Gisborne District Council

WAINUI BEACH COASTAL HAZARD ASSESSMENT

16 AUGUST 2023

WAINUI COASTAL ADAPTATION PROGRAM

Gisborne District Council

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ABBREVIATIONS

ARI	Annual Recurrence Interval
GDC	Gisborne District Council
MSL	Mean Sea Level
BMAP	Beach Morphology Analysis Package
ENSO	El Niño Southern Oscillation
PDO	Pacific Decadal Oscillation
IPO	Interdecadal Pacific Oscillation
NZST	New Zealand Spring Tide
LAT	Lowest Astronomical Tide
SLR	Sea Level Rise

GLOSSARY

Key Term	Definition	Simplified Definition
Mean High Water Spring (MHWS)	Mean high water spring is the average of levels of each pair of successive high waters and each pair of successive low waters, during a period of about 24 hours in each semi-lunation (approximately every 14 days), when the range of the tide is greatest (spring range) over a 10-20 year average.	The long term average of the highest high-tide that water levels reach at the time of spring tides.
Extreme Sea Level (ESL100)	Storm tide driven extreme sea level for a 100-year annual recurrence interval event, calculated from storm tide (which includes high tide, storm surge and monthly sea-level anomalies) and wave setup at the shoreline	Extreme sea level from a storm which has a statistical 1% chance of being exceeded in any given year based on present day conditions.
Shared Socioeconomic Pathways	Shared Socio-economic Pathways (SSPs) are scenarios comprised of different socio-economic assumptions that drive future greenhouse gas emissions. The scenarios span a wide range of plausible societal and climatic futures, based on greenhouse gas emissions, land-use changes, energy supply, radiative forcing and possible mitigation, that result in the stabilisation of global warming between 1.5°C to over 4°C warming by 2100. The pathways were developed in IPCC's 6th Assessment Report	Range of future climate change pathways determined by a series of socio-economic assumptions that drive future greenhouse gas emissions.
SSP2-4.5	Shared Socio-economic Pathway 2-4.5 is a climate scenario in a world with moderate emissions (+2.7°C warmer world)	Climate change scenario under medium future emissions and warming.
SSP3-7.0	Shared Socio-economic Pathway 3-7.0 is a climate scenario in a world with high emissions (3°C warmer world)	Climate change scenario under medium-high future emissions and warming.
SSP5-8.5	Shared Socio-economic Pathway 5-8.5 is a climate scenario in a world with very high emissions (>4°C warmer world)	Climate change scenario under very-high future emissions and warming.
Vertical Land Movement (VLM)	Vertical land movement (VLM), which is the rate of motion in mm/year of the local landmass. It is influenced by tectonics, sediment basin compaction, localised subsidence of historic reclamations or groundwater pumping, and glacial isostatic adjustment (the ongoing crustal adjustment to the past icesheet advance and retreat). Negative VLM rates indicate land subsidence, while positive rates show uplift.	Rate per year (mm) by which the land is subsiding or uplifting.

1 PROJECT BACKGROUND

WSP New Zealand Ltd (WSP) have been engaged by the Gisborne District Council (GDC) to prepare a coastal hazard assessment for Wainui Beach. This assessment will be used to identify the level of exposure of areas to coastal hazards along the Wainui Beach coastline (Figure 1.1). This will then help inform the development of a range of local planning frameworks.

To understand the overall degree of risk to the infrastructure and development within the Wainui Beach margin, it is necessary to focus on the natural hazards that may present themselves in the coastal environment, and the overall potential risk they may pose.

The purpose of this report is to assess the degree to which areas of land along the Wainui Beach coastline are exposed to different coastal hazards. This hazard assessment considers coastal hazards related to coastal storm processes and sea level rise. The best practice for understanding the overall trends and the risk that the hazards present is to conduct a qualitative analysis from available data. In this assessment beach profile data, wave data, and aerial imagery is used to analyse the coastal hazards of *erosion* and *inundation*. This hazard assessment includes the assessment and mapping of the following coastal hazards:

- Coastal inundation - with the exclusion of other sources of inundation, such as from extreme rainfall, fluvial flows, and tsunami.
- Coastal erosion.

Future stages of the project intend to develop an understanding of risk from coastal hazards for shoreline infrastructure and to provide insight on potential management options that may be required.

The outputs of this screening will be used to inform future risk assessments and risk management planning as part of the next stages of Wainui Beach coastal adaptation plan.

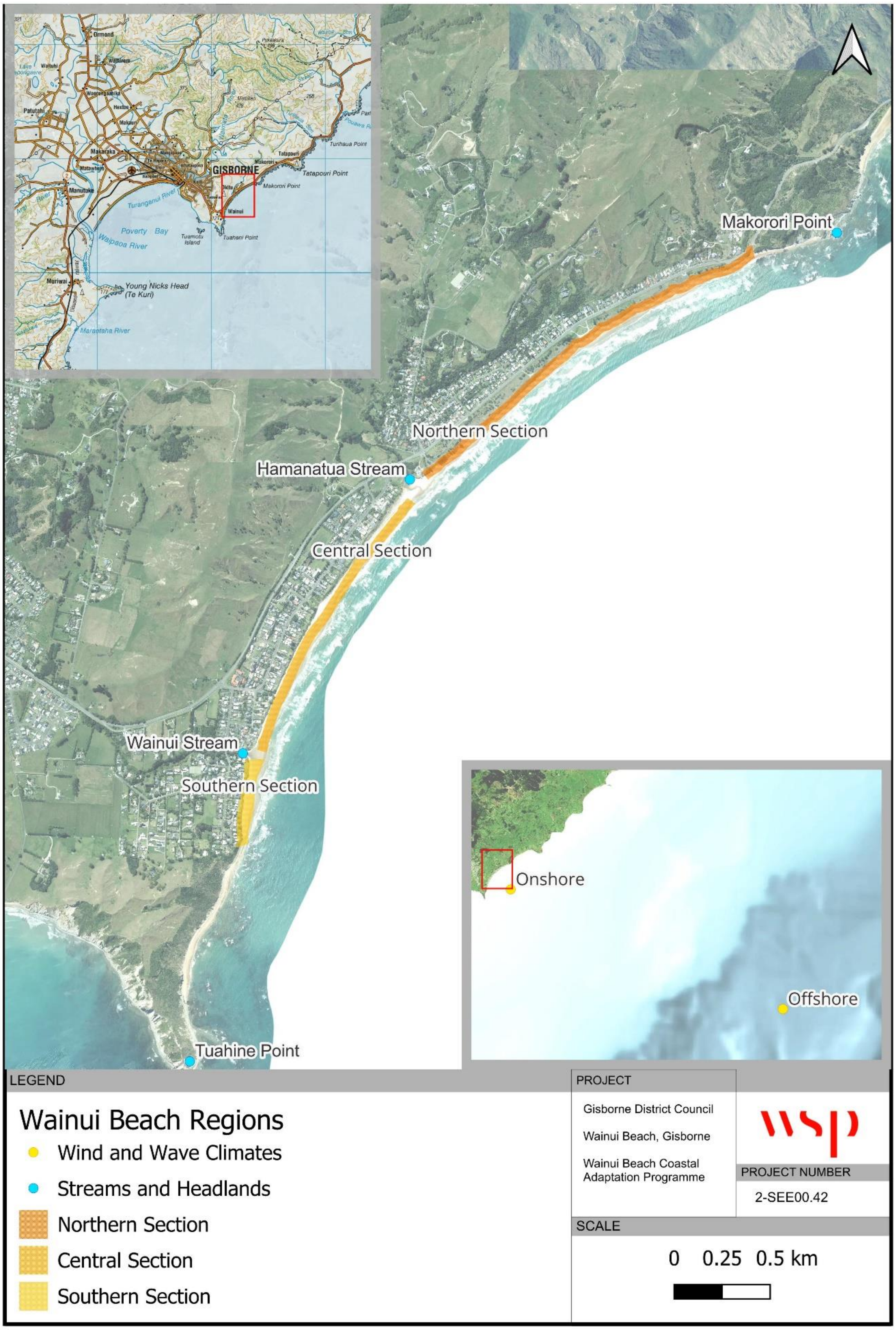

Figure 1.1: Wainui Beach overview

1.1 LITERATURE REVIEW

Prior investigations have provided insight into coastal hazard regimes and past mitigation attempts at Wainui Beach. Gibbs (2001) previously investigated the coastal hazards at Wainui Beach. The key findings of this report are as follows:

- Since 1942, erosion at Wainui Beach has been slow, at approximately -0.15m/yr. Makorori Point and Tuahine Point retreated at an approximate rate of -0.25m/yr.
- In addition to erosion, the headlands were susceptible to landslip events, noting that a significant landslip occurred on the Tuahine point in 2001.
- Wave runup from large storm swells has been known to temporarily flood land within the storm wave runup level.

Additionally, Tonkin and Taylor (T&T) (2013) previously assessed erosion trends for the Wainui Beach profiles. They concluded that there was a predominant retreat in the southernmost section of the beach (between Profiles 1 and 7) with an annual average erosion rate as great as -0.37m/yr (profile 3). The northern beach did not show a significant long-term trend and it was suggested that short-term fluctuations had a greater influence; some profiles showed an overall accretion during the survey period.

Many past attempts at protecting the beach with engineered structures have been unsuccessful due to the lack of knowledge around local coastal processes and poor design. The frequent exposure to the wave action means the ongoing maintenance of the protection works can be costly. Dunn and de Lange (2003) summarise the history of protection works at Wainui Beach with structures established as early as 1926. They suggest that structures built before the mid 1990's were generally inadequate due to the lack of integral information regarding the causes of erosion. Additionally, it was recognised that structures were often established as an immediate response to storm events.

With respect to the remaining coastal protection structures, it is our understanding that there is no formal asset management program in place to address maintenance issues. Formal and informal maintenance of the structures has been known to be undertaken by both private property owners and GDC contractors. These works are often performed following, and a result of damage incurred during storm events. For these reasons the nature of the work in terms of extent and quality is often inconsistent and record keeping of such work poor.

The presence of structures along the beach have clearly influenced beach behaviour at different times. The monitoring data discussed below illustrates the influence of the prior groyne system in place along the beach and changes along beach following their removal as highlighted by Dunn and de Lange (2003). The presence of seawall structures of various forms along the beach will have invariably influence the stability of the dune slopes above. This complicates and understanding of beach behaviour along Wainui and driven the methodology prescribed in analysis of beach monitoring data. Similarly, the groyne at the true left bank of the Hamanatua Stream has stabilised the dune toe position and allowed the establishment foredune areas within the Central Beach section.

1.2 SCOPE

GDC have responsibilities for the control of the use of land in coastal areas under the Resource Management Act 1991 (RMA 1991), these responsibilities include the management of risks from natural hazards. GDC recognise that there are coastal hazards which could affect people, properties, and infrastructure along Wainui Beach. These risks are likely to increase with sea level rise and further development.

The New Zealand Coastal Policy Statement 2010 (NZCPS, 2010) Policy 24 requires the identification of areas that are potentially affected by coastal hazards[1]. The physical factors to be assessed when identifying a coastal hazard are:

- Physical drivers and processes that cause coastal change including sea level rise,
- Short-term and long-term natural dynamic fluctuations of erosion and accretion,
- Geomorphological character,
- Cumulative effects of sea level rise, storm surge and wave height under storm conditions,
- Anthropogenic influences,
- Extent and permanence of built development,
- The effects of climate change on the above matters, on storm frequency and intensity and on natural sediment dynamics.

GDC are looking to raise the standard of coastal hazard information along the Wainui Beach coastline to help direct and prioritise future detailed risk assessments. The purpose of this detailed hazard assessment will be to inform decisions on the management of identified risks, such as shoreline management, land use and resource management planning.

Incorporation of other hazards (such as cliff erosion and fluvial flooding) will be performed within the risk analysis component of this project as it is reliant upon prior reporting undertaken by others.

1.2.1 REPORT LAYOUT

This report provides a detailed assessment of coastal hazards along the Wainui Beach coastline. The assessment evaluates the extent of coastal hazards now and with future land use changes, and how the exposure and risk to coastal hazards might change through time with climate change and sea level rise. This report will outline the methodologies used to evaluate coastal erosion and coastal inundation. Results of the hazards assessment will then be presented and discussed. Limitations of the methods used and recommendations for future assessments will be highlighted.

1.2.2 LEVEL OF DETAIL

The level of detail for the analysis of hazards may differ along the coastline to suit the available information, the exposure and the context. The “Coastal Hazards and Climate Change” guidance

[1] NZCPS (2010) Policy 24: Identify areas in the coastal environment that are potentially affected by coastal hazards (including tsunami), giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, are to be assessed.

issued by Ministry for the Environment (MfE, 2017) recommends the use of a two-level approach for coastal hazard assessments:

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

The adopted level of service for this assessment is equivalent to the detailed hazard assessment that enables a more thorough understanding of coastal hazards.

2 COASTAL SETTING

Wainui Beach is located approximately 5km east of Gisborne on the east coast of New Zealand. The beach is approximately 6km in length and orientated to the south-east. The beach is situated in between the headlands of Tuahine Point to the south and Makorori Point to the north (Figure 1.1). The hazard assessment encompasses the Wainui Beach coastline that is impacted or likely to be impacted in the future by coastal processes and hazards, including the increase of sea level in the future.

The sediment transport is semi-confined by the reef systems that extend out from both Tuahine and Makorori Points, however there is an opening between these reefs, leaving Wainui Beach exposed to large swells approaching directly from the south-east (Gibbs, 2001). Refer to Figure 2.1 for the bathymetric survey.

Wainui Beach comprises of a thin layer of generally medium to fine sand material with an approximate shell content of 50% (Gibbs, 2001). Sand sediments are mainly of volcanic origins with some comprising of eroded material from the headlands. Past erosion associated with storm events has been known to expose the Holocene estuarine silt substrate, which is highly erodible when affected by wave attack. Additionally, the tertiary bedrock is often exposed in the northern beach.

There are two streams located along the beach; Wainui Stream to the south, and Hamanatua Stream at the Central Beach. Gibbs (2001) suggest the streams do not significantly contribute to the sediment supply of Wainui Beach. Additionally, the low discharge rates of the streams are recognised to only influence the beach morphology within the immediate vicinity of the stream mouths.

2.1 TIDES

The Gisborne region experiences semidiurnal (two high and two low tides) micro tidal (<2m) conditions. Information with respect to the local tidal constituents has been obtained from LINZ ([Standard port tidal levels | Marine information Guidance (linz.govt.nz)]) and based upon tide gauge readings from the Eastland Port buoy. This information is provided in Table 1 below.

Table 1: Assumed tidal constituents for Wainui Beach.

Tidal Level	Chart Datum (m)	Gisborne Vertical Datum 1926 Reduced Level (m)
Mean High Water Springs	2.1	1.05
Mean High Water Neap	1.71	0.66
Mean Sea Level	1.22	0.17
Mean Low Water Neap	0.8	-0.25
Mean Low Water Springs	0.43	-0.62

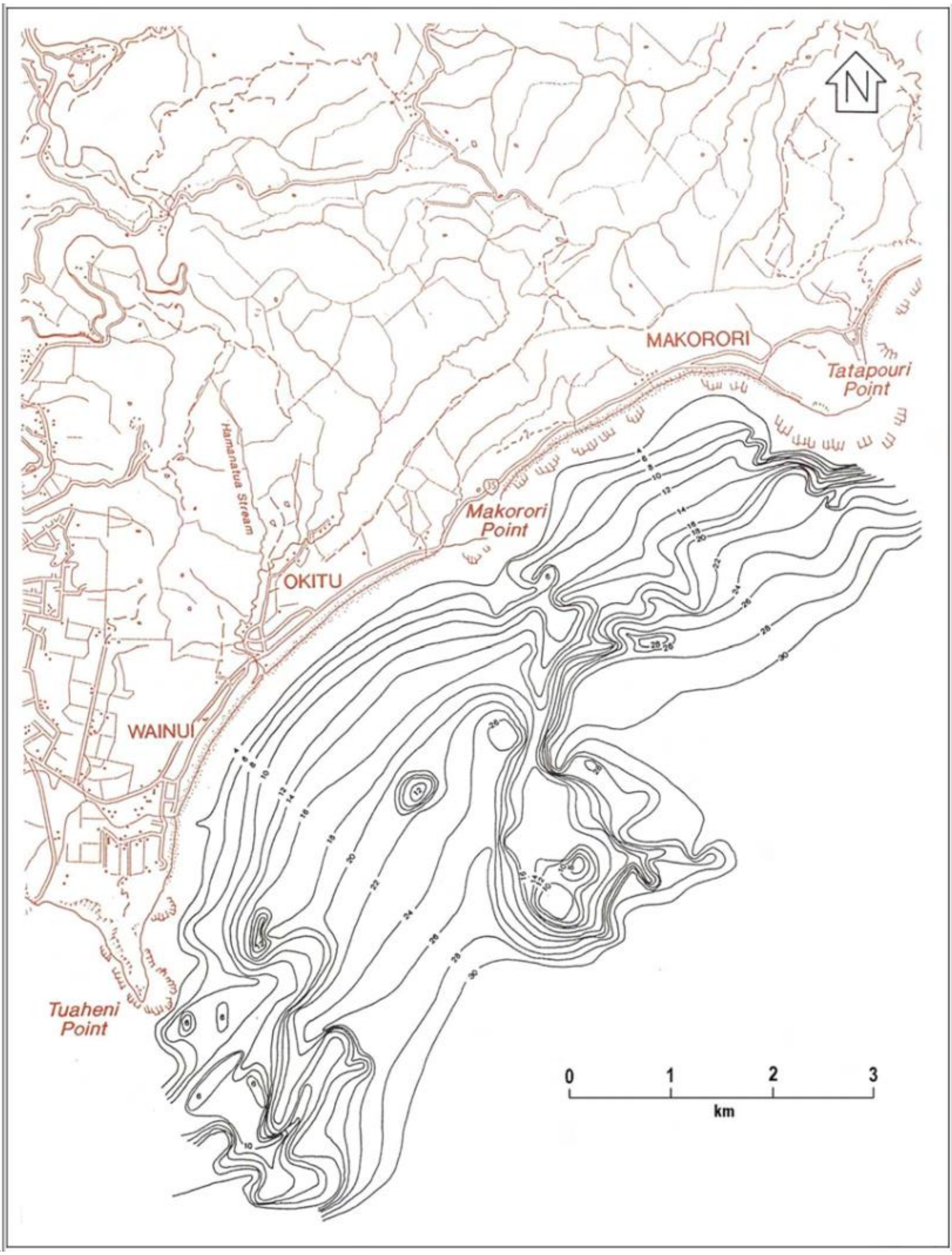

Figure 2.1: Bathymetry of Wainui Beach (Gibbs, 2001). Contours in metres below MSL GVD.

2.2 WAVE AND WIND CLIMATE

Wainui Beach is an intermediate rhythmic bar and beach system and occasionally switches to a longshore bar and trough system. NIWA (2012) suggests these beach types are generally characteristic of a high energy beach with typical breaking wave heights of 1.5-2.0m.

The spectrum of offshore swell direction generally ranges from the north-east to south, with a notable mention for the predominant south swells. The nearshore environment shows a spectrum of swell direction ranging from east to south; with expected refraction from nearshore reefs and headlands, nearshore swells most frequently approach at a perpendicular angle to the beach (I.e., south-east).

As per

Figure 2.2, typical offshore swell heights generally range between 1.0-3.0m. Wave size generally diminishes as it approaches the shoreline; and as the wave rose suggests (Figure 2.2), the typical nearshore wave height is 0.5-2.0m. Relative to the nearshore swells, peak periods with an occurrence greater than 5% typically range between 9-12 seconds (MetOceanView, 2023).

The wave extreme data indicates that a 1 in 100-year Annual Recurrence Interval (ARI) storm could create a nearshore significant wave height as great as 6.7m associated with ~45m/s winds (MetOceanView, 2023).

The offshore winds vary in direction; south-westerly, north-westerly, and northerly winds tend to be the most frequent. Commonly, winds tend to range between 0-10m/s; these light winds are particularly characteristic of the more northerly winds. Stronger winds of up to 20m/s are recognised to generally approach from the south-west. Winds that exceed 20m/s are rare but are most associated with south-westerly winds.

Nearshore winds predominantly flow from the north-west (i.e., offshore) at Wainui Beach most commonly at 0-10m/s. Like the offshore winds, stronger winds of 10m/s and greater, most frequently blow from the south-west.

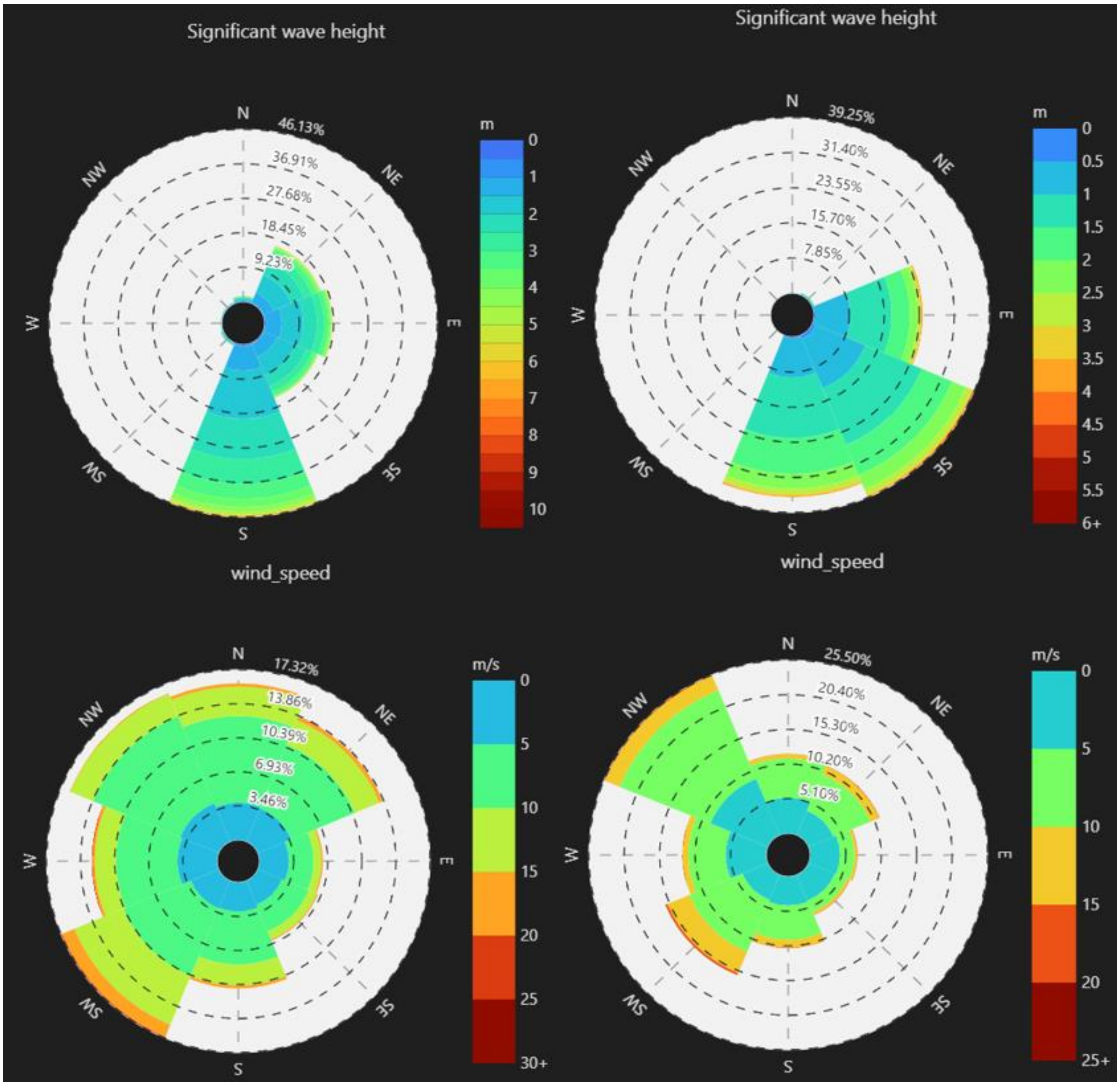

Figure 2.2: Spectral wave (top) and wind (bottom) roses for Wainui Beach. The left-hand side charts represent the offshore (178.5000, -38.8100) wind and wave climate; the right-hand side charts represent the nearshore (178.1050, -38.6950) wind and wave climate (MetOceanView, 2023).

2.3 NEARSHORE CURRENTS

With an extensive offshore reef system and headlands at each end of the beach; the sediment transport regime is semi enclosed and therefore, no prevalent current is recognised.

Nearshore currents at Wainui Beach are generally a response of the wind and swell direction and strength. With a predominant south swell direction, a net northerly sediment transport regime would be expected.

Additionally, rhythmic bar and beach systems typically form strong cell circulations with rips driving sediment to nearshore sandbars, and waves driving sediment onto the beach. The net sediment transport regime for the cell circulation typically depends on the wave energy.

2.4 SEA LEVEL RISE

The NZCPS 2010 requires that the identification of coastal hazards includes the consideration of sea level rise over at least a 100-year planning period. Predicted sea level rise over this timeframe is likely to significantly influence the exposure of Wainui Beach to coastal hazards.

In line with recent recommendations (MfE, 2022), the Shared Socioeconomic Pathways (SSP) scenarios comprising socioeconomic assumptions and changes that influence future emissions trajectories, should be used in place of the previous Representative Concentration Pathway (RCP) scenarios used in previous coastal hazards guidance (MfE, 2017).

The SSP scenarios include two sets of projections labelled "medium confidence" out to 2150 and "low confidence" out to 2300. MfE (2022) recommend using the "medium confidence" SSP scenarios. MfE (2022) also recommends the consideration of vertical land movement (VLM), such as uplift or subsidence, because these changes in land levels can enhance or reduce the localised effects of sea level rise.

The NZ SeaRise research programme released updated sea level rise projections in May 2022 for New Zealand (NZ SeaRise, 2022). These projections combine the 2021 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report Sea level data using the SSP scenarios, while also considering localised rates of VLM around the New Zealand coastline. To quantify a range of potential hazards, the 'medium confidence' of the scenario's SSP2-4.5, SSP3-7.0 and SSP5-8.5 were used for this assessment.

Marker 2126 from the NZ SeaRise portal is located on Wainui Beach, therefore was used to obtain the relevant SLR elevations used in this analysis. The SLR + VLM predictions were derived for three different time periods; 2050, 2070, and 2125 to allow for an understanding of the potential changes in both the short and long term, and showing the uncertainty in long term predictions. A diagram of the scenarios derived by NZ SeaRise for Wainui Beach and the variability and uncertainty associated with each scenario are shown in Figure 2.3. The associated SLR increments for each scenarios used are outlined in Table 2.1 below.

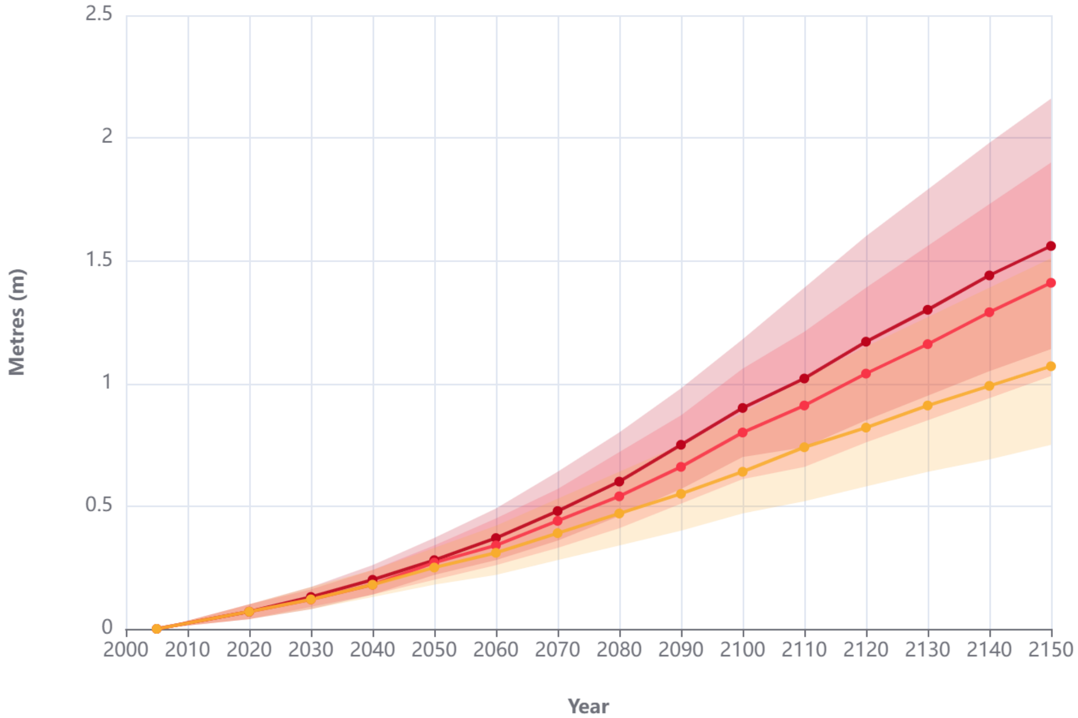

Figure 2.3: Sea level rise predictions by decade for marker 2126 on Wainui Beach from the NZ SeaRise programme. Yellow represents the SSP2-4.5 scenario, red represents the SSP3-7 scenario and maroon represents the SSP5-8.5 scenario (used in this analysis). The shading indicates the range of variability/ uncertainty associated with each of the scenarios.

Table 2.2 - Shared Socio-economic Pathway scenarios used to quantify the inundation and erosion hazard along the Wainui coastline.

Scenario	2050	2070	2120
SSP2-4.5+VLM	0.25 m	0.39 m	0.82 m
SSP3-7.0+VLM	0.27 m	0.44 m	1.04 m
SSP5-8.5+VLM	0.28 m	0.48 m	1.17 m

3 ASSESSMENT METHODS

A range of methodologies to assess coastal hazards are available. The objective of this section is to present the methodologies used for the coastal hazard screening along with key parameters and factors that were included. The beach has been divided into in 5 different geomorphic subunits to allow for an assessment of the different parts of the beach according to their different characteristics. Both streams along Wainui Beach have been assigned respective geomorphic subunits due to the complex nature of stream fluctuations. The respective subunits are listed and described below:

- Southern Beach- this unit has been taken from the southern groyne around Tuahine Point up to Wainui Stream subunit. The Southern Beach is characterized by a relatively narrow and ephemeral high tide beach which sits on top of relic estuarine muds (locally known as the "Grey Pug") which on occasion becomes exposed. The backshore margin is typically armed by a mix of rip-rap and log rail walls at the southern portion and retaining walls and gabion baskets toward the stream.
- Wainui Stream- the catchment for the stream is in the order of 5.9km^2. The coastal embankments at the stream mouth are armed by a combination of timber retaining walls and gabion baskets.
- Central Beach- this subunit encapsulates the area between the two stream mouths. This area is characterized by a wider high tide beach margin and small area of foredune along the northern portion of the subunit.
- Hamanatua Stream- as mentioned stream mouths are complex systems and accordingly require a different approach. The true left embankment of the stream mouth appears more prominent and influences stream flow. A groyne on the opposing side to this feature has been installed in order to counteract this influence. This presumably relates to some underlying bedrock which becomes increasingly apparent north of this point. The catchment for the Hamanatua Stream is in the order of 8.7km^2.
- Northern Beach- this subunit runs north from the Wainui Surf Life Saving Club up to the Makarori Headland. The high tide beach margin fluctuates inland depending on dune alignment. However, it is generally considered to narrower than the beach within the Central Beach subunit. This subunit beach is underlain by a shallow exposure of bedrock which when sand levels are low can be exposed from the "Pines" carpark to northern extent of the beach.

3.1 BEACH MONITORING DATA

Beach survey data from 21 profiles along the beach was provided by the GDC (Figure 3.1) for analysis. Profiles 1 through to 14 were first established in the 1970's. In 1993, an additional three profiles (8A, 8B, and 8C) were established near the Hamanatua Stream with the intentions of assessing the stream mouth morphology. In 1998-1999 a further four profiles (1A, 1B, 3A, and 4A) were established from the southern end of the beach to Wainui Stream, however, were discontinued between 2005 and 2006 and only present a short period of data.

The short-term datasets have mostly been excluded from sections of the analysis. Survey frequency has varied over the monitoring period with almost monthly surveys being conducted during the early 1980's. Post 1987 surveys typically occurred on a 6 monthly basis. Profiles were grouped based on the geomorphic subunits to compare trends across the beach. These groupings are as follows:

- 1 – 2: Southern Beach
- 3 – 4A: Wainui Stream
- 5 – 8: Central Beach
- 8A – 8C: Hamanatua Stream
- 9 – 14: Northern Beach.

The data was processed in the Beach Morphology Analysis Package (BMAP) software and the following sections (Section 3.1.1 to 3.1.3) were assessed.

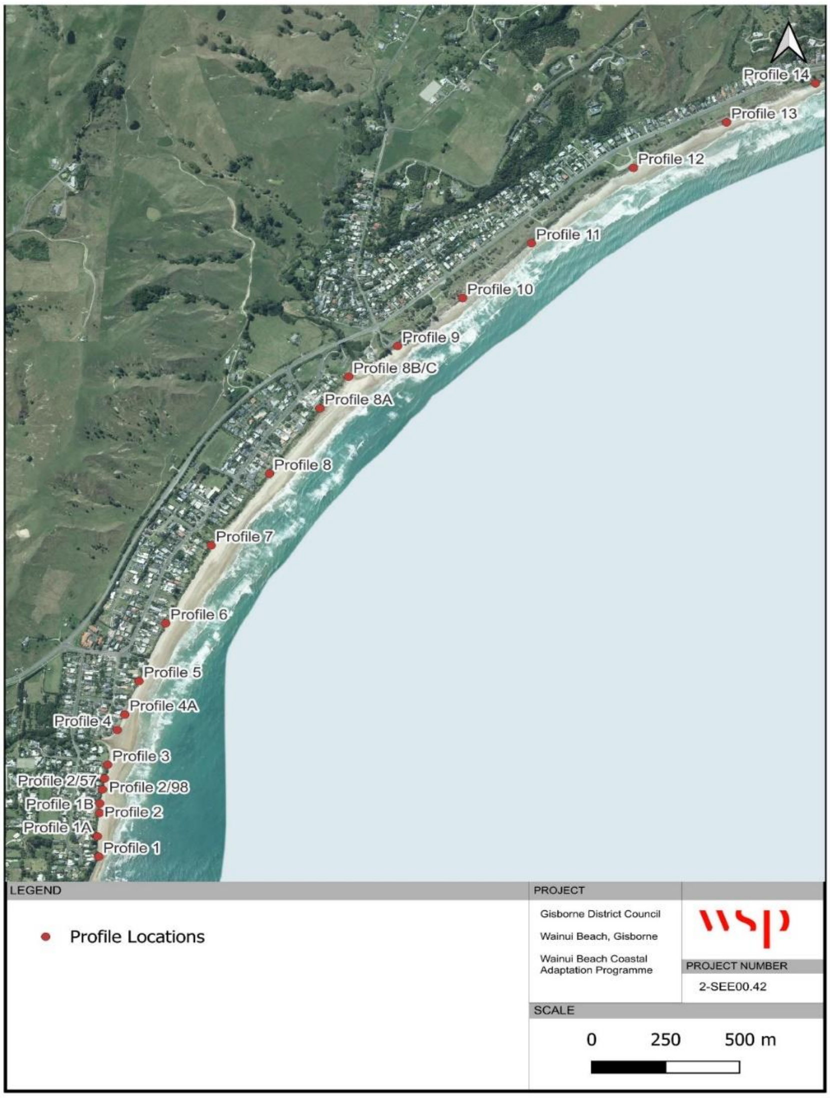

Figure 3.1: Profile locations along Wainui Beach (Location of the profiles are indicative only and are not mapped to a survey accurate scale).

3.1.1 5-YEAR AVERAGE

The average beach position based on 5-year intervals was assessed for each profile. This approach reduced the influence of short-term fluctuations and enabled long term trends to be identified. To ensure consistency throughout the analysis, the 5-year averages were categorised as:

- Early decade (e.g., 80-84) and,
- Late decade (e.g., 85-89).

Accordingly, the earliest and most recent averages may not present a full 5-year set of data considering the dates of the surveys. The envelope of the minimum and maximum beach position was also included to show the overall variations in beach position.

3.1.2 BEACH CONTOUR EXCURSION DISTANCE ANALYSIS

To identify changes in beach position at the 0m, 1m, and 2m contour, excursion distance analysis was carried out on the profile data and was used to examine the temporal and spatial variations between the different profiles along Wainui Beach. Excursion distance analysis provides useful information about the history of a beach profile and the short-term fluctuations and long-term trends of the beach. Contours above RL2m (being 2.0m above MSL in the Gisborne Vertical Datum) were excluded from analysis due to the influence of coastal protection structures and the quality of data.

Contour excursions were determined within the BMAP software and then transferred into Excel to plot. Within Excel, linear trendlines were applied to identify trends over the monitoring time series. To enable a geomorphic assessment of beach change the contours examined were assumed to represent the following beach margins:

- Mid-tide beach position = 0m contour
- High-tide beach position = 1m contour
- Foredune = 2m contour.

3.1.3 CLIMATE VARIATIONS

Beach monitoring data was analysed against several climate cycle variations in order to ascertain if fluctuations in beach position were related to larger climatic trends. For this assessment the three climate variables discussed below were analysed against the fluctuations in the 2m beach contour position. The 2m beach contour position was analysed as this was the contour least susceptible to regular beach fluctuations.

3.1.3.1 EL NIÑO SOUTHERN OSCILLATION (ENSO) TRENDS

ENSO is a climatic oscillation that is defined by fluctuations in water temperature in the Pacific Ocean in respect to the mean sea surface temperatures and strength of the trade winds. ENSO fluctuates approximately every 3-7 years between the following phases:

- El Niño: Refers to a warm pocket of water in the tropical Eastern Pacific Ocean, and cooler waters in the Western Pacific Ocean, including New Zealand waters.
- La Niña: Vice versa to El Niño – cooler waters in the tropical Eastern Pacific Ocean, and warmer waters in the Western Pacific Ocean.

- Neutral: Tropical sea surface temperatures are relatively close to the respective mean sea surface temperatures.

The oscillation influences climate and localised weather patterns and can therefore influence beach position trends. To analyse how the beach profile varies with ENSO, the mean beach position for the El Niño and La Niña phases were graphed for each beach profile to show any potential variations between the phases.

3.1.3.2 INTERDECADAL PACIFIC OSCILLATION (IPO) TRENDS

Similar to ENSO, the IPO is characterised by positive and negative phases that refer to cooler and warmer water temperatures for the South-west Pacific Ocean that tend to fluctuate approximately every 20-30 years. A negative IPO refers to cooler temperatures in the south-west Pacific Ocean and the positive IPO refers to warmer temperatures. During a positive IPO the mean sea level pressures are higher than normal west of the international dateline, which results in a southern flow anomaly during the positive phase.

To assess the potential relationship between IPO and beach position, the mean annual IPO phases were plotted with the 1m beach contour excursion as this would show the increased fluctuations associated with climatic variables.

3.1.3.3 PACIFIC DECADAL OSCILLATION (PDO) TRENDS

The PDO oscillates on a similar time scale to the IPO, however, the interior of the parcel is located in the Northwest Pacific Ocean. The PDO is defined by ocean temperature anomalies in the northeast and tropical Pacific, where a positive PDO has anomalously cool sea surface temperatures in the interior North Pacific and when sea level pressures are below average over the North Pacific.

The mean annual PDO phases were plotted with the 1m beach contour excursion to assess the potential relationship between the PDO and beach position.

3.2 HISTORICAL SHORELINE ANALYSIS

Identifying coastline variability and coastline erosion or accretion is fundamental towards understanding long-term trends of the coastline. The analysis of aerial imagery in coastal hazard assessments is a common method used to assess historical trends in erosion or accretion as it is a cheap, effective and a simple to use method. To explore the historical changes along the Wainui Beach coastline, a series of aerial photographs from LINZ, Google Earth and RetroLens were used.

The RetroLens images span the timeframe from 1942 to 1982, the Google Earth Images span the timeframe from 2007 to 2023, and the LINZ images span the timeframe from 2013 to 2023. The timescale investigated has important implications for trends in coastal landforms related to fluctuations in sediment supply from cliffs, rivers and the seabed; changes in land use in adjacent catchments; and variation in sea level and weather patterns.

The aerial imagery was first georeferenced in ArcGIS by setting common ground control points within each image. Around 10 ground control points were used to georeference each photograph to provide the beach aerial triangulation and all the images were referenced to the most recent 2023 LINZ aerial imagery.

The dynamic boundary between the land and the sea, on the temporal and spatial scale which is being considered has resulted in the use of a range of shoreline indicators. A shoreline feature is used as a proxy to represent the "true" shoreline position. The shoreline indicator used in this study was the seaward edge of the vegetation. This indicator was chosen as vegetation is present and can be identified relatively easily in the aerial imagery. Stream position was also mapped at the mouth of the river and the beach to identify any trends of changes in stream position over time.

3.2.1 SHORELINE AVERAGES

Due to the number of shorelines identified from the aerial imagery, in order to display these in a way that will help identify trends in shoreline change, the shoreline positions were averaged. To do this the shorelines that followed similar trends and within similar timeframes were averaged. The shorelines were averaged between the following years:

- 1942 to 1957
- 1966 to 1972
- 1977 to 1982
- 2007 to 2013
- 2016 to 2023

3.2.2 LIMITATIONS

Historical shoreline analysis using aerial imagery is a commonly used method, however it is important to acknowledge that there are limitations and assumptions associated with this methodology. These limitations need to be understood when using this data for further hazard assessments, such as quantifying any trends of erosion or accretion to the beach shoreline over time. The key limitations associated with this methodology are outlined below.

- Human interpretation and accuracy play a major role in the potential error and identification of photographic parameters that contributes to feature identification. Human error is not quantifiable, however the overall fit of the georeferenced imagery was able to be monitored through the root mean square error (RMS). The error is the difference between where the former control point ended up as opposed to the actual location that was specified. The total error is computed by taking the RMS sum of all the residuals to compute the RMS error. This value describes how consistent the transformation is between the different control points. When the error was particularly large, control points were removed and added to adjust the error. Residuals closer to zero are considered more accurate. Additional points were added as necessary to achieve acceptable root mean square (RMS) error less than 3.0m, as advised by Hapke et al (2015).
- Feature identification is affected by the resolution of the photographs. The aerial photographs from 2007 to present were available in colour, allowing for good digitisation of beach features. Whereas the older photographs prior to 2007 were not available in colour, which may have had an effect on the accuracy of the excursion distances of each feature. The vegetation line was chosen as it was easy to identify, and because of its relevance and importance towards coastline change (Boak and Turner, 2005). Coastal features were mapped as accurately and consistently as possible by trying to keep the residual error of control points as low as possible.

3.3 FUTURE EROSION POTENTIAL

It is recognised that with projected SLR there is an increased risk of the erosion across Wainui Beach. Given the unique nature of Wainui Beach a combination of quantitative and qualitative assessments have been undertaken in order to ascertain the potential future erosion potential along Wainui Beach. The perched dune setting with exposures of bedrock and relic estuarine material have been taken into account in the estimation of future erosion potential.

For the Northern Beach section the exposure of underlying bedrock was considered to be a control on the dune toe position. Accordingly, a dune slope retraction calculation (Eq.1) was estimated based on industry standard sand slope settlement equations. These were applied to a dune toe retreat based upon an elevation of SLR and Storm Surge above an assumed bedrock crest of RL1.5m.

The assumed bedrock level was conservatively estimated based upon beach monitoring data and onsite observations. Erosion of the bedrock crest was conservatively estimated to be 300mm over the next 100 years based upon reporting of shore platform change in other parts of New Zealand. (Walkden and Dickson, 2008)

$$DS = \frac{H}{2(\tan a_{SAND})} \qquad \text{Eq.1}$$

Where:

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).

H = the dune height from the eroded base to the crest

a_{SAND} = is the stable angle of repose for beach sand (ranging from 30 to 34 degrees).

For the Central and Southern portions of the beach an adapted Brunn Rule equation (Eq.2) (Figure 3.2) was applied with conservative variables of historic beach erosion ascertained from the beach monitoring data (Shand *et al.*, 2015). Short to medium term fluctuations were taken from extremes within the beach monitoring data. This was considered to be the best measure of change given the frequency of data collection, particularly between 1978 and 1987 and aligns well with prior reporting of historic erosion events.

$$CEHA_{BEACH} = ST + DS + (LT \; x \; T) + SLR_T \qquad \text{Eq.2}$$

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). Where *H* is the dune height from the eroded base to the crest and a_{SAND} is the stable angle of repose for beach sand (ranging from 30 to 34 degrees).

$$DS = \frac{H}{2(\tan a_{SAND})}$$

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

T = Timeframe (year)

SLR_T = Horizontal coastline retreat due to possible accelerated sea level rise over the timeframe (T) considered). Where *l* is the extent of the seabed influenced by wave action, *a* is the increase in water level from present day to *T* (timeframe) as a result of climate change, *h* is the height of the dune crest and *d* is the depth of closure (theoretical depth along a beach where there is deemed to be no or very little sediment transport)

$$SLR_T = \frac{(l\ x\ a)}{(h + d)}$$

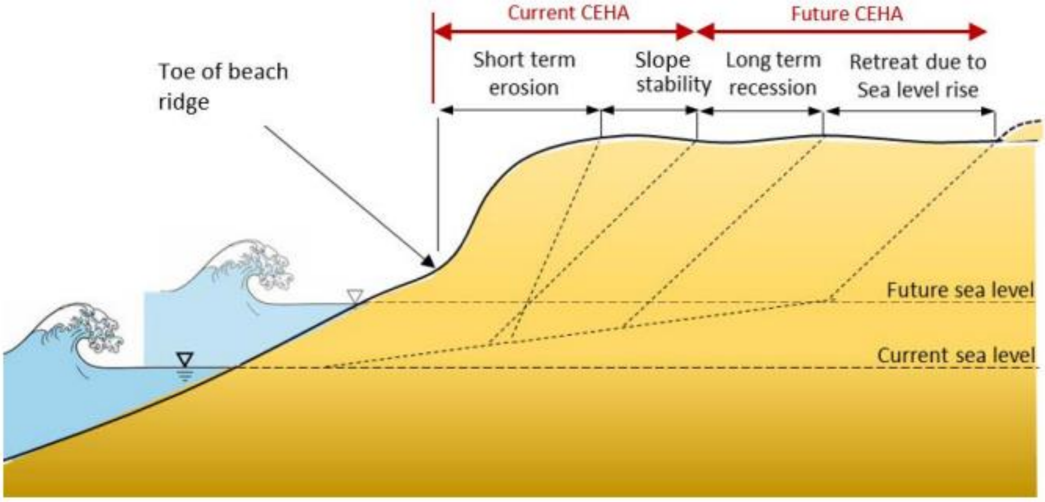

Figure 3.2 - Definition sketch for the coastal erosion hazard area for unconsolidated beaches (Shand Et al., 2015)

It is noted that toe erosion within the Southern Beach subunit has been estimated on the position RL2m contour. This contour is in general below the position of any coastal protection structures. It is recognised that these structures may still influence the position of this contour but in general there is a good correlation between the RL2m, 1m and 0m contours in terms beach trends.

