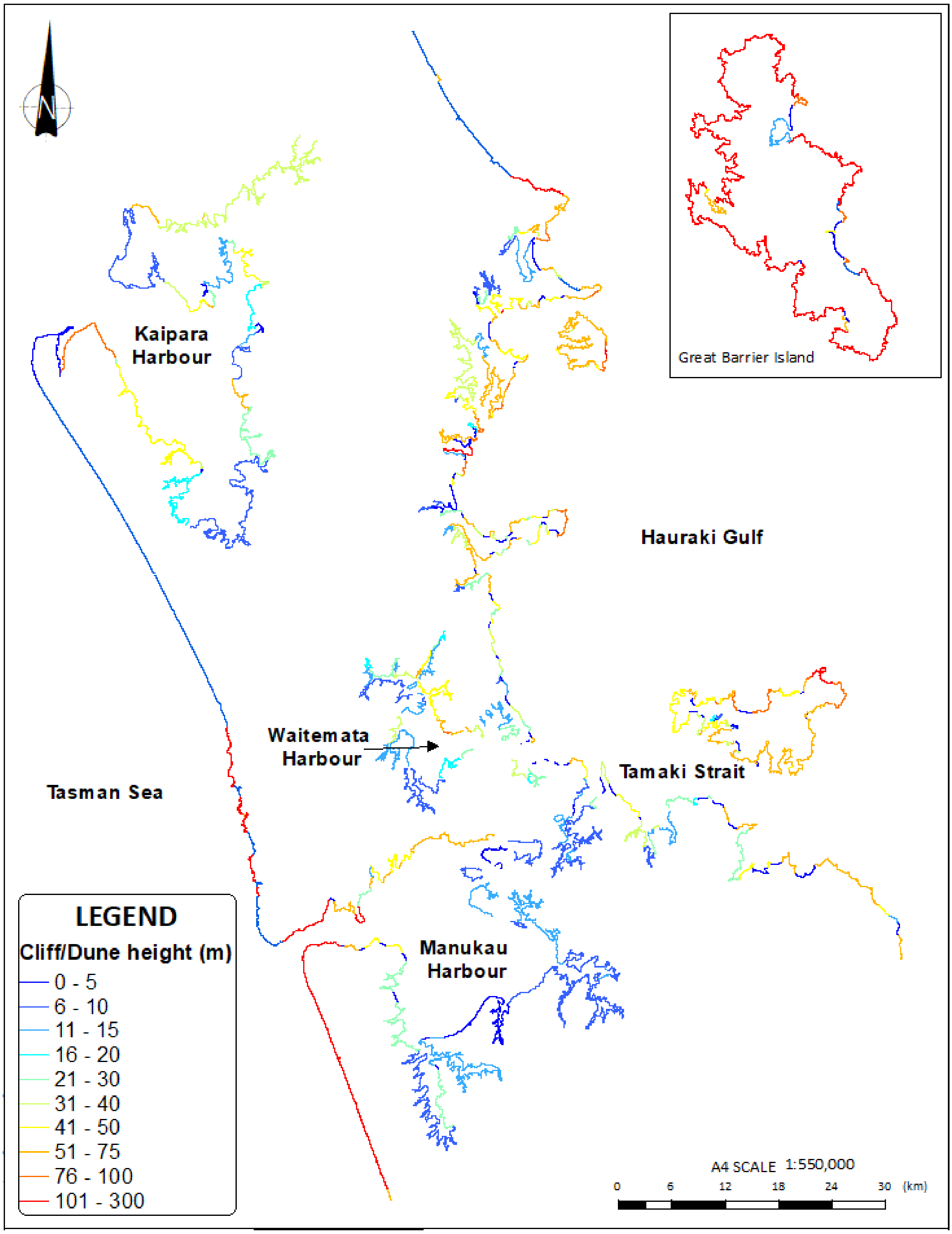

Figure 5.15: Cliff and dune heights in Auckland region

5.7 Coastal instability

5.7.1 Review of Reinen-Hamill et al. (2006) cliff slopes

Reinen-Hamill et al. (2006) undertook analyses to evaluate potential correlations between the cliff height and slope angle based on the geological unit presented in the cliff face. However, it was observed that other factors, such as structure and surface conditions also influenced the profile of the cliff face, particularly in the non-volcanic rock types.

Field data from observations of cliff slope angles and the geological strength index (GSI) (Marinos & Hoek, 2001) were recorded, graphed and tabulated. From this data the mean and standard deviation (SD) of the angles of repose of the cliff slopes were evaluated.

Numerical limit equilibrium analyses (RocScience, SLIDE) were then undertaken using the GSI values and a cliff height of 30 m. The 30 m cliff height was used as the field data indicated that this was the median of the measured values within the Auckland region. As a result of the analysis two curves were developed for a Factor of Safety (FoS) of 1.0 and 1.5 for various slope angles with different GSI and uniaxial compressive strengths (UCS). The results of that analysis identified that:

- The plotted curve for a FoS of 1.5 fell just below the observed data set and approximates to the 95th percentile of measured slope angles (i.e., instability unlikely to occur beyond this layback an angle).
- The curve for a Factor of Safety of 1.0 plotted close to the mean of the observed data set (i.e., instability 'Possible' on the seaward side of the resultant slope profile).

The study concluded with the values for a as shown in Table 5.8.

Table 5.8: Reinen-Hamill et al. (2006) slope angles for determining coastal areas susceptible to erosion

GSI/Category	Slope angles (°)	
	Possible	Unlikely
Alluvium	26	18
Coastal Sediments	32	22
GSI: 20 ±10	32	22
GSI: 40 ±10	36	26
GSI: 60 ±10	49	36
GSI: 80 ±10	67	45

5.7.2 Coastal instability numerical modelling

A series of cross sections were taken through the LiDAR topography at 100-500 m alongshore intervals to develop coastal cliff profiles. From these profiles the cliff toe and crest positions were identified to derive a cliff height and slope angle. The definition of the slope crest is the intersection of the actively eroding or unstable cliff face and the land behind, as shown in Figure 4.6.

Published lithology (Edbrooke, 2001) was used to spatially characterise the cliff slope materials and link these to the coastal cliff profiles. The GSI values derived from Reinen-Hamill et al. (2006) were not re-evaluated for this study. Following the LiDAR interpretation of the cliff profiles, analyses were undertaken to more clearly define the application of the Auckland Council CoP Section 2 (ACCoP, 2012) and Auckland Council AC2229 (Auckland Council, 2019) frameworks to the coastal cliffs.

Numerical modelling was undertaken in SLIDE (RocScience, to align with Reinen-Hamill et al., 2006), with a series of different cliff heights and slope angles. The results from these analyses were used to develop a series of slope stability curves for Factors of Safety of 1.0 and 1.5, which is in line with the ACCoP (2012).

Due to the uncertainty in the modelling, two different approaches were considered for material characterisation (utilising either a generalised Hoek-Brown (GSI and UCS) or a Mohr-Coulomb (Cohesion and friction angle, c and ϕ)). A comparison between the different modelling methods was required as the approaches had the potential to produce different slope angles.

The results of the numerical analysis were plotted graphically to develop a slope angle verses cliff height curve (e.g., Hoek & Bray 1981; Styles et al. 2011; Martin 2019). A process of validation was undertaken comparing the slope stability curves with selected actual cliff profile data.

The method used for the determination of the cliff characteristics included manual extraction of cross-shore profiles from the LiDAR DEM data and visual interpretation from LiDAR and aerial photography. The resultant data points were plotted against slope stability curves as shown in Figure 5.16 (for ECBF).

The results indicate that the coastal slopes composed of ECBF, as shown in Figure 5.16, are generally "stable" under current climatic conditions (left of the FoS curve 1.0). This is confirmed by the low frequency of mass instability (i.e., where rock mass becomes unstable due to its low strength) of ECBF in Auckland's regional cliffs. Most occurrences of instability are sporadic and relate to localised high angle topples and falls and denudation of the coastal slope over time. These observations are reflected by numerous data points plotting to the left of the FoS 1.5 curve.

In order to use this methodology for the prediction of cliff stability there should be a linear, or semi linear relationship between slope angle and cliff height (i.e., as slope angle decreases cliff height should increase if morphologically possible). However, the data does not show this trend for any of the lithologies examined. This could be due, but not limited to;

- Instability mechanisms provided by SLIDE (limit equilibrium modelling) were either circular or semi-circular rotational, which in the field are not generally observed as they are more structurally controlled or high angle topples or rock falls. These high-angle topples, or falls, are very difficult to model on a regional scale when changes in material parameters are extremely large.
- Underlying geology where higher cliffs are located is more resistant to terrestrial weathering and erosion, therefore having the ability to create higher slopes at steeper angles (the current trend observed). This should have been observed with an increase in the GSI values, but this relationship was also not present as this relates to geological structure not strength. Material strength or cementation could not be analysed at this scale due to the limited data set but may play a significant role in the stability of coastal slopes.

In conclusion, the stable slope angle height curve method was deemed not appropriate for the regional classification of coastal slopes, and therefore, another method to determine the ASCI was required.

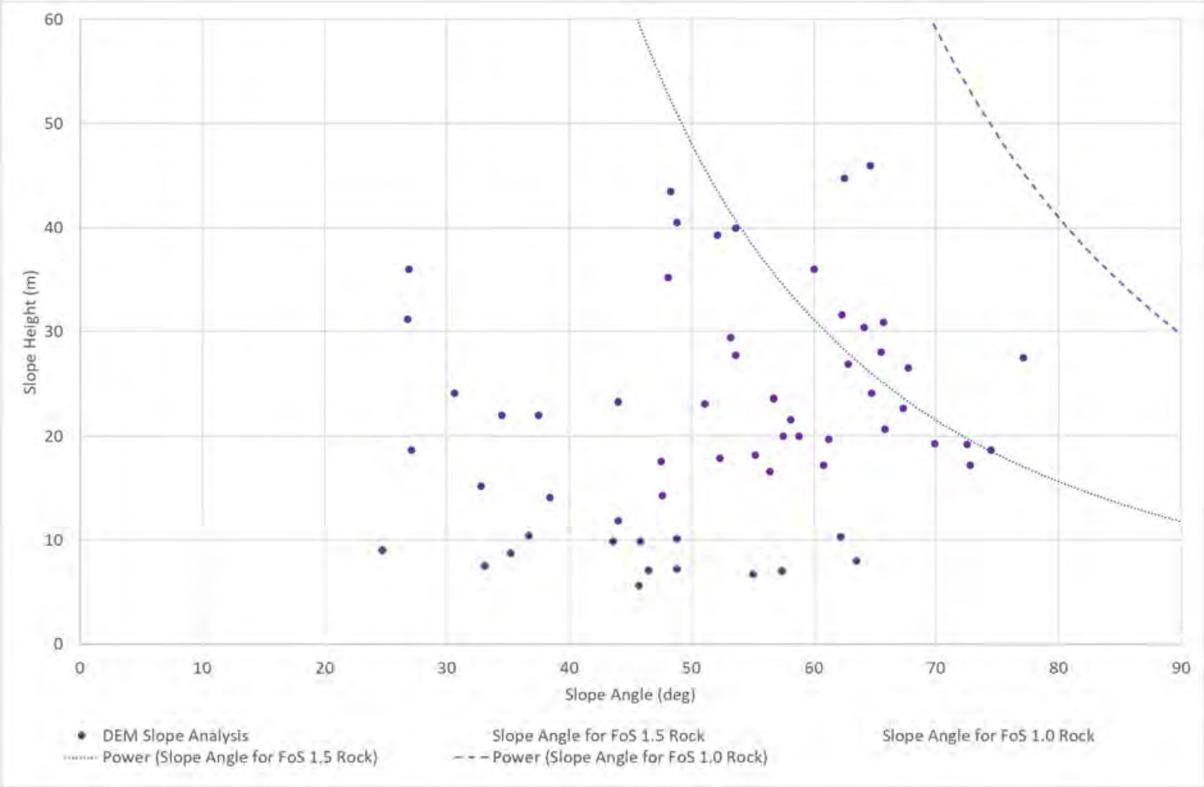

Figure 5.16: Slope stability curves for ECBF compared to measured slope height and angle

5.7.3 Statistical method for slope angles

To create a statistical method for determining the coastal slope angles a dataset was required to be created for the Auckland region. Therefore, each lithological domain or sub domain, presented in Section 2.3, was analysed across roughly 50 selected coastal profiles for different coastal environments. For each profile the cliff toe, crest of the rock layer and crest of the soil layer were derived to obtain the height and slope of both the rock and soil layers (see sketch in Figure 5.17), with an example of cross-shore profiles used to derive slopes for ECBF shown in Figure 5.18.

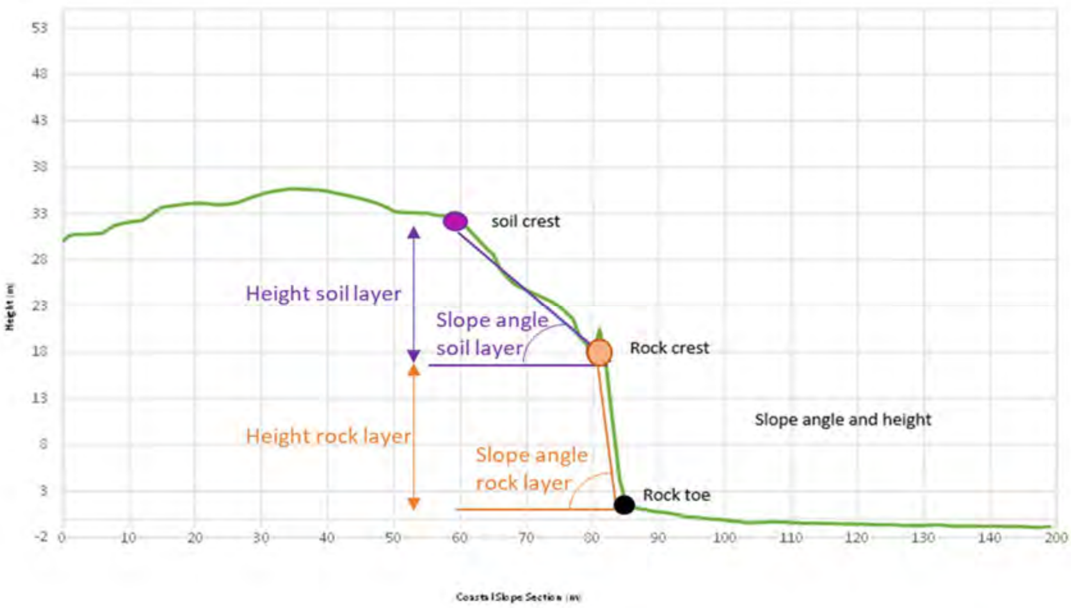

Figure 5.17: Cliff profile sketch showing identified rock toe, rock crest and soil crest to derive angles and heights

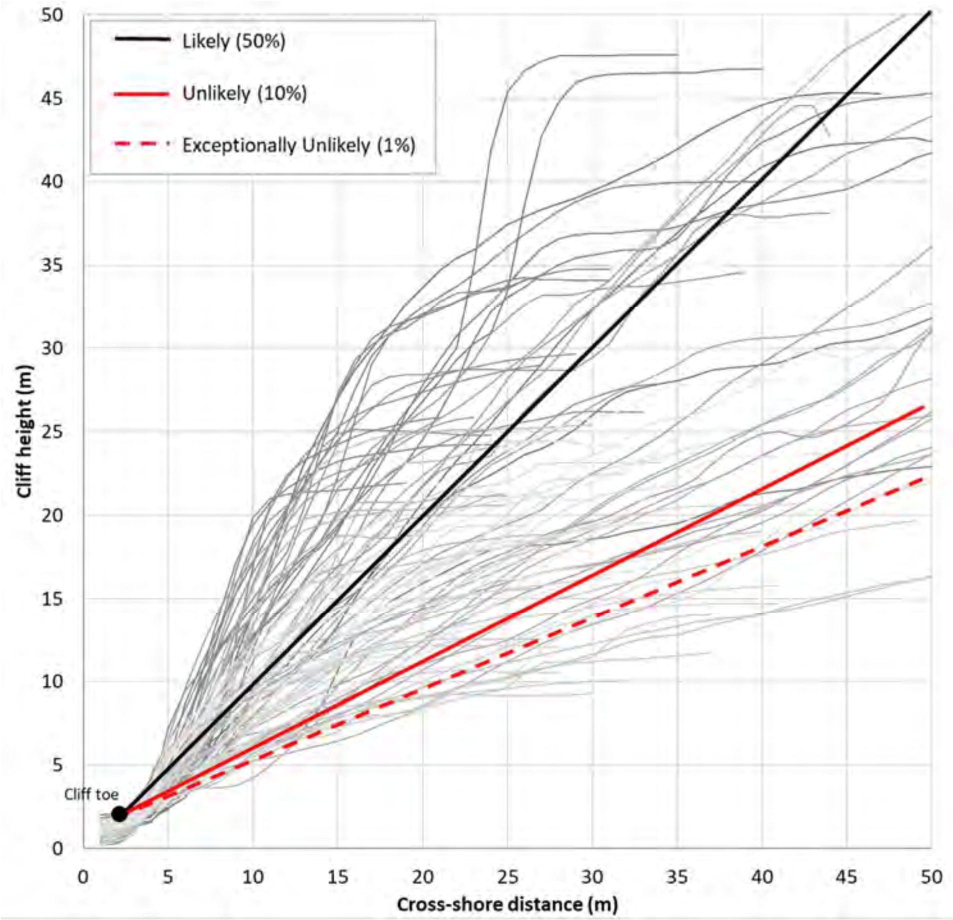

Figure 5.18: Cross-shore profiles (grey) used to derive likely (45°), unlikely (27°) and exceptionally unlikely (24°) slopes

It was not possible to derive separate rock and soil slope angles, and to use the site-specific rock and soil height to apply these angles, as a result of the large-scale resolution of this assessment. The derived heights and angles from each profile were therefore analysed and combined to derive combined slope angles for each lithology. The combined slope angles were plotted as scatter plots (see example Figure 5.19) and slope angle statistics were derived.

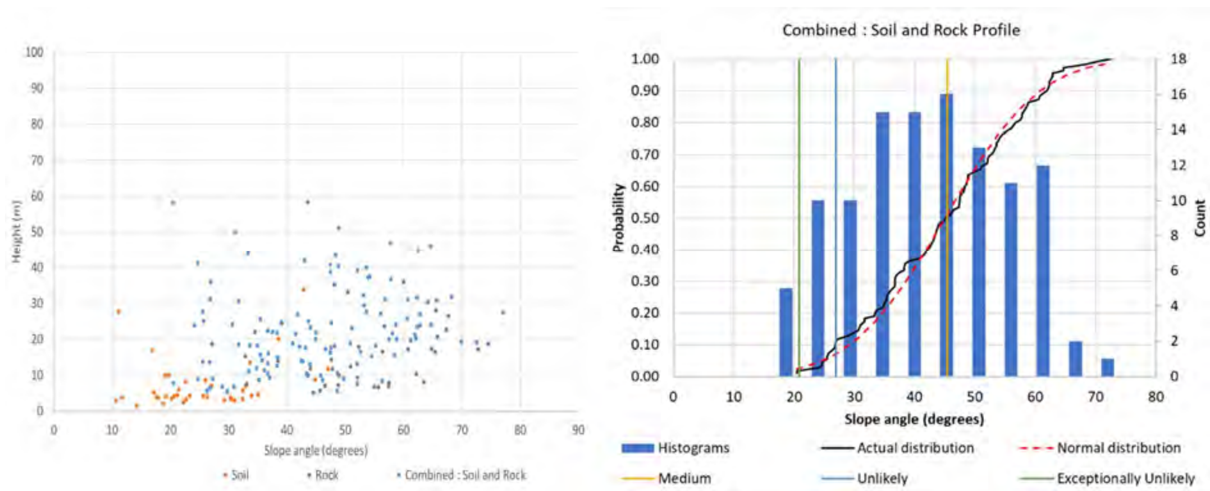

Figure 5.19: Statistical evaluation of the coastal instability slope angle for ECBF, with scatter plot of rock, soil and combined slope angles (left) and histograms of combined slope angles including likelihoods and cumulative distribution functions (right)

Figure 5.19 shows the distribution of combined slope angles for ECBF including the medium, unlikely, and exceptionally unlikely likelihood slope angles. The definitions of the likelihood of occurrence adopted here have been taken from the Intergovernmental Panel on Climate Change (IPCC) methodology (refer IPCC, 2013). The lower three categories from IPCC have been used including Medium likelihood (33-66%), Unlikely (10-33%) and Exceptionally Unlikely (1%)). The 50%, 10% and 1% likelihoods of occurrence have been adopted as the medium, unlikely, and exceptionally unlikely.

5.7.3.1 Adopted values

Once all of the lithologies for the Auckland region had been graphed and analysed, slope profile values for 'Medium', 'Unlikely' and 'Exceptionally Unlikely' conditions were rationalised, as set out in Table 5.9. The unlikely cliff slope has been adopted for the regional assessment, with the exceptionally unlikely cliff slopes representing the slope angle including the greatest uncertainty.

This study has adopted slope angles based on statistical analysis of a relatively small sample of existing cliff slopes that are considered representative across the region. This also includes existing very flat slopes, which dominate the lower probability slope angles (i.e., unlikely and exceptionally unlikely slope angles). The exceptionally unlikely slope angles therefore tend to be close to the flattest slope angle derived from existing cliff profiles and are unlikely applicable across the wider region, hence the unlikely value has been adopted. It should be noted that the inclusion of valley slopes with cliffs (refer to limitations set out in Section 1.4) likely skews the data towards the flatter slopes.

Table 5.9: Adopted ASCIE cliff slope angles

Lithology	Composite slope profile (°)		
	Medium	Unlikely	Exceptionally Unlikely
	50% exceedance	10% exceedance	1% exceedance
Tauranga Group	48	34	31
Awhitu Group	38	33	30
AVC/CVZ	42	32	28
Waitakere Group	63	38	28
ECBF	45	27	24
Pākiri Formation	54	28	25
Northland Allochthon	26	14	9
Waipapa Group	42	31	26

Adopting the 10% exceedance cliff slope profile means that for 10% of the coastal cell the coastal instability area could potentially be underpredicted. An example of the variability within a coastal cell and potential under- or overestimating the cliff instability area is shown in Figure 5.20. This figure shows that for some areas the cliff instability area may potentially be larger than the mapped area (left figure) and for some areas the cliff instability area could be smaller than the mapped area (right figure). The middle cross-section (Figure 5.20) shows that the mapped instability area is roughly expected.

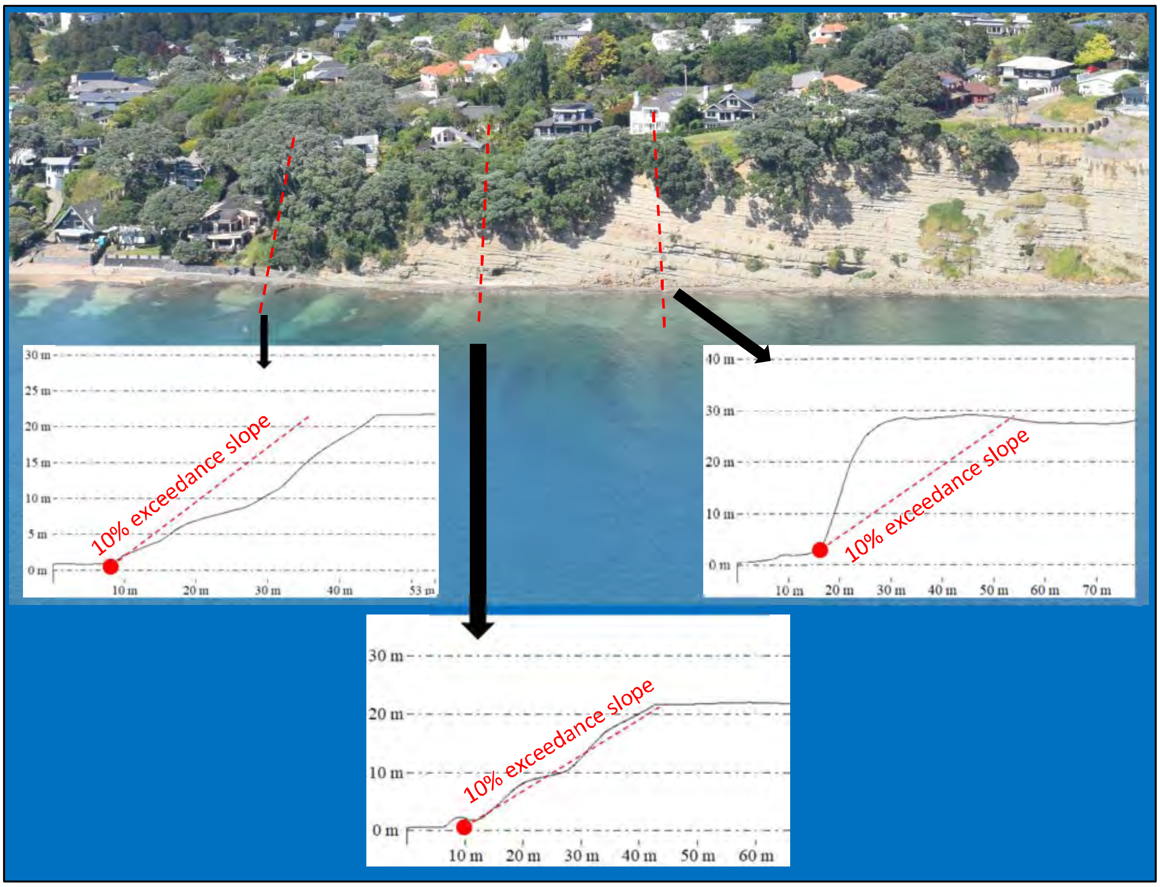

Figure 5.20: Example of projected ASCIE within a coastal cell showing alongshore variability

Compared to the slope angles adopted by Reinen-Hamill et al. (2006), the adopted ASCIE cliff slope angles shown in Table 5.9 are typically flatter. However, as the slope angles by Reinen-Hamill et al. (2006) are based on an assumed GSI and the slope angles adopted for this study are grouped by lithology, a direct comparison of slope angles derived for each lithology cannot be made. The unlikely slope angles by Reinen-Hamill et al. (2006) are slightly steeper and range from 18 to 45 degrees whereas the unlikely slope angles derived for this assessment range from 14 to 38 degrees. The exceptionally unlikely slope angles derived for this study range from 9 to 31 degrees are even flatter. This is likely a result of the different approach adopted by Reinen-Hamill et al. (2006) who used a combination of numerical modelling and expert judgement.

5.7.4 Dune slope

The dune stability factor delineates the area potentially susceptible to erosion landward of the erosion scarp. The parameter assumes that storm erosion results in an over-steepened scarp which must adjust to a stable angle of repose for loose sand. The dune stability width is dependent on the height of the existing dune and the angle of repose for loose sand. The dune stability factor is outlined below:

$$DS = \frac{H}{2(\tan\alpha_{sand})} \qquad \text{(Equation 5.7)}$$

Where H is the dune height from the eroded base to the crest and α_{sand} is the stable angle of repose for beach sand (ranging from 30 to 34 degrees) and beach gravel (ranging from 25 to 30 degrees). The formation of a talus slope at the toe will allow the scarp to stand at steeper slopes (unless subsequently removed), hence the dune height is divided by 2. Like cliffs it was assumed that the groundwater does not affect the slope stability. Dune heights were obtained from 2016-2018 LiDAR DEM (refer to Section 5.6).

5.8 Summary of adopted methods and values

Table 5.10 sets out a summary of the adopted values and uncertainty for the regional-scale assessment as described in Sections 5.2-5.6.

Table 5.10: Adopted method and values for beach and cliff erosion components

Model	Component		Regional-scale assessment	
			Value	Uncertainty
Beach	ST		100-year ARI	Standard deviation of residuals
	MT[1]		Rationalised values based on literature or beach profile analysis	Rationalised values based on literature or beach profile analysis
	LT		Upper bound long-term trend	95% CI of long-term trend
	SL	SLR	Single SLR value	N/A
		Response	Rationalised inner closure depth slopes for open coast beaches and active beach face slopes for harbour coast beaches using the Bruun method	Outer closure slope for open coast beaches and upper bound typical beach face slope
	DS	Slope	Typical upper bound value	N/A
		Height	Typical upper bound value of typical height	Uncertainty of spatial dataset
Cliff	LT_H		Upper bound long-term trend value	Engineering judgement and uncertainty in data.
	LT_F	SLR	Single SLR value	N/A
		Factor	Modal *m* value	$m = 0.1$
	Cliff instability	Slope	Derived based on existing slope statistics (i.e. 10% exceedance)	Derived based on existing slope statistics (i.e. 1% exceedance)
		Height	Cliff projection method	Accuracy of LiDAR DEM

[1]Note that MT is only used for beaches where it is evident (i.e. not every beach)

6 Results and discussion

For each coastal cell, the relevant components influencing the ASCIE have been combined as described in Sections 4.3 and 4.4 to derive the resultant ASCIE. The resulting component distances including uncertainty values and resulting ASCIE distances for each coastal cell are shown in Appendix E for beaches. Resulting component values and resulting ASCIE distances for cliffs based on the cliff projection mapping are shown in Appendix F. Summary tables of resulting ASCIE distances (excluding uncertainty) are shown in Table 6.1 for cliffs and Table 6.2 beaches respectively.

6.1 Cliffs

The resulting ASCIE distance for cliffs is a combination of the cliff instability component, which has been derived using the cliff projection method, and long-term cliff toe regression. The short-term ASCIE for cliffs excludes the long-term component for cliff toe regression and is composed of the cliff instability component only. Table 6.1 shows the resulting mean and typical upper bound ASCIE distances for the cliff instability component (i.e., short-term ASCIE) and future ASCIE scenarios for the eight geological types (excluding uncertainty), including mean toe regression distances for future timeframes. The typical upper bound values for ASCIE distances have been taken as the 95th % values. A boxplot showing the median, 25-75% range and 5-95% range for the 8 geology types for the 4 scenarios is shown in Figure 6.1.

Table 6.1: Summary of mean (and typical upper bound) resulting ASCIE distances (m) for short-term and future timeframes including mean toe erosion distances for future time frames

Scenario	Component	Tauranga Group	**Ā**whitu Group	Waitakere Group	AVF/ CVZ	ECBF	**Pā**kiri Formation	Northland Allochthon	Waipapa Group
Short-term	ASCIE[1]	-17 (-52)	-147 (-272)	-117 (-283)	-79 (-214)	-48 (-114)	-92 (-277)	-67 (-183)	-79 (-224)
2050 (RCP8.5M)	Toe regression	-3	-2	-1	-1	-2	-1	-2	-1
	ASCIE	-20 (-53)	-149 (-274)	-118 (-284)	-80 (-215)	-50 (-117)	-93 (-278)	-69 (-183)	-80 (-225)
2080 (RCP8.5M)	Toe regression	-8	-4	-1	-3	-4	-1	-4	-2
	ASCIE	-25 (-55)	-151 (-276)	-118 (-284)	-82 (-216)	-52 (-118)	-93 (-278)	-71 (-184)	-81 (-225)
2130 (RCP8.5M)	Toe regression	-18	-9	-1	-6	-8	-3	-7	-4
	ASCIE	-35 (-65)	-156 (-281)	-118 (-284)	-85 (-218)	-56 (-123)	-95 (-280)	-74 (-186)	-83 (-225)
2130 (RCP8.5H+)	Toe regression	-20	-9	-1	-6	-8	-3	-7	-5
	ASCIE	-37 (-68)	-156 (-284)	-118 (-284)	-85 (-218)	-56 (-124)	-95 (-280)	-74 (-186)	-84 (-225)

The mean values across the region are shown in the table with the typical upper bound values (95th %) between brackets.
[1]Cliff instability distance as long-term toe erosion is zero

Table 6.1 shows a wide range of cliff instability distances (i.e., short-term ASCIE) for each geology type, with the largest cliff instability distances (typical upper bound) found for Āwhitu Group, Waitakere Group and Pākiri Formation, and smallest distances for the Tauranga Group. The large cliff instability distances are a combination of high cliffs (e.g., up to 200 m cliff height along the west coast of the Āwhitu peninsula) and relatively flat slope angles resulting in distances of almost 300 m from the present baseline. Figure 6.2 shows an example of the large cliff instability distance (e.g., 250 m) for high cliffs (e.g., 170 m) along the Āwhitu open coast, for which the existing setback is already 150 m. The remaining 100 m is related to a potentially flatter slope that may occur along the Āwhitu peninsula cliff shoreline.

The typical upper bound instability distances for AVF/CVZ and Waipapa Group are in the order of 200 m likely related to the high cliffs or hillslopes situated at the north-eastern part of the region and the offshore islands. ECBF cliffs and hillslopes are typically lower and show typical upper bound instability distances in the order of 100 m.

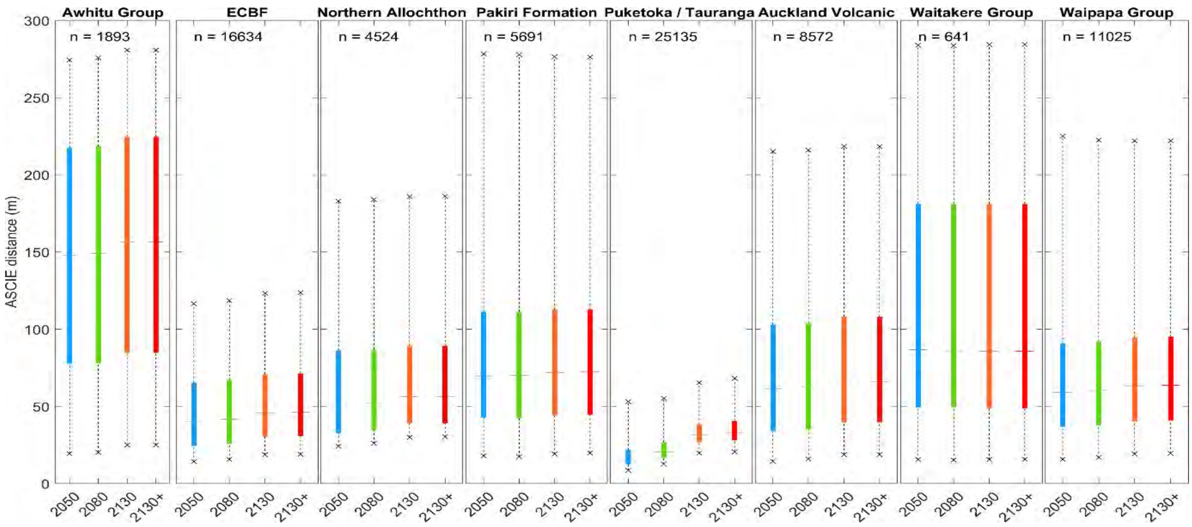

Figure 6.1: Boxplot of resulting ASCIE values for cliffs for the 8 geology types and 4 scenarios. The coloured bars represent the 25-75% range, with the whiskers representing the 5-95% range

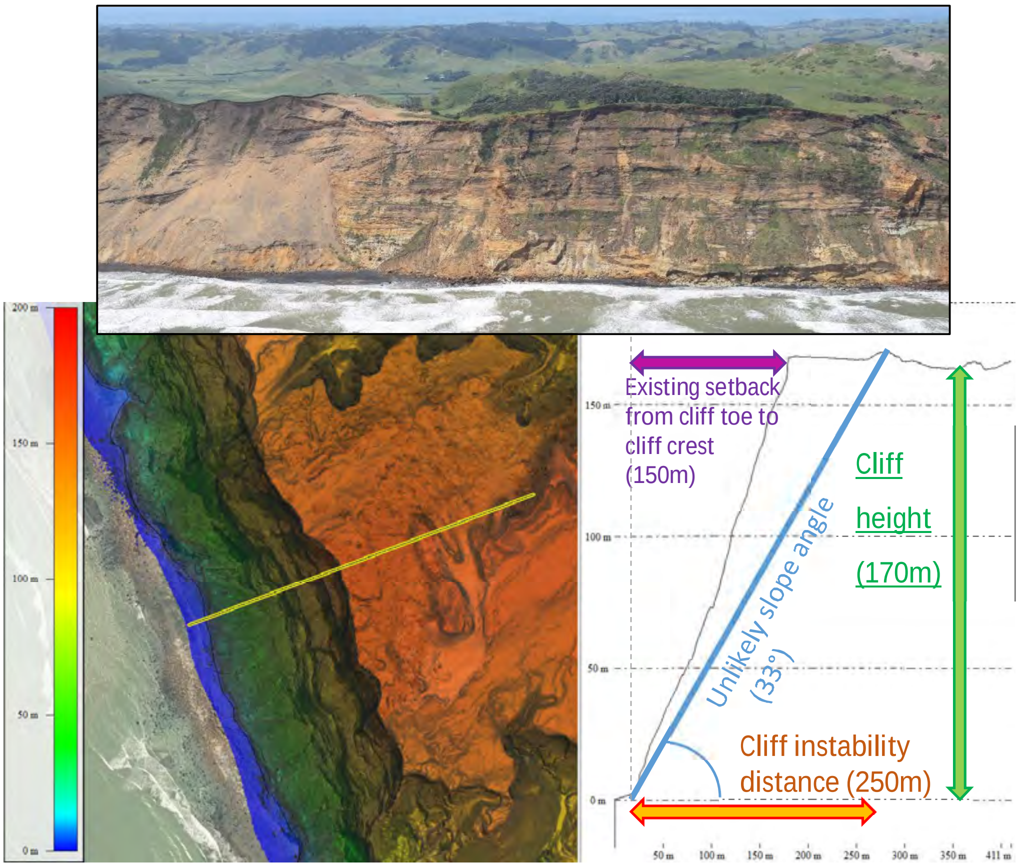

Figure 6.2: Example of large cliff instability distance due to high cliff height at Āwhitu peninsula

The resulting ASCIE for the short-term and future timeframes are very similar, in the order of 10 m for the majority of geology types, with the exception of the Tauranga Group cliffs (refer to Figure 6.1). This means that they are mostly dependent on the cliff instability component, with the long-term rate including a factor for SLR having a lesser effect. It should be noted that for low cliffs that are retreating at high rates (i.e., >-0.1 m/year), the long-term rate including a factor for SLR may become more dominant. This likely explains the larger variance in ASCIE values for different timeframes for Tauranga Group.

Table 6.1 shows that the largest future scenario ASCIE distances are found for the Āwhitu Group, Waitakere Group and Pākiri Formation, which are up to around -300 m. This is largely due to high cliffs and hillslopes along the West Coast. Waipapa Group and AVF/CVZ also show large ASCIE distances that are over -200 m, which are mainly situated at the northern East Coast and Great Barrier Island. The cliffs within the harbour environments are predominantly composed of soil materials (e.g., Tauranga Group), with typically flatter slope angles and larger toe regression rates for the more exposed cells. Figure 6.3 shows an example for a Tauranga Group cliff shoreline for which the toe regression component is larger than the cliff instability component. Due to the low cliffs the smallest ASCIE distances are found for the weak materials, despite the possible larger toe retreat. The minimum mean ASCIE distances are in the order of -10 to -20 meters (e.g., for Tauranga Group). However, due the presence of some high cliffs and hillslopes (i.e., >30 m), the typical upper bound ASCIE distances are significantly larger (e.g., up to -68 m for Tauranga Group).

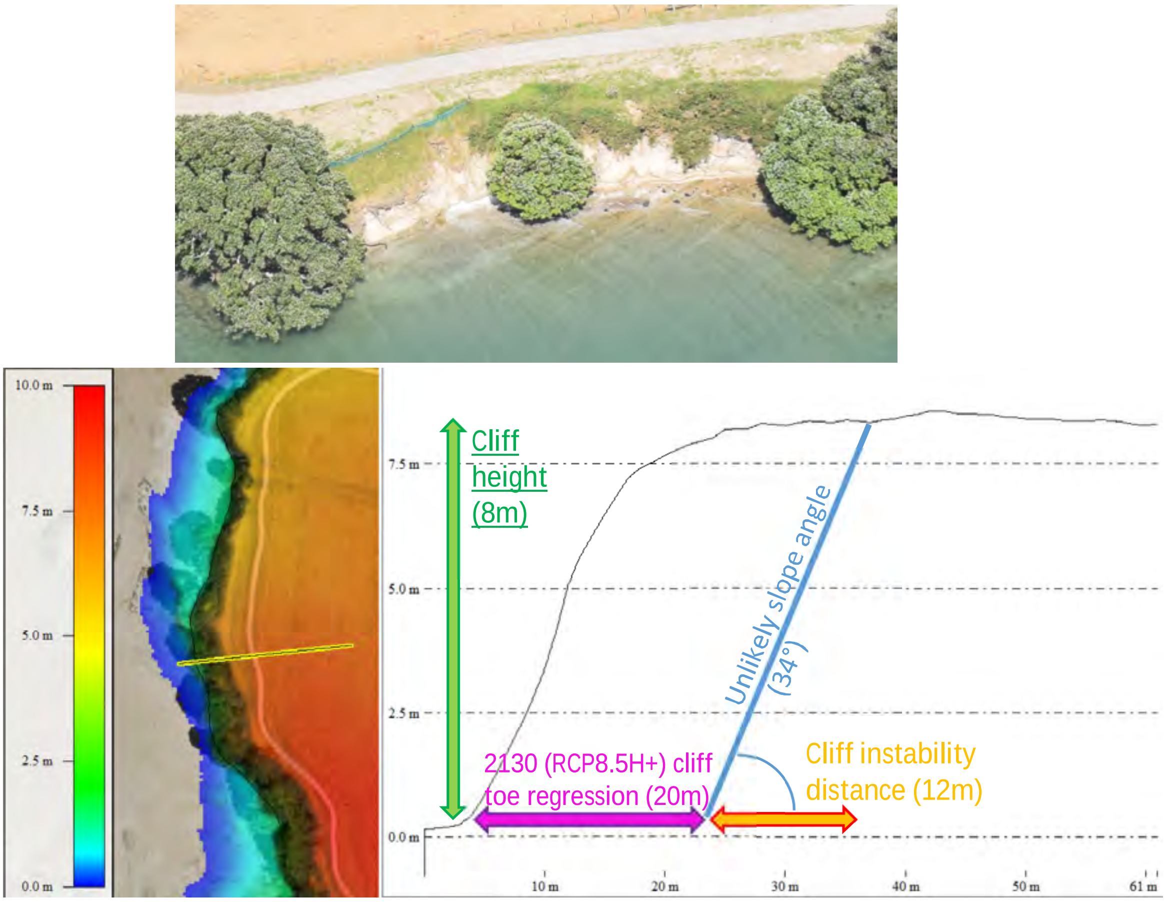

Figure 6.3: Example of large future cliff toe regression (at 2130) due to large historical long-term toe regression rate and high factor for SLR effects (RCP8.5H+) for Tauranga Group cliff situated within Tamaki River

Example maps have been generated in the form of colour maps showing banded ASCIE distances. Figure 6.4, Figure 6.5 and Figure 6.6 show examples of the cliff toe regression, typical upper bound cliff instability and resulting typical upper bound ASCIE colour maps for the 2130 (over 100 years) timeframe adopting the RCP8.5M for cliffs. These maps provide an overview of the spatial variation of the ASCIE distances across the Auckland region and highlights the shorelines for which the resulting ASCIE distances are large. For instance, the ASCIE distance is larger than 200 m for the cliffs on the southern end of Great Barrier Island (see Figure 6.6) The colour maps for the five selected timeframes are included in Appendix G.

Note that due to the adopted approaches and generalisations for this regional-scale assessment, the resulting ASCIE provided in this section are high-level first-pass results. However, there may be areas within a coastal cell that may potentially be susceptible to coastal erosion instability but are not included within the identified ASCIE. Likewise, there may be areas within the coastal cell that are identified as ASCIE but may not be susceptible to coastal erosion. For instance, by adopting 70% of the dominant geology for each coastal cell, potentially 30% of the coastal cell could either be under- or overpredicted.

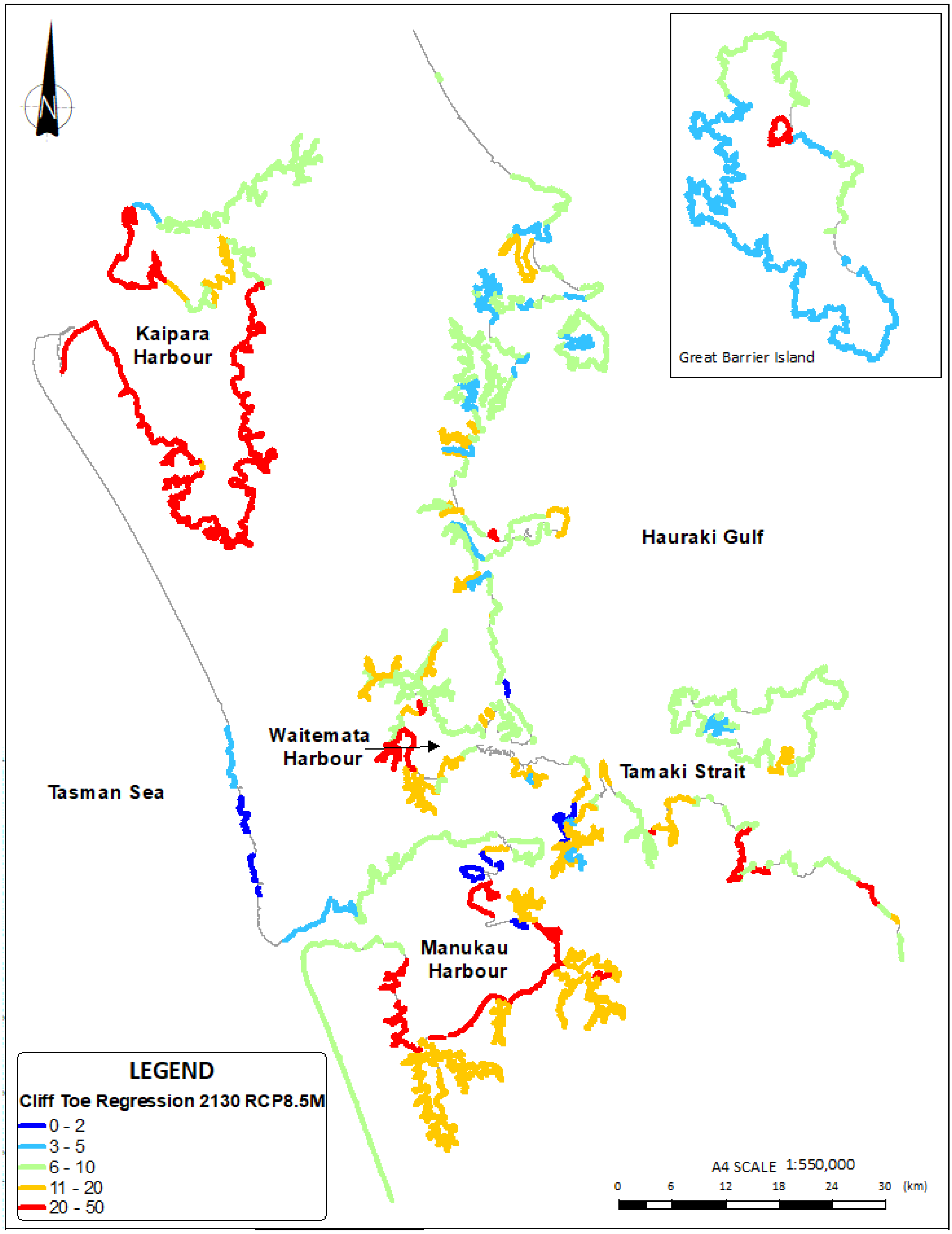

Figure 6.4: Colour map of banded toe regression distances at 2130 including effects of RCP8.5M SLR

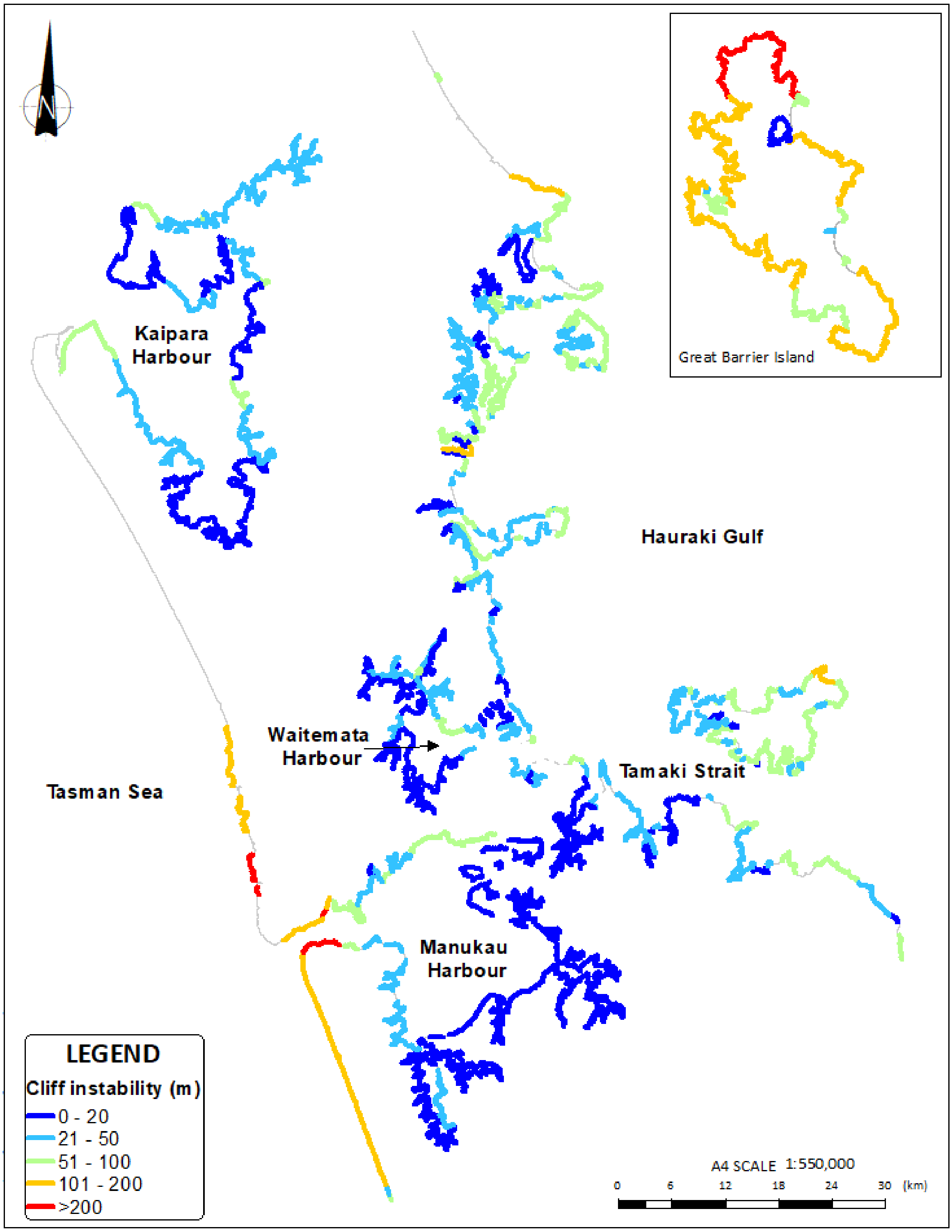

Figure 6.5: Colour map of the banded cliff instability distances

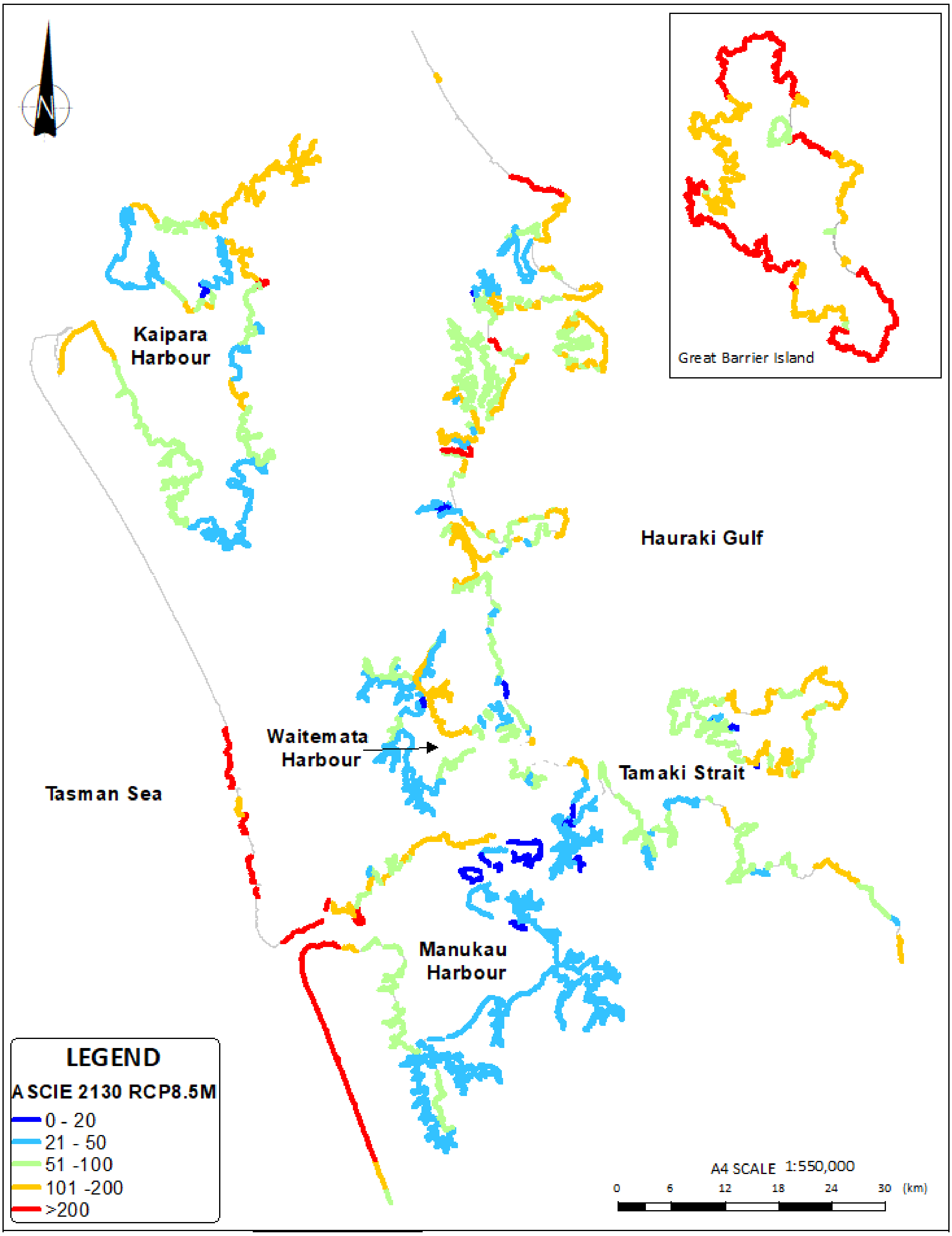

Figure 6.6: Colour map of the banded ASCIE distances for cliffs at 2130 adopting the RCP8.5M

6.2 Beaches

Table 6.2 includes the resulting maximum and minimum ASCIE distances for beaches separated in the five different areas as shown in Figure 2.1, with the Kaipara, Manukau and Waitematā Harbours combined into one area. The ASCIE distance are provided for the short-term and future timeframes, with the latter adopting the SLR scenarios as shown in Section 5.5.1. ASCIE distances excluding uncertainty are shown in the tables.

Table 6.2 shows that the smallest short-term ASCIE distances are found within the harbour environments (i.e., -5 m to -8 m) and the largest distances along the West Coast (i.e. -22 m to -29 m) and Outer Hauraki Gulf (i.e., -18 m to -33 m) shorelines. This difference is predominantly due to the highly exposed shorelines along the Outer Hauraki Gulf and West Coast compared to the more sheltered harbour coast beaches.

The future ASCIE distances are predominantly dependent on wave exposure and active translation slope. This is reflected by the significant increase in future ASCIE distance when adopting a longer timeframe or higher SLR scenario for the West Coast and Outer Hauraki Gulf beaches (>100 m). The largest future ASCIE distances along the West Coast are due to the large SL component (i.e., 95 m) as a result of the relatively flat closure slope. The future ASCIE distances along the Tamaki Strait and harbour coast beaches are smallest and are up to roughly -50 m to -60 m for 2130 using RCP8.5+ excluding uncertainty.

Distances for Whatipu and Waionui Inlet (> 800 m) have not been included in Table 6.2 as these cells are subject to large medium-term fluctuations and would make ASCIE for the Open West Coast not directly comparable with the other areas.

Figure 6.7 shows ASCIE colour maps for beaches for the 2130 timeframe and RCP8.5M scenario. This map highlights for instance the locations with the largest ASCIE distances, such as at Whatipu (see Figure 6.7).

Table 6.2: Summary of resulting ASCIE distances for short-term and future timeframes excluding uncertainty for beaches

Area	Outer Hauraki Gulf	Inner Hauraki Gulf	Open West Coast[1]	Tamaki Strait	Harbour environments
Short-term ASCIE	-18 to-33	-7 to-18	-22 to-29	-5 to-12	-5 to-8
ASCIE 2050 (RCP8.5M)	-26 to-43	-13 to-30	-41 to-61	-6 to-18	-7 to-16
ASCIE 2080 (RCP8.5M)	-38 to-68	-23 to-45	-61 to-105	-9 to-25	-11 to-26
ASCIE 2130 (RCP8.5M)	-67 to-121	-46 to-77	-109 to-195	-16 to-48	-19 to-46
ASCIE 2130 (RCP8.5H+)	-83 to-137	-59 to-90	-134 to-220	-20 to-61	-23 to-50

[1]Note that these results exclude Whatipu and Waionui Inlet which are subject to large medium-term fluctuations of hundreds of meters.

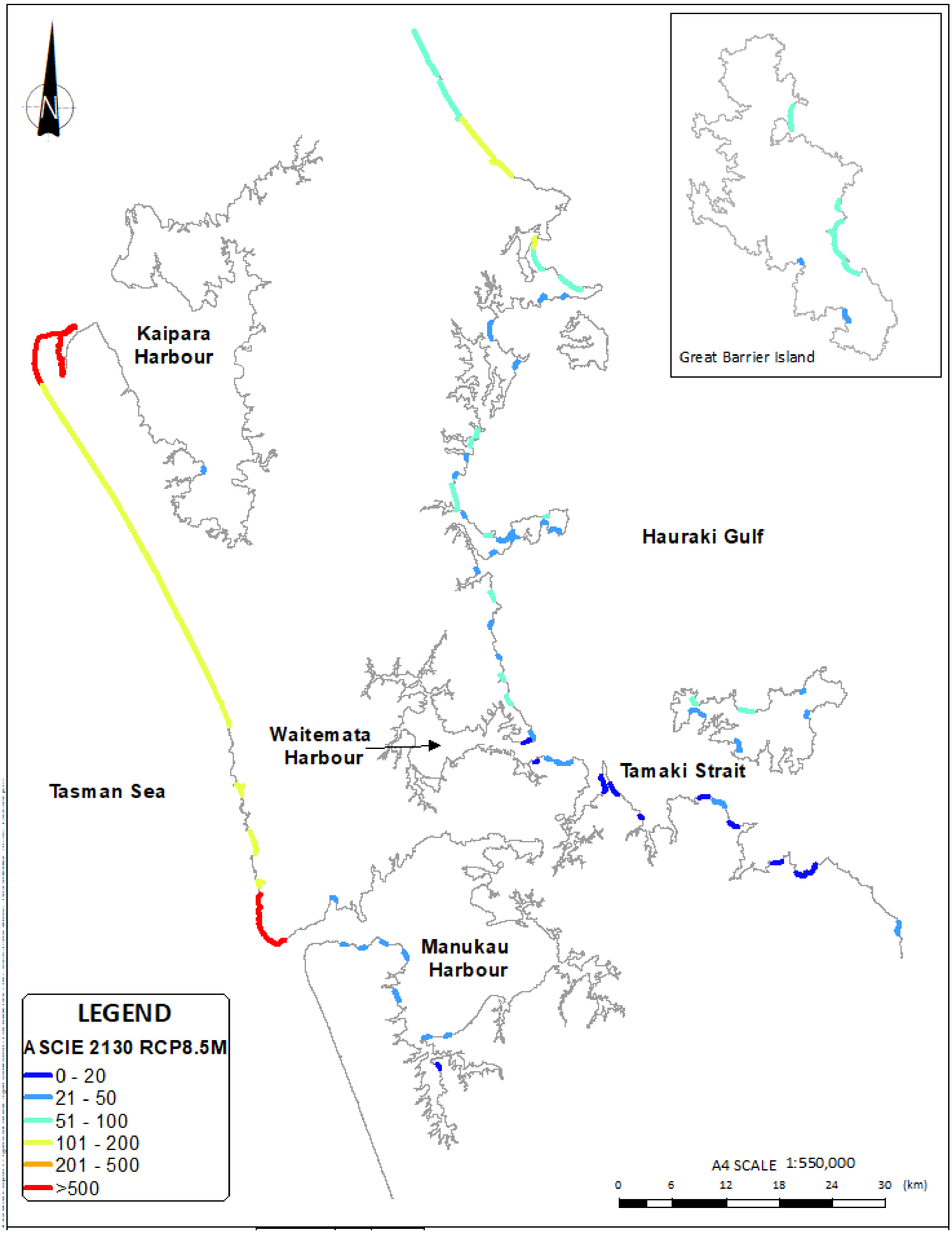

Figure 6.7: Colour map of the banded ASCIE distances for beaches at 2130 adopting the RCP8.5M

6.3 Comparison with Reinen-Hamill et al. (2006)

The resulting ASCIE distances derived for this study have been compared with distances derived by Reinen-Hamill et al. (2006) (termed 'ASCE2006'). For comparison purposes, a SLR value of 0.5 m was adopted for ASCIE as Reinen-Hamill et al. (2006) allowed for SLR of 0.5 m to derive ASCIE distances, and a timeframe of 100 years for the long-term component, with remaining parameter values unchanged (termed 'modified ASCIE'). As the projection method was used for cliffs, the modified ASCIE have been based on the mean cliff height for each cliff cell for comparison purposes. The resulting ASCE2006 and modified ASCIE have been plotted against each other in the form of scatter plots. These plots are shown in Figure 6.8 and Figure 6.9 for cliffs and beaches respectively, with the ASCE2006 along the vertical axis and modified ASCIE along the horizontal axis.

Figure 6.8 shows that the majority of the differences in ASCIE distances for cliffs are between 0 m and -50 m, with some differences up to -250 m. The difference bands included in Figure 6.8 shows that the difference between ASCE2006 and modified ASCIE is less than ±25 m for about 60% of all the cliff shoreline cells. The difference is less than ±50 m for about 85% of all the cliff shorelines, while about 15% of the cliff shoreline cells show a difference larger than ±50 m. For both the smaller ASCIE distances (<-50 m) and larger distances (>50 m), the ASCE2006 are typically smaller than the modified ASCIE distances. The differences between ASCE2006 and modified ASCIE are typically related to the flatter slope angles adopted for this study (refer to Section 5.7.3.1 for comparison of slope angles). Furthermore, cliff heights have been based on more accurate data (i.e., 2016-2018 LiDAR) for this study compared to using 20 m contour from topographic charts by Reinen-Hamill et al. (2006).

The largest differences for which the modified ASCIE is larger than the ASCE2006 (>100 m) are typically found at the northern West Coast. The adopted cliff heights are similar, but the adopted cliff slopes are significantly flatter (i.e., 38° versus 67°). The flatter slope adopted for this study is a result of the statistical approach, which is based on samples for each geology type taken from across the region and are therefore generally applicable across the region. At a more site-specific scale these slopes may be under- or overpredicting the actual slope. The combination of the flat slope angle and high cliff results in large ASCIE distances.

The largest differences for which the ASCE2006 distances are larger than the modified ASCIE distances (>100 m) are found along the west coast of the Āwhitu peninsula. The exposed west coast of the Āwhitu peninsula was split up in two coastal cells as a result of limited spatial data. For this assessment LiDAR data is available which was used to more accurately derive cliff heights and split the shorelines based on varying cliff heights. As this study included coastal cells along the west coast of the Āwhitu peninsula for which the cliff heights were significantly lower (e.g., 35 m versus 120 m) the resulting modified ASCIE distances are significantly smaller (e.g., 80 m versus 220 m).

Figure 6.9 shows that the difference between ASCE2006 and modified ASCIE is less than ±25 m for all beach shoreline cells except for six cells, which are between 25 and 50 m. For about half of the beach shoreline cells the difference is less than ±10 m. This comparison excludes the comparison of ASCIE distances at Whatipu and Waionui inlet, which are due to the large MT components adopted.

The largest differences for beach shorelines between the modified ASCIE and ASCE2006 ranging from 25 m to 50 m are mainly found at the West Coast beaches (i.e., Karekare to Muriwai South), Pākiri North and at a few other locations such as Snells Beach and Tindalls Beach. This is mainly due to the adopted long-term rate, which are based on an additional 12 years of annual or bi-annual surveyed beach profile data. For the West Coast beaches an MT component, which reflects climatic and sediment fluctuations (refer to Section 5.4), has been included for this study and was not considered by Reinen-Hamill et al. (2006).

It should be noted that the actual differences between the ASCE distances derived by Reinen-Hamill et al. (2006) and the ASCIE distances derived for this study are different as a result of different timeframes and SLR values adopted (outside of the comparative exercise with 0.5m SLR presented).

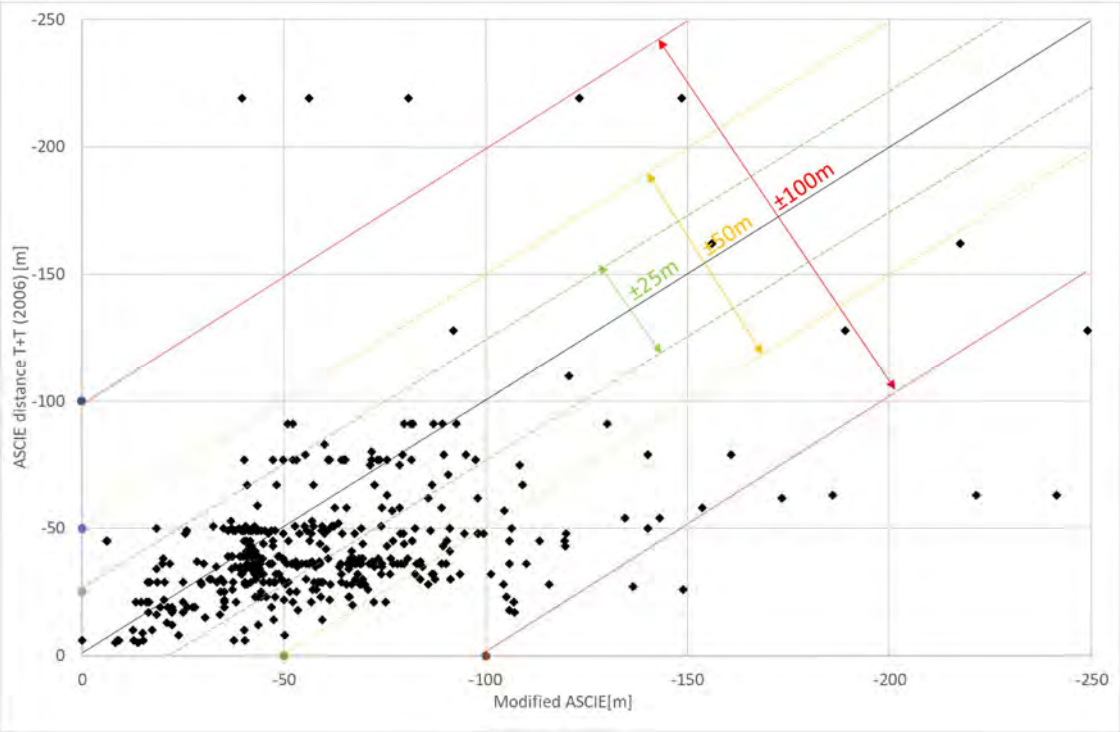

Figure 6.8: Comparison of ASCIE distances for cliffs derived by Reinen-Hamill et al. (2006) and modified ASCIE including ±25 m, ±50 m and ±100 m difference bands

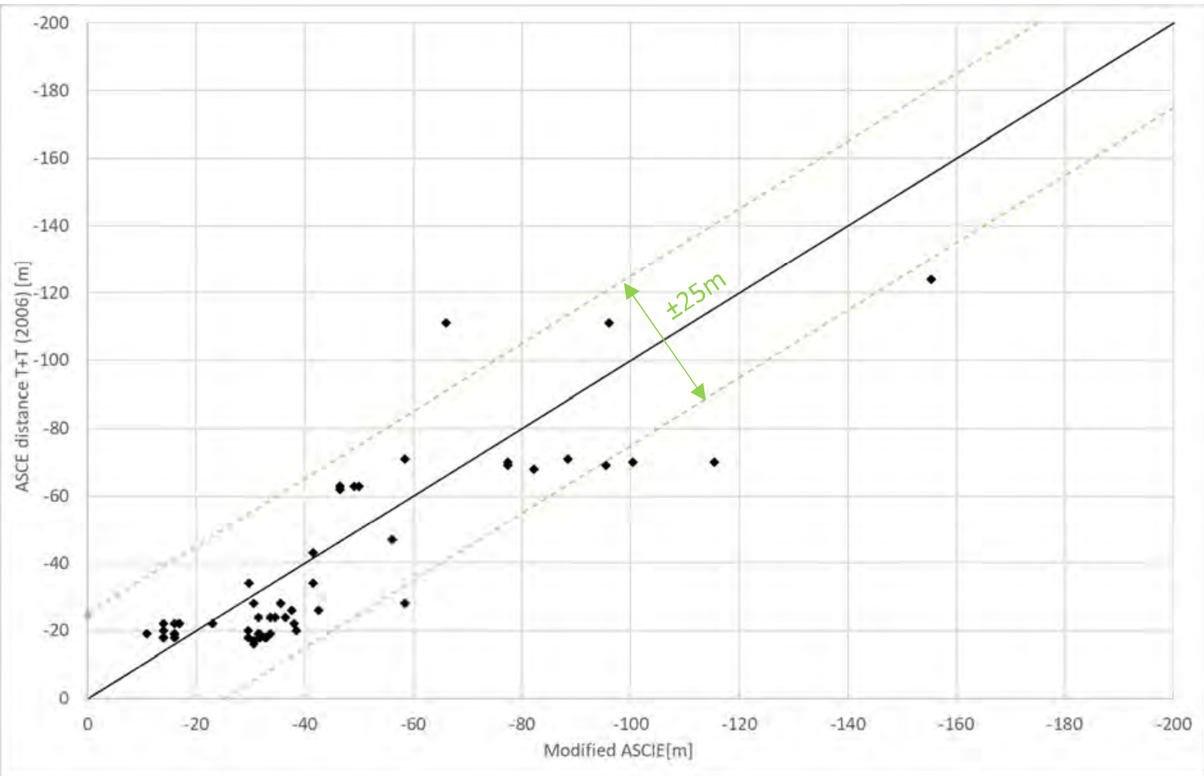

Figure 6.9: Comparison of ASCIE distances for beaches derived by Reinen-Hamill et al. (2006) and modified ASCIE including ±25 m difference bands

6.4 Comparison between local-scale and regional-scale assessment

The resulting ASCIE distance as derived by the local-scale assessments for Stanmore Bay and Omaha Beach have been compared with the ASCIE distances derived by the regional assessment. Table 6.3 and Table 6.4 show the resulting ASCIE distance for 2130 adopting the RCP8.5M scenario for both the regional assessment and local-scale assessment at Stanmore Bay and Omaha Beach respectively.

For the regional-scale assessment the mean and typical upper bound (i.e., 95th %) ASCIE distances are shown for cliffs and the ASCIE excluding and including uncertainty for beaches. For the local-scale assessment the ASCIE distances and selected, related probabilities of exceedance are shown in Table 6.3 and Table 6.4. For consolidated shorelines these include 50%, 10% and 1% probability of exceedance which related to both the cliff toe regression component and cliff instability component (i.e., combination of 10% exceedance distance for cliff toe regression and 10% exceedance slope angle). For unconsolidated shorelines these include the 66%, 50%, 10% and 1% probabilities of exceedance, and probable minimum (>99.9% exceedance) and probable maximum (<0.1% exceedance) distances. Due to the full probabilistic approach used for Omaha Beach, a larger number of probabilities of exceedance can be derived compared Stanmore Bay for where a semi-probabilistic approach was adopted (i.e., cliff slope steepness was only assessed for 50%, 10% and 1% exceedance probabilities).

Table 6.3 shows the ASCIE for 2130 adopting the RCP8.5M scenario and includes the future cliff toe regression and cliff instability components. This shows that the future cliff toe regression distance (regional-scale) is the same as the 1% exceedance distance (local-scale) for Cell 87 and within the range for Cell 87. The difference between the maximum 1% exceedance distance (local-scale) and typical upper bound value (regional-scale) can be explained by not including uncertainty in the typical upper bound value (regional-scale) and showing the 95% distance instead of the maximum. The typical upper bound cliff instability distance (regional-scale) sits around the upper end of both the 10% and 1% exceedance distances (local-scale). This is expected as the cliff projection method was used for both scales, with the adopted slopes for the regional-scale assessment typically at the flatter end of the range used for the local-scale assessment.

Table 6.3: Comparison of regional and detailed assessments at Stanmore Bay

Component	Regional assessment ASCIE 2130 RCP8.5M		Detailed, local-scale assessment (multiple cells) ASCIE 2130 RCP8.5M			
	Cliff cell No.	Mean distance [m] (Typical upper bound distance [m])	Cell No.	Distance (m) probability of exceedance		
				50%	10%	1%
Future cliff toe regression	86[1]	-34[3]	A-E	-12 to -33	-18 to -42	-22 to -48
	87[2]	-22[3]	F-I	-12	-18	--22
Cliff instability	86[1]	-66 (-87)	A-E	-14 to -85	-19 to -97	-23 to -97
	87[2]	-40 (-74)	F-I	-9 to -54	-13 to -73	-13 to -110
Resulting ASCIE	86[1]	-100 (-121)	A-E	-26 to -97	-37 to -115	-45 to -119
	87[2]	-62(-96)	F-I	-21 to -66	-31 to -91	-35 to -132

[1]West and north side of Stanmore Bay
[2]East side of Stanmore Bay
[3]Single value as only one distance was used for entire cell.

Overall, the typical upper bound ASCIE distance (regional-scale) is slightly larger than the maximum 1% value (local-scale) for Cell 86. For Cell 87, the typical upper bound ASCIE (regional-scale) is larger than the maximum 10% exceedance value (local-scale) but sits around the upper end of the range of the 1% exceedance value.

Table 6.4 show that the resulting ASCIE distance excluding uncertainty as derived by the regional assessment typically sits between the 1% exceedance probability and the probable maximum distance for the largest cell at local scale for Omaha Beach. The resulting ASCIE distances including uncertainty as derived using the regional-scale approach are typically slightly larger than the probable maximum values except at the northern end of Omaha Beach where it sits within the probable maximum range. This comparison shows that the resulting ASCIE distances as derived using the regional-scale approach are similar to the upper bound values derived using local-scale approach.

Table 6.4: Comparison of regional and detailed assessments at Omaha Beach

Regional assessment ASCIE 2130 RCP8.5M		Detailed, local-scale assessment ASCIE 2130 RCP8.5M						
Beach cell No.	ASCIE (m) ± uncertainty	Cell No.	ASCIE (m) probability of exceedance					
			Probable Minimum	66%	50%	10%	1%	Probable Maximum
3[1]	-113 ±19	A-B	+51 to +53	-34 to -36	-50 to -53	-89 to -91	-110 to -114	-130 to -145
4[2]	-79 ±20	C-F	-36 to +19	-20 to -53	-26 to -57	-47 to -69	-62 to -77	-77 to -82

[1]North side of Omaha Beach in vicinity of groynes
[2]Center and south side of Omaha Beach

7 Future mapping methodology

7.1 Introduction

Because the method used to generate ASCIE distances for each cell is at a scale appropriate for a regional assessment, detailed site-specific maps of these distances presented as individual lines on a map could be misleading. However, the techniques used to develop these distances can be refined to provide more detailed mapping showing areas susceptible to coastal instability and erosion at a sub-regional level.

The methodology as set out in Section 7.3 will be used for mapping ASCIE, and the results will be provided separately in digital format for the four selected scenarios:

- 2050 RCP8.5M (excl. uncertainty).
- 2080 RCP8.5M (excl. uncertainty).
- 2130 RCP8.5M (excl. uncertainty).
- 2130 RCP8.5H+ (excl. uncertainty).

These maps showing the more detailed lines will not be intended for site-specific use; for example, when making decisions about building design. Rather, they present the areas within which more detailed studies such as site-specific hazard assessments should be considered to define the risk. The mapping will enable Aucklanders to review and engage with our current understanding of long-term coastal change and climate change impacts and will inform future sustainable hazard management approaches for the region.

7.2 Sample output

An example map for Okoromai Bay including the four scenarios and baseline is shown in Figure 7.1. The mapped ASCIE lines are subject to the limitations set out in Section 1.4.

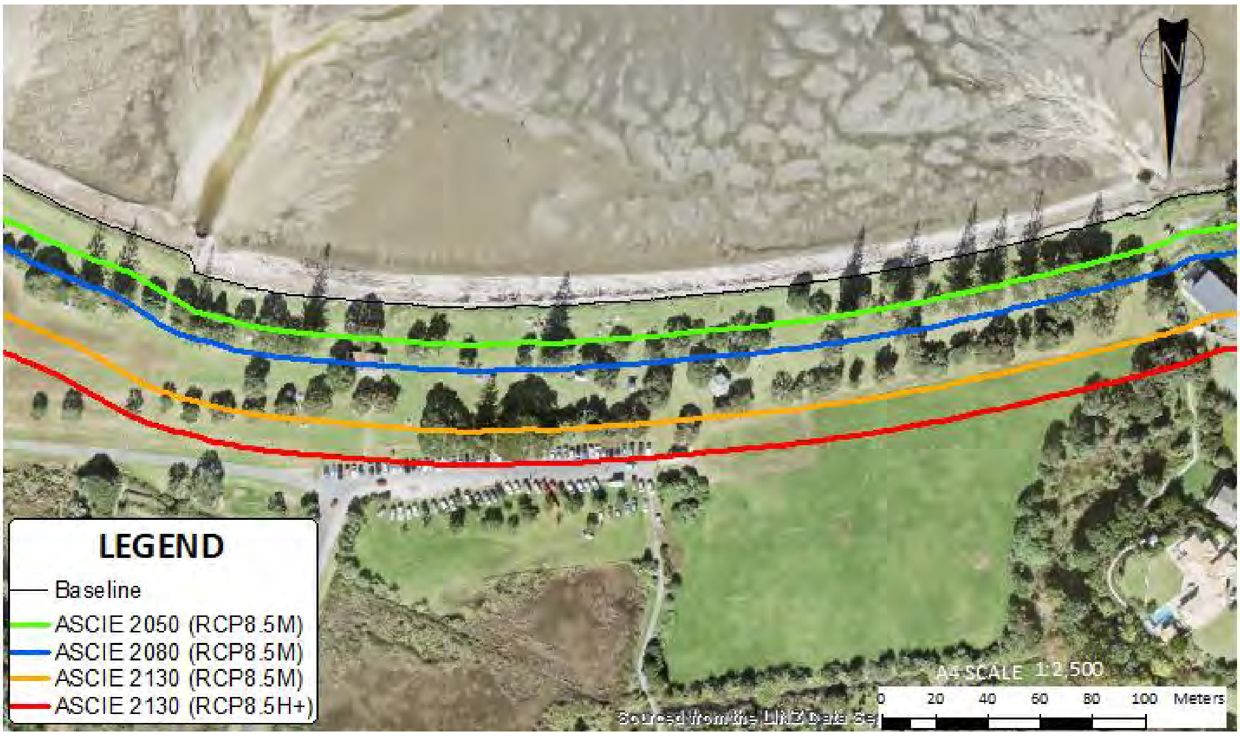

Figure 7.1: Example of mapped ASCIE for beach shoreline at Okoromai Bay (aerial sourced from LINZ)

7.3 Mapping methodology summary

7.3.1 Cliffs

The ASCIE for cliffs will be mapped using the cliff projection method. This method will map the ASCIE at 20 m intervals along the cliff profile by projecting the derived composite slope profile into the Digital Elevation Model (DEM) from the future toe position. The intersection point between the project slope profile and DEM/cliff profile is the resulting ASCIE. This will be significantly more accurate than the cell-wide approach using the 95th percentile cliff height to represent the whole cell. A schematisation of this method is shown in Figure 7.2.

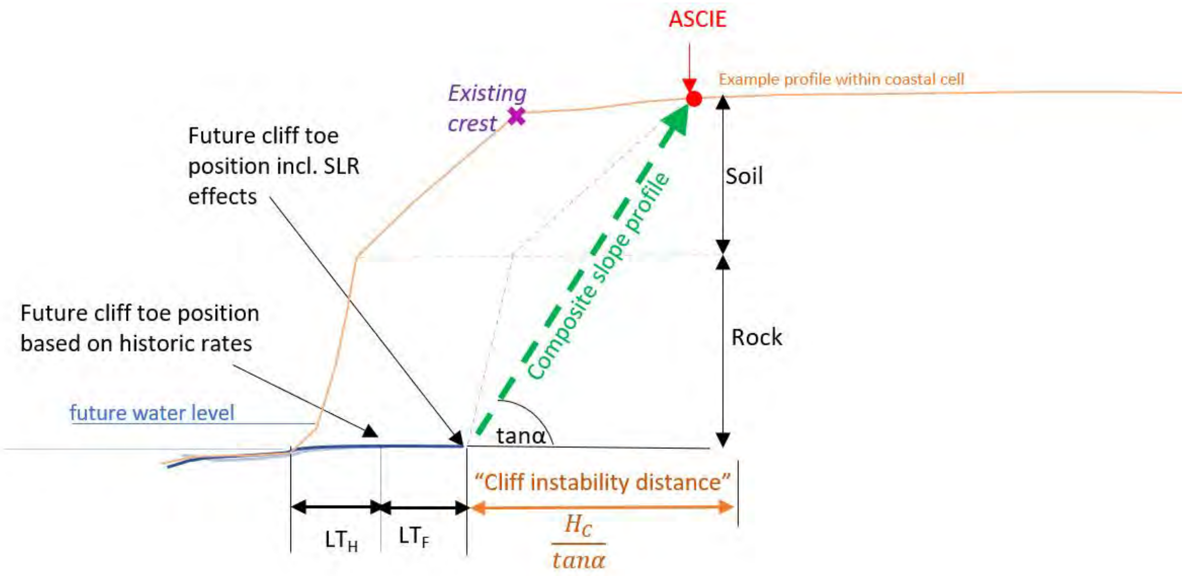

Figure 7.2: Schematisation of cliff projection mapping

For this regional-scale assessment cross-section profiles have been extracted from the 2016-2018 LiDAR DEM at 20 m alongshore intervals and were used to map resulting ASCIE points. The ASCIE points were then joined together into lines. At cell boundaries they will be transitioned into adjacent cells. As adjacent cliff cells typically have similar geology and similar cliff height at the boundary, the difference in ASCIE distance is typically small, with a straight line drawn between ASCIE lines. However, where differences are large, smoothing will be applied over a distance either side of the boundary. This smoothing will occur over a zone that is 10 times the difference in ASCIE distance. Any outliers that that would locally cause a jump in the ASCIE lines and deemed unrealistic will be manually removed.

7.3.2 Beaches

The resulting ASCIE for beaches will be mapped by offsetting the resulting distances from the baseline for each coastal cell. The baseline will be slightly generalised (where required) for mapping purposes to minimise unrealistic ASCIE lines (e.g., due to interrupting streams or structures or small irregularities in the current shoreline that will be smoothed over time). The ASCIE lines extend along the full length of each coastal cell and transition between beach cells (i.e., where ASCIE distances vary between cells). Transitions between beach cells are based on 10 times the difference between the ASCIE distance. For instance, if ASCIE distances for adjacent cells are 90 and 100 m respectively, the alongshore distance over which the transition is applied is 100 m (i.e., (100 m - 90 m) * 10 = 100 m). Transitions are smoothed or following topographic features (e.g., cliff toe).

7.3.3 Reclamations

No ASCIE lines will be shown for reclaimed shorelines as it is assumed that structures supporting these shorelines will be maintained, supporting the planning definition of reclaimed land as permanent.

7.4 Methodology adjustments for mapping

7.4.1 Mapping around streams

Mapping ASCIE on a regional scale has resulted in some limitations. Mapped ASCIE around streams within estuaries or along beaches may be affected by the position of the baseline. Therefore, where small streams interrupt the shoreline, the ASCIE lines continue across these streams as if there was no stream. An example of this is shown in Figure 7.3. For larger streams interrupting the shoreline the ASCIE lines are stopped at either side of the baseline. An example at Te Henga beach is shown in Figure 7.4.

As erosion around streams is typically site-specific and mapping for this assessment was done on a regional scale, it will not possible to refine the resulting ASCIE for this assessment but should be undertaken in more detailed scale assessments.

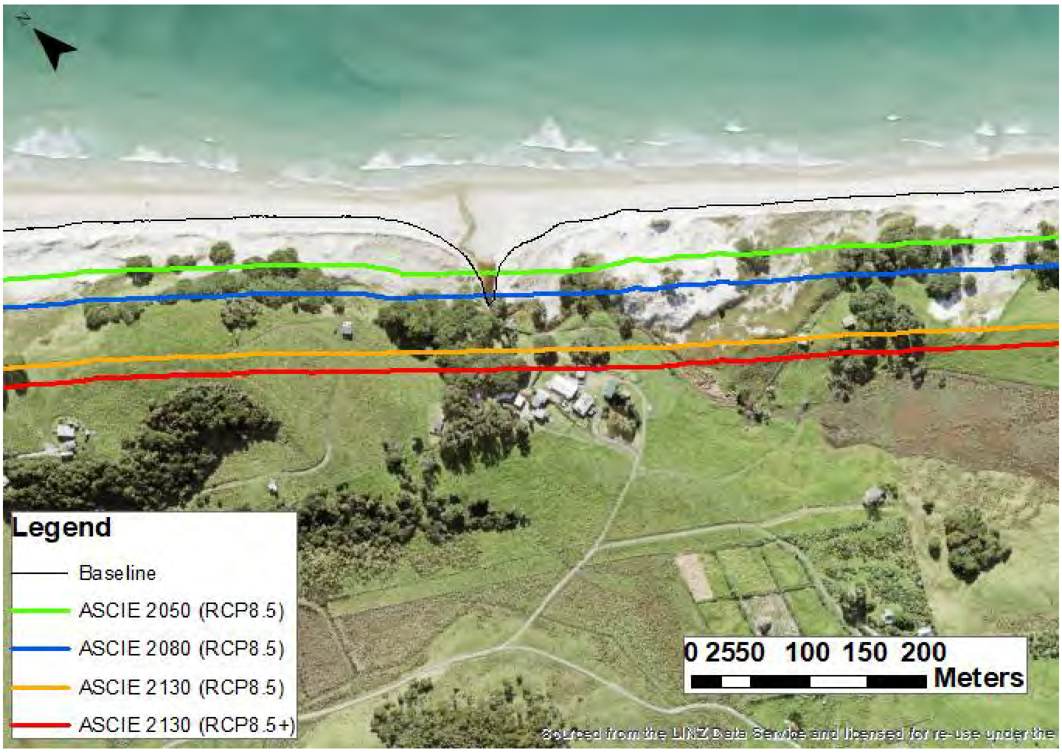

Figure 7.3: Example of ASCIE continues alongshore across small stream (aerial sourced from LINZ)

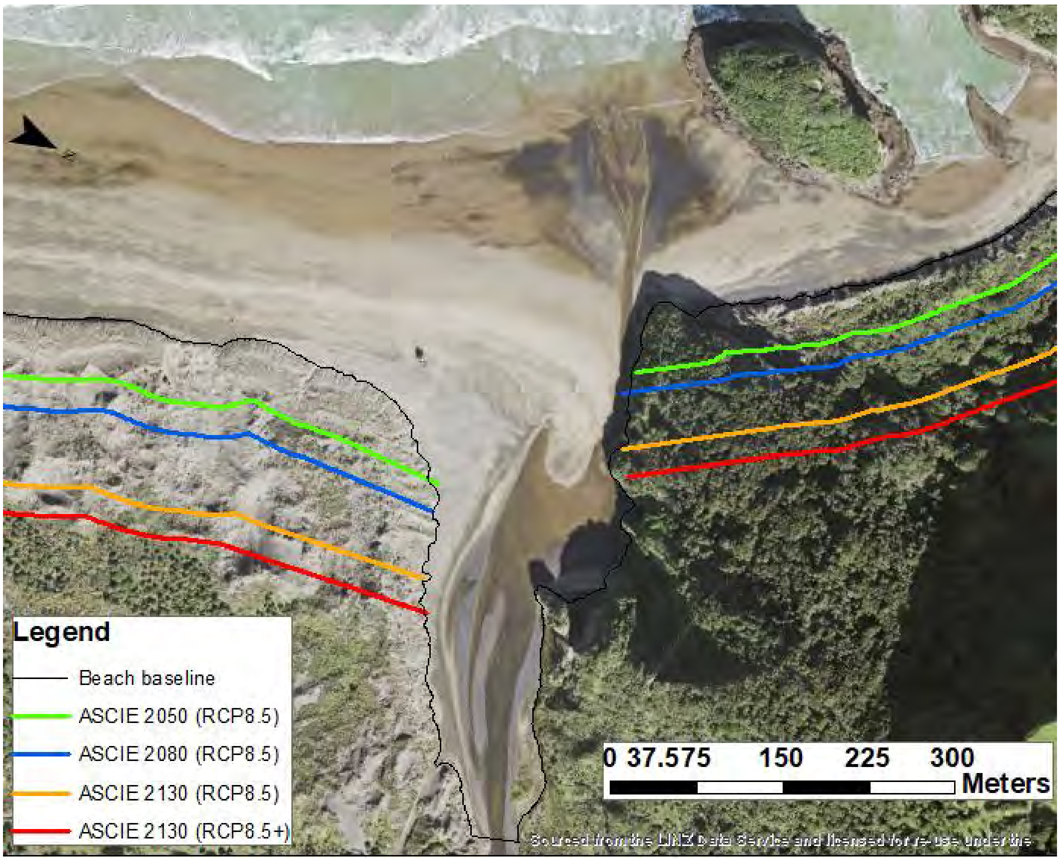

Figure 7.4: Example of ASCIE stopped at large stream (aerial sourced from LINZ)

7.4.2 Mapping areas with coastal protection structures

Where structures protect the shoreline, the baseline is situated along the toe of these structures, which typically extend further seaward than the adjacent unprotected beaches or embankments. This results in ASCIE lines that move landward and seaward along a coastal cell where shorelines transition between protected and non-protected. As coastal protection structures are typically less than 500 m long (except major reclamations, ports, etc.), it is not possible to refine the resulting ASCIE lines in a regional scale study, and this should be undertaken in later, more detailed scale assessments. For this assessment the ASCIE lines have been generalised as far as practicable to show realistic ASCIE lines.

7.4.3 Mapping transitions between beaches and cliffs

Transitions between beach and cliff cells at the geographic boundary will not be mapped as there is greater uncertainty in future response of the shoreline in these areas. Creating transitions at these boundaries would give a false indication of the ASCIE.

ASCIE lines have therefore been truncated at the geological boundary, which may result in gaps between adjacent ASCIE lines. An example of this is shown in Figure 7.5.

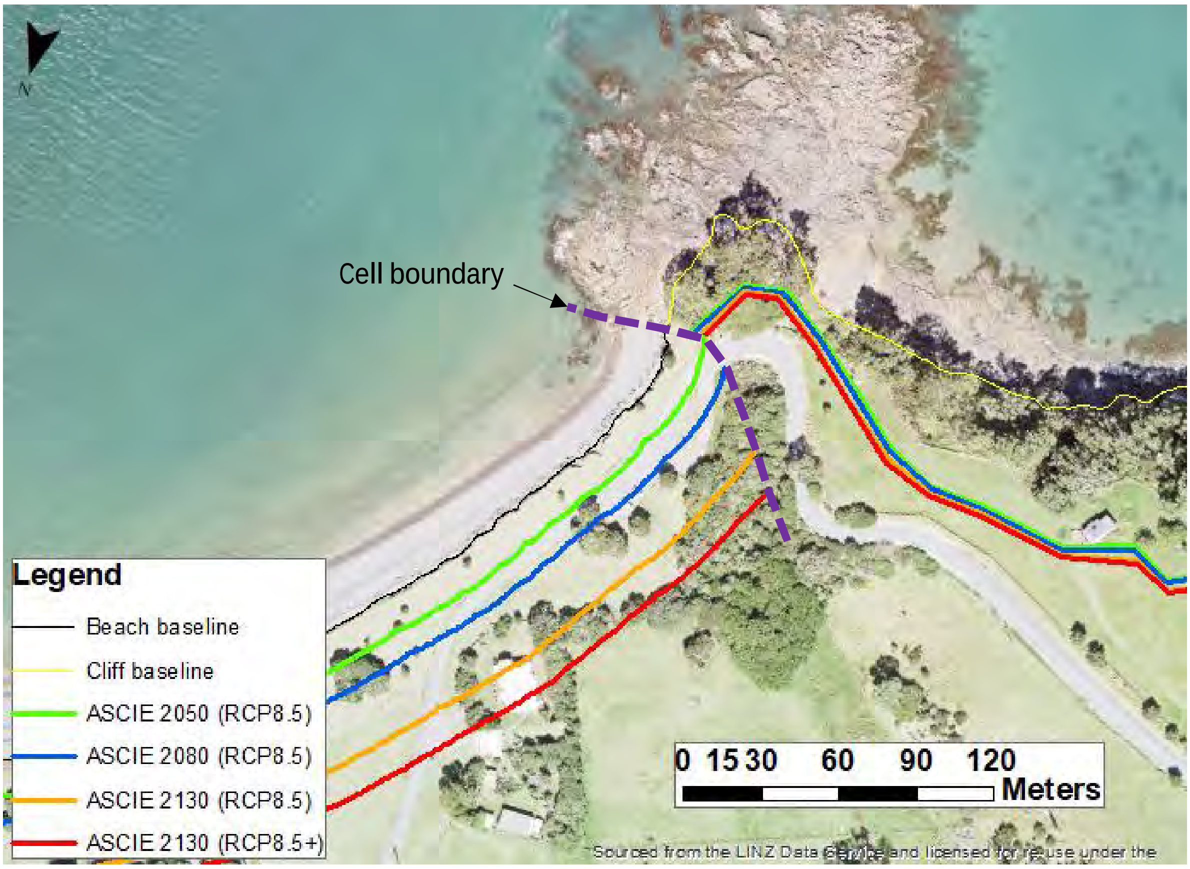

Figure 7.5: Example of ASCIE lines at geological boundary (aerial sourced from LINZ)

7.4.4 Smoothing and expert judgement

As a result of the mapping approach for cliffs (e.g., cliff projection at 20 m intervals), the resulting ASCIE lines may appear slightly angular (see example in Figure 7.5). The shoreline is highly variable along some sections with rapid changes in elevation and orientation. As a result, the mapped ASCIE lines have been modified along these sections using engineering judgement where required to make the lines more realistic.

8 Framework for refinement of ASCIE

ASCIE values have been assessed on a regional scale for this study. This may introduce errors and uncertainties due to the scale of the study (i.e., as a result of simplifications applied and classifications made). The limitations of the regional-scale ASCIE (refer to Section 1.4) should therefore be considered and the intent of these ASCIE should be understood before using the regional-scale ASCIE. The ASCIE have been assessed as a first-pass assessment in line with MfE (2017) and identify the areas *potentially* susceptible to erosion or instability.

Site specific hazard assessments may be needed for risk assessment or potential development in the ASCIE zone(s). Such assessment should be undertaken by a suitably qualified and experienced practitioner.

In undertaking a more detailed scale assessment for beaches, the following approach is recommended:

1 Use the model described by Equation 4.6 to derive current or future ASCIE for beaches.
2 Use site specific data to derive component values or value distributions:
   a Short-term: use site-specific beach profile analysis or numerical model.
   b Long-term: use site-specific historical shorelines/aerial photographs.
   c Medium-term: review beach profile dataset to assess whether a medium-term fluctuation is visible.
   d Dune slope allowance: use site-specific spatial data to determine height of dune above toe.
   e SLR response: use site-specific wave data and cross-shore profile data to determine closure depth and use required sea level rise value to determine sea level respond.
3 Combine components using either building block or stochastic simulation to derive resulting ASCIE value(s) as shown within Figure 4.7.
4 Determine appropriate baseline at the dune toe and map ASCIE distance(s).

In undertaking a more detailed scale assessment for cliffs, the following approach is recommended:

1 Use the model described by Equation 4.4 to derive current or future ASCIE for cliffs.
2 Use site specific data to derive component values or distributions:
   a Historical long-term regression: assess historical toe regression rate.
   b Future long-term regression: determine appropriate *m* value, and relevant SLR value to determine future LT_F using Equation 5.3 and multiply with LT_H.
   c Cliff instability:
      i determine lower rock height and appropriate slope based on specific geological conditions.
      ii determine upper residual soil depth and appropriate slope considering any site-specific structures or drainage (see definition sketch in Figure 4.6).
3 Combine the future toe erosion with the cliff instability zone to derive ASCIE as shown within Figure 4.6.
4 Determine appropriate baseline along the cliff toe and map ASCIE distance(s).

9 Summary and recommendations

This study provides a regional-scale assessment of Areas Susceptible to Coastal Instability and/or Erosion (ASCIE) for the Auckland shoreline. It is a "*first-pass*" assessment, in line with the NZCPS (2010), Carpenter et al. (2017) and MfE (2017), that provides high-level information on possible ASCIE on a regional scale.

The results are intended for use by Auckland Council in understanding the potential extent of the ASCIE and the long-term implications of climate change, contributing to future natural hazards education and decision making. The intended use and limitations of this study (see Section 1.4) should be considered and understood before the results of this study are used.

The entire Auckland region shoreline has been digitised using the 2016-2018 LiDAR DEM and this shoreline has been used as the baseline to which coastal erosion distances are referenced. The ASCIE baseline represents the coastal edge for different coastal types (e.g., dune toe, cliff toe or coastal structure toe). This may not be the same as the mean high water spring (MHWS) line which is elevation based. The shoreline was then initially split into coastal types (i.e., unconsolidated beaches, consolidated embankments and cliffs, and reclaimed shorelines), and later further split based on differences in geology, geomorphology, dune/cliff height, exposure or long-term trends. This has resulted in the Auckland region shoreline being split into 568 cells of between 0.5 and 5 km in length.

The methodologies used in this study are standard and well-tested approaches for defining ASCIE for both consolidated and unconsolidated shorelines by the addition of component parameters. For this regional-scale assessment, single values were derived for each component along with a value for uncertainty, combining to give values applicable for the entire cell. This 'building-block' approach (i.e., combination of individual parameters) is expected to produce 'upper bound', conservative results, which is in line with recommendations in MfE (2017) for first-pass 'high level' assessments to identify areas potentially exposed to coastal erosion.

The ASCIE have been assessed for the short-term (applicable to 2030), over 30 years (2050), over at least 50 years (2080) and at least 100 years (2130) planning timeframe for four climate change scenarios recommended by MfE (2017) (median projections for RCP2.6, RCP4.5 and RCP8.5 and the 83rd percentile of RCP8.5). Resulting ASCIE areas will be mapped for the following scenarios:

- 2050 RCP8.5M.
- 2080 RCP8.5M.
- 2130 RCP8.5M.
- 2130 RCP8.5H+.

The resulting ASCIE for beaches is a combination of five parameters of which the short-term component (e.g., erosion due to storms) typically dominates for timeframes between 2030 and 2050, while the SLR response and long-term component dominate for the longer timeframes (i.e., 2080-2130). The smallest ASCIE distances for beaches are found within the harbour environments and the largest distances along the West Coast and Outer Hauraki Gulf shorelines. This difference is predominantly due to the higher short-term erosion components on the exposed shorelines and flatter offshore slopes resulting in greater response to sea level rise along the Outer Hauraki Gulf and West Coast sites. The largest future ASCIE distances along the West Coast are a result of the large medium-term fluctuations (i.e., at Whatipu) and SLR effect components.

The resulting ASCIE for cliffs is a combination of cliff instability and cliff toe regression (erosion), of which the cliff instability component typically dominates high cliff areas and at shorter timeframes (i.e., 2030-2050), while the cliff toe regression component becomes more important over longer timeframes (i.e., 2080-2130) and for lower cliffs. The largest resulting ASCIE distances for cliff shorelines are found along the West Coast (including both the Āwhitu peninsula open coast and cliffs north of the Manukau Harbour), with distances up to roughly 300 m, which is largely due to the high cliffs. The smallest ASCIE distances for cliffs are typically found within the harbour due to low cliff heights. The resulting ASCIE for the short-term (i.e., cliff instability) and future (i.e., cliff instability + cliff toe regression) timeframes are very similar for differing SLR scenarios. This means that they are mostly dependent on the cliff instability component, with the long-term rate including a factor for SLR having a lesser effect. It should be noted that for low cliffs that are retreating at high rates (i.e., >-0.1 m/year) the long-term rate including a factor for SLR may become more important.

Comparison of the ASCIE distance derived by Reinen-Hamill et al. (2006) and derived in this study showed that for about 60% of all the cliff shoreline cells the difference is less than ±25 m. The difference is less than ±50 m for about 85% of all the cliff shorelines. The differences for cliff shorelines are typically related to the adopted slope angles, for which a different approach was used in this study, and cliff height, for which LiDAR data was available for this study. The difference between the ASCIE distance derived by Reinen-Hamill et al. (2006) and derived in this study for beach shorelines is less than ±25 m for all beach shoreline cells except for six cells. For about half of the beach shoreline cells the difference is less than ±10 m. The differences for beach shorelines are typically related to updated long-term rates as a result of longer surveyed beach profile records.

This study has assessed ASCIE at a regional scale (i.e., order of 0.5-5 km shoreline length) and may be superseded by a more detailed, local scale or site-specific assessment (i.e., order of 1-10 m, 10 – 100 m or 0.1 – 1 km shoreline length) undertaken by a suitably qualified and experienced practitioner using improved data and/or undertaken at a higher resolution from that presented in this report. This could include better site-specific geotechnical information to confirm subsurface soil conditions, more detailed topographic data as well as site-specific analysis and modelling of erosion. Note that due to the scale of this regional assessment the change in geology may not be considered in detail (e.g., transition from unconsolidated material into consolidated rock), which could affect the potential ASCIE. This should be assessed for a more detailed scale assessment. Furthermore, a probabilistic approach may be adopted for local-scale and site-specific assessments giving likelihood of erosion and instability based on parameter ranges rather than single values.

The two local-scale assessments have been undertaken in parallel with this 'first-pass' assessment report (refer to T+T, in prep. a for Omaha Beach and T+T, in prep. b for Stanmore Bay) show examples of how the regional-scale assessment can be downscaled. Comparison of the resulting ASCIE distances (as derived by the local-scale assessments) with the ASCIE distances derived by the regional assessment showed that the regional assessment results are similar to the upper bound values derived by local-scale assessments. The resulting ASCIE distance as derived by the regional assessment typically sits between the 1-5% exceedance probability and the probable maximum distance.

This assessment has used the best available tools and available data to derive regional-scale ASCIE, which may be refined using more detailed data and may be improved when better tools and methods become available. The following recommendations are provided that could improve the quality of the data and tools/methods that may become available for future assessments:

- Ongoing monitoring of beach profiles

  Beach profiles provide valuable information on coastal change including long-term trends and short-term changes. Data can be used to derive component values for hazard assessment with longer datasets providing more accurate results. It is therefore recommended to continue to survey the existing beach profiles and potentially add profiles at new locations where no data is available (e.g., Onetangi Beach and Oneroa Beach at Waiheke Island) or at other similar sites.

- Additional storm focussed beach profile monitoring

  While beach profiles collected at regular (6 monthly) intervals provide useful information on long-term trends or shorter-term (inter-year) movement, they can underestimate the erosion caused by single or clusters of storm events as some beach recovery may have occurred prior to surveys. Undertaking surveys before or after significant storm events can provide data which better describes these erosion processes and can be used to better calibrate numerical models. This should be undertaken at targeted sites identified as being particularly vulnerable.

- Establish cliff monitoring profiles

  Similar to surveying beach profiles, benchmarks for cliff profiles should be established and profiles should be surveyed using laser scanners bi-annually or annually. This would provide better information on short- and long-term cliff toe and crest erosion rates, and slope angles. Long-term erosion rates are typically derived from analysing historical aerials; however, these are typically obscured by vegetation along the cliff crest and large uncertainty in shoreline or cliff toe position. It is recommended to start these surveys as soon as practicable so that in 10 years this data can be used to verify the long-term erosion rates and slope angles. Laser cliff profiles are recommended at cliff shorelines where development is situated close to the existing cliff crest (e.g., Clovelly Road, Stanmore Bay, etc.) and other representative sites (e.g., that represent similar wave exposure and geology across a wider area).

- Review and incorporate new technologies for monitoring coastal change

  Traditional methods of monitoring coastal change include profile surveys and digitisation of the beach/cliff toe within historic aerial photographs. New technologies are emerging such as using UAVs to capture full terrain models, low cost 'citizen-science' techniques such as CoastSnap (refer to Splinter et al., 2018) to monitor shoreline position or use of satellite imagery or InSAR data to examine shoreline change and mass movement. These technologies may provide improved and/or lower cost data to be used in future updates or subsequent local scale assessment but their accuracy, cost and the usefulness of output data requires review and potentially trial.

- Location and extent of coastal structures

  This present assessment has included a high-level identification of coastal structures. It is recommended to assess and document in detail the location, extent and condition of coastal structures to enable these to be considered in more detailed-scale assessments. By assessing the precise extent and condition of each structure, the risk of failure can be estimated and incorporated into assessments.

- Refined scale assessment for high-risk areas

  It is recommended to undertake refined scale and more detailed assessments for high-risk areas to better understand susceptibility to erosion. As this first-pass assessment identified areas potentially exposed to coastal hazards on a regional scale, the ASCIE distances may be refined over smaller areas using more detailed and site-specific data and/or a probabilistic assessment method. This would provide the likelihood of occurrence of the ASCIE and enable better decisions may be made based on a more complete understanding of likelihood.

10 Applicability

This report has been prepared for the exclusive use of our client Auckland 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

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REPORT

Regional Assessment of Areas Susceptible to Coastal Instability and Erosion

Appendices

Prepared for
Auckland Council
Prepared by
Tonkin & Taylor Ltd
Date
January 2021
Job Number
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Table of contents

Appendix A: List of relevant T+T studies since 2004

Appendix A Table 1: List of relevant T+T jobs since 2004 including cliff and beach erosion rates

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
17560.003	2007	Kawakawa Bay, Manukau, Auckland	• Beach erosion • Cliff erosion • Geology • Vegetation and structures • Information on faults, slips, ongoing erosion etc. • Erosion rate (low)	No rates available: Qualitative erosion risk assessment presented in report	No rates available. Qualitative erosion risk assessment presented in report.
19367.2	2004	Piha, Auckland	• Beach erosion • Erosion rates for dune (40 cm/month)		Accretion of +2.5 m/year at North Piha spit (1980-2000). Erosion at south side of North Piha stream +4.25 m/year (1980-2000).
19744.005	2006	Eastern coastline of Manukau, Auckland Orere Point to 13c Pakuranga Road	• Vegetation and structures • Information on faults, slips, ongoing erosion, etc.	No rates or GIS files available	No rates or GIS files available
19773.4	2004	Half Moon Bay, Auckland	• Geology • Vegetation and structures	No rates or GIS files available	No rates or GIS files available
20388.2	2004	Torpedo Bay, Devonport	• Geology • Vegetation and structures		No rates or GIS files available. The site data is from before construction of beach and alignment structures.
20765.001	2004	Te Atatu Walkway/Henderson Creek	• Coastal erosion • Vegetation and structures	No rates or GIS files available	No rates or GIS files available
21189.003	2011	Torkar Road, Clarkes Beach	• Cliff erosion • Geology • Information on faults, slips, ongoing erosion, etc.	No rates or GIS files available	

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
21481	2004	Scott Road, Hobsonville	• Cliff erosion/ slope instability • Geology • Vegetation and structures • Information on faults, slips, ongoing erosion, etc. • Erosion rates	No rates or GIS files available	
22167.12	2005	St. Heliers Beach	• Beach erosion • Geology • Vegetation and structures		Beach has not experienced significant erosion but is confined by development. No erosion rate available.
22167.22	2007	Pt. Chevalier	• Beach erosion • Geology • Vegetation and structures		No rates or GIS files available
23130	2005	Muriwai	• Beach erosion • Erosion rates		No rates or GIS files available
23408	2006	Karepiro Bay	• coastal erosion		+0.4 m/year accretion between 1954 and 2004.
24873	2007	Riddell Road, Glendowie	• Information on faults, slips, ongoing erosion, etc.		No erosion rates of GIS files available
25046	2007	Maraetai Beach	• Beach erosion • Vegetation and structures • Information on faults, slips, ongoing erosion, etc.		No erosion rates of GIS files available
25450	2008	Karaka Harbourside	• Erosion rates	-0.05 to -0.25 m/year erosion	
25454	2008	Takapuna Boat Ramp	• Geology • Vegetation and structures		No erosion rates of GIS files available
25742	2010	Judges Bay Beach	• Geology • Vegetation and structures		No erosion rates of GIS files available

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
26877.001	2010	Argyle St, Herne Bay	• Cliff stability	No assessment of coastal erosion	
27209	2010	Cockle Bay Reserve	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	
28040	2011	Cliff Road, Torbay	• Cliff erosion/stability • Geology • Information on faults, slips, ongoing erosion, etc. • Erosion rate (4m/100years)	-0.04 m/year	
28544	2011	Karaka Harbourside seawall	• Erosion rates • Geology	-0.05 to -0.25 m/year erosion	
28601.2603	2011	Melba St, Beachhaven	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	
28601.5151	2011	Clovelly Road, Bucklands Beach	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	
28601.8681	2011	Pohutukawa Avenue, Shelly Park	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	
28621.1511	2011	Neptune Avenue, Beach Haven	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	
28641.002	2013	Auckland Region	• Cliff hazard "hot spots" in Auckland	No erosion rates of GIS files available	
28777.01	2016	Karekare Beach, Waitakere	• Beach erosion • Vegetation and structures • Information on faults, slips, ongoing erosion, etc.		Surf club assessment. Erosion rates from the 2006 assessment were referred to.
28805.1321	2012	Telstar Place, Beach Haven	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	
28805.1843	2012	Shelly Beach Road, Surfdale	• Information on faults, slips, ongoing erosion, etc.	No assessment of coastal erosion	

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
28931	2013	Wilson Beach, Hobson Bay	• Beach erosion • Geology • Vegetation and structures		Erosion evident, but no rate available
29159	2013	Shelly Beach Road, Waiheke Island	• Cliff erosion • Geology • Information on faults, slips, ongoing erosion, etc. • Erosion/retreat rates	Comment in report of cliff erosion at Kennedy Bay being 0.05-0.1 m/yr (2016 T+T report). No measurements taken at site	
29286	2013	Navy Museum, Torpedo Bay, Devonport	• Cliff stability • Geology • Information on faults, slips, ongoing erosion, etc.	Not coastal	
29820.4609	2014	Brigantine Drive, Beach Haven	• Information on faults, slips, ongoing erosion, etc.	Not coastal erosion	
29897	2015	Cremorne Street, Herne Bay	• Geology • Vegetation and structures	Not coastal erosion	
30363	2015	South Piha, Auckland	• Beach erosion		0.4 m/yr accretion over 60 years
31114.001	2017	Sandspit Beach, Waiuku	• Beach erosion • Geology • Vegetation and structures • Information on faults, slips, ongoing erosion, etc.		Shoreline constrained by structures. Natural beach position estimated to be 10 m landward of engineered shoreline.
31147.001	2018	Orakei Basin	• Coastal erosion • Vegetation and structures	Estimated long term erosion rate of 0.04 m/yr	
31375	2017	Sergeants Beach	• Beach erosion • Geology • Vegetation and structures		0.15-0.2 m/yr

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
			• Erosion rates (0.15-0.2 m/year)		
31635	2016	Scott Rd, Hobsonville	• Cliff erosion • Geology • Vegetation and structures • Information on faults, slips, ongoing erosion, etc. • Cliff stable angle • Erosion (long-term retreat) rates	Refer to 31668	
31668	2016	Scott Rd	• Erosion rates • Geology • Cliff stable angle • Historic shorelines	Southern: 0.1 m/yr, Central 0.03 m/yr; Northeastern 0.15 m/yr	
31731	2017	Mairangi Bay	• Coastal erosion • Geology • Erosion rates		0.4 m/yr erosion (1963 to 2015)
31808	2016	Takutai Avenue, Buckland Beach	• Information on faults, slips, ongoing erosion, etc.		Not coastal erosion
31875.001	2017	Andersons Bay, Glendowie	• Beach erosion • Cliff erosion • Cliff stability • Geology • Vegetation and structures Information on faults, slips, ongoing erosion etc. • Erosion rate (low)	0.04 m/yr assumed based on ECBF cliffs in the Eastern Beaches	
61146.004	2007	Hingaia Peninsula	• Cliff erosion • Geology • Vegetation and structures	0.05-0.25 m/yr	

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
			• Information on faults, slips, ongoing erosion, etc. • Erosion rates		
1001202	2017	Clark Road, Scott Point	• Coastal erosion • Cliff erosion • Cliff stable angle • Geology • Vegetation and structures • Erosion (long-term retreat) rates	0.05-0.1 m/yr	
1002540	2017	Seacliff Avenue, Belmont	• Information on faults, slips, ongoing erosion, etc.	No information on erosion rate	
1003206	2018	Hawke Crescent, Beachlands	• Information on faults, slips, ongoing erosion, etc.	No information on erosion rate	
1003234	2017	Brigham Inlet, Whenuapai	• Cliff erosion • Geology • Information on faults, slips, ongoing erosion etc. • Cliff stable angle • Erosion (long-term retreat) rates	0.03 m/yr from report	
1004483	2018	Bucklands Beach / Little Bucklands / Cockle Bay	• Beach erosion • Geology • Vegetation and structures		Shoreline change constrained by development. No specific long-term rate is provided in the report.
1005174	2018	Clovelly Rd, Bucklands Beach	• Cliff erosion • Geology • Cliff stable angle • Erosion (long-term retreat) rates	No erosion rates available	

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
1005901	2018	Palm Beach, Waiheke	• Beach erosion • Geology • Vegetation and structures • Information on faults, slips, ongoing erosion, etc. • Dune stability • Erosion (long-term fluctuation) rate		0 m/yr erosion. Land used change and reclaiming masks an accurate assessment of natural variation from available images
1006066	2018	Clarks Beach, Waiuku	• Beach erosion Geology • Vegetation and structures • Information on faults, slips, ongoing erosion, etc. • Erosion rates		Erosion of 0.1 m/yr based on 2006 report. Assessment of natural shoreline change is complicated by land-use change
1006635	2018	Sunde Beach, Motutapu Island	• Beach erosion • Information on faults, slips, ongoing erosion, etc.		No erosion rate of GIS files available
1006861	2018	Saxton St, Waterview	• Coastal erosion (no coastal erosion) • Cliff erosion • Vegetation and structures	No erosion rates available	
1007772	2019 and ongoing	Omana Beach, Maraetai	• Beach erosion • Geology • Vegetation and structures • Erosion (long-term retreat) rates		Historic shoreline changes rates not calculated
10004393	2018	Ferry Basin/ Princes Wharf/ Quay Street	• Coastal effects • Geology • Vegetation and structures	n/a	n/a

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
19346.4 19346.5 19346.6	2007	Eastern Beach, Auckland	• Beach erosion		Beach profile monitoring implemented following nourishment. No long-term erosion rate provided
28156.402 28156.403 28641.007	2016	Eastern Beach, Auckland	• Beach erosion • Vegetation and structures • Information on faults, slips, ongoing erosion, etc.		No calcs of long-term rate
29071.1477 29071.349	2013	Brigantine Drive, Beach Haven	• Information on faults, slips, ongoing erosion, etc.	No erosion rates available	
29071.4583 29071.4617	2013	Jacaranda Avenue, Beach Haven	• Information on faults, slips, ongoing erosion, etc.	No erosion rates available	
29820.3383 29820.3673	2014	Clovelly Road, Bucklands Beach	• Cliff stability • Information on faults, slips, ongoing erosion, etc.	No erosion rates available	
27130	2011	Stanley Bay Beach	• Beach erosion • Geology • Vegetation and structures • Information on faults, slips, ongoing erosion, etc.	No rate or GIS files available	
28156.402	2017	Eastern Beach, Auckland	• Beach erosion • Vegetation and structures		No calculations of long-term rate
28846.11	2016	Aeroview Drive, Beach Haven	• Information on faults, slips, ongoing erosion.	No erosion rates available	
30510.1	2015	Orapiu Bay Beach	• Beach erosion • Vegetation and structures	No erosion rates available	
31401.5613	2016	Lot 240, Stockyard Bay, Kawau Island	• Cliff erosion • Information on faults, slips, ongoing erosion.	No rate or GIS files available	

Job number	Year	Location (suburb or street)	Type of information	Cliff Erosion	Beach erosion
31401.5637	2017	North Cove Beach, Kawau Island	• Cliff erosion • Information on faults, slips, ongoing erosion.	No rate or GIS files available	
31401.6171	2016	Aeroview Drive, Beach Haven	• Cliff erosion • Geology	No rate or GIS files available	
1005943	2018 and ongoing	Patros Place, Bucklands Beach	• Cliff erosion • Cliff stable angle • Erosion rates	-0.06m/yr - based on a review of existing data	
1007177	2018	Clovelly Road, Bucklands Beach	• Cliff erosion • Cliff stable angle • Erosion rates	No erosion rates available	
1003974.3	2019	Pararekau Island	• Cliff erosion • Cliff stable angle • Erosion rates	NW coast 0.1 - 0.2 m/yr, SE coast 0.01 - 0.05 m/yr	
31097	2016	Waiwera	• Coastal erosion rate		Erosion -0.15m/yr

Appendix B: Aerial survey of Auckland shoreline

B1 Aerial survey

An aerial survey of the Auckland coastline was undertaken in December 2018. The purpose of this survey was to obtain high resolution oblique photographs of the beach and cliff coastline. This type of survey has proved to be much more useful and efficient for a region-wide assessment than a ground-based inspection and photographs. The obliqueness of the photographs is particularly useful for interpretation of coastline slopes, heights and relief, and validation of geological type, lithology and susceptibility to landsliding. This data is intended to be used in combination with available LiDAR information and right angle photographs.

B1.1 Flight route

The aerial survey was undertaken on 7, 8 and 17 December 2018. The flight dates and routes are shown in Figure Appendix B.1 and Appendix B Table 1, with departures were from the Ardmore airport in Papakura.

On 7 December the flight included Waiheke Island, Great Barrier Island and a part of the Firth of Thames coastline. On 8 December the flight along the east coast was from south to north, with a stop at Northshore airport. The Kaipara Harbour and west coast were flown in the afternoon. The flight around the Manukau Harbour was done on 17 December in the afternoon due to poor weather conditions between 8 and 17 December.

The airplane was flown at an elevation of roughly 500 ft (~150 m) and typical offshore distance of 300-500 m. The offshore distance varies alongshore due to the irregular shoreline. The flights along the east coast were done in the mornings and along the west coast in the afternoons because of the position of the sun, limiting shadowing of the cliffs.

Appendix B Table 1: Flight dates and area

Date	Fly area
7-12-2018	Waiheke Island + Great Barrier Island
8-12-2018	East Coast + West Coast + Waitemata Harbour + Kaipara Harbour
17-12-2018	Manukau Harbour

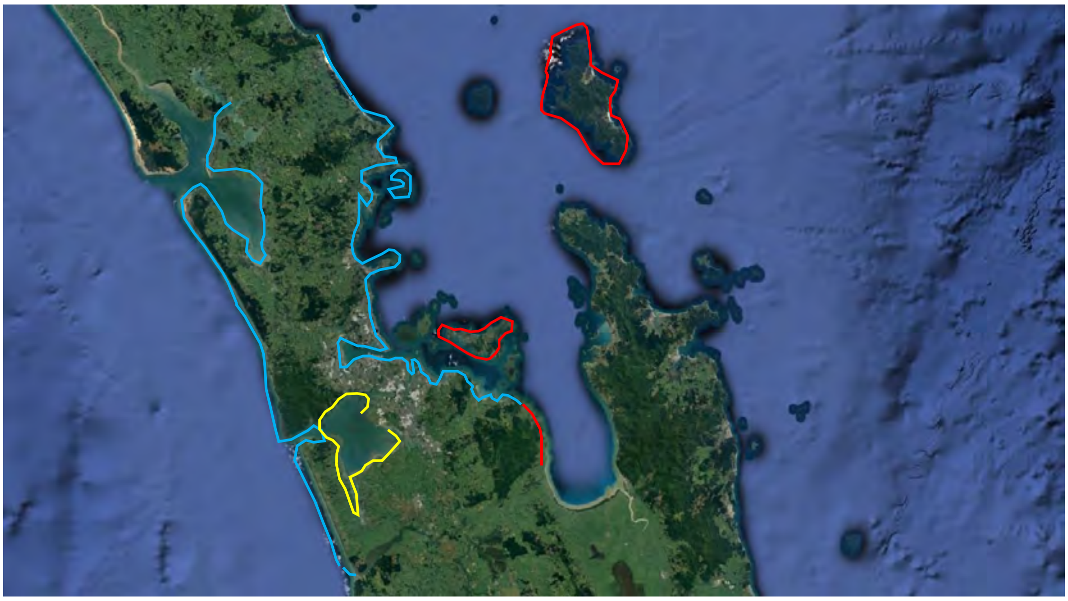


Figure Appendix B.1: Flight scheme (red = 7-12-2018, blue = 8-12-2018, yellow = 17-12-2018)

B1.2 Equipment

The aerial survey was undertaken using a Cessna 172 airplane (see Figure Appendix B.2) chartered from Christian Aviation. The airplane can carry up to four people, including a pilot, has a single engine and can fly up to 175 km/hr.

A Nikon D5300 camera with a focal length of 35 mm was used to take photographs. Photographs were taken at 3 to 5 second intervals to achieve a reasonable overlap. The interval of taking photographs varies depending on the irregularity of the shoreline (e.g. straight coastline versus shoreline transitioning from headlands to embayments). The location of the airplane was recorded at 10 second intervals using a Garmin GPSmap 64s.

Figure Appendix B.2: Cessna 172 airplane

B1.3 Processed photographs

The photographs were sorted, cleaned up and further processed using the program GeoSetter. The photographs were geo-tagged using this program which links the recorded GPS coordinates to the photographs based on synchronised time of both the GPS device and camera. The program was then used to create GoogleEarth files (i.e. *.kml or *.kmz), which allows you to see thumbnails and locations of the photographs in GoogleEarth or other GIS programs (see example in Figure Appendix B.3). Some examples of aerial survey photographs are shown in Figure Appendix B.4.