The presence of existing coastal protection structures (or similar) was not accounted in the assessment of future erosion potential.

Around the respective stream mouths an examination of surrounding contour levels was undertaken in order to ascertain the extent of prior stream erosion extent. Potential stream toe erosion as a result of future climate change was qualitatively estimated at 3m, 5m and 10m with an additional allowance for dune slope settlement applied at this point. Given the relatively small catchments of the respective streams and the ephemeral nature of their seaward connection the estimates of the toe erosion are considered to be conservative.

It is important to note due to the level of uncertainty with site specifics (like extent of underlying geology) and future impacts, we have applied conservative variables in the estimation of future erosion potential. Accordingly, the results are only intended to inform the risk analysis and adaptation of planning process and should not be applied beyond this purpose.

3.3.1 SEA LEVEL RISE

To account for the effects of predicted increases to sea level rise in the future, three different climate scenarios have been used to map out the potential erosion hazard zones along the Wainui Beach. Within the erosion equations used to identify the potential erosion zone, the predicted 100-

year sea level rise with vertical land movement under SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios were incorporated.

As part of the hazard assessment that was carried out for Wainui Beach, an analysis of the potential inundation extents under different SLR scenarios was undertaken. These inundation extents were then used to identify the exposure of Wainui beach to coastal inundation hazards.

Inundation is the process in which water from the coast extends landward, both at regular intervals, such as high tides, as well as during storm events. Inundation is important to consider as it can pose a hazard to the built environment such as commercial, industrial, and residential developments, as well as transport infrastructure. Additionally, understanding the potential extent of inundation can help to inform the location and design of required coastal protection structures.

This inundation analysis is based on the bathtub approach, whereby all land lying below the calculated water line elevation (with a direct flow path to the coast) is assumed to be inundated in its entirety.

This analysis took into consideration predicted inundation under current conditions as well as under future climate change. The methodologies used to derive the inundation extents under different climate change scenarios are outlined below in Section3.4.1.

3.4 COASTAL INUNDATION

3.4.1 METHODOLOGY

To identify the potential inundation hazard for Wainui Beach the topography and associated elevations were analysed. To determine the elevation of the study area, LiDAR from the Gisborne District was used. This LiDAR provided a digital elevation model (DEM) at 1m resolution. The LiDAR was flown for the entire Gisborne District between December 2018 and September 2020 and has a vertical and horizontal accuracy of 95%.

The 1m DEM was used to derive elevation contours of the study area, these contours were derived for 0.1m intervals between 0m and 20m in elevation. These contours were then used to identify the landward extent of inundation under the different scenarios used in the analysis. Therefore, allowing the mapping of the coastal inundation extents and the exposure of different parts of the beach to the coastal inundation hazard.

3.4.2 INUNDATION SCENARIOS

Three different base elevation scenarios were used for the inundation analysis, these were mean high water spring (MHWS), storm surge/ storm tide elevation (STE), and extreme sea level (ESL100). Descriptions of each of these scenarios and the associated climate change adjustments are outlined below.

3.4.2.1 MEAN HIGH WATER SPRING (MHWS)

The MHWS represents the average levels of each pair of successive high waters during a period of about 24 hours in each semi-lunation (approximately every 14 days), when the range of the tide is greatest (spring range).

Land Information New Zealand (LINZ) data for the MHWS level for the nearest port was used. The nearest port to Wainui Beach is Gisborne Port. The MHWS level was converted from local chart datum to NZVD2016 to ensure consistency with all other elevations used within the analysis.

In addition to the base MHWS elevation that was used for the inundation analysis, adjustments for potential future sea level rise (SLR) and the associated vertical land movement (VLM) have been taken into consideration. Using the NZ Sea Rise Scenarios (SSP2-4.5, SSP3-7.0, and SSP5-8.5) and the VLM based on a marker on Wainui Beach a range of SLR scenarios were considered for the time periods of 2050, 2070, and 2120. The elevations used to represent the MHWS inundation hazard are shown in Table 3.1.

Table 3.1: Elevations used to represent MHWS inundation hazard with three sea level rise scenarios for SSP2-4.5, SSP3-7.0, and SSP5-8.5. All values in NZVD2016 datum.

SSP Scenario	Elevation (m NZVD2016)			
	MHWS	MHWS + SLR and VLM (2050)	MHWS + SLR and VLM (2070)	MHWS + SLR and VLM (2120)
SSP2-4.5	0.69	0.94	1.08	1.51
SSP3-7.0		0.96	1.13	1.73
SSP5-8.5		0.97	1.17	1.86

3.4.2.2 STORM TIDE ELEVATION (STE)

As part of a study by NIWA in 2014 (Stephens et al., 2014) the predicted extreme storm tide elevations (STE) in the Gisborne District were derived. The NIWA study broke the coastline into smaller coastal segments, one of which was Wainui Beach. The STE values from this report have been used to identify the elevations at which inundation from storms may affect the coast at Wainui Beach.

The STE values were derived by Stephens et al. (2014) based on different ARI storms. The components used for the STE equation were:

- Tide levels;
- Storm surge under a range of ARIs (1 year to 200 year ARI); and
- Monthly mean sea level anomaly.

As there are multiple time periods for the STE elevations, the 20 year, 50 year, and 100 year time periods have been chosen for analysis to give a range of potential inundation values over time (

Table 3.2).

The inundation values need to be rounded to 1 decimal place in order to align with the 0.1m interval that the contours have been derived at. Because of this necessary rounding the SLR adjusted values for the 20 year and 50 year ARI values are the same. Due to these similarities the 20 year ARI inundation values are not used within the analysis.

Table 3.2: Elevations used to represent the STE inundation hazard for three different ARI with sea level rise scenarios. All values in NZVD2016 datum.

SSP Scenario	Elevation (m NZVD2016)				
	ARI	Storm Tide Elevation	STE + SLR and VLM (2050)	STE + SLR and VLM (2070)	STE + SLR and VLM (2120)
SSP2-4.5	20 Year	1.03	1.28	1.42	1.85
	50 Year	1.06	1.31	1.45	1.88
	100 Year	1.09	1.34	1.48	1.91
SSP3-7.0	20 Year	1.03	1.30	1.47	2.07
	50 Year	1.06	1.33	1.50	2.10
	100 Year	1.09	1.36	1.53	2.13
SSP5-8.5	20 Year	1.03	1.31	1.51	2.20
	50 Year	1.06	1.34	1.54	2.23
	100 Year	1.09	1.37	1.57	2.26

3.4.2.3 EXTREME SEA LEVEL (ESL100)

The third scenario used to derive the potential inundation hazard for Wainui Beach was ESL100. The ESL100 points indicate the maximum elevation level to which coastal areas are at risk of flooding from extreme sea levels. The ESL100 points used in this study were sourced from a study carried out by NIWA (Paulik et al., 2020), which derived the 100 year ARI extreme sea level values for the New Zealand coastline. Therefore, the methodology used to derive the ESL100 elevation is similar to that of the 100 year ARI STE value (Section 1.3.2) but at a larger scale (national) and using slightly different inputs. The components used to derive the ESL100 value by Paulik et al. (2020) were:

- Mean sea level;
- Storm tide for the 100 year ARI event– combination of high tide, meteorological effects (storm surge) and monthly sea level anomalies;
- Additional wave set up where breaking waves are present for the 100 year ARI event; and
- Mean sea level rise prediction.

The allowance for the mean sea level prediction for the dataset provided by NIWA does not account for any sea level rise as it is based on present day extreme sea levels from the tide and storm surge driven 100 year ARI event. These values of ESL100 were calculated using tide gauges along the New Zealand coastline and were applied to segments of coastline around New Zealand based on proximity. These ESL100 values were calculated by NIWA based on the prevailing storm tracks, existing tide levels and sea level anomalies, and they range from 1.4m to 4.5m elevation.

Unlike the STE values there was not an ESL100 value derived specifically for Wainui Beach. The closest ESL100 points to Wainui Beach are shown in Figure 3.3. The ESL100 values converted into NZVD2016 for the two points were 2.76m (marker 312) and 2.55m (marker 80). To account for the variation between these points an average ESL100 point for Wainui Beach was calculated using these two values. The ESL100 elevation and the associated SLR adjustments used for the Wainui Beach analysis are shown in Table 3.3.

Table 3.3: Elevations used to represent the ESL100 inundation hazard for three different ARI with the sea level rise scenarios. All values in NZVD2016 datum.

SSP Scenario	Elevation (m NZVD2016)			
	ESL100	ESL100 + SLR and VLM (2050)	ESL100 + SLR and VLM (2070)	ESL100 + SLR and VLM (2120)
SSP2-4.5		2.9	3.04	3.47
SSP3-7.0	2.65	2.92	3.09	3.69
SSP5-8.5		2.93	3.13	3.82

Figure 3.3: ESL100 points from Paulik et al., 2020 that were used for the Wainui Beach inundation analysis.

4 RESULTS AND DISCUSSION

4.1 BEACH MONITORING DATA AND SHORELINE POSITION

4.1.1 SOUTHERN BEACH

The foredune (RL2.0m) for Profile 1 (Figure 4.1) tends to be relatively stable with an approximate long-term rate of change around -0.04 m/yr. The high-tide beach position (RL1m) demonstrated a similar trend, while the MSL beach position showed significant fluctuation with some degree of neutral behaviour post 1987.

Profile 2 (Figure 4.2) showed an approximate long-term foredune erosion rate of -0.11 m/yr. It is noted that the lower contours demonstrate a great degree of variability and for this reason have not been relied upon for an overall interpretation of beach behaviour.

The short-term fluctuations have a potential high influence on the long-term trends, but the accuracy of these long-term trends is not certain. A notable short-term event is the rapid retreat in 1982 for Profile 1 (see Figure 4.1 below). Between 5-7m of foredune erosion occurred during this event. Dunn and de Lange (2003) indicate that the removal works of the beach groyne system also occurred during this time. This suggests that the removal works potentially led to unnatural short-term fluctuations in the beach position.

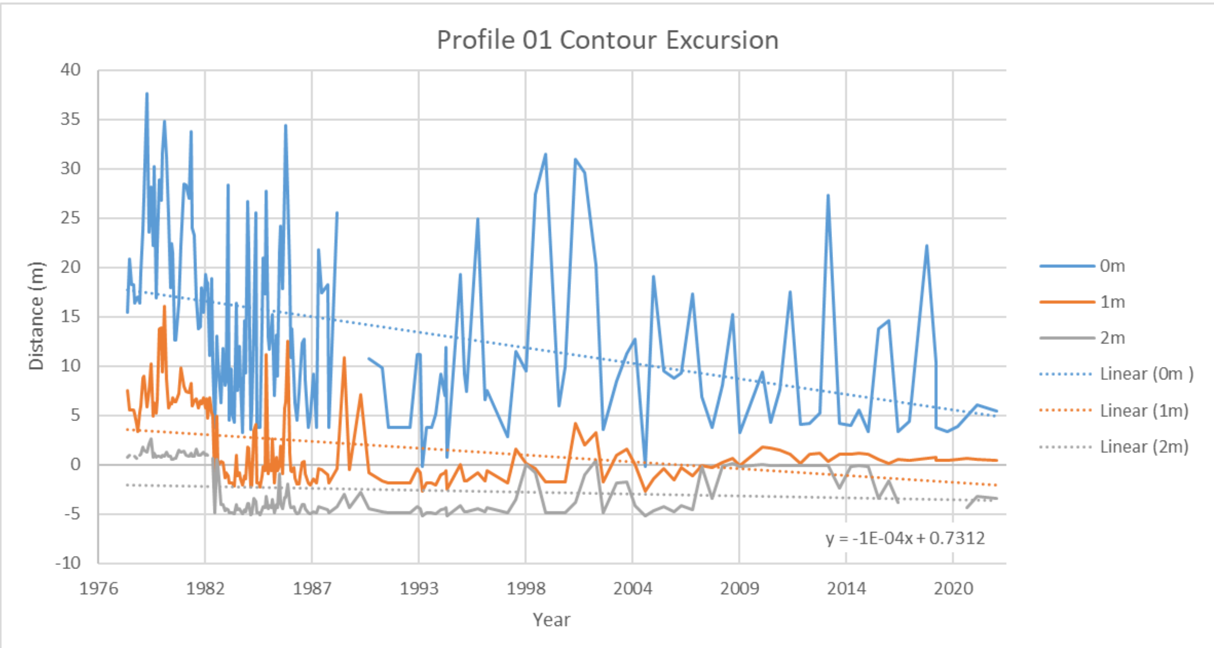

Figure 4.1: Profile 1 contour excursion chart with the 2m linear trendline equation.

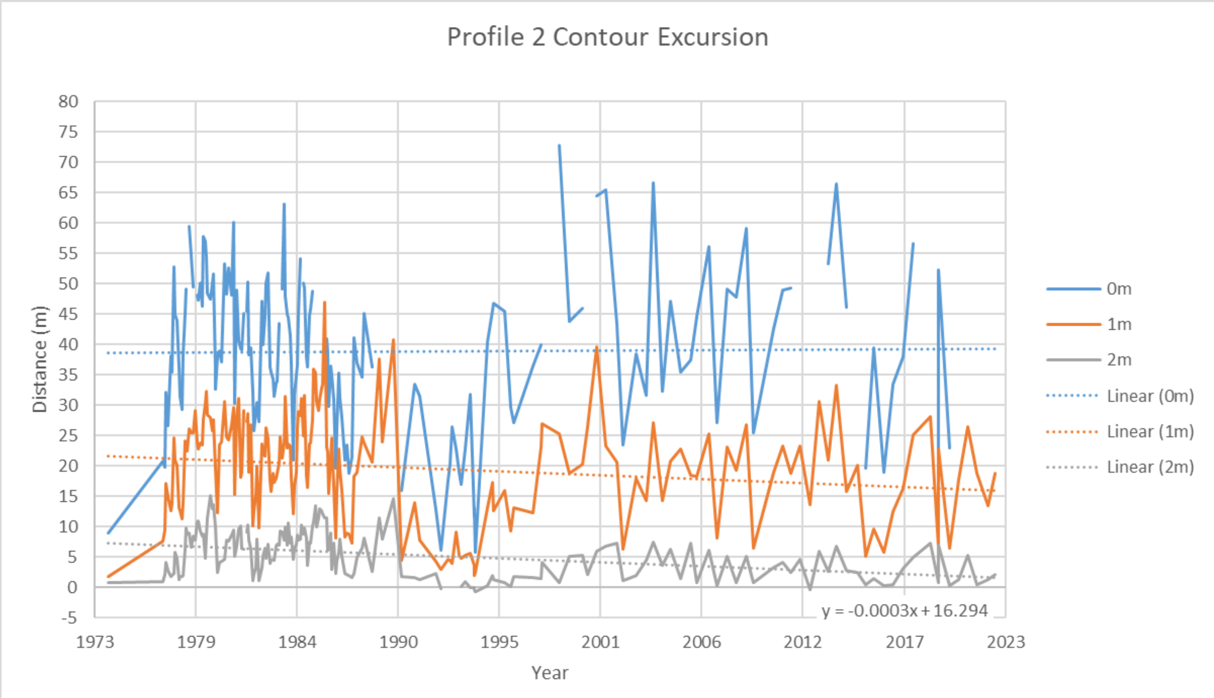

Figure 4.2: Profile 2 contour excursion chart with the 2 m linear trendline equation.

The long-term trends change considerably by isolating the excursion distance charts from 1988-2022. Isolation of these dates was undertaken to align with more consistent data collection methods and allowance for the removal of control structures such as groynes. This can be observed in Figure 4.3 below that shows Profile 1 to have an overall accreting trend at an approximate rate of 0.11m/yr. The foredune for Profile 2 (Figure 4.4) demonstrates relatively neutral trend with an approximate rate of change around -0.03m/yr.

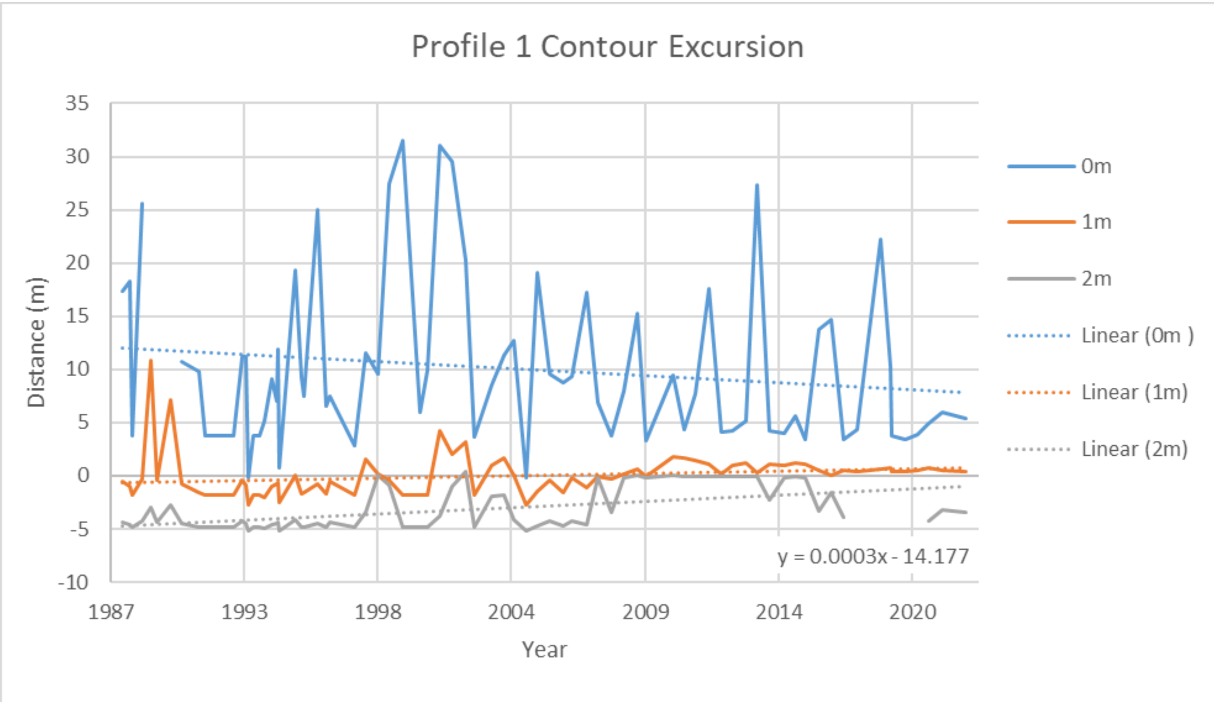

Figure 4.3: Profile 1 contour excursion chart 1988-2022 with the 2m linear trendline equation.

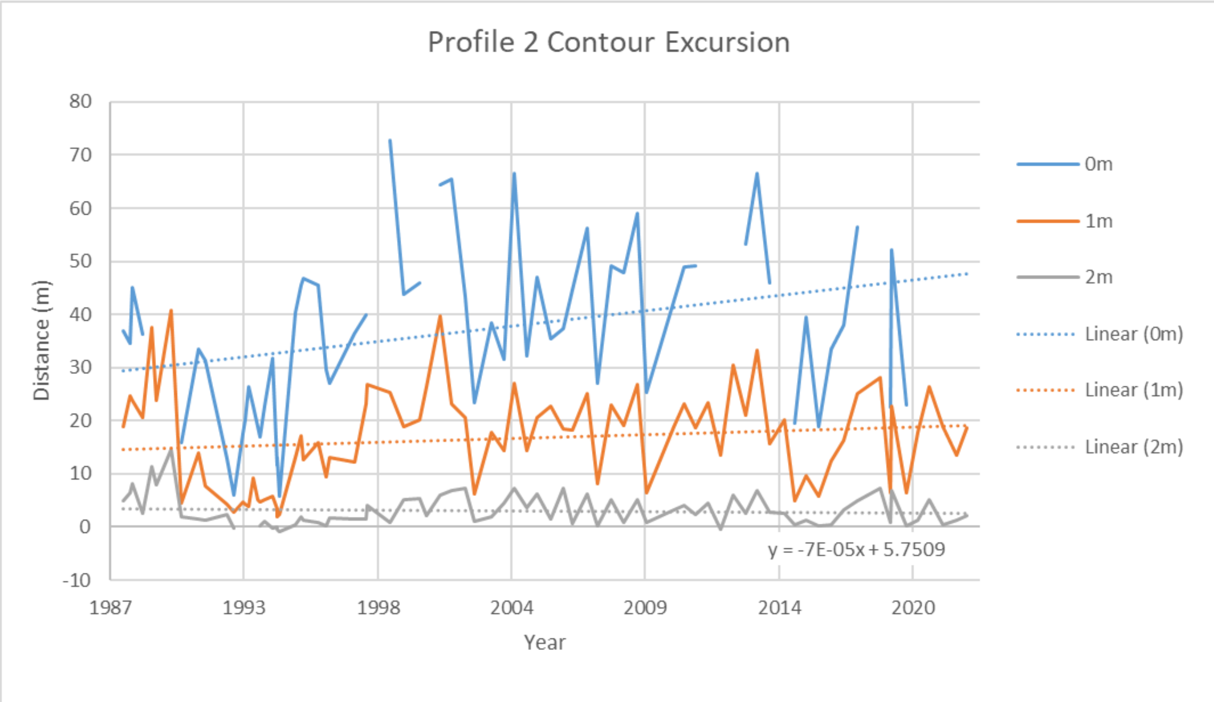

Figure 4.4: Profile 2 contour excursion chart 1988-2022 with the 2m linear trendline equation.

The 5-year averages for Profile 1 show the beach largely operating within the envelope of change (see Appendix A, Figure 10.1). There was a period of erosion noted from the start of the monitoring period through to the late 1980's. The average beach levels observed between 2020-2022 have been shown to be toward the lower reaches of the envelope of change. However, this maybe be reflective of the shorter monitoring period included within the average profile over this period.

The 5-year average for Profile 2 shows in general the average profiles to be operating approximately within the middle of the beach envelope for this profile (Appendix A, Figure 10.2). It is noted the 1990-1994 profile is considerably lower than the majority of the average profiles and particularly between RL1m and -0.5m where is approximately 1m lower than the others.

The Southern beach tends to be relatively sensitive to ENSO (see Figure 4.5 and Figure 4.6). The La Niña average profile tends to be more seaward than the El Niño average profile. The variation is pronounced for the low to mid tide zone for Profile 1 (below 0m), and the mid to high tide zone for Profile 2 (0-1m).

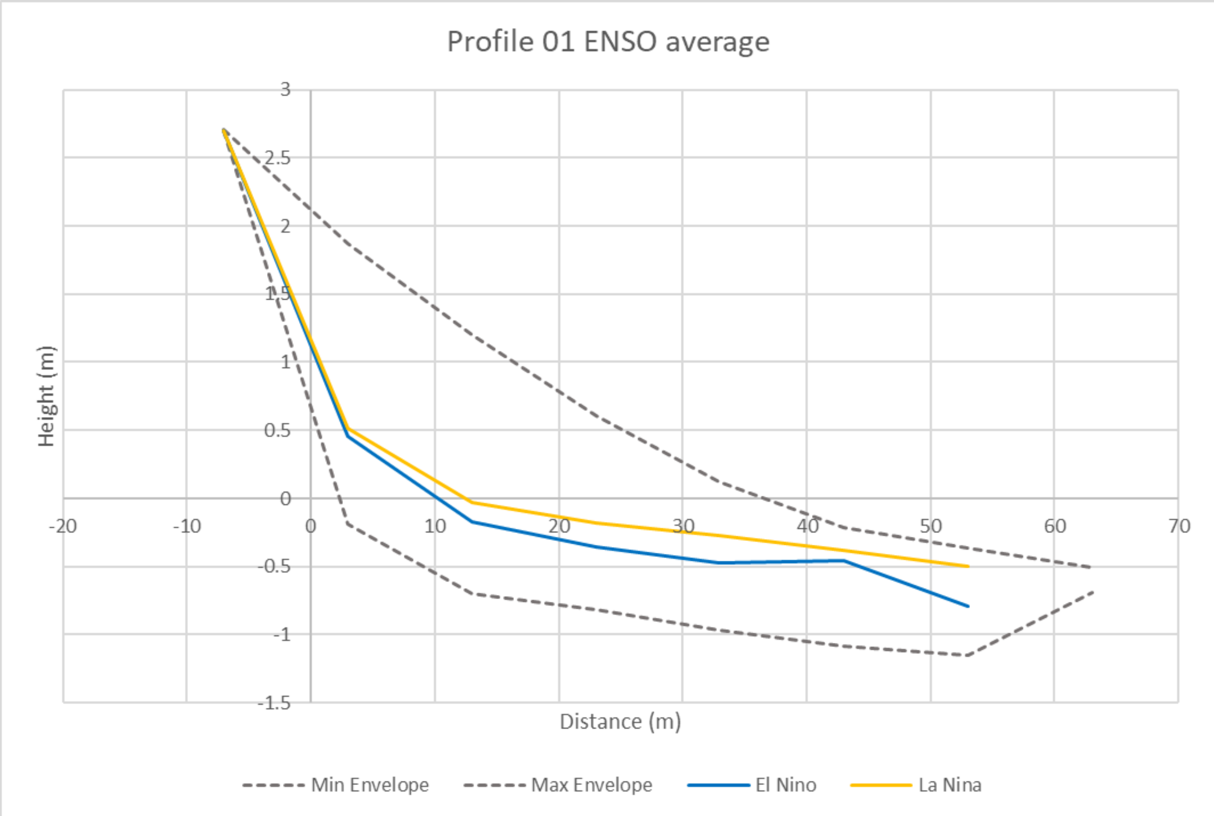

Figure 4.5: Profile 1 ENSO average chart.

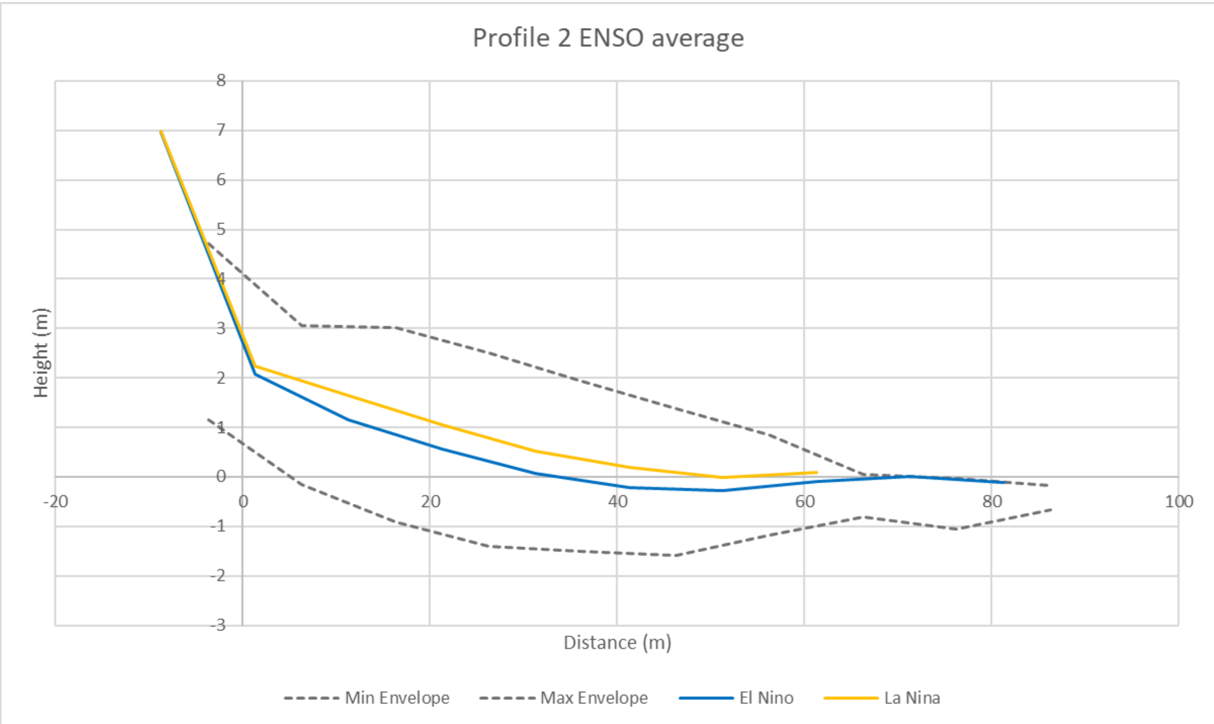

Figure 4.6: Profile 2 ENSO average chart.

The analysis of IPO and PDO fluctuations along the beach did not reveal any clear trends. The respective plots are contained within Figure 13.1 and Figure 13.2 of Appendix D and Figure 14.1 and Figure 14.2 of Appendix E.

4.1.2 WAINUI STREAM

As per the excursion distance chart, Profile 3 (

Figure 4.7: Profile 3 contour excursion chart with the 2m linear equation trendline

) shows long-term retreat for the foredune of approximately -0.29m/yr. However, analysis of the data post 1988 (Figure 4.8) indicates that the beach at this profile is largely neutral in its behaviour with a rate of foredune change in the order of -0.03m/yr. A similar pattern of behaviour is noted from Profile 4 albeit apart from a minor erosion trend of -0.11m/yr is still considered to operating at this part of the beach. Chart plots from Profile 4 are contained in Appendix B.

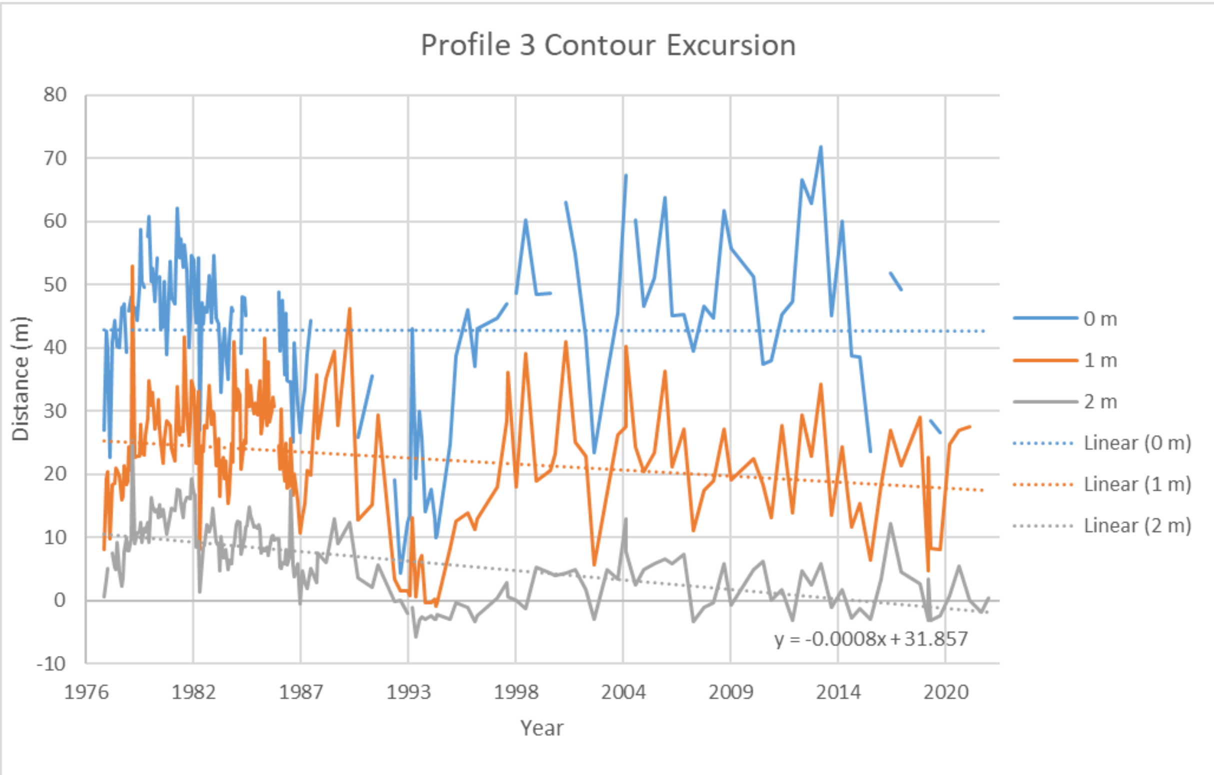

Figure 4.7: Profile 3 contour excursion chart with the 2m linear equation trendline

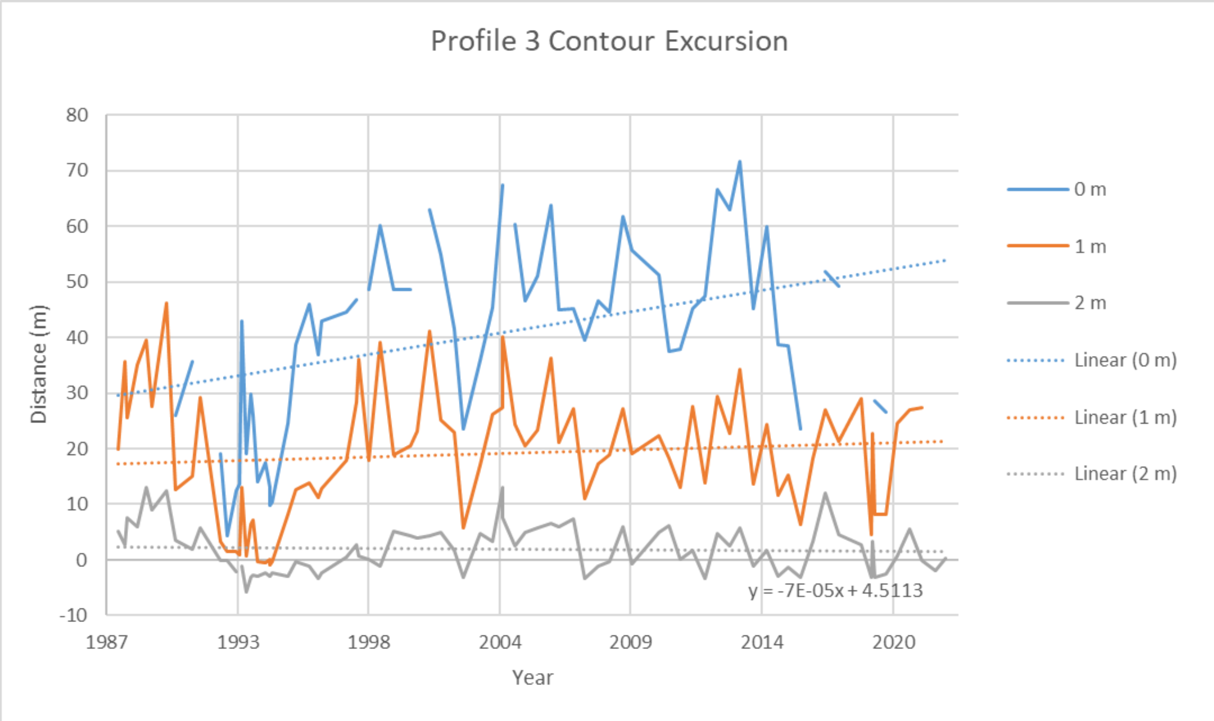

Figure 4.8: Profile 3 contour excursion chart 1988-2022 with the 2 m contour linear equation.

The 5-year averages for Profiles 3 and 4 (Figure 10.3 and Figure 10.4 in the Appendix) shows in general the average profiles operating approximately within the middle of the beach envelope for this profile. It is noted the 1990-1994 profile is considerably lower than the majority of the average profiles and particular between RL1m and -0.5m where it is approximately 1m lower than the others.

The ENSO plots at this part of the beach indicate that the Profile 3 is sensitive to El Niño (Appendix Figure 12.3) but no clear trend is apparent from Profile 4.

The IPO charts for Profiles 3 and 4 do indicate a potential relationship between IPO and beach position (Figure 4.9 and Figure 4.10). The analysis indicates that a negative IPO may result in erosion across this part of the beach.

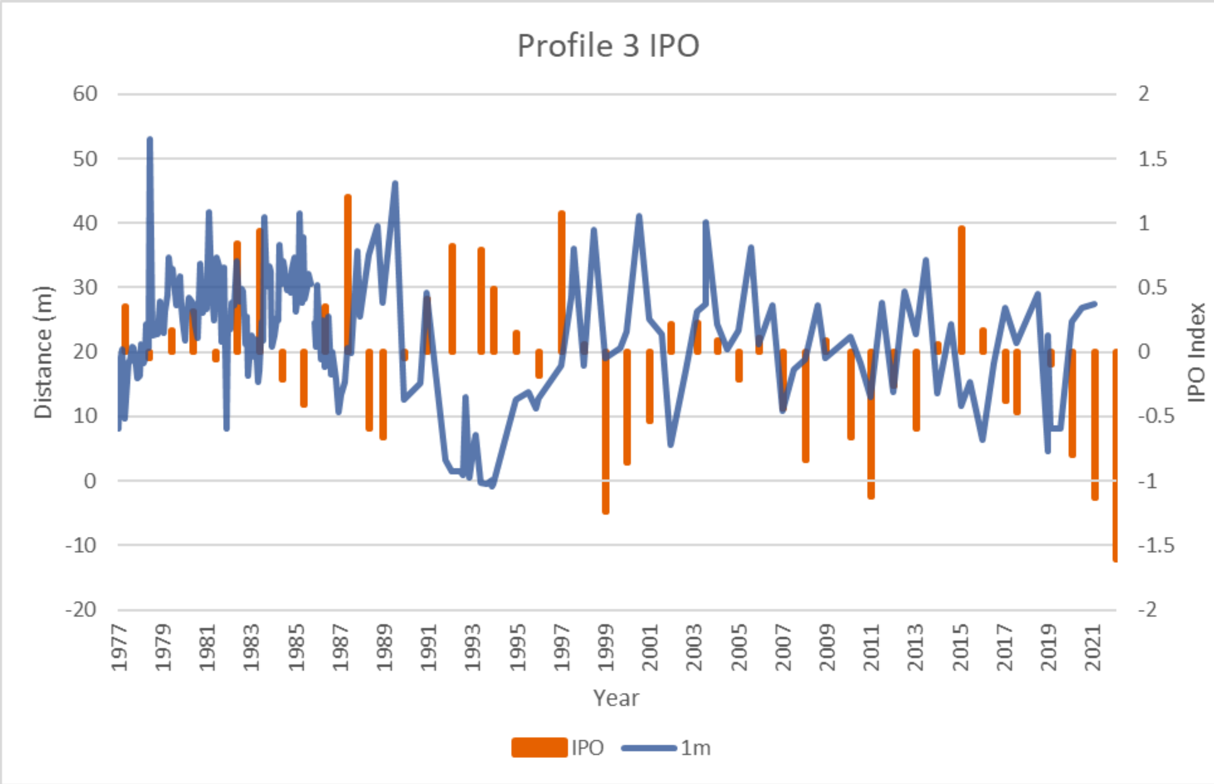

Figure 4.9: Profile 3 IPO chart.

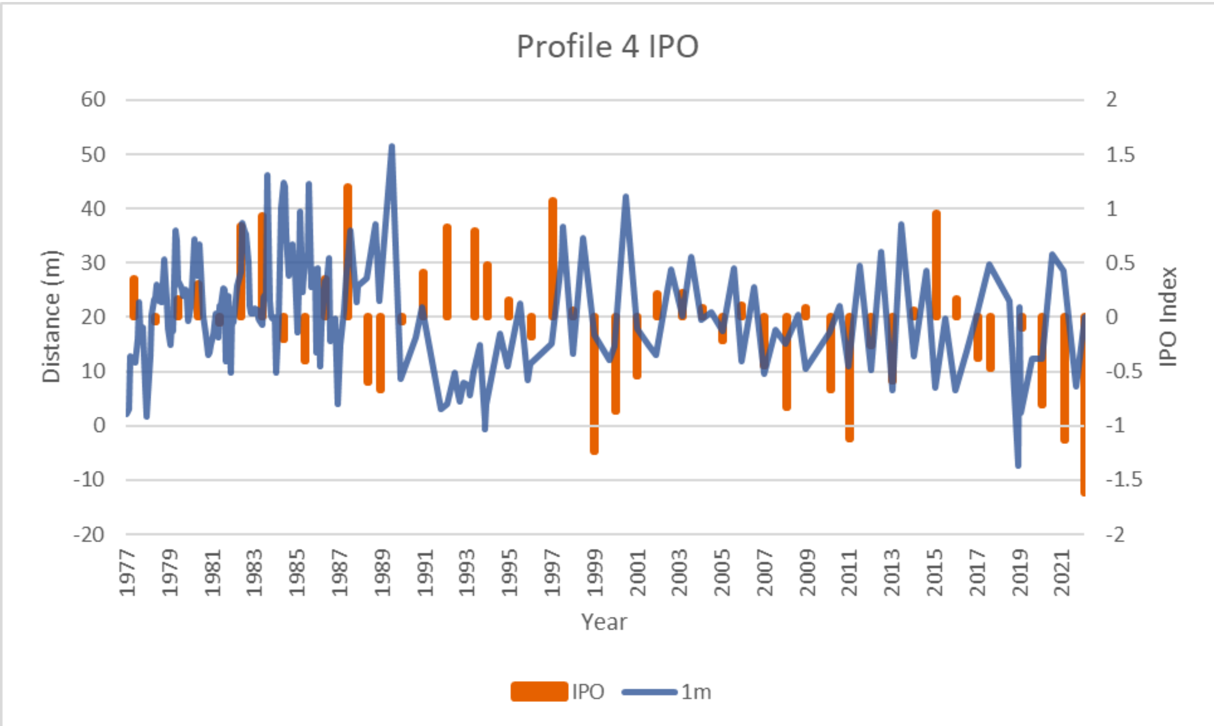

Figure 4.10: Profile 4 IPO chart.

Result of the PDO analysis are contained within Appendix D. The relationship between PDO and beach position is comparable to that of IPO with beach position where the stronger negative PDO aligns with the general retreat in beach position (Figure 14.3 and Figure 14.4). However, the negative PDO phase is not as prominent between 1999 and 2022.

4.1.3 CENTRAL BEACH

Contour positions across the Central Beach subunit over the complete monitoring period indicate a relatively neutral to minor erosional trend (Figure 4.11 to Figure 4.13). The most significant foredune erosional rate from this period noted is from Profile 6 and is estimated to be in the in the order of -0.18m/yr (Figure 4.11). Post 1988 the monitoring data indicates increased rates of foredune erosion along Profiles 7 and 8 of up to 0.29 m/yr (Figure 4.12 Figure 4.13).

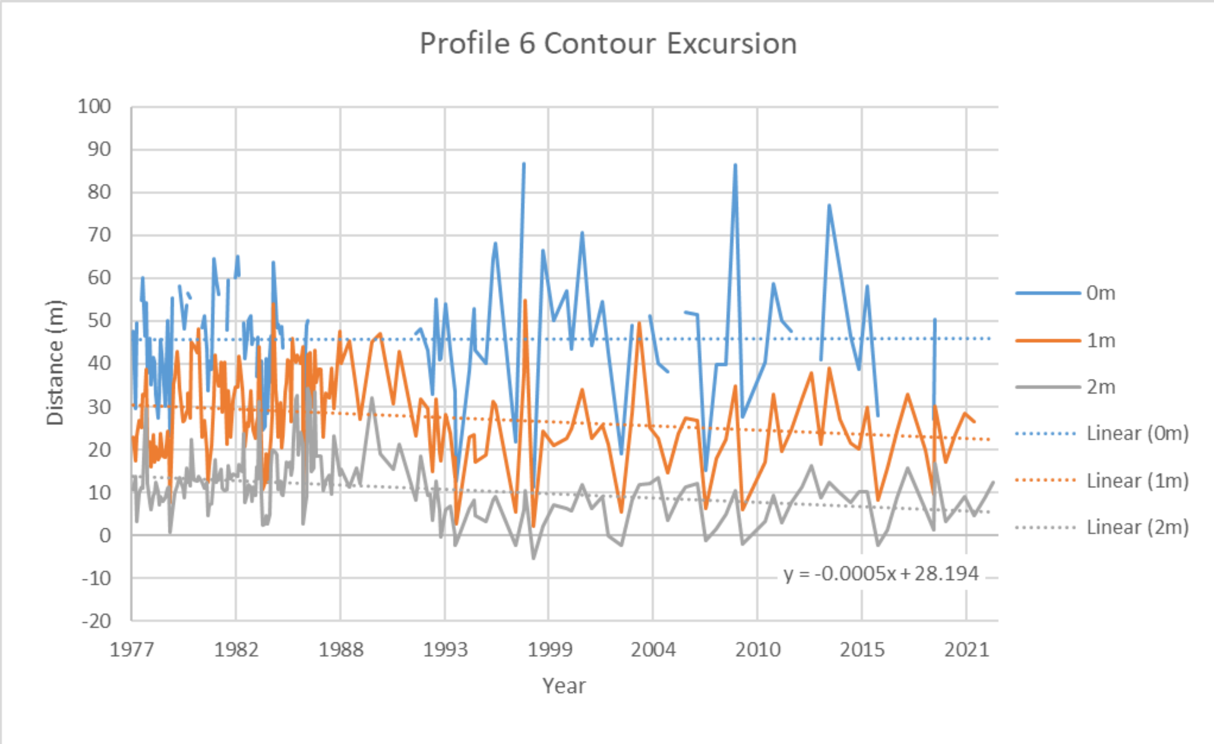

Figure 4.11: Profile 6 contour excursion chart with the 2 m linear trendline equation.

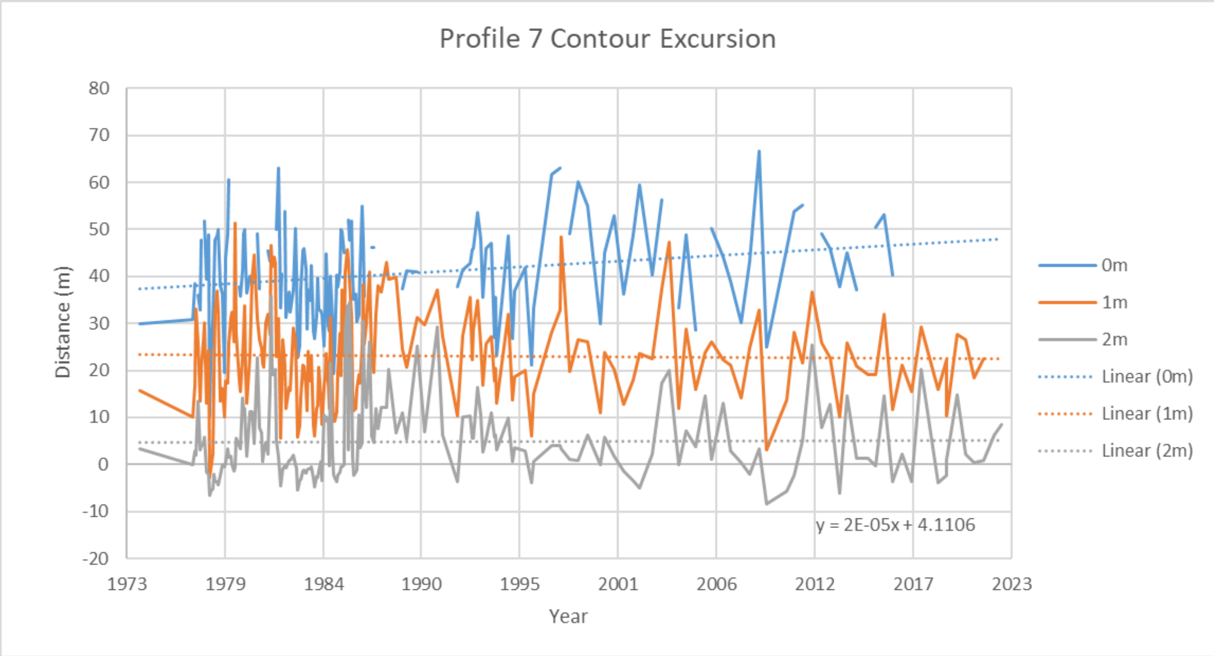

Figure 4.12 Profile 7 contour excursion chart 1988-2022 with the 2m linear trendline equation.

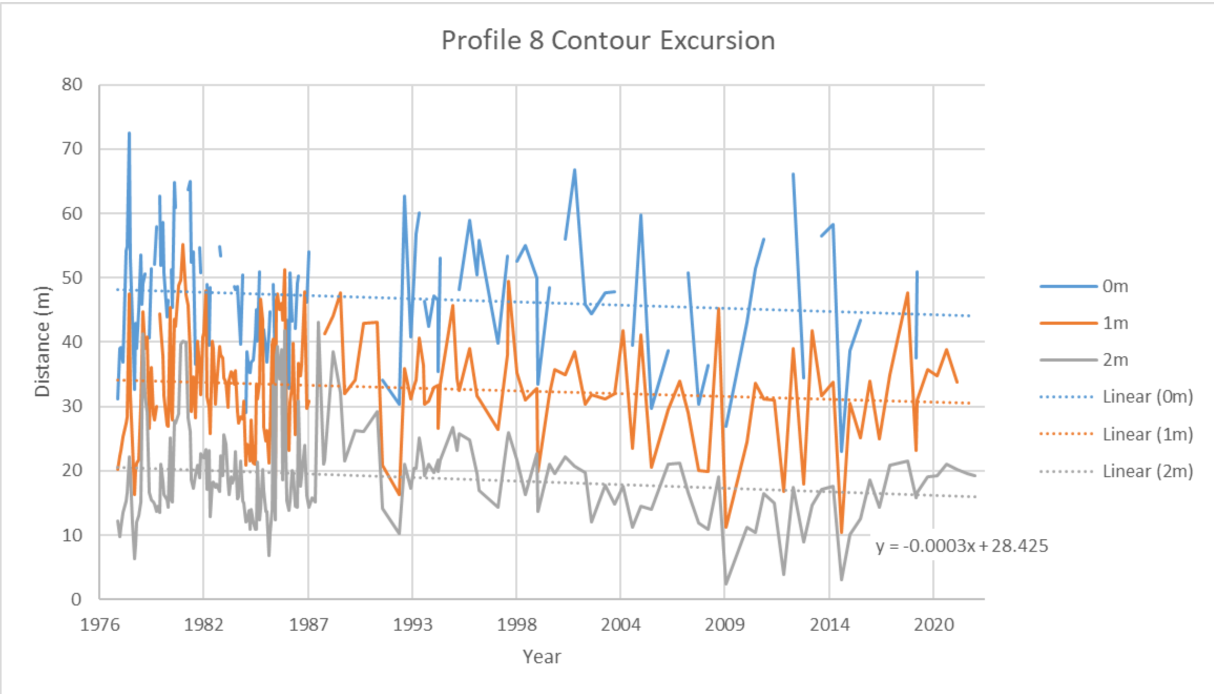

Figure 4.13: Profile 8 contour excursion chart 1988-2022 with the 2m linear equation trendline.

The 5-year averages for the Central Beach tend to fluctuate approximately within the middle of the beach envelopes for each of the respective profiles (see Appendix A Figure 10.5 to Figure 10.8).

The ENSO plots (see Appendix C Figure 12.5 to Figure 12.8) generally do not demonstrate any strong trend across the Central Beach portion of Wainui Beach. There are some differences noted in Profiles 7 and 8 but given the contrasting nature no trends have been assumed for the Central Beach zone.

The IPO shows a potential influence on the beach position (Figure 4.14 and Figure 4.15 below) from Profiles 7 and 8. There is a general tendency for a positive IPO to relate to a period of accretion and a negative IPO value linked to erosion events. However, a clear interpretation is complicated by the fluctuating nature of the beach and sporadic nature of data collection. The IPO for other profiles along the Central Beach can be found in Appendix D Figure 13.3 to Figure 13.6.

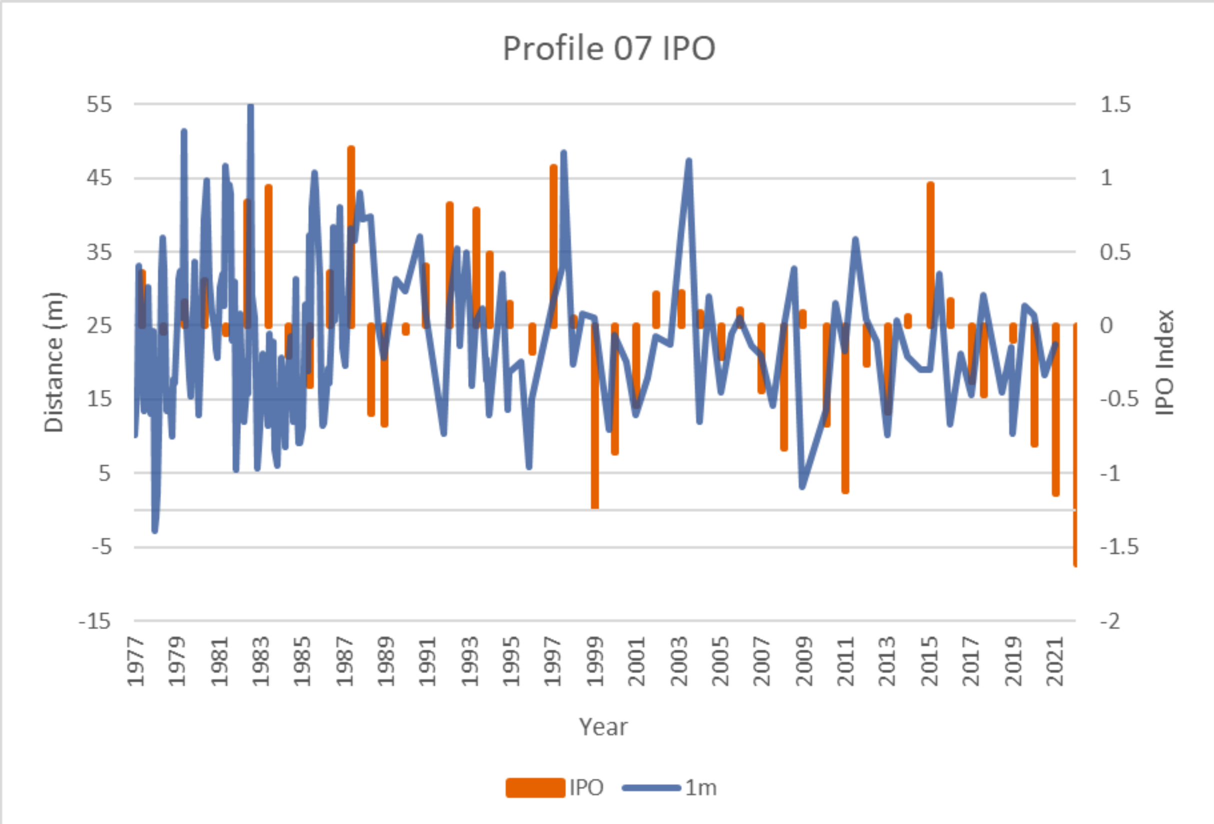

Figure 4.14 Profile 7 IPO chart.

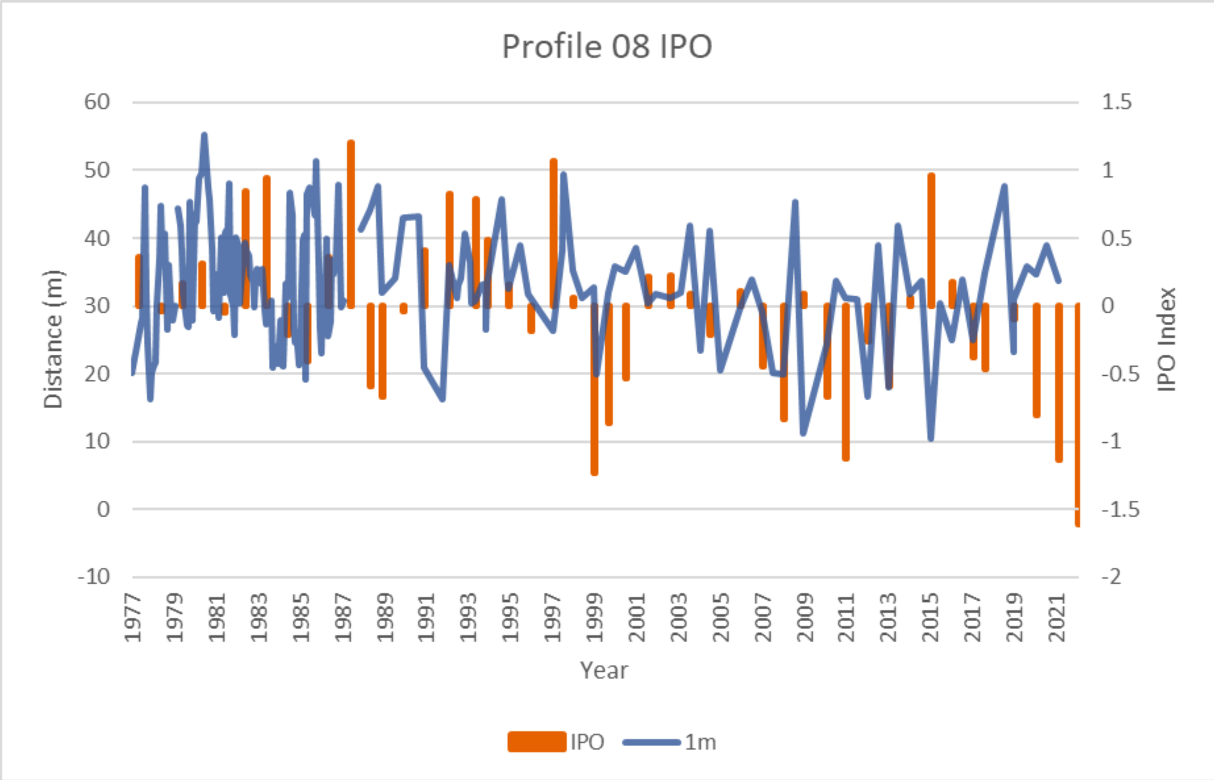

Figure 4.15 Profile 8 IPO chart.

The PDO analysis does not indicate any clear relationship between this climatic variable and beach position. The plots are contained within Appendix E (Figure 14.5 to Figure 14.8).

4.1.4 HAMANATUA STREAM

The excursion distance charts indicated a minor to moderate erosion trend for this beach section. Profile 8C (Figure 4.16) shows the highest foredune long-term retreat at an average rate of -0.37m/yr. However, given the profile(s) proximity to the stream and nature of extreme fluctuations within the contour excursion plot this is considered to be influenced by the stream mouth position.

This is supported by the 5-year average plots which demonstrate the 20-22 average beach position to be the most seaward and the most landward plots occurring between 10-14 (Figure 4.17).

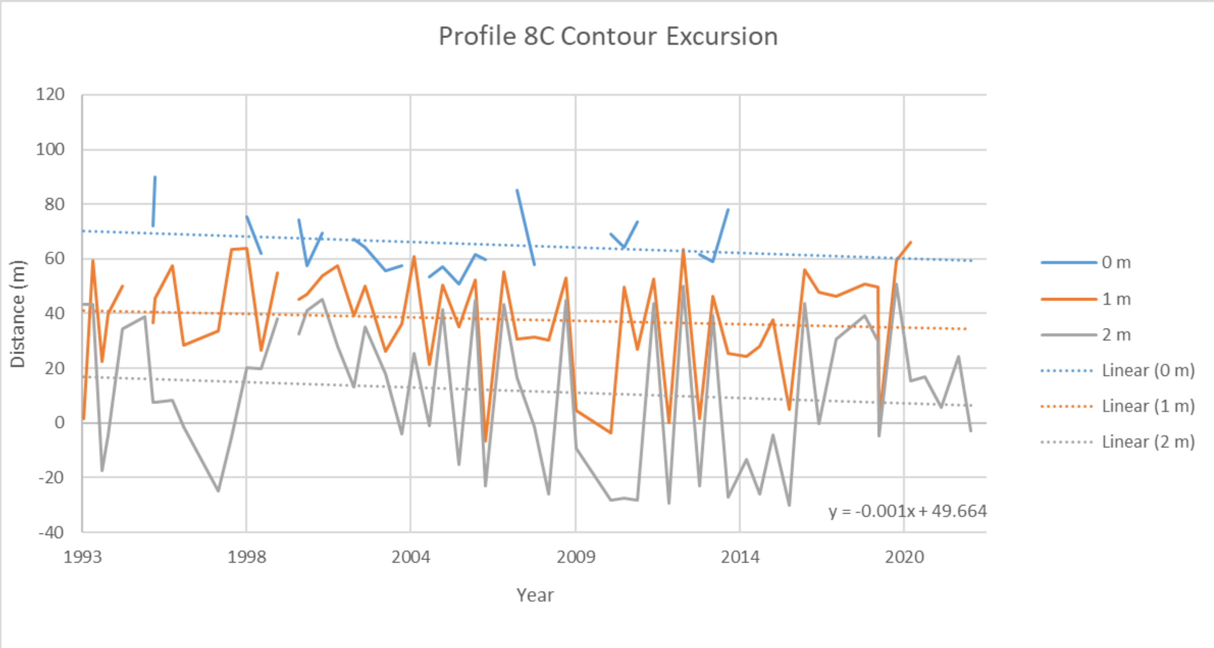

Figure 4.16: Profile 8C contour excursion chart with the 2 m contour linear trendline equation.

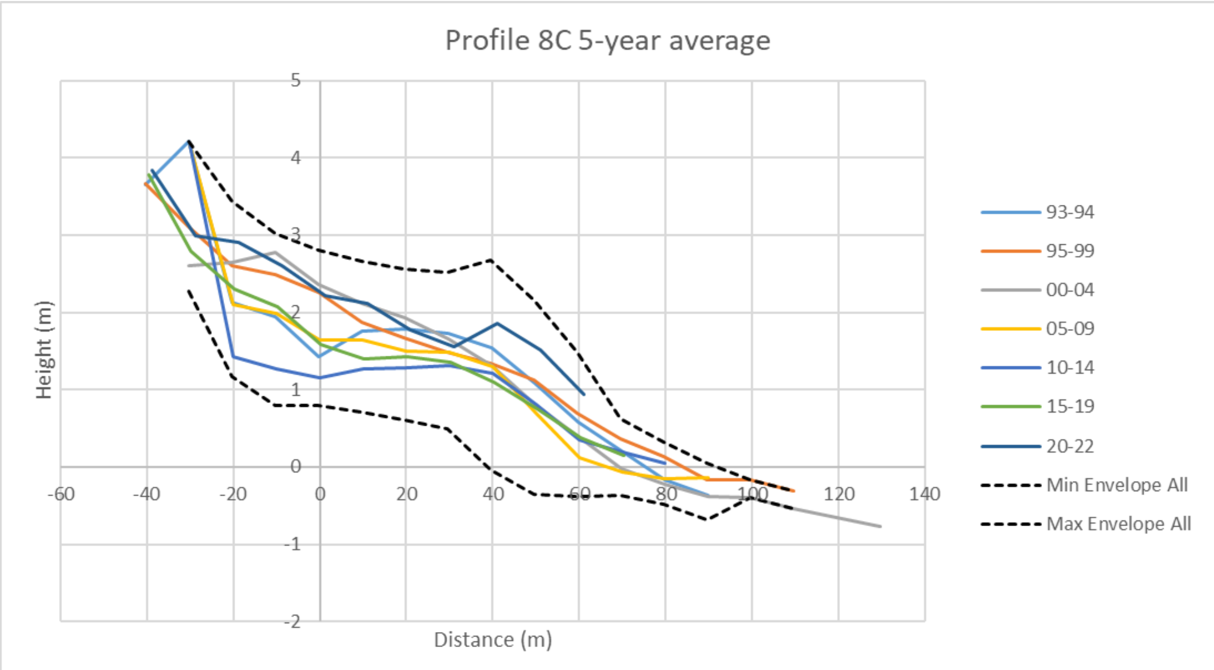

Figure 4.17 5-year average Profile 8C

The ENSO charts for the Hamanatua Stream profiles indicated that the foredune feature tends to accumulate sand under La Niña profile conditions, with the sand seemingly being borrowed from below the high-tide mark where beach levels were generally lower (Figure 4.18 and Figure 4.19) .

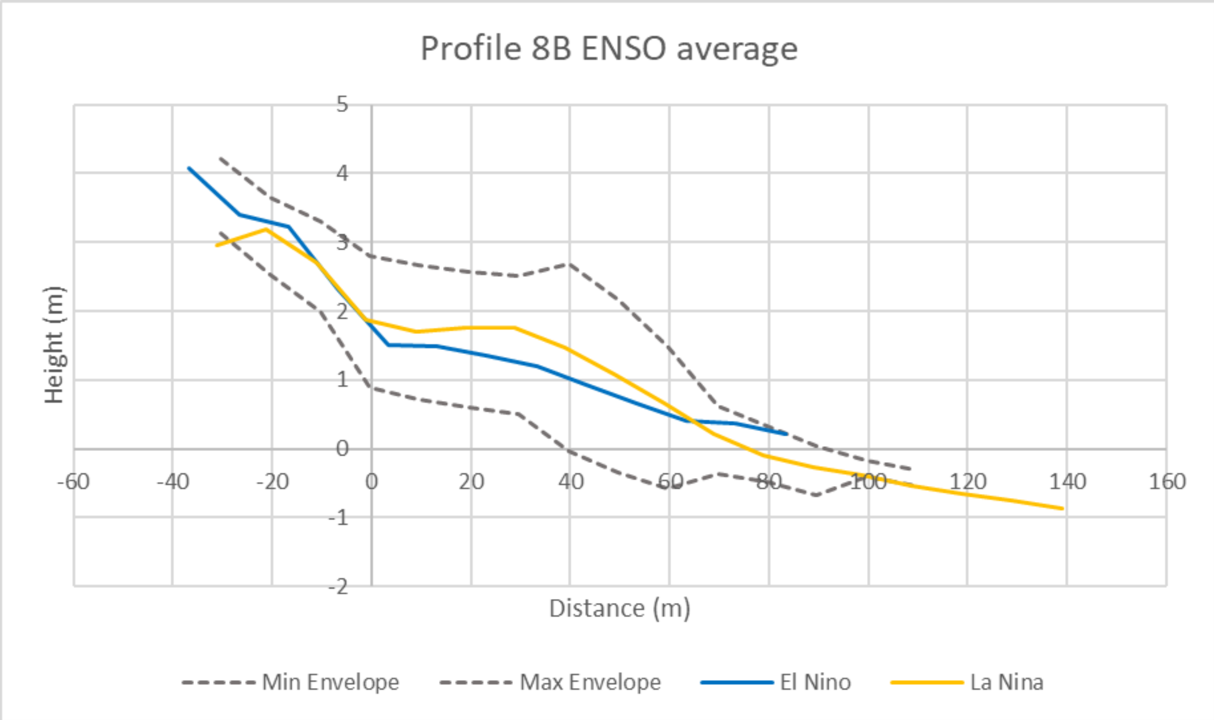

Figure 4.18: Profile 8B ENSO average chart.

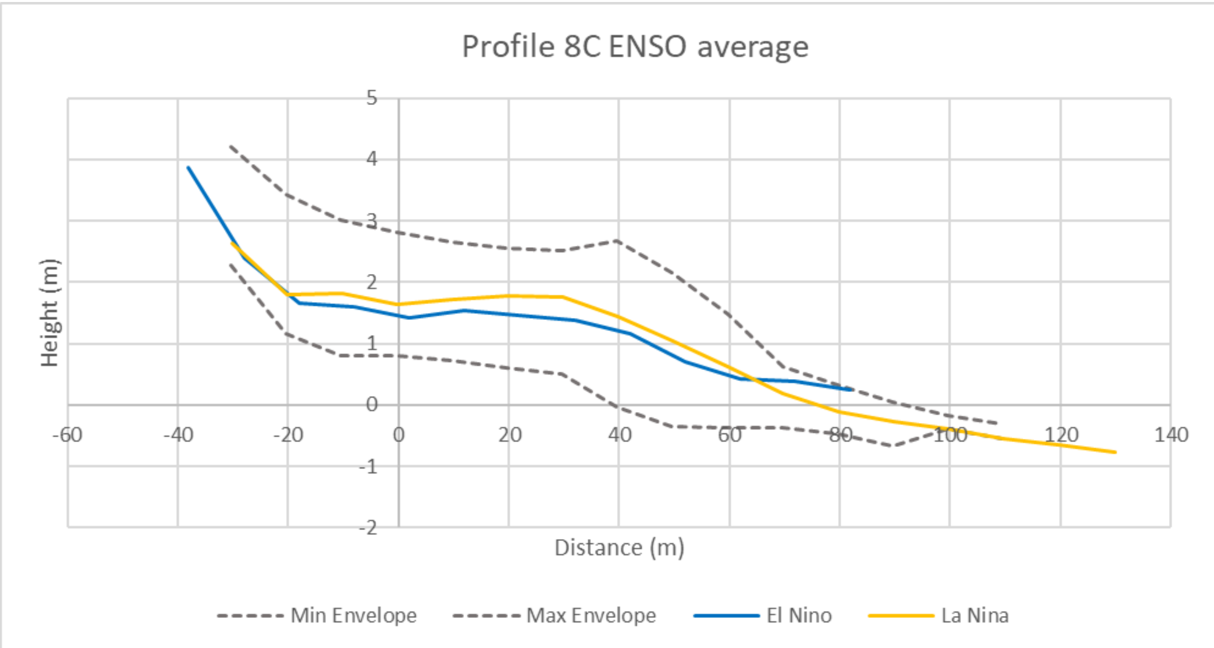

Figure 4.19: Profile 8C ENSO average chart.

No clear relationship was observed between IPO and PDO beach positions (Appendix D and Appendix E). The duration of the survey may be too short to make comparisons as the expected oscillation period for PDO is approximately 20-30 years.

4.1.5 NORTHERN BEACH

Over the length of the monitoring period, the southernmost profiles for the Northern Beach demonstrate a neutral to minor erosion trend. Profile 9 and 11 show an approximate long-term rate of change between of -0.07m/yr and -0.4m/yr respectively. Profile 10 (Figure 4.20) indicates an approximate erosion rate of -0.18m/yr. By contrast the northern profiles of the Northern Section tend to be demonstrating minor to moderate accretionary trends with the most notable occurring at Profile 13 (Figure 4.21).

Analysis of the monitoring data post 1988 indicates increased rates of erosion for the southern profile group. Profile 9 in particular was observed to have undergone a rate of retreat in the order of -0.37m/yr (Figure 4.22). Profile 14 was observed to switch from an accretionary trend to one of erosion (Figure 4.23).

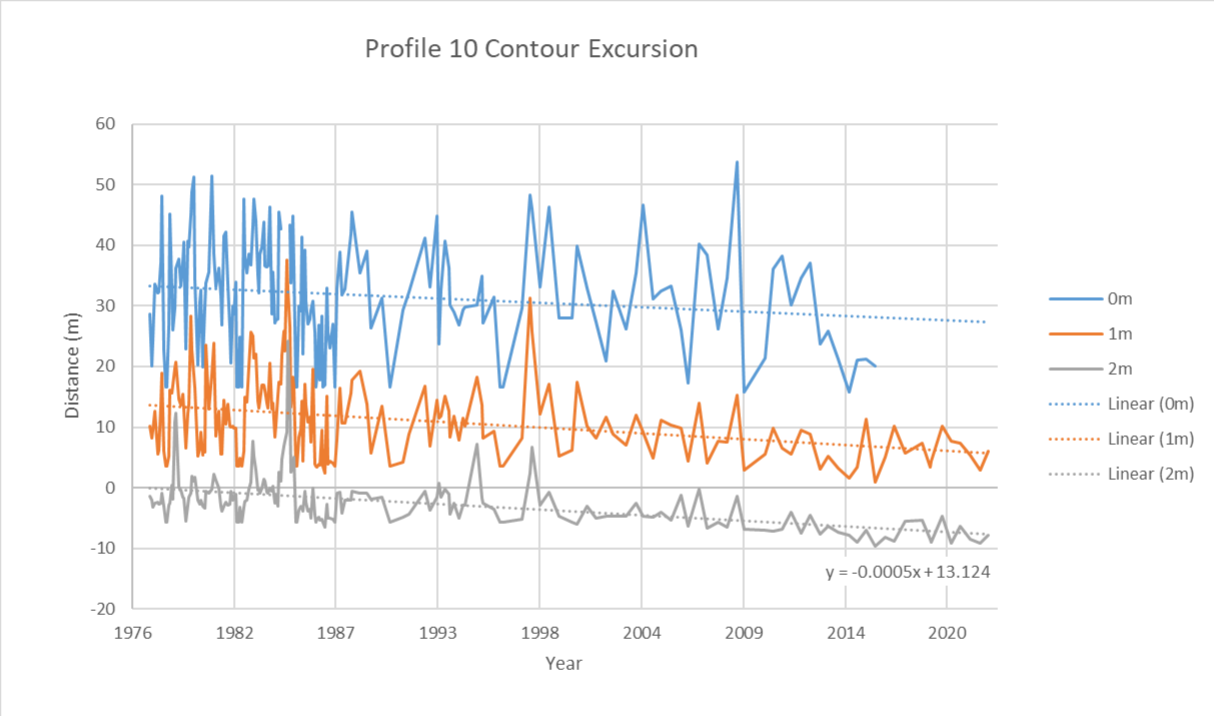

Figure 4.20: Profile 10 contour excursion chart with the 2 m contour linear equation.

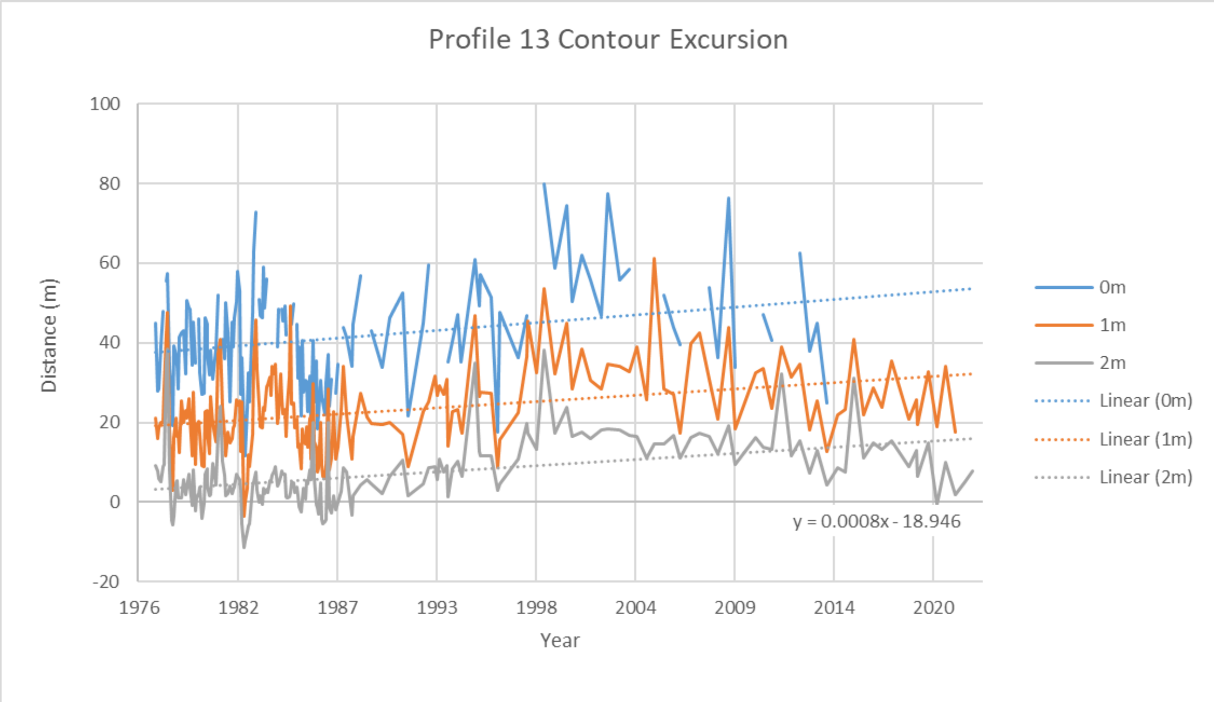

Figure 4.21: Profile 13 contour excursion chart with the 2 m contour linear trendline equation.

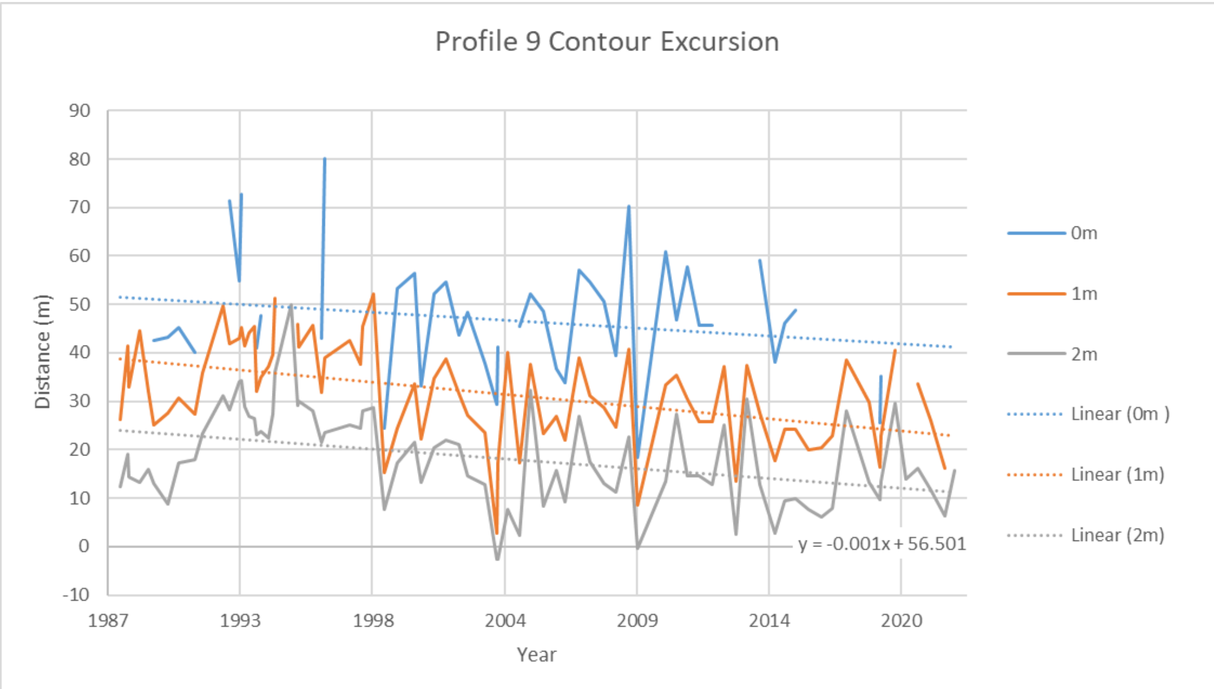

Figure 4.22: Profile 9 contour excursion chart 1988-2022 with the 2 m contour linear trendline equation.

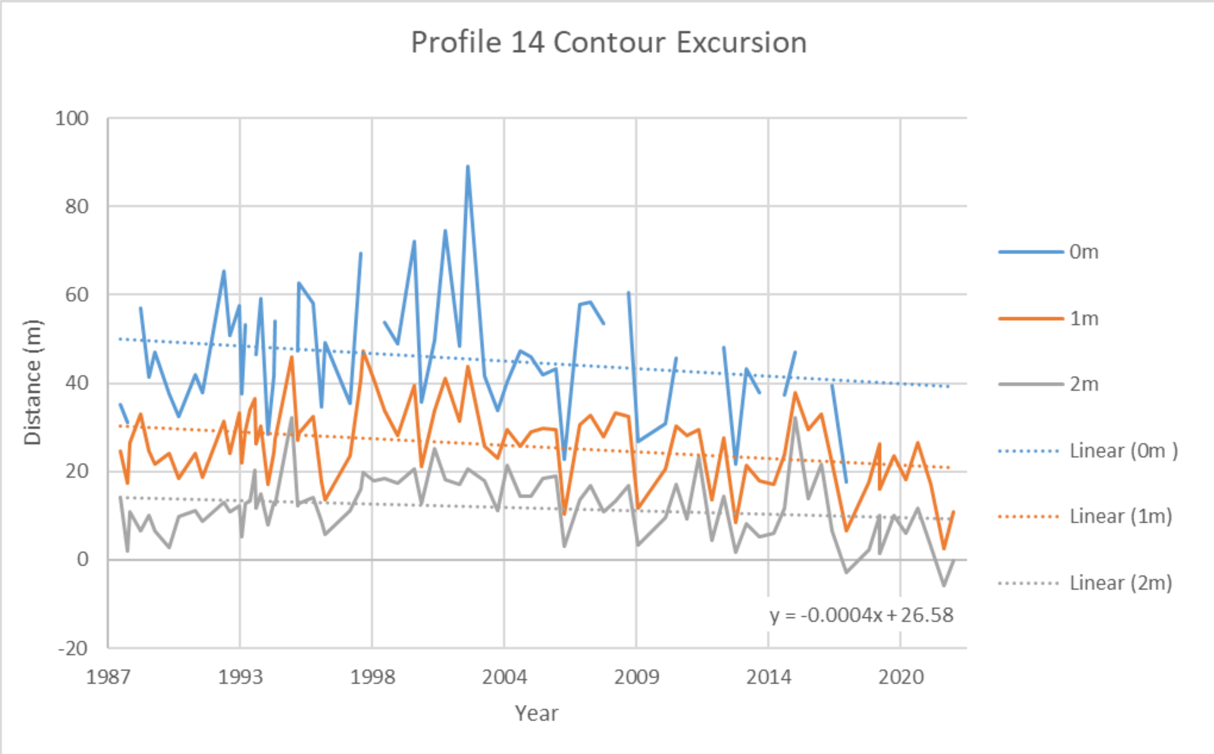

Figure 4.23: Profile 14 contour excursion chart 1988-2022 with the 2 m contour linear trendline equation.

The 5-year averages for the Northern Beach are contained within Appendix A (Figure 10.12 to Figure 10.17. From this analysis it is noted that Profile 9 (Figure 10.12) indicates the formation of a foredune between 1990 and 1998 presumably comprised of sand eroded from the southern portion of the beach in the early 1990's. Profile 10 tends (Figure 10.13) to be toward the lower limits of the beach envelope, while Profiles 13 and 14 tend to be in the upper margins of the beach envelope above the RL2m contour (Appendix A, Figure 10.16 and Figure 10.17).

In general, the ENSO plots for the Northern Beach (Appendix C Figure 12.12 to Figure 12.17) do not indicate clear variations between the average La Niña and El Niño profiles. Profile 13 (Figure 4.24) shows the largest variation with a generally seaward La Niña profile.

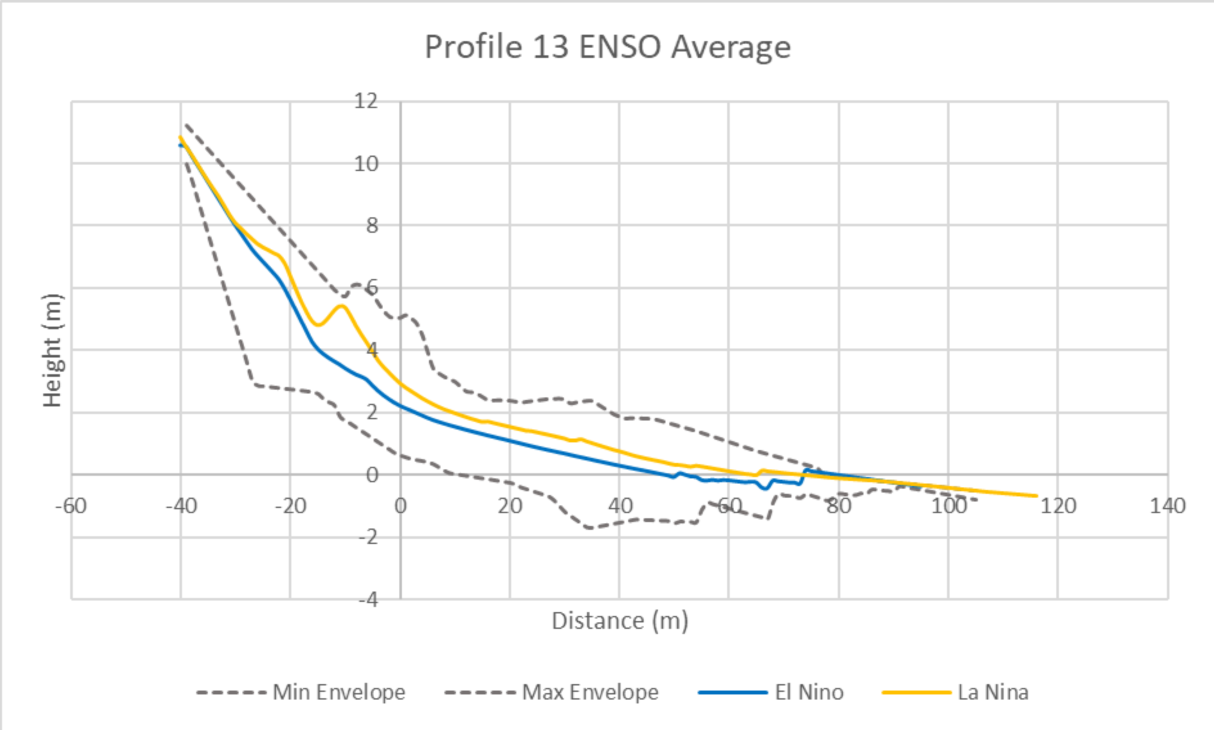

Figure 4.24: Profile 13 ENSO average chart.

The IPO shows a potential trend for the Northern Beach. Profiles 9 and 10 (Figure 4.25 and 4.1-26) shows a general landward shift in beach position as the IPO moves from a positive to a negative IPO. In contrast, Profiles 12 and 13 (Appendix D Figure 13.10 and Figure 13.11) indicate a converse relationship to this but the data signals are not considered strong enough to determine a clear trend.

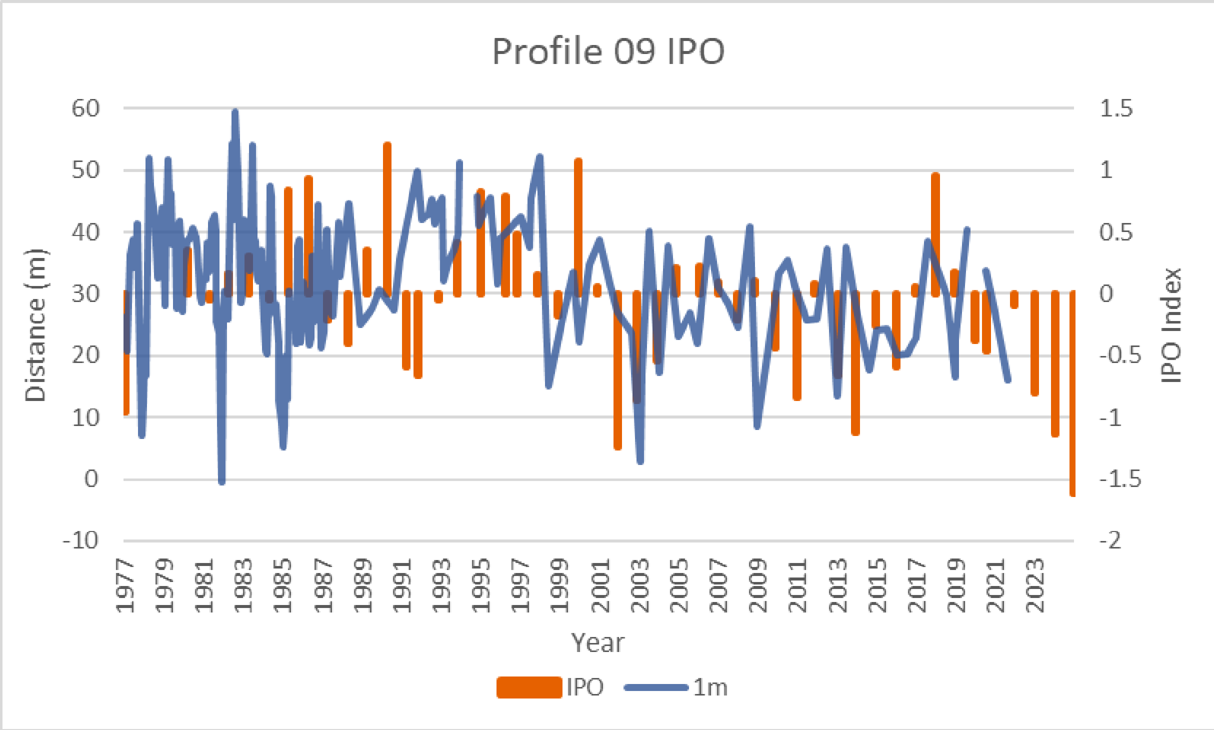

Figure 4.25 Profile 9 IPO Chart

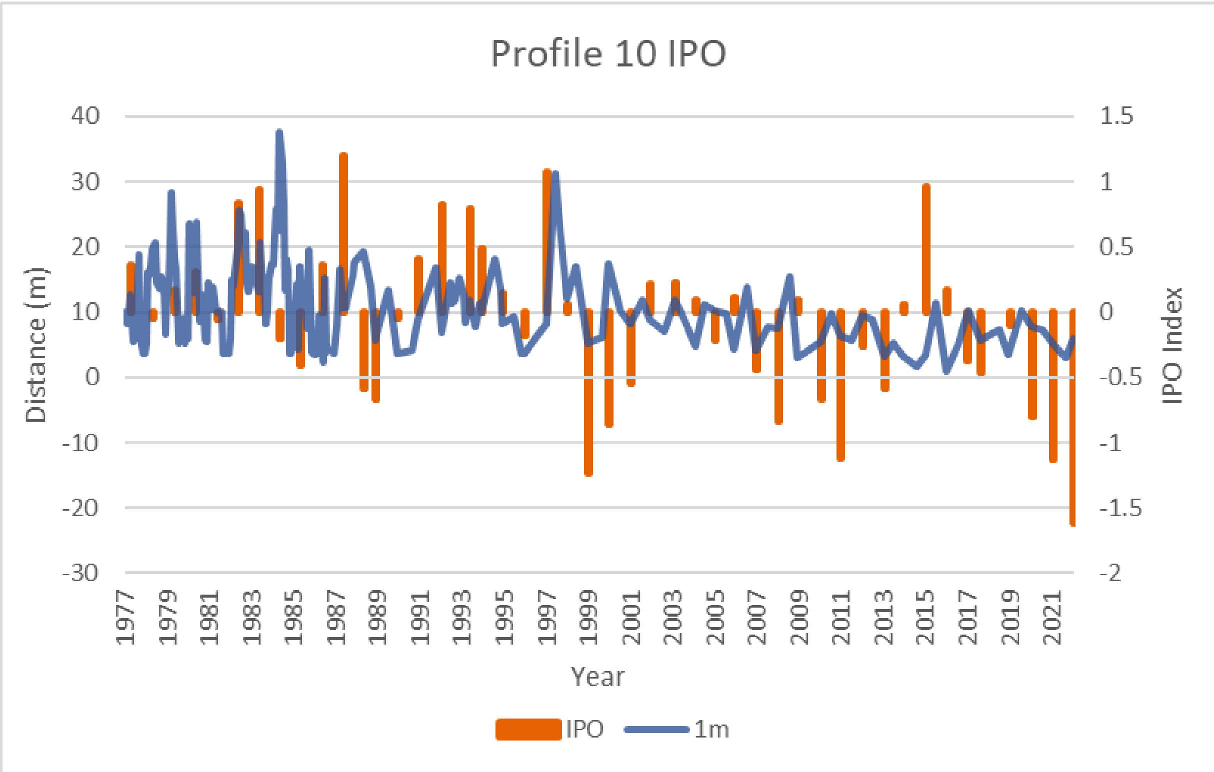

Figure 4.26 Profile 10 IPO Chart

No clear trends were apparent from the PDO analysis of the Northern Section of the beach.