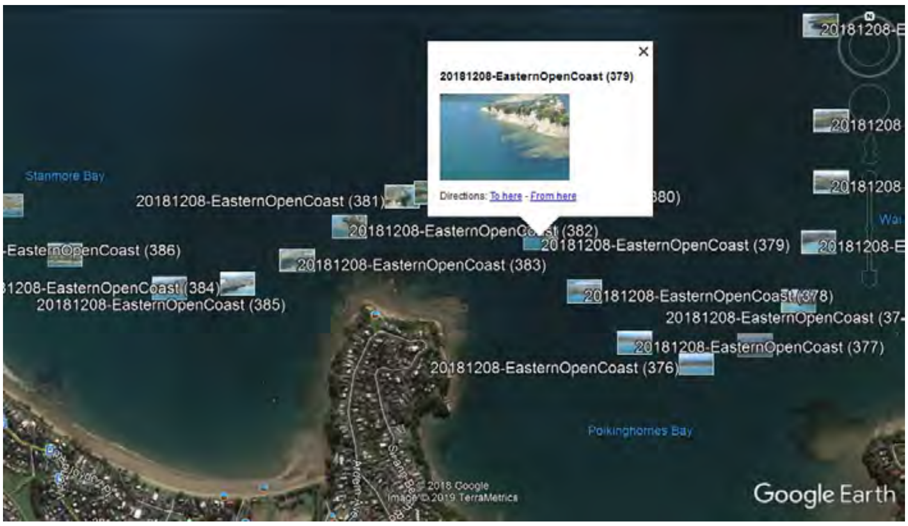


*Figure Appendix B.3: Example of *.kmz file showing locations and thumbnails of photographs in vicinity of Stanmore Bay*

Figure Appendix B.4: Example photographs of aerial survey taken at Torbay (top left), Whatipu (top right), Kawakawa Bay (middle left), Howick (middle right), Awhitu open coast (bottom left) and Orere Point (bottom right)

Appendix C: Beach profile data and analysis

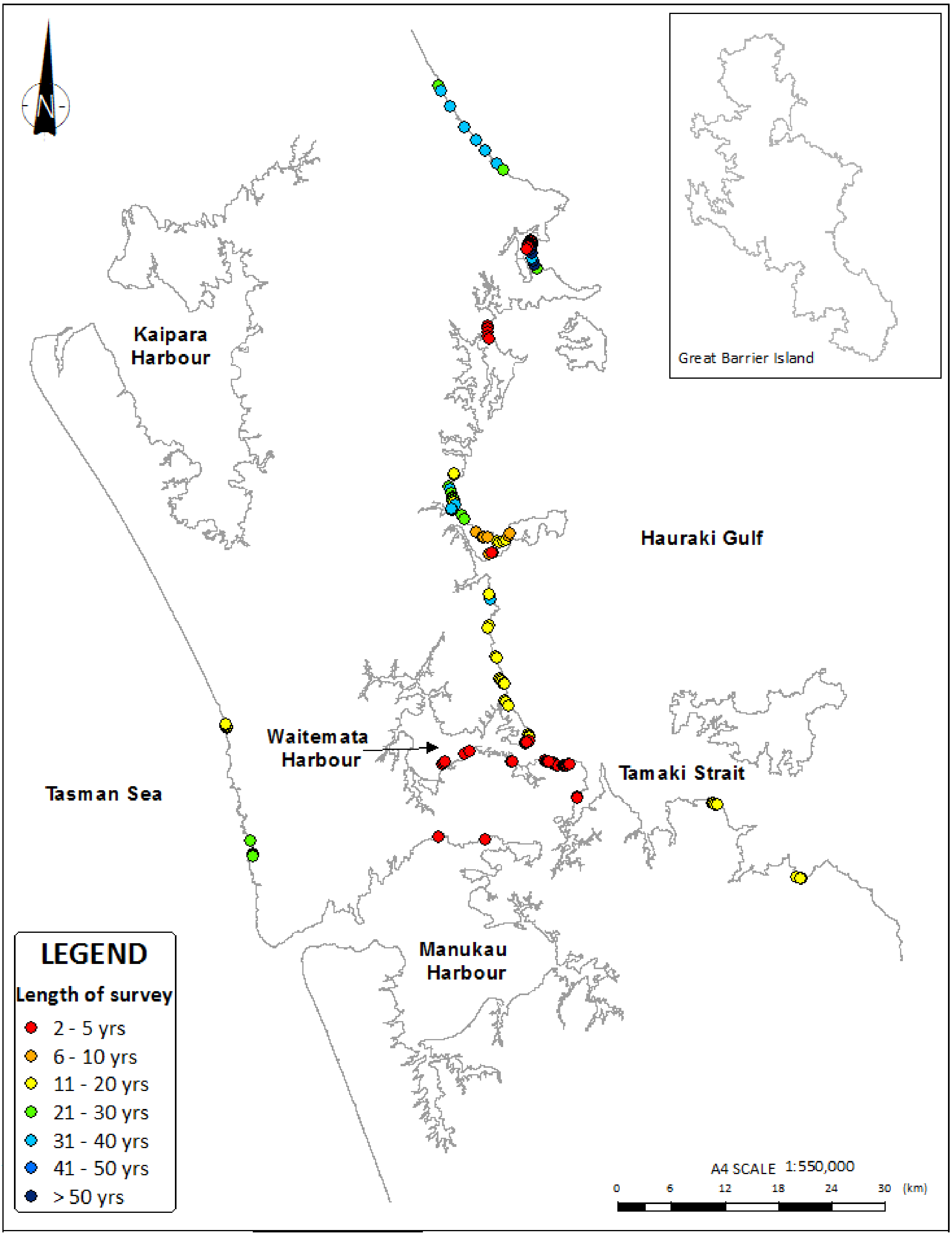


Figure Appendix C.1: Locations where beach profile data is available (including length of survey period)

Appendix C Table 1: Summary of beach profile data for Auckland region

Beach	Profile	NZTM N (survey start point)	NZTM E (survey start point)	Initial Survey Year	End survey year	Frequency	Length (years)
Pakiri North	P1	6002053	1745308	1978	2014	Bi-annual	36
	P2	5999292	1746788	1988	2014		26
	2B	5998029	1747408	1993	2014		21
	2A	5995924	1748629	1990	2018		28
	P3	5995349	1748902	1981	2018		37
	P4	5993535	1750048	1978	2018		40
Pakiri South	P5	5991288	1751760	1984	2018	Bi-annual	34
	P6	5989851	1753078	1978	2018		40
	P7	5988717	1754093	1978	2018		40
	P8	5987305	1755476	1978	2018		40
	P9	5986620	1756179	1989	2018		29
Omaha North	P1	5975779	1760415	1993	2018	Bi-annual	25
	P2	5976188	1760113	1965	2018		53
	P3	5976613	1759881	1965	2018		53
Omaha South	P4	5976935	1759775	1978	2018	Bi-annual	40
	P5	5977432	1759688	1965	2018		53
	P6	5977876	1759642	1965	2018		53
	P7	5978304	1759712	1965	2018		53
	P8	5978574	1759735	1993	2018		25
	P9	5978760	1759694	1993	2018		25
Snells Beach	P1	5969104	1755062	2015	2018	4 times 2 years then Bi-annual	3
	P2	5968796	1755036	2015	2018		3
	P3	5968347	1755058	2015	2018		3
	P4	5967948	1755119	2015	2018		3
	P5	5967666	1755225	2015	2018		3
Hatfields Beach	H1	5952289	1751778	2006	2017	2/3 times per year up to 2009, then bi-annual from 2015	11
	H4	5952378	1751802	2006	2017		11
Orewa Beach	01	5950953	1751357	1994	2018	2/3 times per year	24
	02	5950711	1751434	1981	2018	2/3 times per year up to 2009, then bi-	37
	04	5950193	1751614	1988	2018		30
	08	5949815	1751751	1988	2018		30
	010	5949615	1751828	1988	2018		30

Beach	Profile	NZTM N (survey start point)	NZTM E (survey start point)	Initial Survey Year	End survey year	Frequency	Length (years)
	011	5949501	1751872	1988	2018	annual from 2015	30
	012	5949385	1751853	1988	2018		30
	012A	5949280	1751910	2006	2018		12
	012B	5949204	1751930	2006	2018		12
	013	5948919	1752051	1981	2018		37
Red Beach	R1	5947715	1752851	1989	2017	2/3 times per year up to 2009, then bi-annual from 2015	28
	R2	5947286	1753121	1989	2017		28
Stanmore Bay	S1	5945918	1754613	2008	2018	Bi-annual	10
	S2	5945410	1755355	2008	2018		10
	S3	5945369	1755505	2008	2018		10
	S4	5945364	1755848	2008	2018		10
Manly Beach	M1	5944963	1756857	2006	2018	Bi-annual	12
	M2	5944907	1757163	2006	2018		12
	M3	5944985	1757595	2006	2018		12
	M4	5945142	1757853	2006	2018		12
Tindalls Bay	T1	5945698	1758176	2008	2018	Bi-annual	10
	T2	5945956	1758392	2008	2018		10
Arkles Bay	A1	5943702	1756453	2008	2018	Bi-annual	10
	A2	5943617	1756306	2008	2018		10
	A3	5943465	1756144	2008	2018		10
Long Bay	P1	5938433	1756468	1982	2018	Monthly until 2009 then bi-annual	36
	P2	5938972	1756277	1999	2018	bi-annual	19
	P2A			2002	2006	Monthly	4
	P3			2001	2006	Monthly	5
	P4			2001	2006	Monthly	5
Browns Bay	P1	5935562	1756293	1998	2015	Monthly until 2009 then bi-annual	17
	P2	5935163	1756227	1998	2015		17
Campbells Bay	P1	5931989	1757262	1998	2015		17

Beach	Profile	NZTM N (survey start point)	NZTM E (survey start point)	Initial Survey Year	End survey year	Frequency	Length (years)
	P2	5931882	1757348	1998	2015	Monthly until 2009 then bi-annual	17
Takapuna	P1	5927173	1758414	1998	2015	Bi-annual	17
	P2	5926931	1758580	1998	2015		17
	P3	5926635	1758830	1998	2015		17
Milford	P1	5929653	1757753	1998	2015	Monthly until 2009 then bi-annual	17
	P2	5929499	1757836	1998	2015		17
	P3	5929303	1757991	1998	2015		17
	P4	5929025	1758247	1998	2015		17
	P5	5928969	1758284	1998	2015		17
Cheltenham	CHBP1	5923476	1761152	1998	2015	Monthly until 2009 then bi-annual	17
	CHBP2	5923300	1761232	1998	2015		17
	CHBP3	5923186	1761350	1998	2015		17
Mission Bay	P1	5920568	1763119	2014	2018	4 times first year then Bi-annual	4
	P2	5920524	1763211	2014	2018		4
	P3	5920461	1763326	2014	2018		4
	P4	5920433	1763430	2014	2018		4
	P5	5920413	1763508	2014	2018		4
Kohimaramara	P1	5920294	1764112	2014	2018	4 times first year then Bi-annual	4
	P2	5920235	1764212	2014	2018		4
	P3	5920166	1764376	2014	2018		4
	P4	5920130	1764487	2014	2018		4
	P5	5920097	1764613	2014	2018		4
St Heliers	P1	5920074	1765244	2014	2018	4 times first year then Bi-annual	4
	P2	5920067	1765385	2014	2018		4
	P3	5920104	1765499	2014	2018		4
	P4	5920149	1765629	2014	2018		4
	P5	5920196	1765756	2014	2018		4
	P6	5920223	1765835	2014	2018		4
Maraetai	MABP1	5916452	1782052	1998	2018	Bi-annual	20
	MABP2	5916370	1782214	1998	2018		20
	MABP3	5916323	1782374	1998	2018		20
	MABP4	5916294	1782594	1998	2018		20
Kawakawa	P1	5908505	1791849	1998	2018	Bi-annual	20
	P2	5908373	1792412	1998	2018		20

Beach	Profile	NZTM N (survey start point)	NZTM E (survey start point)	Initial Survey Year	End survey year	Frequency	Length (years)
	P3	5908376	1792322	1998	2018		20
	P4	5908375	1792238	1998	2018		20
	P2A	5908642	1792998	2016	2018	Annual	2
	P2B	5908701	1793259	2016	2018		2
Orere Point	P1			1998	2006	Bi-annual	8
	P2			1998	2006		8
Piha South	P1	5910385	1730385	1990	2018	Bi-annual	28
	P2	5909057	1730762	1993	2018		25
	P3	5908913	1730778	1993	2018		25
	P4	5908780	1730707	1981	2018		37
Piha North	P5	5908737	1730676	1993	2018	Bi-annual	25
	ACB1	5909939	1730678	2012	2018	Quarterly	6
	AC2	5909887	1730652	2012	2018		6
	AC3	5909824	1730652	2012	2018		6
Muriwai North	P1	5849052	1612183	1997	2013	Bi-annual	16
	P2	5838849	1618215	1990	2013		23
Muriwai South	P3	5825863	1625006	1981	2014	Bi-annual	33
	P4	5923003	1727323	1990	2018		28
	PA	5923003	1727323	2005	2018	3/4 per year until 2010 then bi-annual	13
	PB	5923061	1727276	2005	2018		13
	PC	5923101	1727265	2005	2018		13
	PD	5923148	1727277	2005	2018		13
	PE	5923194	1727260	2005	2018		13
	PF	5923225	1727275	2005	2018		13
	PG	5923266	1727257	2005	2018		13
	PH	5923344	1727247	2005	2018		13
	PI	5923363	1727248	2005	2018		13
	PJ	5923420	1727223	2005	2018		13
	PK	5923461	1727225	2005	2018		13

Appendix C Table 2: Summary of short-term erosion distances based on analysis of beach profiles for Auckland region

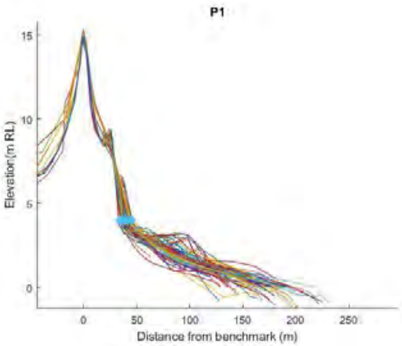
Beach	Profile	Short-term erosion distance (m)	
		10-year ARI	100-year ARI
Pakiri North	P1	3	9
	P2	5	9
	2B	4	8
	2A	6	15
	P3	4	8
	P4	5	11
Pakiri South	P5	7	14
	P6	7	17
	P7	4	10
	P8	4	8
	P9	4	11
Omaha South	P1	15	27
	P2	15	32
	P3	12	25
	P4	Not used as location is not representative to derive short-term erosion	
	P5	16	30
	P6	15	30
Omaha North	P7	Not used as location is not representative to derive short-term erosion	
	P8	10	18
	P9	9	17
Snells Beach	P1	2	3
	P2	3	5
	P3	2	3
	P4	2	4
	P5	1	2
Hatfields Beach	H1	5	9
	H4	4	9
Orewa Beach	01	11	20
	02	4	8
	04	4	6
	08	4	9
	010	5	11
	011	5	11
	012	5	15
	012A	Not used as profile not situated along open coast	
	012B	Not used as profile not situated along open coast	

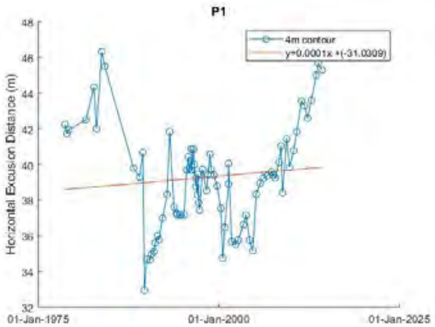
Beach	Profile	Short-term erosion distance (m)	
		10-year ARI	100-year ARI
	013	4	8
Red Beach	R1	4	6
	R2	3	5
Stanmore Bay	S1	3	5
	S2	3	8
	S3	2	10
	S4	1	2
Manly Beach	M1	Not used due to limited data points	
	M2	Not used due to limited data points	
	M3	2	6
	M4	Not used due to limited data points	
Tindalls Bay	T1	3	5
	T2	1	1
Arkles Bay	A1	1	4
	A2	1	5
	A3	3	5
Long Bay	P1	2	4
	P2	4	7
	P2A	3	5
	P3	2	4
	P4	Not used as profile is located close to stream mouth	
Browns Bay	P1	Not used as shoreline fronted by structure	
	P2	2	4
Campbells Bay	P1	3	6
	P2		
Takapuna	P1	1	4
	P2	3	7
	P3	Not used as potentially affected by stream	
Milford	P1	3	5
	P2	Not used as potentially affected by structure	
	P3	5	9
	P4	2	3
	P5	3	5
Cheltenham	CHBP1	4	8
	CHBP2	6	10
	CHBP3	4	8
Mission Bay	P1	Not used due to limited data points	
	P2		
	P3		

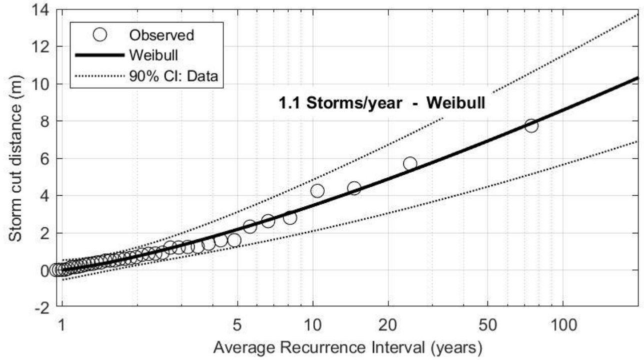
Beach	Profile	Short-term erosion distance (m)	
		10-year ARI	100-year ARI
	P4		
	P5		
Kohimaramara	P1	Not used due to limited data points	
	P2		
	P3		
	P4		
	P5		
St Heliers	P1	Not used due to limited data points	
	P2		
	P3		
	P4		
	P5		
	P6		
Maraetai	MABP1	5	7
	MABP2	6	12
	MABP3	4	11
	MABP4	4	10
Kawakawa	P1	1	1
	P2	1	3
	P3	1	3
	P4	1	2
	P2A	Not used due to limited data points	
	P2B	Not used due to limited data points	
Orere Point	P1	Not used due to limited data points	
	P2		
Piha South	P1	4	15
	P2	5	15
	P3	4	9
	P4	2	4
Piha North	P5	6	17
	ACB1	Not used due to location of profile	
	AC2	5	11
	AC3	12	28
Muriwai North	P1	9	20
	P2	4	16
Muriwai South	P3	4	13
	P4	4	10
	PA	Not used due to location of profile	
	PB	Not used due to location of profile	

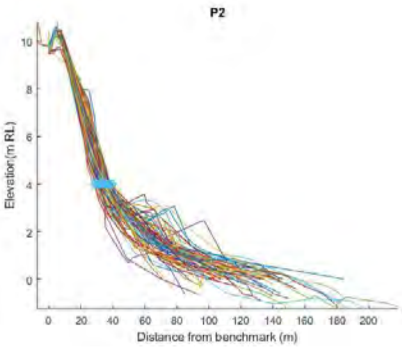
Beach	Profile	Short-term erosion distance (m)	
		10-year ARI	100-year ARI
	PC	Not used due to location of profile	
	PD	Not used due to location of profile	
	PE	Not used due to location of profile	
	PF	Not used due to location of profile	
	PG	Not used due to location of profile	
	PH	Not used due to location of profile	
	PI	Not used due to location of profile	
	PJ	Not used due to location of profile	
	PK	Not used due to location of profile	

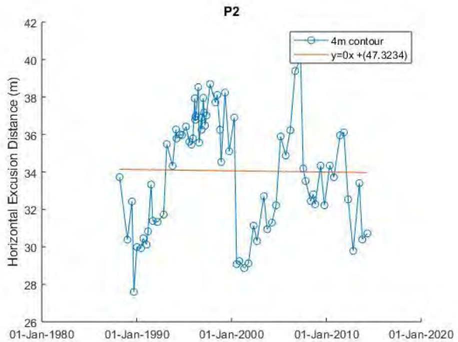
Pakiri North

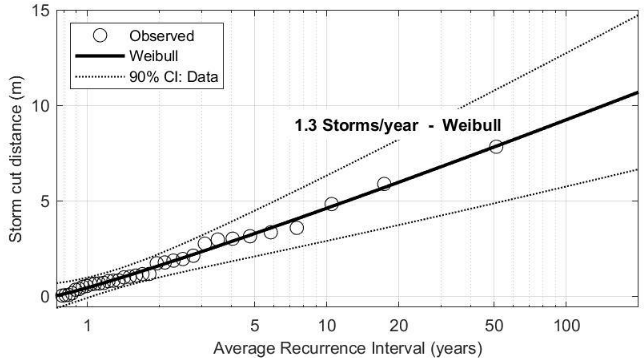


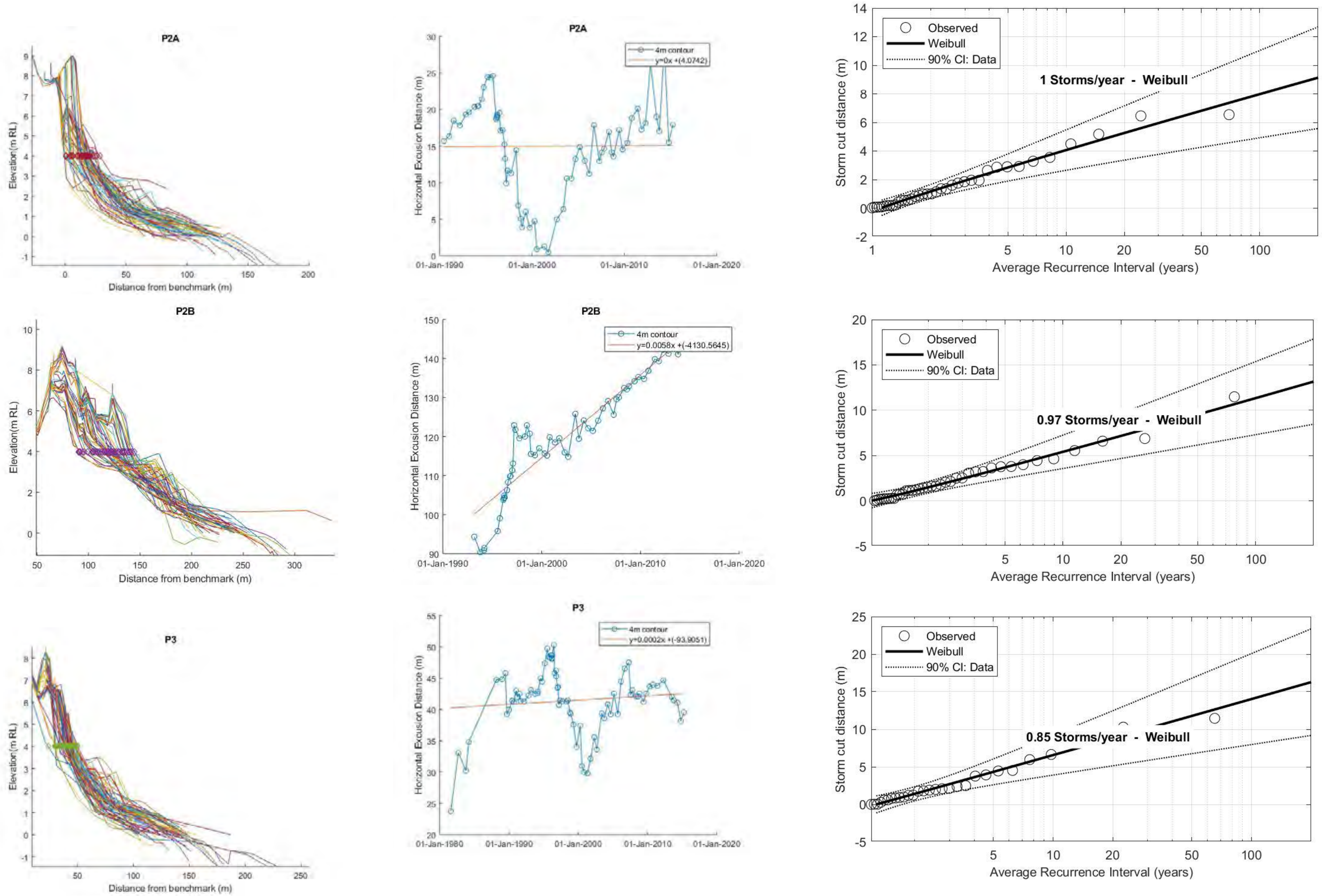












P2A
Elevation(m RL)
Distance from benchmark (m)
P2A
4m contour
y=0x +(4.0742)
Horizontal Excusion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
1 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
P2B
Elevation(m RL)
Distance from benchmark (m)
P2B
4m contour
y=0.0058x +(-4130.5645)
Horizontal Excusion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
0.97 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
P3
Elevation(m RL)
Distance from benchmark (m)
P3
4m contour
y=0.0002x +(-93.9051)
Horizontal Excusion Distance (m)
01-Jan-1980
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
0.85 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

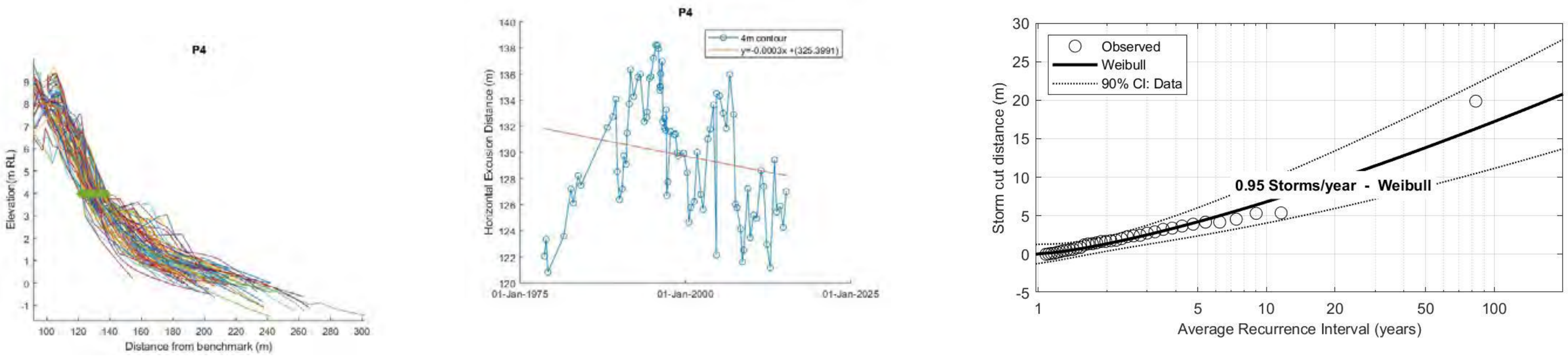
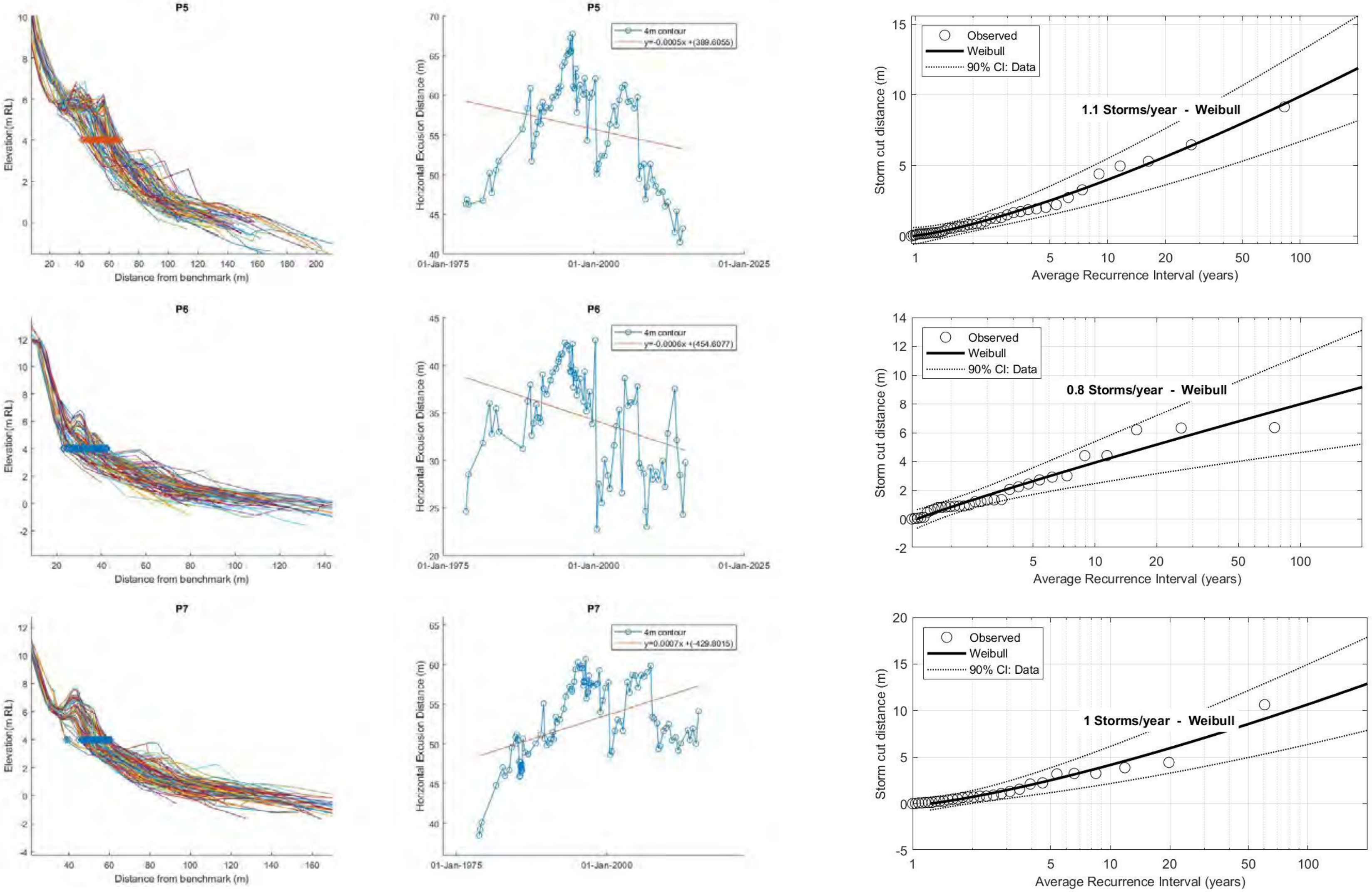


Figure Appendix C.2: Beach profiles at Pakiri North (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Pakiri South



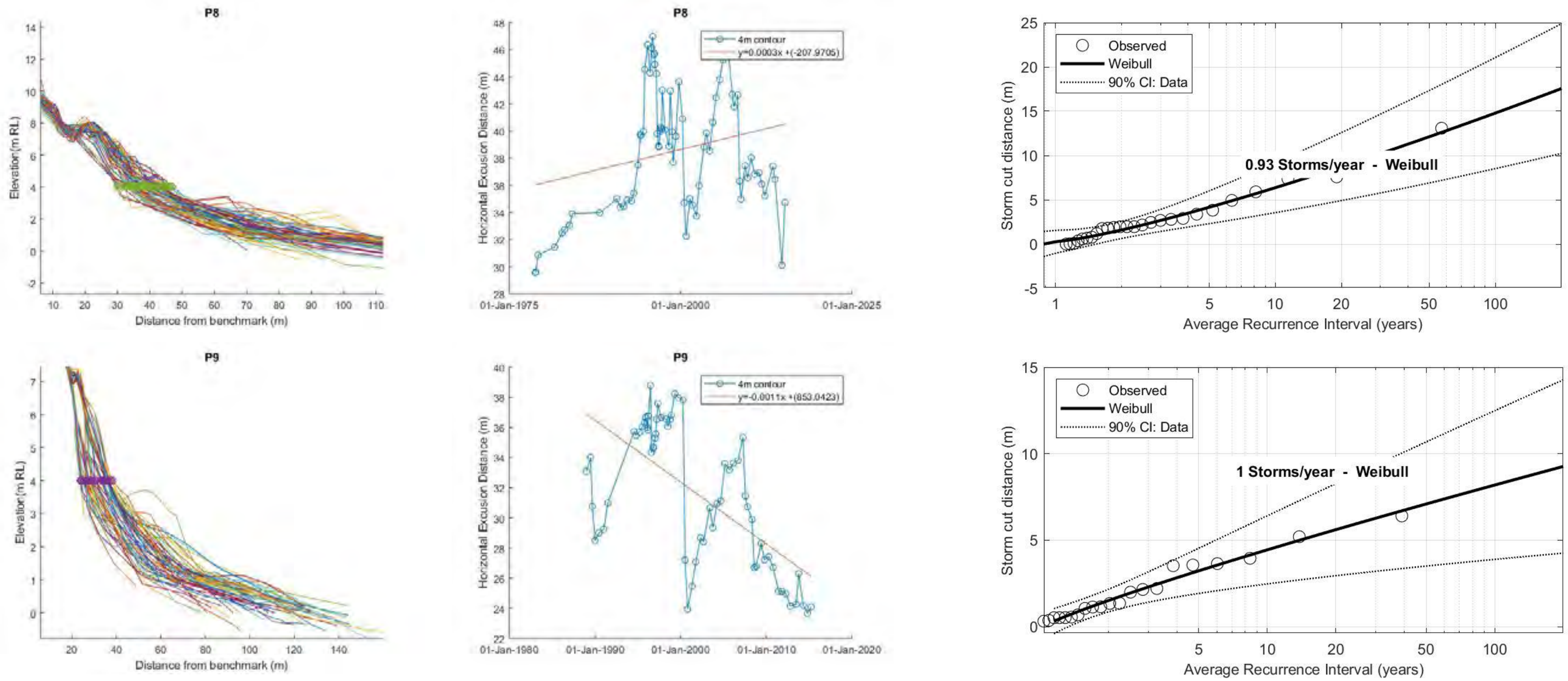
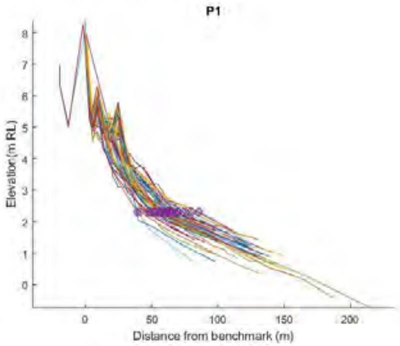
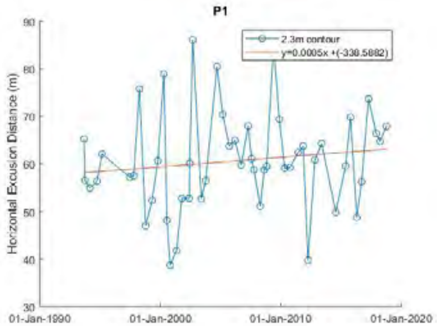
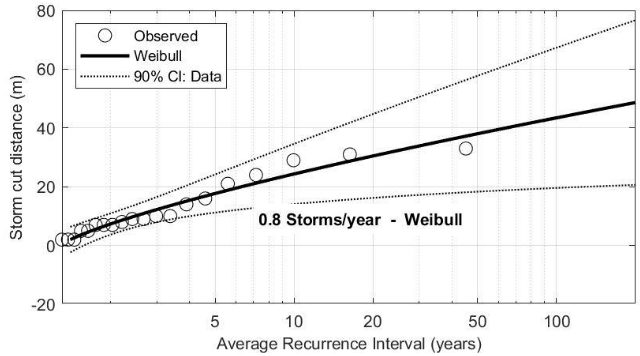


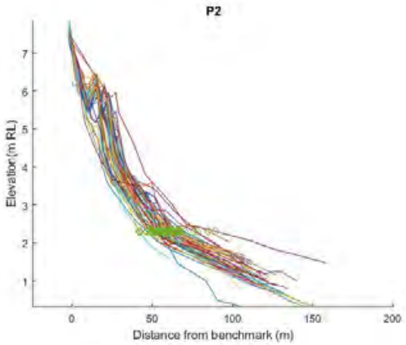
Figure Appendix C.3: Beach profiles at Pakiri South (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

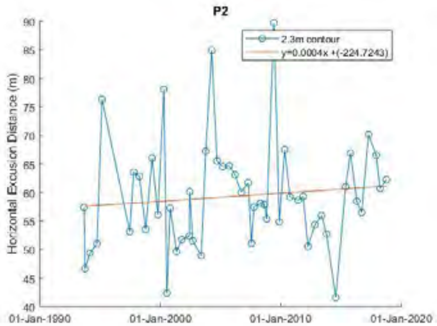
Omaha North

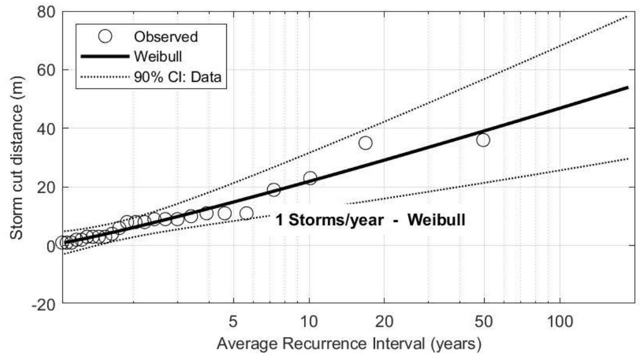

P1
Elevation (m RL)
Distance from benchmark (m)


P1
2.3m contour
y=0.0005x +(-338.5882)
Horizontal Excusion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
0.8 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)


P2
Elevation (m RL)
Distance from benchmark (m)


P2
2.3m contour
y=0.0004x +(-224.7243)
Horizontal Excusion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
1 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

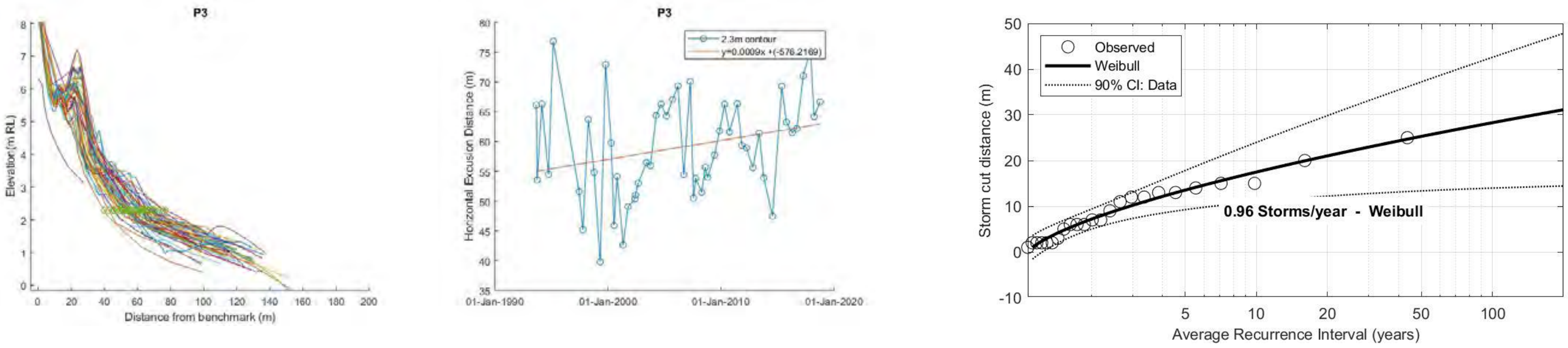
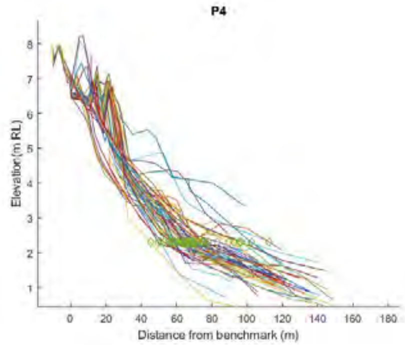
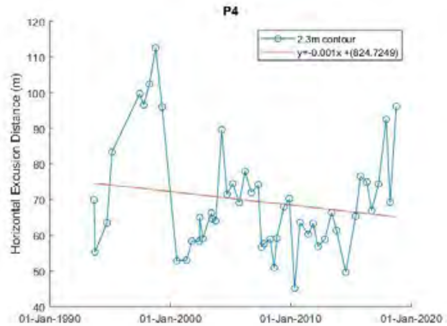
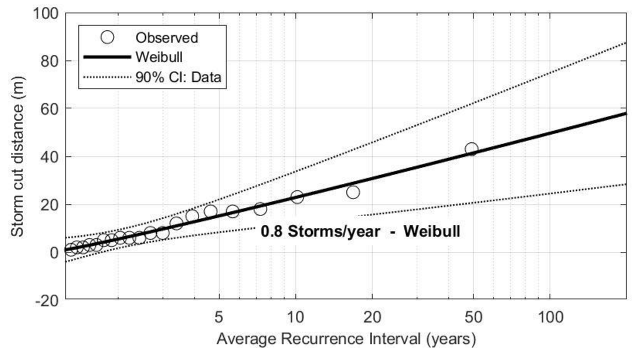


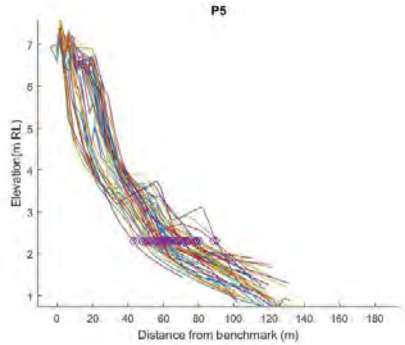
Figure Appendix C.4: Beach profiles at Omaha North (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

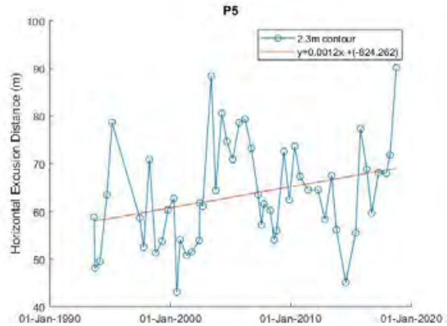
Omaha South

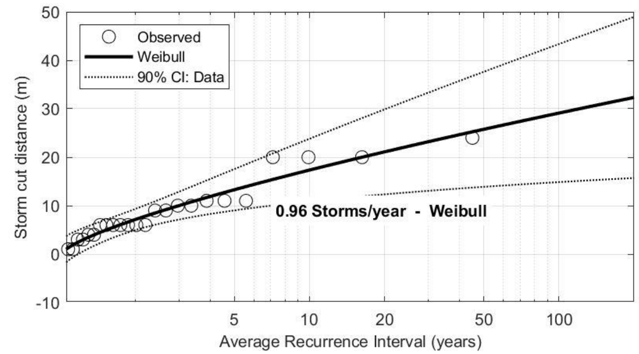

P4
Elevation (m RL)
Distance from benchmark (m)

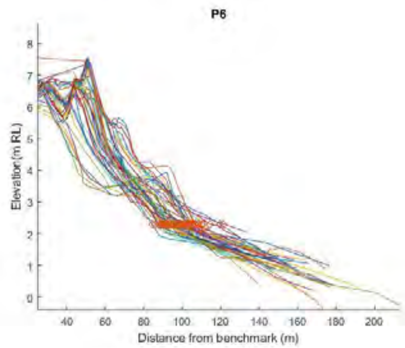

P4
2.3m contour
y=-0.001x +(824.7249)
Horizontal Excursion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020

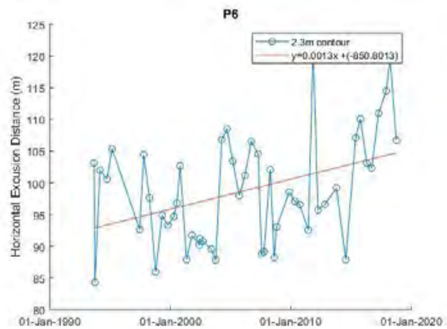

Observed
Weibull
90% CI: Data
0.8 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

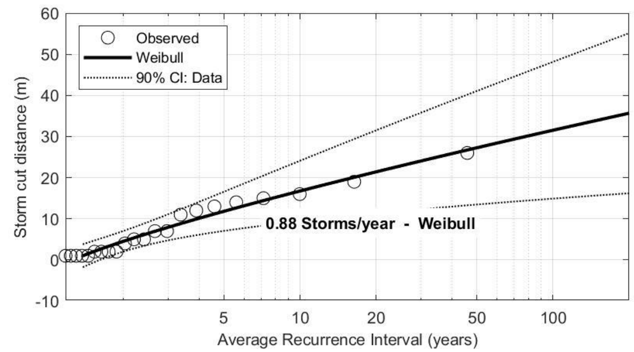

P5
Elevation (m RL)
Distance from benchmark (m)


P5
2.3m contour
y=0.0012x +(-824.262)
Horizontal Excusion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
0.96 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)


P6
Elevation (m RL)
Distance from benchmark (m)


P6
2.3m contour
y=0.0013x +(-850.8013)
Horizontal Excusion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
0.88 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

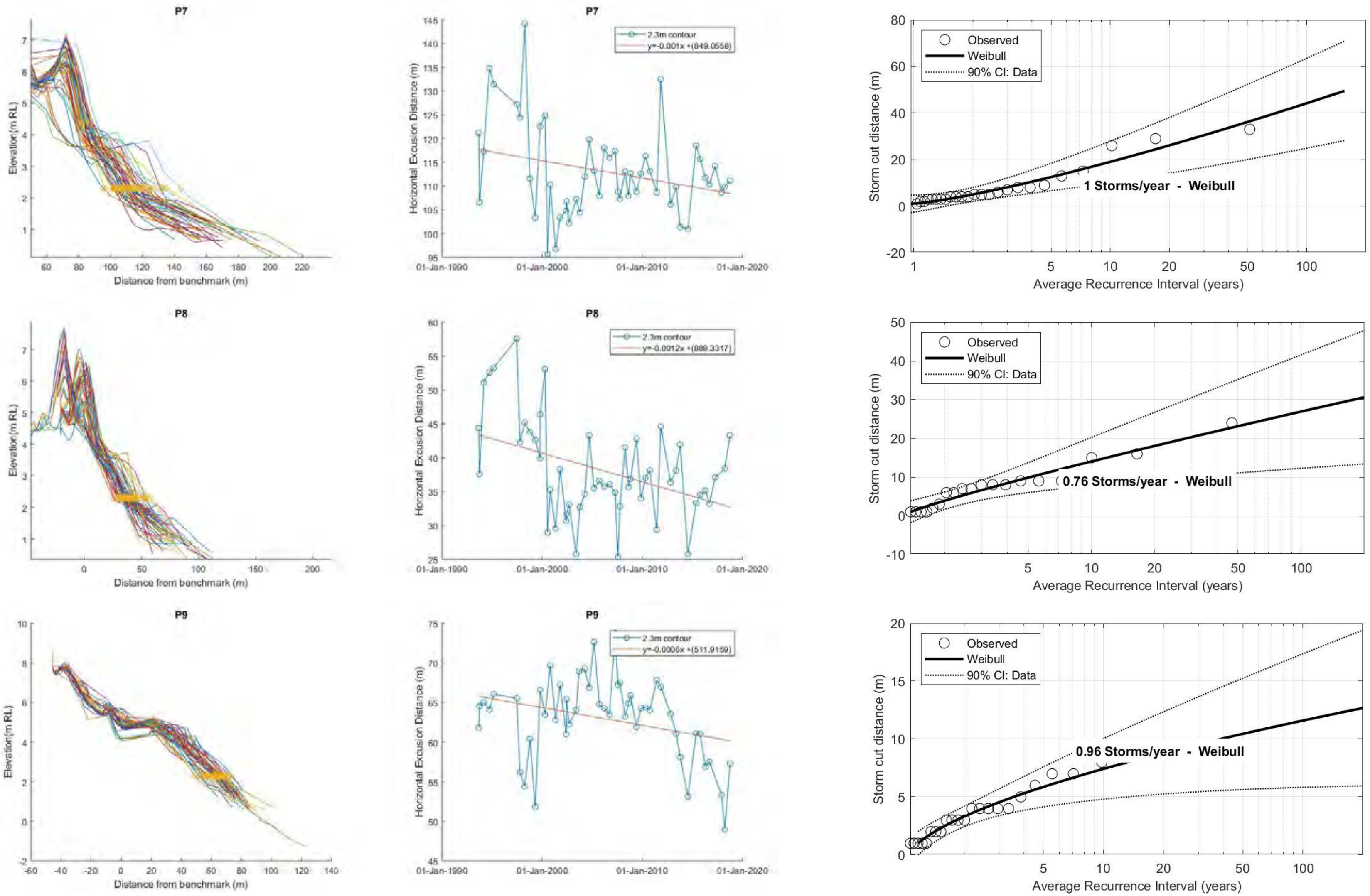
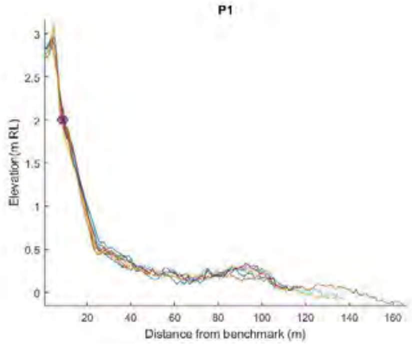
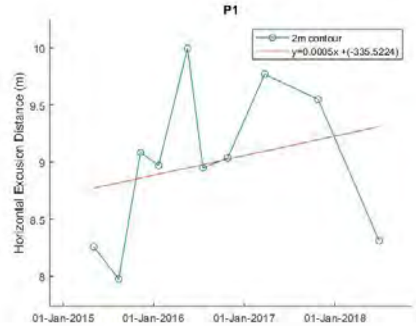
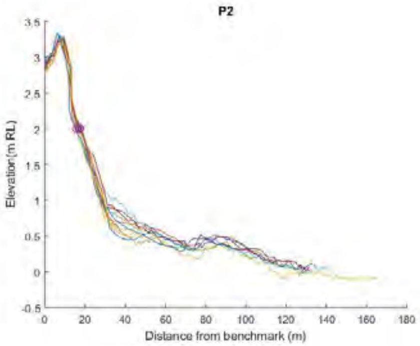


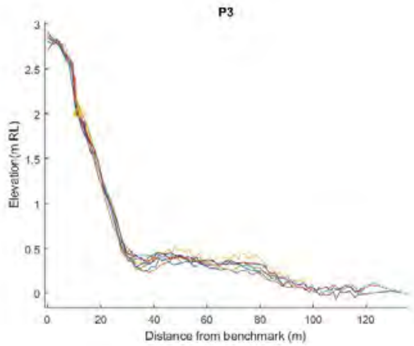
Figure Appendix C.5: Beach profiles at Omaha South (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

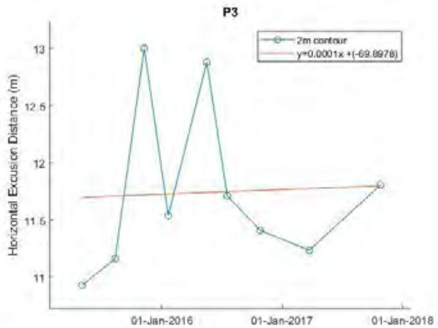
Snells Beach











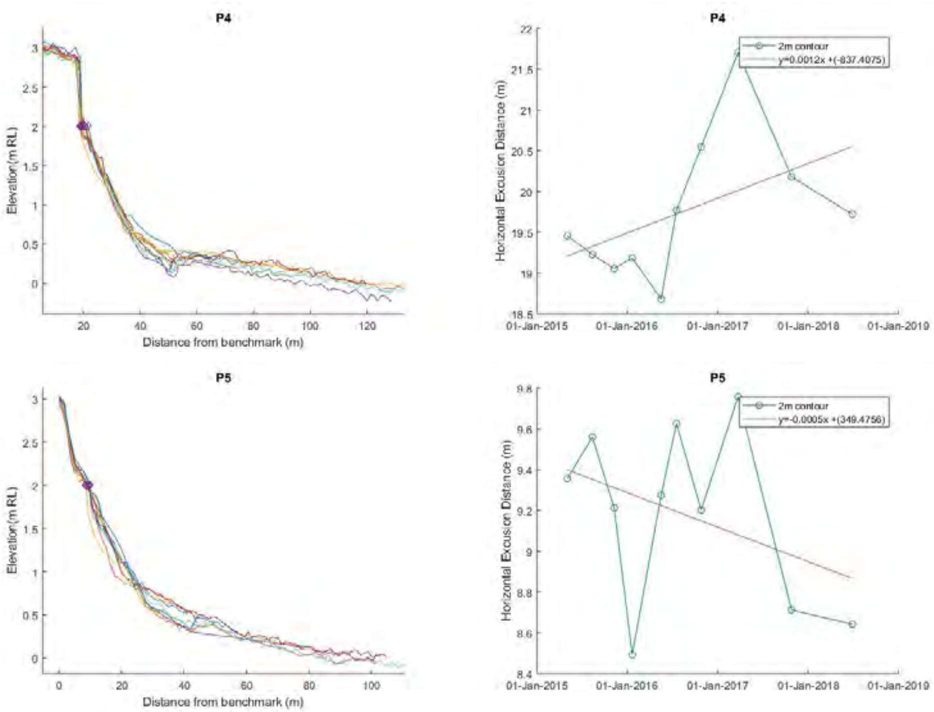


Figure Appendix C.6: Beach profiles at Snells Beach (left) and long-term regression (right)

Hatfields

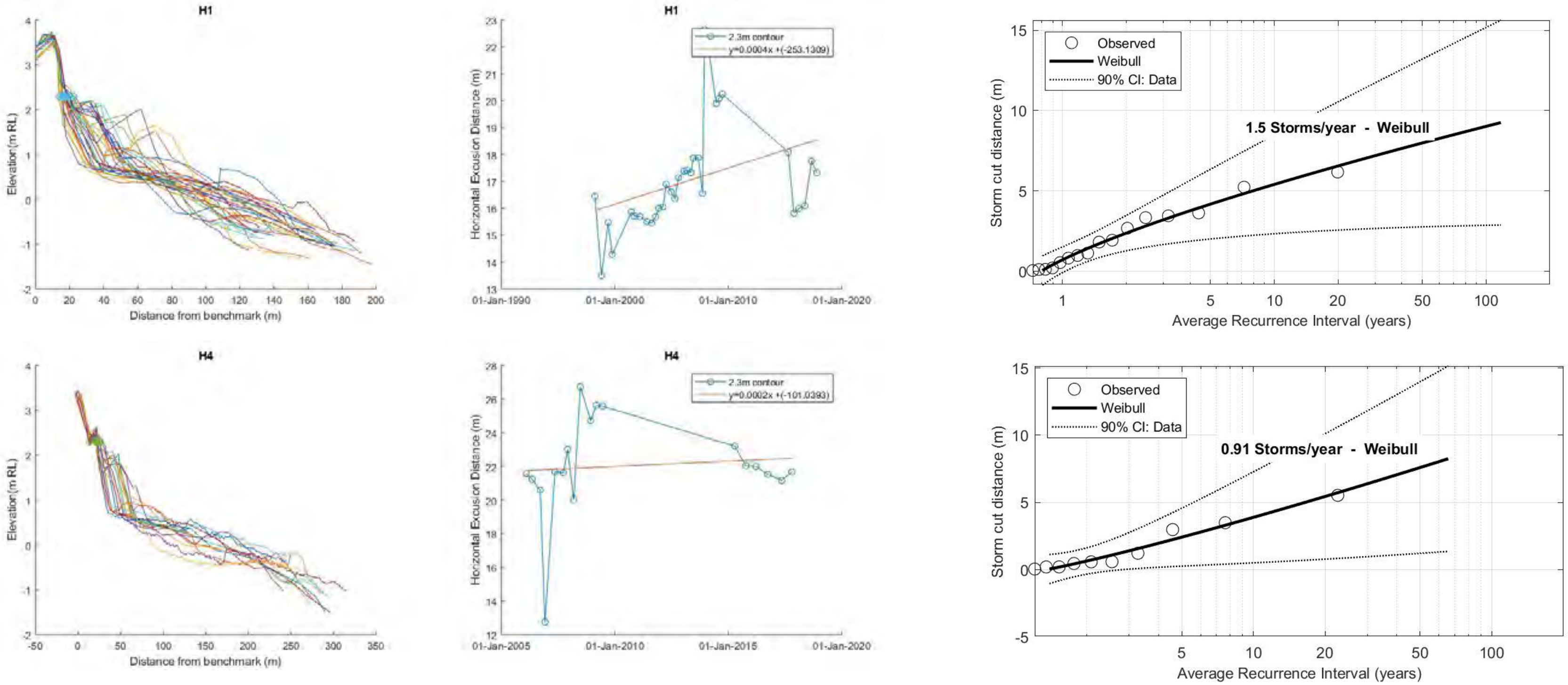
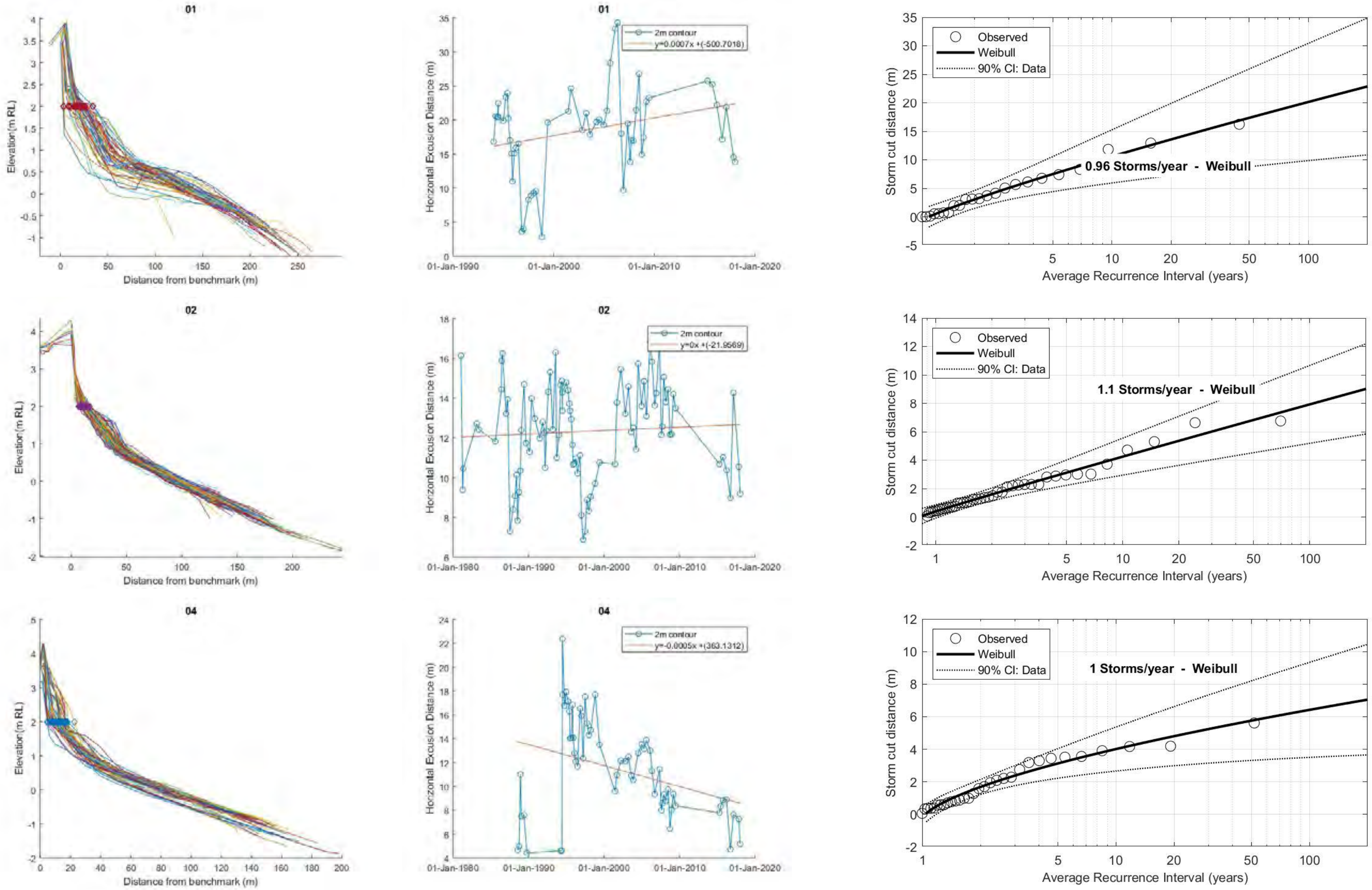
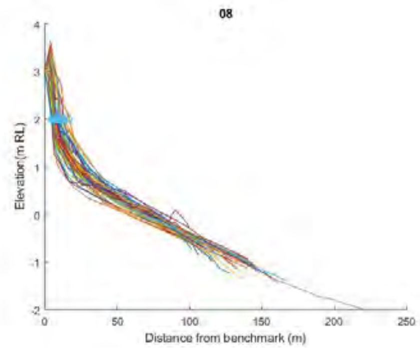


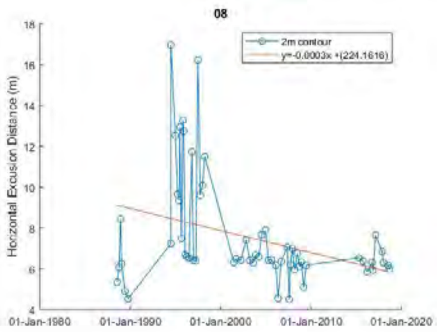
Figure Appendix C.7: Beach profiles at Hatfields (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

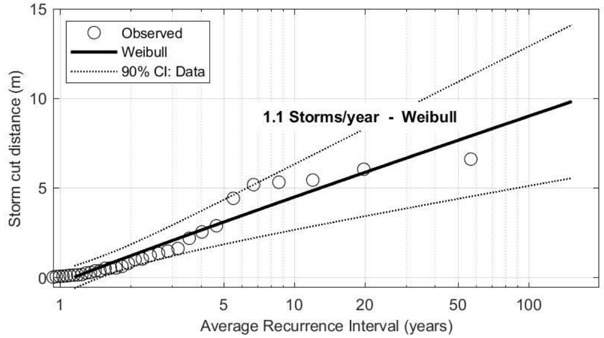
Orewa

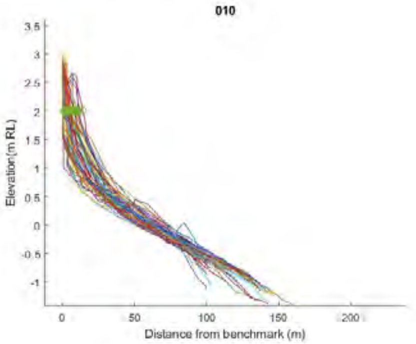


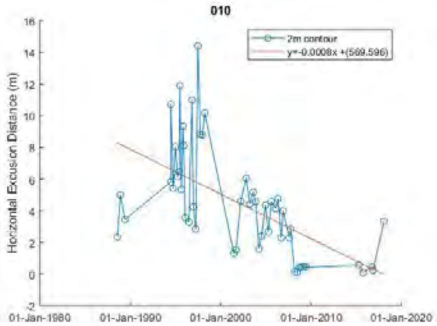
01
Elevation (m RL)
Distance from benchmark (m)
01
2m contour
y=0.0007x +(-500.7018)
Horizontal Excursion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
0.96 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
02
Elevation (m RL)
Distance from benchmark (m)
02
2m contour
y=0x +(-21.9569)
Horizontal Excursion Distance (m)
01-Jan-1980
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
1.1 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
04
Elevation (m RL)
Distance from benchmark (m)
04
2m contour
y=-0.0005x +(363.1312)
Horizontal Excursion Distance (m)
01-Jan-1980
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
1 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

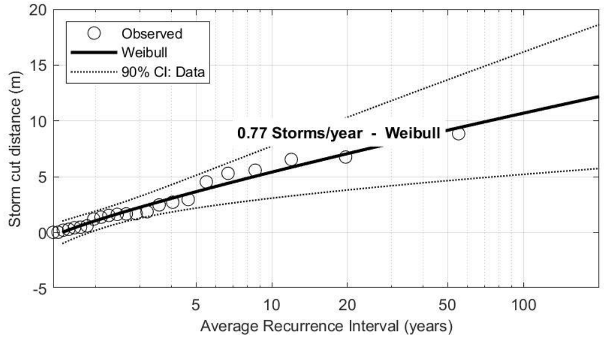

08
Elevation (m RL)
Distance from benchmark (m)

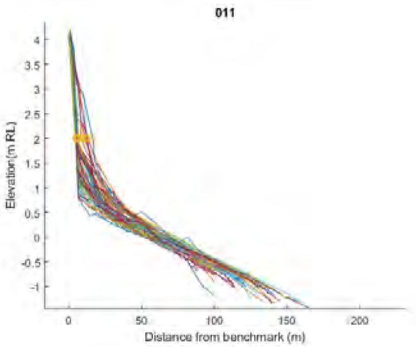

08
2m contour
y=-0.0003x +(224.1616)
Horizontal Excursion Distance (m)
01-Jan-1980
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020

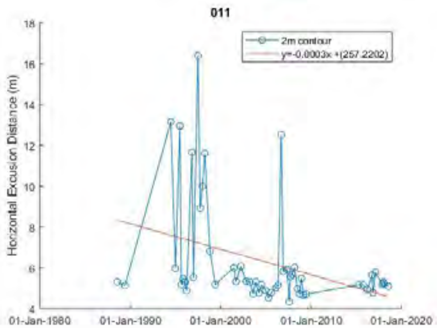

Observed
Weibull
90% CI: Data
1.1 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

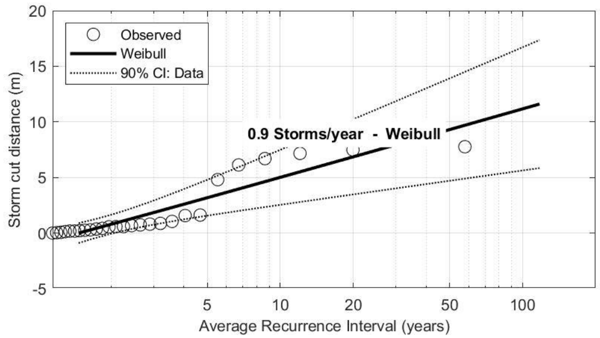

010
Elevation (m RL)
Distance from benchmark (m)

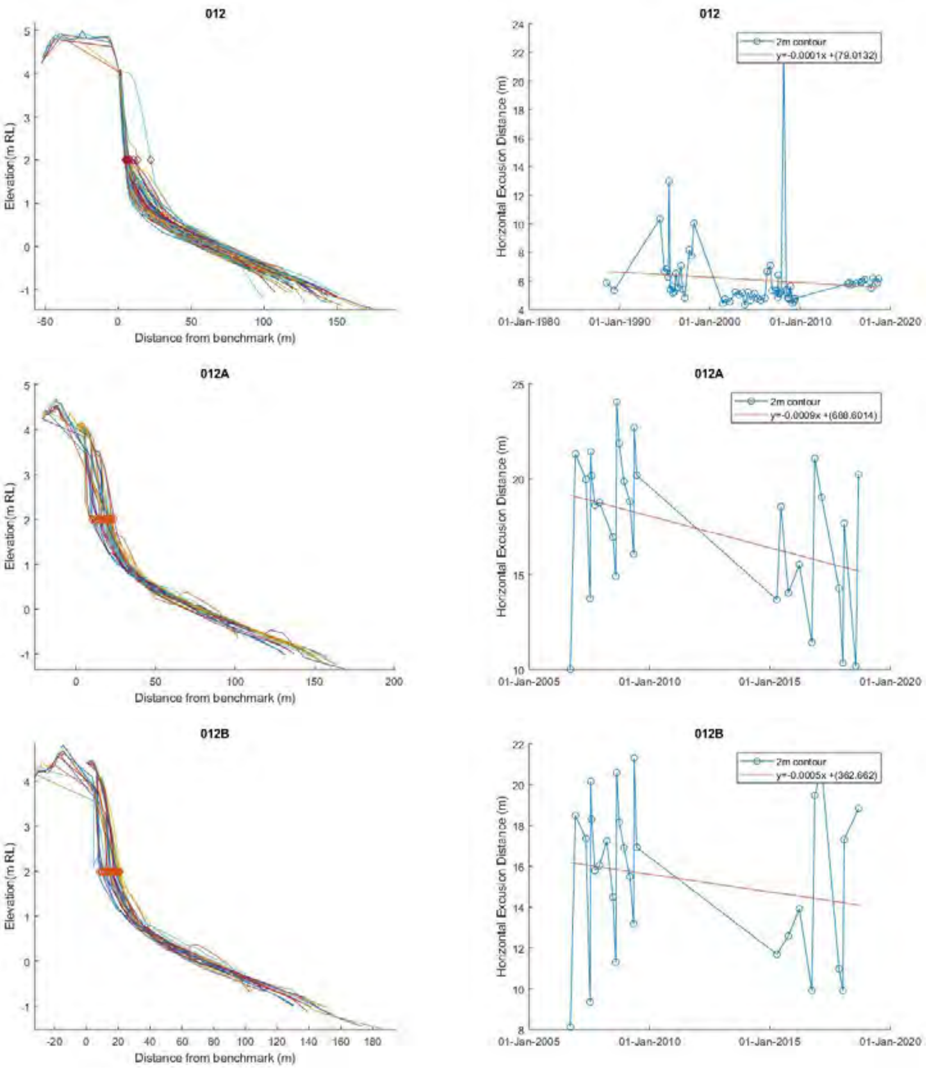

010
2m contour
y=-0.0008x +(569.596)
Horizontal Excursion Distance (m)
01-Jan-1980
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020

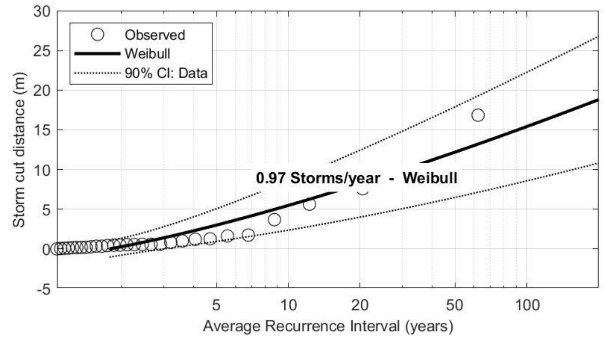

Observed
Weibull
90% CI: Data
0.77 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)


011
Elevation (m RL)
Distance from benchmark (m)


011
2m contour
y=-0.0003x +(257.2202)
Horizontal Excursion Distance (m)
01-Jan-1980
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
0.9 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)


012
Elevation (m RL)
Distance from benchmark (m)
012
Horizontal Excusion Distance (m)
2m contour
y=-0.0001x +(79.0132)
012A
Elevation (m RL)
Distance from benchmark (m)
012A
Horizontal Excusion Distance (m)
2m contour
y=-0.0009x +(688.6014)
012B
Elevation (m RL)
Distance from benchmark (m)
012B
Horizontal Excusion Distance (m)
2m contour
y=-0.0005x +(362.662)


Observed
Weibull
90% CI: Data
0.97 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

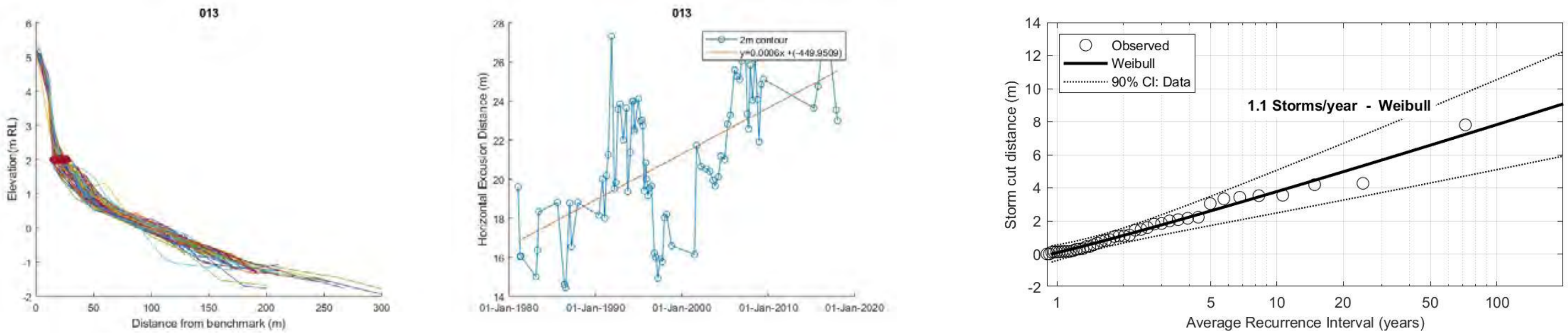


Figure Appendix C.8: Beach profiles at Orewa Beach (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Red Beach