4.1.6 HISTORIAL SHORELINE ANALYSIS

A series of aerial imagery from as early as 1942 were analysed using ArcGIS to assess the changes in the position of the coastline along the 6km stretch of the Wainui Beach. The historical shoreline analysis was also used to compliment the profile data analysed above to provide a greater spatial representation of the entire Wainui beach shoreline.

Shoreline positions from 1942 to 2023 are superimposed on the LINZ 2023 aerial imagery with the envelope of change (for all shorelines) for visual comparison from south to north (Figure 4.27 and Figure 4.33). The historical shoreline analysis of the study area reveals variation of coastline retreat and accretion alongshore over time.

Along the Southern Beach section and the section of the beach around the Wainui Stream (Figure 4.27 and Figure 4.28) the shoreline follows a very similar trend over time, with smaller sections of this part of the coastline between 1977 and 1982 that show landward retreat of the shoreline. The Southern Beach and Wainui stream section of the shoreline was at its most landward point in 1957 and most seaward point in 1942.

Figure 4.27 Historic shoreline position of the Southern Beach section of Wainui beach

Figure 4.28 Historic shoreline position along the Wainui Stream section of Wainui beach

Along the Central Beach section, the shoreline continues to follow a similar trend over time, with smaller sections between 1942 and 1957, and 1977 and 1982 that show the landward retreat of the shoreline (Figure 4.29 and Figure 4.30). The Central Beach section of the shoreline was at its most landward point in 1957 and most seaward point in 2022-2023.

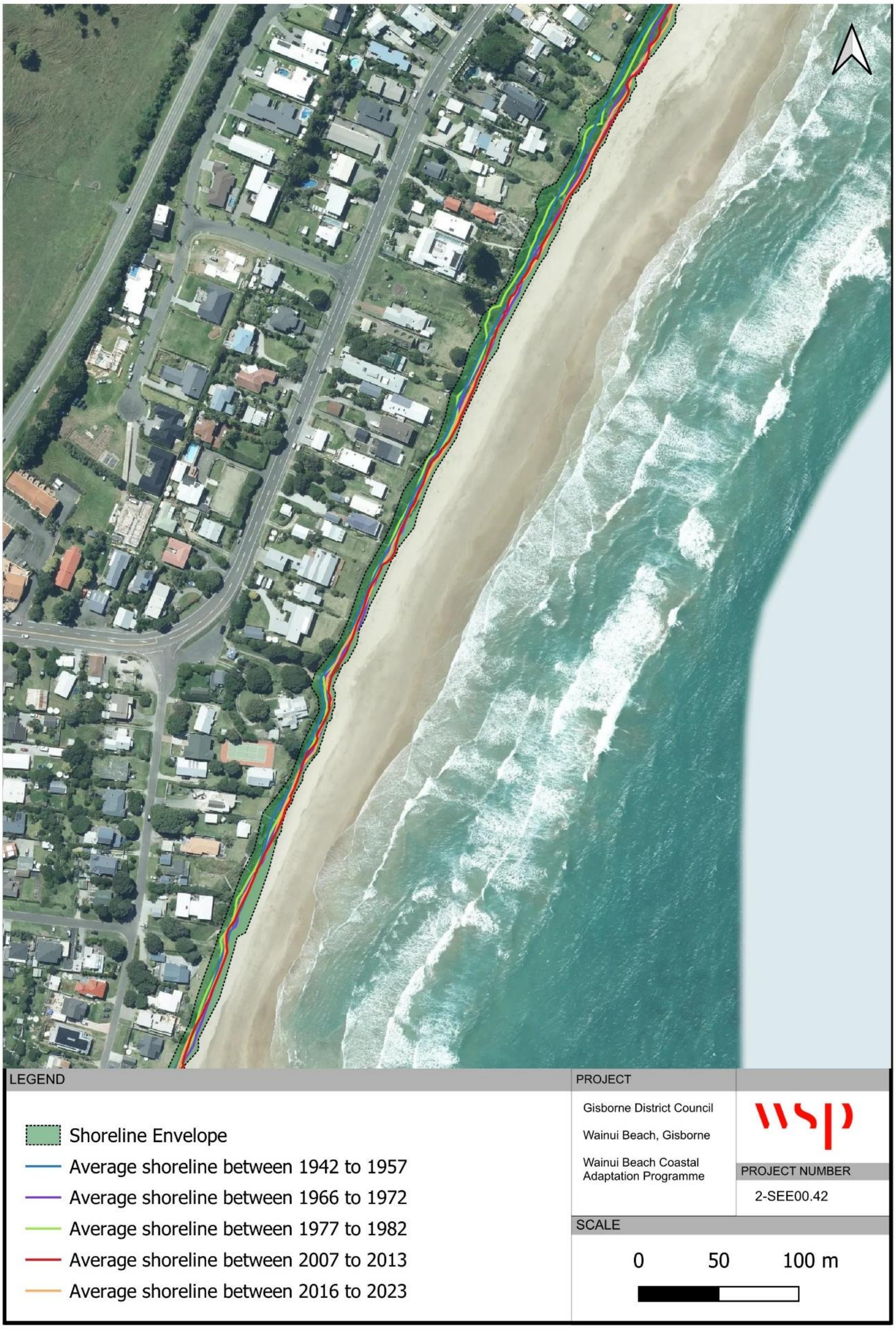

Figure 4.29 Historic shoreline position of the southern section of the Central subunit of Wainui beach

Figure 4.30 Historic shoreline position of the northern section of the Central subunit of Wainui beach

Along the section of coastline adjacent to the mouth of the Hamanatua Stream, a positive trend in shoreline position over time can be seen (Figure 4.31) where the shoreline has accreted over time. Whereas the shoreline directly to the north the stream, shows greater variation in shoreline position over time. The shoreline is at its most landward extent between 1977 and 1982, whereas the shoreline during other timeframes follows a similar shoreline position.

Figure 4.31 Historic shoreline position of the shoreline adjacent to the Hamanatua Stream section of Wainui beach

There is variation of shoreline position along the Northern Beach north of the Hamanatua Stream (Figure 4.32 and Figure 4.33). The shoreline position is shown to be at its most landward extent during the period between 1977 and 1982. The most northern section of the Northern Beach is at its most seaward extent between the period 1942 to 1972.

Figure 4.32 Historic shoreline position of the southern section of the Northern subunit of Wainui beach

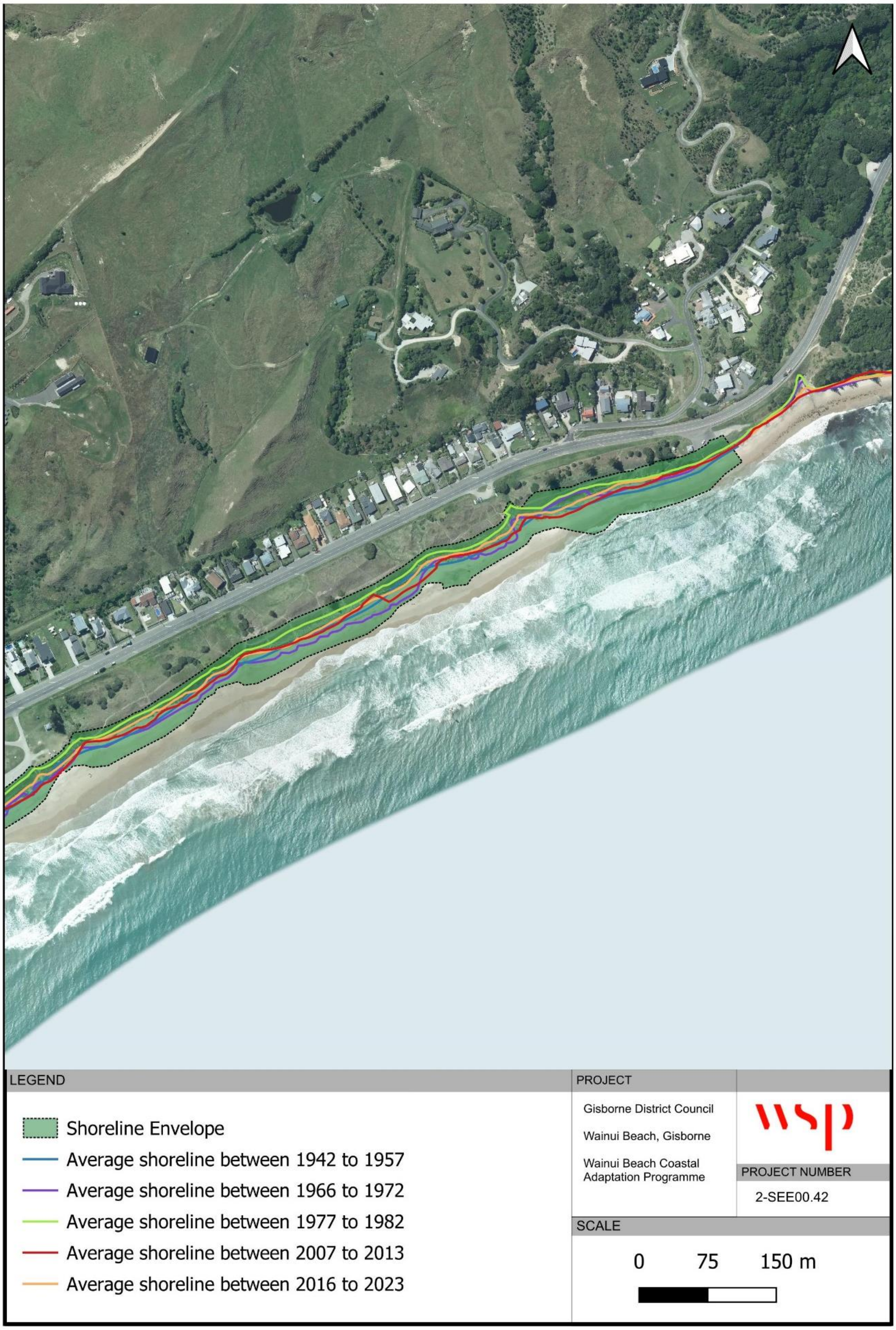

Figure 4.33 Historic shoreline position of the northern section of the Northern subunit of Wainui beach

The stream position for the Hamanatua Stream and Wainui Stream was mapped between 1942 and 2023 (Figure 4.34 and Figure 4.35). The Hamanatua Stream position over time follows a trend where the stream is generally located along the true right bank of the stream mouth with the exception in 1957 when the stream position is located along the true left bank of the stream mouth. The Wainui Stream position over time does not show any trend in position and is generally centred along the current stream mouth.

Figure 4.34 Position of Hamanatua Stream over time

Figure 4.35 Position of Wainui Stream over time

4.2 SUMMARY OF HISTORIC BEACH POSITION

Overall, the beach appears to be fluctuating in its position subject to changes in climatic conditions. The beach around and south of the Wainui Stream has been shown to be susceptible to erosion with minor to moderate erosion trends noted within the contour excursion analysis. On balance the rates of erosion are offset by areas of accretion or neutral beach trends and the beach does not appear to be suffering from a sediment deficit.

For these reasons the beach is generally considered to be acting in a dynamic equilibrium, with areas of "erosion hotspots". These erosion hotspots are a response to former beach management practices and/or the location of prior development within the limits of the systems envelope of change. The recognised erosion hotspots are:

- Tuahine Crescent
- Wainui Stream
- Pines carpark (associated with overland flows)
- Whales carpark

The nature of erosion issues at both Tuahine Crescent and Whales carpark are related to the transition from beach to cliff geomorphic settings (noting cliffs do not have the ability to recover from erosion events like beach settings).

It is noted that the beach is subject to strong phases of erosion as observed within the beach monitoring data. Within the beach profile monitoring data, the most significant of these erosion phases occurred between 1992 and 1996 and was most pronounced in the southern portion of the beach. Prior reporting has highlighted significant erosion events in the 1940s, 1955 and 1978 with retreat of the dune position between 15-20 m (Gibb, 2001). For incorporation of these events within this assessment we are reliant upon the analysis of aerial imagery discussed above.

From this analysis, shoreline retreat was noted in southern and central portions of the beach in the 1957 and 1977 aerial images and was noted in the northern portion of the beach in 1957 and 1982 but in general the beach is considered to have recovered following these events. Allowance for these events has been made within the short/medium term fluctuation components in the estimate of the current beach erosion risk.

There is some alignment of erosional and accretionary phases with ENSO and IPO climatic drivers. This is most pronounced at the northern and southern sections of the beach and in areas where foredunes are present. At the northern and southern areas, the beach has been shown to be generally lower during El Niño and this is related to the narrow high tide beach and lack of foredune features which would provide additional sand storage.

This will invariably leave these parts of the beach susceptible to large storm events as the drivers to specific erosion events. Those areas of the beach where a foredune feature is present sand has been shown to accumulate within the dune system. However, phases of erosion are known to occur outside of these periods suggesting cycles operating in the system there have not been identified within the analysis of the beach monitoring data.

Analysis of the stream mouth positions did not reveal any clear trends likely due to the complex nature of the interaction between environment variable such as rainfall and wave conditions. However, the impact of stream mouth position is apparent from observations of the beach where sand levels are lowered by stream flows which allows for increased wave run-up and its impacts on the backshore margins.

5 COASTAL INUNDATION RESULTS

Three different scenarios were used to assess the potential hazard to Wainui Beach from coastal inundation, the results of which are shown in this section. Using the three different scenarios of SSP2-4.5, SSP3-7, and SSP5-8.5 for ESL100, STE and MHWS; any assets that are potentially at risk of inundation can be identified. Appropriate mitigation measures such as coastal protection structures can therefore be effectively planned for.

Comparison of the three different inundation scenarios indicate that the predicted ESL100 inundation extend the most landward of the three scenarios followed by the STE scenarios and then the MHWS scenarios. Analysis of both the MHWS and the STE inundation elevations indicates there appear to be no dwellings within the hazard zone covered by MHWS and STE. The only assets that appear to be at within the hazard zone in these two scenarios is the groyne on the southern end of the Wainui settlement.

There are several buildings identified using the LINZ building outline layers that are within the ESL100 hazard scenario zone along the Wainui Stream Beach Section (Figure 5.1) In addition, the groyne at the southern end of the Wainui settlement is also shown to be within the hazard zone under current day ESL100 and future ESL100 scenarios (Figure 5.2). The figures showing the inundation hazard zone along other sections of the beach for ESL100 under current and future climates are in Appendix F, these show that no infrastructure or properties could potentially be affected.

The areas that are most vulnerable to the inundation hazard for all of the scenarios across Wainui Beach are at the mouth of each of the two streams that enter the coast along the study area (Wainui Stream and Hamanatua Stream). These are a result of the low-lying nature of the riverbeds that form a channel to allow potential high waters from the coast to move landward.

The figures showing the inundation hazard zone for MHWS with SLR and STE100 with SLR are in Appendix F, these show that no infrastructure or properties are affected under current and future MHWS and STE100 scenarios.


LEGEND
Extreme Sea Level 100 Year Scenarios
ESL Contour: SSP2-4.5 Scenario
ESL100 + SLR (2120)
ESL Contour: SSP3-7 Scenario
ESL100 + SLR (2120)
ESL Contour: SSP 5-8.5 Scenario
ESL100 + SLR (2120)
PROJECT
Gisborne District Council
Wainui Beach, Gisborne
Wainui Beach Coastal Adaptation Programme
PROJECT NUMBER
2-SEE00.42
SCALE
0 10 20 m

Figure 5.1

Figure 5.1: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for the Southern Beach section.

Figure 5.2: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Wainui Stream section of Wainui Beach

6 POTENTIAL EROSION HAZARD ASSSESSMENT

The Wainui Beach shoreline was zoned according to the degrees of actual or potential hazard from coastal processes, with the coastal erosion hazard zones subdivided into likely, probably and potential/unlikely erosion zones for 2125 based on the three different climate scenarios (SSP2-4.5, SSP3-7.0 and SSP5-8.5) that includes sea level rise and vertical land movement.

Incorporation of potential cliff erosion will be performed within the risk analysis component of this project as it is reliant upon prior reporting undertaken by others.

6.1 SOUTHERN BEACH SECTION

Erosion of the shoreline with associated sea level rise in 100 years using the three different SSP scenarios was calculated for the Southern Beach section of Wainui Beach (Figure 6.1). The erosion potential was quantified for two regularly monitored beach profiles along the southern section of the beach Profiles 1 and 2). Across these two profiles, this section of the beach has an erosion potential that ranges between 45.5m and 80.1m (Table 6.1). Several residential buildings and a small section of road are within these potential erosion zones.

Table 6.1 - Range of horizontal shoreline retreat calculations based on different SSP scenarios for SLR in 100 years.

Horizontal retreat of shoreline	SSP2-4.5 - Likely	SSP3-7.0 - Probable	SSP5-8.5 – Potential/Unlikely
Profile 1	45.5 m	53.5 m	58.2 m
Profile 2	66.7 m	75.1 m	80.1 m

Figure 6.1 - Potential erosion hazard zone along the Southern Beach B section of Wainui Beach

6.2 WAINUI STREAM AND HAMANATUA STREAM

Potential stream toe erosion as a result of future climate change was qualitatively estimated at 3m, 5m and 10m with an additional allowance for dune slope settlement applied at this point.

For the Wainui Stream current day erosion hazard zone was identified at the 3.2m contour. Using the potential stream toe erosion values outlined above and applying these horizontal retreat values to the current day position at 3.2m, a likely, probable, and potential/unlikely hazard zone were identified (Figure 6.2). Several residential buildings are within these potential erosion zones.

Figure 6.2 - Potential erosion hazard zone along the Wainui Stream section of Wainui Beach

For the Hamanatua Stream, the current day erosion hazard zone was identified at the 4.4m contour. Using the potential stream toe erosion values outlined above and applying these horizontal retreat values to the current day position at 4.4m, a likely, probable and potential/unlikely hazard zone was identified (Figure 6.3).

Figure 6.3 - Potential erosion hazard zone along the Hamanatua Stream section of Wainui Beach

6.3 CENTRAL BEACH SECTION

Erosion of the shoreline with associated sea level rise in 100 years using the three different SSP scenarios was calculated for the Central Beach section of Wainui Beach (Figure 6.4 and Figure 6.5). The erosion potential was quantified for four regularly monitored beach profiles along the central section of the beach (Profiles 5,6,7,8). Across these four profiles, this section of the beach has an erosion potential that ranges between 69.7m and 99.6m across the three SSP scenarios (Table 6.2). Several residential buildings along this section of beach are within these potential erosion zones.

Table 6.2 - Range of horizontal shoreline retreat calculations based on different SSP scenarios for SLR in 100 years.

Horizontal retreat of shoreline	SSP2-4.5 - Likely	SSP3-7.0 - Probable	SSP5-8.5 – Potential/Unlikely
Profile 5	70.6 m	80.3 m	86.1 m
Profile 6	86.4 m	94.7 m	99.6 m
Profile 7	69.7 m	78.1 m	83.1 m
Profile 8	81.8 m	89.7 m	94.4 m

Figure 6.4 - Potential erosion hazard zone along the Central Beach A section of Wainui Beach

Figure 6.5 - Potential erosion hazard zone along the Central Beach B section of Wainui Beach

6.4 NORTHERN BEACH SECTION

Erosion of the shoreline with associated sea level rise in 100 years using the three different SSP scenarios was calculated for the Northern Beach section of Wainui Beach (Figure 16.1 and Figure 16.2). The Northern Beach section was divided up into three sections based on changes in dune and beach topography. For each section a likely (SSP2-4.5), probable (SSP3-7.0) and potential (SSP5-8.5) horizontal shoreline retreat value was calculated (Table 6.3).

The northern area of this section has an erosion potential between 6.63m and 7.15m. The central area of this section has an erosion potential between 9.59m and 10.11m. The southern part of this section has an erosion potential between 10.7m and 11.22m.

Table 6.3 - Range of horizontal shoreline retreat calculations based on different SSP scenarios for SLR in 100 years.

Horizontal retreat of shoreline	SSP2-4.5 - Likely	SSP3-7.0 - Probable	SSP5-8.5 – Potential/Unlikely
South (North of Hamanatua stream)	10.7 m	11.03 m	11.22 m
Central	9.59 m	9.92 m	10.11 m
Northern	6.63 m	6.96 m	7.15 m

The figures showing the erosion potential for the Northern Beach Section are in Appendix G, these show that no infrastructure or properties are affected in any of the SSP scenarios.

7 ASSUMPTIONS AND LIMITATIONS

7.1 EROSION ASSESSMENT (BEACH MONITORING AND SHORELINE POSITION, AND POTENTIAL EROSION HAZARD

This assessment has noted the presence of coastal defence structures along the beach however the potential impacts of these have not been considered for this assessment. This is due to the difficulty in ascertaining the effectiveness and appropriateness of the structures in their respective settings.

This assessment does not account for sediment transport sources, stores or sinks. Like much of the New Zealand coastline, sediment transport can be significantly influenced by anthropogenic activities, such as structures, extractions, and land use change. There is still some uncertainty around the sediment transport regime and sediment budget trends along the Wainui coastline, in particular around the lower beach and offshore margins which are likely to be affected by SLR and future climate changes.

For the purpose of this assessment, it has been assumed that the beach trends identified within Section 4 will be consistent with possible future changes with climate change and SLR.

As mentioned in Section 3.2.2 there are several limitations within the historical shoreline analysis, in particular around the identification of key shoreline features. The resolution of any aerial imagery used in the analysis determines the number and type of features able to be identified and therefore determines the confidence in the historical shoreline positioning. The second limitation is linked to human error of feature identification which was assessed by the RMS error calculation, which was shown to be less than 3.0m in this assessment.

7.1.1 POTENTIAL EROSION HAZARD

Industry standard equations for erosion potential were applied along the southern and central sections of the beach, as described in Section 3. These equations are reliant upon a range of inputs such as dune toe erosion to determine erosion potential.

The erosion hazard of the stream mouths were based upon prescribed erosion hazards of 3, 5 and 10m for respective scenarios. These are based upon observations of other similar coastal settings but due to the uncertainty associated with stream mouth behaviour are best managed by monitoring and adaptive triggers for future hazard risk mitigation.

The approaches used are considered fit for purpose of highlighting the areas of potential erosion risk along Wainui Beach. Accordingly, this analysis of potential erosion profiles and hazard zones should not be used for the assessment of the erosion hazard to individual properties and infrastructure. This should rather be seen as a 'first-pass' assessment as it may include significant inaccuracies at smaller scales.

Assessment of risk to individual properties should be based on a site-specific assessment prepared by a suitably qualified and experienced person. The hazard areas shown on the maps do not show the future position of the coastline, rather, they show the area that might become unstable as a result of small areas of coastal erosion.

7.2 COASTAL INUNDATION

It is important to acknowledge that there are limitations and assumptions associated with this coastal inundation methodology. These limitations need to be understood when using this data for further hazard assessments, such as quantifying the assets at risk of inundation. The key limitations associated with this methodology are outlined below.

Inherent uncertainties associated with the inundation assessment stem from the resolution of the data and accuracy of the topographical data, including the bathymetry and LiDAR. For this assessment 1m LiDAR data was used for the land topography.

The bathtub inundation approach models static inundation and does not represent the dynamic and time-variant processes of an event, for example it assumes that the peak of any coastal flood event persists long enough to completely inundate any land below that level (NIWA, 2021). This may not always be the case, where the peak of storm-tide only lasts for about 1-3 hours centred around high tide (Stephens et al. 2016) and will not be enough time to inundate a large area. This bathtub approach therefore produces conservative inundation extents as it tends to over-predict rather than under-predict the extent of coastal inundation.

Coastal waters are unlikely to reach as far up narrow corridors connected to the coast as have been mapped because flow during tidal cycles is restricted. Therefore, this approach may over-estimate the extent of inundation for any given coastal flooding scenario (NIWA, 2021). No stormwater or wastewater infrastructure have been included in this stage of the assessment as it is unknown to what extent the infrastructure assets would convey any high coastal waters inland. Therefore, the potential for water infrastructure to convey coastal water has been not been assessed within the inundation assessment.

Coastal inundation for Wainui Beach has been simulated from storm tide elevations (STE), extreme sea levels (ESL100), and the mean high-water spring (MHWS) superimposed with future sea level scenarios. In these scenarios a geomorphologically static landform coastline is assumed with no adjustments to the topography and bathymetry. However, the morphology of the beach profiles, beach ridges and dunes will naturally adjust to sea level rise by either retreating and/or prograding in elevation.

This long-term adjustment of the coastal geomorphology is not taken into account in this assessment. A morphologically static coastline has been assumed for the mapping and assessment of the inundation levels and extents. Future changes in the morphology of the coastline and inland topography which have occurred since the time of the LiDAR survey due to either natural or artificial works may have an impact on the exposure of inundation in future climates. The ESL100 data used is also not based on site-specific high-resolution models, and therefore may not represent the correct storm surge conditions for each section of coastline.

7.2.1 CONTOUR DERIVATION

- The accuracy of the LiDAR can influence the areas categorized as vulnerable to inundation.
- The contours were generated using 1m LiDAR which was flown between December 2018 and September 2020, the exact period in which the Wainui Beach section of the LiDAR was flown is unknown.
- As the beach is a dynamic system the elevations used to generate the contours will be reflective of the beach state when the LiDAR was flown (sometime between 2018-2020).

Therefore, these elevations are only indicative and are constantly changing depending on if the beach is in a period of accretion or erosion.

- The LiDAR used to generate the contours was at a 1m resolution. The contours were generated to intervals of 0.1m, therefore potential issues with the accuracy of these 0.1m contours needs to be understood.

7.2.2 SEA LEVEL RISE

- There are inherent uncertainties with all climate change estimations, including those for SLR. To address this the scenarios and time periods recommended by MfE have been adopted for this analysis.

7.2.3 INUNDATION SCENARIOS

- The MHWS value used in the analysis was sourced from the closest port, in this case Gisborne Port. Although the port is in close proximity to Wainui Beach there may be variations in the MHWS elevations between the two points.

- There was no ESL100 point present at Wainui beach, therefore the two closest ESL100 points from the Paulik et al. (2020) study were averaged to derive a representative value for the study area.

- In the STE inundation calculations neither wave setup nor wave runup were considered. Due to the equations for these wave components not taking into account topography (which is important for steep beaches such as Wainui) it was determined that adding these components into the equations would not be reflective of the actual wave environment at the beach. These components were therefore not considered.

- In the ESL100 calculations wave runup was not considered. Due to the steep topography of the study area and the fact that topography is not considered in wave runup equations, this component was not considered in the ESL100 analysis.

8 CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

The current level of coastal erosion hazard has been assessed to be less than previously reported. This is based upon a detailed assessment of the beach profile monitoring data and supplemented by an updated assessment of both aerial and satellite imagery. Overall, the system is considered to currently be acting in dynamic equilibrium with recognised phases of erosion and accretion occurring.

Despite this assessment there are recognised erosion hotspots along the beach, and these are primarily located in the Southern Beach portion. These erosion hotspots are considered to be a result of housing and infrastructure being situated within the margins of wider natural beach fluctuations.

Further there has been a degree of erosion susceptibility to phases of El Niño and negative IPO. This is most apparent within the Northern and Southern Beach sections. However, this is not to discount the potential impact of significant storms or cluster of storm events outside of these climatic drivers.

The likelihood of erosion is expected to increase as the impacts of climate change and sea-level rise are realised. Due to the unique nature of Wainui Beach it is expected that different parts of the beach will perform differently under future scenarios. This has been allowed for in the future erosion estimations and in general the Southern Beach and the streams mouths are considered to be the most susceptible to future coastal erosion hazard. This is due to the more typical beach geomorphology observed along this part of the beach.

The majority of the Wainui Beach system is considered to be outside of the influence of current and future coastal inundation hazard impacts. This is due to the perched uplifted nature of the dune system. The exception to this is the lower lying areas associated with both stream mouths which show increased susceptibility with the impacts of climate change and SLR.

8.2 RECOMMENDATIONS

The information presented within this report is considered to be appropriate for the determination of potential management, mitigation and planning pathways. Due to the level of uncertainty associated with future sea-level rise and climate change, and indeed how the beach may respond, it is not considered to be appropriate to use this information beyond these purposes.

Future coastal hazard assessments will benefit from updated and targeted monitoring programmes. In particular the inclusion of drone technology will help to better inform these assessments by providing data of beach behaviour across the entire beach rather than isolated profile points. The existing temporal spread of monitoring is considered adequate given the length of the current data set. However, pre and post storm monitoring of beach levels is also considered a useful addition to inform future hazard risk and adaptation triggers.

The inclusion of climate data should be included within the monitoring program to assist in the identification of climatic drivers of beach change. This should utilise wave hindcast data and observations from the Eastland Port wave buoy data.

It is suggested that the number, type, location and condition of coastal defence structures arecollated and fed into an asset management programme to ensure future work programmes are established to manage and monitor these structures appropriately.

Through the development of the adaptation plan ownership and maintenance responsibilities should be discussed and clarified through the engagement process. This should include triggers for maintenance and potential removal of the structures in the future.

It is recommended that this information is used as the basis for a natural hazard risk assessment across Wainui Beach to inform the potential management, mitigation and planning pathways noted above.

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10 APPENDIX A

5-YEAR AVERAGE CHARTS

10.1 SOUTHERN BEACH

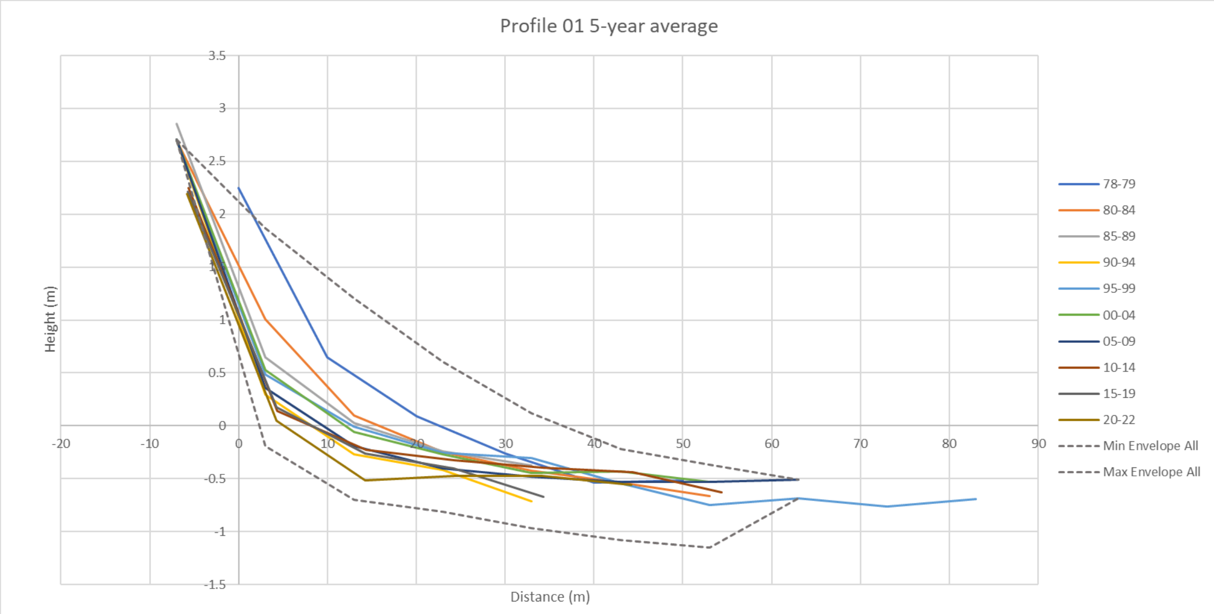

Figure 10.1: Profile 1 5-year average chart.

Figure 10.2: Profile 2 5-year average chart.

10.2 WAINUI STREAM

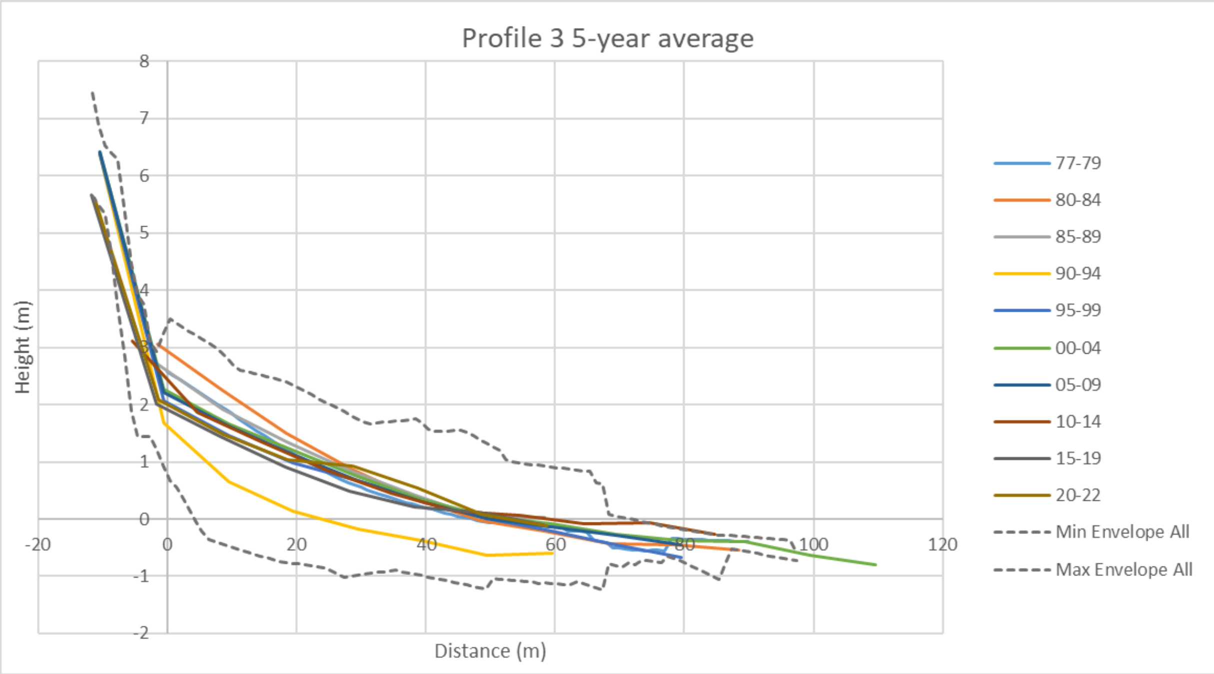

Figure 10.3: Profile 3 5-year average chart.

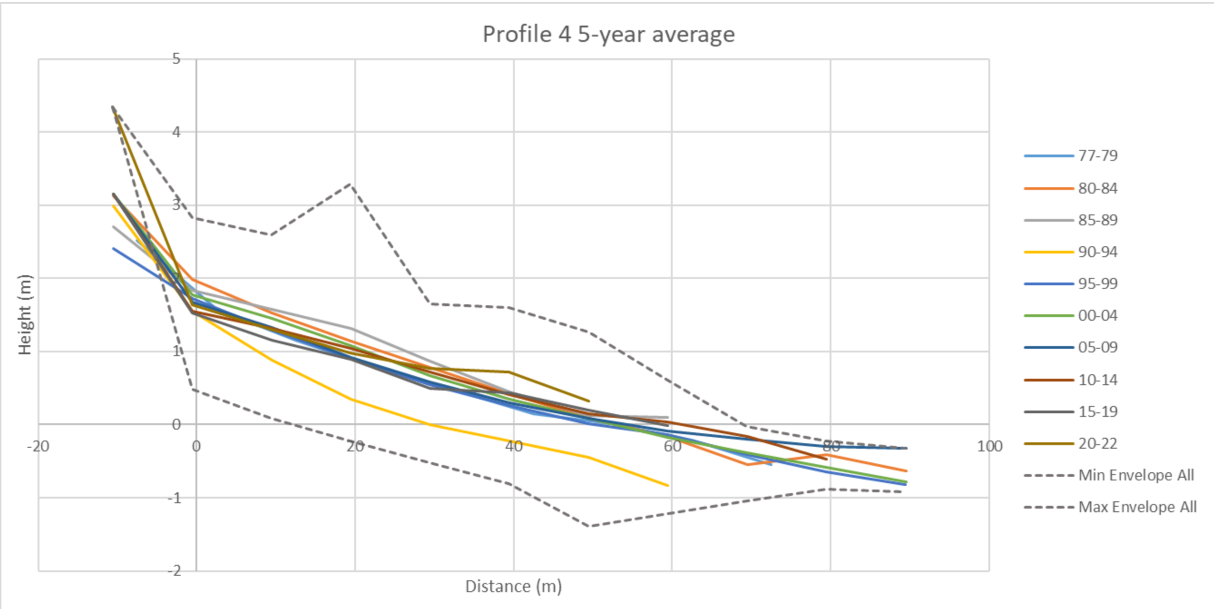

Figure 10.4: Profile 4 5-year average chart.

10.3 CENTRAL BEACH

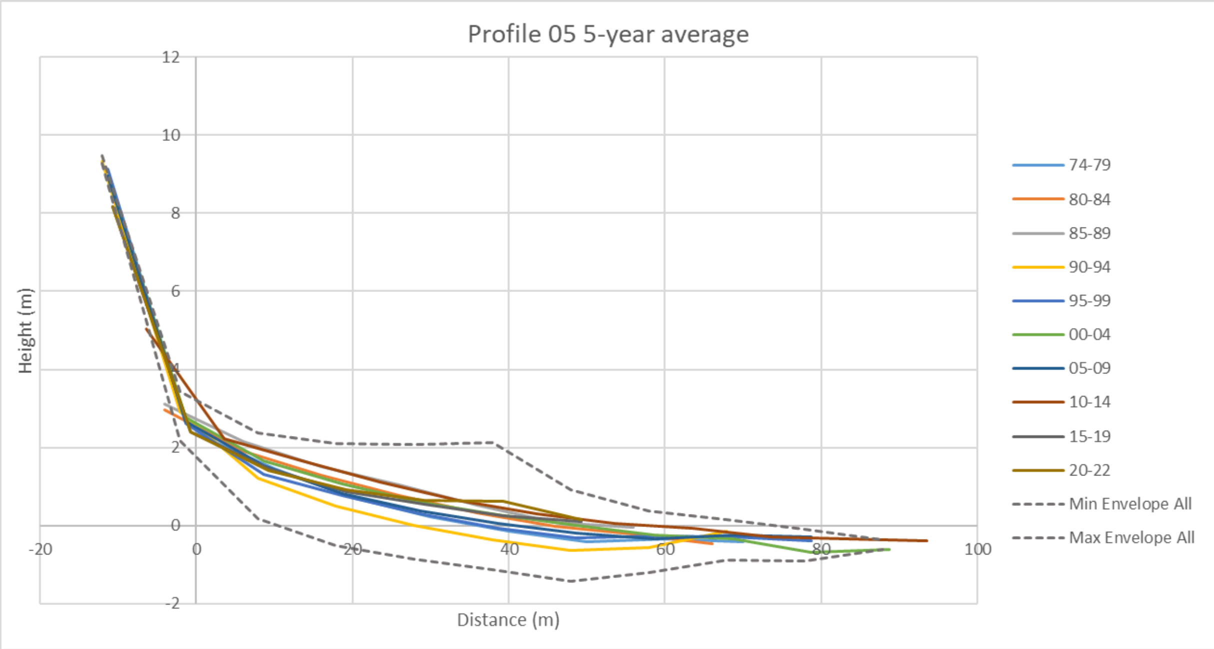

Figure 10.5: Profile 5 5-year average chart.

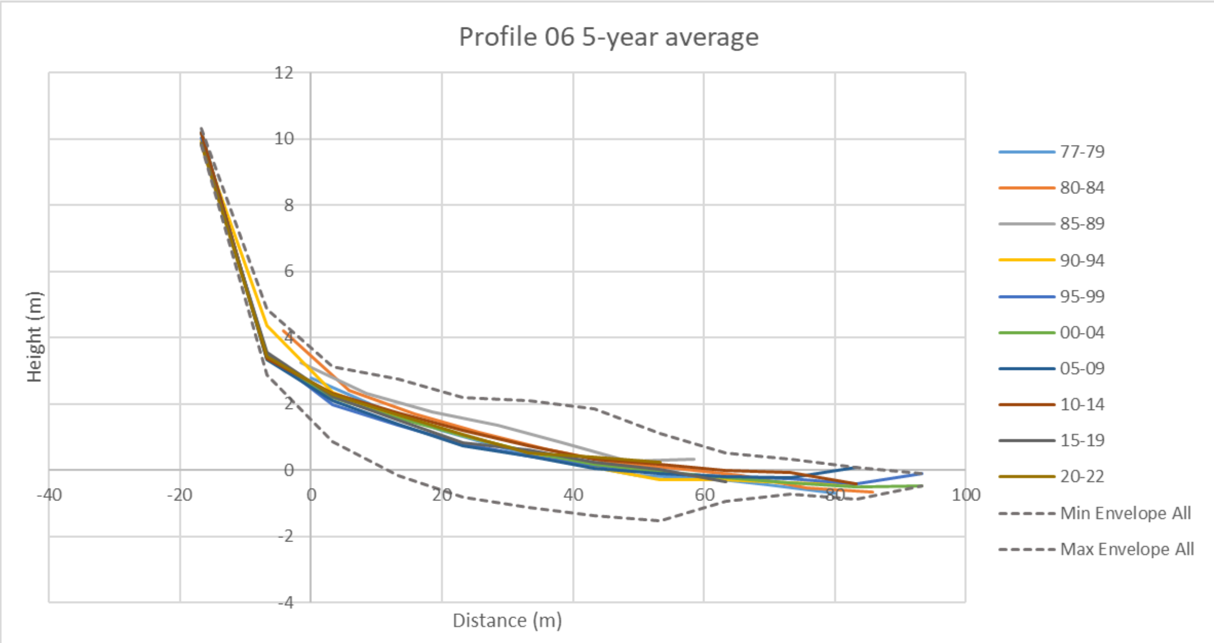

Figure 10.6: Profile 6 5-year average chart.

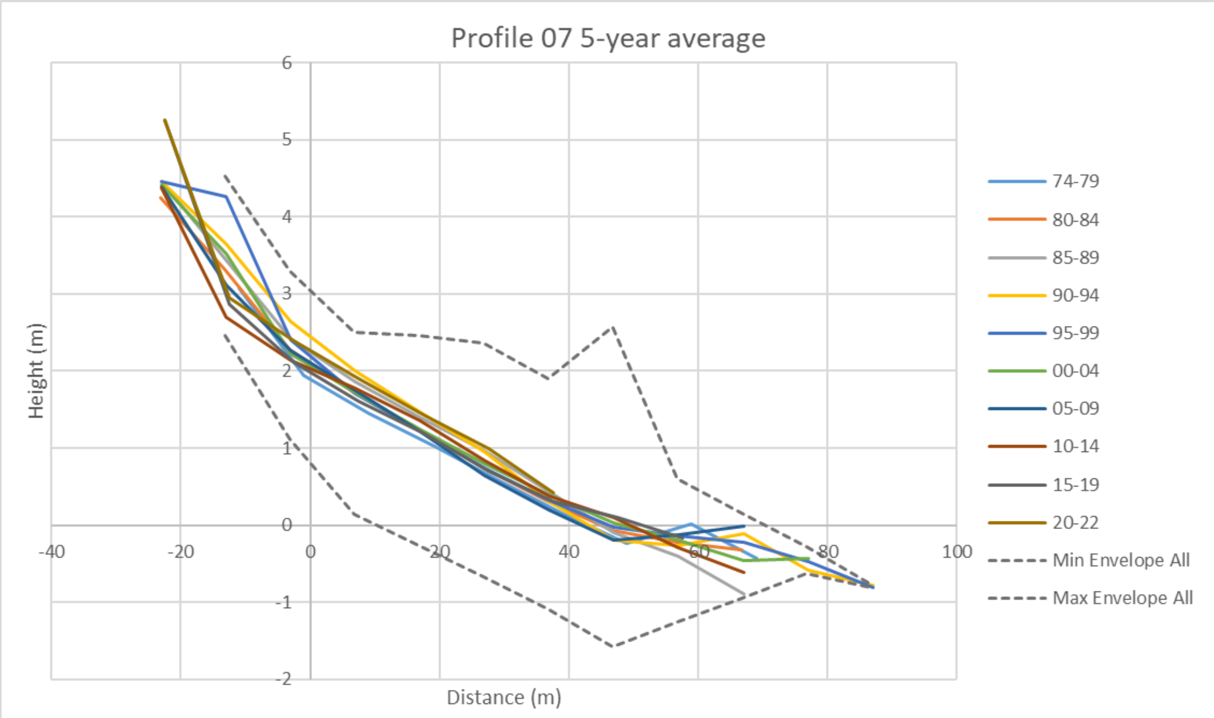

Figure 10.7: Profile 7 5-year average chart.