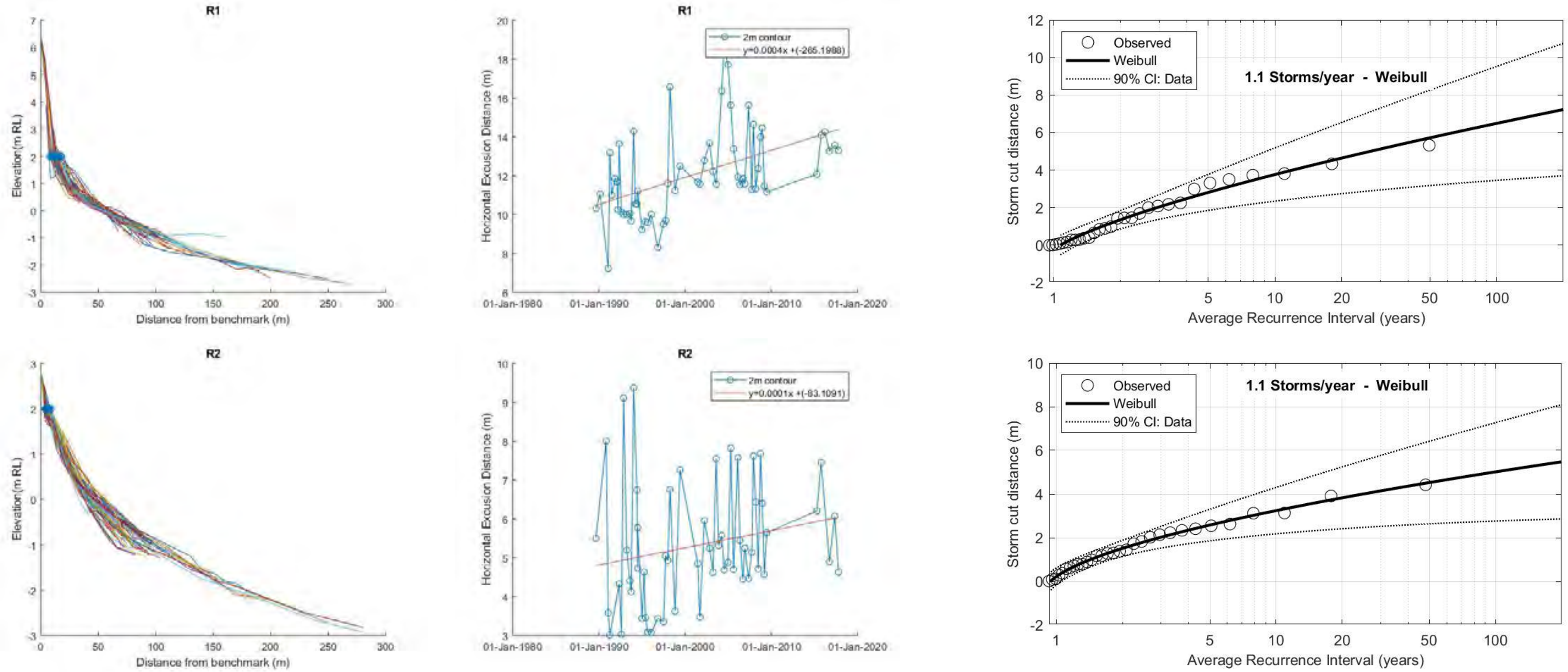
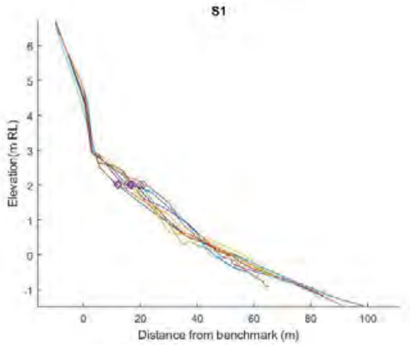
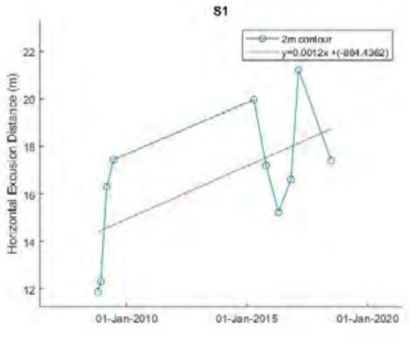
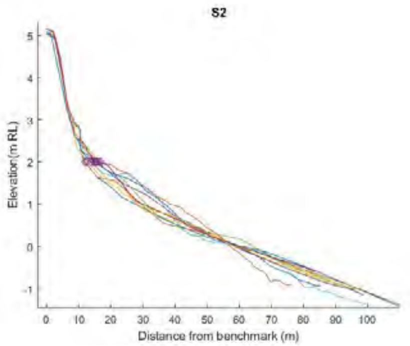


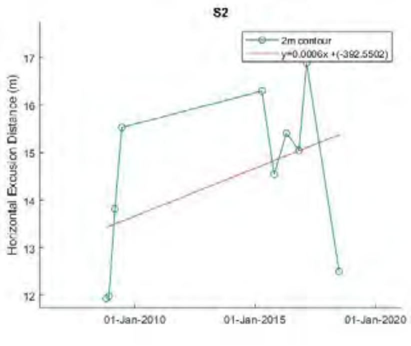
Figure Appendix C.9: Beach profiles at Red Beach (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

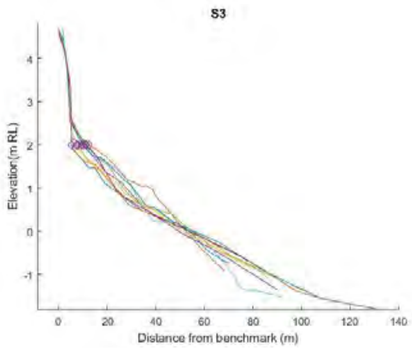
Stanmore Bay

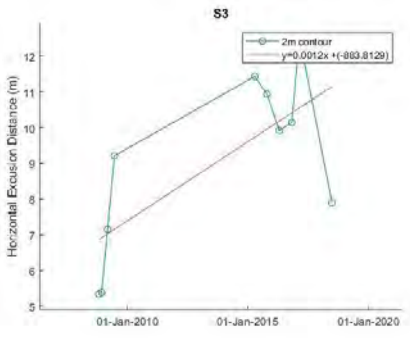


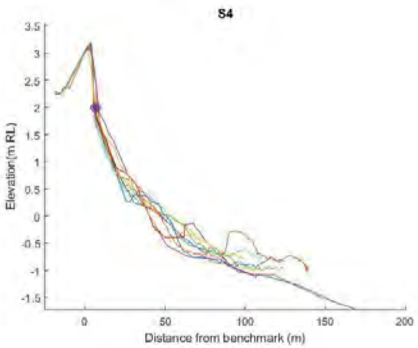












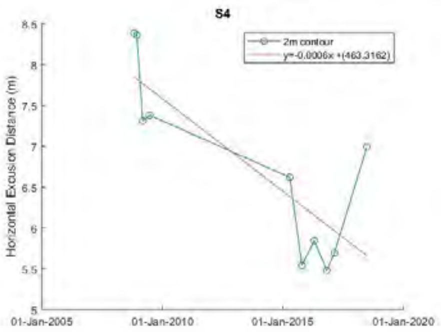
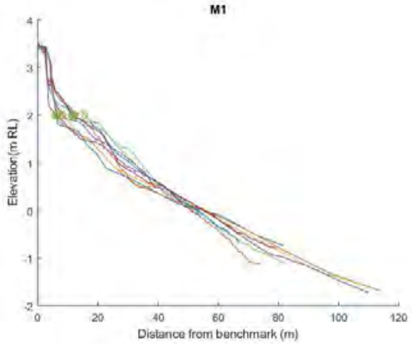
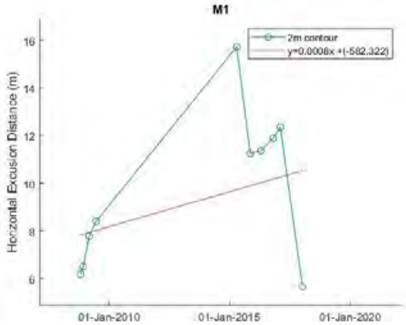
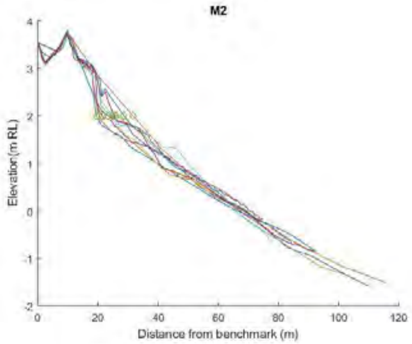


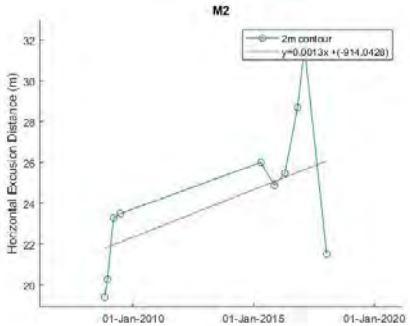
Figure Appendix C.10: Beach profiles at Stanmore Beach (left) and long-term regression (right)

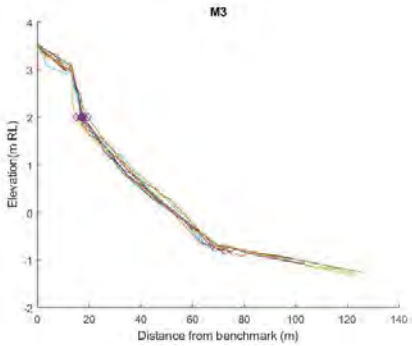
Manly

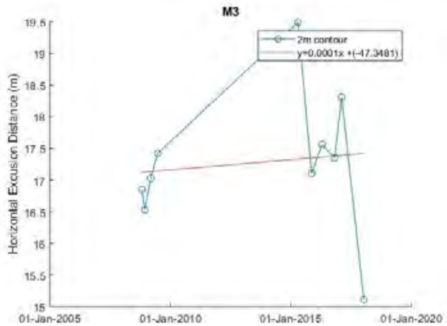

M1
Elevation (m RL)
Distance from benchmark (m)


M1
Horizontal Excusion Distance (m)
2m contour
y=0.0008x +(-582.322)
01-Jan-2010
01-Jan-2015
01-Jan-2020


M2
Elevation (m RL)
Distance from benchmark (m)


M2
Horizontal Excusion Distance (m)
2m contour
y=0.0013x +(-914.0428)
01-Jan-2010
01-Jan-2015
01-Jan-2020


M3
Elevation (m RL)
Distance from benchmark (m)


M3
Horizontal Excusion Distance (m)
2m contour
y=0.0001x +(-17.3481)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020

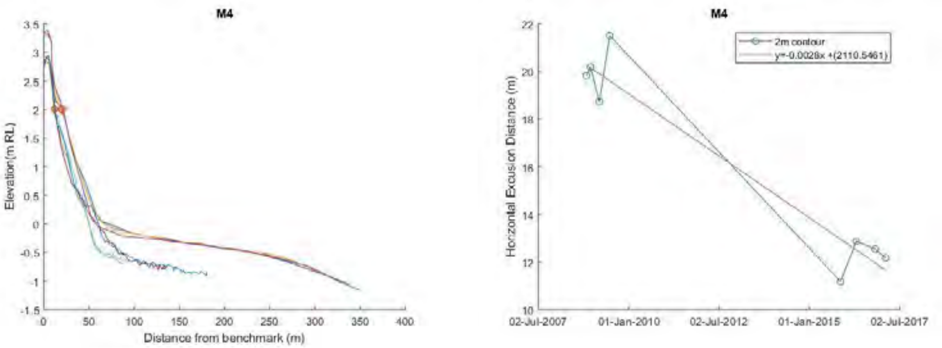


Figure Appendix C.11: Beach profiles at Manly Beach (left) and long-term regression (right)

Tindalls Bay

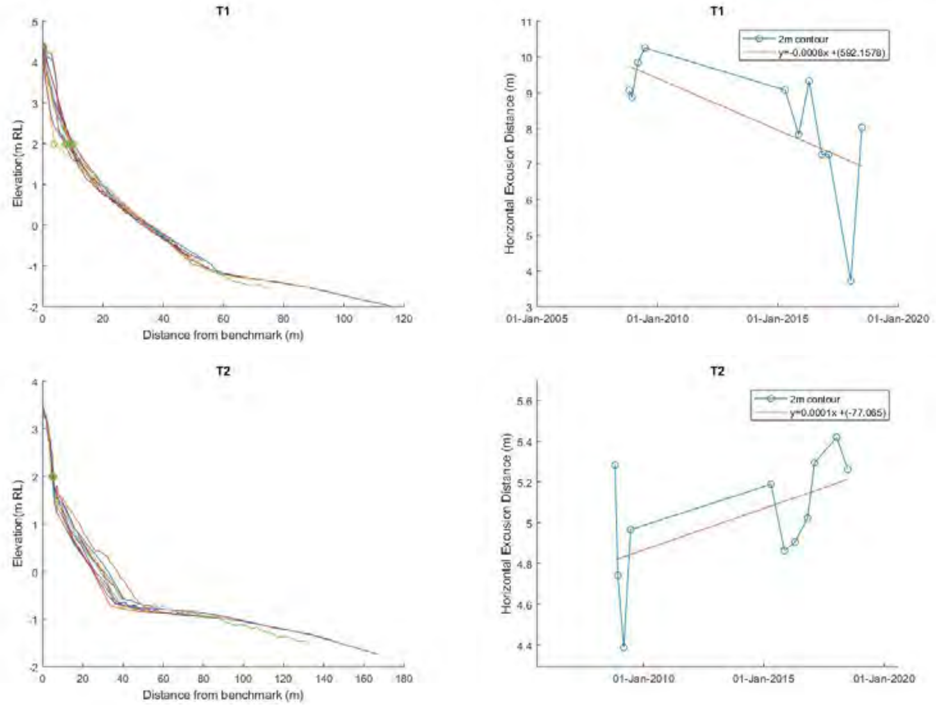


Figure Appendix C.12: Beach profiles at Tindalls Bay (left) and long-term regression (right)

Arkles Bay

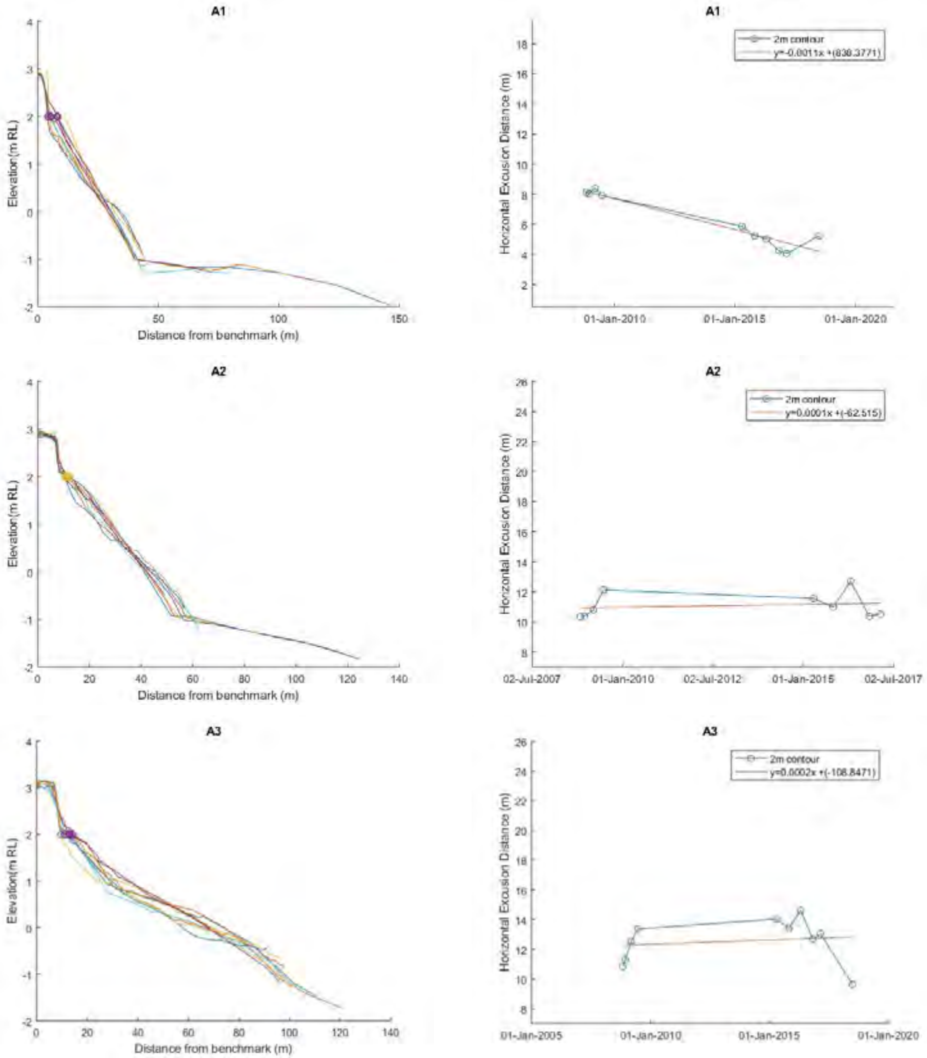
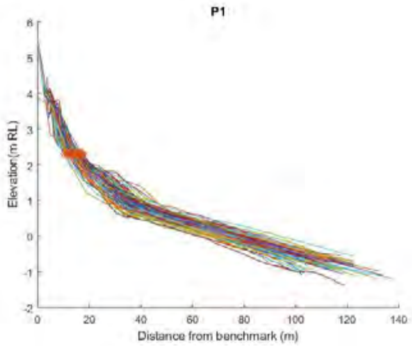
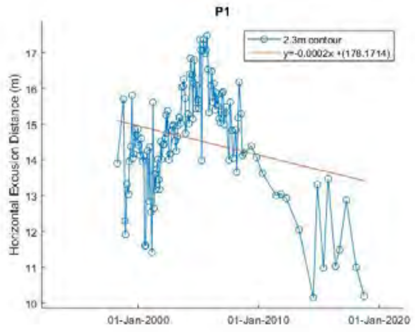
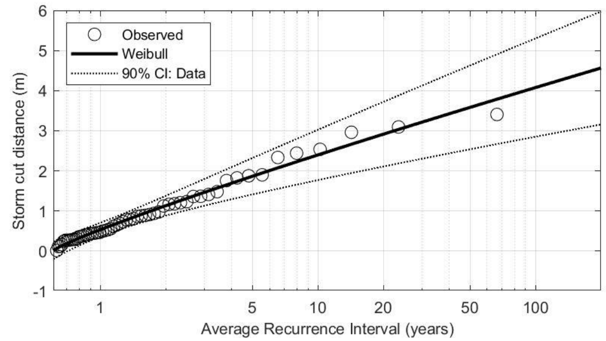


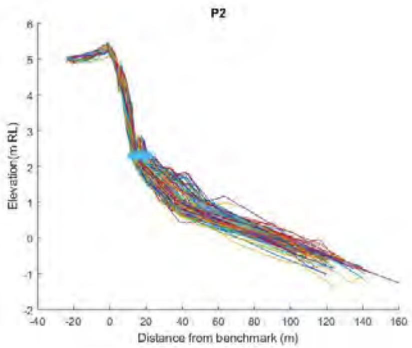
Figure Appendix C.13: Beach profiles at Arkles Bay (left) and long-term regression (right)

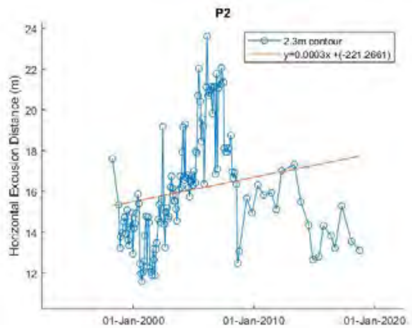
Long Bay

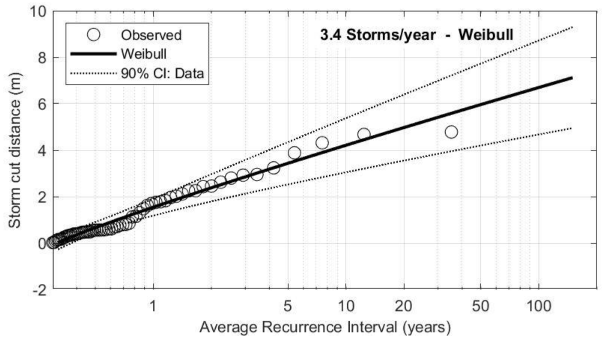

P1
Elevation (m RL)
Distance from benchmark (m)

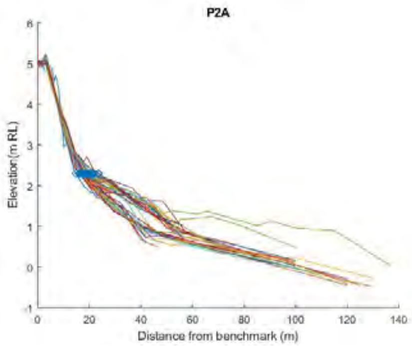

P1
2.3m contour
y=-0.0002x +(178.1714)
Horizontal Excursion Distance (m)
01-Jan-2000
01-Jan-2010
01-Jan-2020

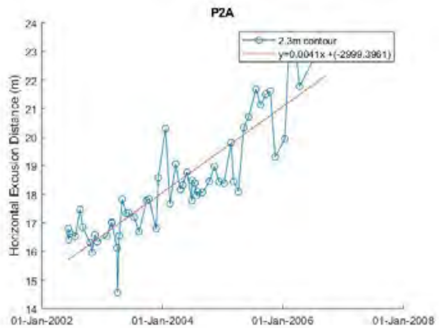

Observed
Weibull
90% CI: Data
Storm cut distance (m)
Average Recurrence Interval (years)

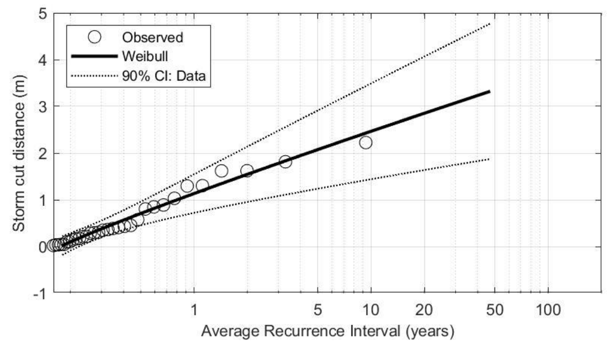

P2
Elevation (m RL)
Distance from benchmark (m)


P2
2.3m contour
y=0.0003x +(-221.2661)
Horizontal Excursion Distance (m)
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
3.4 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)


P2A
Elevation (m RL)
Distance from benchmark (m)


P2A
2.3m contour
y=0.0041x +(-2999.3961)
Horizontal Excursion Distance (m)
01-Jan-2002
01-Jan-2004
01-Jan-2006
01-Jan-2008


Observed
Weibull
90% CI: Data
Storm cut distance (m)
Average Recurrence Interval (years)

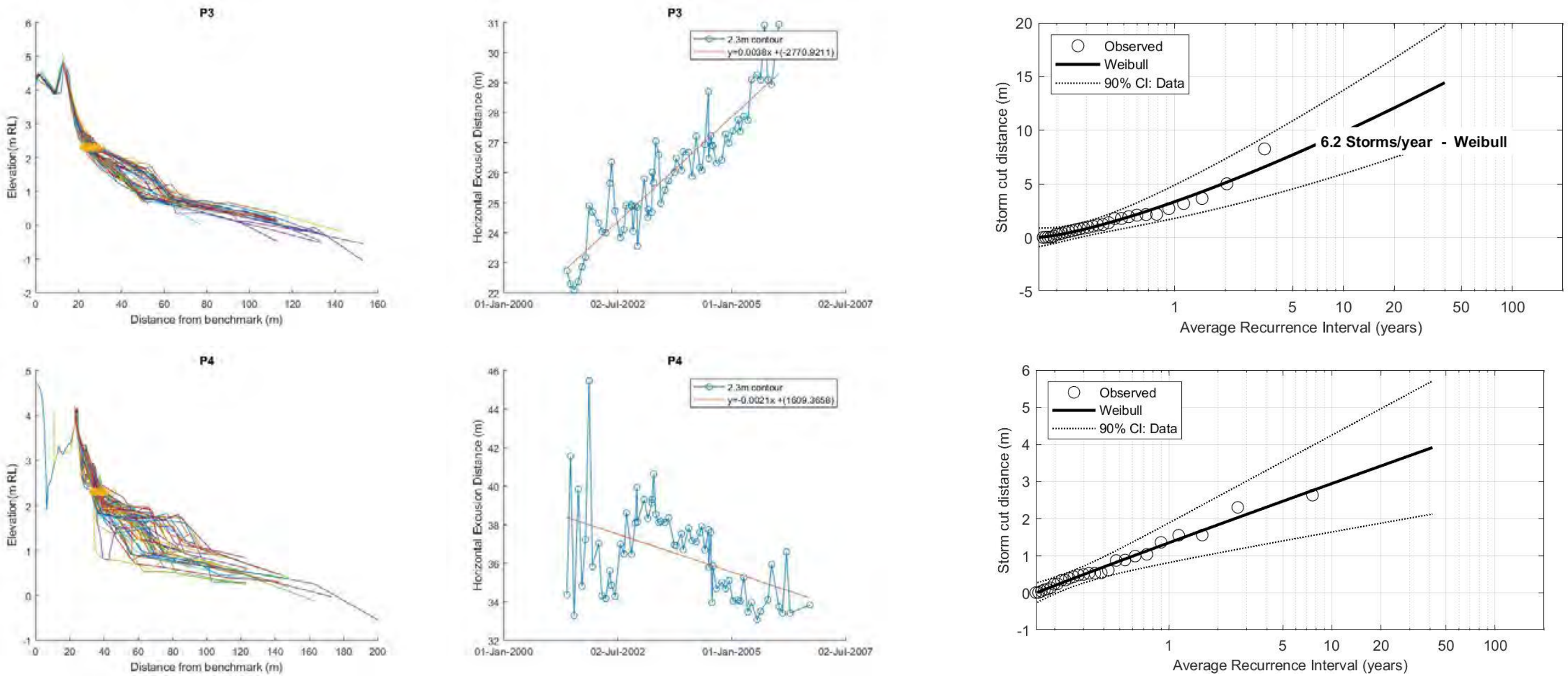


Figure Appendix C.14: Beach profiles at Long Bay (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Browns Bay

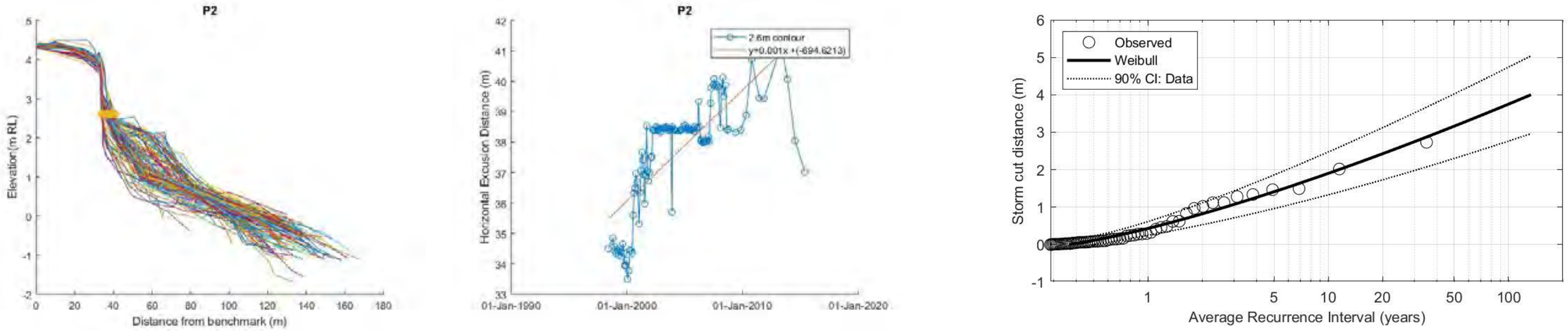


Figure Appendix C.15: Beach profiles at Browns Bay (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Campbells Bay

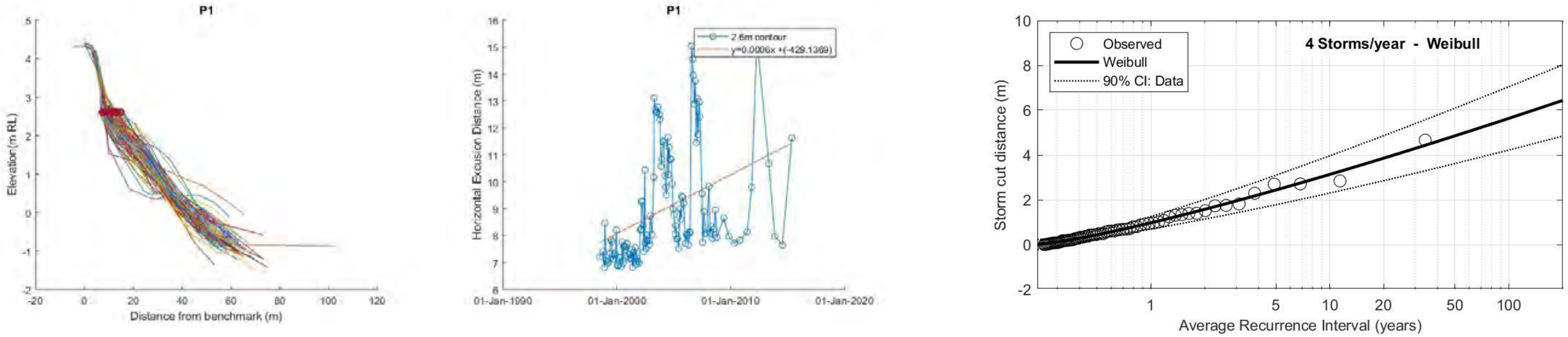
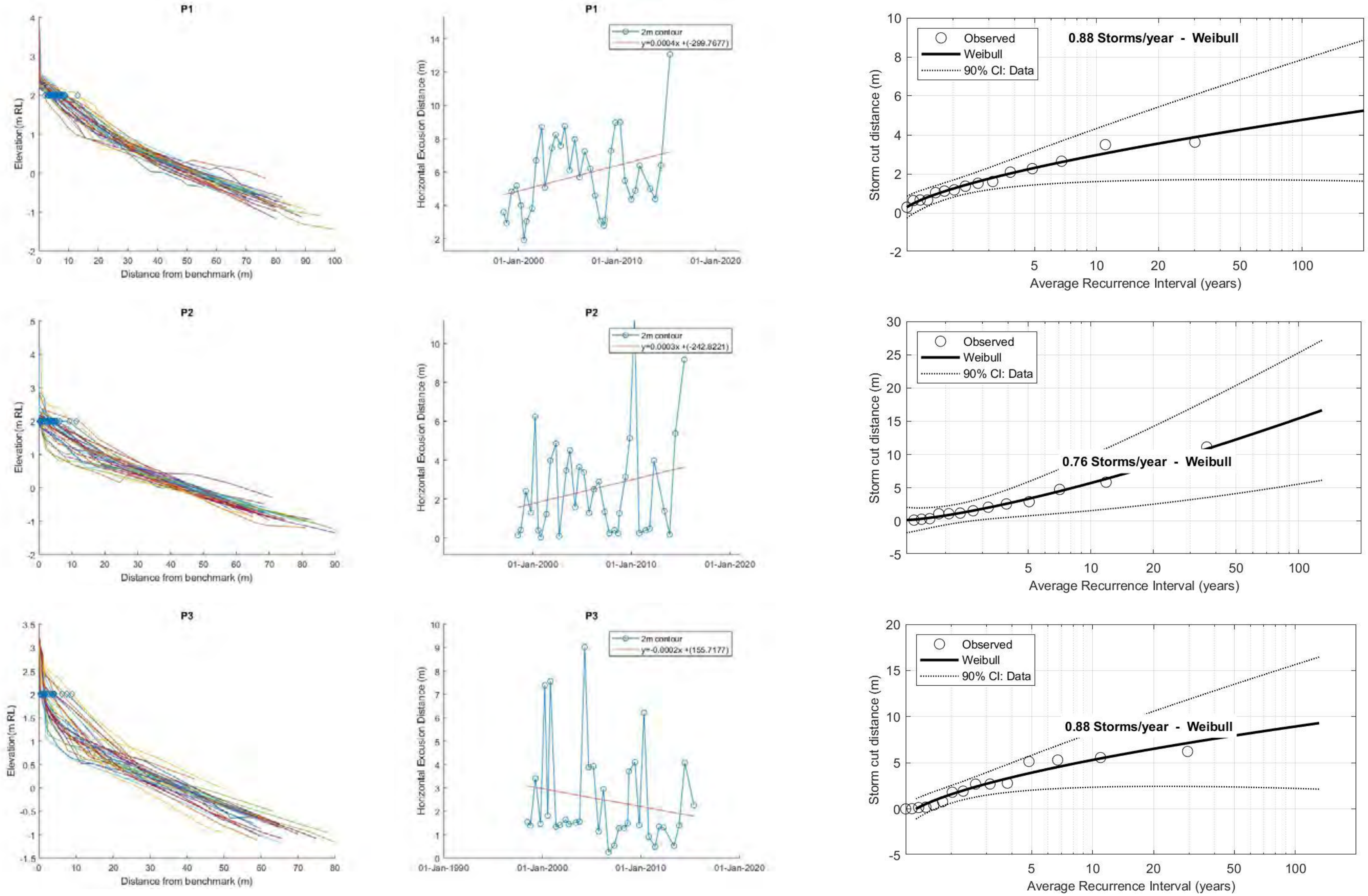


Figure Appendix C.16: Beach profiles at Browns Bay (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Milford



P1
Elevation (m RL)
Distance from benchmark (m)
Horizontal Excusion Distance (m)
2m contour
y=0.0004x +(-299.7677)
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
0.88 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
P2
y=0.0003x +(-242.8221)
0.76 Storms/year - Weibull
P3
y=-0.0002x +(155.7177)
01-Jan-1990
0.88 Storms/year - Weibull

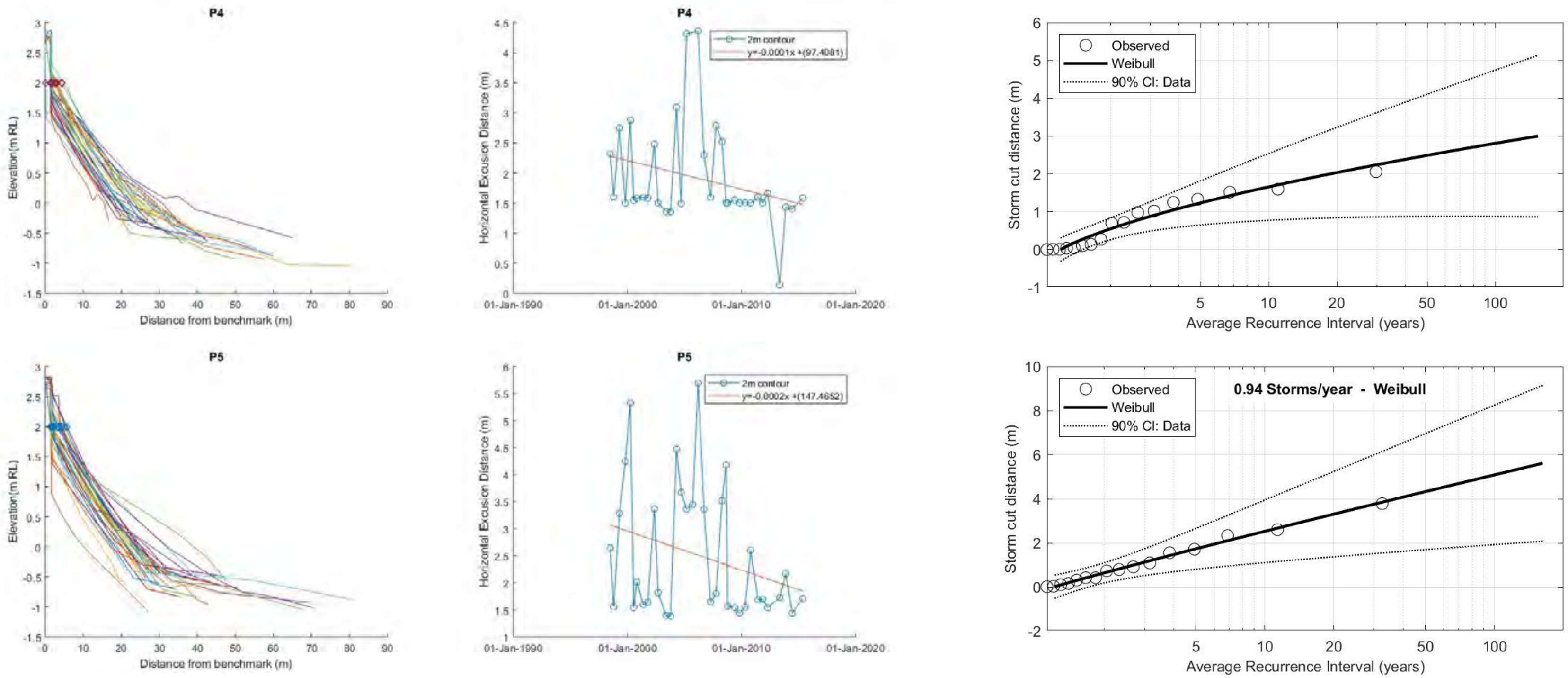


Figure Appendix C.17: Beach profiles at Milford (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Takapuna

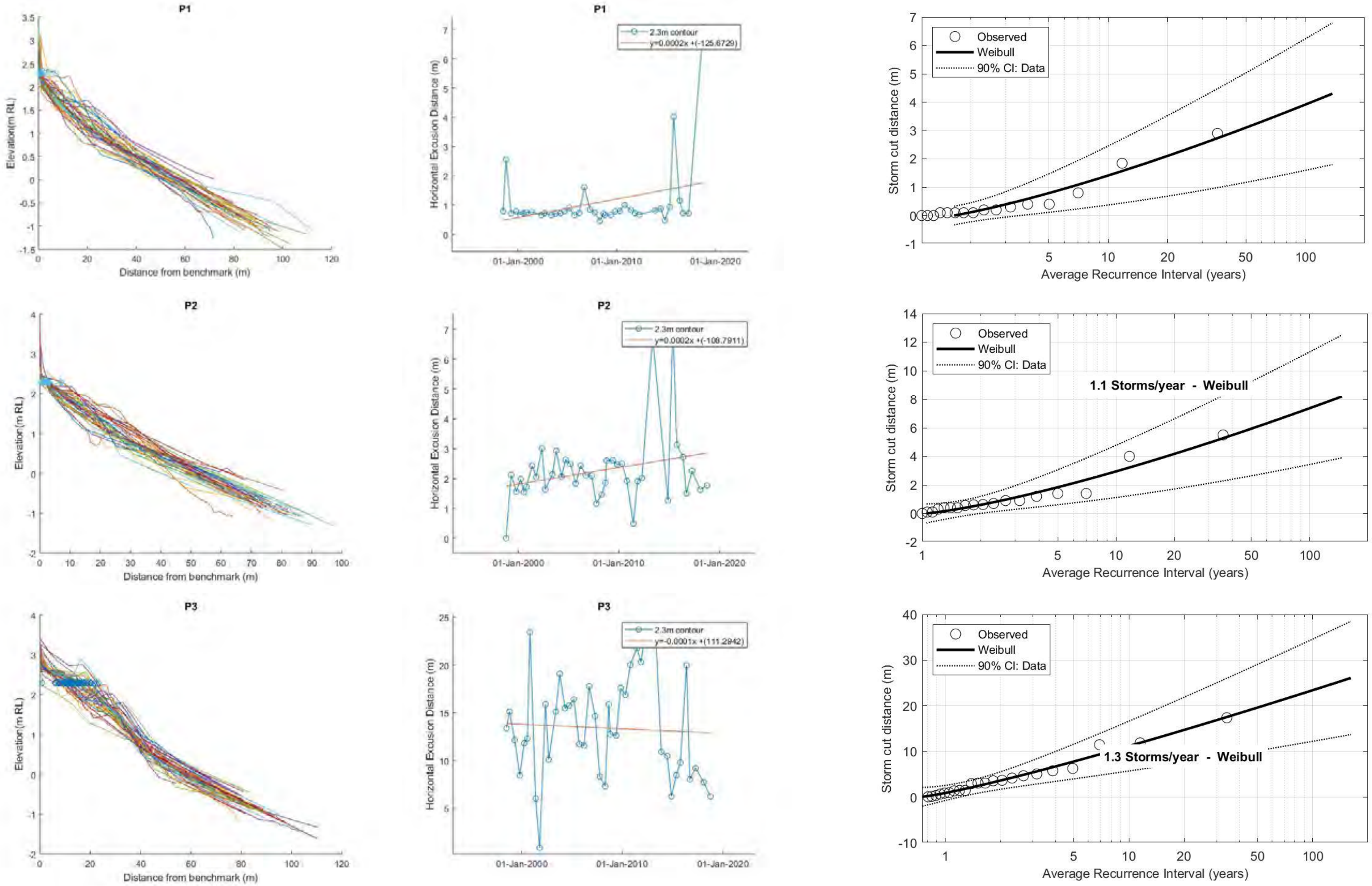


Figure Appendix C.18: Beach profiles at Takapuna (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Cheltenham

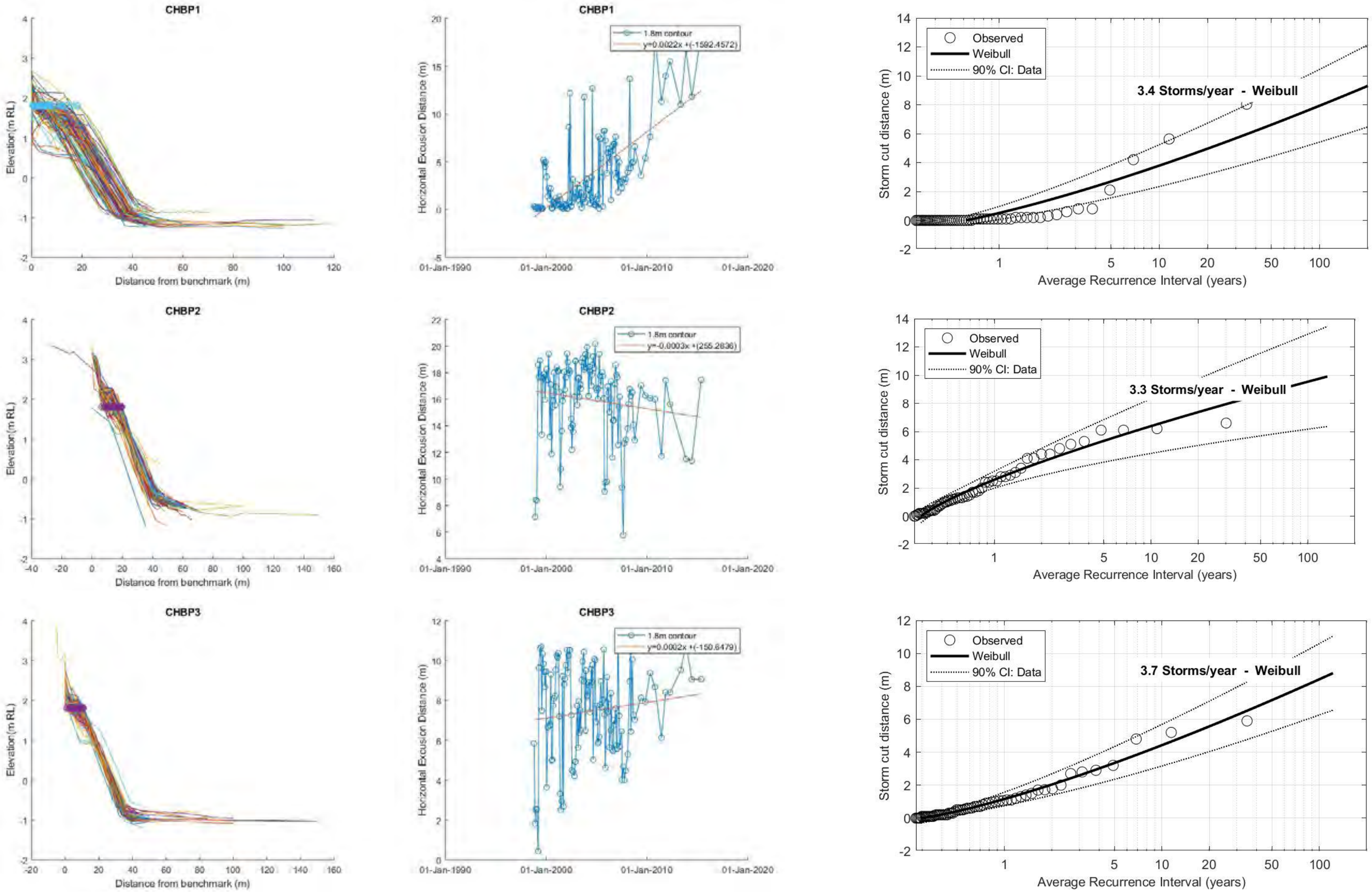
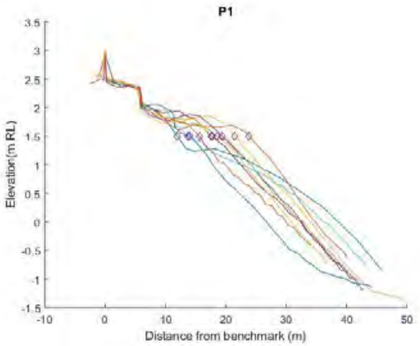
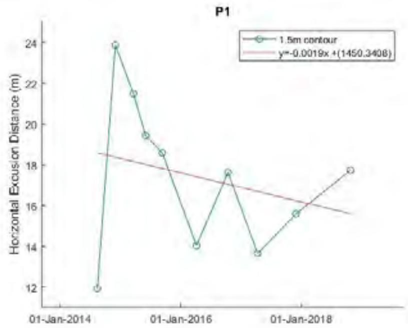
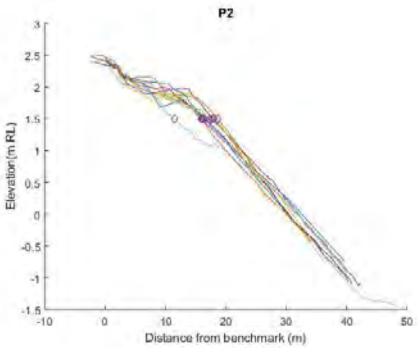


Figure Appendix C.19: Beach profiles at Cheltenham (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

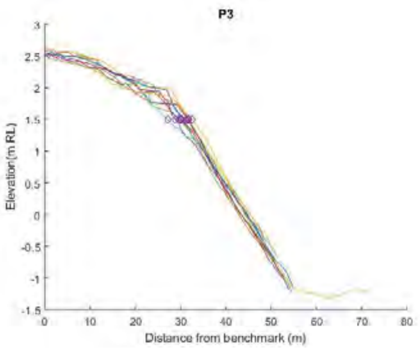
Mission Bay

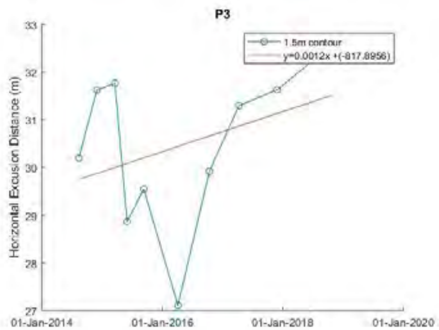

P1
Elevation (m RL)
Distance from benchmark (m)


P1
1.5m contour
y=-0.0019x +(1450.3408)
Horizontal Excusion Distance (m)
01-Jan-2014
01-Jan-2016
01-Jan-2018


P2
Elevation (m RL)
Distance from benchmark (m)


P2
1.5m contour
y=-0.001x +(734.7268)
Horizontal Excusion Distance (m)
01-Jan-2014
01-Jan-2016
01-Jan-2018
01-Jan-2020


P3
Elevation (m RL)
Distance from benchmark (m)


P3
1.5m contour
y=0.0012x +(-817.8956)
Horizontal Excusion Distance (m)
01-Jan-2014
01-Jan-2016
01-Jan-2018
01-Jan-2020

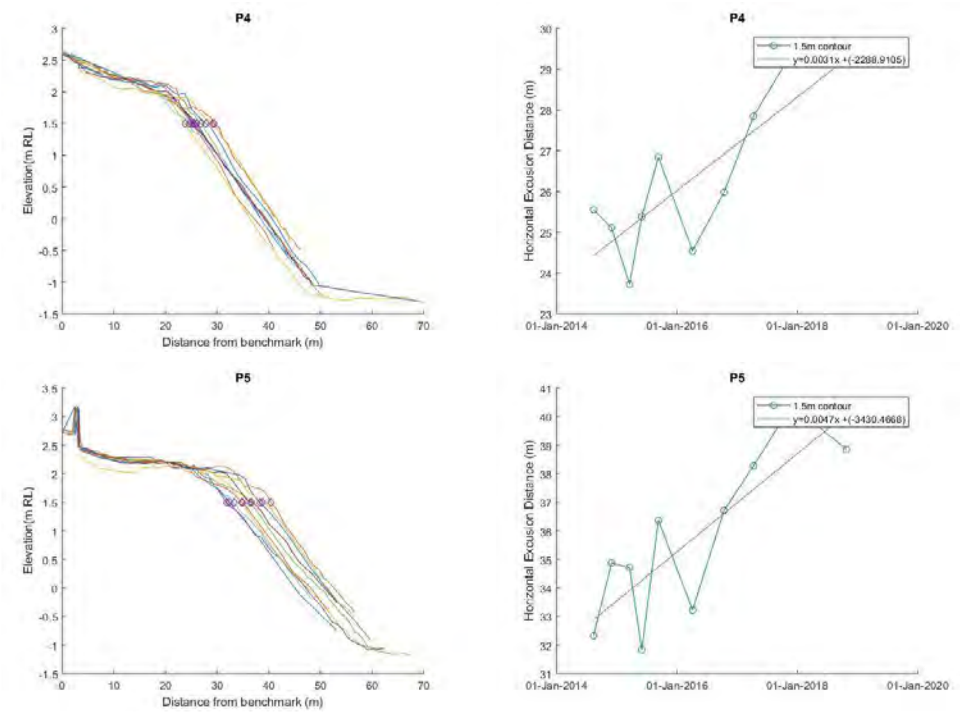
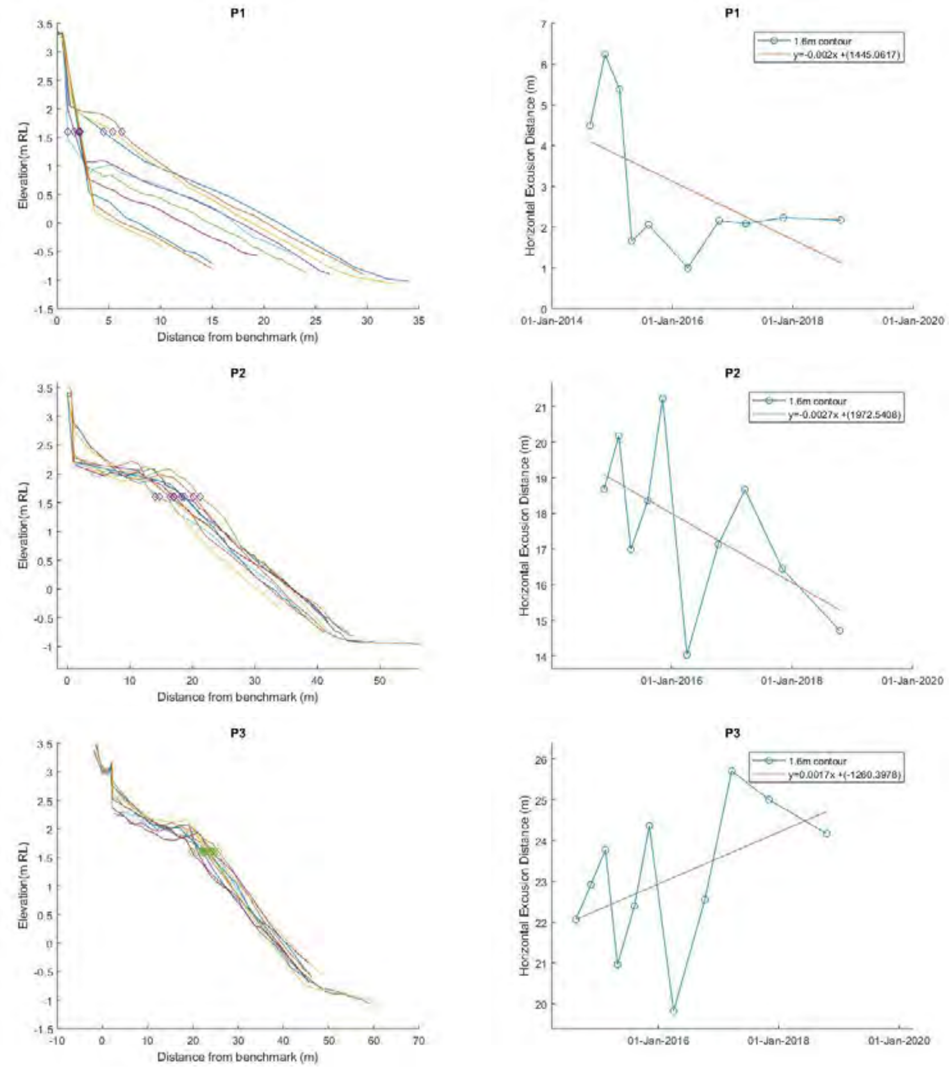


Figure Appendix C.20: Beach profiles at Mission Bay (left) and long-term regression (right)

Kohimarama



P1
Elevation (m RL)
Distance from benchmark (m)
P1
1.6m contour
y=-0.002x +(1445.0617)
Horizontal Excursion Distance (m)
01-Jan-2014
01-Jan-2016
01-Jan-2018
01-Jan-2020
P2
Elevation (m RL)
Distance from benchmark (m)
P2
1.6m contour
y=-0.0027x +(1972.5408)
Horizontal Excursion Distance (m)
01-Jan-2016
01-Jan-2018
01-Jan-2020
P3
Elevation (m RL)
Distance from benchmark (m)
P3
1.6m contour
y=0.0017x +(-1260.3978)
Horizontal Excursion Distance (m)
01-Jan-2016
01-Jan-2018
01-Jan-2020

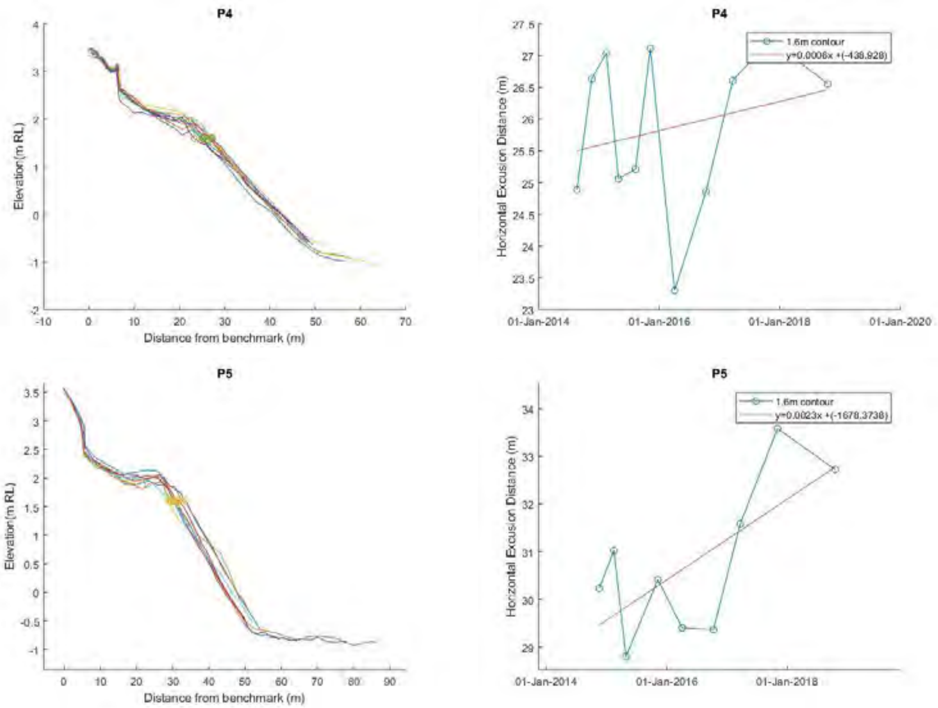
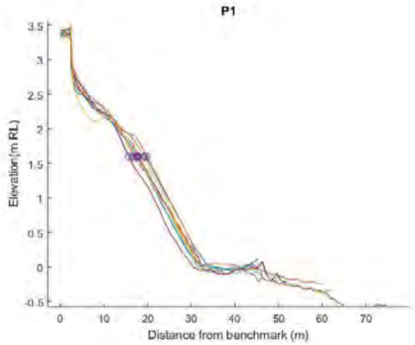
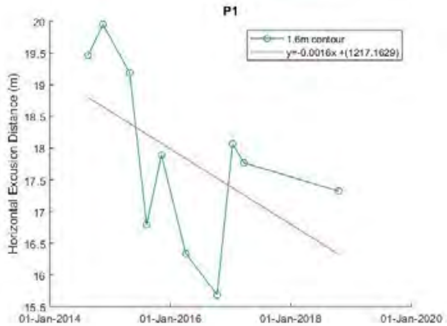
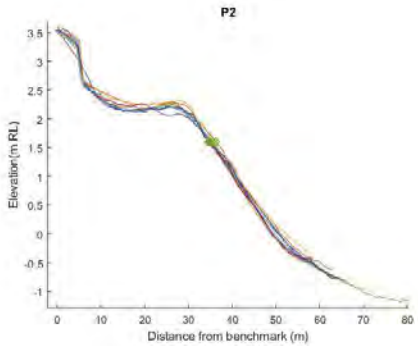


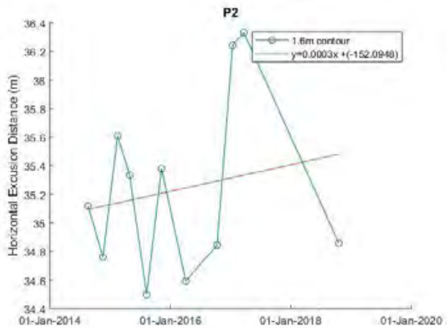
Figure Appendix C.21: Beach profiles at Kohimarama (left) and long-term regression (right)

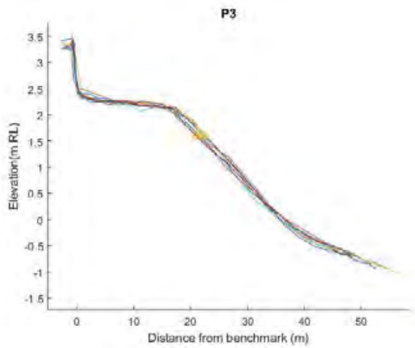
St Heliers

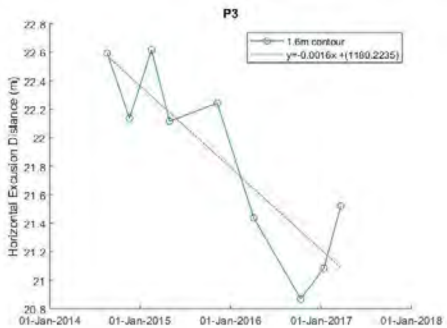

P1
Elevation (m RL)
Distance from benchmark (m)


P1
1.6m contour
y=-0.0016x +(1217.1629)
Horizontal Excusion Distance (m)
01-Jan-2014
01-Jan-2016
01-Jan-2018
01-Jan-2020


P2
Elevation (m RL)
Distance from benchmark (m)


P2
1.6m contour
y=0.0003x +(-152.0948)
Horizontal Excusion Distance (m)
01-Jan-2014
01-Jan-2016
01-Jan-2018
01-Jan-2020


P3
Elevation (m RL)
Distance from benchmark (m)


P3
1.6m contour
y=-0.0016x +(1100.2235)
Horizontal Excusion Distance (m)
01-Jan-2014
01-Jan-2015
01-Jan-2016
01-Jan-2017
01-Jan-2018

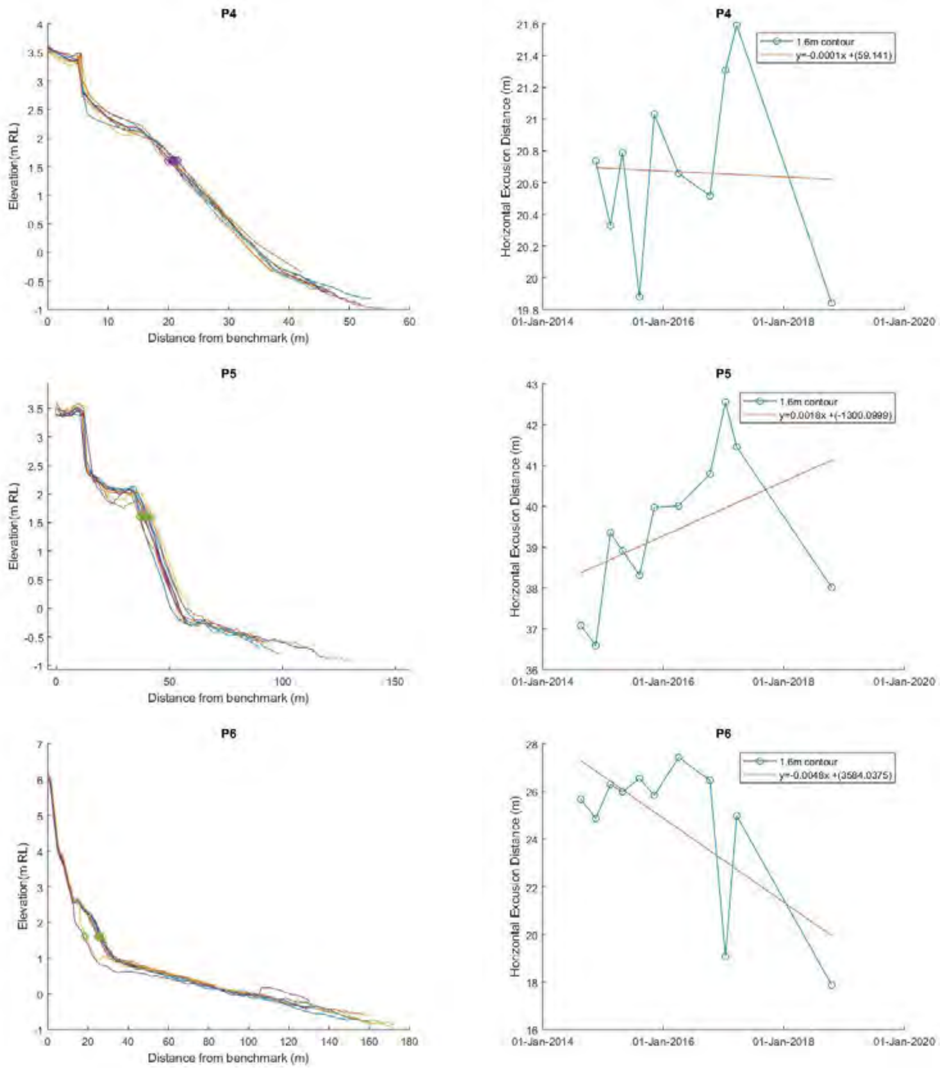
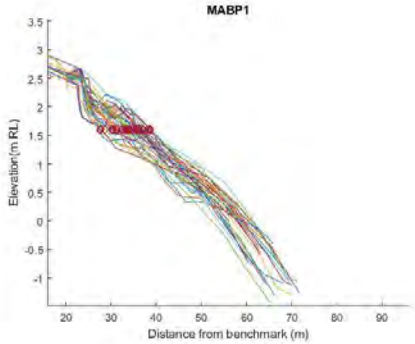
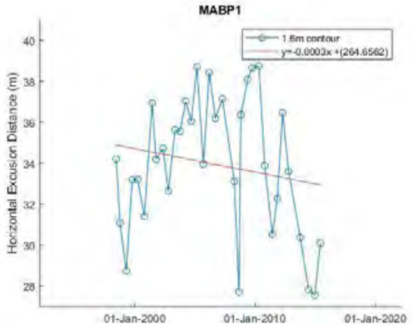
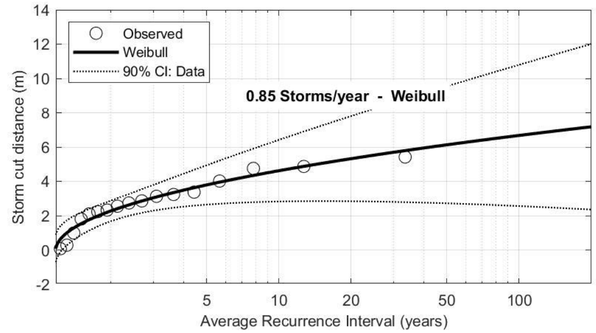


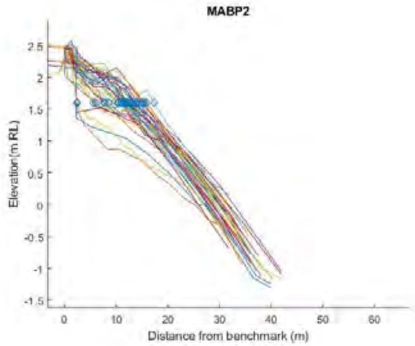
Figure Appendix C.22: Beach profiles at St Heliers (left) and long-term regression (right)

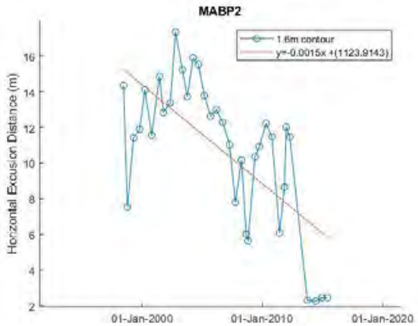
Maraetai

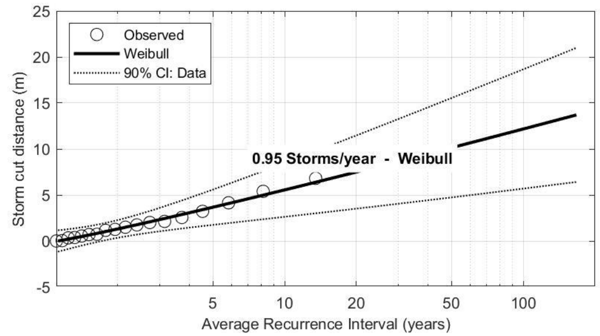

MABP1
Elevation (m RL)
Distance from benchmark (m)

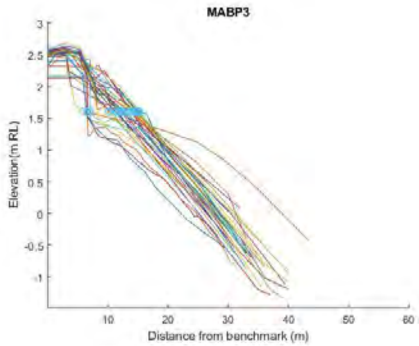

MABP1
1.6m contour
y=-0.0003x +(264.6562)
Horizontal Excusion Distance (m)
01-Jan-2000
01-Jan-2010
01-Jan-2020

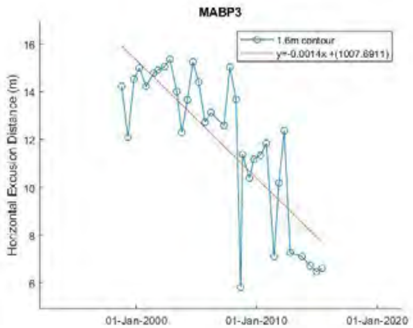

Observed
Weibull
90% CI: Data
0.85 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

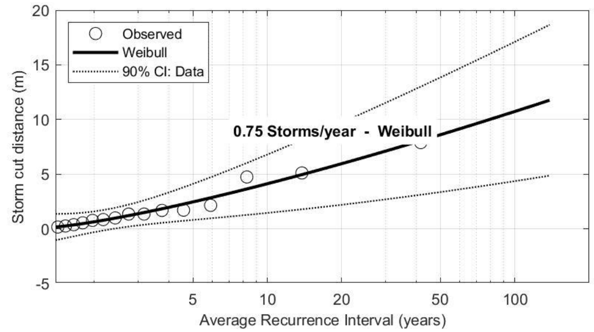

MABP2
Elevation (m RL)
Distance from benchmark (m)


MABP2
1.6m contour
y=-0.0015x +(1123.9143)
Horizontal Excusion Distance (m)
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
0.95 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)


MABP3
Elevation (m RL)
Distance from benchmark (m)


MABP3
1.6m contour
y=-0.0014x +(1007.6911)
Horizontal Excusion Distance (m)
01-Jan-2000
01-Jan-2010
01-Jan-2020


Observed
Weibull
90% CI: Data
0.75 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)

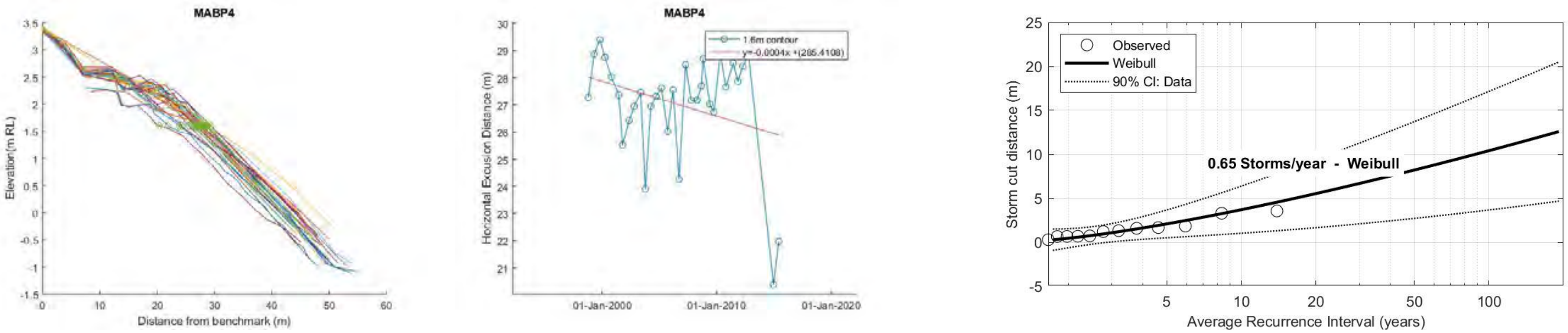
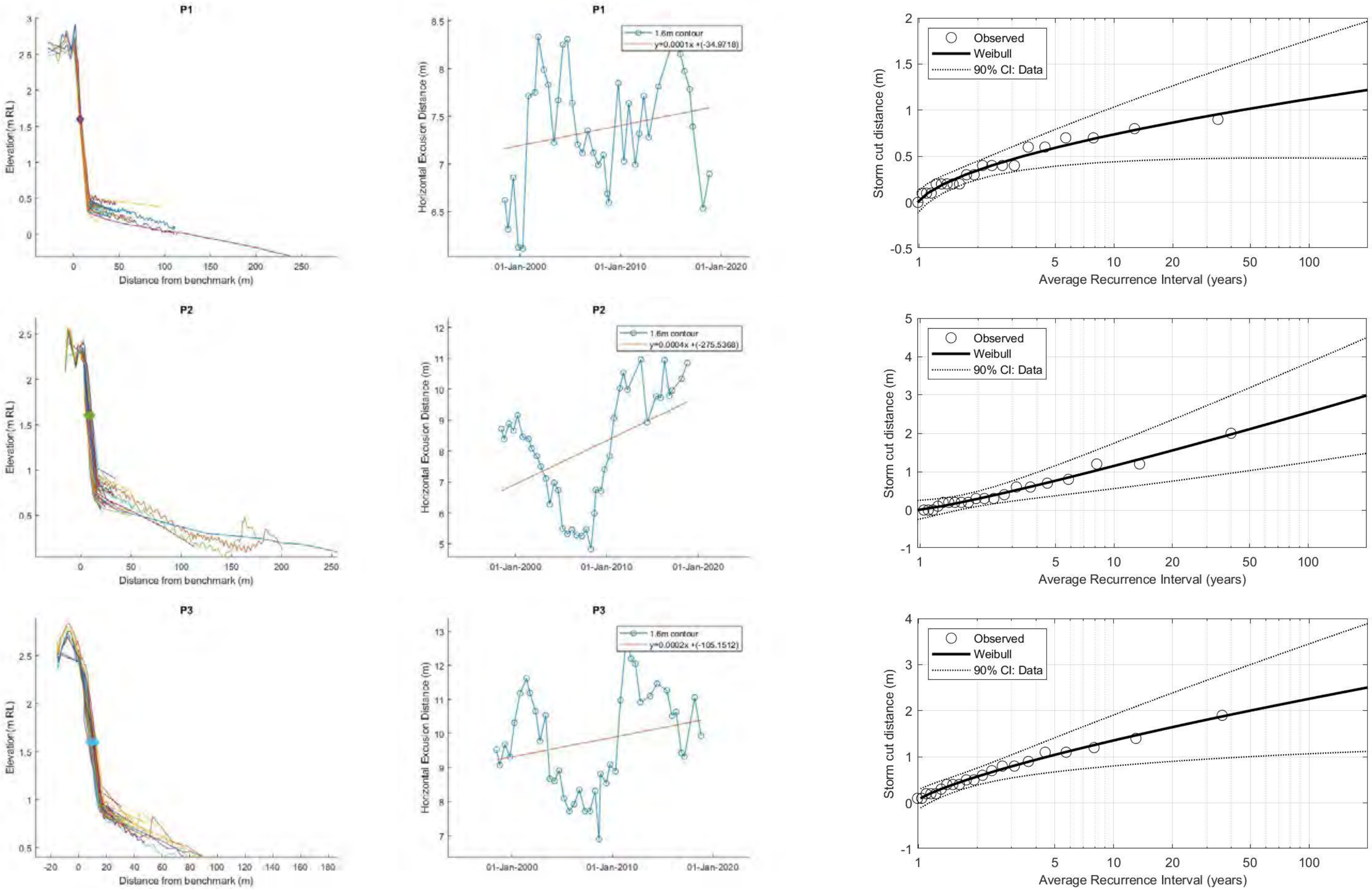


Figure Appendix C.23: Beach profiles at Maraetai (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Kawakawa Bay



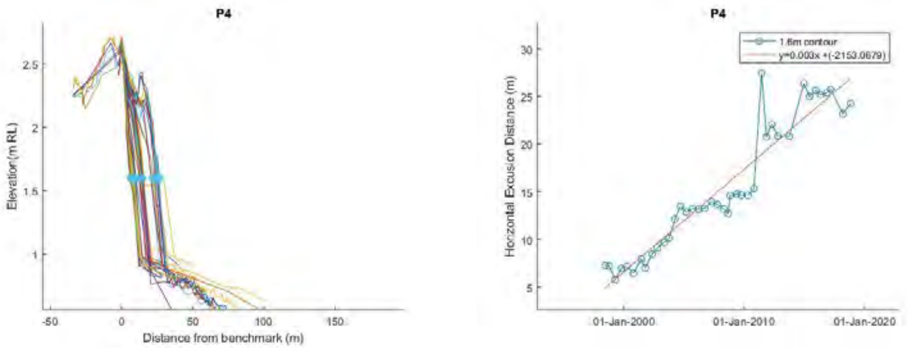


Figure Appendix C.24: Beach profiles at Kawakawa Bay (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Orere Point

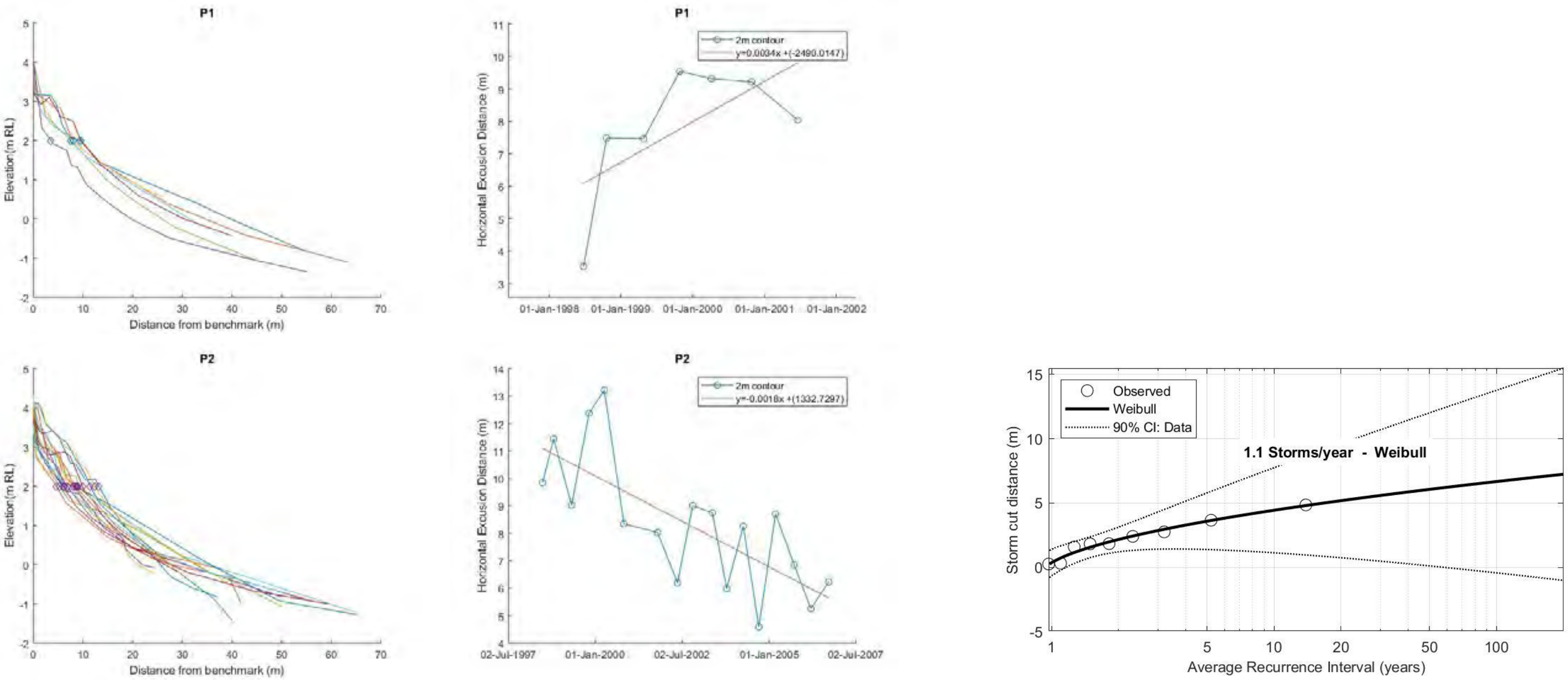


Figure Appendix C.25: Beach profiles at Orere Point (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Piha North

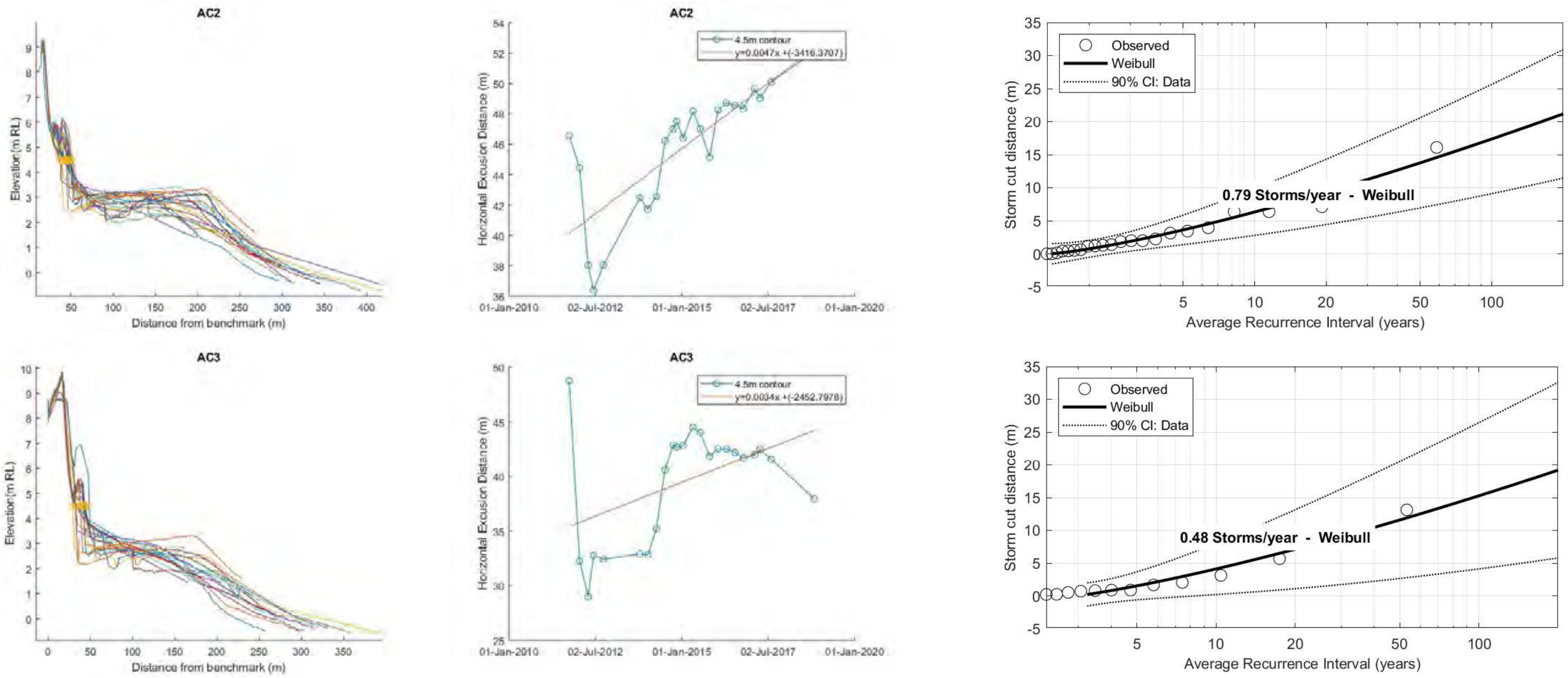
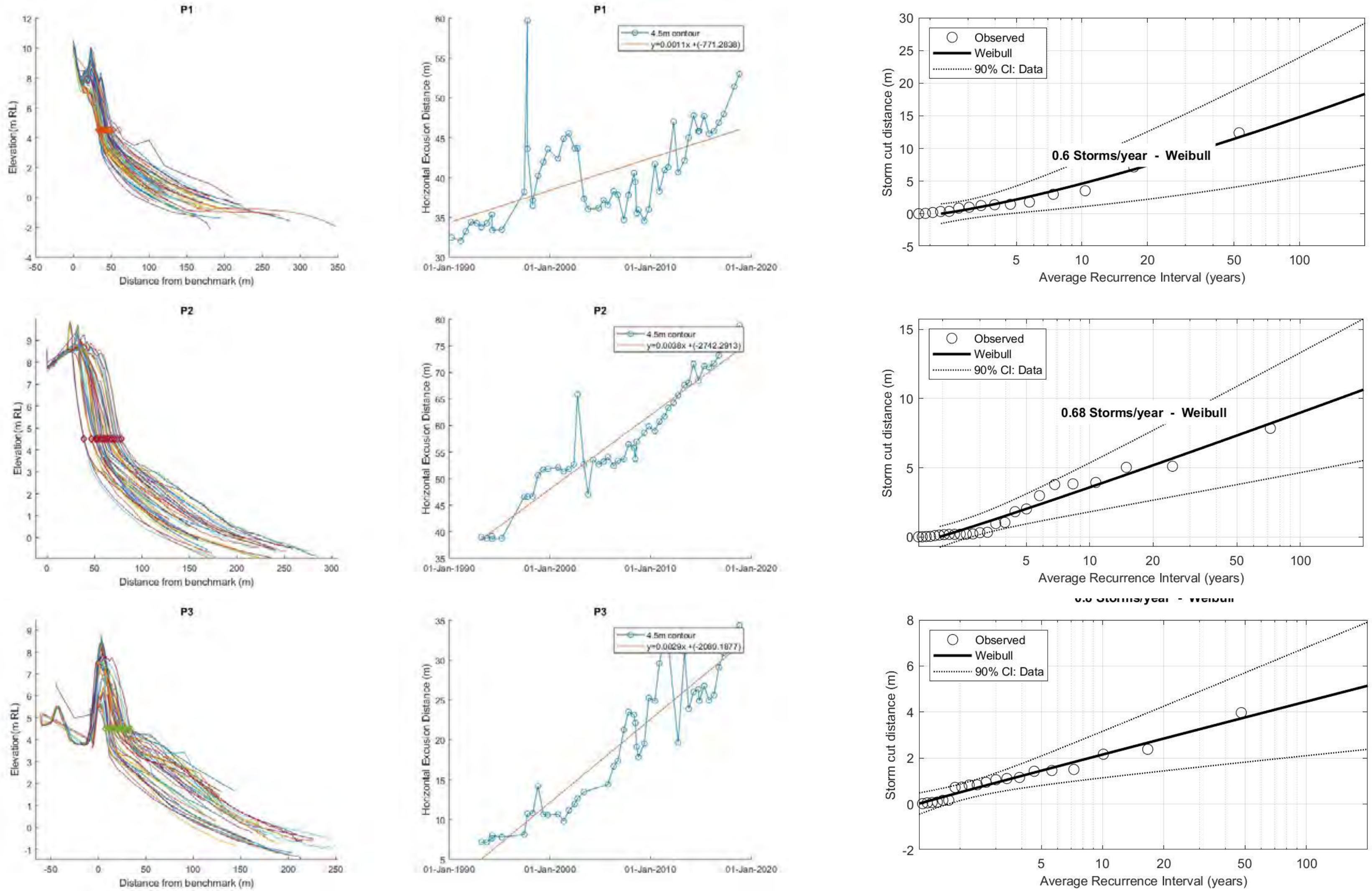


Figure Appendix C.26: Beach profiles at Piha North (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Piha South



P1
Elevation (m RL)
Distance from benchmark (m)
P1
4.5m contour
y=0.0011x +(-771.2838)
Horizontal Excursion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
0.6 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
P2
Elevation (m RL)
Distance from benchmark (m)
P2
4.5m contour
y=0.0038x +(-2742.2913)
Horizontal Excursion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
0.68 Storms/year - Weibull
Storm cut distance (m)
Average Recurrence Interval (years)
P3
Elevation (m RL)
Distance from benchmark (m)
P3
4.5m contour
y=0.0029x +(-2080.1877)
Horizontal Excursion Distance (m)
01-Jan-1990
01-Jan-2000
01-Jan-2010
01-Jan-2020
Observed
Weibull
90% CI: Data
Storm cut distance (m)
Average Recurrence Interval (years)

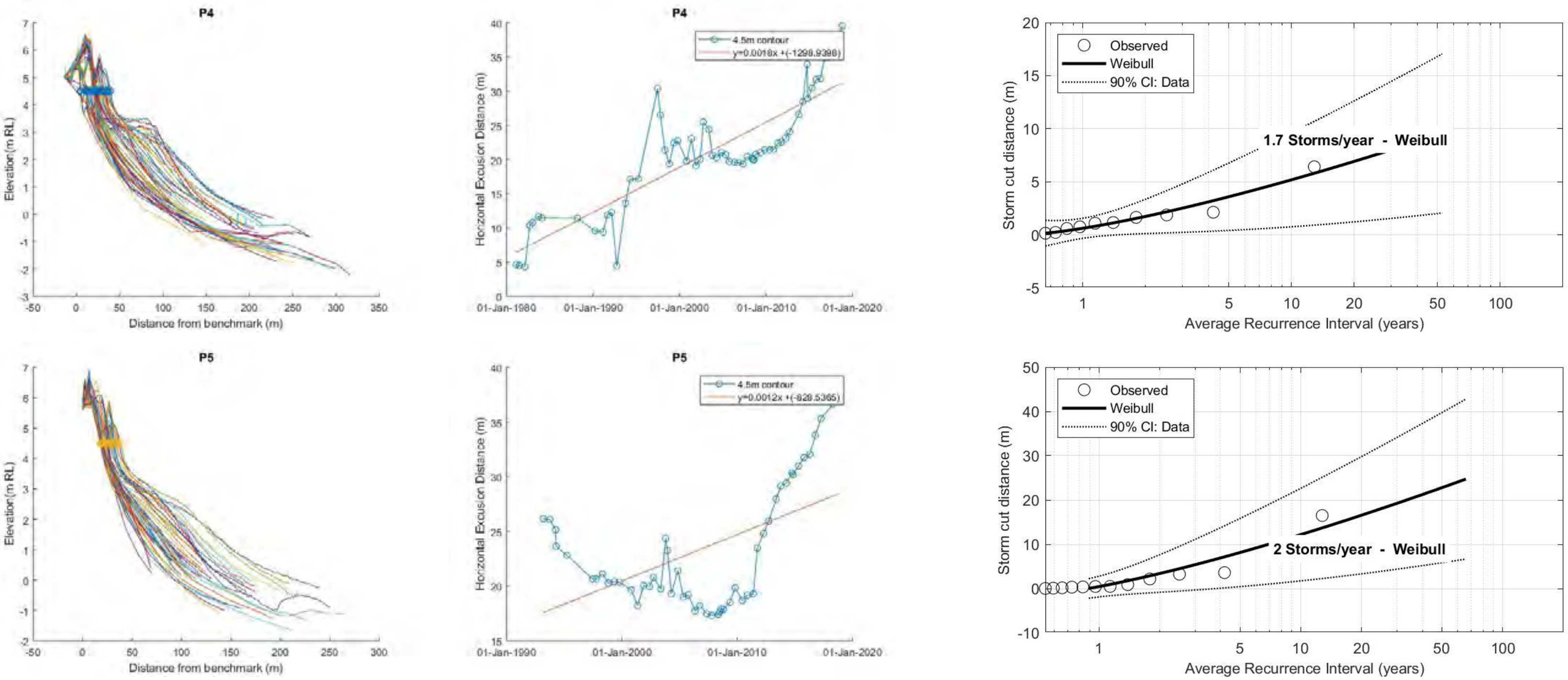


Figure Appendix C.27: Beach profiles at Piha South (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Muriwai North

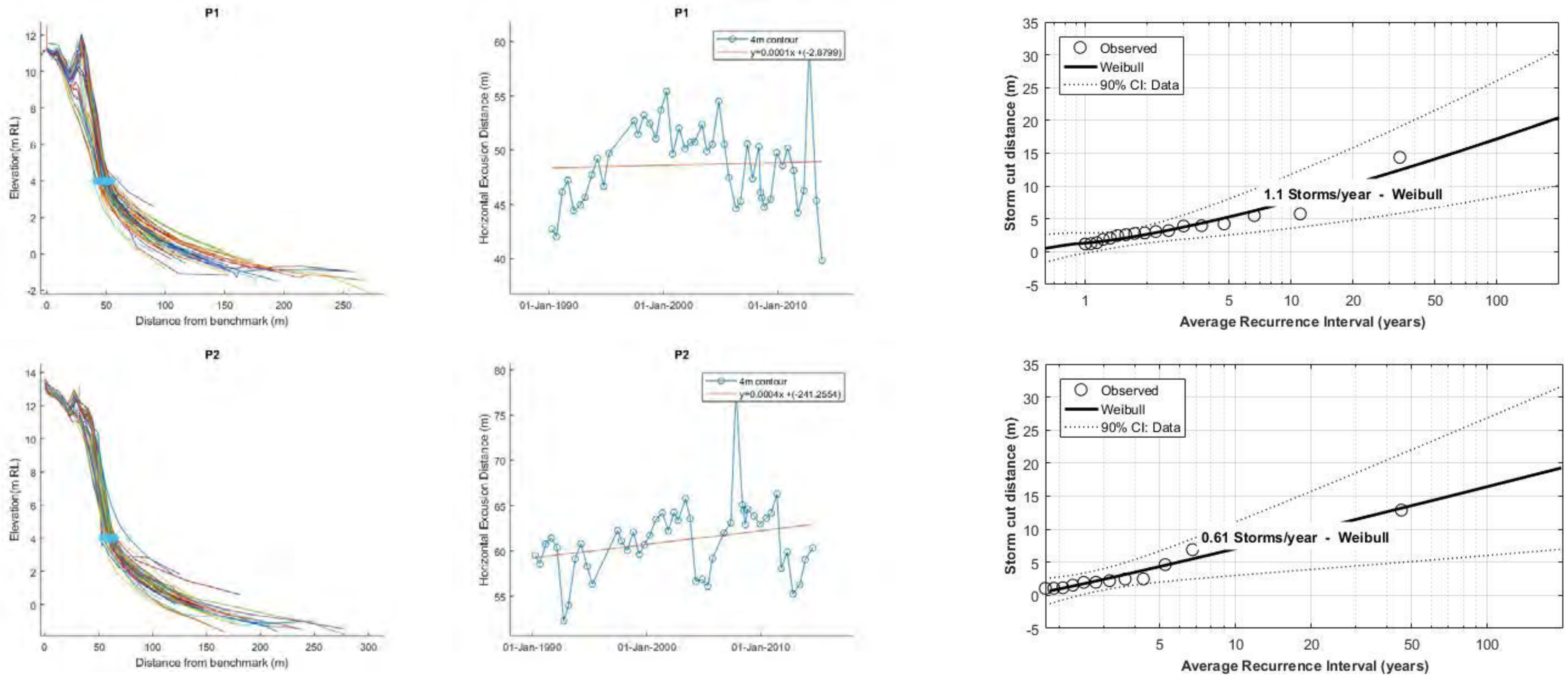
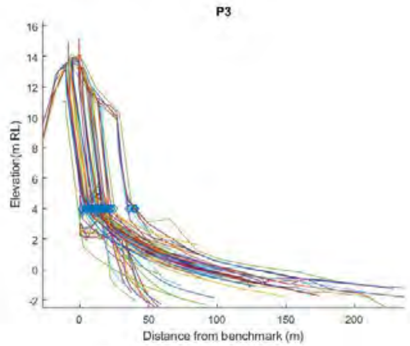
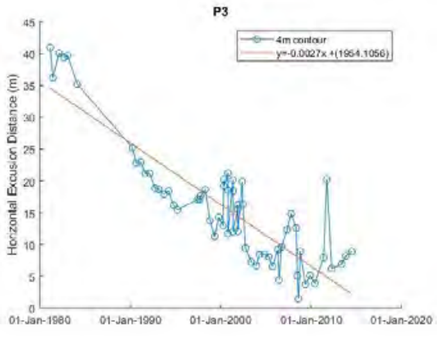
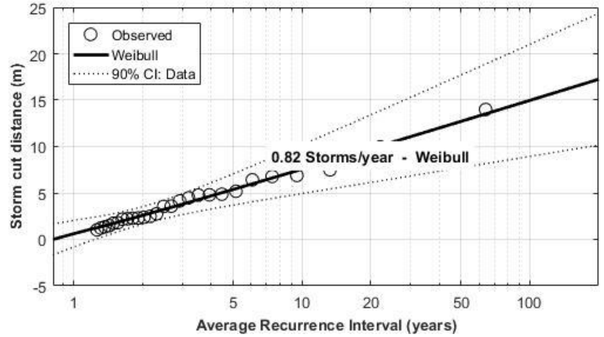


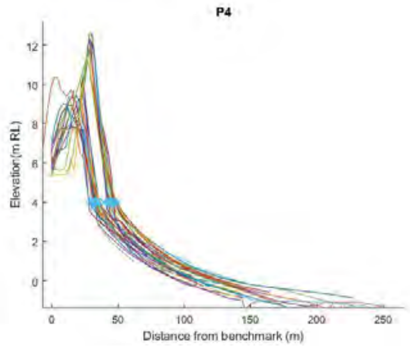
Figure Appendix C.28: Beach profiles at Muriwai North (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

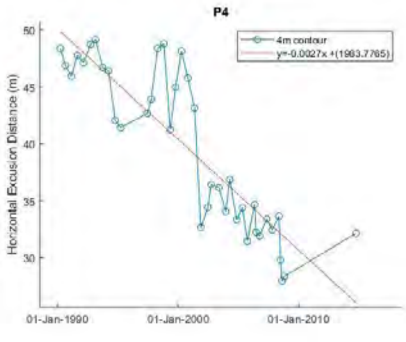
Muriwai South

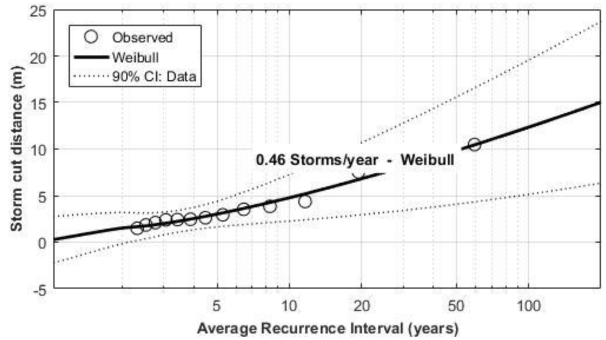


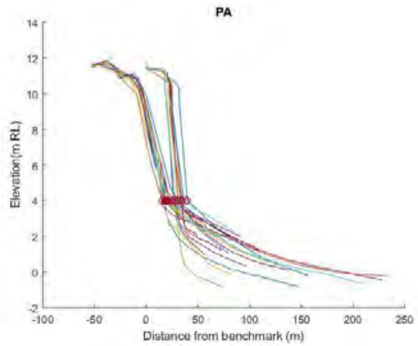


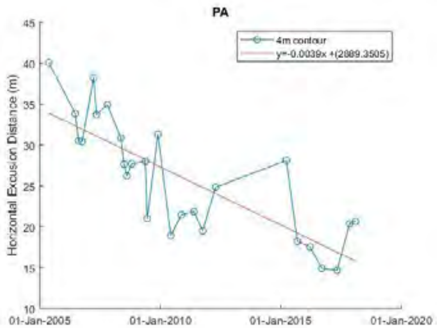


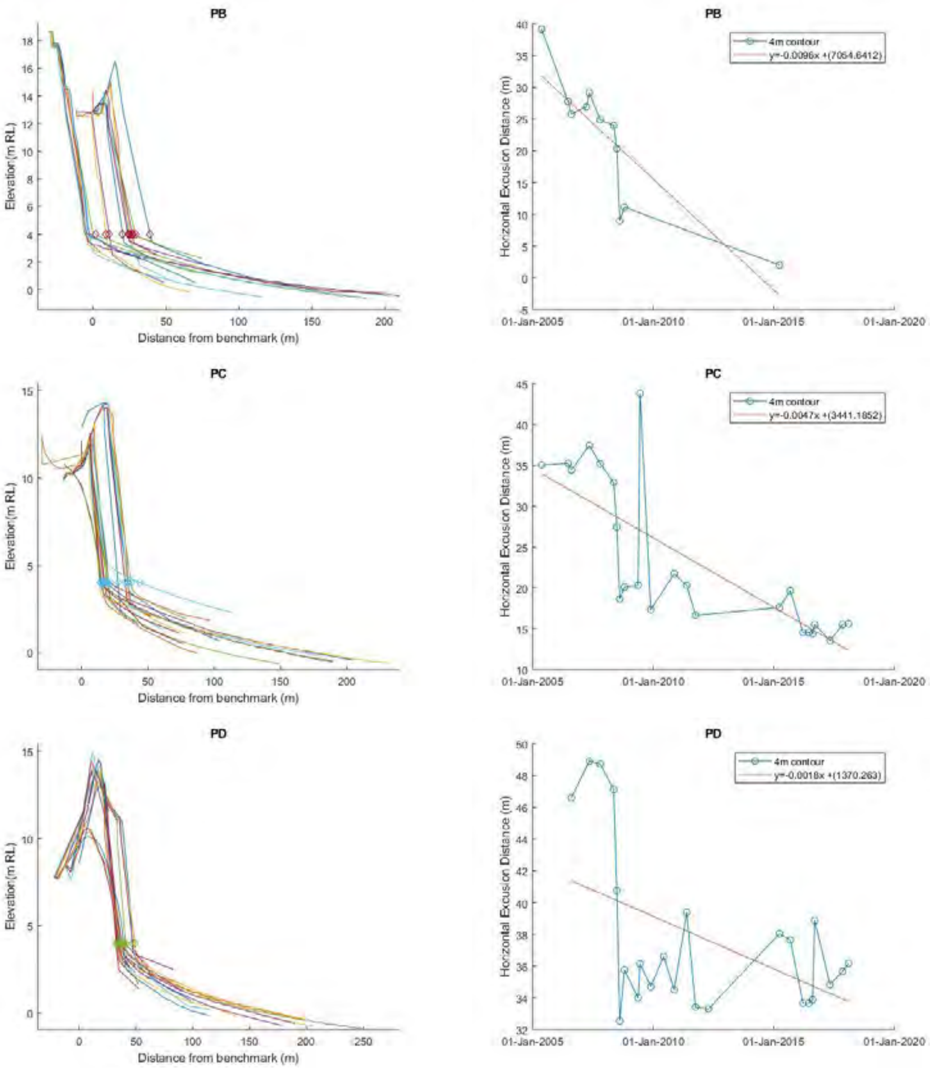




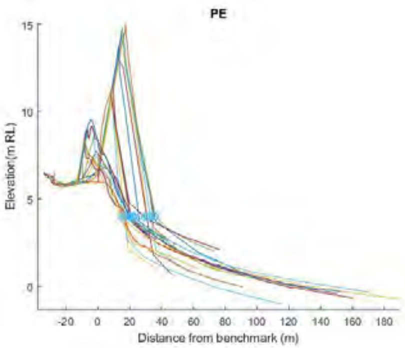


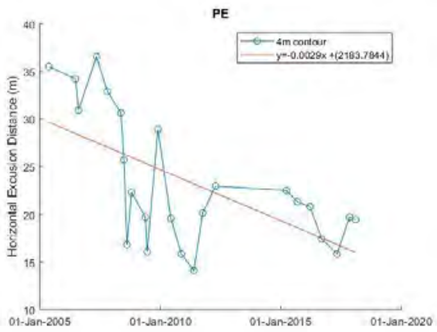


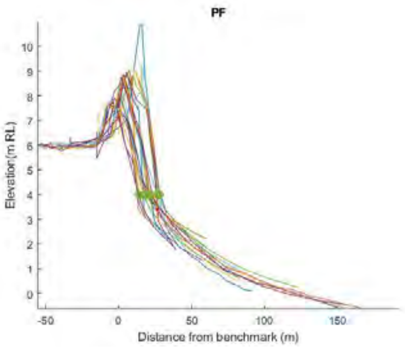


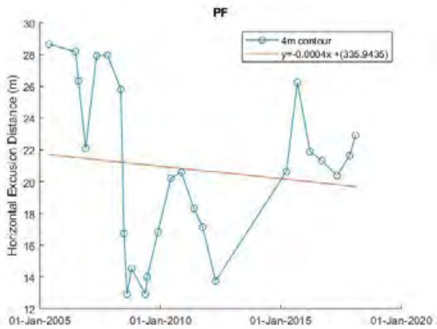


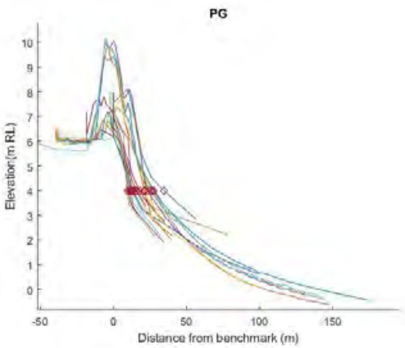
PB
Elevation (m RL)
Distance from benchmark (m)
Horizontal Excusion Distance (m)
4m contour
y=-0.0096x +(7064.6412)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020
PC
Elevation (m RL)
Distance from benchmark (m)
Horizontal Excusion Distance (m)
4m contour
y=-0.0047x +(3441.1852)
PD
Elevation (m RL)
Distance from benchmark (m)
Horizontal Excusion Distance (m)
4m contour
y=-0.0018x +(1370.263)


PE
Elevation (m RL)
Distance from benchmark (m)

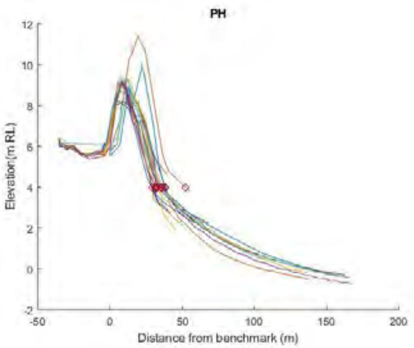

PE
4m contour
y=-0.0029x +(2183.7844)
Horizontal Excursion Distance (m)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020

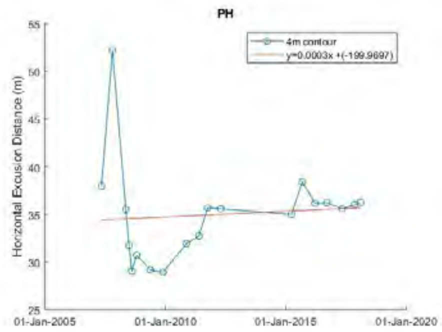

PF
Elevation (m RL)
Distance from benchmark (m)

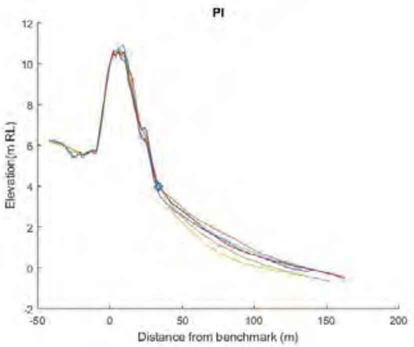

PF
4m contour
y=-0.0004x +(335.9435)
Horizontal Excursion Distance (m)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020

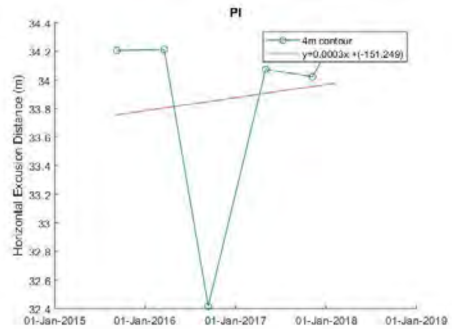

PG
Elevation (m RL)
Distance from benchmark (m)

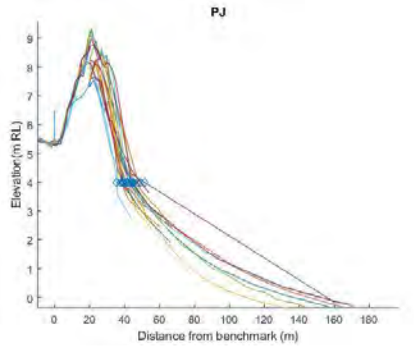

PG
4m contour
y=0.0027x +(-1947.8472)
Horizontal Excursion Distance (m)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020

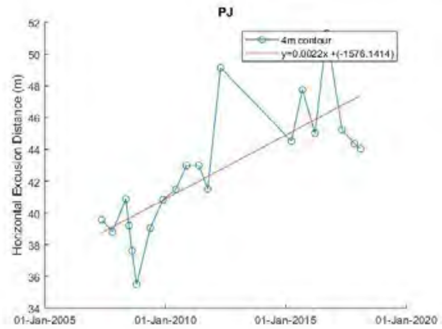

PH
Elevation (m RL)
Distance from benchmark (m)


PH
4m contour
y=0.0003x +(-199.9697)
Horizontal Excusion Distance (m)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020


PI
Elevation (m RL)
Distance from benchmark (m)


PI
4m contour
y=0.0003x +(-151.249)
Horizontal Excusion Distance (m)
01-Jan-2015
01-Jan-2016
01-Jan-2017
01-Jan-2018
01-Jan-2019


PJ
Elevation (m RL)
Distance from benchmark (m)


PJ
4m contour
y=0.0022x +(-1576.1414)
Horizontal Excusion Distance (m)
01-Jan-2005
01-Jan-2010
01-Jan-2015
01-Jan-2020

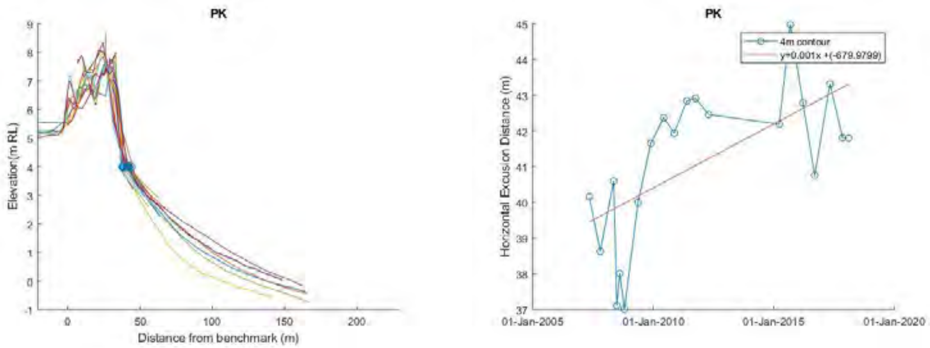


Figure Appendix C.29: Beach profiles at Muirwai South (left), long-term regression (centre) and Extreme Value Analysis using inter-survey erosion distances (right)

Appendix D: Auckland region coastal stability assessment

REPORT

Tonkin+Taylor

Regional Assessment of Areas Susceptible to Coastal Instability and Erosion

Appendix D: Auckland Region Coastal Stability Assessment

Prepared for
Auckland Council
Prepared by
Tonkin & Taylor Ltd
Date
January 2021
Job Number
1007104.v5

Exceptional thinking together
www.tonkintaylor.co.nz

Document Control

Title: Regional Assessment of Areas Susceptible to Coastal Instability and Erosion					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
August 2019	1	Draft for internal review	B. Westgate		
October 2019	2	Final draft for client review	B. Westgate	Kevin Hind	Kevin Hind
March 2020	3	Final draft for client review	B. Westgate	Robert Hillier	Robert Hillier
August 2020	4	Final draft	B. Westgate	Robert Hillier	Robert Hillier
January 2021	5	Final report	B. Westgate	Robert Hillier	Robert Hillier

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Table of contents

1 Introduction

A stability assessment of the consolidated coastal slopes[1] around the Auckland region has been undertaken as part of the regional-scale study to determine Areas Susceptible to Coastal Instability (ASCI) and Erosion (ASCIE). Auckland Council has developed a reporting requirement for the ASCIE to be undertaken in the hierarchy shown in Table 1.1, which can be divided into two broad categories:

1. Macro or small scale for the entire ~2,500 km of coastline which aligns with Level A and B; and
2. Local or large-scale detailed study of a specific area of coastline, which aligns with Level C and D.

Table 1.1: Auckland Councils assessment hierarchy

Level	Description
A	Basic desktop regional assessment
B	Calibrated desktop assessment
C	Detailed area wide assessment
D	Site specific assessment

This report presents the results of the macro or small-scale studies, Level A and B.

In support of the above presentations Section 1 provides a review of the previous work from 2006 and the basis from which the 2019/20 study was developed. Section 2 provides an overview of the underlying geology of the Auckland region, how this influences the ASCIE and how it has been divided into a series of different lengths of coastline. Section 3 identifies mechanisms that influence coastal instability and the different effects they have on the coastal slope.

Once the coastal instability influences and mechanisms were defined, two methods were developed to assess the ASCI. Section 4 sets out a slope height-angle curve methodology. Section 5 sets out an alternative statistical method for the assessment of field based slope angles. The ASCI values were then combined with erosion (E) to determine the ASCIE for the Auckland region.

1.1 Review of 2006 assessment

In 2006 Tonkin & Taylor (Reinen-Hamill et al., 2006) completed a geotechnical study to define a 'coastal instability zone' for an Auckland regional assessment. The following provides a summary overview of the previous study relating to cliff erosion

A Coastal Instability Zone (CIZ) was developed in the 2006 study to define the area landward of the toe of a sea cliff which was deemed susceptible to long-term erosion ('Area Susceptible to Erosion' or ASE). Figure 1.1 was presented to define the ASE as a distance from the toe of the sea cliff, as follows:

Equation 1-1: ASE Cliffs (2006)

$$ASE_{Cliffs} = \left[(LTR_H \; x \; T) \; x \; F + \left(\frac{H_t + 2.5}{tan\alpha}\right)\right]$$

Where:

H_t = Height (m) of the cliff from LINZ topographical map or site data (m)

[1] Consolidated shorelines, which include soil and rock cliffs, are not able to rebuild following periods of erosion but rather are subject to a one-way processes of degradation.

2.5 (m)= Error associated with the height of the cliff.

α = Characteristic slope angle of the cliff surface measured from the horizontal for a given likelihood outcome

LTR_H = Average historical long-term retreat (m/year)

F = Allowance for uncertainty associated with long term retreat rates

T = Time frame to be considered, in this case for a 100 year time period.

This represented the likely long-term regression of existing/current cliff slope profiles from the present toe position of the cliff, it has two components as illustrated in Figure 1.1 and described below:

1. The magnitude of regression at the toe of the cliff ("LTR_H x T" which represented a best estimate of the position of the toe of cliff at the end of the defined time period multiplied by an uncertainty factor, F, taken as 1.25).
2. A layback distance based on a notional angle of long-term repose (α) and overall cliff slope height (HC), with an allowance for typical error in the assessed cliff height (2.5m) from LINZ data increments. The value of α was selected to reflect the likelihood of that layback angle eventuating.

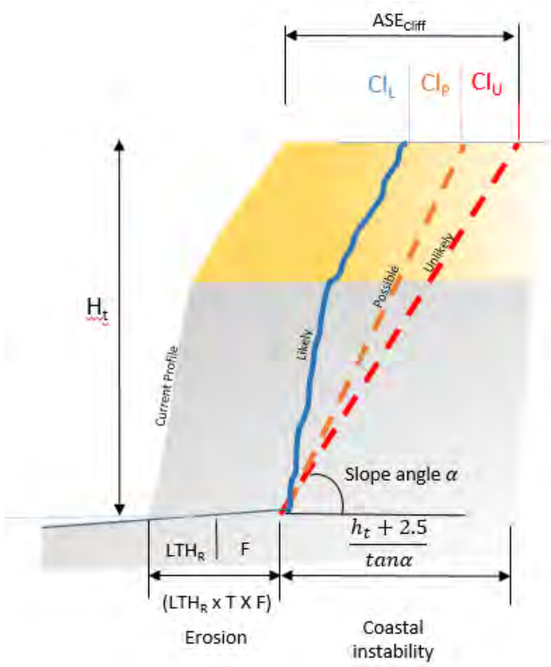


Figure 1.1: Reinen-Hamill et al. (2006) coastal slope instability analysis

Analyses were undertaken to evaluate potential correlations between the cliff height and slope angle based on the geological unit presented in the cliff face. However, it was observed that other factors, such as structure and surface conditions also influenced the profile of the cliff face, particularly in the non-volcanic rock types.

Field data from observations of cliff slope angles and the geological strength index (GSI) (Marinos & Hoek, 2001) were recorded, graphed and tabulated. From this data the mean and standard deviation (s.d.) of the angles of repose of the cliff slopes were evaluated.

Limit equilibrium analyses (RocScience, SLIDE) were then undertaken using the GSI values and a cliff height of 30 m. The 30 m cliff height was used as the field data indicated that this was the median of the measured values within the Auckland region. As a result of the analysis two curves were developed for a Factor of Safety (FoS) of 1.0 and 1.5 for various slope angles with different GSI and uniaxial compressive strength (UCS) values.

The result of analysis identified that

- The plotted curve for a Factor of Safety of 1.5 plotted just below the observed data set and approximates to the 95th percentile of measured slope angles (i.e. mean – 2 s.d.) i.e. instability 'unlikely' to occur beyond this layback an angle.
- The curve for a Factor of Safety of 1.0 plotted close to the mean of the observed data set i.e. instability was probable on the seaward side of the resultant slope profile and 'possible' on the landward side.

The study concluded with the values for α shown in Table 1.2.

Table 1.2: Reinen-Hamill et al. (2006) slope angles for determining coastal areas susceptible to erosion

GSI/Category	Slope angles (°)	
	Possible	Unlikely
Alluvium	26	18
Coastal Sediments	32	22
GSI: 20 ±10	32	22
GSI: 40 ±10	36	26
GSI: 60 ±10	49	36
GSI: 80 ±10	67	45

The long-term (100 year) erosion (as represented by the term $(\mathrm{LTR_H \; x \; T})$ in Equation 1-1) was also evaluated by the GSI value for a range of exposure values for observed shore platforms from 1 to 4 (exposure values were taken as 4 being the most exposed to 1 being the most sheltered i.e. small estuaries and tributaries). The data was distilled, including allowance for the uncertainty factor (F=1.25), to simplified values of long term retreat (LTR_H) as shown in Table 1.3.

Table 1.3: Reinen-Hamill et al. (2006) LTR_H retreat

GSI range	Historical LTR_H (m/100yrs)	LTR_H x F (m/100yrs)
>80	1	1.25
75 ±5	2	2.5
65 ±5	3	3.75
52.5 ±5	4	5
35 ±5	5	6.25
<20, soft cliffs	10	12.5

1.3 Conceptual model for current assessment

Areas susceptible to coastal erosion and coastal land instability along cliff (consolidated) shorelines typically have two mechanisms contributing to the degradation:

- **Toe Erosion (E)**

  A gradual retreat of the cliff toe caused by weathering, marine and bio-erosion processes. This retreat will be affected by global process such as sea level rise (SLR) and potentially increase soil moisture. The future cliff toe position can be estimated based on historic erosion rates (LTR_H) with a factor applied to allow for the effect of future sea level rise (LT_F) over time (T). These are gradual and continue as an ongoing process that happen over a large time scales (years to decades).

  If erosion of the cliff toe is halted through either natural (i.e. establishment of a beach) or artificial (i.e. through rock protection) processes, then the profile of the cliff above the toe will continue to regress until a stable profile is reached.

- **Cliff Instability (CI)**

  The coastal environment results in cliff faces that are over-steepened and prone to regression through a variety of processes. The regression can be slow and incipient but more generally episodic in nature. Instability and regression results from degradation of material properties of the cliff or yielding along a geological structure initiated by exposure. Instability causes the cliff slope to flatten to an angle below which it is 'stable' ($\tan\alpha$). Cliff slope instabilities are influenced by processes that erode and destabilise the cliff toe, including marine processes, weathering and biological erosion or change the stress within the cliff slope. Instability may range from small-scale (block or rock falls) on discontinuities, to large-scale and deep-seated mass movement. These events cannot be predicted with certainty. They can only be monitored once signs of initial movement are observed, often these are sudden and without warning. To generate a rate from episodic events the time-period needs to be long enough to enable the cliffs to undergo a full cycle of regression (toe erosion, over steepening, instability, removal of failed material).

The conceptual models for toe erosion component (i.e. "E", Equation 1-2) and cliff instability (i.e. "CI", Equation 1-3) component are as follows:

Equation 1-2: Cliff Erosion

$$\text{Cliff Toe Erosion (E)} = ((LTR_H \times LT_F) \times T)$$

Equation 1-3: Cliff Instability

$$\text{Cliff Instability (CI)} = (h_C / \tan\alpha)$$

Where:

h_C	=	Height (m) of cliff based on DEM
α	=	The characteristic composite slope angle (i.e. composite of lower rock and upper soil slope angle if applicable)
LTR_H	=	Historic long-term retreat (regression rate), m/year
LT_F	=	Factor for the potential increase in future long-term retreat due to SLR effects.
T	=	Timeframe over which erosion occurs.

These can then be combined into the models for consolidated shoreline for the present day ASCIE and future ASCIE. The present day ASCIE is a function of the cliff instability component only as regression of the cliff toe is a long-term process. The future ASCIE is a function of both cliff instability and cliff toe regression, with the latter likely being affected by increased SLR rate effects.

The models for consolidated shorelines are expressed in *Equation 1-4* (current ASCIE) and *Equation 1-5* (future ASCIE), where the ASCIE is established from the cumulative effect of the components (Figure 1.2):

Equation 1-4: Current ASCIE

$$Current\ ASCIE = (h_{Cr}/\tan\alpha_r) + (h_{Cs}/\tan\alpha_s)$$

Equation 1-5: Future ASCIE

$$Future\ ASCIE = ((LT_H \times LT_F) \times T) + (h_{Cr}/\tan\alpha_r) + (h_{Cs}/\tan\alpha_s)$$

Note that coastal cliffs may be comprised of more than one geological type with different characteristics. If the cliff slope is comprised of two geotechnical domains, soil and rock, they will have different observed field angles. If a cliff is comprised of only one geotechnical domain, only the relevant component (i.e. either rock or soil) should be used in the equations. The height and slope for each domain are assessed separately where applicable (see definition sketch Figure 1.2). For those cliffs where the cliff height (h_c) and the slope angle (α) are subdivided in an upper "soil" (h_{cs} and α_s) and lower "rock" (h_{cr} and α_r) section, the composite slope proxy (i.e. combination of rock and soil slopes) is used to derive the horizontal cliff instability distance.

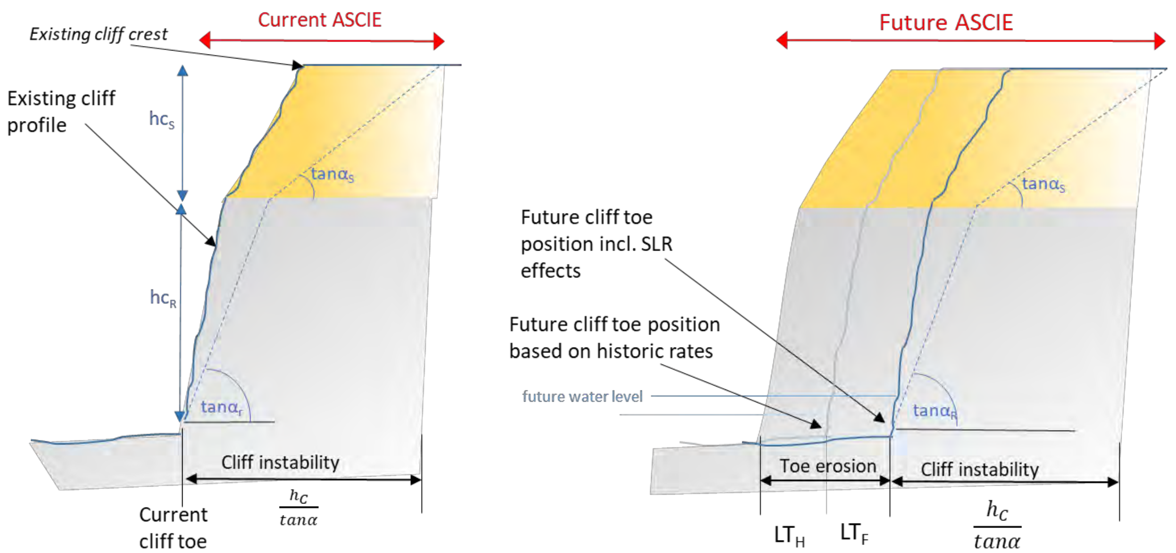


Figure 1.2 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

1.4 Coastal cliff profiles

For the analysis of cliff slope angles and heights, the 2016 LiDAR digital elevation model (DEM) was used to create a series of coastal slope profiles. The position of three-point locations on the coastal profile were then processed to provide a spatial database from which statistics of slope heights and face angles were evaluated (see sketch in Figure 1.3). The three-point locations were:

1 Toe of the coastal slope – position of maximum concave cliff slope curvature, generally occurring at or close to the high water mark.

2 Rock crest or soil toe – position of the break in slope created by the change in material properties and local conditions.
3 Soil crest – crest of the slope where the maximum convex slope curvature occurs. This is the change point where the slopes are influenced by land based conditions as opposed to coastal processes.

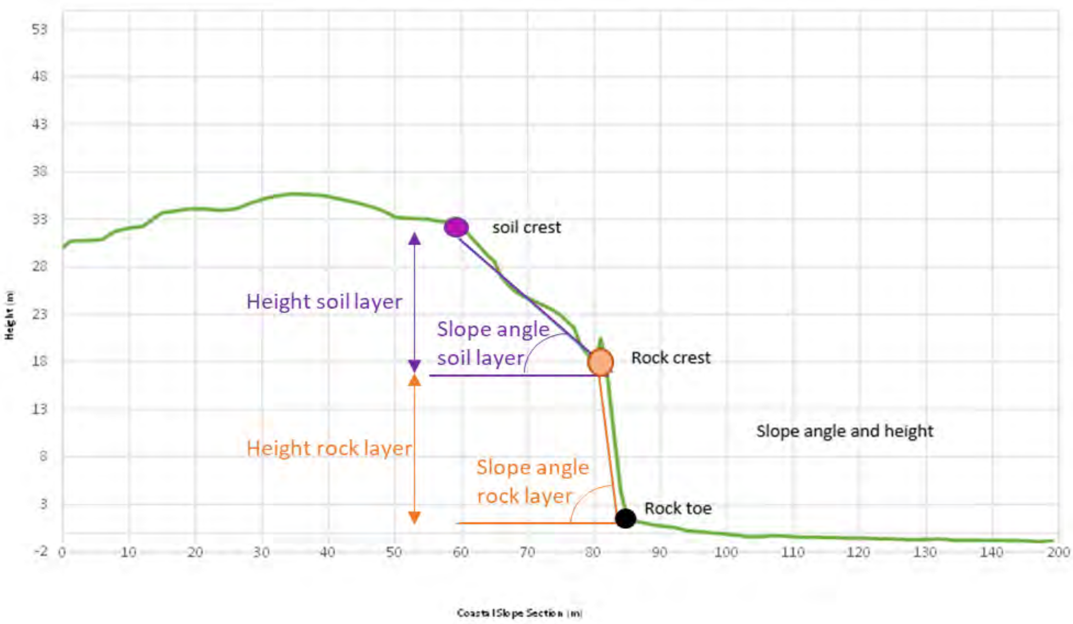


Figure 1.3: Conceptual cliff profile showing identified rock toe, rock crest and soil crest

2 Geology

The geology of the Auckland region can be divided into a range of lithologies based on series or age, stage and formation, and composition, as shown on the geological maps (Edbrooke 2001 - Figure 2.1; Kermode 1992) and Table 2.1.