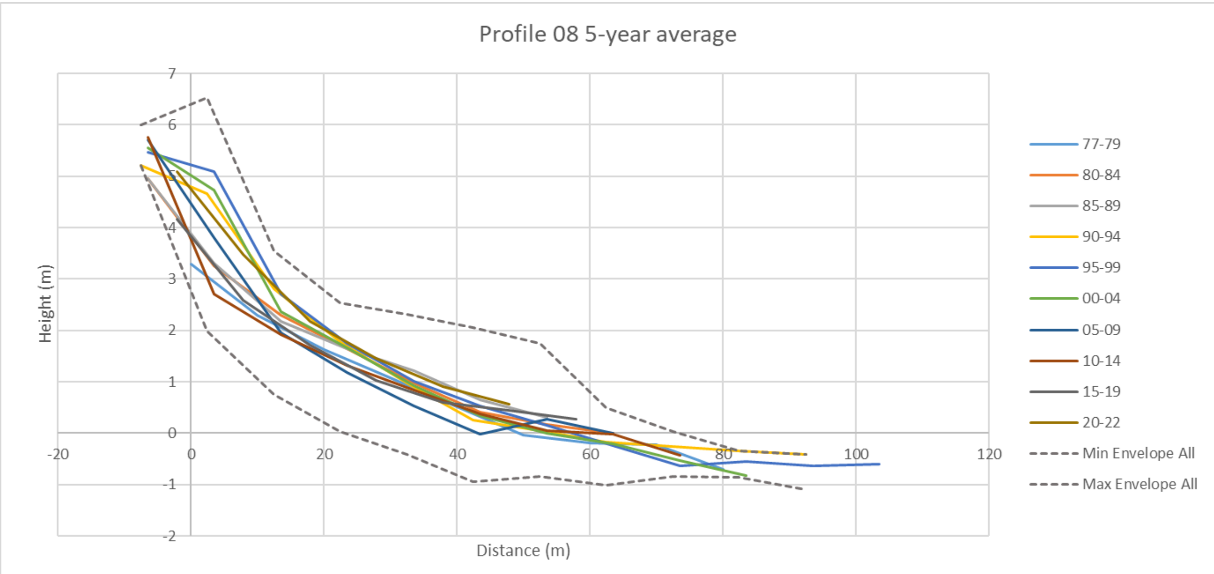

Figure 10.8: Profile 8 5-year average chart.

10.4 HAMANATUA STREAM

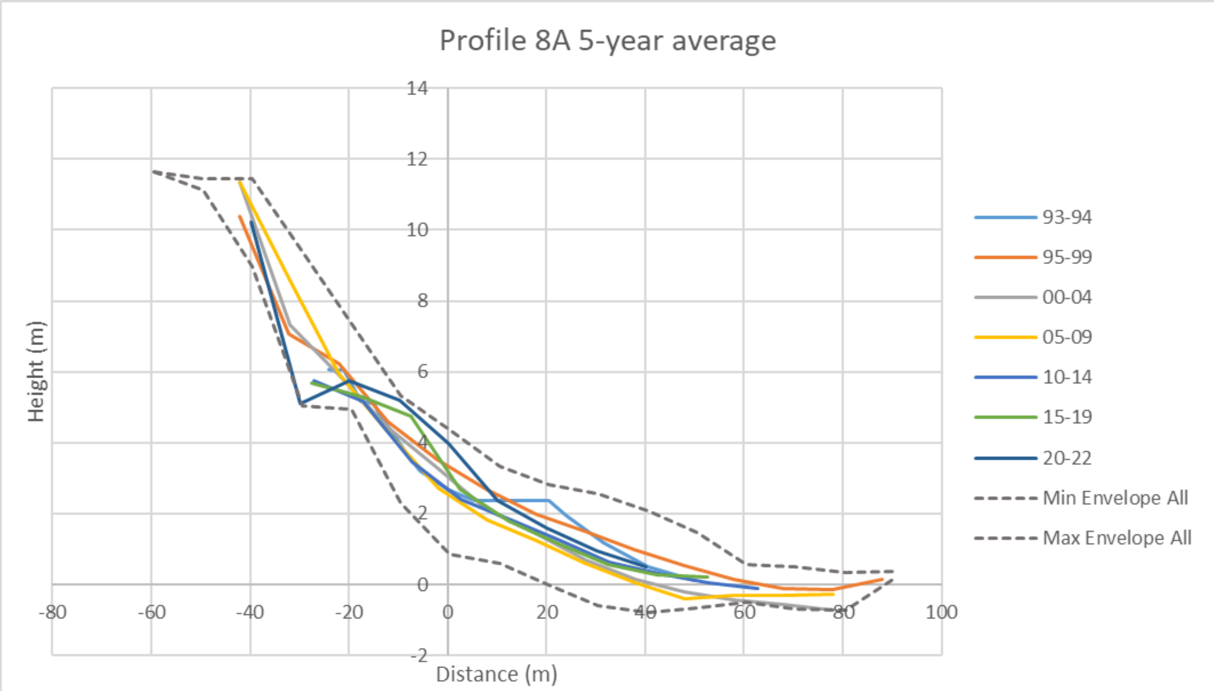

Figure 10.9: Profile 8A 5-year average chart.

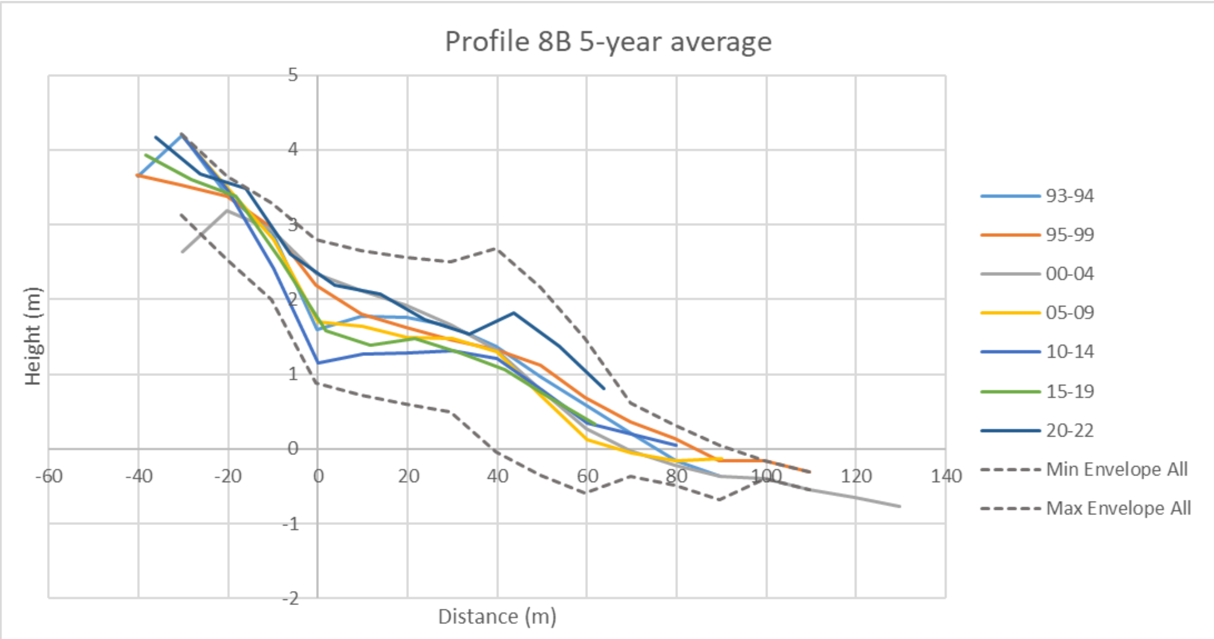

Figure 10.10: Profile 8B 5-year average chart.

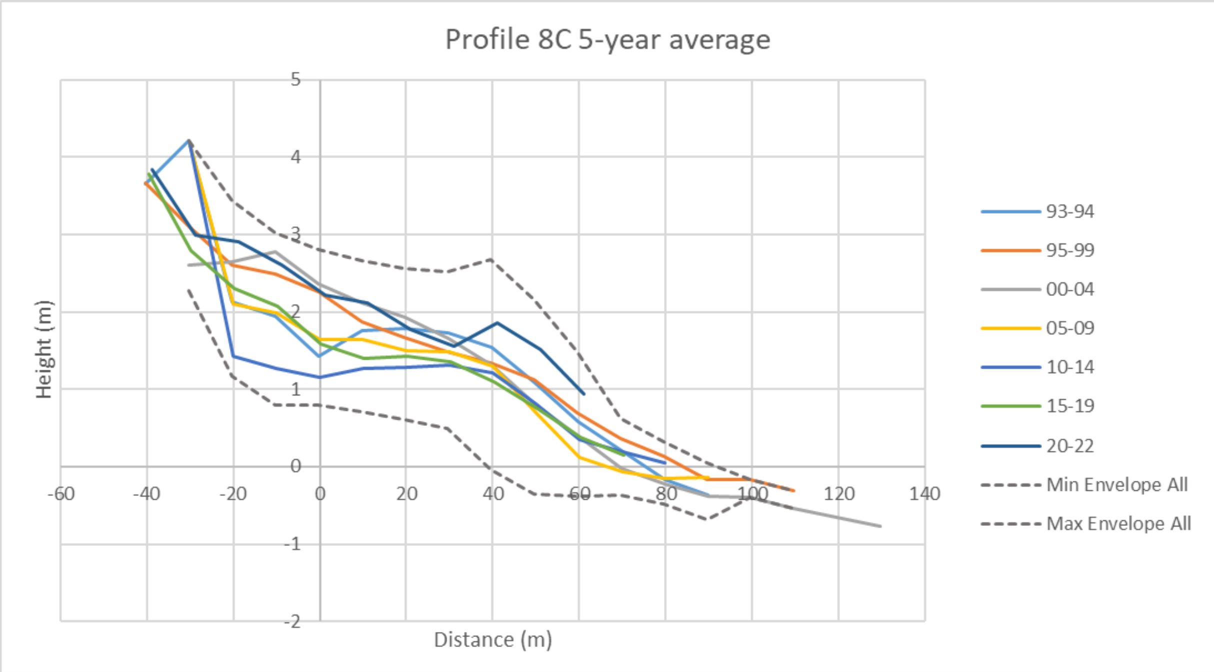

Figure 10.11: Profile 8C 5-year average chart.

10.5 NORTHERN BEACH

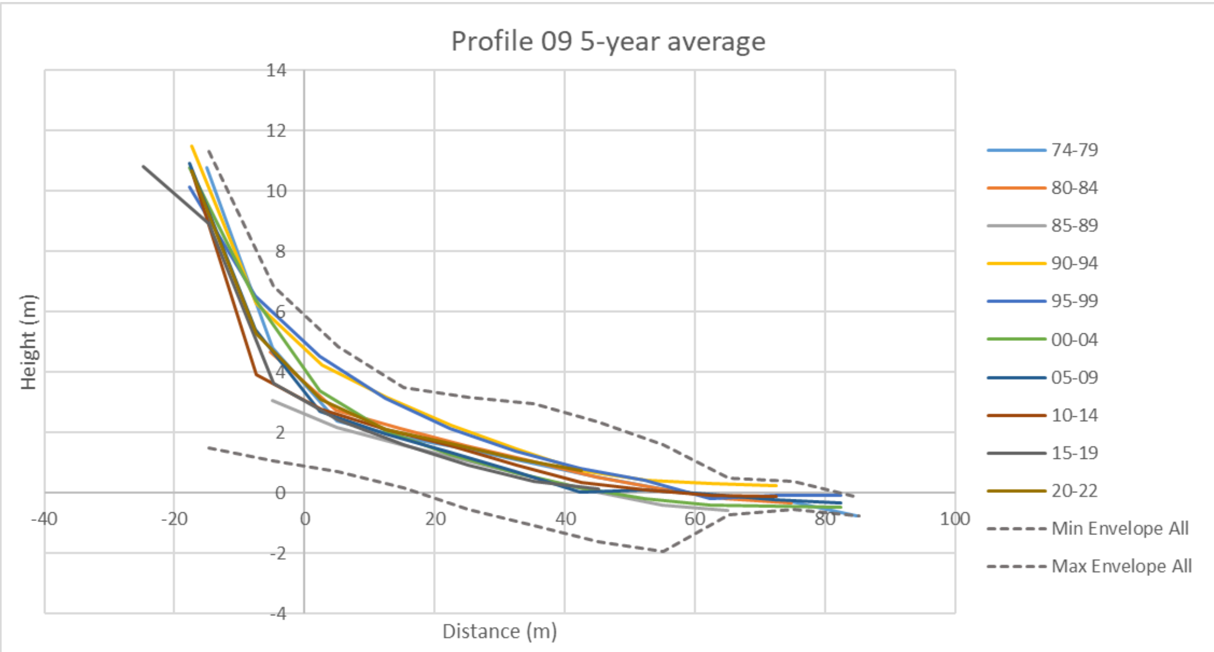

Figure 10.12: Profile 9 5-year average chart.

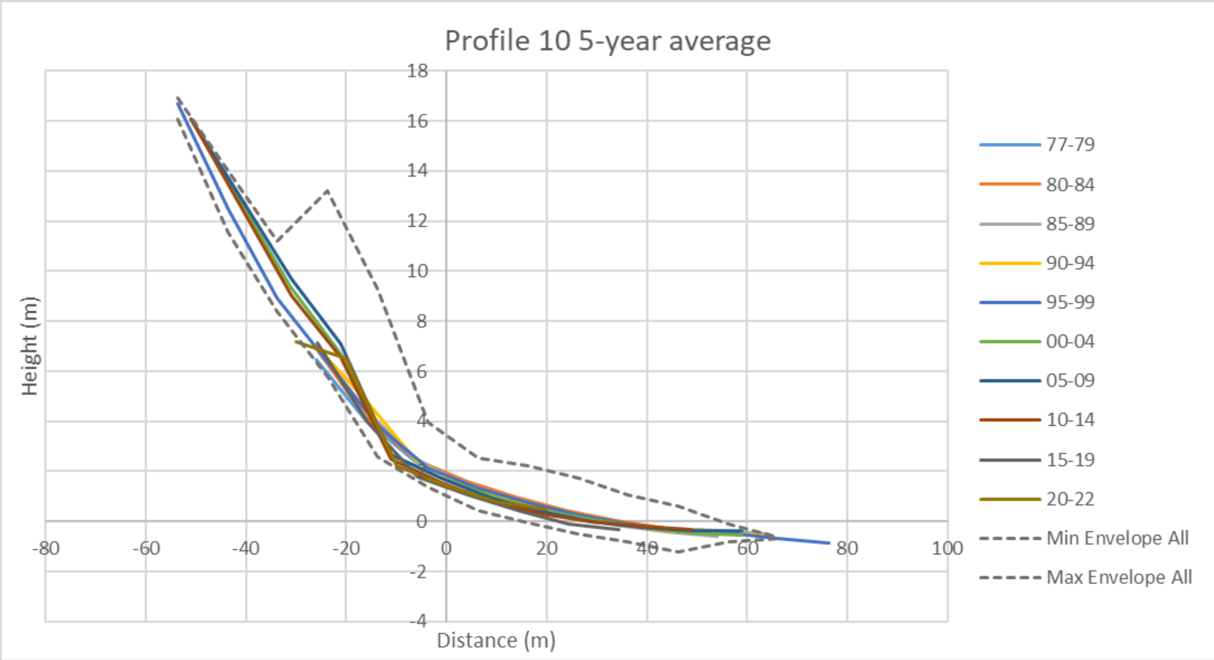

Figure 10.13: Profile 10 5-year average chart.

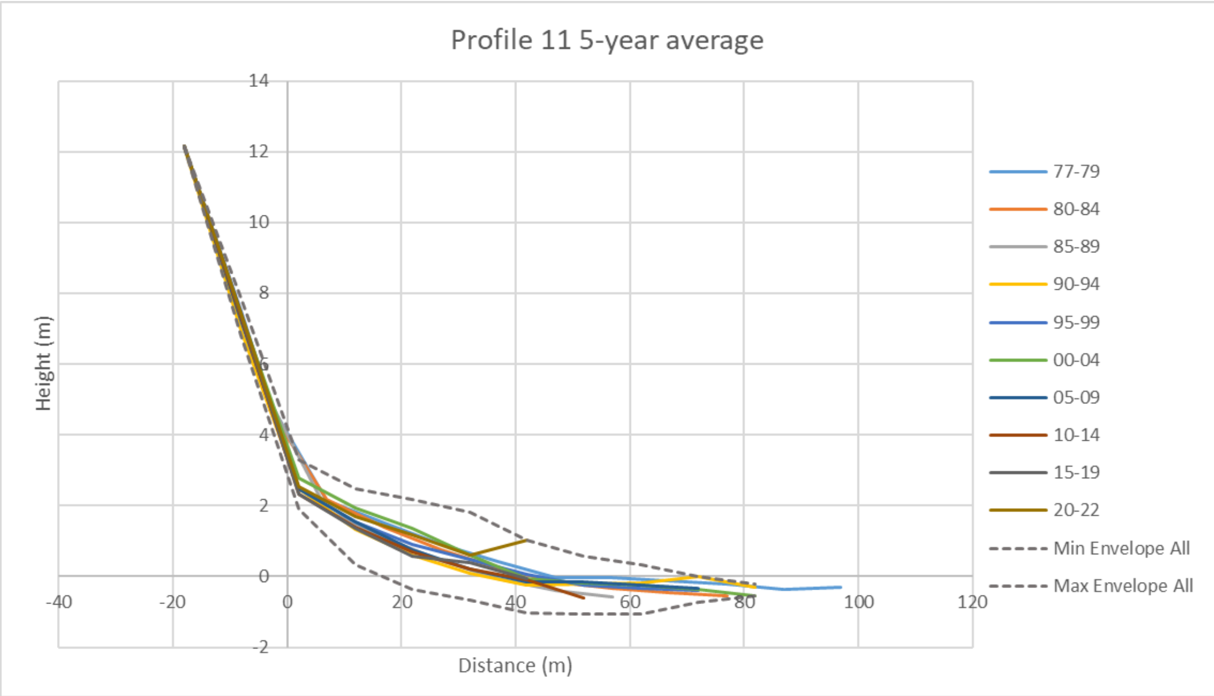

Figure 10.14: Profile 11 5-year average chart.

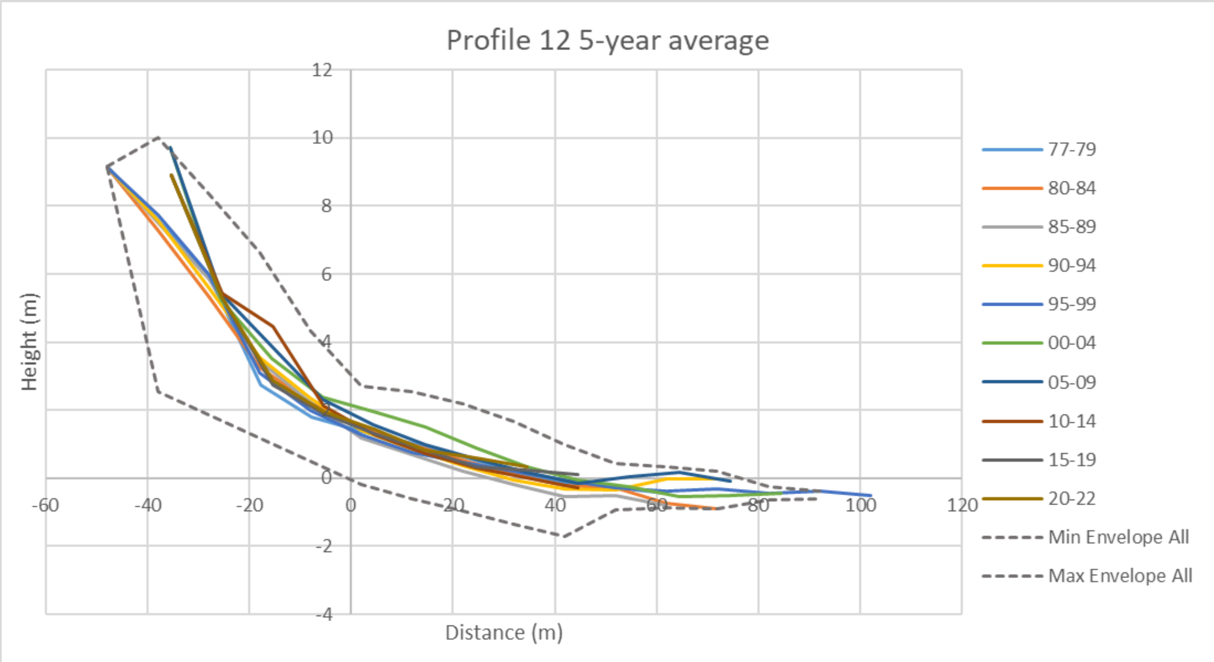

Figure 10.15: Profile 12 5-year average chart.

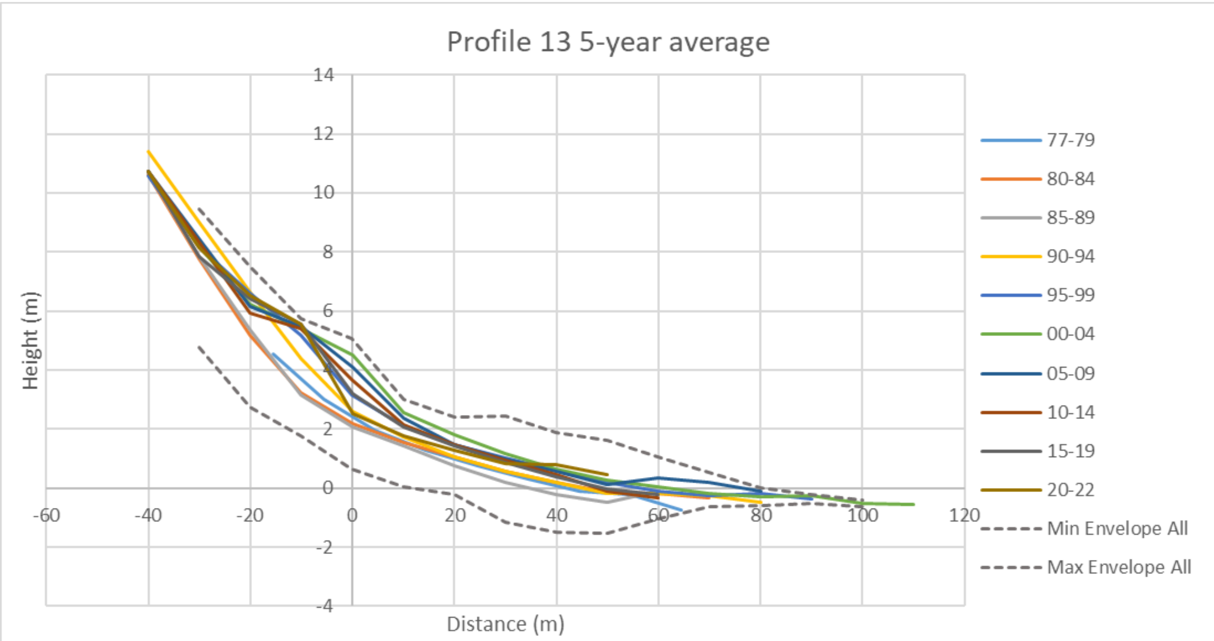

Figure 10.16: Profile 13 5-year average chart.

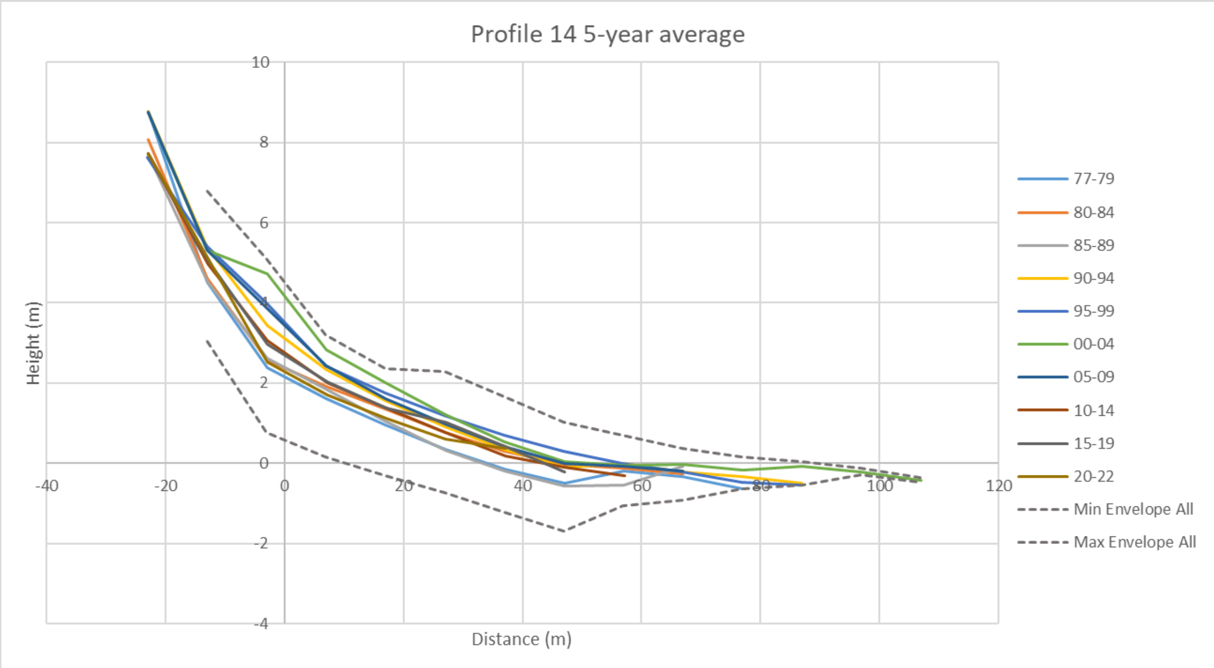

Figure 10.17: Profile 14 5-year average chart.

11 APPENDIX B

CONTOUR EXCURSION CHARTS

11.1 WAINUI STREAM

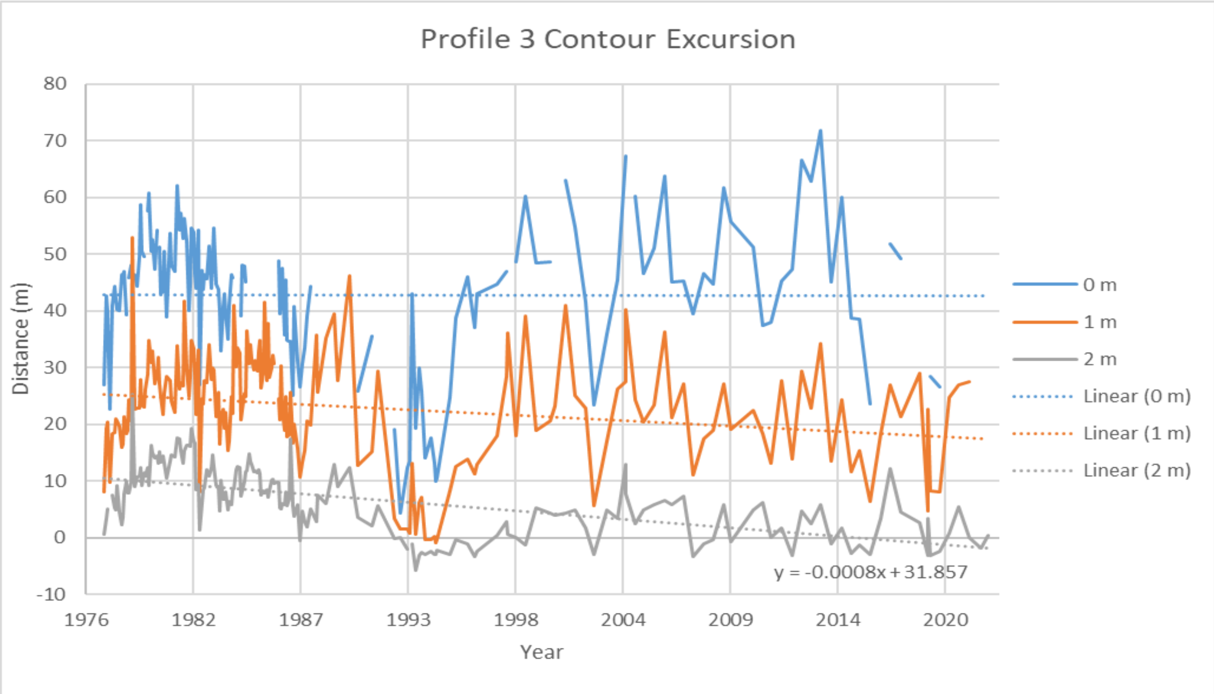

Figure 11.1: Profile 3 contour excursion chart.

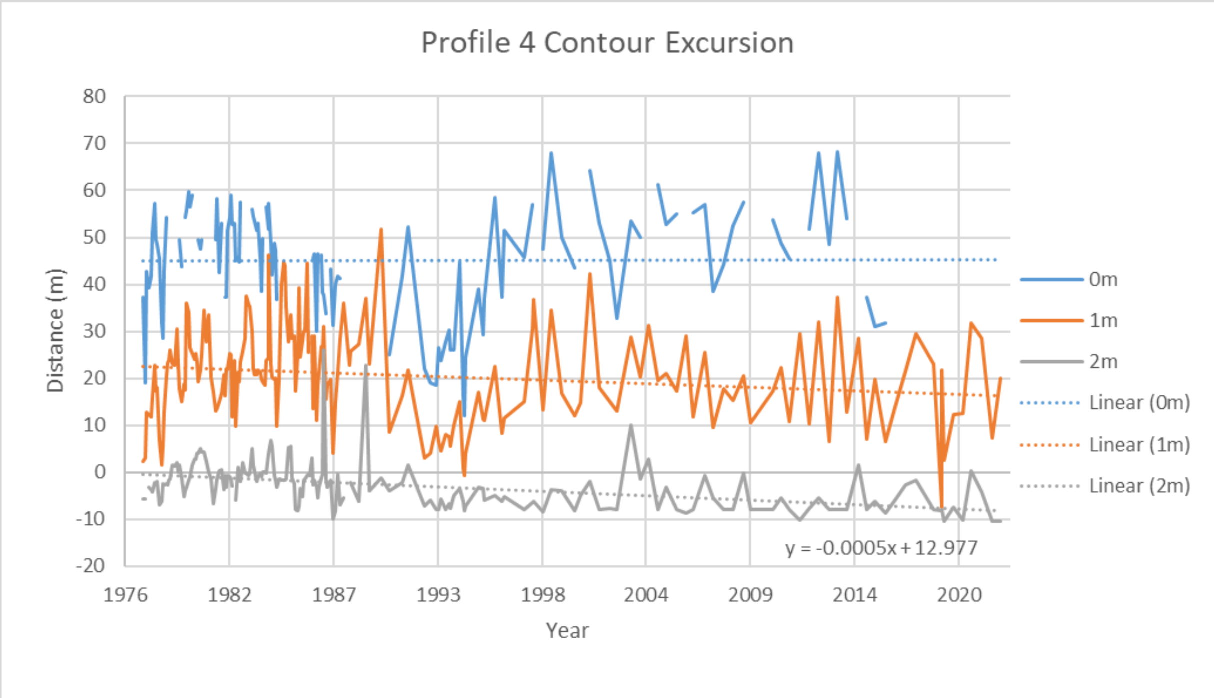

Figure 11.2: Profile 4 contour excursion chart.

11.2 HAMANATUA STREAM

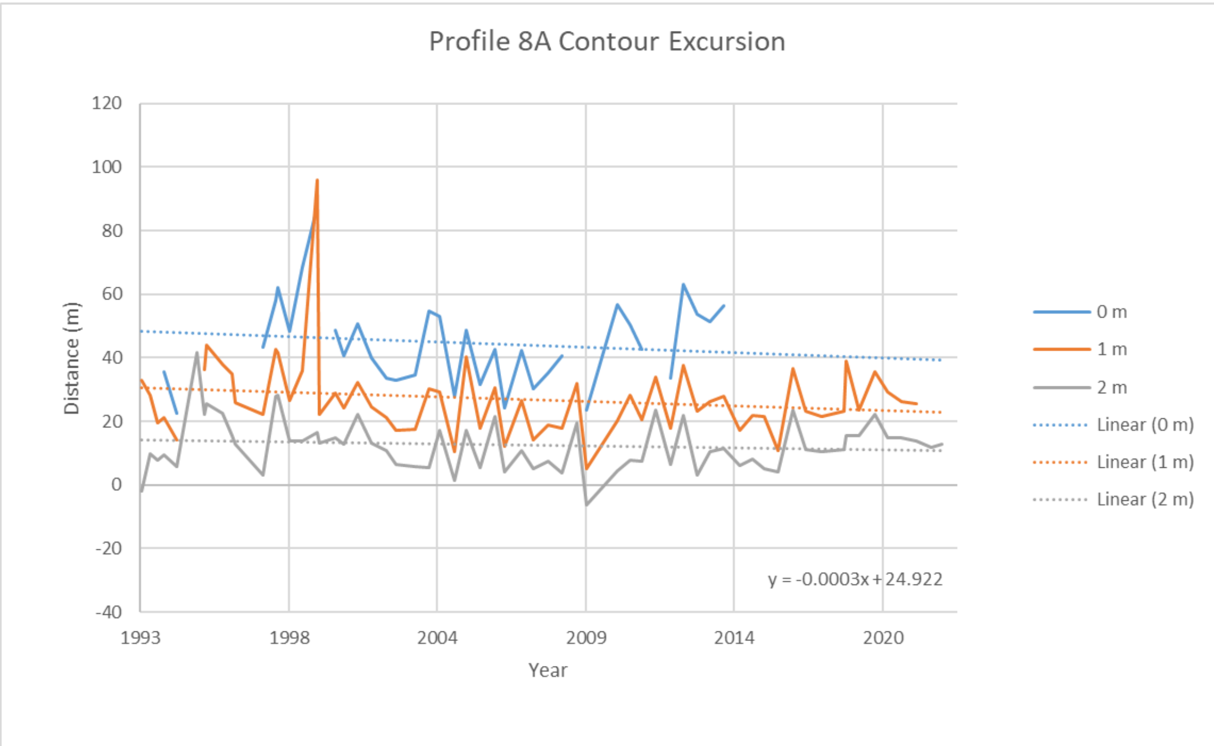

Figure 11.3: Profile 8A contour excursion chart.

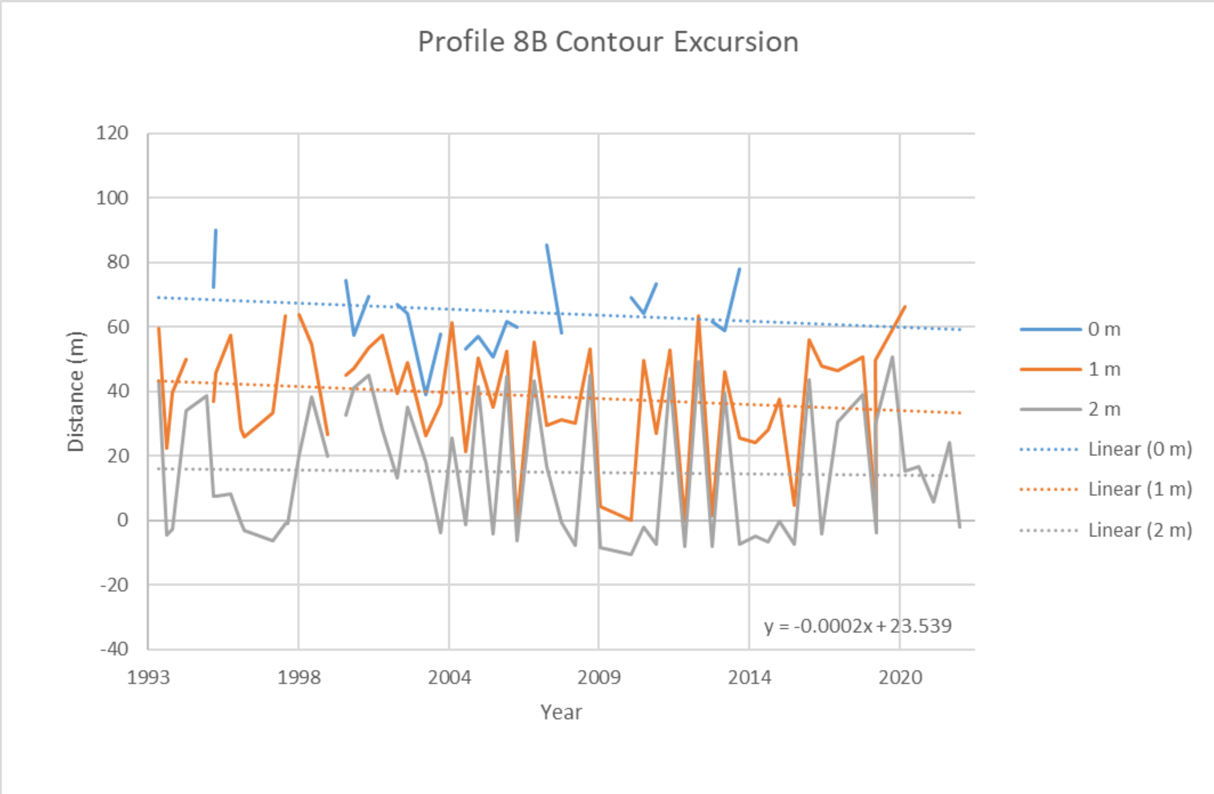

Figure 11.4: Profile 8B contour excursion chart.

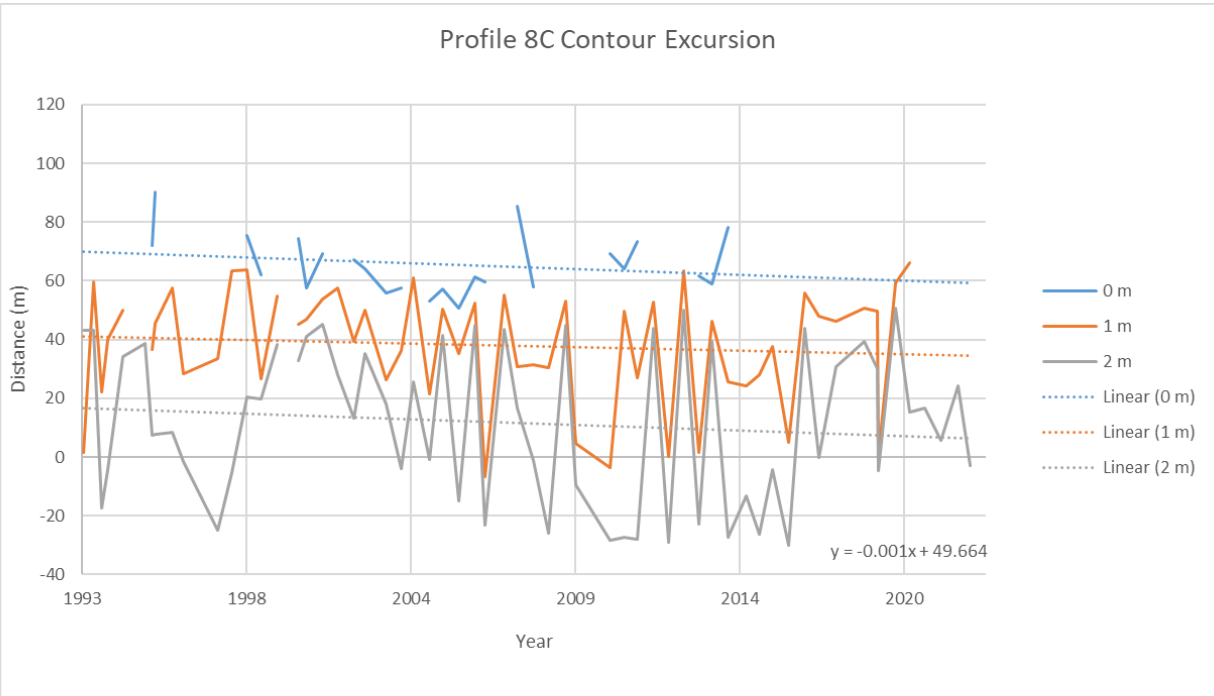

Figure 11.5: Profile 8C contour excursion chart.

11.3 NORTHERN SECTION

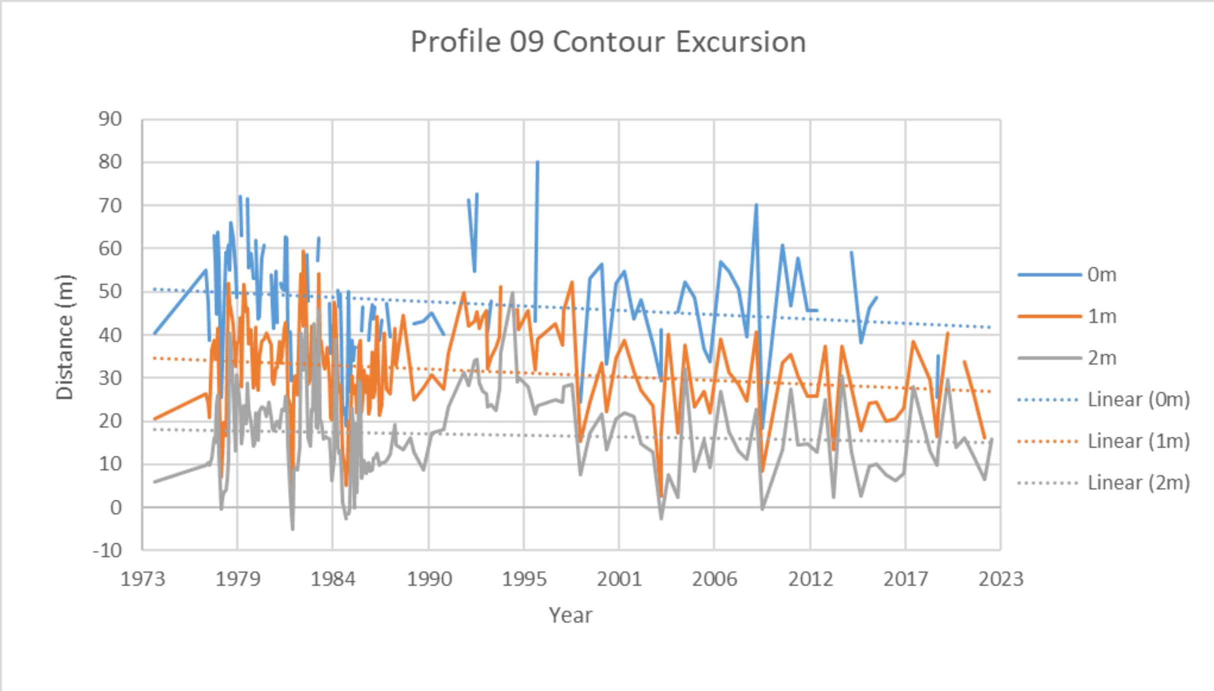

Figure 11.6: Profile 9 contour excursion chart.

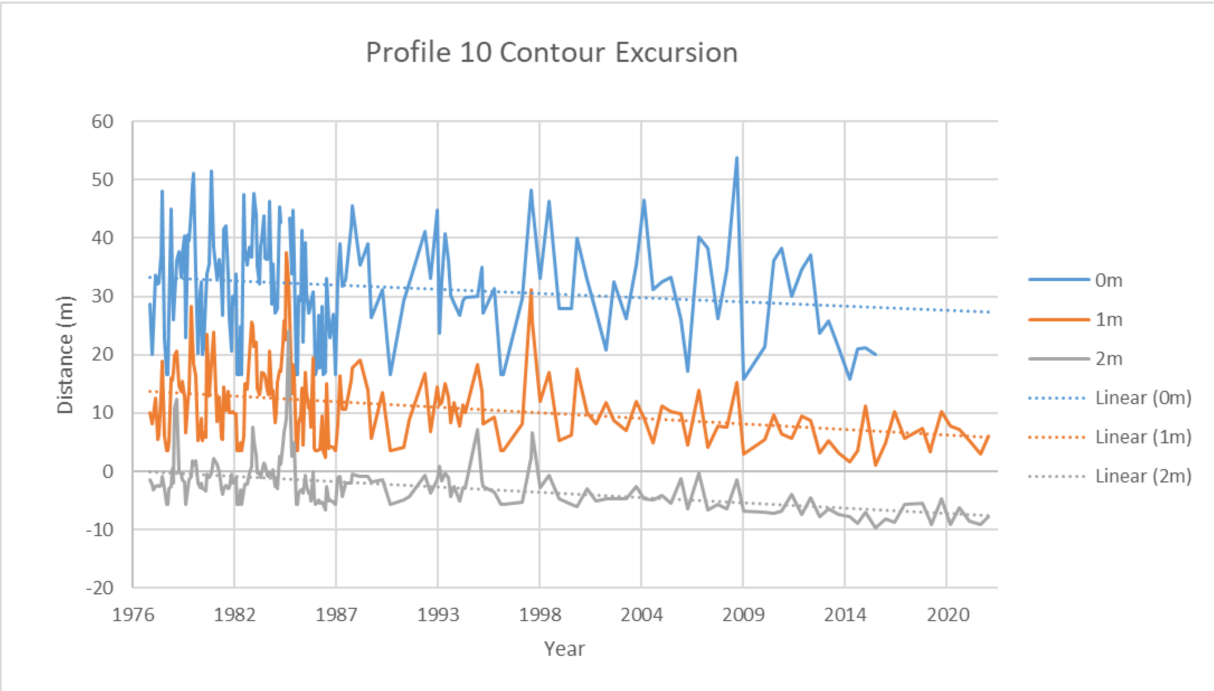

Figure 11.7: Profile 10 contour excursion chart.