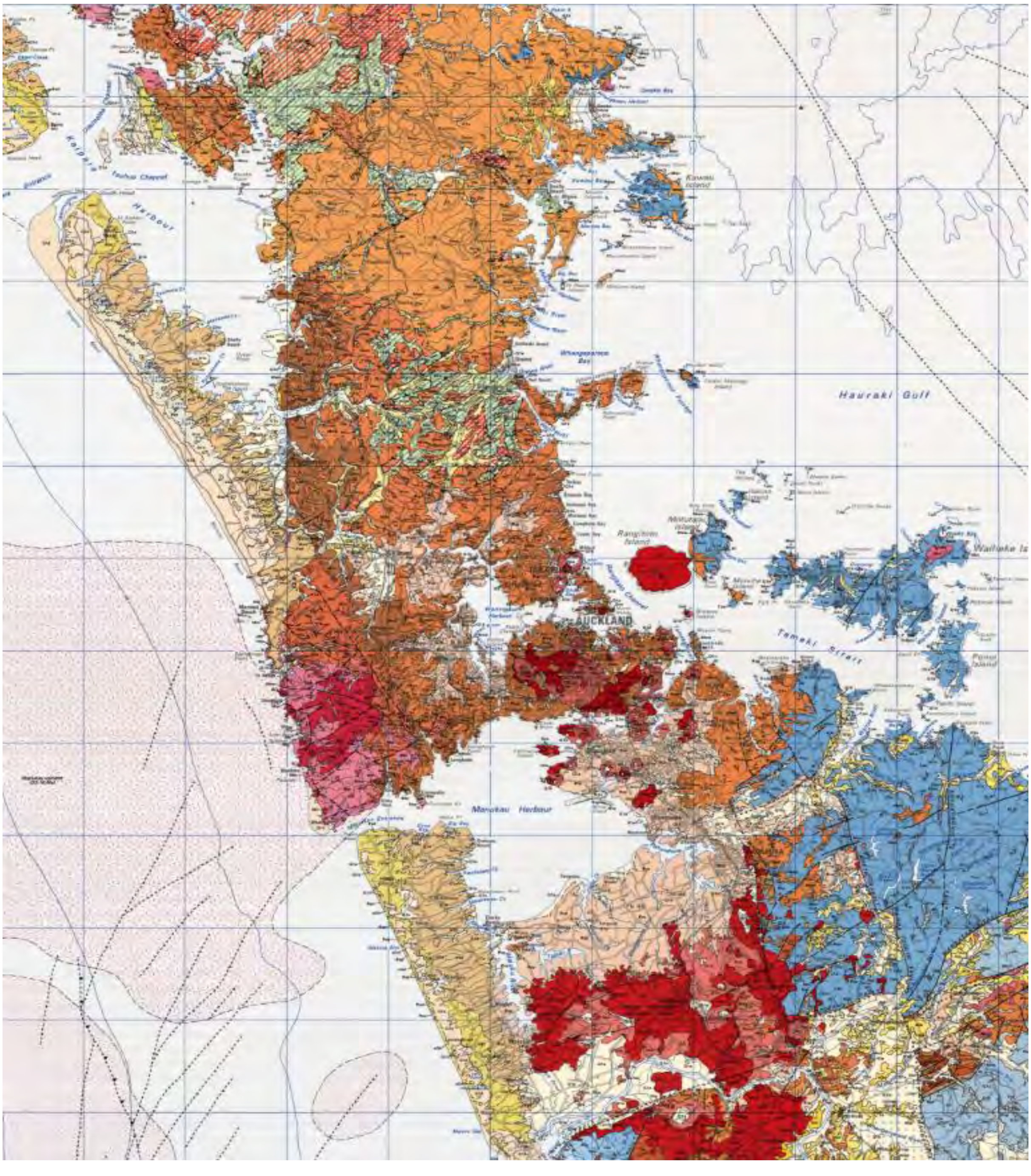


Figure 2.1: Simplified geological map for Auckland region from Edbrooke (2001)

Table 2.1: Geological units of the Auckland Region combined Edbrooke (2001) and Kermode (1992)

Geological Unit Code	Series	Geological Unit Name		Geological Unit Material Description	Group - Soil / Rock	Adopted Descriptor for Geotechnical Domain in analysis
Q1a	Pleistocene/ Holocene	Alluvial Sediments		Alluvial Sediments	Soil	Tauranga Group
Q1b / Q1d / eQd		Karioitahi Group		Coastal Sediments	Soil	Awhitu Group
Pad		Awhitu Group		Awhitu Group	Exception	Awhitu Group
ava		Auckland Volcanic Field		Basalt to Ash and lapilli	Rock	AVF
avl				Basalt and Basanite lava	Rock	AVF
avs				Basalt and basanite scoria	Rock	AVF
avt				Lithic tuff	Soil	AVF/ Residual Soil
eQa / pup / ta / tp	Pliocene/ Pleistocene	Tauranga Group		Puketoka Formation	Soil	Tauranga Group
Qvh / iPvw	Pliocene/ Pleistocene	Hautura Volcanic Group		Dacite lava and breccia	Rock	AVF
Mhc / Mhm / iPho	Miocene / Pliocene	Whitianga Group		Pumice, rhyolite flows, hydrothermal activity, lithic ignimbrite and rhyolitic pumice breccia	Rock	AVF
Mcu / Mci / Mco / Mca	Miocene / Pliocene	Coromandel Group		Andesite, dacite intrusives and lave flows, tuff and tuff breccias	Rock	AVF
Mkm / Mkw / Mkt	Miocene	Kiwaitahi Group		Pyroxene basaltic andesite dacite, agglomerates, tuff, dykes, breccia	Rock	AVF
Mvt		Kuwautaga Volcanic Group		Ti Point Group	Rock	AVF
Mtl		Akarana Supergroup	Waitakere Group	Lone Kauri Formation	Rock	Waitakere / Volcanic (West)
Mtw				Waiatarua Formation	Rock	Waitakere / Volcanic (West)
Mtt				Tirikohua Formation	Rock	Waitakere / Volcanic (West)
Mtp				Piha Formation	Rock	Waitakere / Volcanic (West)
Mto				Oruawharo Hyaloclastite	Rock	Waitakere / Volcanic (West)
Kk			Northland Allochthon	Mangakahia Complex	Exception	Northland Allochthon
rc			Waitemata Group	Cornwallis Formation	Rock	Waitemata - Pakiri Formation
Mwo				Matapoura Conglomerate	Rock	Waitemata – ECBF
Mwl				Helensville Conglomerate	Rock	Waitemata – ECBF
Mwb				Timber Bay Formation	Rock	Waitemata - ECBF
Mwp				Pakiri	Rock	Waitemata - Pakiri Formation
Mwe / re				ECBF	Rock	Waitemata – ECBF
Mwr				Cape Rodney	Rock	Waitemata – ECBF
TJw	Triassic to Jurassic	Waipapa		Waipapa	Rock	Waipapa Group
Jmt				Te Mata Subgroup	Rock	Waipapa Group

The coastal slopes and cliffs have been grouped using the following geological, geotechnical and geo-environmental characteristics:

1 Groups, based on material strength properties:
   - Soils (generally less than 1000 kPa/1 MPa uniaxial compressive strength, or as defined in Section 2.1 below).
   - Rock (generally greater than 1000 kPa/1 MPa uniaxial compressive strength, or as defined in Section 2.2 below).
2 Geological Units: defined mainly by material type and age, and mapped through Edbrooke (2001) and Kermode (1992) for the Auckland region.
3 Domains: specific characteristics combinations (which may be unique to a location such as strength, weathering, geological structure, material, aspect, physical environment (estuaries, cliffs, tidal areas) or instability mechanism.
4 Sub-Domains: where the characteristics of a domain can be further differentiated into a series of smaller areas.

2.1 Soil Group

Soils are defined as generally lightly cemented, cohesive soils consisting of marine, alluvial and organic materials, generally within the Tauranga Group, or residual soils derived from the parent material. Soils are occasionally predominantly non-cohesive (low fines content) and uncemented. These materials are typically the youngest within each area and are often derived from the erosion of older formations.

Shorelines formed against soil cliffs/slopes are typically characterised by a low inter-tidal flat, backed by a slope or cliff up to 10 to 15 m high. The inter-tidal flats, which generally consist of material eroded off the slopes, are typically submerged at high tide. Soil-shores primarily exist in estuarine environments such as the Waitematā, Manukau and Kaipara Harbours. But can also be located on exposed shorelines with or without a shore platform, such as bays and where streams and rivers enter onto the coastline.

Material consistencies for soils (NZGS, 2005) are generally firm to hard (for clays and silts, with undrained shear strengths generally in the range of 25 to 500 kPa) or loose to dense (sands and gravels), occasionally entering into the lower end of extremely weak rocks (at 500 kPa) when lithified or cemented. The instability mechanism within these materials are primarily dependent on the cohesive and frictional properties on the type of material (clays, silts, sands and gravels, with/without organics), with instability mechanisms manifesting as rotational and/or translational slides or high angle topples and slides. Instability in such soils are also often controlled by groundwater conditions and the characteristics of the interface of the soil with the underlying rock.

The soil cliffs were taken from the geological maps (Figure 2.1) which were characterised by the following geotechnical soil domains, as in Table 2.2.

Table 2.2: Soil Domains

Domain	Domain Description
Residual soil	Highly to completely weathered parent rock (structure and fabric of the parent rock is not evident)
Coastal sediments, Karioitahi	Dunes, weakly cemented dune and inter-dune facies
Alluvial sediments, Tauranga Group	Soft sediments ranging from clays to sand with gravels and peat
Āwhitu Group:	Moderately consolidated dune sands south of Awhitu Peninsula, Manukau Heads to the west of the region which appear to be spatially uniform.

Soils domains are mainly contained within the Tauranga Group and are highly variable in composition throughout the Auckland region. The exception is the moderately consolidated dune sands such as the Awhitu Peninsula, south of Manukau Heads. The instability mechanisms in these areas appear to be primarily a result of toe erosion and homogeneous regression of over-steepened material.

The locations of the cliffs formed of soils were determined directly from geological maps and supplemented by local experience and knowledge of the project team. Knowledge and experience indicated that the soil domains are highly variable in composition throughout the Auckland region and local factors need careful consideration when assessing these.

2.2 Rock Group

The mass properties of rocks cannot be solely assessed from their geological unit identifiers, as these do not take into account strength, weathering and tectonic history, each having an influence on the rock mass structure and discontinuity networks. As the intact rock strength increases the instability mechanism transitions from being dominated by the strength of the intact parent material (rotational, semi rotational slides) to structurally controlled instability (high angle falls/topples along planes or wedges) governed by the joint/bedding strengths.

Each rock unit can also be sub-divided into six weathering grades, ranging from highly weathered (V) to unweathered (I). An increase in material strength generally occurs with depth below surface level, corresponding to transitions from highly weathered to unweathered grades.

Rock strengths vary from very weak to strong and can be divided into two sub-domains based on the intact rock strength (NZGS 2005) which effects the rocks behaviour:

- Very weak to moderately strong rocks (under standard classification identified as having uniaxial compressive strengths in the range 1 MPa to 50 MPa but generally encountered in the Auckland Region as less than 10 MPa, but can be locally higher) ; and
- Moderately strong to strong rocks (under standard classification identified as having uniaxial compressive strengths with uniaxial strengths greater than 50 MPa)

This adopted division into two rock sub-domains is due to the strength of the material being a critical factor in the stability analysis. Once strength increases above 10 MPa (>25 MPa quoted by Hungr et al, 2014) the instability mechanism changes from being material strength driven to becoming more structurally driven. Therefore, as a result the analysis type needs to change between the two rock group sub-domains. To classify a sub-domain for a particular rock mass, the lithology and weathering needs to include the unique structures (joints, beds, faults, folds). The structures divide the rock up into a series of interlocking blocks of varying sizes and shapes that are used in qualitative or quantitative classification of the rock mass strength. The individual discontinuity properties then have the most significant effect on the rock mass strength and are fundamental in the understanding of the coastal slope global stability. Therefore, by reference to Figure 2.1 and Table 2.1, the geological rock units have been assigned to the domains as presented in Table 2.3

Table 2.3: Rock Domains and Sub Domains

Domain	Sub-domain	Domain description	Spatial description
Auckland Volcanic Field (AVF) and Coromandel Volcanic Zone	N/A	Lava / lava-breccia, andesite, dacite, tuff, ash, lapilli and scoria. The lavas range from moderately strong, to very strong (20 to 250 MPa). GSI values greater than 40	
Akarana Supergroup, split into:			
	Waitematā Group rocks	While more uniform in their weathering profile, differed markedly in geological structure. Some were horizontally and uniformly layered, with little apparent discontinuities, while other areas were intensely deformed and faulted. These rocks appeared to be of lower height, flatter slopes and undergoing more recent erosion. They are extremely weak to very weak mudstones, siltstones and sandstones, particularly the East Coast Bays Formation (ECBF); 500 kPa to 5 MPa, to the weak to moderately strong Pākiri Formation (10-25 MPa) with a GSI value ranging between 35 and >70.	Whilst relatively uniform in their weathering profiles, there are marked differences in geological structure. Some were horizontally and uniformly layered, with little apparent defects, whilst other areas are intensely deformed and faulted. These latter features are associated with lower heights, flatter slopes and have undergoing more of an erosive regression opposed to instability related.
	Waitakere Group rocks	More complex that the Waitemata Group with the inclusion of andesite tuff breccias, pillow lava flows, intrusions, volcaniclastic sandstones and siltstones. This increases the material strength ranging from very weak to strong (2 to 50 MPa) with a ranging GSI (generally greater than 40).	
Northland Allochthon	N/A	Sheared mudstones, siltstone and limestones that was emplaced into the Waitemata Group in the north of the region.	
Waipapa Group	N/A	Greywacke (sandstones and siltstones) that vary from extremely weathered, low strength cliffs in the Firth of Thames to much fresher, more competent material on the more exposed Tawharanui Peninsula. The group is generally weak to moderately strong (5 to 25 MPa) with a range of GSI values.	Varied from extremely weathered, low strength cliffs in the Firth of Thames to much fresher, more competent material on the more exposed Tawharanui Peninsula.

2.3 Geotechnical investigations

No specific intrusive investigations have been undertaken for this present study. The T+T and NZ Geotechnical databases (NZGD) were utilised for the collation of ground investigation data and interpretation of rock mass properties. On review, the spatial locations of ground investigation data in the coastal zone were sparse. Investigation points which were recorded are generally located in areas of known instability or ground movement within the coastal zone. The location of the investigation data therefore tends to highlight areas of the shoreline where there is a higher probability of instability occurring. Therefore a database approach was used for obtaining material properties from the geological units provided in Table 2.1 and put into the domains shown in Table 2.2 and Table 2.3.

3 Coastal slope instability

This section provides background information on the dynamic coastal slope instability element of coastal cliff regression only (as opposed to more incipient/gradual erosion) and provides some further context as to how different factors affect the way cliffs behave and ultimately regress.

3.1 Instability types

Dynamic instability events are random events which happen episodically through time (they occur very infrequently and with little warning). The development of instability can arise from one, or a combination of the following underlying control types:

1 Material properties - instability events are caused when the loadings within the cliff (resulting from the slope angles, heights and material weights) exceed the resisting forces available (cementation. friction and cohesion) to support the mass of material above. The form of the instability could be a combination of either circular and/or non-circular failure modes depending on the material properties. These types of instability events are most commonly associated with:

- ground modification (either natural, through the potential undercutting or steepening of the slope by wave action, or man-made through construction), or
- changes to groundwater conditions in response to prevailing weather patterns or changes to groundwater (and surface water) regimes due to construction, or
- degradation of materials.

2 Geological structures - Instability events occur when slopes become unstable or fail along a pre-determined plane(s); the plane(s) being either discontinuities (joints, bedding) or structures (folds, faults). These generally occur when the intact material strength/properties within the cliff are high.

Unless the structures are large scale and can be observed at the toe or in the cliff face, the probability of predicting instability events which occur along a geological structure is generally low.

When the data and observations from site walkovers and field photographs were analysed it was noted that coastal slopes are generally expected to regress at a similar angle to their current angle. Therefore, analysis of general regression, if taken over a long enough period, will be reflective of the current local profiles.

3.2 Influence of Geological structures

Geological structures are formed as a consequence of the changes in depositional environments and ground forces through geological time (including burial, uplift, tectonics, volcanism, dewatering). Once materials have undergone semi or full lithification or consolidation the material can also then physically change through dislocation. Such conditions create geological structures and discontinuities. These effects are summarised further below:

- Eruption or intrusion of volcanic or igneous materials have different emplacement and cooling structures and discontinuities.
- Deposition resulted in the creation of the bedding structures, alternating muds, silts and sands, in a fluvial/estuarine/marine environment. The discontinuities are formed through burial, tectonics, and uplift (fold and faults) along with changes to bedding orientation. The stresses that are involved in these processes create different discontinuity orientations. These are shown in the coastal slopes through the presence of joints, folds or faults.

- Burial and uplift are related to the tectonic environment that the rocks have undergone, each dependant on their age and way they were created.
- Erosion and coastal process are a key component in the instability of the Auckland region's coastal slopes. Erosion of the grounds surface causes stress relief in a horizontal direction. The erosion of the coastal slope produces the change in vertical stresses.

The extremely variable nature of the conditions have induced erratic geological changes in the Auckland region and has resulted in a structurally complex rock masses at local scales. Therefore, geological structure analysis for slope stability has not included the geological structure as it is too site specific to be systematically applied to the regional wide, Level A or B, coastal slopes. Areas or zones where coastal instability is known to be related to structure have been highlighted within the regional mapping and will require a local-scale or site-specific assessment.

3.3 Cliff slope stability mechanisms

The review of the coastal slope and cliff profiles around the Auckland region highlighted four (4) predominant instability mechanisms, as shown in Figure 3.1. These mechanisms are inter-dependent with their geotechnical domains and rock mass properties, and are as follows:

1. **Individual falls (soil and rock)**

   Erosion of soils and less resistant rock between more competent rock layers can form an undercut. When these cuts reach a geological structure or discontinuities the stresses within the material reach a yield point, individual blocks fail and rock falls occur. This generally occurs as a brittle failure or failure along a predetermined discontinuity or plane of weakness.
2. **High angle topple/tension, slides or toe buckles (soil and rock)**

   High angle topples/tensional instability is caused by the over-steepening of the slope resulting in a stress concentration in the unstable rock mass toe. These mechanisms are likely to be developed due to denudation, and a cyclic wetting and drying of the cliff slope, either through tidal cycles, storm events or precipitation. Research into this mechanism has been undertaken by Styles et al. (2011) and Martin (2019) amongst others, however further development of these models is outside of the scope for this regional-scale assessment. Styles et al. (2011) and Martin (2019) identified that these failure mechanisms are very difficult to model and are expected to be associated with a range of coastal regression mechanisms opposed to purely rock mass instability.

   The visual observations of the shore platform of the Waitematā and Waitakere Groups for the regional assessment has identified that these are a series of face parallel structures which could be related to either within the tectonic evolution of the rock mass or created through stress-relief from unloading caused by erosion of the face.
3. **Rotational or circular failures (soil and rock)**

   In residual soil, highly to completely weathered material or unconsolidated alluvial or coastal sediments (e.g. Kariotahi, Tauranga and Awhitu Groups) the instability mechanism are generally related to the internal loss of material strength. These failures occur through the change in the physical properties of the material, or a change in the groundwater regime or change in the slope geometry or stress (undercutting of the toe zone) the main drivers. These physical changes create a change or re-distribution of the internal stresses and strains within the slope leading to instability.
4. **Structural failures (rock)**

   Geological structures are formed as a consequence of changes in ground forces through geological time (e.g. due to the materials burial, uplift, tectonics, volcanism, dewatering). These are shown in the coastal slopes through the presence of joints, folds or faults. Structural failures are caused through the release of material along these pre-determined plane(s) as a result of tectonics, faulting or folding, forming planes (low to high angle). These planes can be:

– singular and face parallel, resulting in planar or toppling failure, or
– two or more intercepting planes that form wedge failure and rock falls.

These mechanisms are shown in Figure 3.1. These instability events are extremely episodic and random. They are based on the daylighting of the plane or planes with the slope surface/face. These failures could be triggered through increases in pore water pressures, either naturally or human induced (i.e. burst pipes, changes in surface water drainage and discharge) which decrease the available resistance along discontinuity plane(s).

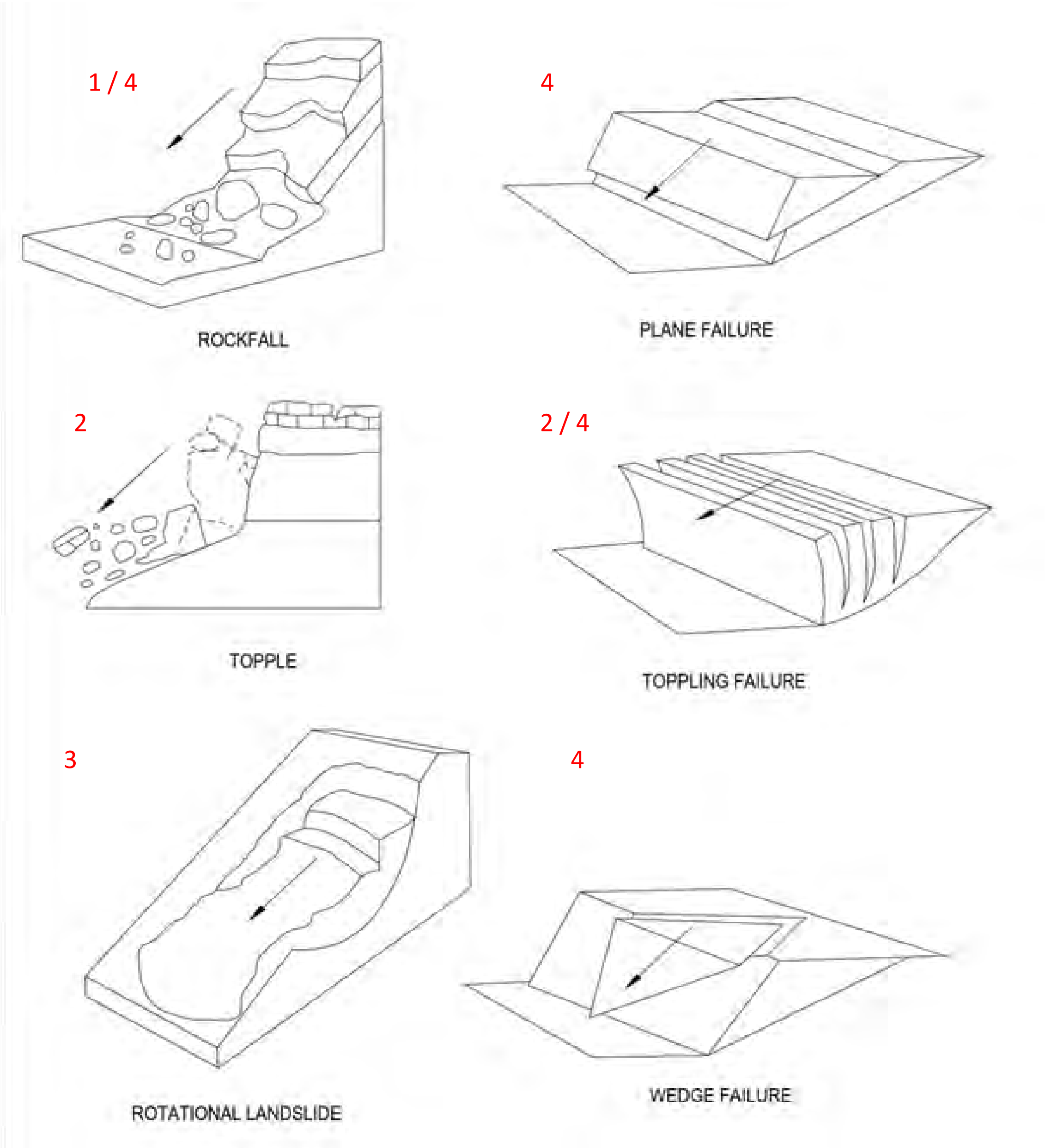


Figure 3.1: Instability mechanisms

4 Slope instability methodologies

The coastal slopes of the Auckland Region were assessed through two different methodologies:

1. Slope stability curves through the application of Auckland Council CoP Section 2 (AC 2012) and Auckland Council AC2229 (AC 2019); and
2. Statistical evaluation of field values for the development of slope profile probabilities.

Each methodology is described below.

5 Slope instability curve methodology

The development of a methodology for a revised ACSIE was undertaken after reviewing the cliff profile cross sections taken from the 2016 LiDAR DEM. These were developed at 100-500 m alongshore intervals across the entire region. From these profiles the cliff toe and crest positions were identified to derive a cliff height and slope angle, as shown in Figure 1.2. The definition of the slope crest is the intersection of the actively eroding or unstable cliff face and the land behind. The coastline characteristics then needed to be classified and categorised for analysis. This was undertaken through a series of processes from the creation of domains, consideration of the instability criteria within the Auckland Council code of practice, material properties and analysis, followed by adoption of coastal instability values and validation and review of outcomes.

5.1 Instability Criteria for Auckland region

Auckland Council CoP Section 2 (AC 2012) and Auckland Council AC2229 (AC 2019) set out the existing stability assessment framework for the coastal slopes within the Auckland region, this was:

"2.3.13: Coastal Cliffs

Assessment of coastal cliffs in the Waitemata and Manukau Harbour should consider regression of the cliff face and weathered mantel material likely to occur from natural coastal erosion processes over a 100-year period. Assessment of this regression should take account of site-specific investigation of the ground model, including its structural geology, and historical records or erosion processes. Cliff stability also needs to be considered and where machine bores and other investigation techniques lead to a complex ground model, additional assessment techniques such as "stereonet" analysis may be applicable." (AC 2012)

These documents require the analysis of the coastal slope to determine a stable slope angle based on it's assessed characteristics. Therefore, this methodology was developed to be compatible with Auckland's coastal slope assessment methodology, especially 2.3.13 (V) for the stability assessment to check the slopes overall safety.

The geotechnical domains (Table 2.2 and Table 2.3) were then integrated with the material properties (identified below) from the Reinen-Hamill et al. (2006) study and the T+T databases. This provided two different sets of material property data types for analysis:

1 Geological Strength Index (GSI) (Hoek et al., 2000; Marinos and Hoek, 2001) and Uniaxial Compressive Strength (UCS) – Reinen-Hamill et al. (2006) study and field observations;
2 Cohesion and friction angle (c and ϕ)) – T+T material properties database and field observations.

5.2 Domains

Initially the coastline was split into the geological groups (soil or rock), then by strength and material properties into different domains. These were:

- The soil domains were derived based on material composition; clay, silt, sand, organic content; as well as strength (soft to very stiff/hard) and mode of formation (e.g. alluvial, estuarine, Aeolian, and proximal or distal from shorelines).
- The rock domains were derived based on field observations and classifications considering the works of Walker and de Bruyn (2006), Cai et al. (2004), Hoek et al. (2013), Marinos and Hoek (2001), Palmstrom and Broch (2006), and Sonmez and Ulusay (1999).

The Geological Strength Index ('GSI' ; Marinos and Hoek, 2001; and others) was used, based on observed geological structure and surface conditions for each of the geotechnical domains, as presented in Table 2.1 and Figure 5.1 The GSI values ranged from very good rock mass (i.e. intact or massive structure with rough surface conditions, high GSI values >70) to poor rock mass (disintegrated mass with poor surface conditions, low GSI values, <35).

The Reinen-Hamill et al. (2006) coastal study had previously classified areas of coastline into different GSI categories which were combined within ArcGIS to develop an overlay on the geological units. The resultant ArcGIS layer identified a highly variable coastline, with a range of different GSI values within each geological unit. As a result the coastline was divided into coastal cells of different GSI value and cross referenced through aerial photographs. This resulted in geotechnical rock domains or sub-domains, as defined in Table 2.3 for each coastal cell.

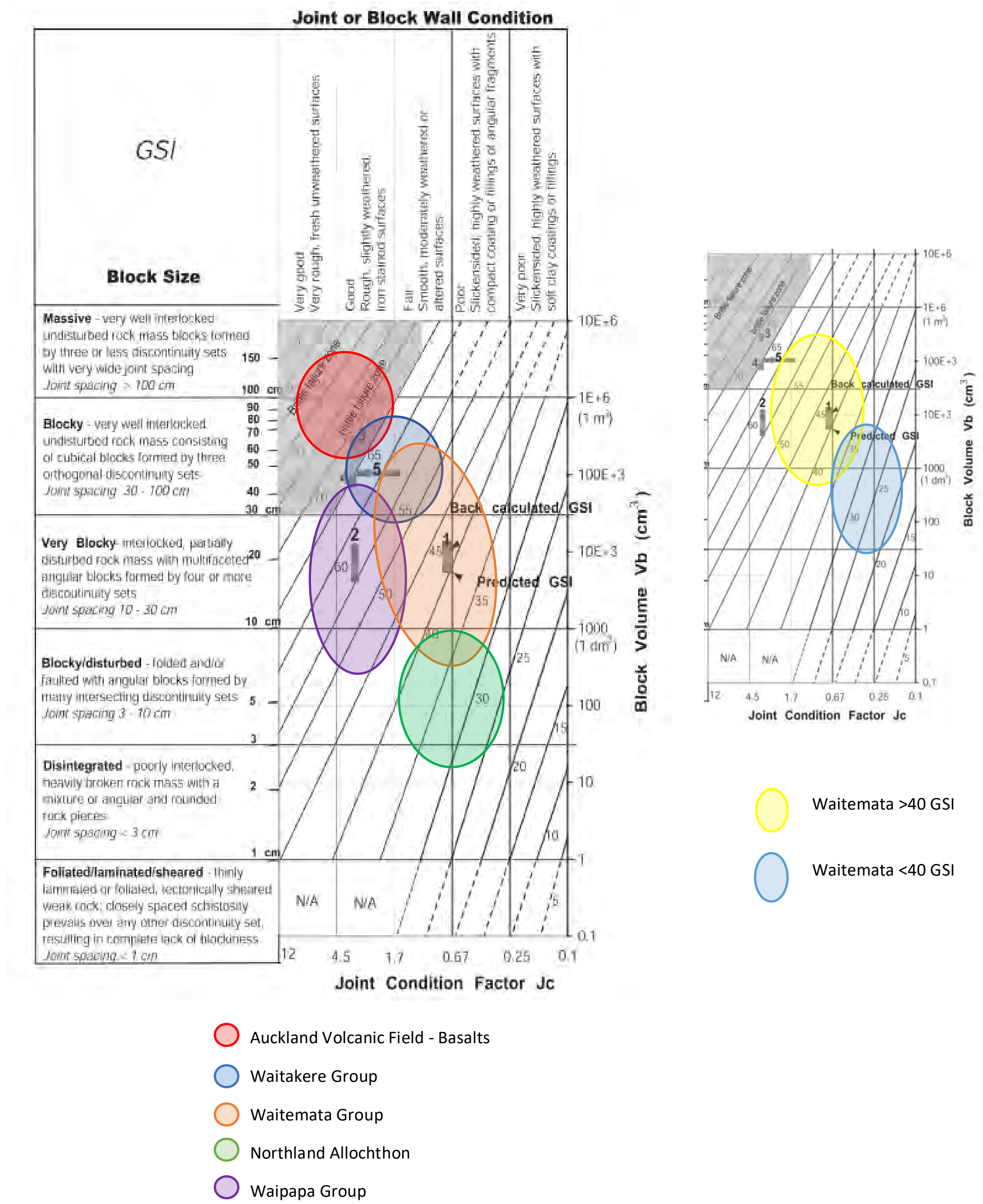


Figure 5.1: Geological Strength Index (GSI) from Cai et al., (2004) based on Marinos & Hoek (2001) for geological domains

5.2.1 Modelling of Coastal Stability

Coastal slope profiles were created from LiDAR data to assess where the coastal slopes had single geological unit (soil or rock) or a composite (soil and rock) slope characteristics. The break point from soil to rock was generated spatially within ArcGIS from the 2016 LiDAR data (Section 1.4). Profiles were developed every 500 m to 5,000 m of coastline through this method. A simplification of the slopes was then undertaken into the soil and rock group and geotechnical domains. The profiles were then populated with the material properties to determine the profiles Factor of Safety (FoS). The two methods were modelled for each slope profile:

- Generalised Hoek-Brown (GSI, UCS, Mi); and
- Mohr-Coulomb (c and ϕ))

A comparison between the different modelling methods was required as the approaches had the potential to produce different results for each geotechnical domain within the Auckland region for a FoS =1.5.

The regional scale assessment fixed the slope heights and varied the slope angles to generate a failure profiles with a FoS 1.5 (an example model is shown in Figure 5.2), to be compatible with the Auckland Council CoP Section 2 (AC 2012), as developed in the Reinen-Hamill et al. (2006) study. The slope height was then increased, in increments, from 5 m to 50 m with the slope angle being varied until a FoS=1.5 was reached. A best fit trendline, a power law in most cases, was then applied to these points to develop a slope angle verses cliff height curve, as shown in Figure 5.3 for every geotechnical domain (Table 2.2, Table 2.3). This follows established methodologies presented Hoek & Bray (1981), Read & Stacey (2009), Styles et al. (2011), Martin (2019), Styles & Vakili (2020) for slope stability analysis in soil and rock in the Construction or Mining Industries. The analysis has been proven that the high the slope, the lower the slope angle to obtain a FoS=1.5.

The application of the slope height-angle curve was to input the slope height for a particular coastal cell and match it to a geotechnical domain equation from Figure 5.3). This then provides the landward crest ASCI. To create a composite slope the lower geotechnical domain would be combined with the upper geotechnical domain with the respective slope heights to facilitate the projection of the ASCI.

The above approach creates the coastal instability (CI) component under the ACCoP (2012) guidelines which could be combined with the toe erosion (E) component to form the ASCIE.

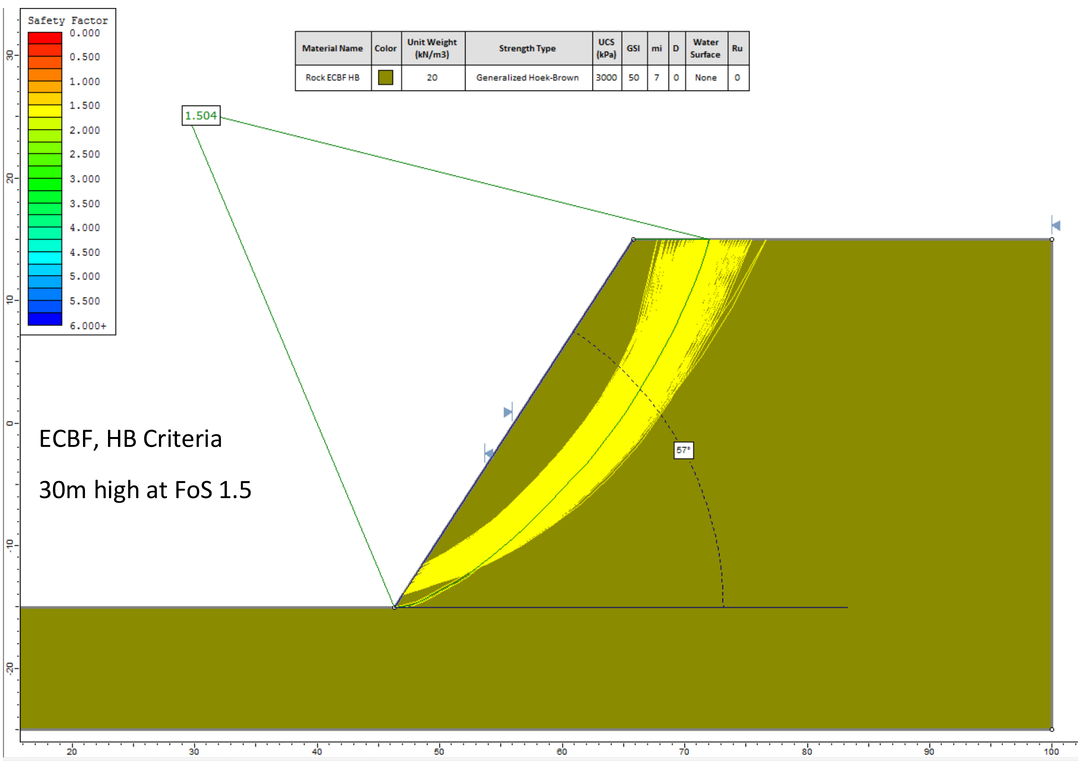


Figure 5.2: SLIDE analysis for FoS 1.5 under ACCoP (2012) for Waitemata Group (ECBF)

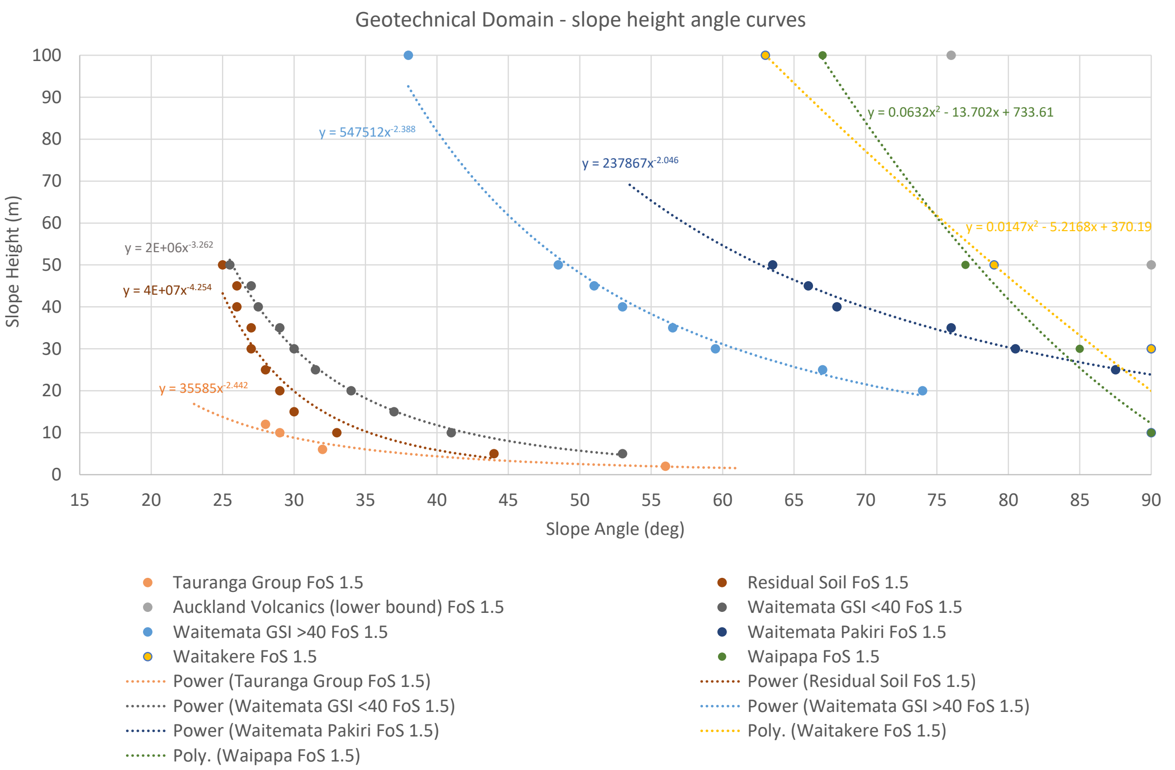


Figure 5.3: Geotechnical Domain SLIDE analysis for FoS 1.5 under ACCoP (2012) with fitted trend lines based on power law.

5.2.2 Considerations and assumptions

There were a series of considerations and assumptions made within the analysis, these are summarised as follows:

- Analyses was undertaken using Limit Equilibrium Modelling (LEM) software due to the number of assumptions in each geotechnical domain, with a circular or non-circular failure path defined by constraining the toe and the crest to ensure full slope height failed. This was to generate high level regional slope height-angle curves in very weak to weak rocks and soils. The models were run defining a non-circular slip surface through an ‘Auto refine search’ method.
- Finite Element Modelling (FEM) and with discontinuity networks were not modelled as these were considered too site specific and should only be undertaken at a site specific (Level D) assessment.
- Material strength modelling was undertaken using both Mohr-Coulomb and Gen Hoek-Brown (based on GSI values) strength parameter values to ensure that the resultant instability mechanisms and geometry produced compatible FoS (Pradhan and Siddique, 2020). The results of these two approaches were averaged to form one value for the Overall Slope Profile (OSP);
- The disturbance factor (D) within GSI was set at 0, but the research of Eberhardt (2012) and Hoek (2012) was considered in setting this parameter. Back analysis of the slope profiles indicated that if D was elevated to 0.5 or 1 the current slopes fail which was not observed and therefore 0 was adopted;
- Works undertaken by Baddiley (2012) on ground water and anisotropy were reviewed for the regional context. However, these characteristics were not modelled in this study as the variability was too high within each geotechnical domain. This should be considered at a local level, Level D.

- Coastal slopes within the Auckland region were generally observed as having a groundwater table at or near the toe of the slope profile. This is due to the free face created by the coastal slope drawing down the groundwater table, with seepage faces often at or close to the toe. Therefore, all slopes were modelled dry.
- The most common coastal failures within the Auckland region are residual soils failing above the rock (very weak to moderately strong), frequently as a result of temporal elevations in perched ground water conditions. This is not usually related to regional groundwater levels but a result of saturation (natural, seasonal and/or occasionally development related) of the upper section of the coastal slope. Modelling this variability has not been undertaken at a regional scale due to the complexity locating the position of the 'zero groundwater pressure' zone.
- The slope modelling is relatively reliable where the domains reflect relatively homogeneous soils and rock profiles where stability is not governed by structure and bedding.

5.3 Slope height curve method validation

For comparison purposes, a series of cliff profile cross sections were taken through the 2016 LiDAR DEM at 100-500 m alongshore intervals to develop coastal cliff profiles within the Waitemata Group. These were created by manually extracting cliff profiles from LiDAR DEM with visual interpretation from aerial photographs (purple in Figure 5.4**)**.

During the validation process it was noted that the natural slope heights and angles significantly less than the derived curve for a FoS 1.0, and more generally less that for FoS 1.5 (Waitemata Group - ECBF) rock layer. The slope curves will flatten (reducing slope angle, move to the left) when the upper soil slopes are included, as tentatively indicated on Figure 5.4. This is due to the soil or upper slope profiles being composed of a weaker strength geotechnical domain, resulting in a lower slope angles.

The results do generally indicate that the coastal slopes composed of Waitemata Group - ECBF, as shown in Figure 5.4 generally "stable" under current climatic conditions (left of the FoS 1.0 curve). This is confirmed in the field, as instability within the Waitemata Group - ECBF coastal slopes are rare, with most occurrences being sporadic and relating to localised geological structures (high angle topples and falls). These observations are also reflected by numerous data points plotting to the left of the FoS 1.5 Waitemata Group – ECBF rock curve.

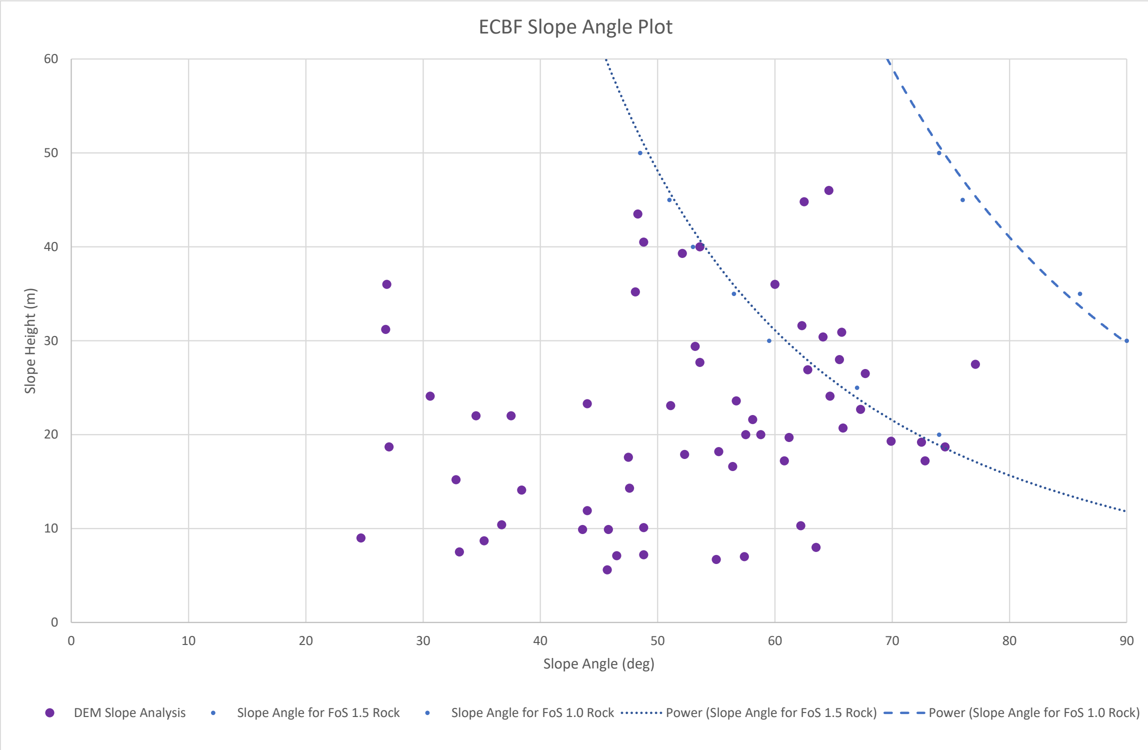


Figure 5.4: Slope stability curves for Waitemata Group ECBF comparing and manually measured combined slope heights and angles, and rock slope height and angles, with a FoS 1.0 and 1.5 trendline.

5.3.1 Discussion

The default failure or instability mechanisms adopted within the stability models were semi-rotational or non-circular, not representative of the high angle slides and high angle wedges observed in the field. International research supports similar methodologies to derive of ASCI or slope profiles through the generation of slope height angle curves for different geotechnical domains. The works of Styles et al. (2011) and Martin (2019) focus on similar mechanisms to the ones observed in the Auckland regional shoreline, but with substantially more information, data and sophisticated modelling packages suited to a site-specific scale, Level D not Level A (Table 1.1). The Auckland geology lacks the laboratory and field strength databases, along with the stress data that such stability models require to present meaningful results.

The slope height angle curves have been compared to those derived from the Reinen-Hamill et al. (2006) study to identify the influence of changing methodology (from one of fixed GSI and UCS to variable lithological specific material properties). A process of validation was then undertaken to compare the slope stability curves with selected actual cliff profile data. This indicated the Reinen-Hamill et al. (2006) slope height slope curves were lower than the T+T 2020 study, with associated wider ASCI zones.

At a regional scale, Levels A or B, rock structure can dominate the instability mechanisms resulting in the limit equilibrium analyses having significant limitations for the prediction of the ASCI. This then requires a local scale or site-specific scale assessment, such as a Level C or D assessment.

5.3.2 Summary

The slope angle-height curve methodology presented above follows from, and is a refinement of, the 2006 study (using geotechnical domains based on geological units of Figure 2.1 opposed to only GSI values). The adoption within this framework of a target FoS 1.5 also provides alignment of the outputs with the ACCoP (2012) for a regional level assessment (Level A or B, Table 1.1).

The applicability of the stable slope angle-height curve method is constrained by the particulars and limitations of the analytical techniques and parameters used. The modelling results demonstrate that the derived failure mechanisms, for a FoS=1.5, do not replicate actual observed failure mechanisms. The resultant outputs therefore provide only a relative proxy in the assessment of instability. This modelling techniques can be refined to local or site-specific assessments (Level C or D, Table 1.1) with the addition of location specific geotechnical data and coastal profiles.

In summary, it is likely the slope angle-height methodology, whilst useful at a regional scale, will generally result in over optimistic assessments of the ASCI.

6 Statistical method for coastal slope angles

Recognising the limitations of the slope angle-height methodology to determine ASCI (Section 4.3.2), an alternative method, based on statistical evaluation of data, was also developed to assess cliff slopes angles. The basic steps of this process are identified as follows, and presented in more detail in the following sections:

1 Extraction of data (including cliff profiles, heights and slopes)
2 Analyses of slope data
3 Rationalisation of cliff slope angles
4 Statistical validation

6.1 Extraction of data

To create a statistical method for determining the coastal slope angles a dataset was required to be created for the Auckland region. Therefore 50 selected coastal profiles, shown in Figure 6.2, are representative of each of the geotechnical domains or sub domains as identified in Section 2 (i.e. Table 2.1) and coastal environments (see locations in Figure 6.2), were evaluated.

For each profile the cliff toe, the crest of the rock layer and the crest of the soil layer were derived manually through the 2016 LiDAR DEM and interpretation of aerial photographs to obtain the height and slope of both the rock and soil layers (see Section 1.4).

6.2 Analysis of slope data

The derived cliff heights and slope angles from each profile were analysed to develop single composite slope angles for each geotechnical domain, or a combination of geotechnical domains. The composite slope angles were then plotted as scatter plots and slope angle statistics were derived. Figure 6.3 shows an example of a scatter plot including the rock, soil and combined slope angles for Waitemata Group - ECBF. This shows that slope angles for soil range from 10 to 50 degrees, for rock range from 26 to 80 degrees, and combined angles range from 20 to 75 degrees. The scatter plots of the other adopted lithologies are shown in Figure 6.4.

The derived slope angles were then graphed in the form of histograms, including cumulative distribution functions (CDFs) to further assess the data. For comparison the data was normalised, with a normal CDF included in the graphs to characterise the relative distribution of slope angles. An example showing both the scatter plot and histograms for Waitemata Group - ECBF is shown in Figure 6.3. The histograms of the other adopted lithologies are shown in Figure 6.5.

The scatter plots shown in Figure 6.3 and Figure 6.4 indicate the variability of the materials from soil to rock and the effect of slope height on the combined slope angles. The most variable material was the Auckland Volcanic Field/Coromandel domain with large slope heights and a large distribution of slope angles, Figure 6.5. The scatter of data is associated with the higher strength rocks and highly heterogeneous structures. The most uniform plot is that for the Awhitu domain, with a steep distribution and a low range of slope angles over a range of different heights, with the composite angles being clustered between a slope angle of 35 to 45° (due to the relativity homogeneous silts and sands).

The slope angle statistics were then derived from the distribution of slope angles for each lithology by relating the slope angle to a probability of exceedance. A range of associated domain slope angles were then evaluated, adopting The Intergovernmental Panel on Climate Change (IPCC) definitions for likelihood of occurrence. Only the lower three probability categories from the IPCC definitions were adopted for this assessment, as these provided the lower bound scenarios: Medium (33-66% - 50% Mean adopted), Unlikely (10-33% - 10% adopted) and Exceptionally Unlikely (1% adopted).

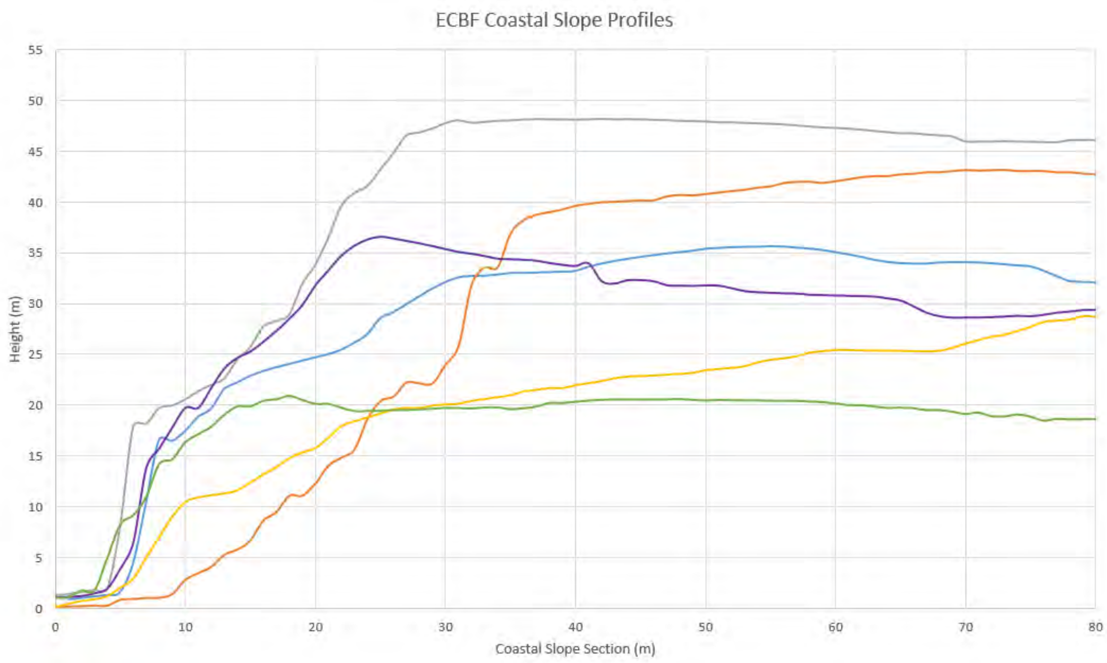


Figure 6.1: Six profiles developed from a single cell of ECBF on the east coast

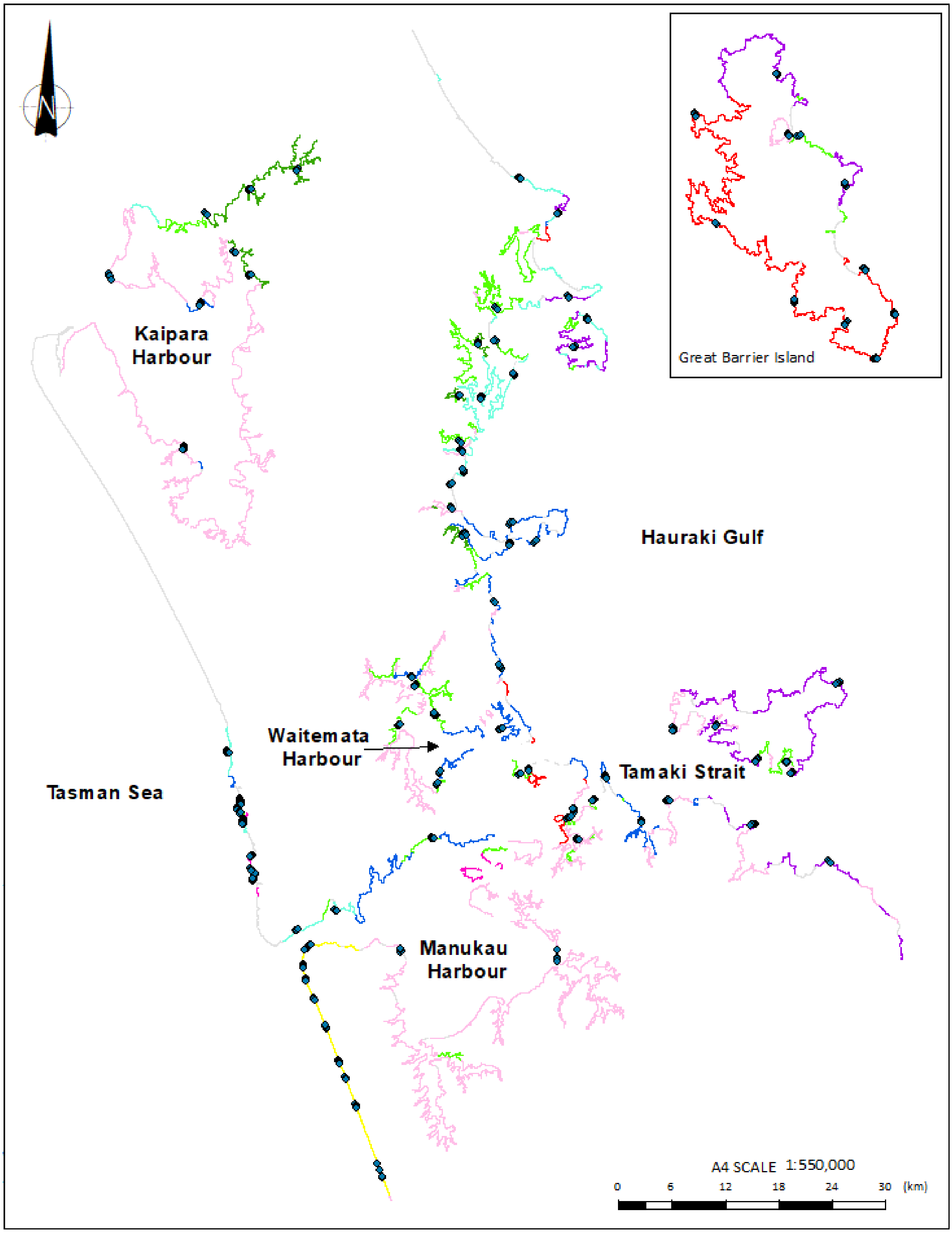


Figure 6.2: Cliff profile locations

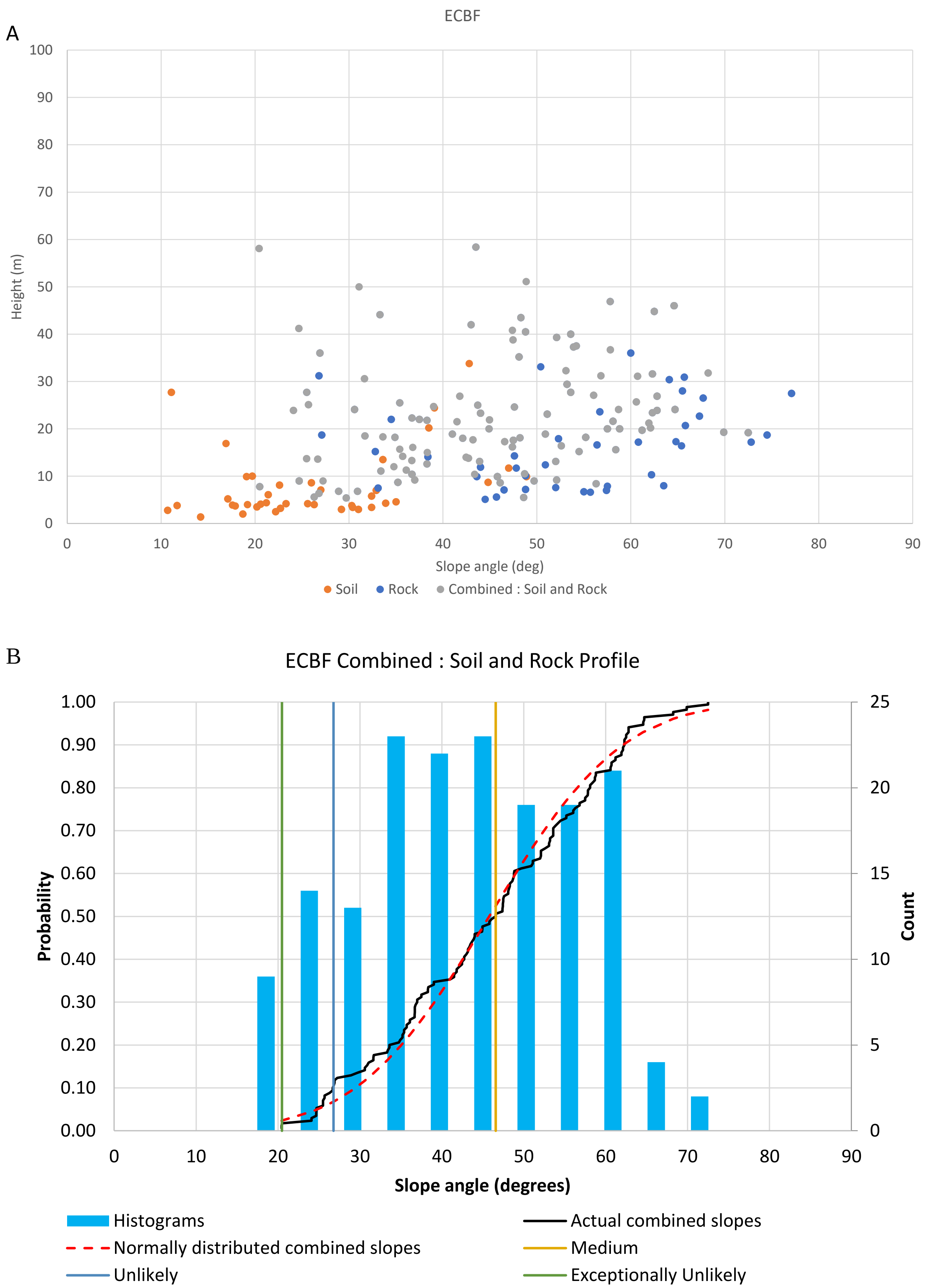
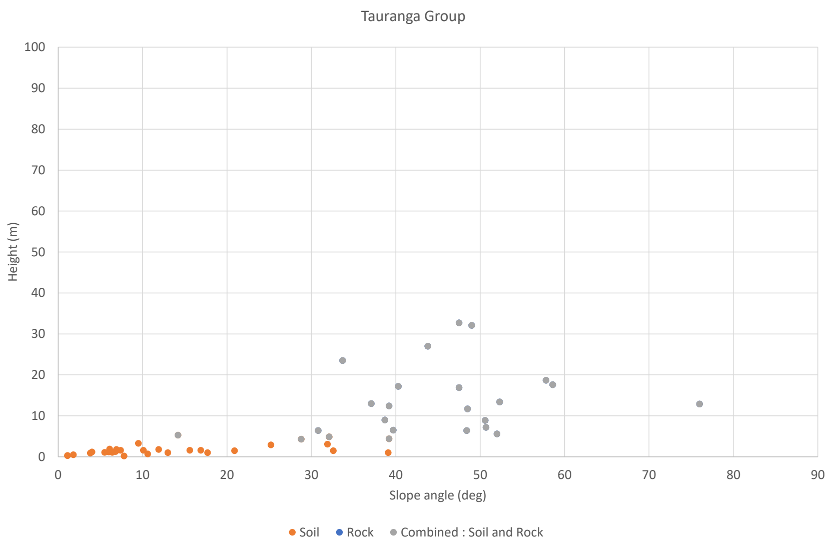
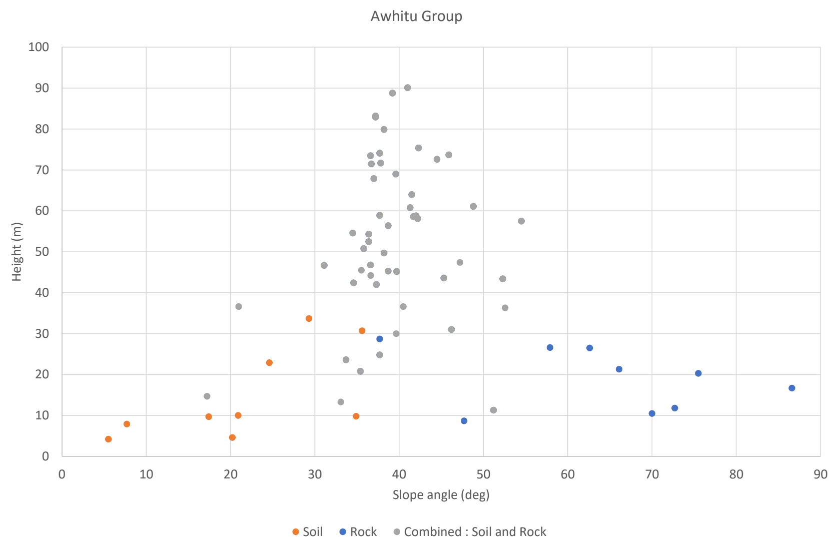
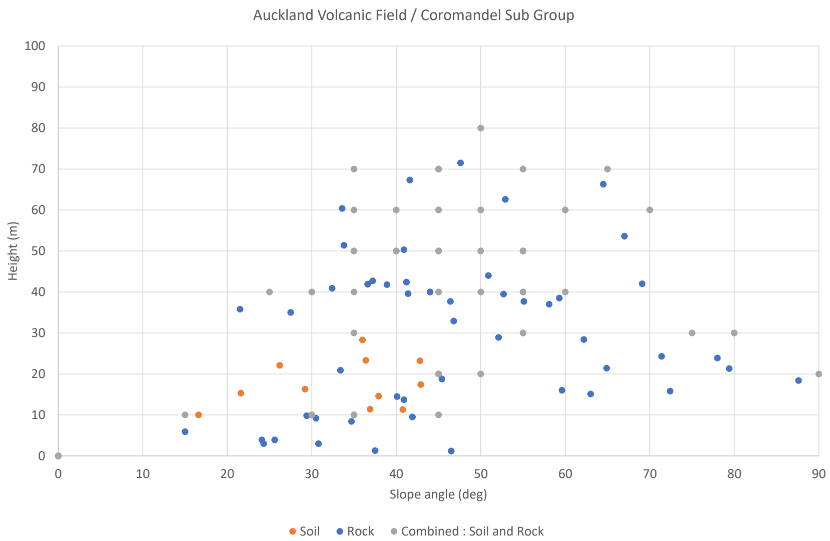
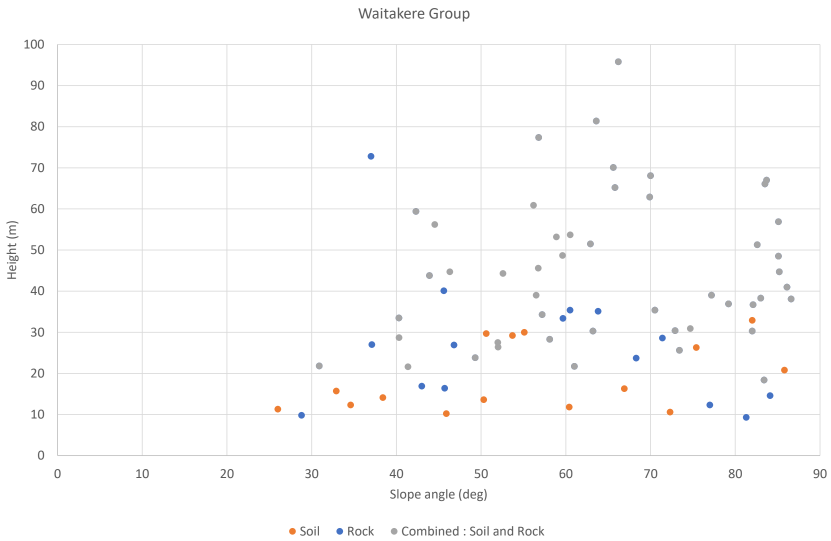


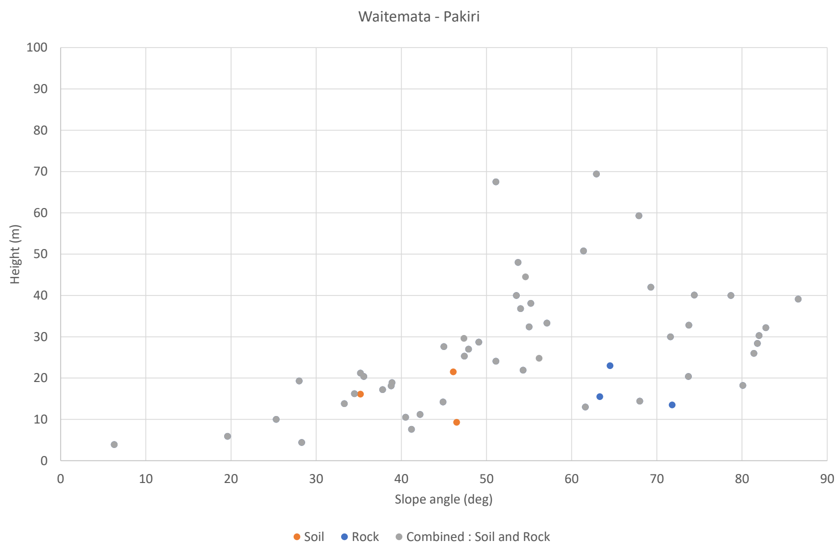
Figure 6.3: Statistical evaluation of the coastal instability slope angle for Waitemata Group - ECB, with scatter plot of rock, soil and combined slope angles (A) and histograms of combined slope angles including likelihoods and cumulative distribution functions (B)

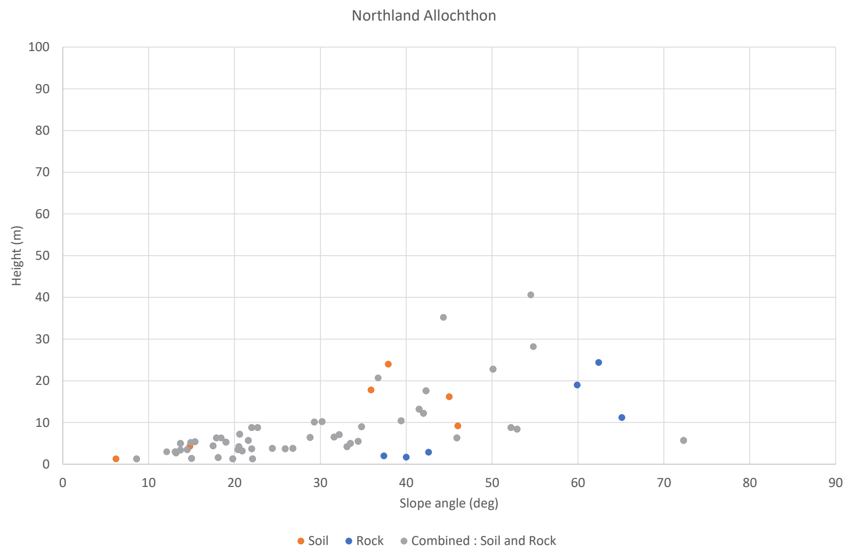

Tauranga Group
Height (m)
Slope angle (deg)
Soil
Rock
Combined : Soil and Rock


Awhitu Group
Height (m)
Slope angle (deg)
Soil
Rock
Combined : Soil and Rock


Auckland Volcanic Field / Coromandel Sub Group
Height (m)
Slope angle (deg)
Soil
Rock
Combined : Soil and Rock


Waitakere Group
Height (m)
Slope angle (deg)
Soil
Rock
Combined : Soil and Rock





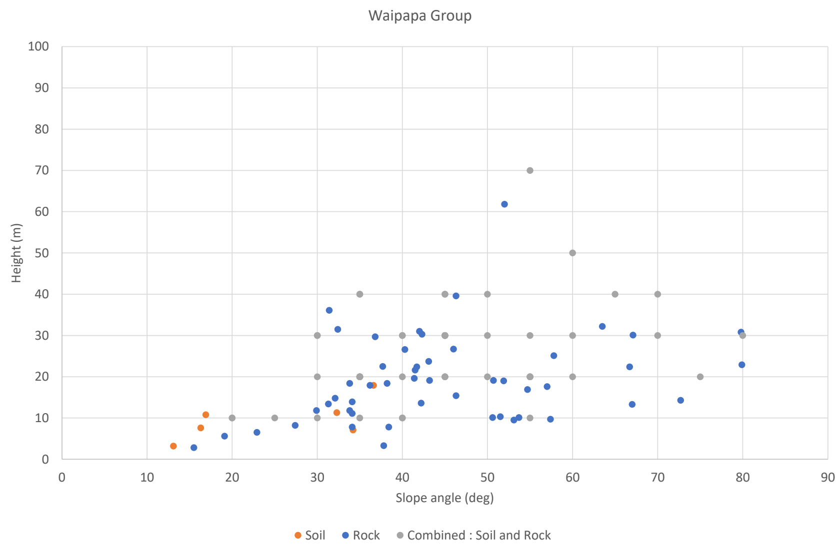
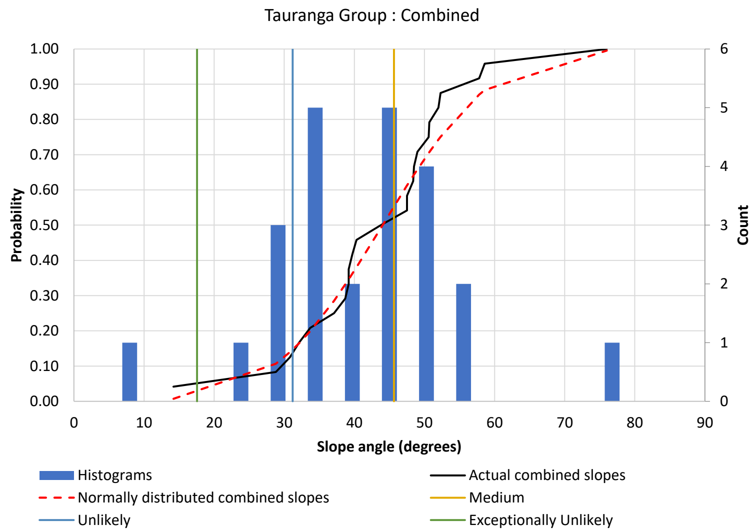
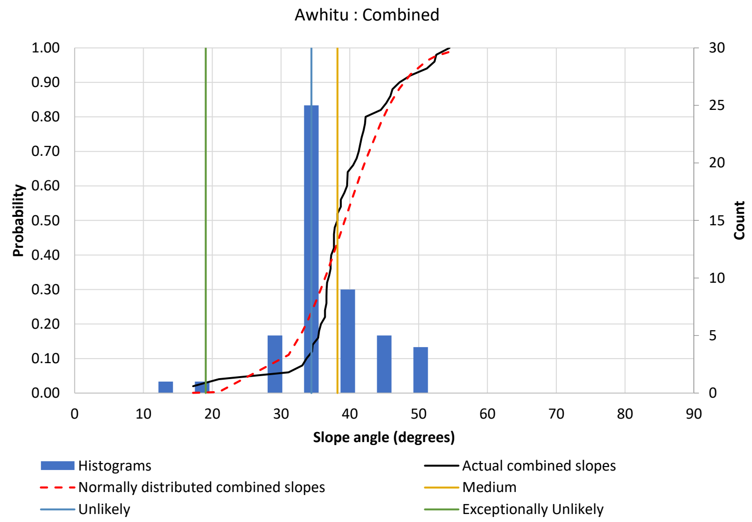
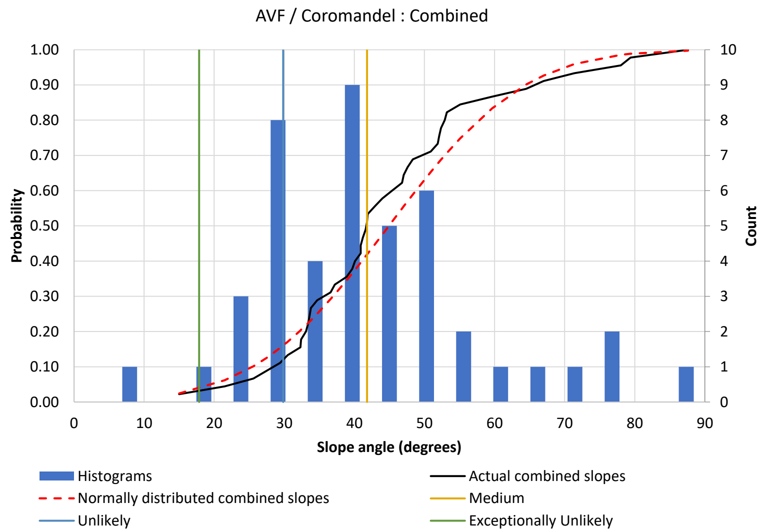
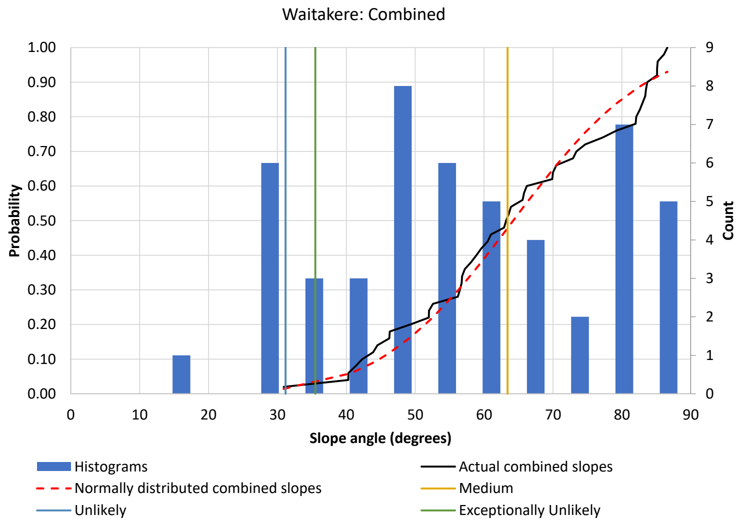


Figure 6.4: Slope angle scatter plots for remaining 8 units


Tauranga Group : Combined
Probability
Count
Slope angle (degrees)
Histograms
Normally distributed combined slopes
Unlikely
Actual combined slopes
Medium
Exceptionally Unlikely


Awhitu : Combined
Probability
Count
Slope angle (degrees)
Histograms
Normally distributed combined slopes
Unlikely
Actual combined slopes
Medium
Exceptionally Unlikely


AVF / Coromandel : Combined
Probability
Count
Slope angle (degrees)
Histograms
Normally distributed combined slopes
Unlikely
Actual combined slopes
Medium
Exceptionally Unlikely


Waitakere: Combined
Probability
Count
Slope angle (degrees)
Histograms
Normally distributed combined slopes
Unlikely
Actual combined slopes
Medium
Exceptionally Unlikely

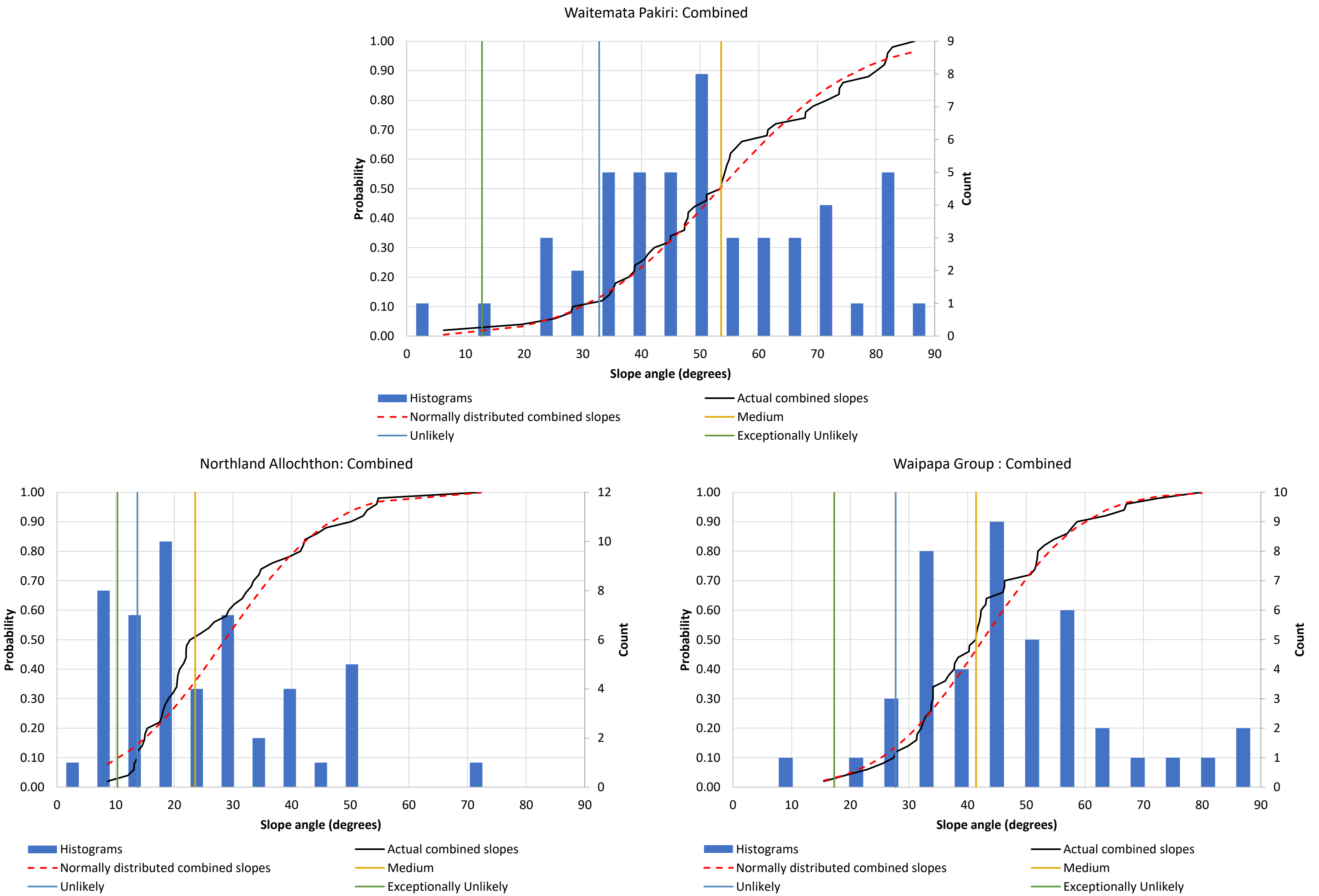


Figure 6.5: Slope angle Histograms and statistical distributions for remaining 8 units

The analysed slope angles for each geotechnical domain, separated into soil and rock groups, have then been combined to form a composite slope (rock toe to soil crest), as shown in Table 6.1. A ratio of rock to soil height was included as it has a significant impact on the composite slope angle.

Table 6.1: Analysed slope profile (rock, soil and combined) for each lithology

Geotechnical Domain	Rock (°)				Soil (°)				Rock/Soil ratio	Composite (°)			
	Mean height (m)	50%	10%	1%	Mean height (m)	50%	10%	1%		Mean height (m)	50%	10%	1%
Tauranga Group / Puketoka Formation					15	48	34	31		13	48	34	31
Awhitu Group	50	39	35	31	15	21	18	15	77%	53	38	33	30
Auckland Volcanic Field / Coromandel sub-group (East)	30	42	26	15	18	36	22	15	63%	37	42	24	15
Waitakere / Volcanic (West)	68	66	40	29	47	52	33	26	59%	48	63	38	28
Waitemata - ECBF	20	51	27	23	7	26	14	11	74%	24	48	27	24
Waitemata - Pakiri Formation	28	54	28	25	16	40	36	25	64%	29	54	28	25
Northland Allochthon	7	26	14	9	-	-	-	-		-	26	14	9
Waipapa Group	19	42	30	16	10	25	16	13	67%	20	42	31	16

6.3 Adopted slope angles

Once all of the geological domains for the Auckland region had been graphed and analysed, values of α (slope profile in degrees) for 'Unlikely' and 'Exceptionally Unlikely' conditions in rock and soil, the values were rationalised to derive composite slope profile. These α values considered the statistics from each geotechnical domain, the soil to rock height ratio along with engineering experience. The final values are set out in Table 6.2. It is proposed that the 'Unlikely' cliff slope is adopted for the regional level assessment of ASCI, with the 'Exceptionally Unlikely' cliff slopes representing the slope angle including uncertainty.

Table 6.2: Adopted ASCIE cliff slope angles

Lithology	Composite slope profile (°)		
	Medium	Unlikely	Exceptionally Unlikely
	50%	10%	1%
Tauranga Group/Puketoka Formation	48	34	31
Awhitu Group	38	33	30
Auckland Volcanic Field/Coromandel Volcanic Zone	42	32	28
Waitakere Group – Sedimentary Volcanics	63	38	28
Waitemata Group - ECBF	45	27	24
Waitemata Group - Pākiri Formation	54	28	25
Northland Allochthon	26	14	9
Waipapa Group	42	31	26

6.4 Validation of the Statistical method

The statistical method of analysis will provide an ASCI which is probably the most conservative for the two categories, “Unlikely” and “Exceptionally Unlikely”. This is due to a number of factors, which include, but are not limited to the following:

- Outlier data is being captured in the profiles analysed, where the coastal environments are significantly different to those where the angles are being applied. This is a product of the high-level regional assessment which needs to encompass all locations. The outliers could be manually removed but that would represent a change in the criteria from a regional scale assessment, Level A or B (Table 1.2) to a Level C, which is covered in a local area assessment.
- The age of the coastal slope has not been considered within this methodology. As the age of slopes increase they become flatter as a result of denudation, stress release and degradation of material properties (predominately cohesion or cementation) and an increase in the thickness or depth of the soil profile.
- This method reflects higher angle slope angles for coastal cliffs that are actively eroding or experience high frequency instability events as they are at equilibrium. This is highlighted by the slope angles of the Tauranga Group, as highlighted in Table 6.2, being steeper than the Auckland Volcanic group. This will be accounted for in the increase erosion (E) element of the ASCIE.
- The change in Waitemata Group ECBF requires rock mass properties to a sub-domain level, along with an account of the coastal slope formation and age. It was considered that the age of the coastal slope has a significant effect on the slope profile, and therefore the ASCIE area.

7 Conclusions and Recommendations

The review of Auckland regional coastline has provided two methodologies for the assessment of ASCI. Both methods use the same underlying geotechnical domains developed from the regional geology shown in Figure 2.1 and Table 2.1.

When the results of the two methods are compared for a sample coastal slope height of 30 m and 50 m in Waitemata ECBF rock the following are observed in Table 7.1.

Table 7.1: ASCI for the two methods

Methodology	Case	Slope Height 30m		Slope Height 50m	
		ASCI (m)	Slope profile (°)	ASCI (m)	Slope profile (°)
Slope curve	FoS 1.5	19.4	57	48.2	46
Statistical	Medium	27.5	48	45.0	48
	Unlikely	61.5	26	102.5	26
	Exceptionally Unlikely	82.4	20	137.4	20

Both methods have merits and limitations in different areas of the coastal slope instability assessment. It was therefore recommended, following conversations with Auckland Council and the Peer Review Panel, that the statistical field-based methodology should be applied for the region wide ASCI assessment. This was due to the highly diverse nature of the Auckland coastline and extremely variable underlying geology and geotechnical domains and a greater confidence in justification of the field-based statistics.

8 Applicability Section

This report has been prepared for the exclusive use of our client Auckland 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: Authorised for Tonkin & Taylor Ltd by:

Ben Westgate Robert Hillier

Senior Engineering Geologist Technical Director

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Appendix E: Summary of regional beach properties

Cell	Beach	Exposure - 12hr exceedance (m) or fetch (km)	Tidal Range (m)	Materials	Component values								
					LT (m/yr.)	uncertainty LT (m/yr.)	Source LT	ST (m)	uncertainty ST (m)	Source ST	MT (m)	Uncertainty MT (m)	Source MT
1	Pakiri North	4 m	2.3	Medium sand	-0.10	-0.05	Pakiri North beach profile analysis	15	5	Pakiri North beach profile analysis	10	5	Observed MT trend from beach profile analysis
2	Pakiri South	4 m	2.3	Medium sand	-0.40	-0.10	Pakiri South beach profile analysis	15	5	Pakiri South beach profile analysis	10	5	Observed MT trend from beach profile analysis
3	Omaha North	3 m	2.3	Fine sand	-0.40	-0.10	Omaha North beach profile analysis	20	5	Omaha North beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
4	Omaha South	3 m	2.3	Fine sand	0.00	-0.10	Omaha South beach profile analysis	30	8	Omaha South beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
5	Tawharanui	3 m	2.3	Sand	-0.05	-0.03	Rationalised based on Reinen-Hamill et al. (2006)	20	5	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
6	Jones Bay	1.5 m	2.5	Gravel	-0.04	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
7	Christian Bay	1.5 m	2.5	Sand (aerial)	-0.04	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
8	Snells Beach	2 m	2.5	Medium sand	-0.03	-0.02	Beach profile dataset too short, adopted -0.05m/year incl. uncertainty	5	3	Beach profile dataset too short, adopted Christian Bay values - similar exposure	N/A	N/A	Beach profile dataset too short, unlikely MT at this beach
9	Martins Bay	2 m	2.5	Fine sand	-0.03	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	8	4	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
10	Te Muri Beach	2 m	2.5	Sand	-0.05	-0.05	Rationalised based on Reinen-Hamill et al. (2006)	8	4	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
11	Wenderholm	2.5 m	2.5	Fine sand	-0.05	-0.05	Rationalised based on Reinen-Hamill et al. (2006)	8	4	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
12	Waiwera Beach	2.5 m	2.5	Sand	0.00	-0.10	T+T site-specific assessment values	8	4	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
13	Hatfields Beach	2.5 m	2.5	Sand	0.00	-0.02	Hatfields Beach beach profile analysis showed positive LT, but set to 0m/year in line with lower 95% CI value	8	4	Hatfields Beach beach profile analysis and Reinen-Hamill et al. (2006)	N/A	N/A	No clear MT trend observed from beach profile analysis
14	Orewa Beach	2.5 m	2.5	Sand	-0.20	-0.10	Orewa Beach beach profile analysis	15	5	Orewa Beach beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
15	Red Beach	2.5 m	2.5	Sand	0.00	-0.02	Red Beach beach profile analysis showed a slight positive LT, but set to 0m/year in line with lower 95% CI value	8	4	Red Beach beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
16	Stanmore Bay	2 m	2.5	Sand	-0.03	-0.02	Stanmore Bay beach profiles surveyed too infrequent to derive LT. Adopted -0.05m/year incl. uncertainty	10	5	Stanmore Bay beach profile analysis and Reinen-Hamill et al. (2006)	N/A	N/A	No clear MT trend observed from beach profile analysis
17	Manly Beach	2 m	2.5	Sand	-0.03	-0.02	Manly Beach beach profiles surveyed too infrequent to derive LT. Adopted -0.05m/year incl. uncertainty	8	4	Manly Beach beach profile analysis and Reinen-Hamill et al. (2006)	N/A	N/A	No clear MT trend observed from beach profile analysis
18	Tindalls Bay	2 m	2.5	Sand	-0.03	-0.02	Tindalls Bay beach profiles surveyed too infrequent to derive LT. Adopted -0.05m/year incl. uncertainty	5	3	Tindalls Bay beach profile analysis and Reinen-Hamill et al. (2006)	N/A	N/A	No clear MT trend observed from beach profile analysis
19	Army Bay	2.5 m	2.6	Sand	-0.03	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	8	4	Manly Beach - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach
20	Shakespeare Beach	2 m	2.6	Sand	-0.03	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	5	3	Arkles Bay - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach
21	Okoromai Bay	2 m	2.6	Sand	-0.03	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	5	3	Arkles Bay - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach
22	Matakatia	2 m	2.6	Coarse sand	-0.03	-0.02	Rationalised based on Reinen-Hamill et al. (2006)	5	3	Arkles Bay - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach
23	Arkles Bay	2 m	2.8	Medium sand	-0.03	-0.02	Arkles Bay beach profiles surveyed too infrequent to derive LT. Adopted Reinen-Hamill et al. (2006) values.	5	3	Arkles Bay beach profile analysis and Reinen-Hamill et al. (2006)	N/A	N/A	No clear MT trend observed from beach profile analysis
24	Karepiro Bay	2 m	2.8	Sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	5	3	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach
25	Long Bay	2.5 m	2.8	Fine sand	-0.08	-0.05	Long Bay beach profile analysis	7	3	Long Bay beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
26	Browns Bay	2.5 m	2.8	Medium sand	0.00	-0.02	Browns Bay beach profile analysis showed positive LT, which is unlikely to be maintained over the next 100years due to uncertainty in sediment budget. Therefore LT set to zero excl. uncertainty	7	3	Long Bay beach profile analysis due to more extensive dataset and similar exposure	N/A	N/A	No clear MT trend observed from beach profile analysis
27	Campbells Bay	2.5 m	2.8	Medium sand	0.00	-0.02	Campbells Bay beach profile analysis showed positive LT, which is unlikely to be maintained over the next 100years due to uncertainty in sediment budget. Therefore LT set to zero excl. uncertainty	7	3	Long Bay beach profile analysis due to more extensive dataset and similar exposure	N/A	N/A	No clear MT trend observed from beach profile analysis
28	Milford	2.5 m	2.8	Medium sand	-0.05	-0.05	Milford beach profile analysis	15	5	Milford beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
29	Takapuna	2.5 m	2.8	Coarse sand	0.00	-0.05	Takapuna beach profile analysis showed positive LT, but set to 0m/year in line with lower 95% CI value	15	5	Takapuna beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
30	Cheltenham	1.5 m	2.8	Coarse sand	-0.03	-0.02	Cheltenham beach profile analysis do not show realistic LT values (i.e. ranging from +0.5m/year to -0.25m/year). Therefore adopted -0.05m/year incl. uncertainty	7	3	Cheltenham beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis
31	Torpedo Bay	5 km	2.9	Coarse sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	No beach profile dataset, so adopted -5m incl. uncertainty - similar exposure to Kawakawa	N/A	N/A	No beach profile dataset, unlikely MT at this beach
32	Devonport Beach	5 km	2.9	Coarse sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	No beach profile dataset, so adopted -5m incl. uncertainty - similar exposure to Kawakawa	N/A	N/A	No beach profile dataset, unlikely MT at this beach
33	Okahu Bay	2.5 km	2.9	Coarse sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	No beach profile dataset, so adopted -5m incl. uncertainty - similar exposure to Kawakawa	N/A	N/A	No beach profile dataset, unlikely MT at this beach

Cell	Beach	Component values											
		DS (m)	uncertainty DS (m)	Closure slope (-)	uncertainty Closure slope (-)	SL 2050 (RCP8.5)	uncertainty SL 2050 (RCP8.5)	SL 2080 (RCP8.5)	uncertainty SL 2080 (RCP8.5)	SL 2130 (RCP8.5)	uncertainty SL 2130 (RCP8.5)	SL 2130 (RCP8.5+)	uncertainty SL 2130 (RCP8.5+)
1	Pakiri North	6.1	1.7	0.020	-0.005	7	2	18	6	46	15	62	21
2	Pakiri South	6.1	1.7	0.020	-0.005	7	2	18	6	46	15	62	21
3	Omaha North	3.5	0.9	0.020	-0.005	7	2	18	6	46	15	62	21
4	Omaha South	3.5	0.9	0.020	-0.005	7	2	18	6	46	15	62	21
5	Tawharanui	6.1	1.7	0.020	-0.005	7	2	18	6	46	15	62	21
6	Jones Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
7	Christian Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
8	Snells Beach	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
9	Martins Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
10	Te Muri Beach	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
11	Wenderholm	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
12	Waiwera Beach	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
13	Hatfields Beach	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
14	Orewa Beach	3.5	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
15	Red Beach	3.5	1.7	0.025	-0.005	6	1	14	4	36	9	49	12
16	Stanmore Bay	3.5	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
17	Manly Beach	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
18	Tindalls Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
19	Army Bay	3.5	1.7	0.025	-0.005	6	1	14	4	36	9	49	12
20	Shakespeare Beach	3.5	1.7	0.025	-0.005	6	1	14	4	36	9	49	12
21	Okoromai Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
22	Matakatia	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
23	Arkles Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
24	Karepiro Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
25	Long Bay	3.5	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
26	Browns Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
27	Campbells Bay	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
28	Milford	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
29	Takapuna	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
30	Cheltenham	2.6	0.9	0.025	-0.005	6	1	14	4	36	9	49	12
31	Torpedo Bay	2.6	0.9	0.080	-0.030	2	1	5	3	11	7	15	9
32	Devonport Beach	2.6	0.9	0.080	-0.030	2	1	5	3	11	7	15	9
33	Okahu Bay	2.6	0.9	0.080	-0.030	2	1	5	3	11	7	15	9

Cell	Beach	Resulting ASCIE									
		Current ASCIE	Current ASCIE including uncertainty	ASCIE 2050 (RCP8.5)	ASCIE 2050 (RCP8.5) including uncertainty	ASCIE 2080 (RCP8.5)	ASCIE 2080 (RCP8.5) including uncertainty	ASCIE 2130 (RCP8.5)	ASCIE 2130 (RCP8.5) including uncertainty	ASCIE 2130 (RCP8.5+)	ASCIE 2130 (RCP8.5+) including uncertainty
1	Pakiri North	-21	-26	-34	-42	-50	-60	-88	-105	-104	-126
2	Pakiri South	-21	-26	-43	-51	-68	-79	-121	-141	-137	-161
3	Omaha North	-23	-29	-42	-49	-65	-75	-113	-132	-129	-153
4	Omaha South	-33	-42	-40	-49	-51	-63	-79	-99	-95	-120
5	Tawharanui	-26	-31	-35	-40	-47	-55	-77	-93	-93	-114
6	Jones Bay	-8	-11	-14	-18	-24	-29	-48	-58	-61	-74
7	Christian Bay	-8	-11	-14	-18	-24	-29	-48	-58	-61	-74
8	Snells Beach	-8	-10	-14	-17	-24	-28	-47	-57	-60	-73
9	Martins Bay	-11	-15	-17	-21	-27	-32	-50	-61	-63	-76
10	Te Muri Beach	-11	-15	-18	-22	-28	-34	-52	-64	-65	-79
11	Wenderholm	-11	-15	-18	-22	-28	-34	-52	-64	-65	-79
12	Waiwera Beach	-11	-15	-16	-21	-25	-33	-47	-62	-60	-77
13	Hatfields Beach	-11	-15	-16	-21	-25	-31	-47	-57	-60	-73
14	Orewa Beach	-18	-24	-30	-36	-45	-54	-77	-92	-90	-107
15	Red Beach	-11	-16	-17	-22	-26	-32	-48	-58	-61	-74
16	Stanmore Bay	-13	-19	-20	-25	-30	-36	-53	-64	-66	-79
17	Manly Beach	-11	-15	-17	-21	-27	-32	-50	-61	-63	-76
18	Tindalls Bay	-8	-11	-14	-18	-24	-29	-47	-57	-60	-73
19	Army Bay	-11	-16	-18	-23	-28	-33	-51	-61	-64	-77
20	Shakespeare Beach	-8	-12	-15	-19	-25	-30	-48	-58	-61	-74
21	Okoromai Bay	-8	-11	-14	-18	-24	-29	-47	-57	-60	-73
22	Matakatia	-8	-11	-14	-18	-24	-29	-47	-57	-60	-73
23	Arkles Bay	-8	-11	-14	-18	-24	-29	-47	-57	-60	-73
24	Karepiro Bay	-8	-11	-14	-18	-24	-29	-47	-57	-60	-73
25	Long Bay	-10	-14	-18	-22	-30	-35	-56	-67	-68	-82
26	Browns Bay	-10	-13	-15	-19	-24	-29	-46	-56	-59	-72
27	Campbells Bay	-10	-13	-15	-19	-24	-29	-46	-56	-59	-72
28	Milford	-18	-23	-25	-30	-35	-42	-59	-71	-72	-87
29	Takapuna	-18	-23	-23	-29	-32	-39	-54	-66	-67	-81
30	Cheltenham	-10	-13	-16	-20	-26	-31	-49	-59	-62	-75
31	Torpedo Bay	-6	-8	-8	-11	-12	-16	-20	-28	-24	-34
32	Devonport Beach	-6	-8	-8	-11	-12	-16	-20	-28	-24	-34
33	Okahu Bay	-6	-8	-8	-11	-12	-16	-20	-28	-24	-34

Cell	Beach	Exposure - 12hr exceedance (m) or fetch (km)	Tidal Range (m)	Materials	Component values																					Resulting ASCIE									
					LT (m/yr.)	uncertainty LT (m/yr.)	Source LT	ST (m)	uncertainty ST (m)	Source ST	MT (m)	Uncertainty MT (m)	Source MT	DS (m)	uncertainty DS (m)	Closure slope (-)	uncertainty Closure slope (-)	SL 2050 (RCP8.5)	uncertainty SL 2050 (RCP8.5)	SL 2080 (RCP8.5)	uncertainty SL 2080 (RCP8.5)	SL 2130 (RCP8.5)	uncertainty SL 2130 (RCP8.5)	SL 2130 (RCP8.5+)	uncertainty SL 2130 (RCP8.5+)	Current ASCIE	Current ASCIE including uncertainty	ASCIE 2050 (RCP8.5)	ASCIE 2050 (RCP8.5) including uncertainty	ASCIE 2080 (RCP8.5)	ASCIE 2080 (RCP8.5) including uncertainty	ASCIE 2130 (RCP8.5)	ASCIE 2130 (RCP8.5) including uncertainty	ASCIE 2130 (RCP8.5+)	ASCIE 2130 (RCP8.5+) including uncertainty
34	Mission Bay	7 km	2.9	Coarse sand	-0.03	-0.02	Mission Bay beach profile dataset too short. Adopted -0.05m/year incl. uncertainty	7	3	Cheltenham beach profile analysis - similar exposure	N/A	N/A	Beach profile dataset too short, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-9	-12	-11	-15	-15	-19	-23	-31	-27	-37
35	Kohimaramara	7 km	2.9	Gravel	-0.03	-0.02	Kohimaramara beach profile dataset too short. Adopted -0.05m/year incl. uncertainty	7	3	Cheltenham beach profile analysis - similar exposure	N/A	N/A	Beach profile dataset too short, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-9	-12	-11	-15	-15	-19	-23	-31	-27	-37
36	St Heliers	7 km	2.9	Coarse sand	-0.03	-0.02	St Helliers beach profile dataset too short. Adopted -0.05m/year incl. uncertainty	7	3	Cheltenham beach profile analysis - similar exposure	N/A	N/A	Beach profile dataset too short, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-9	-12	-11	-15	-15	-19	-23	-31	-27	-37
37	Bucklands Beach	1.6 km	2.9	Sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
38	Eastern Beach	23 km	2.9	Coarse sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
39	Cockle Bay	13 km	2.9	Sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
40	Omana Beach	16 km	2.9	Sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
41	Maraetai	7.5 km	2.9	Coarse sand	-0.15	-0.05	Maraetai beach profile analysis	10	5	Maraetai beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-12	-17	-18	-23	-25	-32	-40	-50	-44	-55
42	Umupuia Beach	9.8 km	2.9	Medium sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty and Reinen-Hamill et al. (2006)	3	2	Rationalised based on Reinen-Hamill et al. (2006)	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
43	Wairoa Bay	12.5 km	2.9	Sand	-0.03	-0.02	No beach profile dataset, so adopted -0.05m/year incl. uncertainty	3	2	Umupuia Beach - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
44	Kawakawa	4 km	2.9	Sand	0.00	-0.02	Kawakawa beach profile analysis showed positive LT, but set to 0m/year in line with lower 95% CI value	3	2	Kawakawa beach profile analysis and Reinen-Hamill et al. (2006)	3	2	Kawakawa beach profile dataset	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-6	-9	-9	-13	-16	-24	-20	-30
45	Waimango Point	3 m	2.9	Gravel	-0.03	-0.02	Waimango Point beach profile analysis shows unrealistic LT (-0.66m/year), so Reinen-Hamill et al. (2006) value adopted	7	2	Waimanga Point beach profile analysis	N/A	N/A	No clear MT trend observed from beach profile analysis	1.7	0.9	0.025	-0.005	6	1	14	4	36	9	49	12	-9	-11	-15	-18	-25	-29	-48	-58	-61	-74
46	Oneroa Beach	3 m	2.8	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Reinen-Hamill et al. (2006) and Takapuna beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	3.5	0.9	0.025	-0.005	6	1	14	4	36	9	49	12	-18	-24	-25	-30	-35	-41	-58	-69	-71	-84
47	Onetangi Beach	3 m	2.8	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Reinen-Hamill et al. (2006) and Takapuna beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	3.5	0.9	0.025	-0.005	6	1	14	4	36	9	49	12	-18	-24	-25	-30	-35	-41	-58	-69	-71	-84
48	Owhiti Bay	2.5 m	2.6	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.025	-0.005	6	1	14	4	36	9	49	12	-7	-10	-13	-17	-23	-28	-46	-56	-59	-72
49	Man O'war Bay	24 km	2.6	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
50	Whakanewha Bay	15 km	2.8	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
51	Surfdale	13 km	2.8	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
52	Huruhi Bay	13 km	2.8	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
53	Whangapoua Beach	3.5 m	2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Pakiri beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	3.5	0.9	0.020	-0.005	7	2	18	6	46	15	62	21	-18	-24	-26	-32	-38	-46	-67	-83	-83	-104
54	Awana Bay	4 m	2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Pakiri beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	6.9	1.7	0.020	-0.005	7	2	18	6	46	15	62	21	-22	-27	-30	-36	-42	-50	-71	-87	-87	-108
55	Palmers Beach	4 m	2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Pakiri beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	3.5	0.9	0.020	-0.005	7	2	18	6	46	15	62	21	-18	-24	-26	-32	-38	-46	-67	-83	-83	-104
56	Kaitoke	4 m	2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Pakiri beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	3.5	0.9	0.020	-0.005	7	2	18	6	46	15	62	21	-18	-24	-26	-32	-38	-46	-67	-83	-83	-104
57	Medlands Beach	4 m	2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	15	5	Rationalised based on Pakiri beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	6.1	1.7	0.020	-0.005	7	2	18	6	46	15	62	21	-21	-26	-29	-35	-41	-49	-70	-86	-86	-107
58	Mulberry Grove	2 m	2.2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
59	Tryphena	2 m	2.2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
60	Okupu Bay	2.5 m	2.2	Sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Arkles Bay beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
61	Wattle Bay	4.5 km	3	Fine to medium sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	2.6	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-8	-11	-10	-14	-14	-18	-22	-30	-26	-36
62	Orua Bay	9 km	3	Fine to medium sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	2.6	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-8	-11	-10	-14	-14	-18	-22	-30	-26	-36
63	Big Bay	14.5 km	3	Fine to medium sand	-0.25	-0.15	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-16	-22	-26	-36	-46	-64	-50	-69
64	Grahams Beach	17 km	3	Fine to medium sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
65	Awhitu	17 km	3	Fine to medium sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
66	Glenbrook Beach	22 km	3	Fine to medium sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	3	2	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-5	-7	-7	-10	-11	-15	-19	-27	-23	-33
67	Clarkes Beach West	22 km	3	Fine to medium sand	-0.10	-0.05	T+T site-specific assessment values	5	3	Rationalised based on T+T site-specific assessment	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-11	-15	-17	-22	-29	-38	-33	-44
68	Clarkes Beach East	22 km	3	Fine to medium sand	-0.10	-0.05	T+T site-specific assessment values	5	3	Rationalised based on T+T site-specific assessment	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-11	-15	-17	-22	-29	-38	-33	-44
69	Huia	5 km	3	Fine to medium sand	-0.03	-0.02	Rationalised based onReinen-Hamill et al. (2006)	5	3	Rationalised based on Reinen-Hamill et al. (2006) and Clarkes Beach beach profile analysis - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35
70	Whatipu	5.5 m	2.9	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Rationalised based on Piha beach profile analysis - similar exposure	750	250	Rationalisation of the MT based on Blue and Kench (2018)	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-27	-37	-263	-513	-430	-680	-847	-1098	-872	-1123
71	Karekare Beach	5.5 m	2.9	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Rationalised based on Piha beach profile analysis - similar exposure	35	15	Rationalisation of the MT based on Blue and Kench (2018)	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-27	-37	-48	-67	-72	-92	-132	-160	-157	-191

					Component values																					Resulting ASCIE									
Cell	Beach	Exposure - 12hr exceedance (m) or fetch (km)	Tidal Range (m)	Materials	LT (m/yr.)	uncertainty LT (m/yr.)	Source LT	ST (m)	uncertainty ST (m)	Source ST	MT (m)	Uncertainty MT (m)	Source MT	DS (m)	uncertainty DS (m)	Closure slope (-)	uncertainty Closure slope (-)	SL 2050 (RCP8.5)	uncertainty SL 2050 (RCP8.5)	SL 2080 (RCP8.5)	uncertainty SL 2080 (RCP8.5)	SL 2130 (RCP8.5)	uncertainty SL 2130 (RCP8.5)	SL 2130 (RCP8.5+)	uncertainty SL 2130 (RCP8.5+)	Current ASCIE	Current ASCIE including uncertainty	ASCIE 2050 (RCP8.5)	ASCIE 2050 (RCP8.5) including uncertainty	ASCIE 2080 (RCP8.5)	ASCIE 2080 (RCP8.5) including uncertainty	ASCIE 2130 (RCP8.5)	ASCIE 2130 (RCP8.5) including uncertainty	ASCIE 2130 (RCP8.5+)	ASCIE 2130 (RCP8.5+) including uncertainty
72	Piha South	5.5 m	2.9	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Piha beach profile analysis	12	3	Rationalisation of the MT based on Blue and Kench (2018)	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-27	-37	-41	-52	-61	-74	-109	-133	-134	-164
73	Piha North	5.5 m	2.9	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Piha beach profile analysis	30	10	Rationalisation of the MT based on Blue and Kench (2018)	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-27	-37	-47	-61	-70	-86	-127	-153	-152	-184
74	Te Henga South	5.5 m	2.9	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Rationalised based on Piha beach profile analysis - similar exposure	50	25	Rationalisation of the MT based on Blue and Kench (2018)	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-27	-37	-53	-80	-80	-108	-147	-182	-172	-211
75	Te Henga North	5.5 m	2.9	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Rationalised based on Piha beach profile analysis - similar exposure	12	3	Rationalisation of the MT based on Blue and Kench (2018)	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-27	-37	-41	-52	-61	-74	-109	-133	-134	-164
76	Muriwai South	5.5 m	2.9	Medium sand	-0.80	-0.20	Muriwai South beach profile analysis	15	5	Rationalised based on Piha beach profile analysis - slightly less exposed	15	5	Rationalised based Muriwai South profile analysis	6.9	1.7	0.013	-0.003	11	3	28	8	70	21	95	28	-22	-27	-61	-71	-105	-121	-195	-226	-220	-256
77	Muriwai North	5.5 m	2.9	Medium sand	0.00	-0.10	Muriwai North beach profile analysis	20	10	Rationalised based on Piha beach profile analysis - similar exposure	15	5	Rationalised based Muriwai North profile analysis	8.7	2.6	0.013	-0.003	11	3	28	8	70	21	95	28	-29	-39	-44	-56	-64	-79	-114	-140	-138	-171
78	Waionui Inlet	5.5 m	3.1	Medium sand	0.00	-0.05	Set to 0m/year excl. uncertainty as the shoreline is expected to be dynamically stable over the long-term, but fluctuates over the medium-term (i.e. 10-50 years).	20	10	Rationalised based on Piha beach profile analysis - similar exposure	750	250	Rationalised based on Blue and Kench (2018)	1.7	0.9	0.013	-0.003	11	3	28	8	70	21	95	28	-22	-32	-258	-508	-424	-675	-842	-1093	-866	-1118
79	Shelly Beach	3 km	3.7	Coarse sand	-0.03	-0.02	No beach profile dataset, so -0.05m/year adopted	5	3	Rationalised based on Clarkes Beach - similar exposure	N/A	N/A	No beach profile dataset, unlikely MT at this beach	1.7	0.9	0.080	-0.030	2	1	5	3	11	7	15	9	-7	-10	-9	-13	-13	-17	-21	-29	-25	-35

Appendix F: Summary of regional cliff properties

		Component values																	Resulting ASCIE									
Cell_ID	Adopted Geology	Mean projected cliff height (m)	Typical upper bound projected cliff height (m)	Adopted Cliff Slope Angle (deg)	Uncertainty Cliff Slope Angle (deg)	Adopted LT (m/yr.)	Source LT	Uncertainty LT (m/yr.)	*m*	*Uncertainty m*	LTf 2050 (RCP8.5)	Uncertainty LTf 2050 (RCP8.5)	LTf 2080 (RCP8.5)	Uncertainty LTf 2080 (RCP8.5)	LTf 2130 (RCP8.5)	Uncertainty LTf 2130 (RCP8.5)	LTf 2130 (RCP8.5+)	Uncertainty LTf 2130 (RCP8.5+)	Current ASCIE	Current ASCIE including uncertainty	Mean ASCIE 2050 (RCP8.5M)	Typical upper bound ASCIE 2050 (RCP8.5M)	Mean ASCIE 2080 (RCP8.5M)	Typical upper bound ASCIE 2080 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5M)	Typical upper bound ASCIE 2130 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5H+)	Typical upper bound ASCIE 2130 (RCP8.5H+)
1	Pakiri Formation	32	60	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-59	-112	-54	-114	-57	-115	-61	-117	-61	-117
2	Pakiri Formation	95	161	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-179	-303	-178	-306	-181	-314	-185	-320	-185	-320
3	Pakiri Formation	127	178	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-239	-335	-241	-337	-246	-339	-251	-342	-251	-342
4	Pakiri Formation	43	143	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-81	-268	-78	-268	-81	-278	-87	-283	-87	-283
5	Pakiri Formation	74	193	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-138	-363	-138	-366	-141	-369	-144	-373	-144	-373
6	Waipapa Group	28	56	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-47	-94	-46	-97	-49	-99	-53	-103	-53	-103
7	Pakiri Formation	25	64	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-48	-121	-43	-120	-45	-122	-48	-123	-48	-123
8	ECBF	42	64	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-83	-126	-86	-128	-87	-129	-93	-135	-93	-135
9	Auckland Volcanic Field/Coromandel Volcanic Zone	50	72	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-81	-114	-85	-119	-87	-121	-89	-124	-89	-124
10	Auckland Volcanic Field/Coromandel Volcanic Zone	31	86	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-49	-138	-45	-145	-48	-147	-55	-150	-55	-150
11	ECBF	14	31	27	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-1	-1	-2	-2	-4	-4	-5	-4	-28	-61	-28	-64	-29	-65	-33	-68	-36	-69
12	Waipapa Group	24	45	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.10	0.10	-1	-1	-2	-2	-4	-3	-4	-3	-40	-74	-29	-73	-31	-75	-33	-77	-33	-77
13	Waipapa Group	31	36	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.10	0.10	-1	-1	-2	-2	-4	-3	-4	-3	-51	-60	-19	-61	-20	-64	-22	-67	-22	-67
14	Waipapa Group	6	23	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.10	0.10	-1	-1	-2	-2	-4	-3	-4	-3	-10	-39	-10	-13	-11	-34	-14	-40	-14	-40
15	ECBF	8	25	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-16	-49	-16	-50	-16	-50	-19	-52	-21	-53
16	ECBF	3	8	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-6	-17	-10	-20	-14	-31	-23	-45	-23	-45
17	ECBF	3	14	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-5	-28	-11	-18	-13	-29	-19	-43	-19	-43
18	ECBF	5	6	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-10	-13	-11	-14	-10	-18	-18	-27	-18	-27
19	Pakiri Formation	29	54	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-55	-101	-56	-101	-58	-104	-61	-106	-63	-107
20	Pakiri Formation	41	58	28	-3	-0.04	T+T (2020) regional study	-0.06	0.30	0.10	-2	-3	-4	-7	-7	-15	-8	-17	-77	-110	-78	-111	-80	-114	-84	-118	-85	-119
21	Pakiri Formation	16	36	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-29	-68	-23	-65	-24	-66	-26	-70	-27	-72
22	Pakiri Formation	39	61	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-72	-114	-73	-118	-75	-120	-79	-123	-79	-123
23	Pakiri Formation	37	56	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-69	-106	-70	-112	-72	-116	-76	-119	-76	-119
24	Pakiri Formation	51	70	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-95	-132	-98	-136	-100	-138	-104	-140	-104	-140
25	Waipapa Group	44	56	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-73	-93	-77	-98	-79	-101	-82	-104	-82	-104
26	Waipapa Group	41	64	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-69	-106	-72	-112	-74	-113	-80	-117	-80	-117
27	Waipapa Group	20	39	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-34	-65	-34	-69	-35	-70	-38	-73	-40	-74
28	Pakiri Formation	36	64	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-69	-119	-71	-121	-72	-122	-77	-124	-79	-125
29	Pakiri Formation	41	58	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-76	-109	-78	-110	-80	-111	-84	-115	-84	-115
30	Pakiri Formation	18	32	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-33	-61	-26	-62	-27	-65	-32	-73	-32	-73
31	Pakiri Formation	29	52	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-54	-97	-55	-101	-57	-103	-63	-111	-63	-111
32	ECBF	17	46	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-34	-91	-27	-88	-30	-90	-33	-94	-33	-94
33	ECBF	49	85	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-96	-167	-98	-167	-101	-170	-105	-175	-105	-175
34	ECBF	14	58	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-28	-113	-27	-112	-32	-131	-37	-141	-37	-141
35	ECBF	3	10	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-6	-19	-8	-14	-8	-17	-11	-24	-11	-24
36	ECBF	7	25	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-15	-50	-14	-45	-15	-46	-18	-52	-18	-52
37	Tauranga Group	3	9	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-4	-13	-5	-12	-7	-17	-12	-23	-12	-23
38	ECBF	3	9	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-6	-17	-7	-15	-8	-17	-12	-23	-12	-23
39	Tauranga Group	2	5	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-3	-8	-5	-8	-6	-13	-11	-17	-11	-17
40	ECBF	14	43	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-27	-84	-23	-80	-24	-81	-29	-85	-29	-85
41	Pakiri Formation	32	50	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-60	-95	-55	-95	-57	-96	-61	-100	-61	-100
42	Northland Allochthon	31	51	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-123	-205	-125	-215	-130	-221	-135	-230	-136	-231
43	Northland Allochthon	22	54	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-90	-218	-89	-219	-94	-221	-99	-224	-101	-224
44	ECBF	18	39	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-36	-76	-34	-78	-37	-81	-41	-83	-43	-84
45	Pakiri Formation	43	59	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-81	-111	-83	-111	-84	-112	-87	-114	-87	-114
46	Pakiri Formation	55	68	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-103	-128	-103	-129	-104	-130	-105	-132	-105	-132
47	Pakiri Formation	43	61	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-80	-114	-80	-118	-82	-120	-85	-122	-85	-122
48	Pakiri Formation	51	86	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-96	-161	-96	-160	-98	-162	-101	-165	-101	-165
49	Pakiri Formation	38	71	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-71	-134	-70	-134	-73	-136	-77	-138	-77	-138
50	Pakiri Formation	56	82	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-106	-154	-107	-155	-109	-157	-112	-159	-113	-160
51	Pakiri Formation	30	56	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-57	-106	-56	-114	-58	-115	-61	-118	-63	-118
52	Pakiri Formation	33	47	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-63	-88	-64	-90	-66	-93	-70	-98	-71	-99
53	Pakiri Formation	18	51	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-34	-95	-32	-96	-34	-97	-39	-100	-40	-102
54	Northland Allochthon	5	15	14	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-21	-59	-23	-60	-26	-64	-32	-69	-34	-70
55	ECBF	11	37	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-22	-73	-23	-74	-26	-78	-33	-85	-33	-85
56	Pakiri Formation	20	33	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-38	-62	-37	-66	-43	-68	-45	-70	-45	-70
57	Pakiri Formation	18	31	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-33	-58	-30	-59	-33	-62	-37	-65	-37	-65
58	Northland Allochthon	16	40	14	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-63	-159	-63	-158	-64	-159	-69	-160	-70	-161
59	ECBF	3	7	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-6	-14	-9	-17	-11	-18	-16	-23	-17	-24
60	Northland Allochthon	19	35	14	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-75	-141	-74	-145	-75	-151	-80	-157	-81	-158
61	Pakiri Formation	20	40	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-37	-75	-31	-73	-35	-77	-38	-79	-38	-79
62	Pakiri Formation	29	58	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-55	-110	-44	-109	-46	-111	-47	-116	-49	-118
63	Pakiri Formation	51	74	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-96	-139	-97	-140	-99	-141	-104	-147	-106	-148
64	Pakiri Formation	24	60	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-45	-113	-40	-111	-41	-111	-42	-114	-43	-115
65	Pakiri Formation	50	70	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-95	-132	-97	-137	-99	-139	-102	-142	-102	-142
66	ECBF	6	21	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-12	-40	-17	-46	-26	-56	-41	-80	-41	-80
67	Tauranga Group	2	4	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-3	-5	-7	-12	-10	-17	-21	-27	-22	-28
68	Pakiri Formation	50	72	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-94	-136	-88	-139	-90	-140	-95	-142	-95	-142
69	ECBF	18	62	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-34	-121	-37	-127	-46	-134	-60	-154	-60	-154
70	Tauranga Group	1	4	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-2	-6	-6	-9	-7	-14	-16	-27	-17	-28
71	Pakiri Formation	48	116	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-91	-218	-82	-220	-84	-222	-90	-225	-90	-225
72	Tauranga Group	3	15	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-23	-9	-28	-13	-39	-26	-58	-27	-59
73	Pakiri Formation	48	83	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-91	-156	-92	-158	-95	-166	-100	-169	-102	-171
74	Pakiri Formation	32	48	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-60	-90	-61	-94	-63	-96	-66	-99	-67	-100
75	Pakiri Formation	20	40	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-38	-74	-37	-76	-39	-78	-43	-81	-43	-81
76	Pakiri Formation	30	43	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-56	-82	-55	-82	-58	-84	-63	-88	-63	-88
77	Northland Allochthon	2	4	14	-5	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-7	-14	-11	-16	-14	-20	-22	-28	-22	-28
78	Tauranga Group	1	1	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-1	-2	-5	-5	-6	-8	-9	-12	-10	-13
79	Tauranga Group	3	9	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-5	-13	-7	-15	-13	-23	-19	-29	-20	-30
80	Tauranga Group	3	8	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-4	-11	-6	-13	-11	-19	-16	-26	-18	-28
81	Northland Allochthon	3	5	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-11	-19	-15	-22	-16	-24	-19	-32	-19	-32
82	Tauranga Group	1	3	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-2	-4	-4	-6	-5	-9	-8	-13	-9	-14
83	Tauranga Group	7	22	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.50	0.00	-3	-1	-6	-3	-13	-7	-15	-8	-10	-33	-12	-35	-16	-38	-24	-45	-27	-48
84	ECBF	30	62	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-59	-121	-61	-126	-63	-127	-68	-132	-68	-132
85	ECBF	16	37	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-31	-73	-32	-73	-34	-74	-40	-79	-40	-79
86	ECBF	35	44	27	-3	-0.15	T+T (2020) regional study	-0.06	0.40	0.10	-8	-5	-17	-10	-34	-23	-37	-27	-68	-87	-76	-95	-84	-105	-100	-121	-103	-124
87	ECBF	21	37	27	-3	-0.10	T+T (2020) regional study	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-41	-73	-43	-77	-50	-83	-62	-96	-65	-99
88	ECBF	15	23	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-28	-45	-30	-47	-33	-49	-40	-54	-41	-56
89	ECBF	25	46	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-49	-91	-50	-92	-51	-94	-55	-99	-55	-99
90	ECBF	34	47	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-66	-92	-68	-94	-70	-97	-76	-102	-78	-103
91	ECBF	16	24	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-31	-47	-32	-49	-34	-52	-40	-56	-41	-57
92	ECBF	28	38	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-56	-75	-57	-77	-59	-79	-65	-84	-66	-85
93	ECBF	41	58	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-81	-114	-85	-119	-88	-122	-93	-128	-94	-129

		Component values																	Resulting ASCIE									
Cell_ID	Adopted Geology	Mean projected cliff height (m)	Typical upper bound projected cliff height (m)	Adopted Cliff Slope Angle (deg)	Uncertainty Cliff Slope Angle (deg)	Adopted LT (m/yr.)	Source LT	Uncertainty LT (m/yr.)	*m*	*Uncertainty m*	LTf 2050 (RCP8.5)	Uncertainty LTf 2050 (RCP8.5)	LTf 2080 (RCP8.5)	Uncertainty LTf 2080 (RCP8.5)	LTf 2130 (RCP8.5)	Uncertainty LTf 2130 (RCP8.5)	LTf 2130 (RCP8.5+)	Uncertainty LTf 2130 (RCP8.5+)	Current ASCIE	Current ASCIE including uncertainty	Mean ASCIE 2050 (RCP8.5M)	Typical upper bound ASCIE 2050 (RCP8.5M)	Mean ASCIE 2080 (RCP8.5M)	Typical upper bound ASCIE 2080 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5M)	Typical upper bound ASCIE 2130 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5H+)	Typical upper bound ASCIE 2130 (RCP8.5H+)
94	ECBF	22	35	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-43	-69	-46	-72	-49	-76	-56	-85	-57	-87
95	ECBF	39	58	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-77	-114	-80	-117	-85	-123	-92	-134	-93	-136
96	ECBF	41	76	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-81	-148	-83	-152	-87	-155	-92	-164	-94	-165
97	ECBF	42	63	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-82	-124	-86	-127	-89	-130	-93	-133	-94	-134
98	ECBF	32	38	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-62	-74	-64	-76	-68	-78	-72	-82	-73	-82
99	ECBF	19	34	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-36	-66	-37	-70	-41	-73	-47	-78	-48	-79
100	ECBF	15	27	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-30	-54	-30	-53	-32	-55	-36	-58	-36	-58
101	ECBF	28	42	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-55	-83	-55	-85	-58	-87	-62	-92	-62	-92
102	ECBF	14	22	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-28	-43	-29	-45	-32	-47	-35	-50	-36	-52
103	ECBF	38	57	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-75	-112	-78	-120	-81	-124	-87	-134	-87	-134
104	ECBF	37	46	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-73	-91	-74	-92	-76	-94	-78	-97	-78	-97
105	ECBF	12	22	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-24	-43	-23	-41	-24	-43	-27	-46	-27	-46
106	ECBF	23	31	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-45	-61	-45	-63	-47	-65	-50	-68	-50	-68
107	ECBF	30	36	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-59	-71	-61	-73	-63	-75	-67	-78	-67	-78
108	ECBF	39	61	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-77	-119	-79	-121	-80	-123	-83	-126	-83	-126
109	ECBF	37	57	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-72	-111	-75	-114	-76	-115	-79	-116	-79	-116
110	ECBF	34	67	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-66	-132	-64	-132	-66	-132	-72	-156	-72	-156
111	ECBF	20	52	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-38	-102	-38	-103	-39	-104	-45	-109	-45	-109
112	Northland Allochthon	7	18	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-26	-71	-26	-72	-28	-74	-33	-79	-33	-79
113	Northland Allochthon	12	34	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-49	-136	-50	-137	-54	-140	-62	-151	-62	-151
114	ECBF	22	50	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-43	-98	-32	-95	-34	-99	-37	-102	-37	-102
115	ECBF	18	58	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-35	-113	-39	-120	-48	-131	-62	-142	-62	-142
116	Tauranga Group	5	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-13	-11	-19	-17	-27	-29	-54	-31	-56
117	ECBF	10	27	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-20	-54	-18	-56	-20	-57	-23	-59	-23	-59
118	ECBF	30	42	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-58	-83	-54	-84	-55	-86	-59	-89	-59	-89
119	ECBF	27	46	27	-3	-0.03	T+T (2020) regional study	-0.04	0.30	0.10	-1	-2	-3	-5	-6	-10	-6	-11	-54	-90	-54	-90	-56	-92	-59	-95	-59	-95
120	Tauranga Group	13	19	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-19	-29	-19	-29	-21	-32	-27	-37	-28	-39
121	Tauranga Group	16	33	34	-3	-0.07	T+T studies 2006-2018	-0.04	0.40	0.10	-4	-3	-8	-6	-17	-13	-19	-16	-24	-49	-23	-50	-26	-54	-35	-63	-37	-65
122	ECBF	26	39	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-51	-77	-50	-79	-53	-81	-56	-84	-56	-84
123	Tauranga Group	13	27	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-19	-39	-18	-42	-19	-43	-23	-47	-23	-47
124	ECBF	29	44	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-56	-85	-57	-85	-59	-88	-62	-90	-62	-90
125	ECBF	17	32	27	-3	-0.03	T+T studies 2006-2018	-0.02	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-34	-62	-30	-61	-32	-63	-35	-65	-35	-65
126	ECBF	25	35	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-50	-69	-51	-72	-52	-74	-55	-76	-56	-78
127	ECBF	12	25	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-23	-50	-22	-51	-24	-53	-28	-56	-29	-57
128	Tauranga Group	3	11	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-5	-17	-6	-17	-8	-21	-11	-26	-12	-28
129	Auckland Volcanic Field/Coromandel Volcanic Zone	4	12	32	-4	-0.02	T+T studies 2006-2018	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	-6	-20	-8	-14	-8	-15	-10	-19	-10	-19
130	ECBF	26	35	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-50	-68	-51	-71	-55	-74	-59	-79	-60	-80
131	ECBF	15	26	27	-3	-0.05	T+T (2020) regional study	-0.05	0.30	0.10	-2	-3	-5	-6	-9	-13	-10	-15	-29	-50	-26	-51	-29	-54	-30	-58	-31	-59
132	ECBF	17	21	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-33	-41	-33	-41	-36	-45	-40	-49	-41	-51
133	Auckland Volcanic Field/Coromandel Volcanic Zone	34	62	32	-4	-0.05	T+T (2020) regional study	-0.03	0.05	0.05	-2	-1	-3	-2	-6	-4	-6	-4	-55	-99	-56	-99	-59	-102	-66	-107	-67	-108
134	ECBF	11	25	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-21	-49	-20	-49	-21	-50	-24	-53	-25	-54
135	ECBF	4	12	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-7	-24	-10	-25	-11	-27	-14	-31	-16	-32
136	Tauranga Group	3	11	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-17	-13	-22	-18	-36	-32	-54	-34	-57
137	Tauranga Group	5	13	34	-3	-0.10	T+T studies 2006-2018	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-19	-11	-28	-17	-33	-29	-46	-30	-47
138	ECBF	17	28	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-34	-54	-33	-57	-36	-59	-39	-63	-40	-65
139	ECBF	28	47	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-54	-92	-58	-95	-61	-98	-66	-102	-68	-104
140	ECBF	31	55	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-62	-108	-63	-111	-68	-114	-72	-118	-73	-119
141	ECBF	52	86	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-102	-169	-104	-173	-108	-179	-112	-187	-113	-189
142	ECBF	24	60	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-47	-118	-46	-119	-52	-122	-58	-126	-59	-128
143	ECBF	17	49	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-33	-95	-35	-98	-38	-104	-45	-116	-45	-116
144	Tauranga Group	6	14	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-8	-20	-9	-22	-12	-25	-15	-29	-16	-30
145	Tauranga Group	6	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-9	-15	-13	-21	-18	-27	-30	-41	-32	-42
146	Tauranga Group	6	16	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-9	-23	-8	-25	-13	-33	-19	-38	-20	-39
147	Tauranga Group	10	31	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-15	-45	-18	-54	-26	-62	-36	-73	-39	-75
148	ECBF	19	49	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-38	-95	-39	-97	-44	-105	-53	-117	-53	-117
149	ECBF	23	53	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-45	-104	-47	-108	-51	-110	-61	-117	-61	-117
150	ECBF	12	22	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-23	-44	-24	-46	-27	-49	-32	-55	-32	-55
151	Tauranga Group	7	12	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-10	-17	-15	-25	-20	-31	-32	-42	-33	-43
152	ECBF	11	28	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-22	-55	-25	-64	-32	-78	-44	-94	-44	-94
153	Tauranga Group	9	19	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-13	-28	-17	-34	-23	-41	-35	-52	-37	-54
154	Tauranga Group	6	11	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-9	-17	-11	-19	-15	-22	-20	-27	-21	-29
155	Tauranga Group	5	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-13	-11	-19	-16	-24	-28	-36	-29	-37
156	Tauranga Group	4	9	34	-3	-0.03	T+T studies 2006-2018	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-6	-14	-7	-14	-9	-17	-14	-21	-14	-21
157	Tauranga Group	5	11	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-8	-16	-8	-17	-13	-21	-19	-26	-20	-27
158	Tauranga Group	3	6	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-5	-9	-5	-10	-8	-15	-13	-20	-14	-21
159	Tauranga Group	6	11	34	-3	-0.14	T+T studies 2006-2018	-0.07	0.40	0.10	-7	-5	-15	-12	-31	-25	-35	-29	-8	-16	-13	-21	-23	-31	-41	-50	-45	-54
160	ECBF	4	12	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-8	-23	-12	-28	-18	-32	-31	-49	-32	-50
161	ECBF	12	36	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-24	-71	-25	-75	-28	-77	-34	-81	-34	-81
162	Tauranga Group	4	11	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-6	-16	-9	-21	-16	-30	-29	-47	-33	-51
163	Tauranga Group	4	8	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-12	-8	-17	-14	-23	-26	-36	-27	-37
164	Tauranga Group	5	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-7	-14	-8	-18	-17	-23	-28	-34	-31	-37
165	Tauranga Group	3	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-11	-9	-16	-15	-22	-28	-37	-29	-38
166	ECBF	4	10	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-8	-19	-11	-22	-15	-28	-21	-32	-22	-34
167	ECBF	7	16	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-13	-31	-16	-37	-21	-41	-33	-54	-34	-54
168	ECBF	13	23	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-25	-46	-25	-47	-28	-50	-32	-53	-32	-53
169	ECBF	13	30	27	-3	-0.07	T+T studies 2006-2018	-0.04	0.20	0.10	-3	-2	-6	-5	-12	-9	-12	-10	-25	-58	-25	-63	-28	-68	-36	-74	-36	-74
170	ECBF	9	14	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-18	-28	-19	-31	-25	-36	-34	-45	-34	-45
171	Auckland Volcanic Field/Coromandel Volcanic Zone	6	16	32	-4	-0.04	T+T studies 2006-2018	-0.02	0.05	0.05	-1	-1	-3	-2	-5	-3	-5	-3	-10	-26	-12	-33	-17	-38	-24	-47	-26	-50
172	Auckland Volcanic Field/Coromandel Volcanic Zone	10	23	32	-4	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.05	0.05	-3	-1	-6	-2	-12	-4	-12	-5	-15	-36	-21	-43	-27	-50	-41	-66	-43	-68
173	ECBF	38	58	27	-3	-0.05	T+T studies 2006-2018	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-75	-113	-78	-117	-80	-119	-84	-124	-86	-125
174	ECBF	19	47	27	-3	-0.04	T+T studies 2006-2018	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-37	-93	-38	-103	-41	-105	-45	-110	-46	-111
175	Auckland Volcanic Field/Coromandel Volcanic Zone	4	12	32	-4	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.05	0.05	-3	-1	-6	-2	-12	-4	-12	-5	-6	-19	-12	-24	-16	-29	-29	-44	-30	-45
176	Tauranga Group	4	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-13	-10	-17	-12	-23	-24	-35	-25	-37