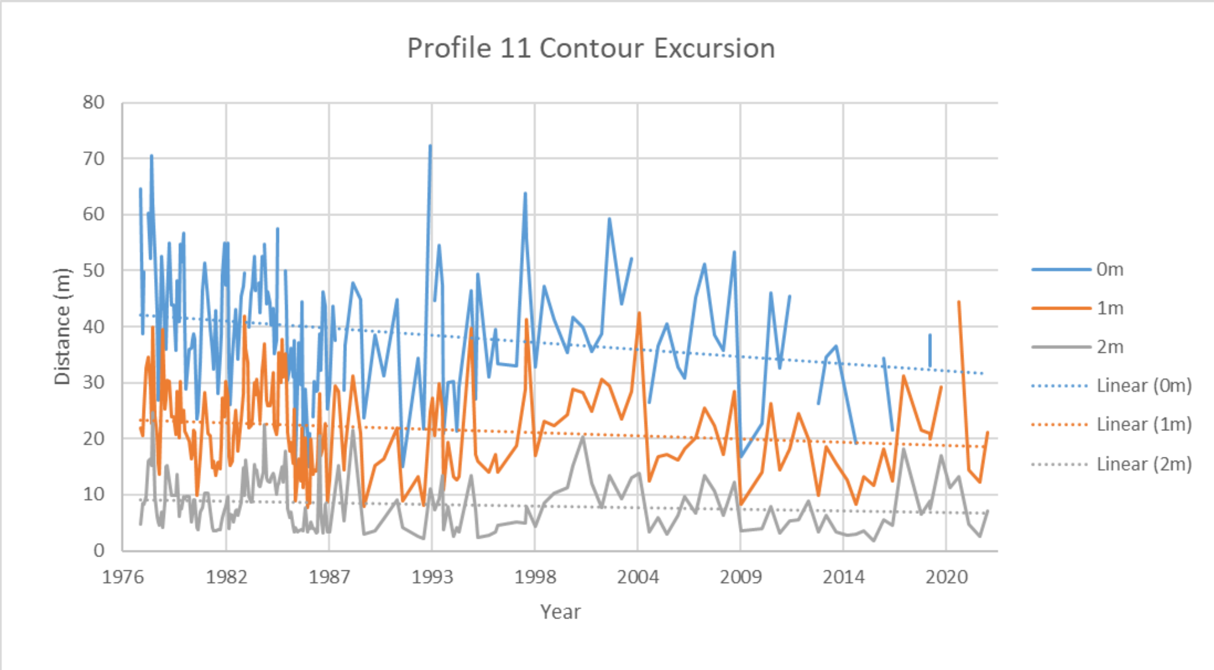

Figure 11.8: Profile 11 contour excursion chart.

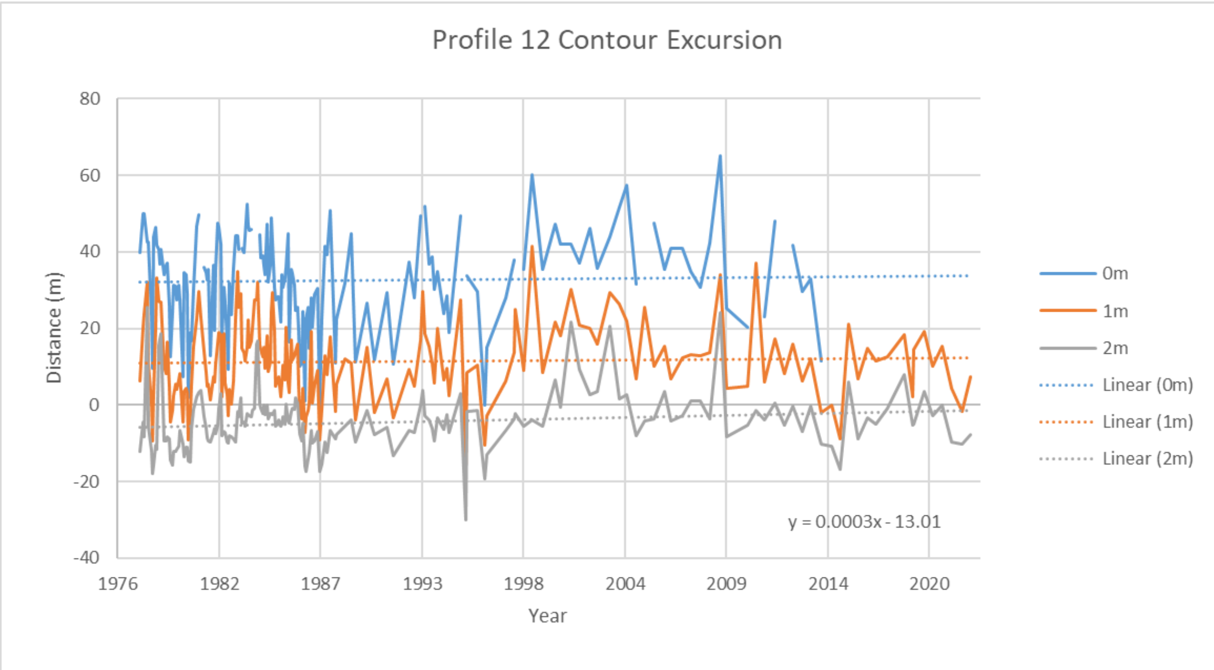

Figure 11.9: Profile 12 contour excursion chart.

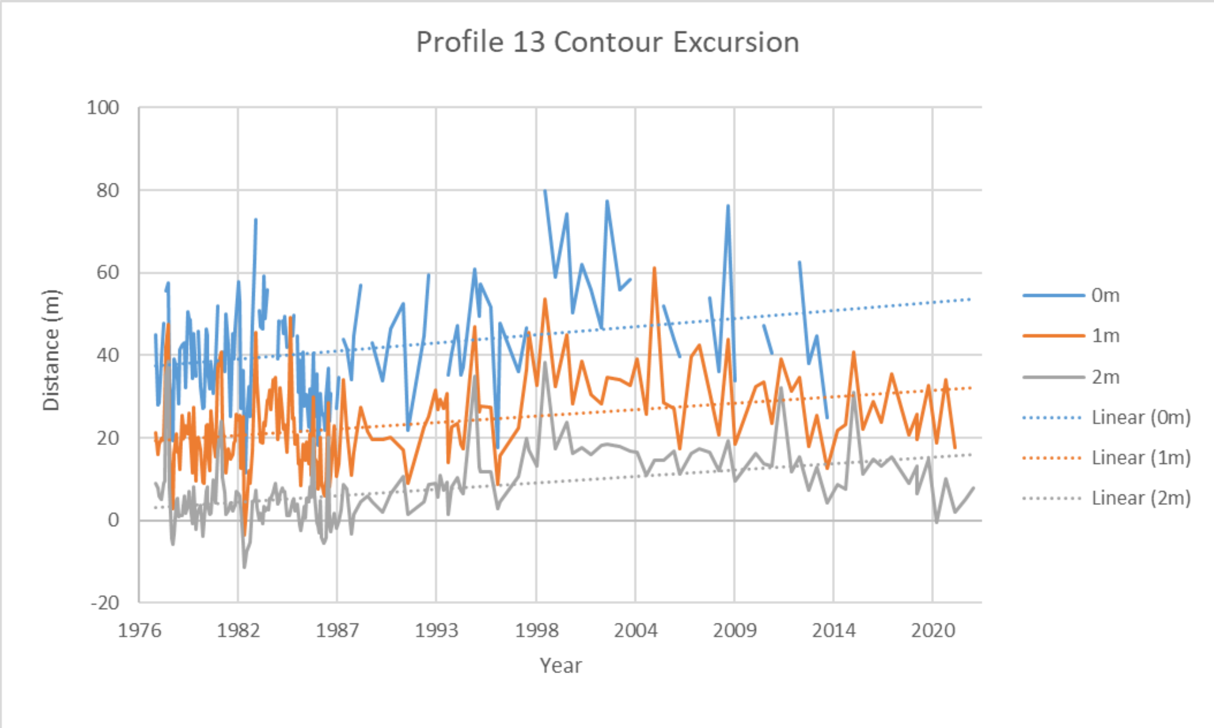

Figure 11.10: Profile 13 contour excursion chart.

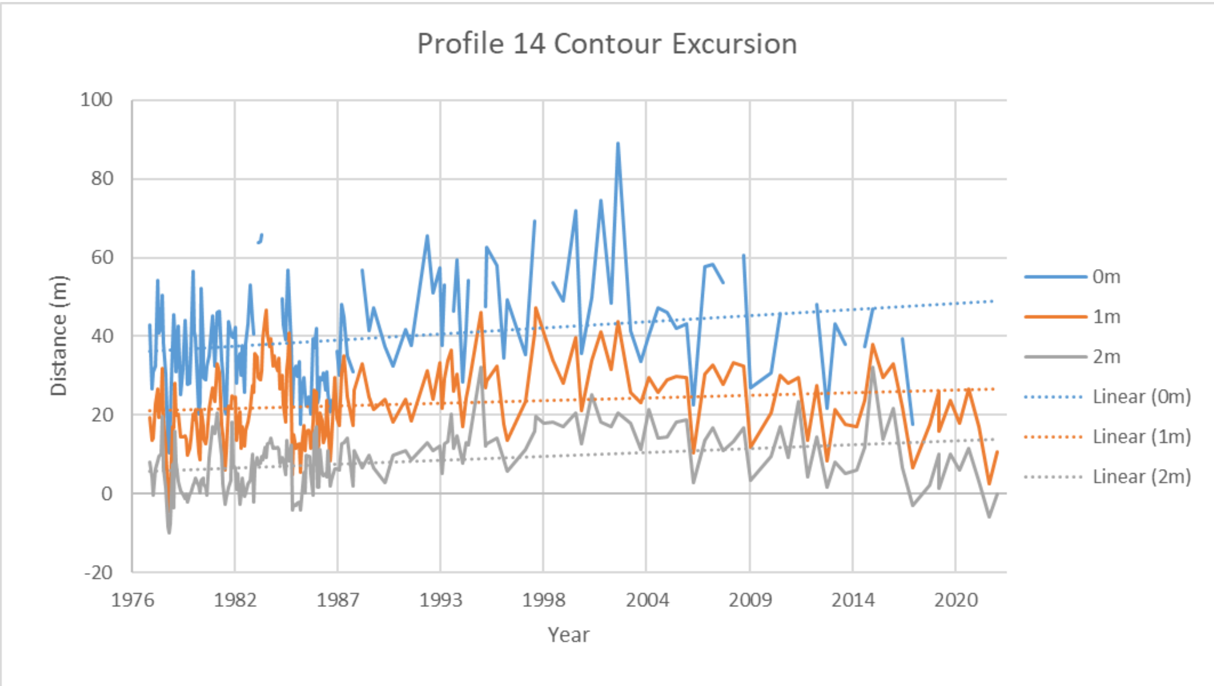

Figure 11.11: Profile 14 contour excursion chart.

12 APPENDIX C

ENSO CHARTS

12.1 SOUTHERN BEACH

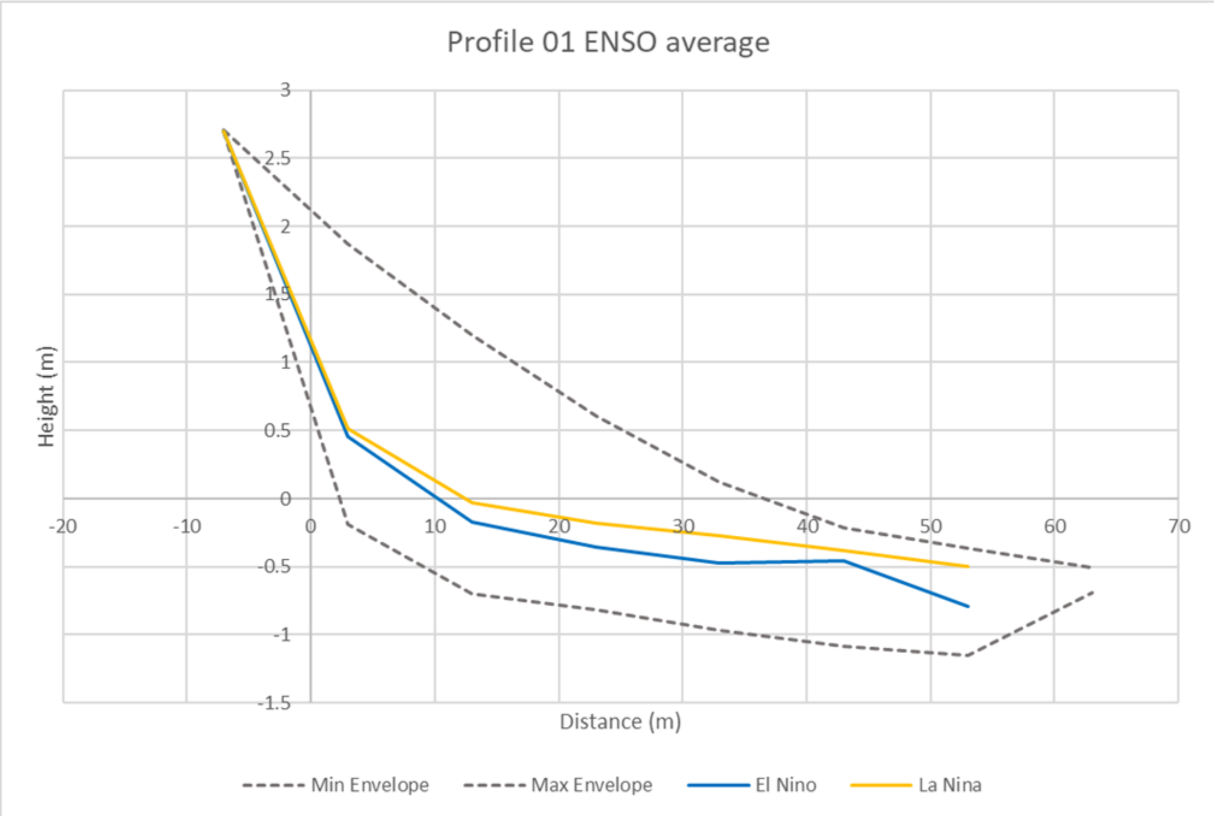

Figure 12.1: Profile 1 ENSO average chart.

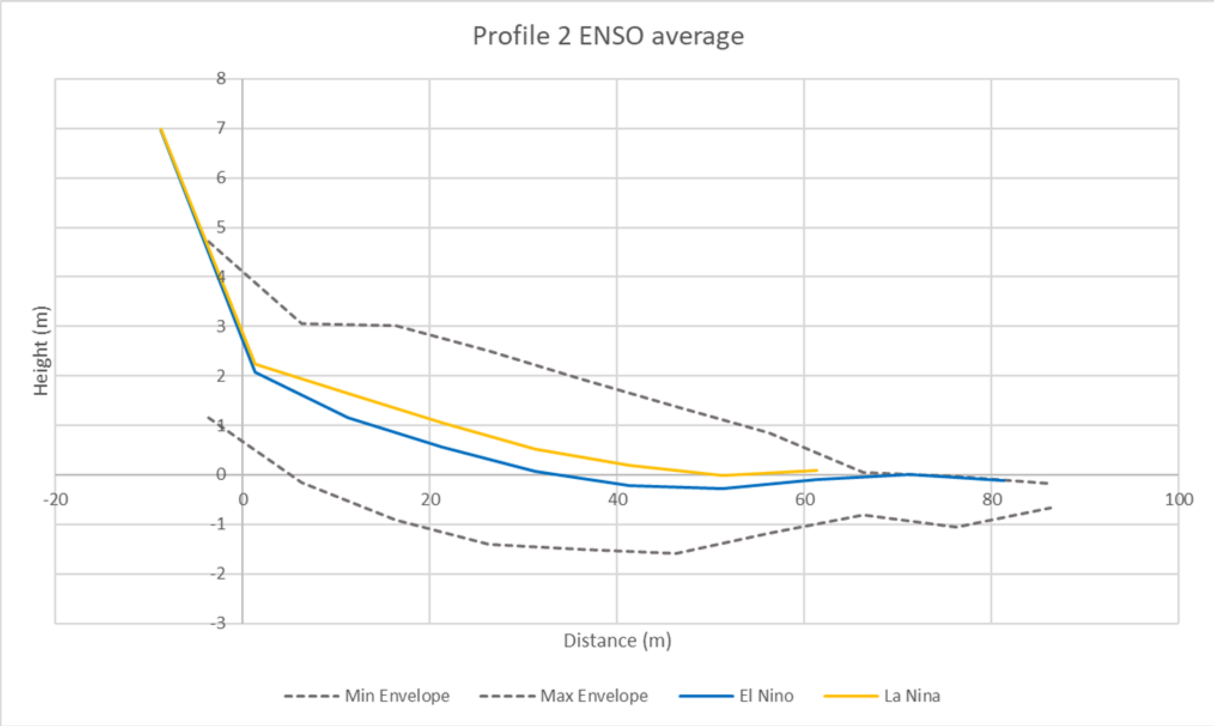

Figure 12.2: Profile 2 ENSO average chart.

12.2 WAINUI STREAM

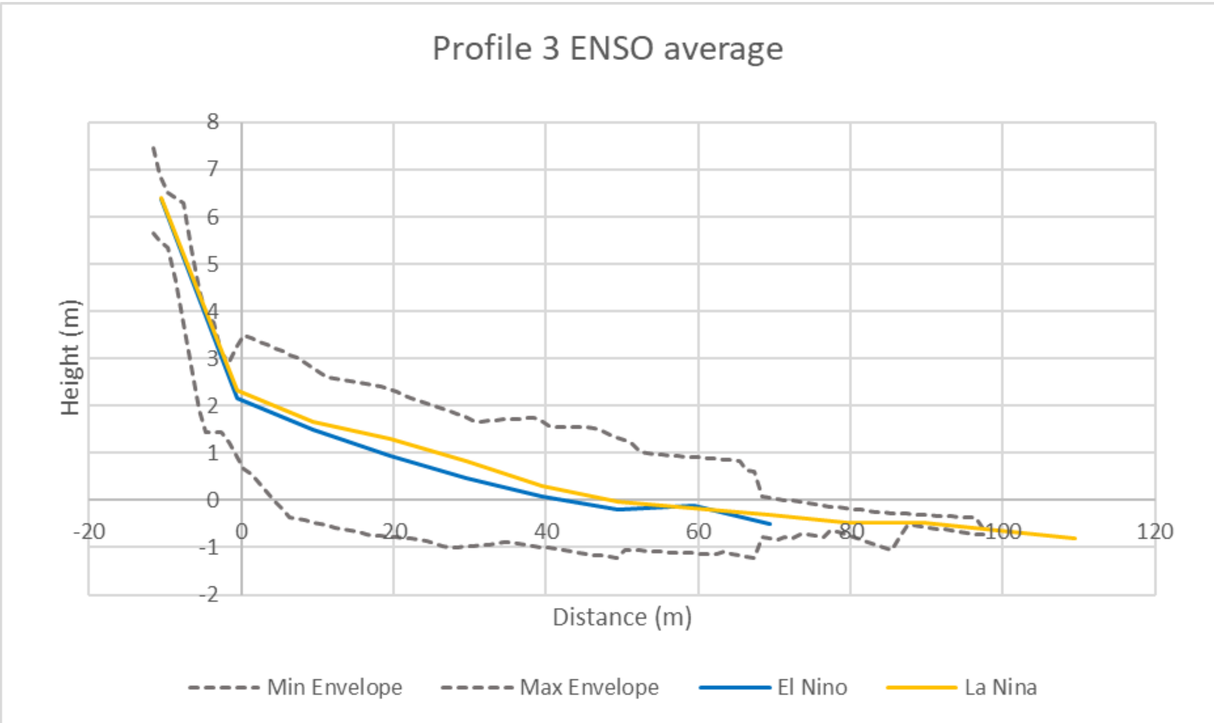

Figure 12.3: Profile 3 ENSO average chart.

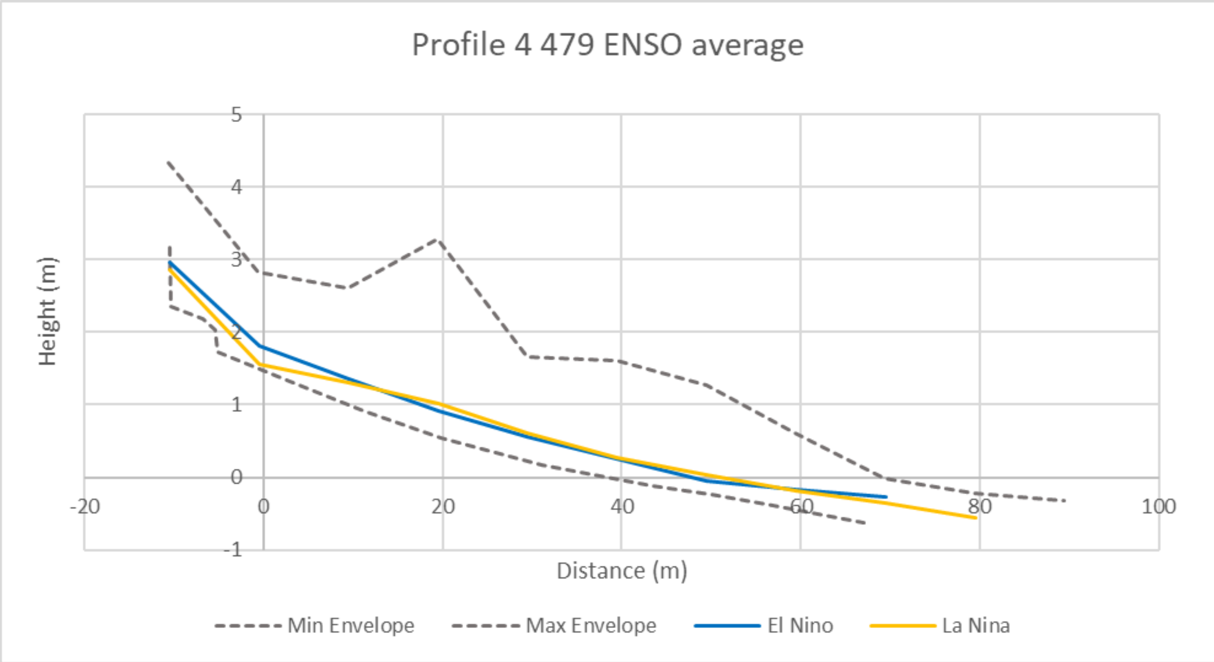

Figure 12.4: Profile 4 ENSO average chart.

12.3 CENTRAL BEACH

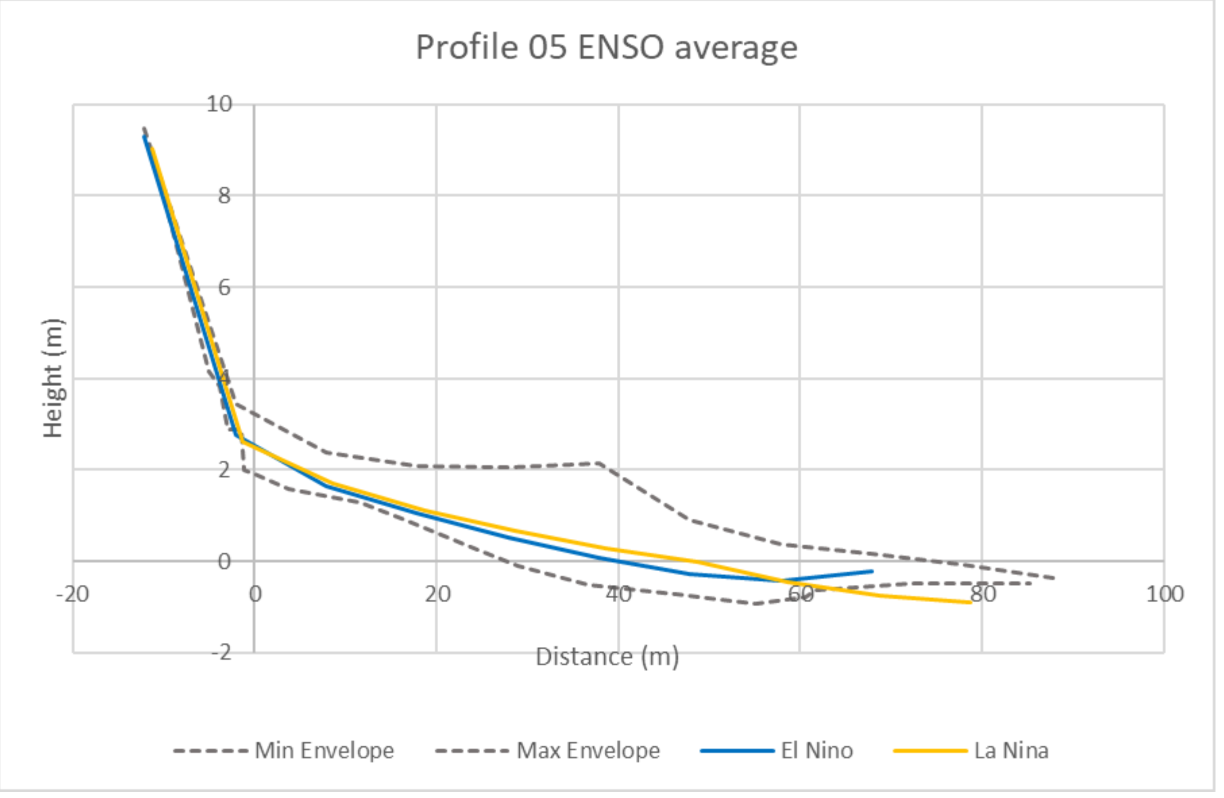

Figure 12.5: Profile 5 ENSO average chart.

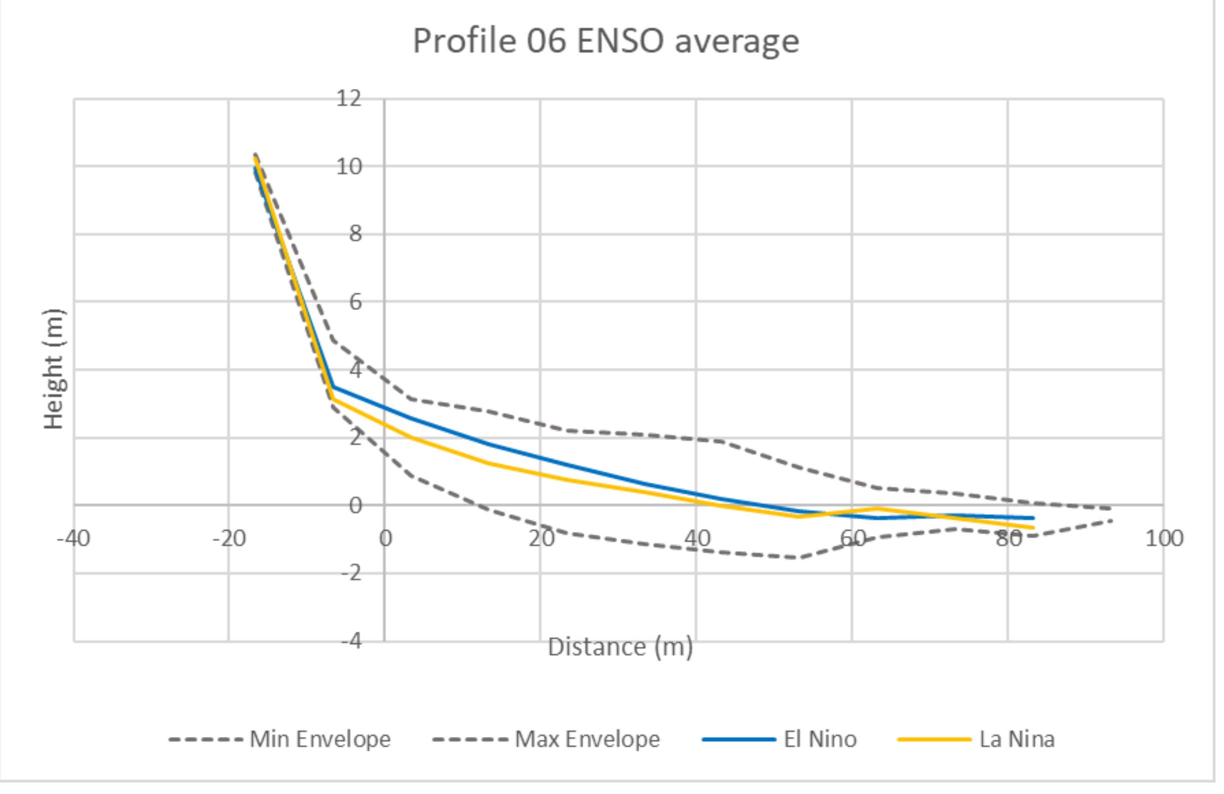

Figure 12.6: Profile 6 ENSO average chart.

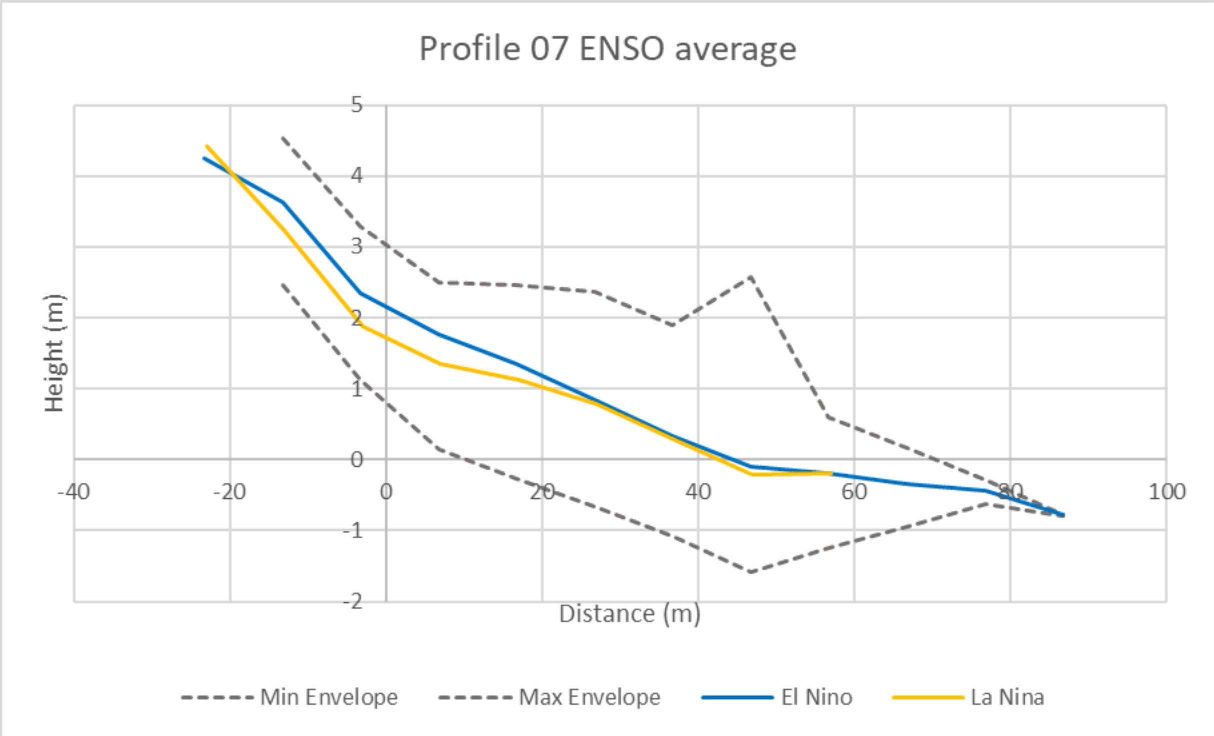

Figure 12.7: Profile 7 ENSO average chart.

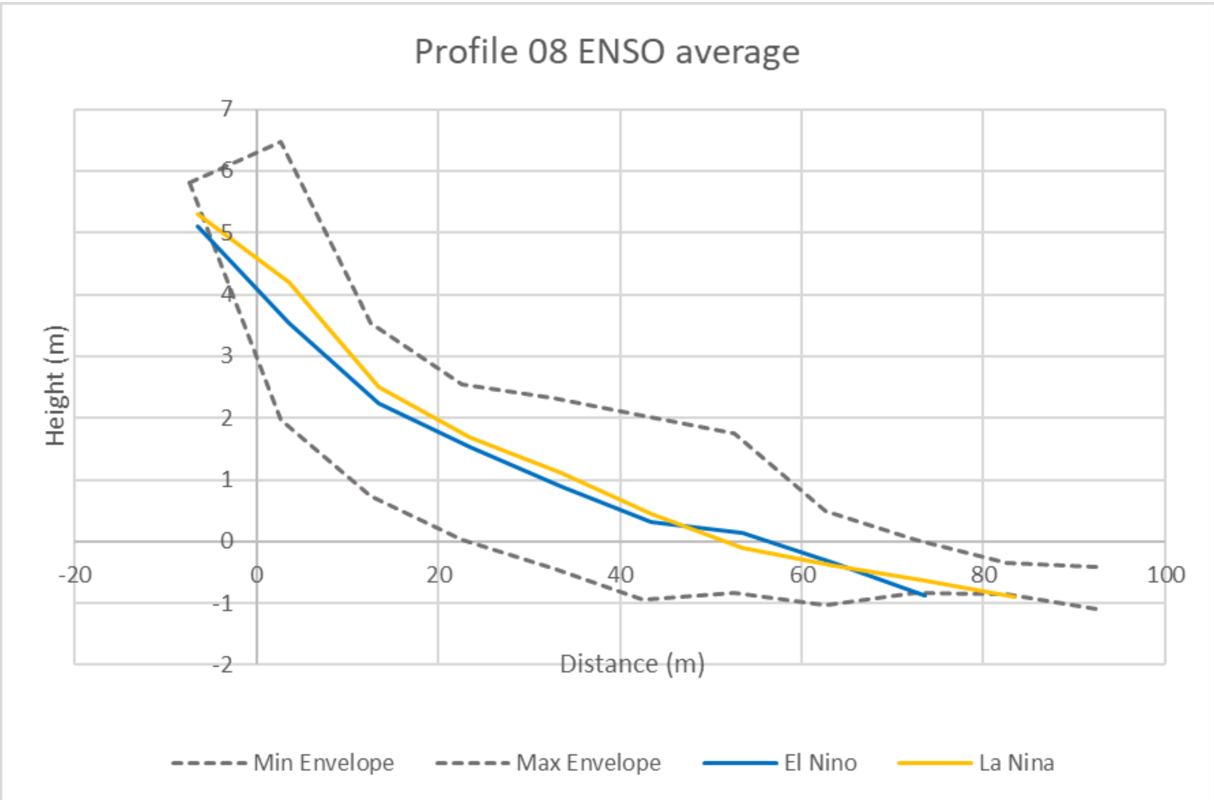

Figure 12.8: Profile 8 ENSO average chart.

12.4 HAMANATUA STREAM

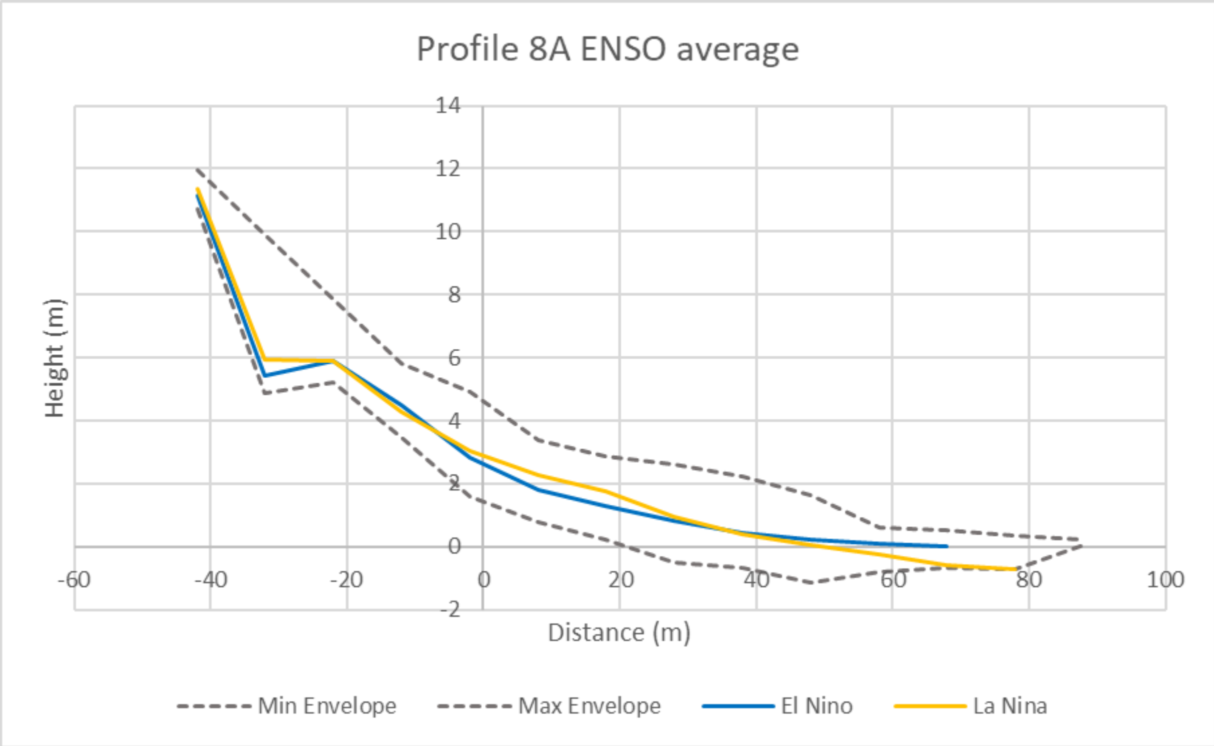

Figure 12.9: Profile 8A ENSO average chart.

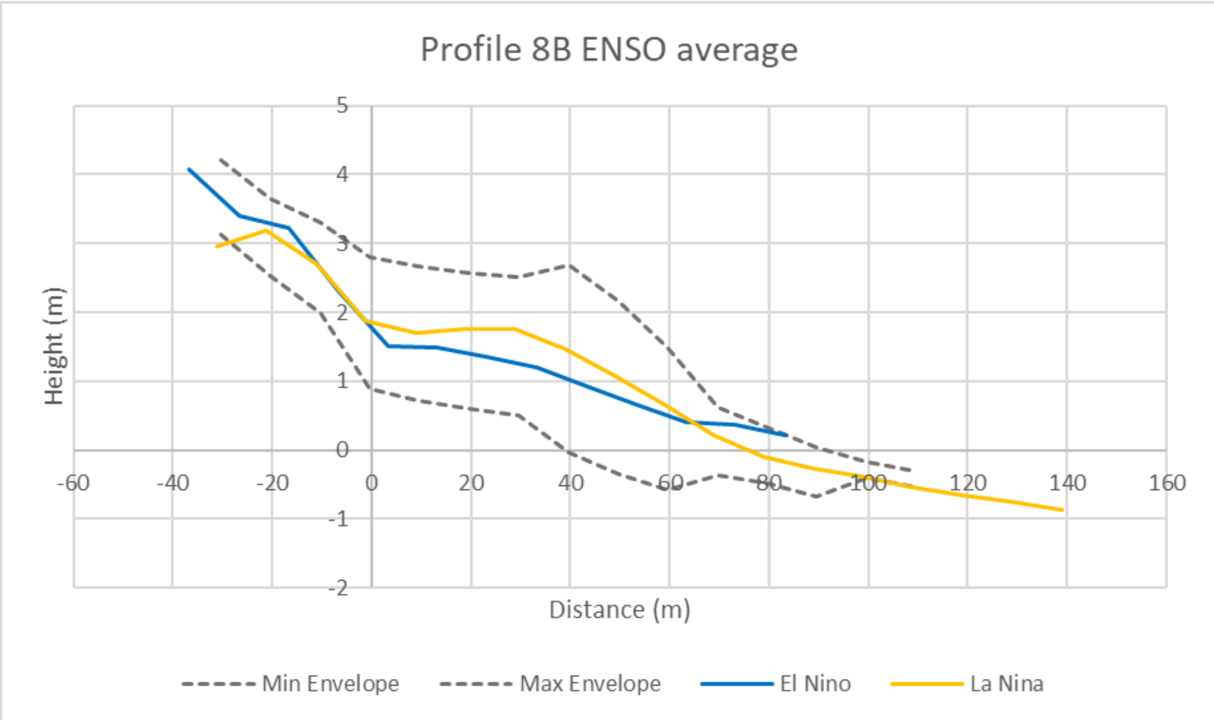

Figure 12.10: Profile 8B ENSO average chart.

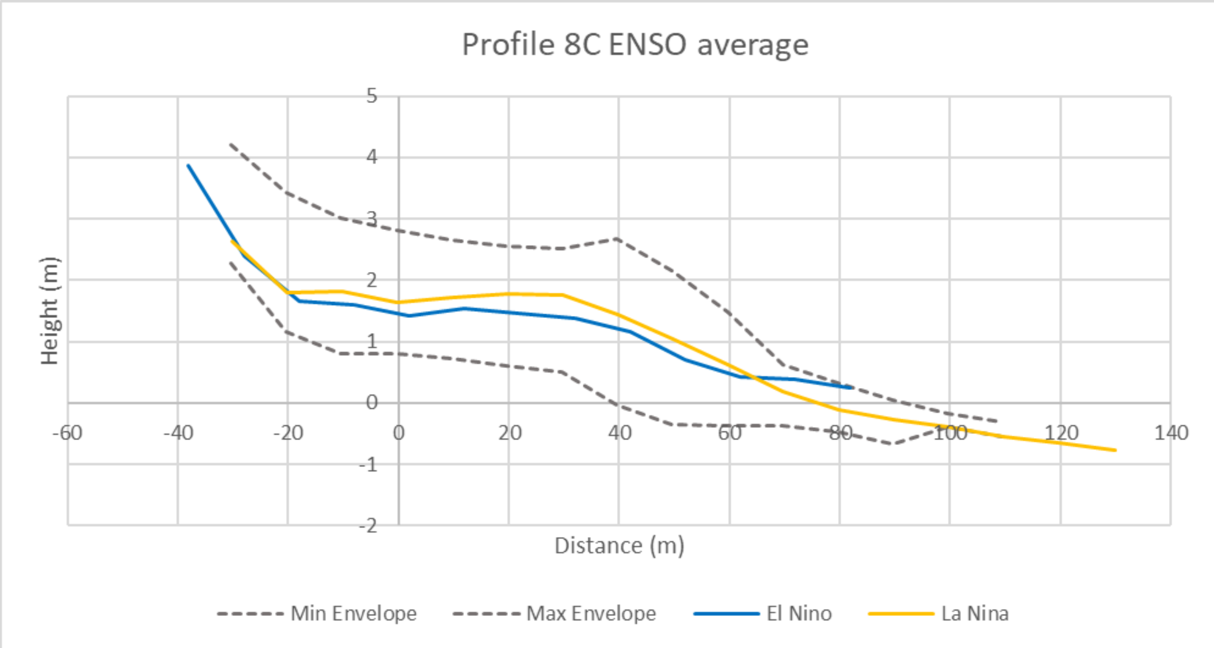

Figure 12.11: Profile 8C ENSO average chart.

12.5 NORTHERN BEACH

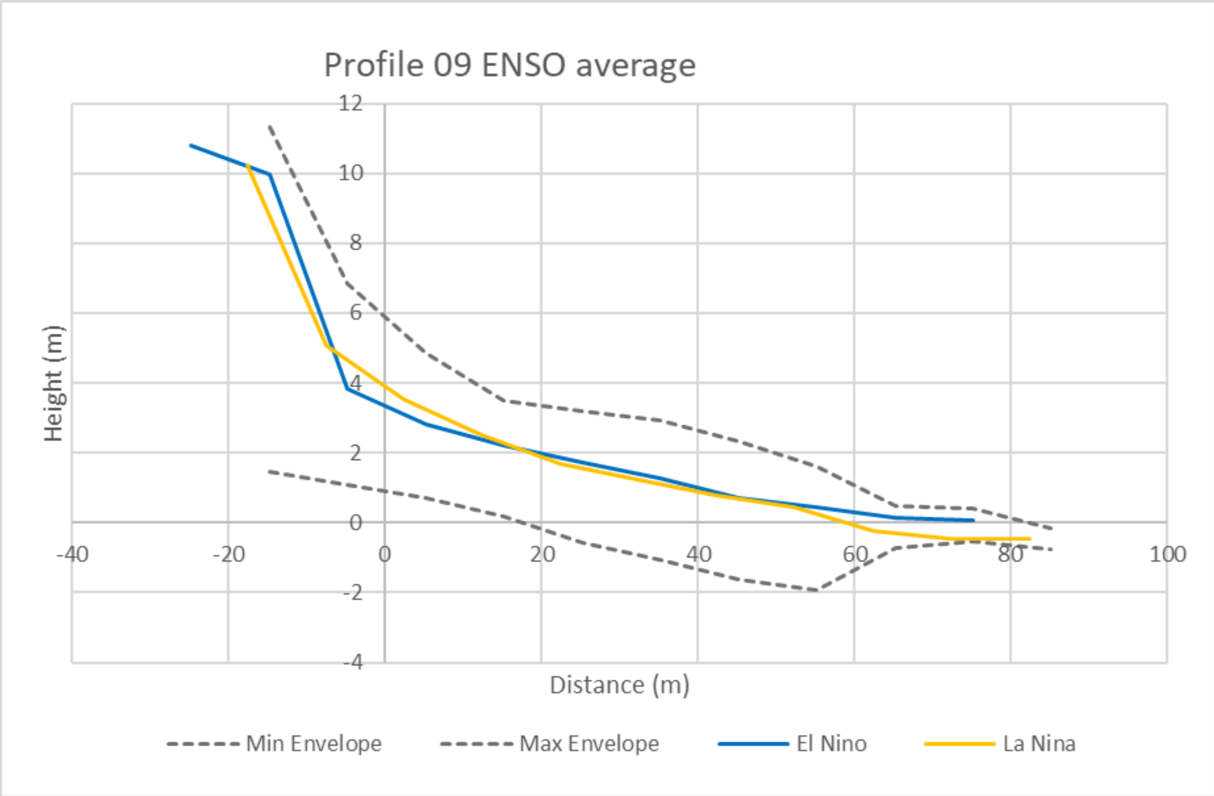

Figure 12.12: Profile 9 ENSO average chart.