		Component values																	Resulting ASCIE									
Cell_ID	Adopted Geology	Mean projected cliff height (m)	Typical upper bound projected cliff height (m)	Adopted Cliff Slope Angle (deg)	Uncertainty Cliff Slope Angle (deg)	Adopted LT (m/yr.)	Source LT	Uncertainty LT (m/yr.)	*m*	*Uncertainty m*	LTf 2050 (RCP8.5)	Uncertainty LTf 2050 (RCP8.5)	LTf 2080 (RCP8.5)	Uncertainty LTf 2080 (RCP8.5)	LTf 2130 (RCP8.5)	Uncertainty LTf 2130 (RCP8.5)	LTf 2130 (RCP8.5+)	Uncertainty LTf 2130 (RCP8.5+)	Current ASCIE	Current ASCIE including uncertainty	Mean ASCIE 2050 (RCP8.5M)	Typical upper bound ASCIE 2050 (RCP8.5M)	Mean ASCIE 2080 (RCP8.5M)	Typical upper bound ASCIE 2080 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5M)	Typical upper bound ASCIE 2130 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5H+)	Typical upper bound ASCIE 2130 (RCP8.5H+)
177	Tauranga Group	6	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-8	-13	-9	-15	-14	-20	-25	-30	-26	-31
178	Tauranga Group	5	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-10	-9	-13	-13	-18	-23	-28	-24	-29
179	Auckland Volcanic Field/Coromandel Volcanic Zone	1	1	32	-4	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	-1	-2	-9	-9	-8	-10	-6	-12	-6	-12
180	Auckland Volcanic Field/Coromandel Volcanic Zone	5	13	32	-4	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	-8	-20	-8	-19	-8	-20	-9	-22	-9	-22
181	Tauranga Group	4	6	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-10	-8	-14	-12	-18	-23	-30	-24	-31
182	Tauranga Group	4	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-11	-10	-15	-16	-23	-27	-36	-28	-37
183	Tauranga Group	4	6	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-6	-9	-9	-13	-14	-18	-24	-28	-25	-29
184	Tauranga Group	4	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-6	-10	-9	-15	-14	-20	-25	-30	-26	-31
185	Tauranga Group	4	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-6	-10	-9	-16	-14	-22	-25	-34	-26	-35
186	Tauranga Group	4	9	34	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-2	-1	-4	-3	-4	-3	-6	-13	-7	-13	-8	-15	-11	-19	-11	-19
187	ECBF	5	16	27	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-1	-3	-2	-3	-3	-10	-32	-11	-31	-11	-32	-12	-33	-12	-33
188	Tauranga Group	6	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-8	-13	-12	-18	-17	-23	-28	-34	-29	-35
189	ECBF	5	8	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-9	-15	-12	-19	-17	-23	-26	-31	-26	-31
190	Tauranga Group	3	5	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-4	-8	-5	-12	-10	-16	-22	-26	-23	-28
191	Tauranga Group	3	6	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-9	-8	-15	-13	-19	-25	-31	-26	-32
192	Tauranga Group	3	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-10	-7	-15	-13	-21	-25	-33	-26	-34
193	Tauranga Group	6	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-8	-14	-13	-19	-19	-25	-32	-40	-33	-41
194	Tauranga Group	4	6	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-9	-8	-14	-13	-18	-24	-29	-25	-30
195	ECBF	4	9	27	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-1	-3	-2	-3	-3	-7	-17	-8	-14	-8	-15	-9	-17	-9	-17
196	Tauranga Group	4	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-14	-9	-20	-14	-25	-27	-36	-29	-37
197	ECBF	11	21	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-21	-41	-21	-42	-23	-46	-26	-50	-28	-51
198	ECBF	17	29	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-34	-58	-36	-67	-40	-71	-49	-80	-50	-81
199	ECBF	28	37	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-54	-73	-60	-79	-64	-83	-74	-94	-75	-95
200	ECBF	24	30	27	-3	-0.06	T+T (2020) regional study	-0.03	0.30	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-47	-59	-48	-62	-51	-65	-56	-70	-57	-71
201	ECBF	34	41	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-67	-80	-69	-84	-71	-86	-74	-89	-76	-90
202	ECBF	16	26	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-31	-51	-31	-54	-35	-56	-38	-60	-39	-61
203	ECBF	32	40	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-63	-79	-64	-81	-67	-83	-70	-87	-71	-88
204	ECBF	21	40	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-42	-78	-40	-81	-42	-83	-46	-86	-47	-87
205	ECBF	16	39	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-30	-77	-32	-85	-34	-87	-39	-91	-40	-93
206	Tauranga Group	3	8	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-5	-11	-6	-12	-9	-17	-13	-23	-15	-25
207	ECBF	10	26	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-20	-51	-21	-51	-22	-53	-28	-60	-29	-62
208	Tauranga Group	3	18	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-4	-27	-9	-28	-12	-33	-22	-43	-25	-45
209	ECBF	16	25	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-32	-50	-39	-62	-45	-65	-59	-80	-60	-81
210	Tauranga Group	4	18	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-6	-26	-11	-31	-15	-37	-27	-52	-28	-53
211	Tauranga Group	11	17	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-17	-25	-18	-28	-22	-31	-27	-37	-28	-38
212	ECBF	7	15	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-14	-29	-15	-32	-18	-36	-23	-40	-25	-41
213	Waipapa Group	9	22	31	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-15	-37	-15	-42	-18	-51	-26	-62	-26	-62
214	Waipapa Group	30	55	31	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-50	-91	-56	-101	-61	-108	-70	-116	-70	-116
215	Waipapa Group	27	54	31	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-45	-91	-45	-90	-49	-93	-56	-100	-56	-100
216	Tauranga Group	6	34	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-9	-50	-12	-56	-18	-64	-32	-81	-35	-85
217	Tauranga Group	16	39	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-24	-57	-20	-60	-25	-70	-35	-78	-36	-79
218	Tauranga Group	1	2	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-1	-3	-8	-15	-13	-21	-26	-33	-30	-39
219	Waipapa Group	20	37	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-34	-62	-36	-63	-39	-64	-43	-67	-45	-68
220	Waipapa Group	26	52	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-44	-86	-42	-88	-43	-89	-47	-92	-49	-93
221	Waipapa Group	27	52	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-46	-86	-45	-88	-47	-89	-52	-93	-53	-94
222	Waipapa Group	24	57	31	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-40	-95	-39	-98	-44	-102	-51	-106	-52	-107
223	Tauranga Group	25	42	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.50	0.00	-6	-1	-13	-3	-27	-7	-30	-8	-37	-63	-40	-68	-48	-76	-64	-91	-68	-94
224	Waipapa Group	17	40	31	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-28	-67	-27	-65	-34	-69	-40	-73	-42	-74
225	Tauranga Group	6	14	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.50	0.00	-3	-1	-6	-3	-13	-7	-15	-8	-10	-20	-9	-19	-13	-22	-21	-32	-24	-34
226	Waipapa Group	21	52	31	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-36	-86	-36	-88	-42	-94	-50	-102	-52	-104
227	ECBF	47	75	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-91	-147	-90	-145	-91	-146	-95	-150	-95	-150
228	Waipapa Group	45	74	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-75	-123	-75	-126	-78	-128	-80	-131	-80	-131
229	Tauranga Group	3	13	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.50	0.00	-6	-1	-13	-3	-27	-7	-30	-8	-5	-20	-8	-24	-17	-38	-33	-67	-36	-71
230	Auckland Volcanic Field/Coromandel Volcanic Zone	55	134	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-88	-214	-76	-212	-79	-215	-84	-222	-84	-222
231	Waipapa Group	48	103	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-80	-172	-76	-173	-78	-175	-81	-177	-81	-177
232	ECBF	41	73	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-80	-142	-79	-145	-80	-146	-84	-149	-84	-149
233	ECBF	18	46	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-36	-90	-26	-88	-27	-90	-30	-95	-30	-95
234	Auckland Volcanic Field/Coromandel Volcanic Zone	38	78	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-61	-125	-50	-125	-52	-126	-56	-128	-56	-128
235	Auckland Volcanic Field/Coromandel Volcanic Zone	69	178	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-110	-285	-108	-282	-111	-284	-115	-288	-115	-288
236	Auckland Volcanic Field/Coromandel Volcanic Zone	28	54	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-45	-87	-45	-88	-49	-92	-55	-99	-55	-99
237	Auckland Volcanic Field/Coromandel Volcanic Zone	35	54	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-56	-87	-58	-89	-64	-104	-70	-110	-70	-110
238	Auckland Volcanic Field/Coromandel Volcanic Zone	43	96	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-68	-154	-64	-153	-67	-156	-71	-160	-71	-160
239	Auckland Volcanic Field/Coromandel Volcanic Zone	89	145	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-143	-233	-136	-232	-140	-233	-144	-235	-144	-235
240	Auckland Volcanic Field/Coromandel Volcanic Zone	40	116	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-64	-185	-54	-185	-59	-186	-63	-189	-63	-189
241	Auckland Volcanic Field/Coromandel Volcanic Zone	47	135	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-76	-217	-73	-210	-76	-217	-81	-223	-81	-223
242	Auckland Volcanic Field/Coromandel Volcanic Zone	23	48	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-37	-77	-31	-74	-34	-79	-38	-88	-38	-88
243	Auckland Volcanic Field/Coromandel Volcanic Zone	25	66	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-41	-105	-38	-100	-43	-105	-50	-120	-50	-120
244	Auckland Volcanic Field/Coromandel Volcanic Zone	45	95	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-71	-151	-71	-151	-74	-152	-82	-153	-82	-153
245	Auckland Volcanic Field/Coromandel Volcanic Zone	42	115	32	-4	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	-1	-2	-1	-4	-2	-4	-2	-67	-184	-62	-182	-66	-185	-71	-190	-71	-190
246	Waipapa Group	88	226	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-146	-376	-142	-380	-144	-381	-148	-384	-148	-384
247	Waipapa Group	124	278	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-207	-463	-209	-460	-210	-461	-212	-464	-212	-464
248	Waipapa Group	98	301	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-163	-501	-162	-506	-164	-508	-168	-510	-168	-510
249	Pakiri Formation	36	53	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-68	-100	-68	-100	-71	-103	-74	-109	-75	-111
250	Pakiri Formation	39	52	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-73	-98	-74	-102	-76	-104	-78	-107	-79	-108
251	Pakiri Formation	40	66	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-75	-124	-77	-129	-80	-131	-85	-136	-86	-137
252	Pakiri Formation	35	55	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-66	-103	-67	-104	-70	-107	-73	-111	-74	-112
253	Waipapa Group	41	69	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-68	-115	-70	-118	-72	-119	-74	-121	-75	-122
254	Waipapa Group	59	85	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-98	-141	-100	-144	-103	-146	-107	-149	-107	-149
255	Waipapa Group	39	71	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-65	-118	-68	-120	-70	-124	-74	-128	-75	-129
256	Pakiri Formation	25	41	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-47	-77	-49	-78	-52	-86	-55	-89	-56	-90
257	Waipapa Group	36	57	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-59	-95	-61	-97	-64	-99	-69	-105	-70	-106
258	Waipapa Group	20	36	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-33	-60	-33	-61	-34	-62	-37	-66	-38	-67
259	Pakiri Formation	36	50	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-68	-94	-70	-97	-71	-98	-75	-102	-77	-103
260	Waipapa Group	36	50	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-60	-83	-60	-88	-62	-89	-65	-94	-66	-96
261	Waipapa Group	37	62	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-62	-104	-63	-105	-64	-106	-68	-109	-70	-110
262	ECBF	43	68	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-84	-133	-85	-133	-87	-135	-91	-137	-92	-139
263	Waipapa Group	28	52	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-47	-86	-46	-89	-48	-90	-53	-94	-54	-95
264	Pakiri Formation	31	57	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-58	-107	-59	-110	-60	-111	-64	-115	-65	-116
265	Waipapa Group	24	36	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-39	-60	-37	-60	-39	-61	-41	-64	-42	-65
266	Waipapa Group	31	44	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-51	-74	-48	-77	-49	-78	-52	-81	-54	-83
267	Waipapa Group	23	41	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-38	-68	-34	-69	-39	-70	-43	-72	-43	-72
268	Waipapa Group	22	48	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-36	-81	-30	-76	-34	-80	-38	-84	-38	-84
269	Waipapa Group	28	39	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-47	-64	-45	-66	-46	-68	-51	-71	-52	-72
270	Waipapa Group	31	49	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-51	-82	-49	-81	-50	-83	-54	-90	-55	-92
271	Waipapa Group	16	28	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-26	-47	-23	-49	-24	-50	-26	-53	-28	-54

		Component values																	Resulting ASCIE									
Cell_ID	Adopted Geology	Mean projected cliff height (m)	Typical upper bound projected cliff height (m)	Adopted Cliff Slope Angle (deg)	Uncertainty Cliff Slope Angle (deg)	Adopted LT (m/yr.)	Source LT	Uncertainty LT (m/yr.)	*m*	*Uncertainty m*	LTf 2050 (RCP8.5)	Uncertainty LTf 2050 (RCP8.5)	LTf 2080 (RCP8.5)	Uncertainty LTf 2080 (RCP8.5)	LTf 2130 (RCP8.5)	Uncertainty LTf 2130 (RCP8.5)	LTf 2130 (RCP8.5+)	Uncertainty LTf 2130 (RCP8.5+)	Current ASCIE	Current ASCIE including uncertainty	Mean ASCIE 2050 (RCP8.5M)	Typical upper bound ASCIE 2050 (RCP8.5M)	Mean ASCIE 2080 (RCP8.5M)	Typical upper bound ASCIE 2080 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5M)	Typical upper bound ASCIE 2130 (RCP8.5M)	Mean ASCIE 2130 (RCP8.5H+)	Typical upper bound ASCIE 2130 (RCP8.5H+)
272	ECBF	26	52	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-51	-102	-49	-103	-55	-106	-60	-111	-62	-113
273	Waipapa Group	30	55	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-50	-91	-49	-93	-50	-94	-54	-97	-55	-98
274	Waipapa Group	48	107	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-80	-179	-75	-177	-77	-179	-80	-182	-80	-182
275	Waipapa Group	46	67	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-76	-111	-75	-111	-78	-113	-81	-116	-81	-116
276	Waipapa Group	37	88	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-62	-147	-58	-137	-61	-141	-65	-148	-65	-148
277	Waipapa Group	28	47	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-47	-79	-47	-83	-50	-87	-56	-96	-56	-96
278	Waipapa Group	21	57	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-34	-95	-36	-100	-40	-101	-45	-103	-46	-103
279	Waipapa Group	26	55	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-43	-92	-40	-94	-41	-96	-45	-99	-47	-100
280	Waipapa Group	29	46	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-48	-77	-42	-78	-42	-81	-46	-85	-48	-86
281	Waipapa Group	27	67	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-46	-112	-45	-113	-47	-114	-53	-116	-54	-117
282	Waipapa Group	29	47	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-48	-78	-42	-76	-43	-80	-47	-85	-49	-86
283	Tauranga Group	19	39	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-29	-58	-23	-60	-25	-62	-32	-71	-33	-73
284	ECBF	20	54	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-39	-106	-40	-109	-47	-119	-63	-142	-64	-143
285	Tauranga Group	24	53	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-36	-78	-33	-77	-36	-82	-44	-96	-46	-100
286	ECBF	27	62	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-54	-122	-43	-118	-45	-125	-50	-129	-51	-131
287	Waipapa Group	4	5	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-6	-8	3	1	2	1	1	0	1	0
288	Waipapa Group	32	80	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-53	-133	-52	-140	-52	-142	-56	-147	-58	-149
289	Waipapa Group	33	57	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-55	-95	-37	-96	-39	-98	-37	-102	-39	-103
290	Waipapa Group	33	50	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-56	-84	-58	-88	-59	-89	-63	-93	-64	-94
291	Waipapa Group	28	56	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-47	-93	-46	-96	-47	-97	-50	-100	-51	-101
292	Waipapa Group	12	26	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-21	-44	-16	-43	-18	-45	-21	-51	-22	-52
293	Waipapa Group	27	52	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-45	-87	-41	-83	-43	-84	-48	-89	-50	-91
294	Waipapa Group	19	33	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-31	-55	-28	-56	-28	-56	-31	-58	-32	-58
295	Waipapa Group	22	41	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-37	-68	-32	-70	-33	-73	-34	-81	-35	-82
296	Waipapa Group	27	51	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-45	-85	-44	-88	-46	-90	-51	-95	-52	-98
297	Waipapa Group	22	52	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-36	-86	-23	-79	-25	-83	-28	-86	-28	-86
298	Waipapa Group	3	7	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-5	-12	-7	-18	-10	-20	-13	-24	-13	-24
299	Tauranga Group	2	5	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-3	-7	-4	-10	-5	-12	-8	-16	-9	-17
300	Tauranga Group	10	27	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-15	-40	-15	-43	-17	-49	-21	-54	-22	-56
301	Waipapa Group	19	42	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-31	-71	-25	-71	-28	-74	-30	-78	-30	-78
302	Tauranga Group	2	3	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-2	-4	-9	-12	-10	-15	-10	-19	-10	-20
303	Tauranga Group	4	9	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.30	0.10	-2	-1	-4	-3	-7	-6	-8	-7	-7	-13	-11	-21	-15	-24	-19	-29	-20	-30
304	Waipapa Group	7	17	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-11	-27	-12	-28	-15	-37	-19	-42	-19	-42
305	Waipapa Group	20	47	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-33	-78	-25	-74	-27	-78	-30	-82	-30	-82
306	Waipapa Group	28	41	31	-5	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-46	-68	-46	-68	-48	-70	-53	-73	-54	-74
307	Tauranga Group	19	33	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-28	-49	-28	-51	-31	-53	-37	-58	-38	-59
308	Tauranga Group	22	35	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-33	-52	-37	-59	-40	-65	-48	-70	-49	-71
309	Tauranga Group	20	44	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-30	-65	-29	-65	-31	-67	-37	-74	-37	-74
310	Waipapa Group	25	48	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-42	-79	-39	-79	-41	-80	-44	-82	-44	-82
311	Waipapa Group	33	51	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-55	-85	-55	-86	-57	-87	-60	-90	-60	-90
312	Waipapa Group	26	50	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-44	-83	-43	-85	-45	-87	-47	-90	-47	-90
313	Waipapa Group	29	48	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-48	-80	-46	-83	-47	-85	-50	-89	-50	-89
314	Waipapa Group	35	47	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-58	-79	-57	-80	-59	-82	-63	-85	-63	-85
315	Waipapa Group	26	44	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-43	-73	-39	-74	-42	-76	-45	-79	-45	-79
316	Waipapa Group	44	62	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-74	-103	-57	-103	-58	-106	-60	-109	-60	-109
317	Tauranga Group	32	38	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.50	0.00	-2	-1	-4	-2	-8	-4	-9	-5	-47	-57	-37	-59	-39	-61	-41	-66	-42	-68
318	Waipapa Group	32	42	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-53	-70	-50	-69	-52	-70	-55	-73	-55	-73
319	Waipapa Group	38	64	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-64	-106	-62	-109	-65	-111	-69	-114	-69	-114
320	Waipapa Group	37	58	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-62	-96	-65	-98	-68	-99	-71	-101	-71	-101
321	Waipapa Group	46	74	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-77	-123	-77	-127	-79	-130	-84	-132	-84	-132
322	Waipapa Group	41	71	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-68	-117	-64	-120	-67	-123	-71	-127	-71	-127
323	Waipapa Group	41	71	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-68	-118	-70	-124	-73	-126	-76	-129	-76	-129
324	Waipapa Group	22	47	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-36	-78	-35	-74	-38	-84	-42	-88	-42	-88
325	Waipapa Group	28	54	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-46	-89	-48	-95	-51	-98	-55	-101	-55	-101
326	Waipapa Group	59	88	31	-5	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-99	-147	-101	-156	-103	-158	-108	-161	-108	-161
327	Tauranga Group	31	52	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.50	0.00	-2	-1	-4	-2	-8	-4	-9	-5	-46	-77	-52	-86	-55	-88	-61	-92	-63	-93
328	Awhitu Group	19	47	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-29	-72	-26	-80	-27	-81	-33	-85	-33	-85
329	Awhitu Group	46	116	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-70	-179	-65	-182	-66	-184	-74	-189	-74	-189
330	Awhitu Group	73	127	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-113	-196	-119	-200	-120	-202	-128	-206	-128	-206
331	Awhitu Group	90	162	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-138	-249	-141	-256	-143	-257	-150	-262	-150	-262
332	Awhitu Group	90	169	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-138	-260	-142	-266	-144	-267	-150	-273	-150	-273
333	Awhitu Group	97	179	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-149	-276	-149	-283	-150	-284	-156	-288	-156	-288
334	Awhitu Group	122	170	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-188	-261	-194	-268	-195	-269	-200	-273	-200	-273
335	Awhitu Group	111	176	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-171	-271	-173	-276	-175	-276	-181	-280	-181	-280
336	Awhitu Group	98	132	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-151	-203	-159	-212	-161	-214	-170	-219	-170	-219
337	Awhitu Group	102	161	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-158	-247	-165	-256	-167	-257	-174	-262	-174	-262
338	Awhitu Group	157	227	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-241	-349	-248	-355	-259	-364	-277	-371	-277	-371
339	Awhitu Group	78	242	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-120	-373	-120	-373	-121	-374	-126	-377	-126	-377
340	Awhitu Group	32	63	33	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-50	-96	-50	-103	-55	-106	-61	-111	-61	-111
341	Tauranga Group	28	38	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-42	-56	-46	-62	-47	-63	-51	-66	-51	-66
342	Tauranga Group	21	33	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-2	-1	-3	-2	-7	-5	-7	-6	-30	-49	-30	-51	-32	-52	-36	-56	-36	-56
343	Tauranga Group	8	21	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-12	-31	-16	-38	-23	-45	-37	-63	-41	-69
344	Tauranga Group	7	22	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-11	-32	-13	-35	-20	-43	-34	-61	-38	-65
345	Tauranga Group	4	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-6	-13	-8	-18	-13	-24	-24	-36	-25	-37
346	Tauranga Group	9	21	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-13	-32	-17	-38	-22	-44	-35	-62	-36	-63
347	Tauranga Group	6	12	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-9	-17	-11	-22	-15	-27	-27	-40	-28	-41
348	Tauranga Group	6	12	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-8	-17	-12	-23	-17	-28	-28	-40	-29	-41
349	ECBF	7	15	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-4	-2	-8	-4	-16	-8	-16	-9	-14	-30	-17	-34	-22	-39	-32	-49	-32	-49
350	Tauranga Group	5	9	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-8	-13	-11	-18	-15	-22	-26	-33	-27	-34
351	Tauranga Group	5	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-7	-15	-12	-19	-23	-36	-37	-48	-40	-51
352	Tauranga Group	1	2	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-2	-3	-7	-15	-10	-21	-23	-37	-26	-41
353	Tauranga Group	2	5	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-3	-8	-7	-15	-11	-21	-22	-34	-23	-36
354	Tauranga Group	2	12	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-3	-18	-9	-18	-14	-29	-27	-49	-31	-53
355	Tauranga Group	4	8	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-11	-8	-17	-13	-22	-24	-35	-25	-36
356	Tauranga Group	5	8	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-12	-9	-15	-14	-21	-26	-39	-28	-40
357	Tauranga Group	5	9	34	-3	-0.15	T+T studies 2006-2018	-0.07	0.30	0.10	-7	-5	-14	-11	-28	-22	-30	-25	-7	-13	-11	-18	-19	-27	-35	-43	-37	-46
358	Tauranga Group	6	12	34	-3	-0.15	T+T studies 2006-2018	-0.07	0.30	0.10	-7	-5	-14	-11	-28	-22	-30	-25	-9	-18	-14	-23	-22	-30	-38	-45	-40	-47
359	Tauranga Group	3	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-5	-11	-9	-16	-14	-21	-25	-33	-27	-35
360	Tauranga Group	6	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-9	-14	-8	-15	-13	-20	-23	-30	-24	-31
361	Tauranga Group	4	8	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-11	-12	-21	-17	-25	-28	-36	-29	-37
362	Tauranga Group	4	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-6	-14	-9	-19	-14	-25	-26	-36	-27	-37
363	Tauranga Group	4	11	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-6	-16	-8	-22	-15	-31	-28	-44	-31	-48
364	Tauranga Group	5	10	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-7	-15	-12	-23	-17	-28	-28	-39	-30	-40
365	Tauranga Group	4	7	34	-3	0.00	Reinen-Hamill et al. (2006)	0.00	0.40	0.10	0	0	0	0	0	0	0	0	-6	-11	-6	-7	-6	-7	-6	-7	-6	-7

		Component values																	Resulting ASCIE									
Cell_ID	Adopted Geology	Mean projected cliff height (m)	Typical upper bound projected cliff height (m)	Adopted Cliff Slope Angle (deg)	Uncertainty Cliff Slope Angle (deg)	Adopted LT (m/yr.)	Source LT	Uncertainty LT (m/yr.)	*m*	*Uncertainty m*	**LTf 2050 (RCP8.5)**	**Uncertainty LTf 2050 (RCP8.5)**	**LTf 2080 (RCP8.5)**	**Uncertainty LTf 2080 (RCP8.5)**	**LTf 2130 (RCP8.5)**	**Uncertainty LTf 2130 (RCP8.5)**	**LTf 2130 (RCP8.5+)**	**Uncertainty LTf 2130 (RCP8.5+)**	**Current ASCIE**	**Current ASCIE including uncertainty**	**Mean ASCIE 2050 (RCP8.5M)**	**Typical upper bound ASCIE 2050 (RCP8.5M)**	**Mean ASCIE 2080 (RCP8.5M)**	**Typical upper bound ASCIE 2080 (RCP8.5M)**	**Mean ASCIE 2130 (RCP8.5M)**	**Typical upper bound ASCIE 2130 (RCP8.5M)**	**Mean ASCIE 2130 (RCP8.5H+)**	**Typical upper bound ASCIE 2130 (RCP8.5H+)**
366	Tauranga Group	4	7	34	-3	0.00	Reinen-Hamill et al. (2006)	0.00	0.40	0.10	0	0	0	0	0	0	0	0	-6	-11	-7	-7	-7	-7	-7	-7	-7	-7
367	Tauranga Group	4	12	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-6	-18	-8	-23	-14	-30	-26	-41	-29	-44
368	Waitakere Group	2	8	38	-10	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	-2	-10	-7	-7	-7	-7	-8	-8	-8	-8
369	Waitakere Group	1	3	38	-10	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	-2	-4	-6	-8	-6	-8	-5	-9	-5	-9
370	Waitakere Group	NaN	NaN	38	-10	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	#VALUE!	#VALUE!	-7	-7	-7	-7	-8	-8	-8	-8
371	ECBF	2	3	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-3	-6	-7	-15	-7	-19	-17	-25	-18	-27
372	Tauranga Group	3	7	34	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-5	-11	-7	-10	-7	-13	-9	-17	-9	-17
373	ECBF	29	69	27	-3	-0.05	T+T studies 2006-2018	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-57	-135	-58	-137	-62	-140	-68	-148	-70	-151
374	ECBF	31	55	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-62	-108	-61	-109	-63	-110	-67	-112	-67	-112
375	ECBF	27	36	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-54	-71	-52	-77	-55	-80	-58	-84	-58	-84
376	ECBF	25	47	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-49	-93	-45	-96	-47	-100	-50	-105	-50	-105
377	ECBF	30	46	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-59	-90	-59	-91	-61	-93	-64	-96	-64	-96
378	ECBF	16	42	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-32	-83	-29	-82	-33	-85	-38	-89	-38	-89
379	ECBF	29	64	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-56	-126	-58	-129	-62	-131	-69	-134	-69	-134
380	ECBF	17	43	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-33	-85	-31	-89	-35	-91	-40	-96	-40	-96
381	ECBF	6	12	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-11	-24	-11	-22	-14	-26	-17	-32	-17	-32
382	ECBF	23	50	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-46	-98	-39	-97	-41	-100	-45	-104	-45	-104
383	ECBF	17	29	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-34	-56	-27	-53	-29	-55	-32	-60	-32	-60
384	ECBF	49	99	27	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-3	-2	-6	-4	-6	-5	-95	-195	-93	-196	-96	-203	-101	-210	-101	-210
385	Pakiri Formation	30	58	28	-3	-0.03	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-2	-5	-4	-5	-4	-56	-108	-47	-107	-48	-108	-52	-112	-52	-112
386	ECBF	35	133	27	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-2	-1	-4	-3	-4	-3	-69	-262	-54	-253	-55	-255	-57	-258	-57	-258
387	ECBF	109	275	27	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-2	-1	-4	-3	-4	-3	-215	-539	-185	-545	-187	-546	-195	-549	-195	-549
388	Pakiri Formation	95	136	28	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-1	-3	-2	-3	-3	-179	-256	-180	-254	-181	-255	-183	-255	-183	-255
389	Pakiri Formation	134	198	28	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.20	0.10	-1	-1	-2	-1	-3	-2	-3	-3	-252	-372	-254	-373	-255	-373	-256	-374	-256	-374
390	Waitakere Group	88	206	38	-10	-0.01	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	0	0	-1	0	-1	-1	-1	-1	-112	-264	-72	-262	-74	-263	-74	-263	-74	-263
391	Waitakere Group	120	238	38	-10	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	-1	0	-1	-1	-2	-2	-2	-2	-154	-304	-152	-307	-152	-307	-153	-308	-153	-308
392	Pakiri Formation	73	134	28	-3	-0.01	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	0	0	-1	-1	-2	-1	-2	-2	-137	-252	-124	-250	-125	-251	-125	-251	-125	-251
393	Waitakere Group	67	163	38	-10	-0.01	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	0	0	-1	0	-1	-1	-1	-1	-86	-209	-72	-209	-73	-211	-73	-211	-73	-211
394	ECBF	26	60	27	-3	-0.01	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-1	0	-1	-1	-2	-2	-2	-2	-52	-117	-43	-113	-43	-113	-44	-116	-44	-116
395	Waitakere Group	71	131	38	-10	-0.01	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	0	0	-1	0	-1	-1	-1	-1	-91	-168	-85	-167	-86	-168	-86	-168	-86	-168
396	Waitakere Group	59	128	38	-10	-0.01	Reinen-Hamill et al. (2006)	-0.01	0.05	0.05	0	0	-1	0	-1	-1	-1	-1	-76	-164	-67	-164	-68	-165	-68	-165	-68	-165
397	ECBF	66	182	27	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.40	0.10	-1	-1	-2	-2	-4	-4	-5	-4	-130	-357	-118	-357	-119	-359	-121	-361	-122	-362
398	Pakiri Formation	125	182	28	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-2	-1	-4	-3	-4	-3	-234	-342	-236	-344	-238	-345	-241	-347	-241	-347
399	Pakiri Formation	72	142	28	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-2	-1	-4	-3	-4	-3	-136	-268	-138	-269	-140	-273	-144	-276	-144	-276
400	Pakiri Formation	68	109	28	-3	-0.02	Reinen-Hamill et al. (2006)	-0.01	0.30	0.10	-1	-1	-2	-1	-4	-3	-4	-3	-128	-205	-130	-208	-131	-210	-134	-212	-134	-212
401	Tauranga Group	27	81	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-39	-119	-41	-121	-48	-129	-62	-150	-65	-153
402	Tauranga Group	12	23	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-18	-35	-19	-39	-24	-45	-35	-56	-38	-59
403	Tauranga Group	9	39	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-14	-58	-17	-53	-23	-62	-36	-76	-40	-79
404	ECBF	28	32	27	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-5	-2	-9	-4	-19	-9	-20	-11	-55	-62	-58	-67	-62	-71	-72	-81	-73	-82
405	Tauranga Group	6	19	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-8	-28	-13	-34	-21	-44	-35	-61	-38	-65
406	Tauranga Group	2	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-3	-10	-9	-15	-14	-23	-26	-37	-29	-41
407	Tauranga Group	6	32	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-9	-48	-13	-44	-17	-57	-32	-77	-35	-81
408	Tauranga Group	21	56	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-31	-83	-29	-89	-35	-98	-52	-125	-56	-134
409	Tauranga Group	2	4	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-3	-6	-10	-11	-12	-17	-24	-30	-30	-33
410	Tauranga Group	3	13	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-5	-20	-13	-19	-19	-30	-32	-54	-36	-59
411	Tauranga Group	2	4	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-2	-6	-10	-15	-14	-22	-29	-36	-32	-42
412	Tauranga Group	5	18	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-7	-27	-14	-33	-22	-48	-36	-65	-40	-68
413	Northland Allochthon	10	55	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-39	-221	-39	-231	-44	-233	-51	-235	-52	-236
414	Northland Allochthon	14	43	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-58	-172	-59	-173	-65	-178	-74	-186	-75	-187
415	Northland Allochthon	9	25	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-35	-100	-36	-106	-44	-113	-53	-126	-55	-127
416	Tauranga Group	4	12	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-5	-17	-7	-21	-12	-28	-20	-40	-21	-41
417	Tauranga Group	2	5	34	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.40	0.10	-2	-1	-4	-3	-9	-7	-10	-8	-3	-7	-4	-9	-6	-12	-13	-20	-14	-21
418	Tauranga Group	8	24	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-11	-36	-13	-41	-18	-51	-26	-59	-28	-61
419	ECBF	34	50	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-66	-97	-70	-102	-75	-105	-82	-110	-84	-111
420	ECBF	21	42	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-41	-83	-38	-85	-43	-89	-48	-93	-49	-94
421	ECBF	28	47	27	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.30	0.10	-2	-2	-5	-4	-9	-7	-10	-8	-54	-92	-55	-95	-60	-100	-66	-105	-68	-107
422	Tauranga Group	11	40	34	-3	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-3	-2	-6	-4	-11	-9	-12	-10	-16	-59	-15	-50	-16	-53	-22	-61	-23	-62
423	Tauranga Group	2	7	34	-3	-0.10	Reinen-Hamill et al. (2006)	-0.03	0.40	0.10	-5	-2	-11	-5	-22	-11	-25	-13	-3	-11	-8	-15	-13	-23	-24	-36	-27	-39
424	Pakiri Formation	25	60	28	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.10	0.10	-1	-1	-3	-2	-5	-4	-5	-5	-46	-112	-43	-112	-47	-115	-51	-117	-51	-117
425	ECBF	11	31	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-21	-61	-22	-60	-24	-64	-31	-71	-33	-74
426	ECBF	47	59	27	-3	-0.04	Reinen-Hamill et al. (2006)	-0.02	0.20	0.10	-2	-1	-3	-2	-6	-5	-7	-6	-93	-115	-97	-121	-99	-122	-103	-125	-105	-125
427	Northland Allochthon	12	40	14	-5	-0.05	Reinen-Hamill et al. (2006)	-0.03	0.20	0.10	-2	-1	-4	-3	-8	-6	-8	-7	-49	-161	-49	-162	-53	-165	-60	-172	-60	-172

Note that resulting ASCIE distances for cliffs vary within a single coastal cell as a result of using the cliff projection method (i.e., multiple projected distances within coastal cell). Therefore, mean and typical upper bound values have been provided.

Appendix G: Regional ASCIE colour maps

- **Regional ASCIE colour maps**

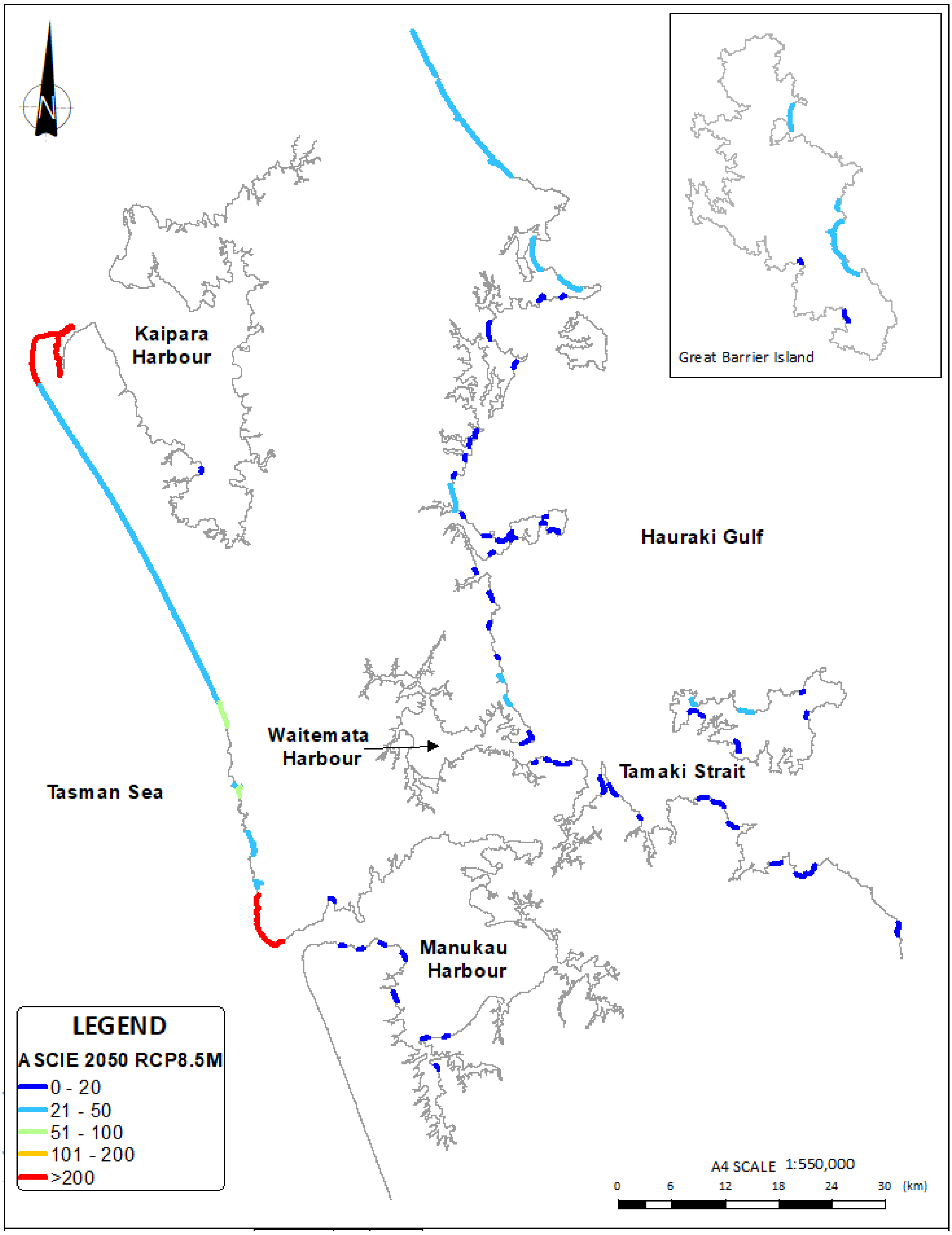

Figure Appendix G.1: Colour map of the banded ASCE distances for beaches at 2050 adopting the RCP8.5M

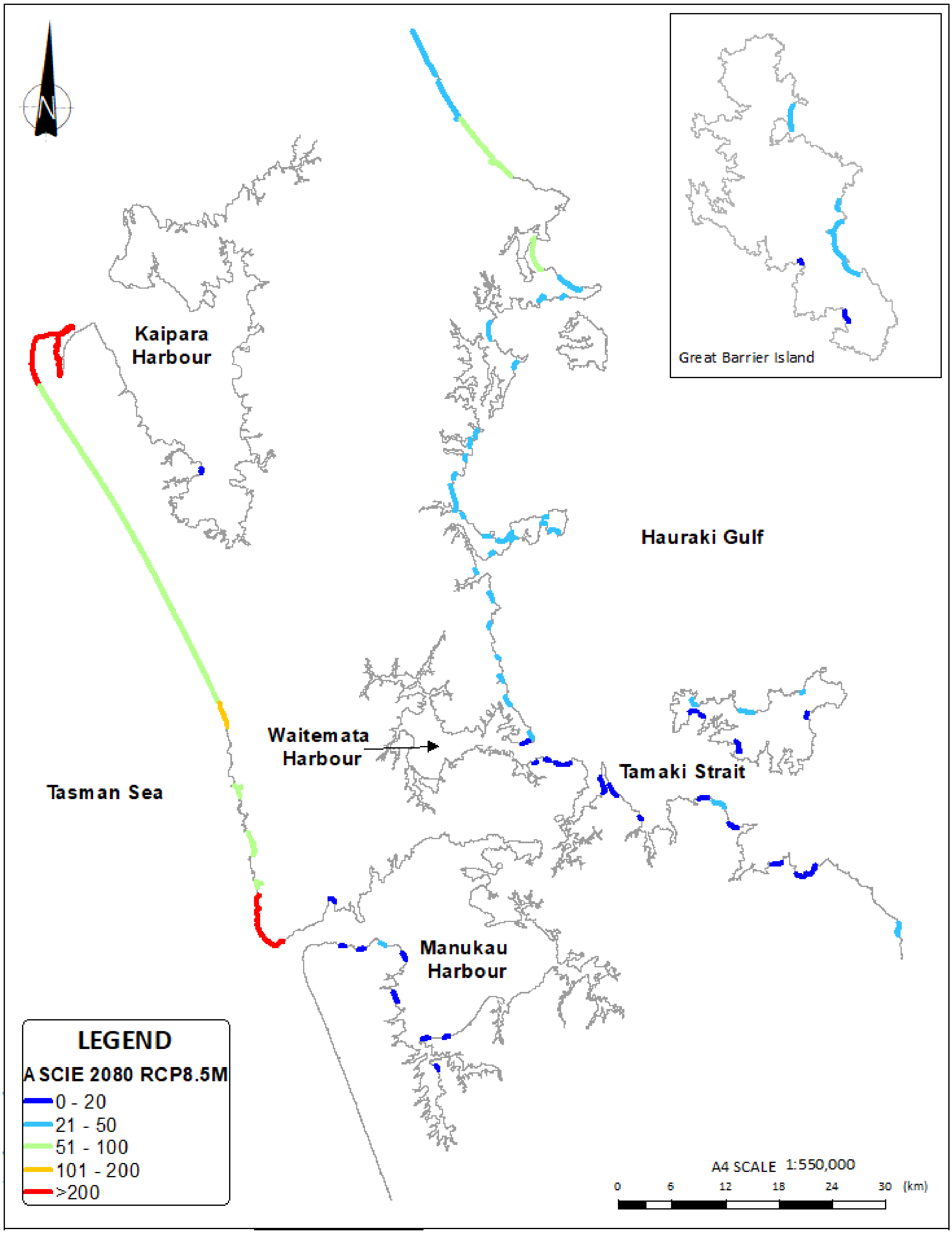

Figure Appendix G.2: Colour map of the banded ASCE distances for beaches at 2080 adopting the RCP8.5M

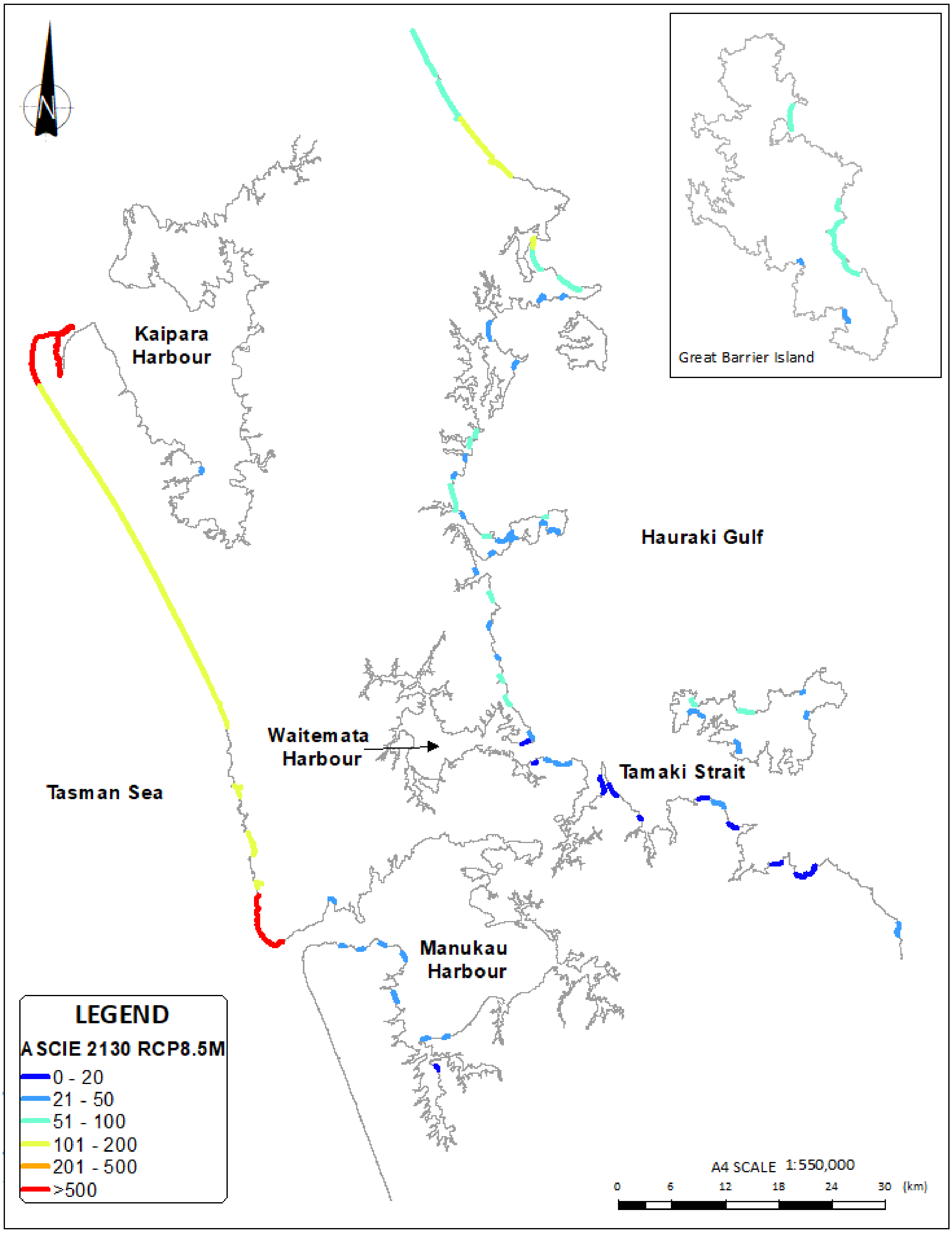

Figure Appendix G.3: Colour map of the banded ASCE distances for beaches at 2130 adopting the RCP8.5M

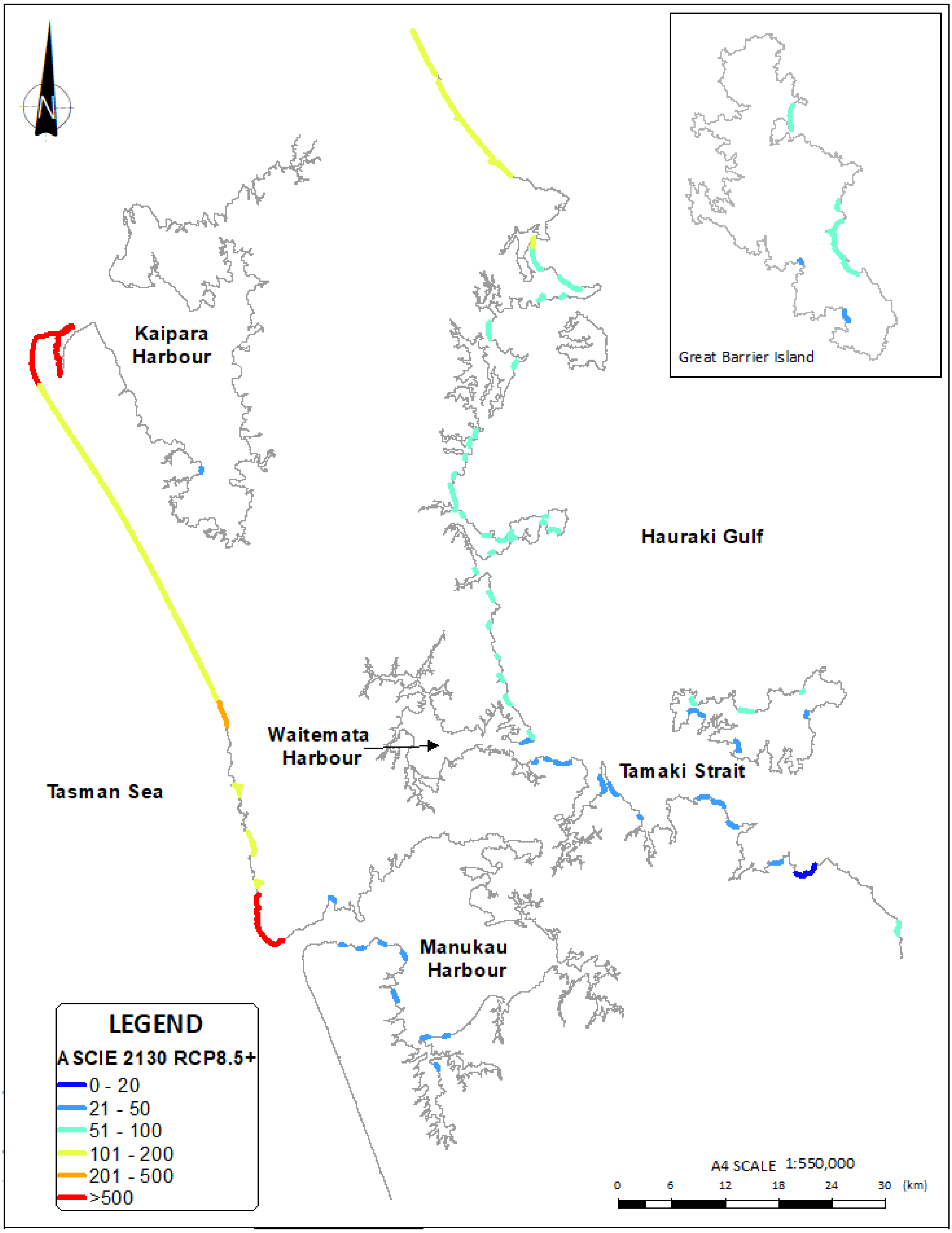

Figure Appendix G.4: Colour map of the banded ASCE distances for beaches at 2130 adopting the RCP8.5+

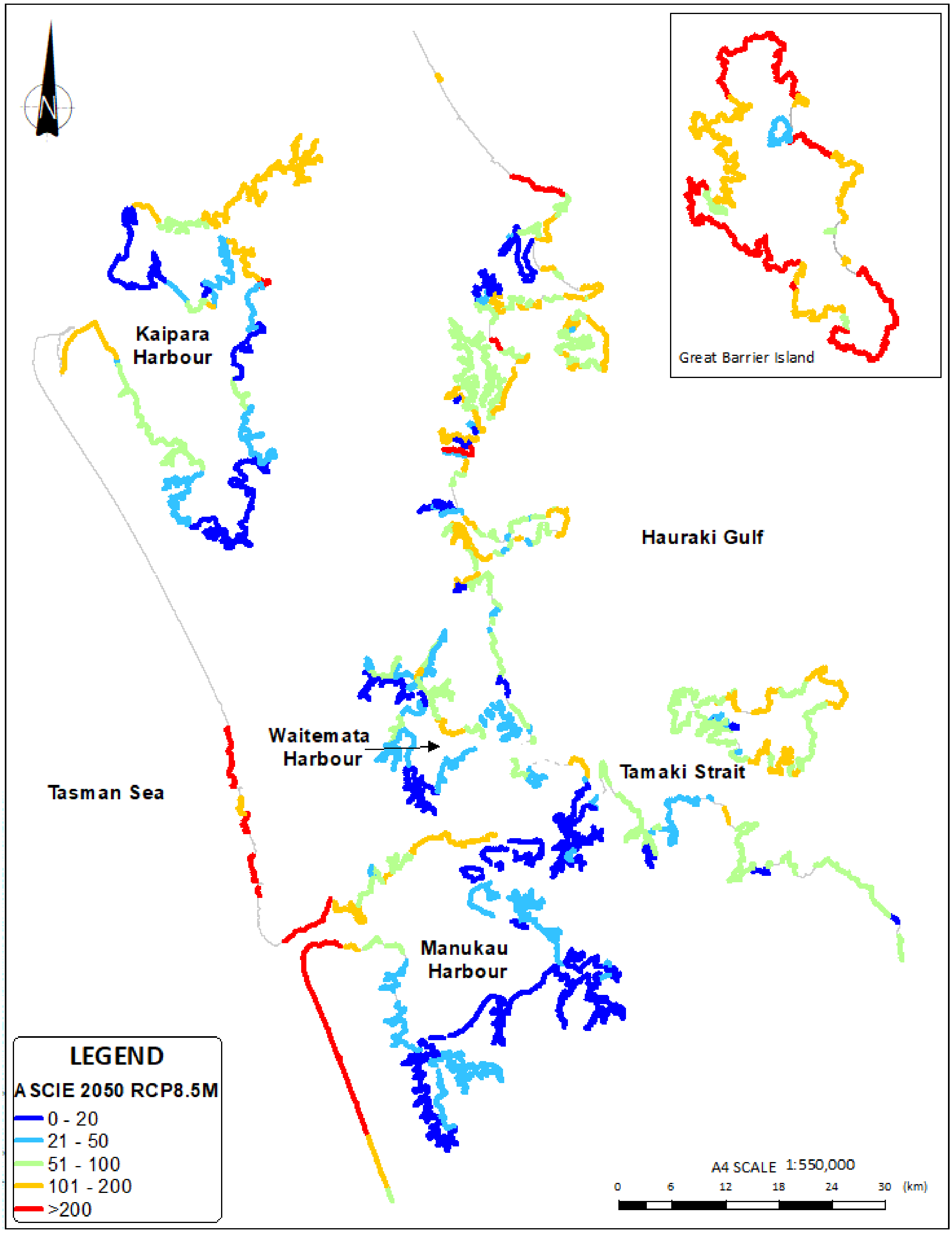

Figure Appendix G.5: Colour map of the banded ASCE distances for cliffs at 2050 adopting the RCP8.5M

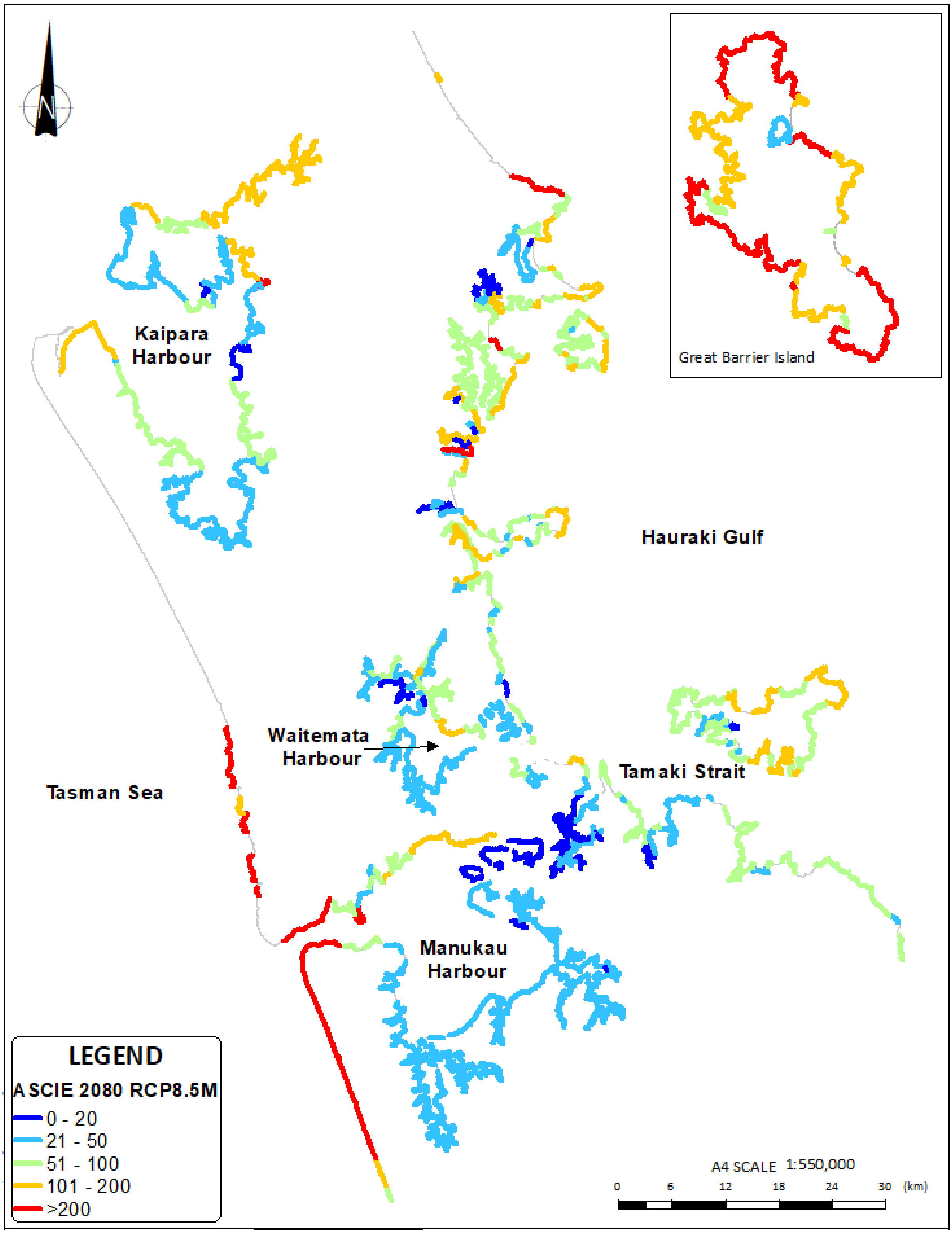

Figure Appendix G.6: Colour map of the banded ASCE distances for cliffs at 2080 adopting the RCP8.5M

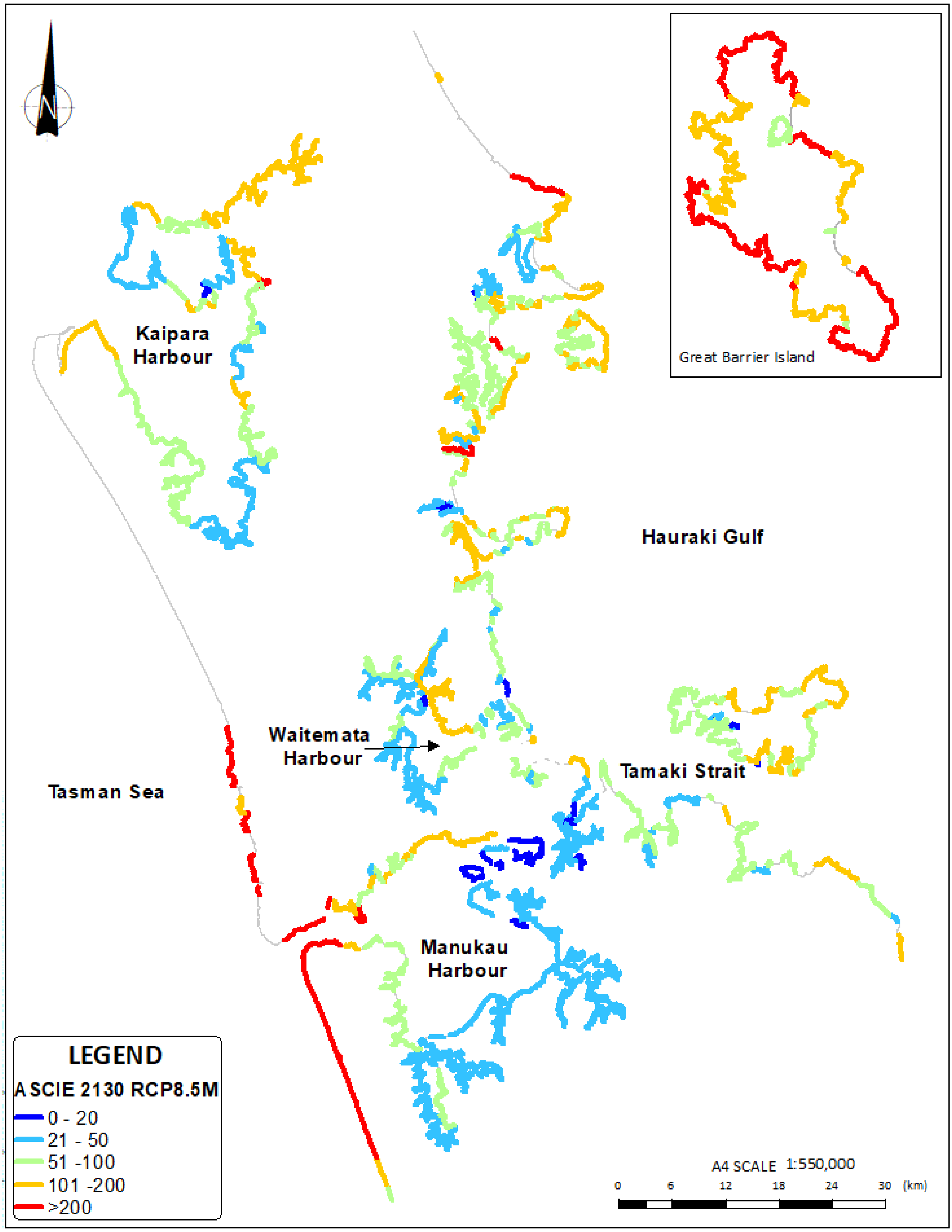

Figure Appendix G.7: Colour map of the banded ASCE distances for cliffs at 2130 adopting the RCP8.5M

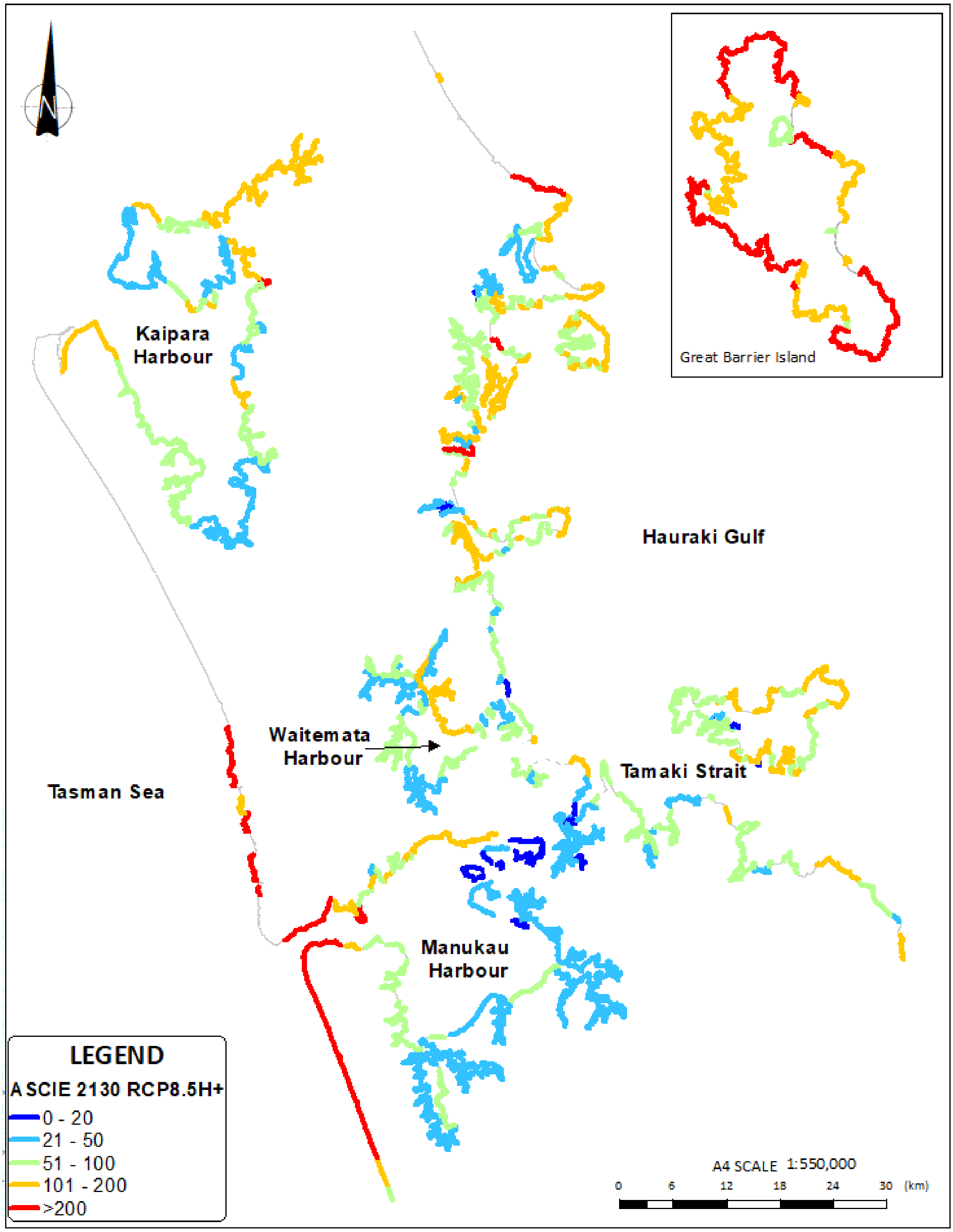

Figure Appendix G.8: Colour map of the banded ASCE distances for cliffs at 2130 adopting the RCP8.5+