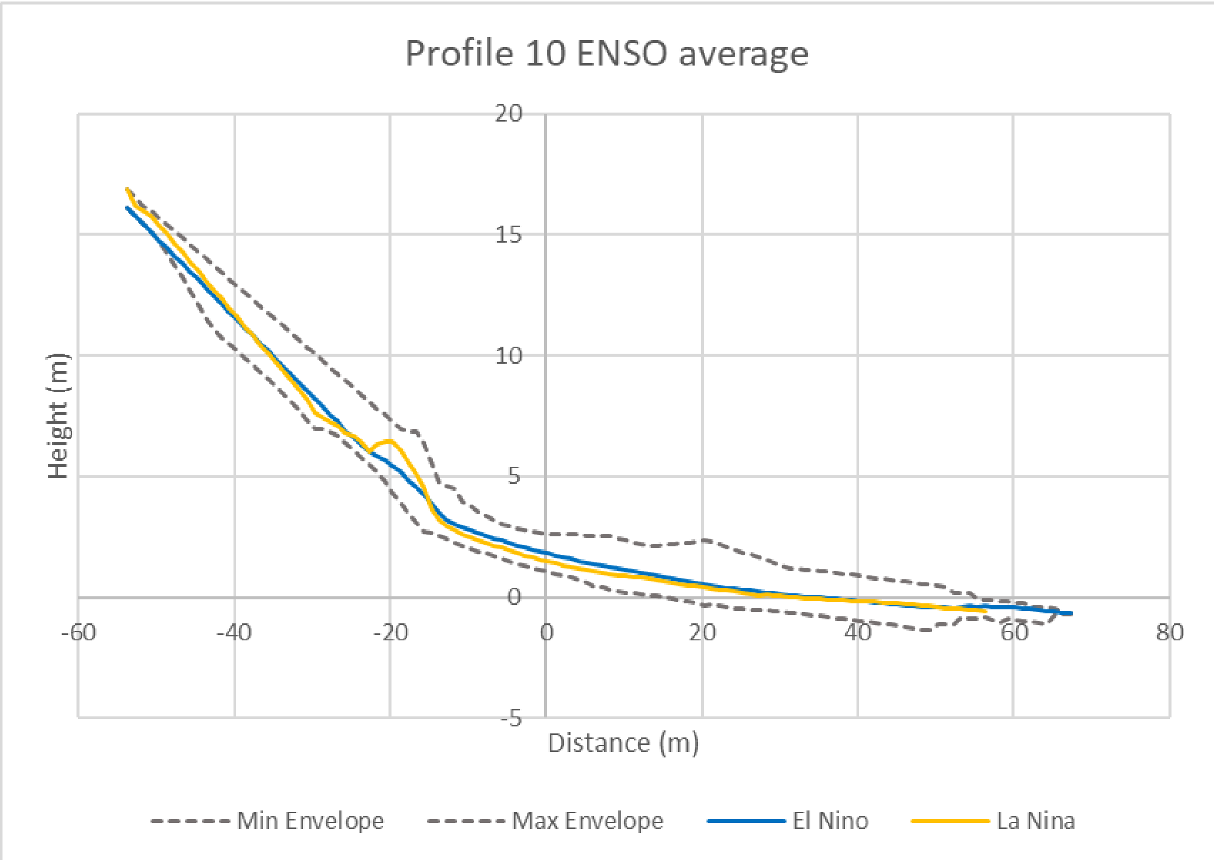

Figure 12.13: Profile 10 ENSO average chart.

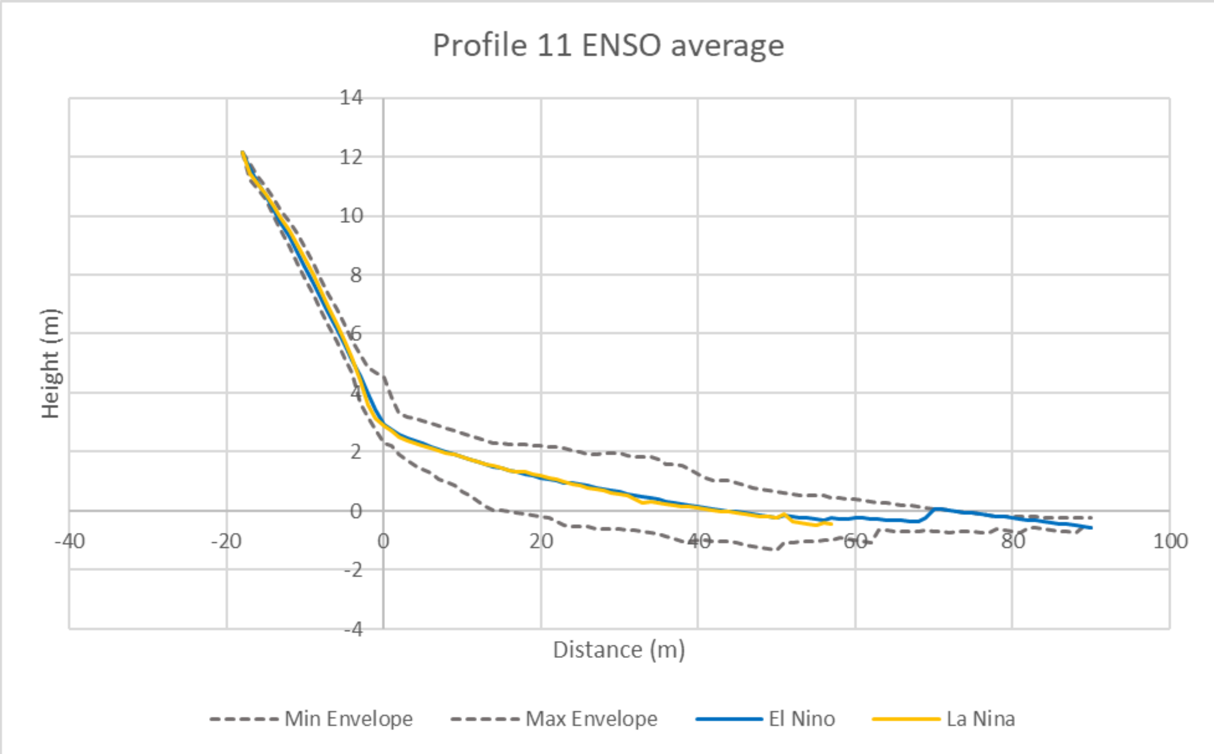

Figure 12.14: Profile 11 ENSO average chart.

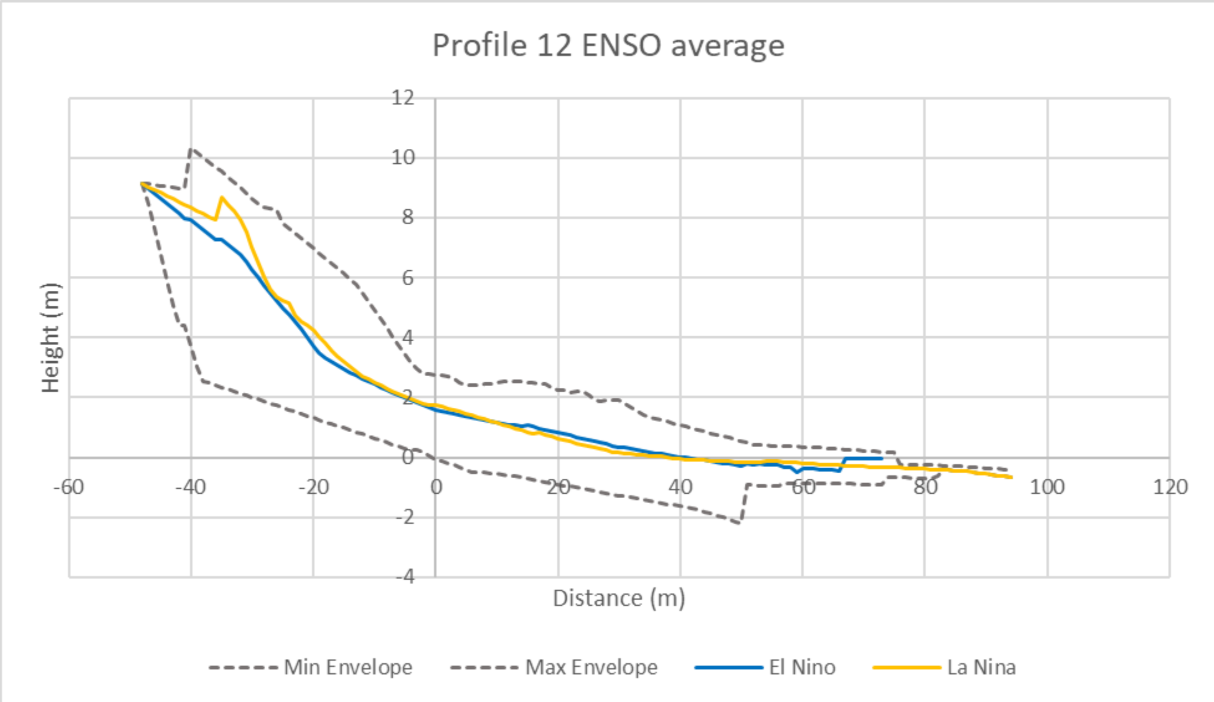

Figure 12.15: Profile 12 ENSO average chart.

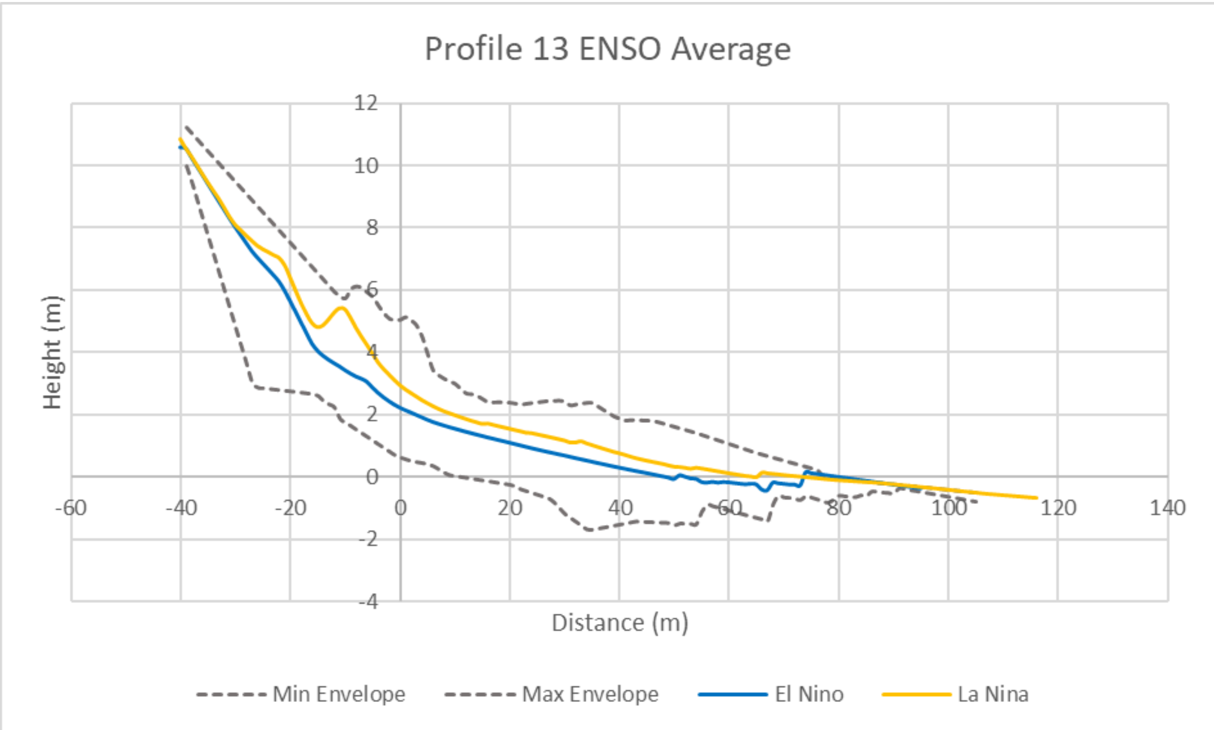

Figure 12.16: Profile 13 ENSO average chart.

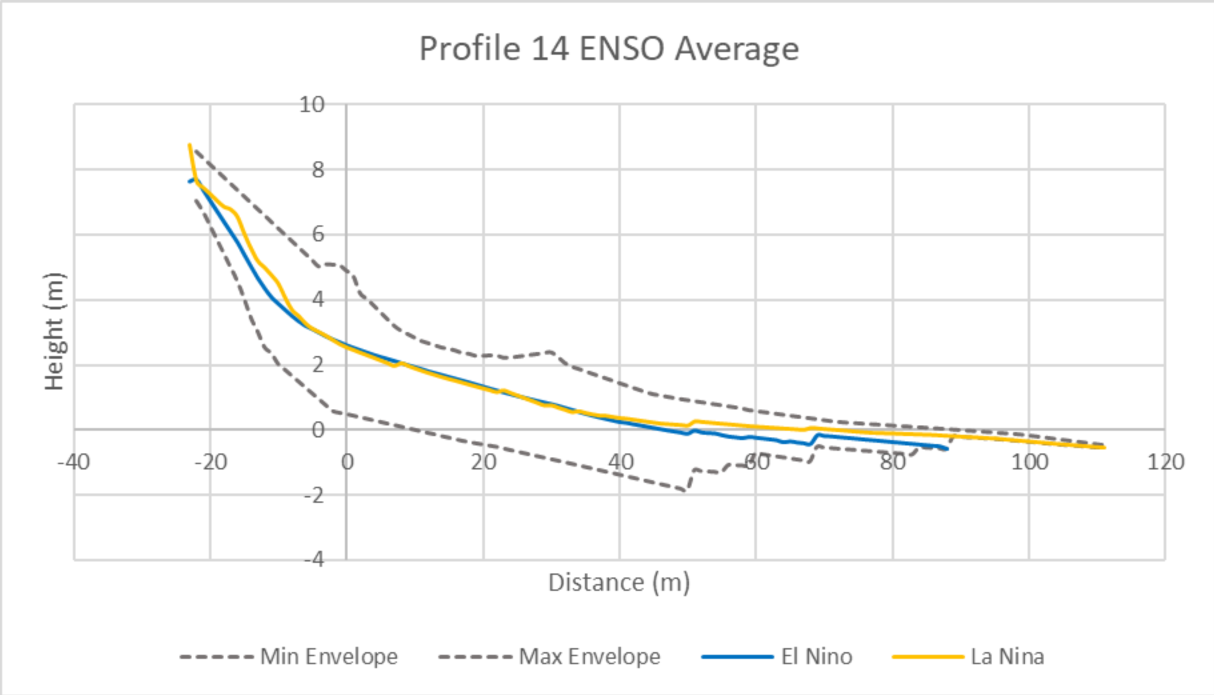

Figure 12.17: Profile 14 ENSO average chart.

13 APPENDIX D

IPO CHARTS

13.1 SOUTHERN BEACH

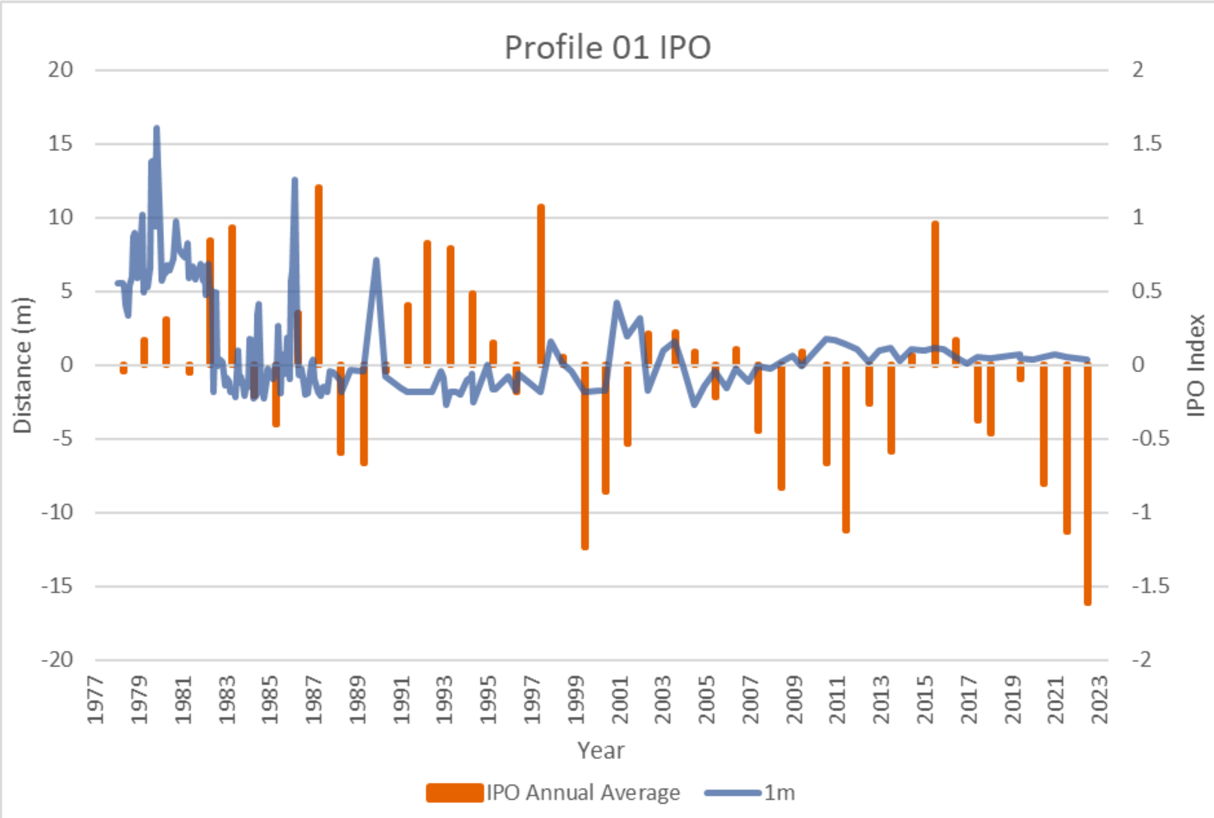

Figure 13.1: Profile 1 IPO chart.

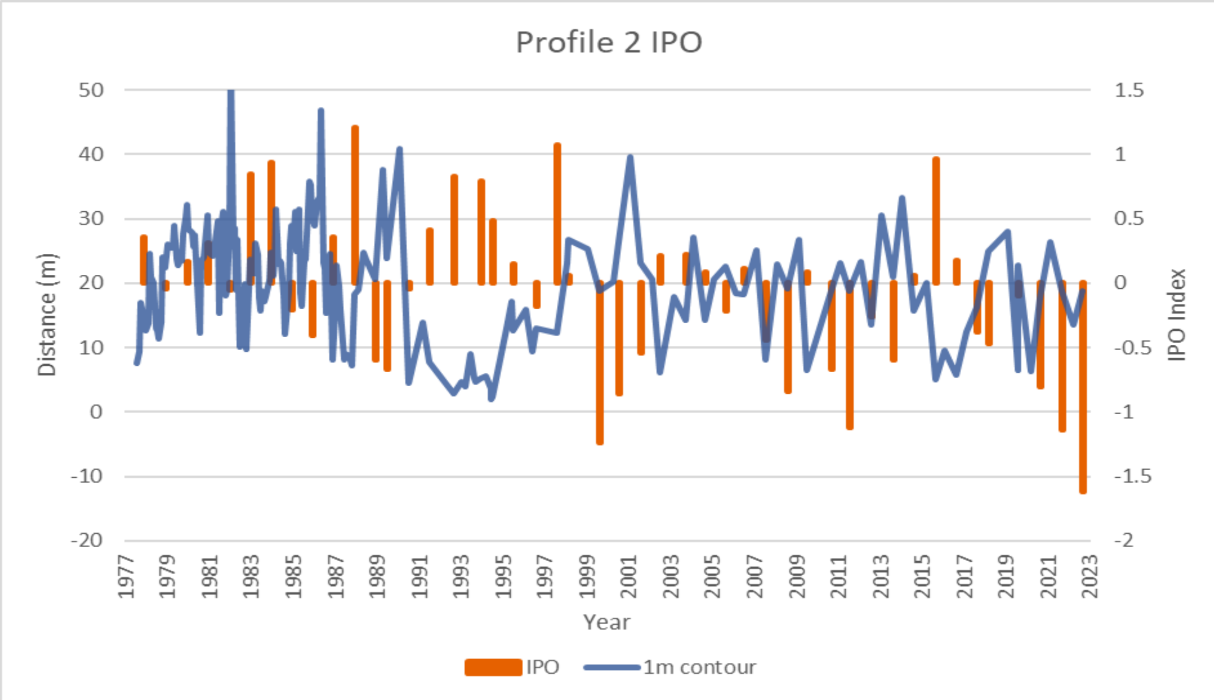

Figure 13.2: Profile 2 IPO chart.

13.2 CENTRAL BEACH

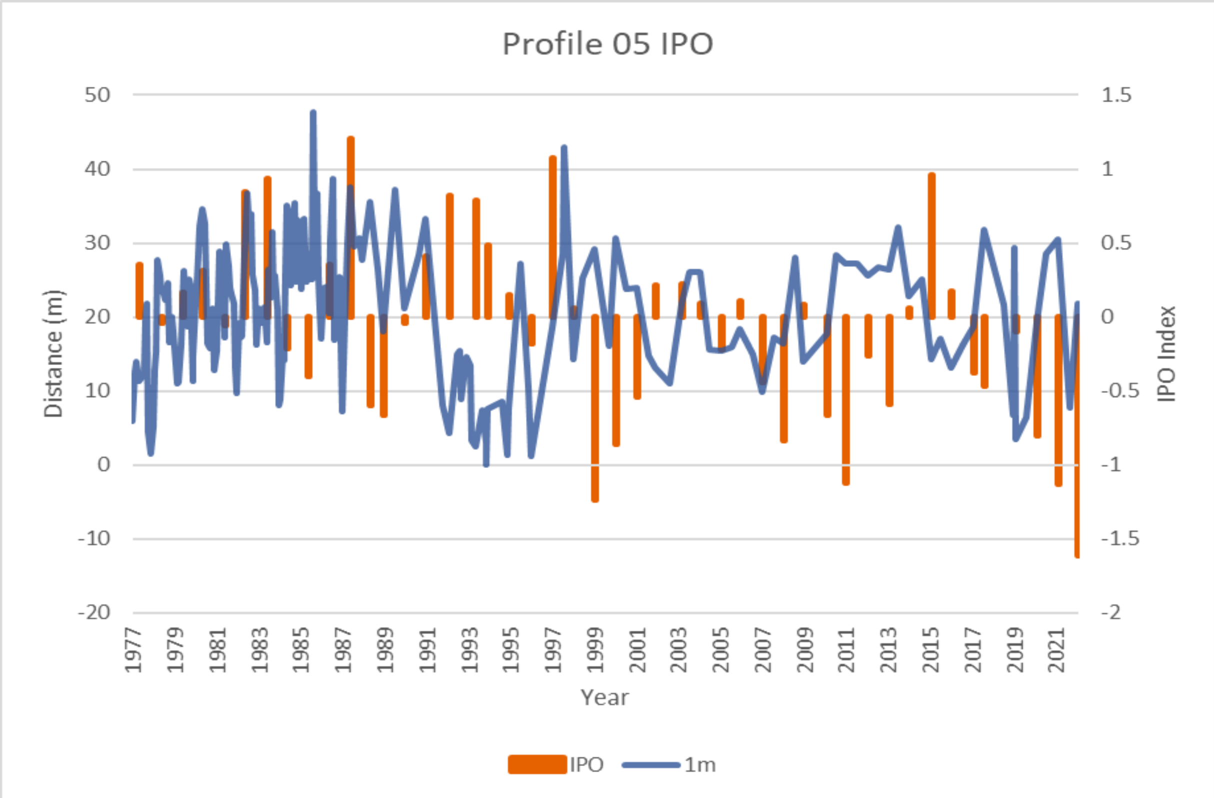

Figure 13.3: Profile 5 IPO chart.

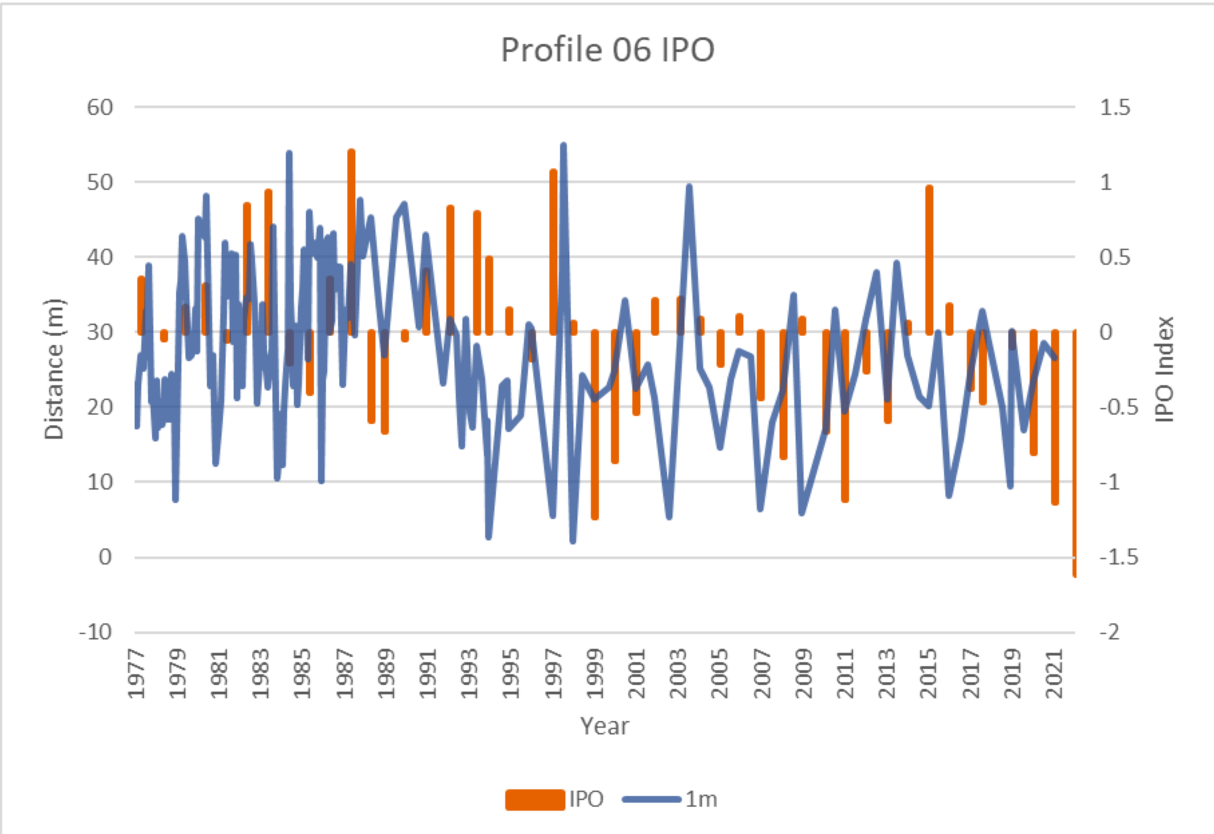

Figure 13.4: Profile 6 IPO chart.

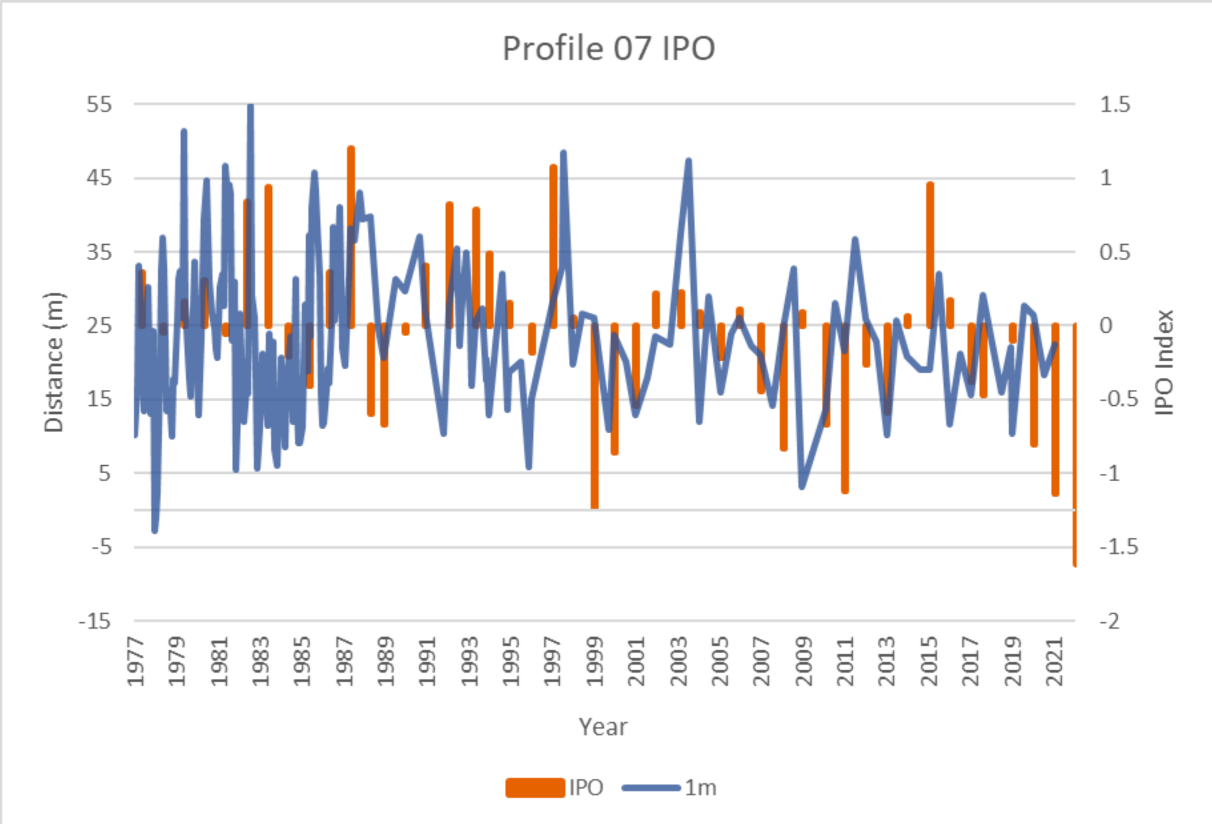

Figure 13.5: Profile 7 IPO chart.

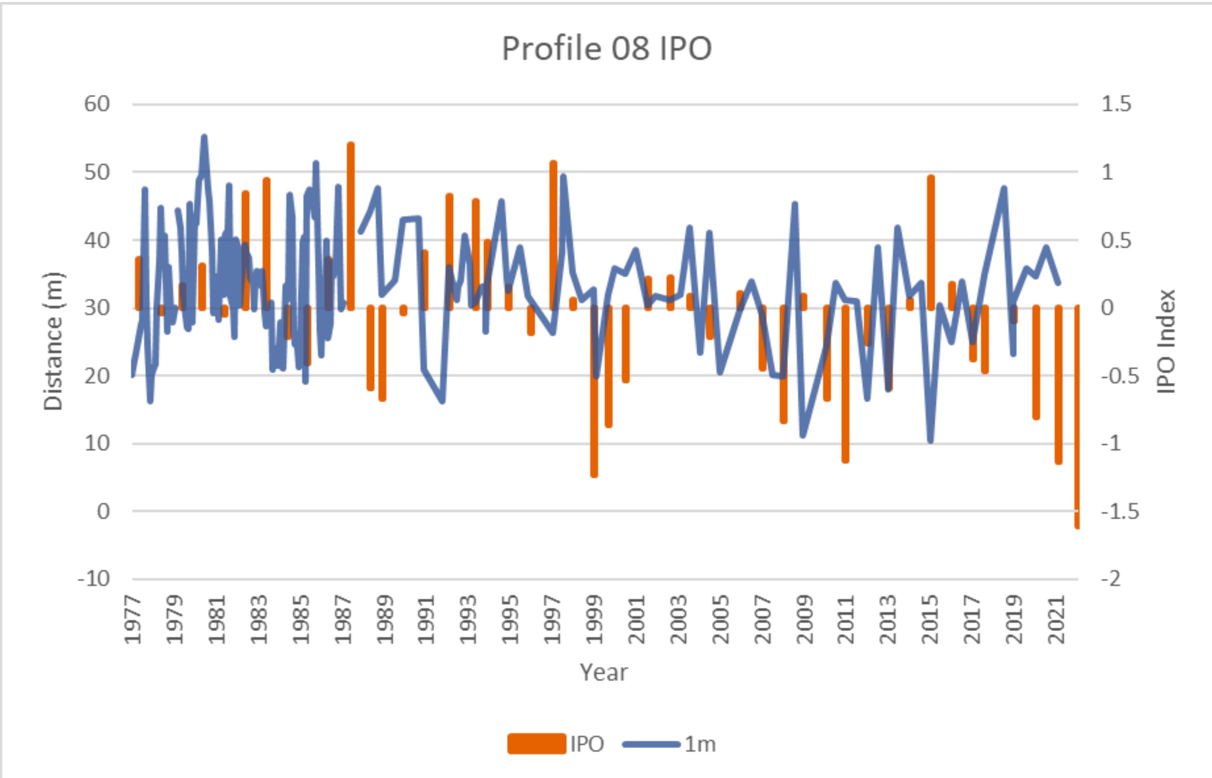

Figure 13.6: Profile 8 IPO chart.

13.3 NORTHERN BEACH

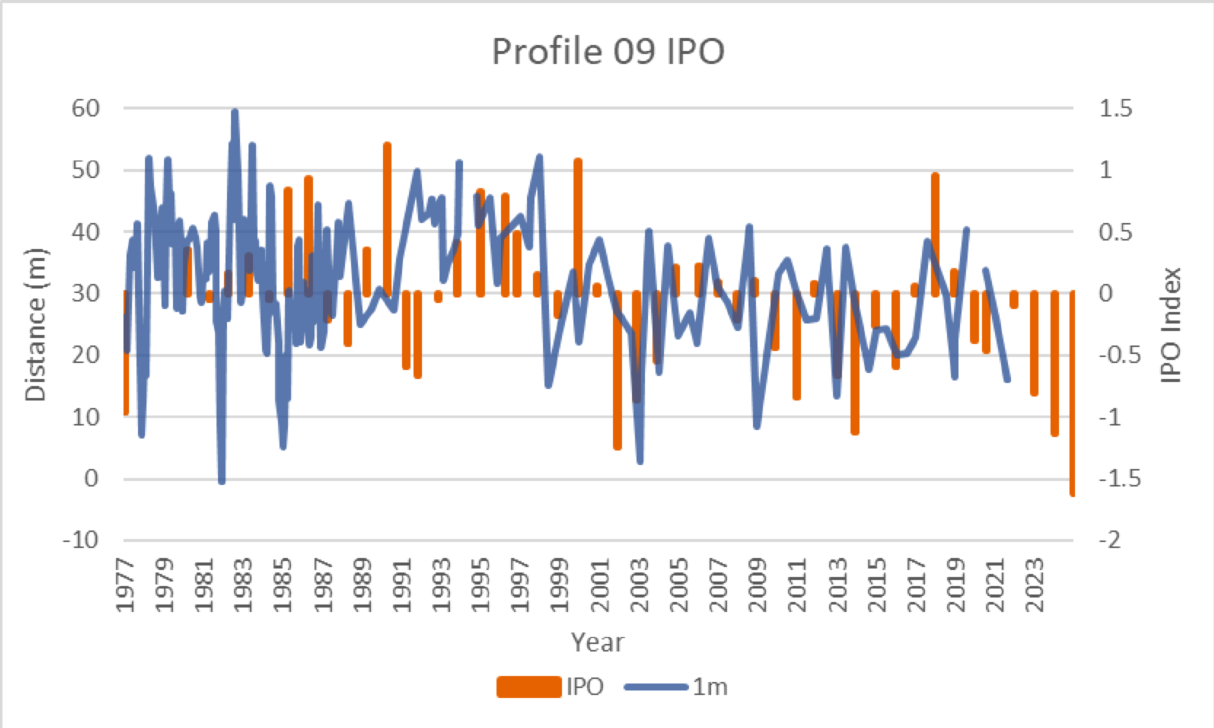

Figure 13.7: Profile 9 IPO chart.

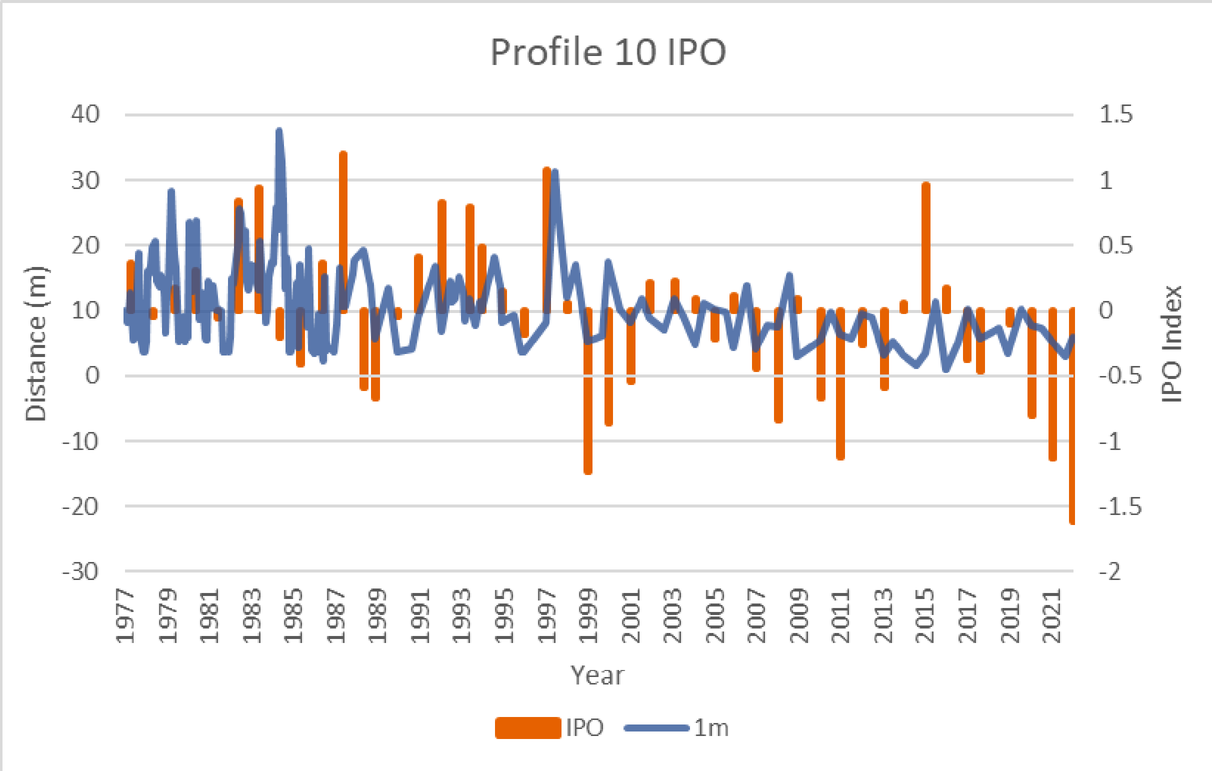

Figure 13.8: Profile 10 IPO chart.

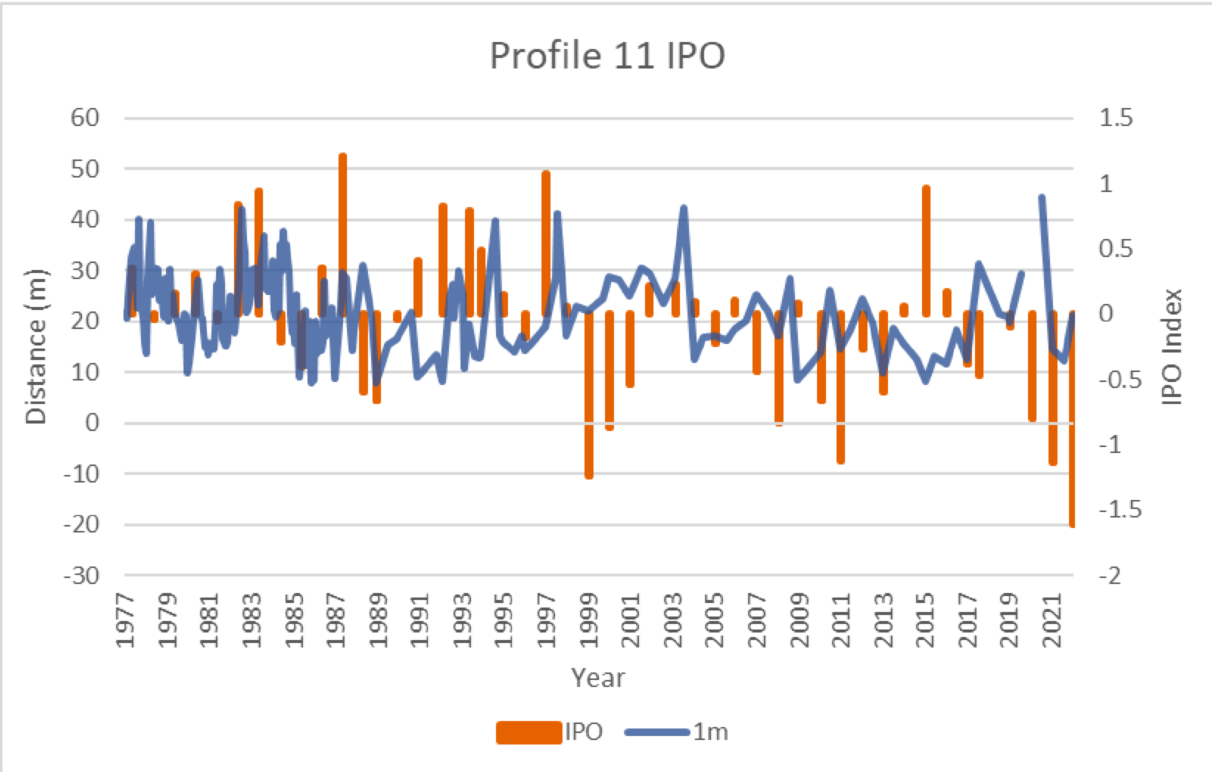

Figure 13.9: Profile 11 IPO chart.

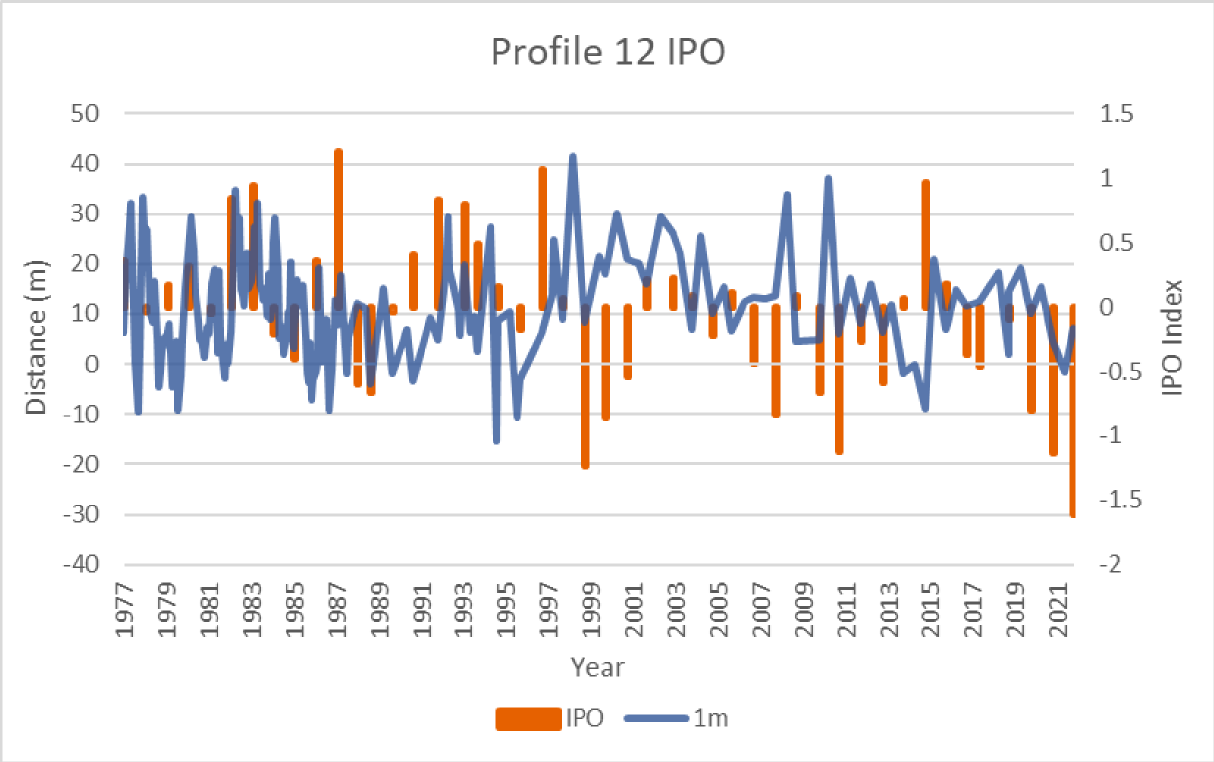

Figure 13.10: Profile 12 IPO chart.

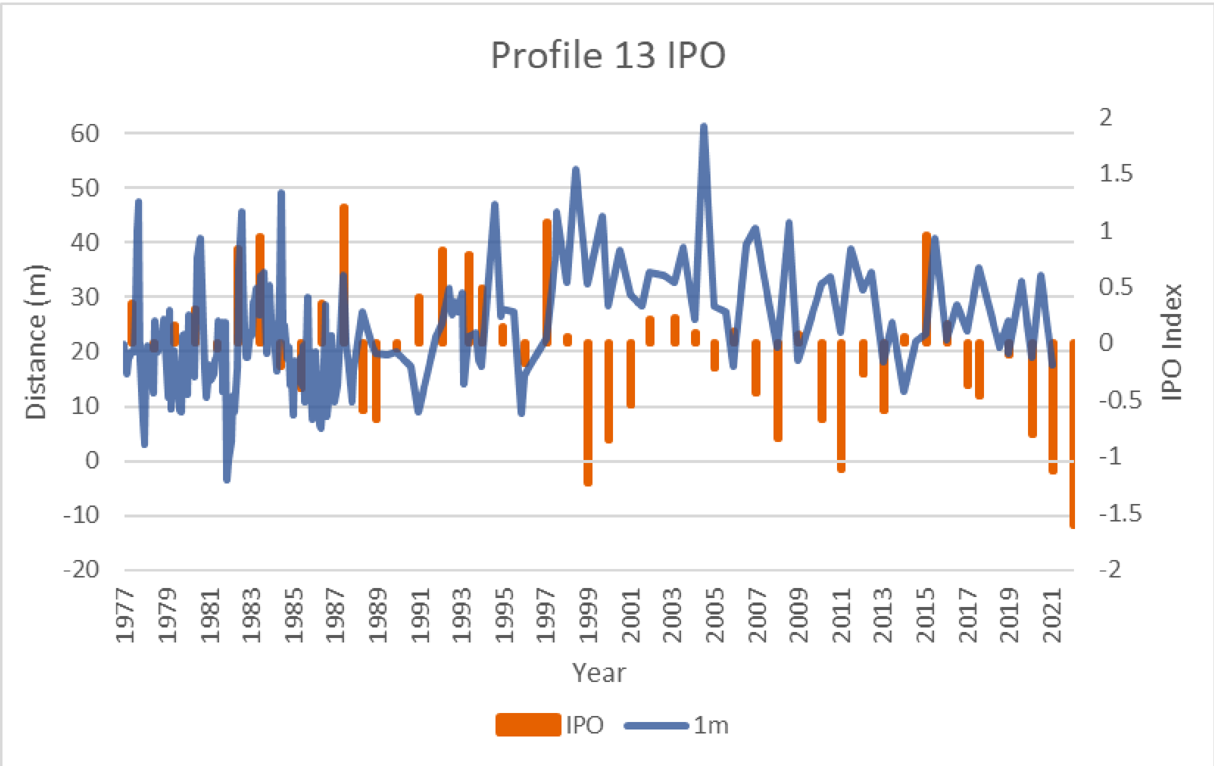

Figure 13.11: Profile 13 IPO chart.

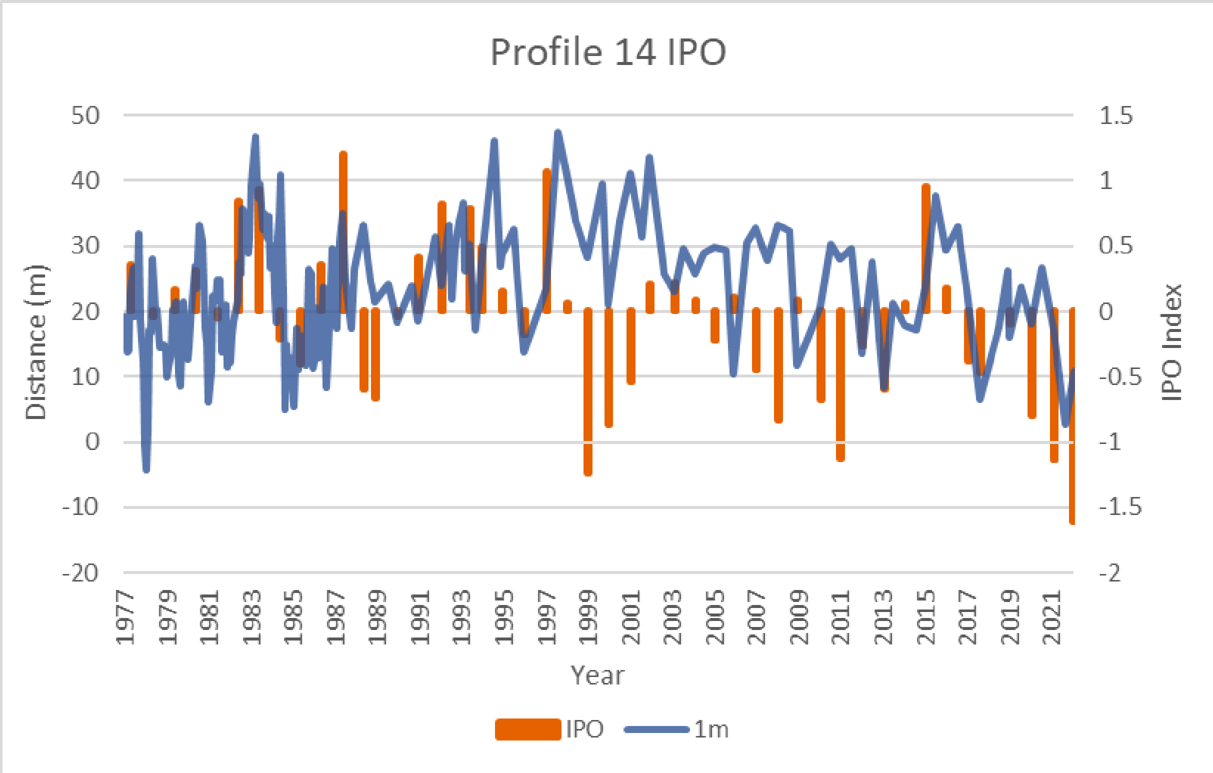

Figure 13.12: Profile 14 IPO chart.

14 APPENDIX E

PDO CHARTS

14.1 SOUTHERN BEACH

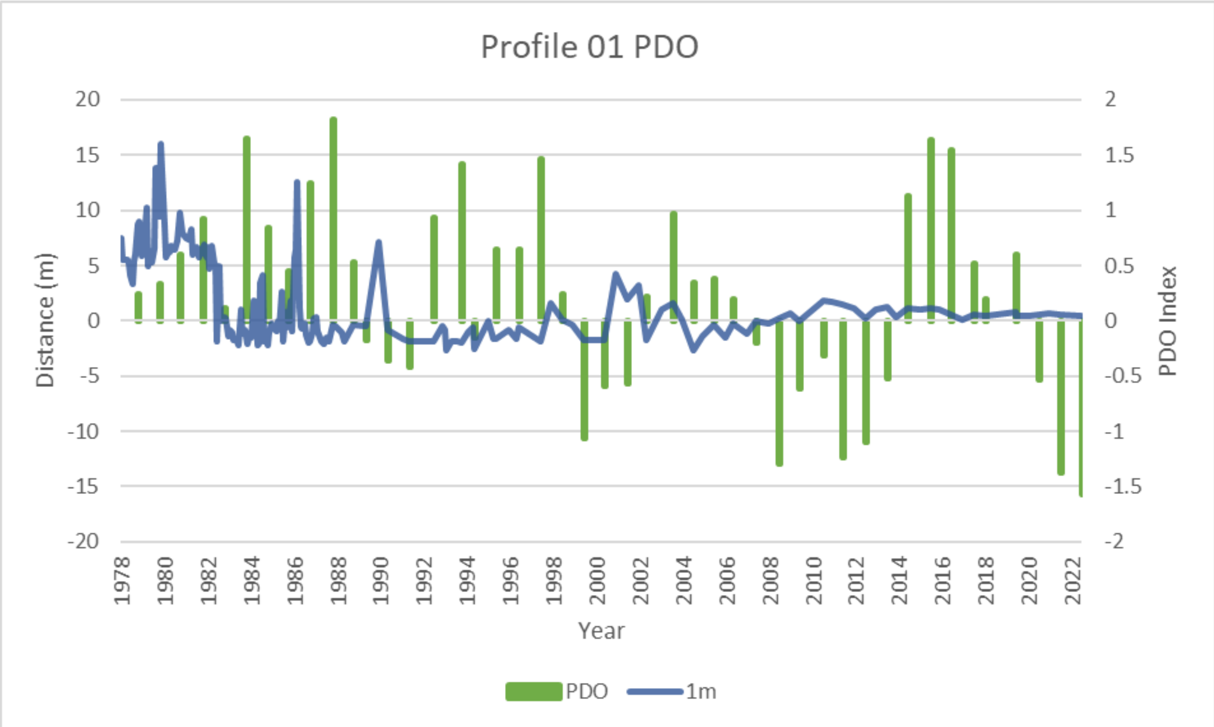

Figure 14.1: Profile 1 PDO chart.

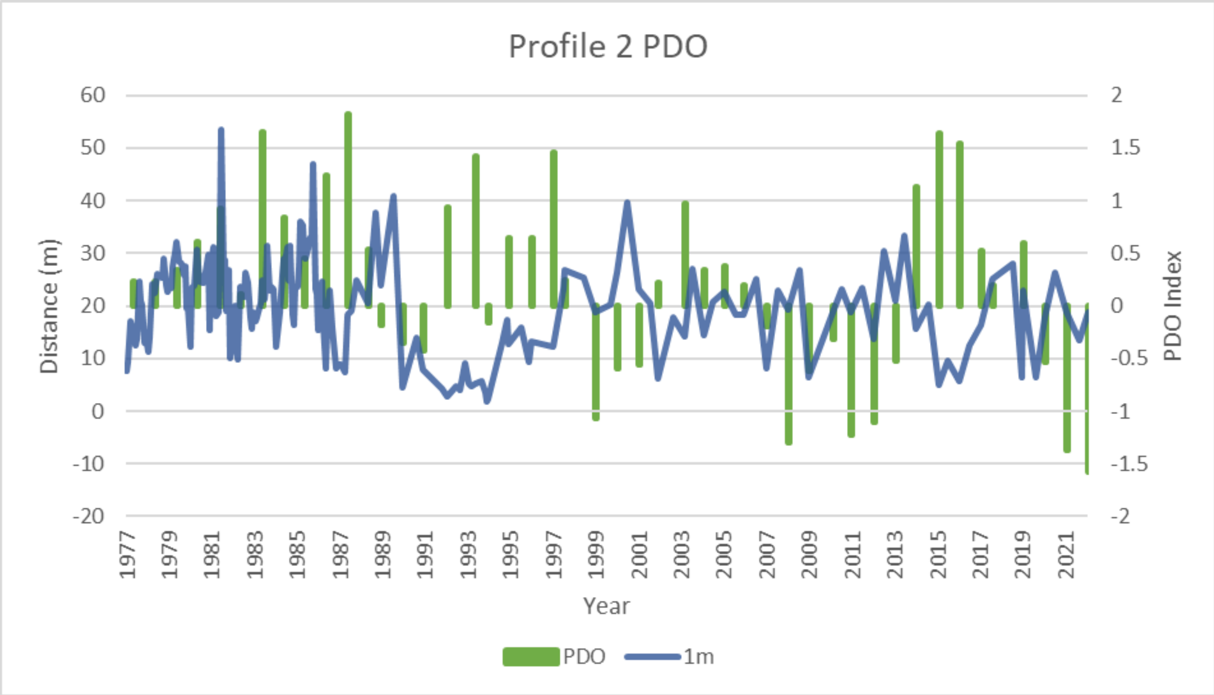

Figure 14.2: Profile 2 PDO chart.

14.2 WAINUI STREAM

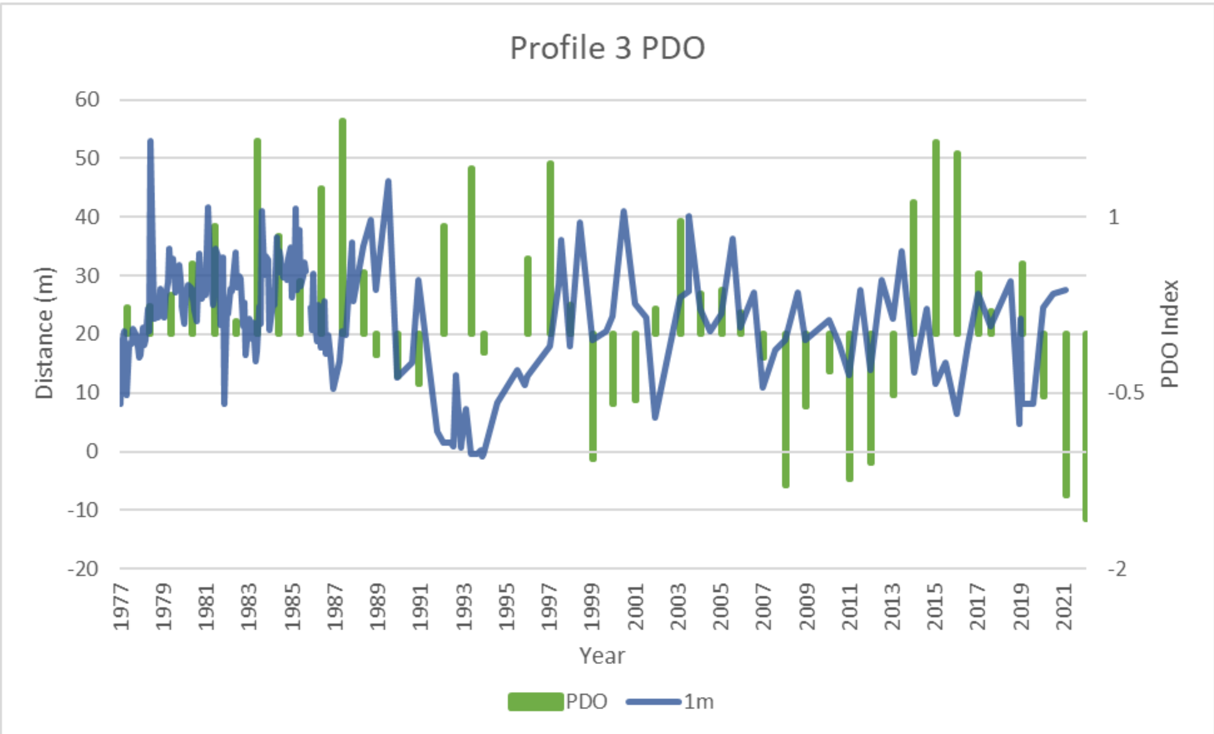

Figure 14.3: Profile 3 PDO chart.

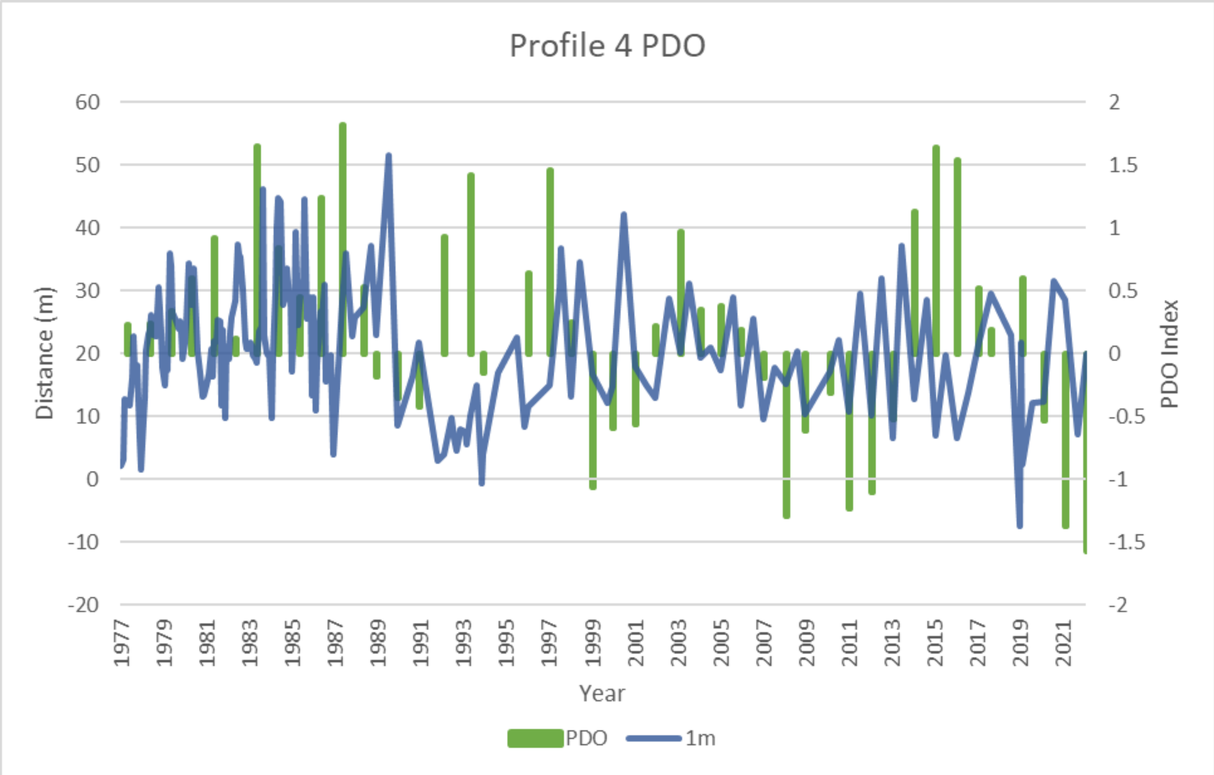

Figure 14.4: Profile 4 PDO chart.

14.3 CENTRAL BEACH

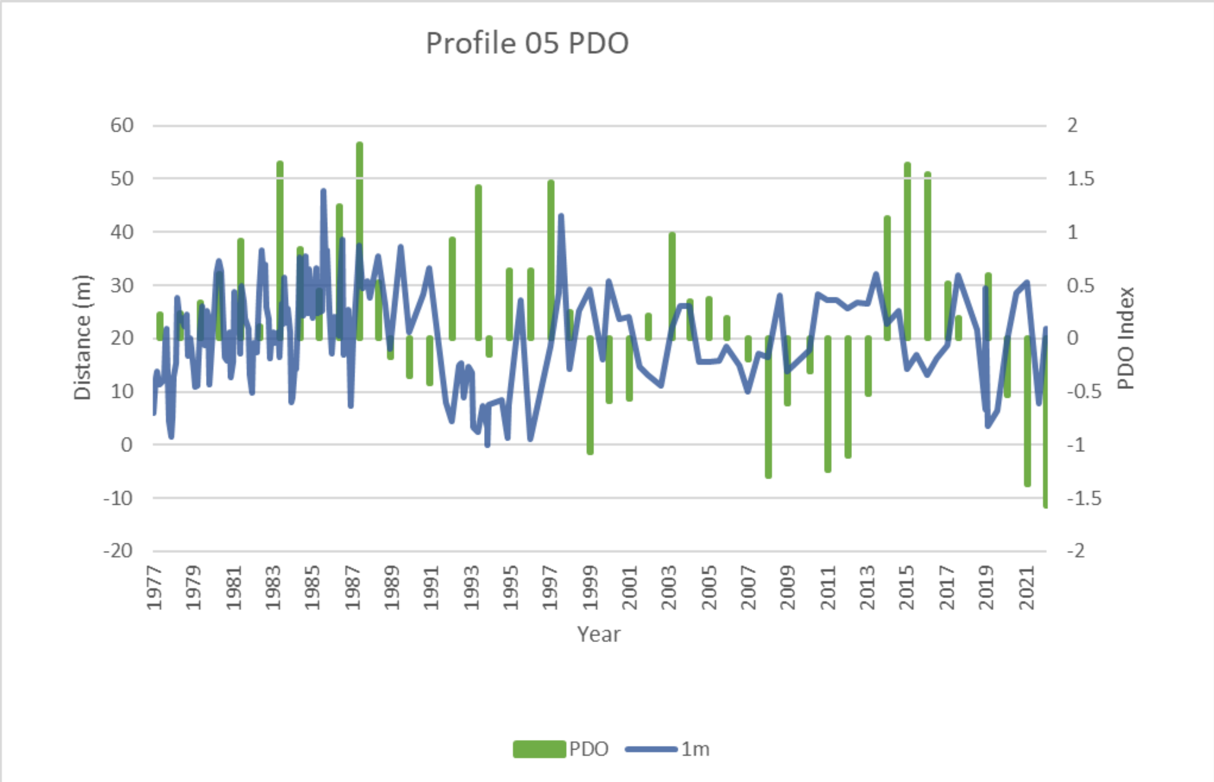

Figure 14.5: Profile 5 PDO chart.

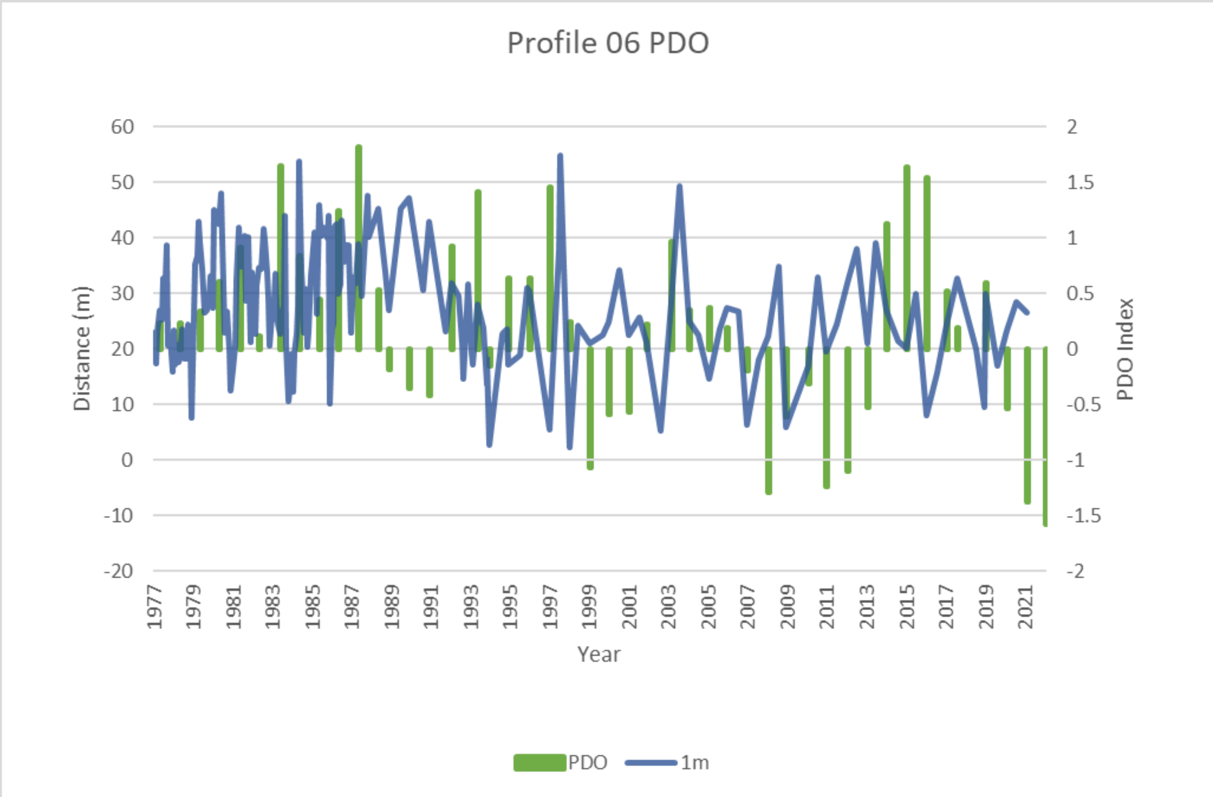

Figure 14.6: Profile 6 PDO chart.

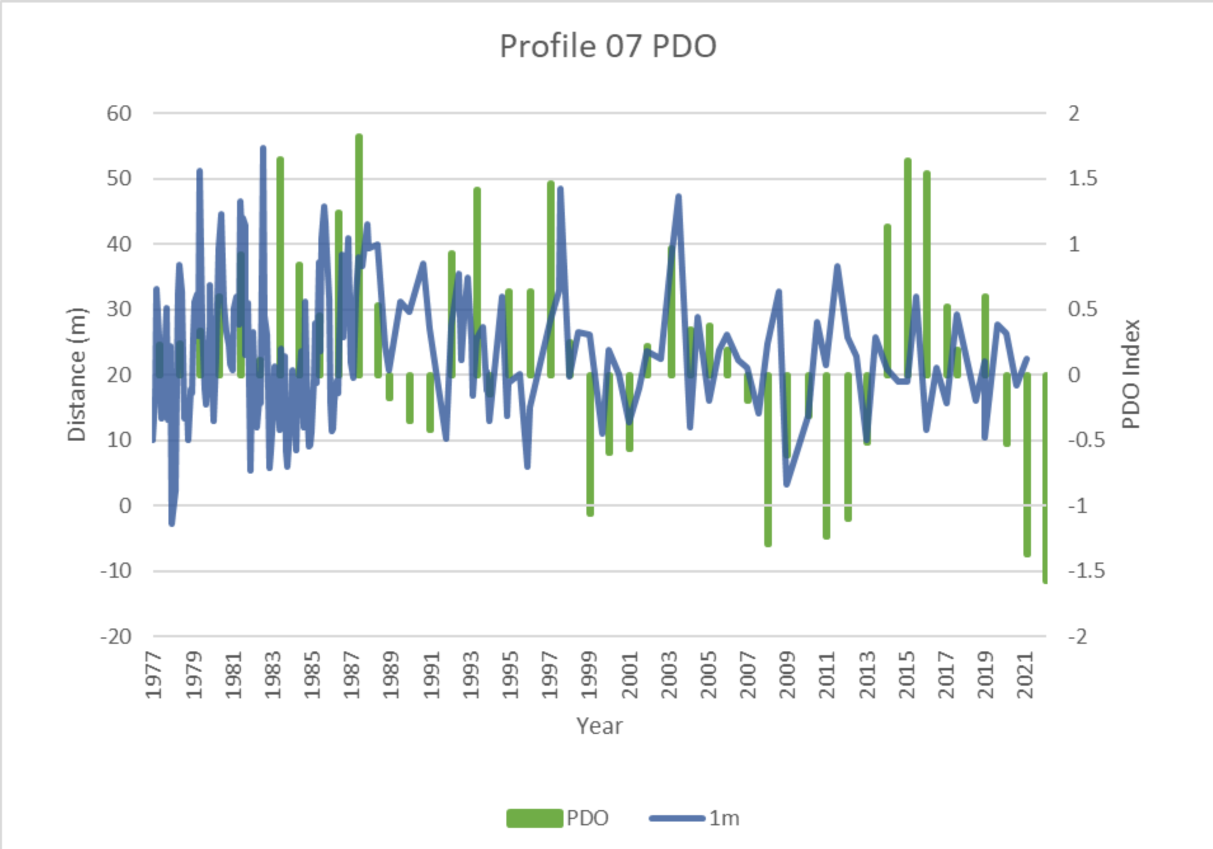

Figure 14.7: Profile 7 PDO chart.

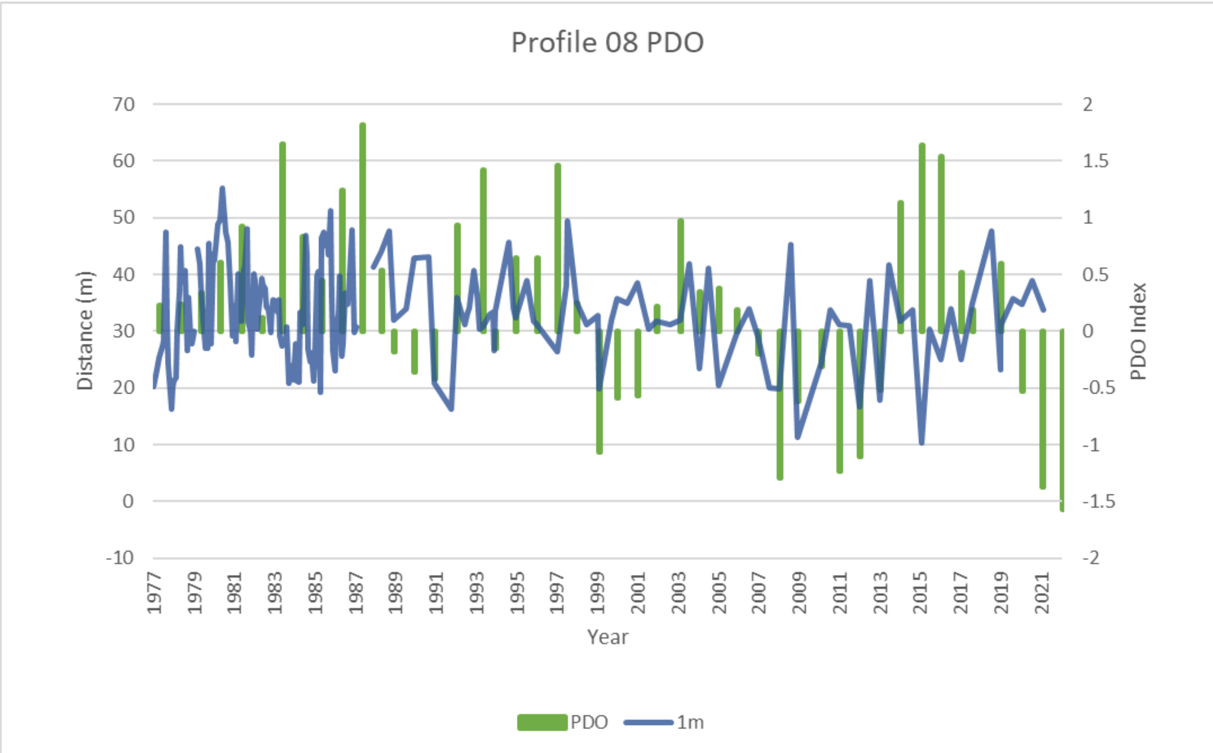

Figure 14.8: Profile 8 PDO chart.

14.4 HAMANATUA STREAM

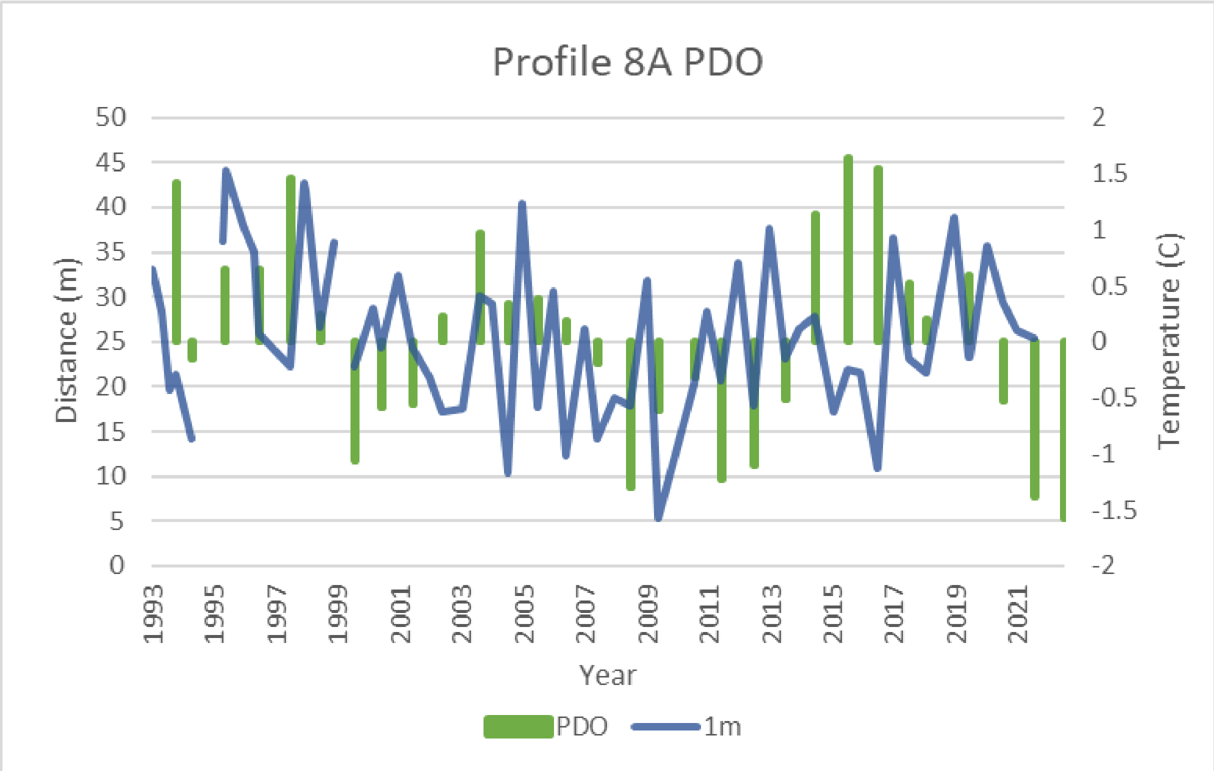

Figure 14.9: Profile 8A PDO chart.

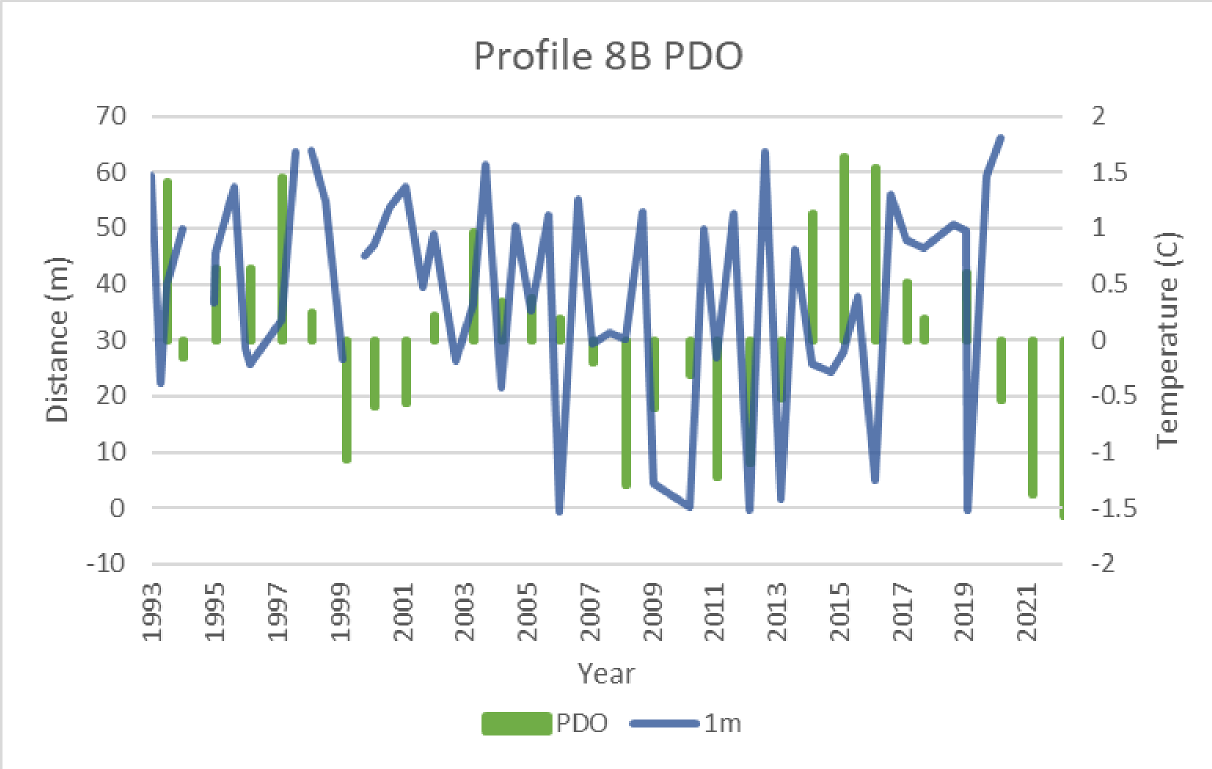

Figure 14.10: Profile 8B PDO chart.

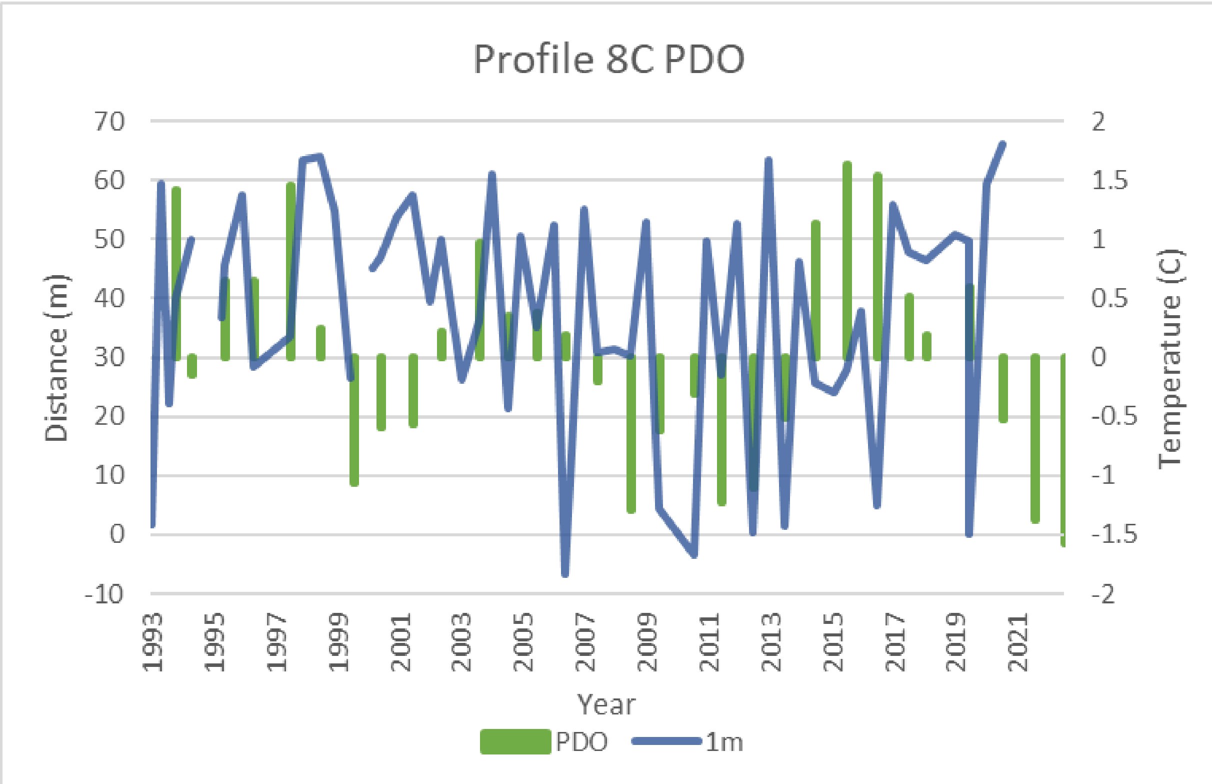

Figure 14.11: Profile 8C PDO chart.

14.5 NORTHERN BEACH

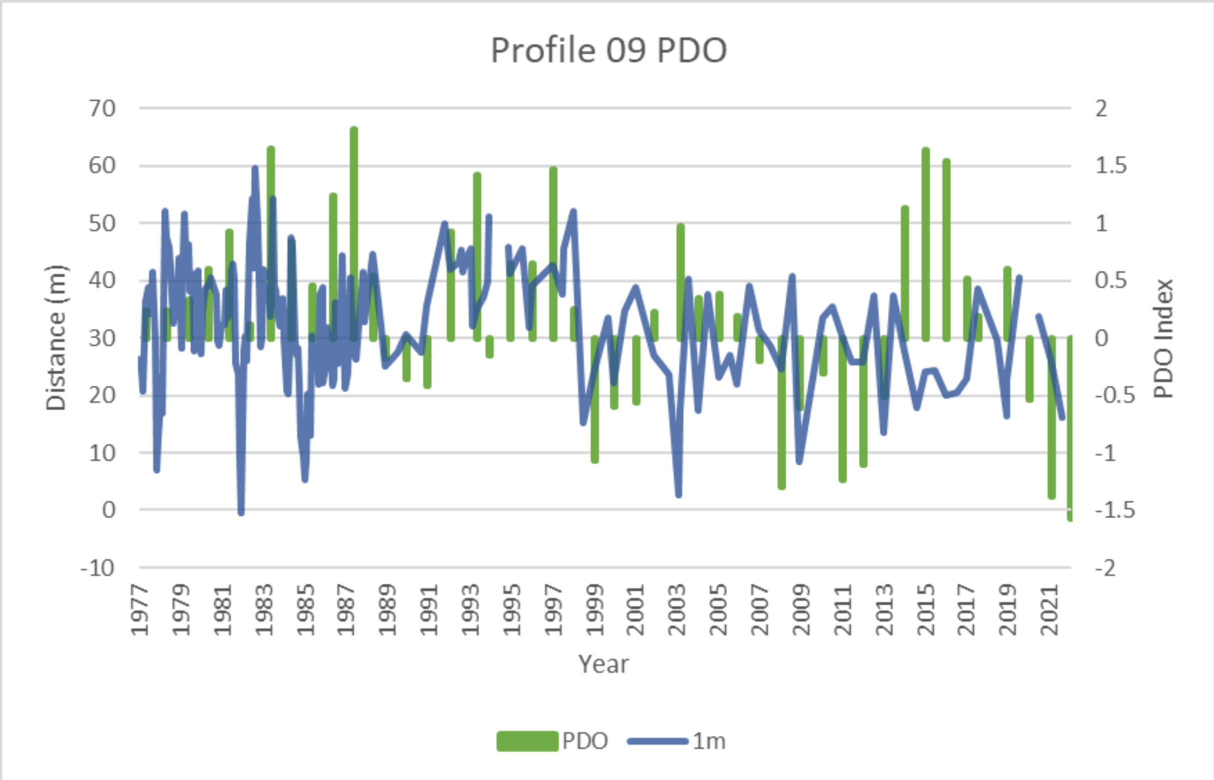

Figure 14.12: Profile 9 PDO chart.

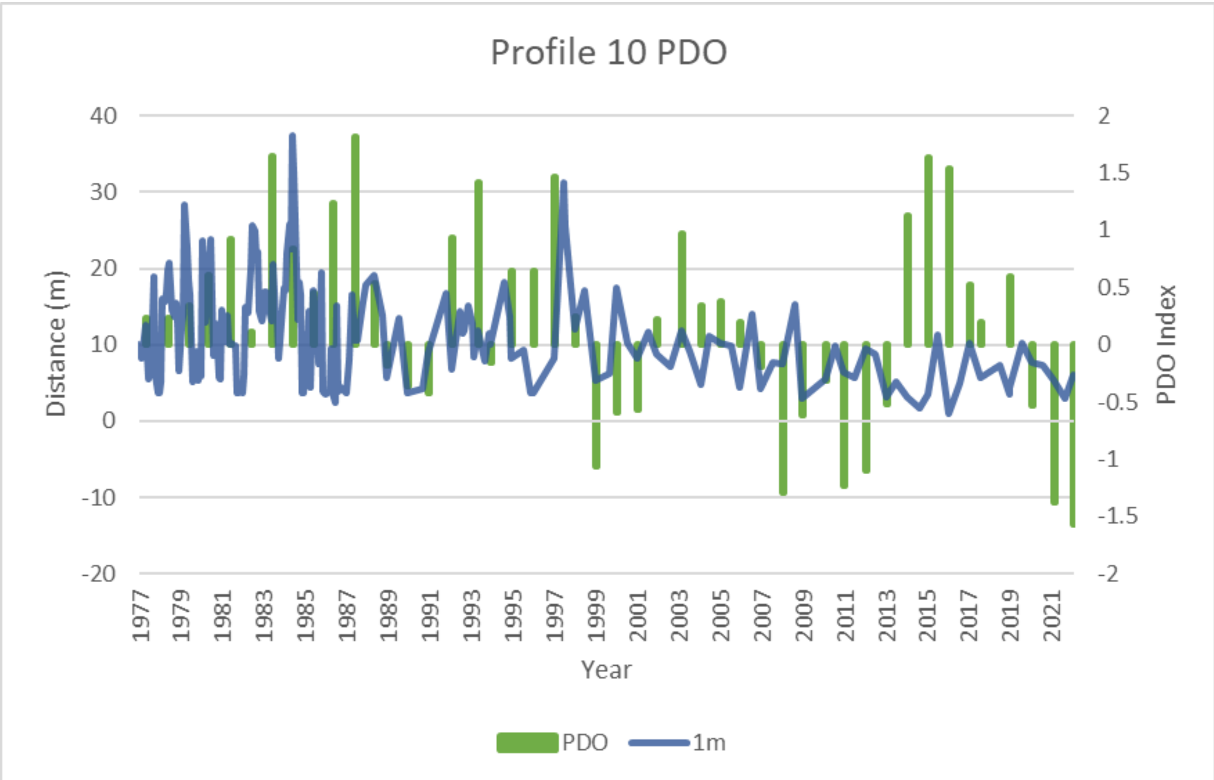

Figure 14.13: Profile 10 PDO chart.

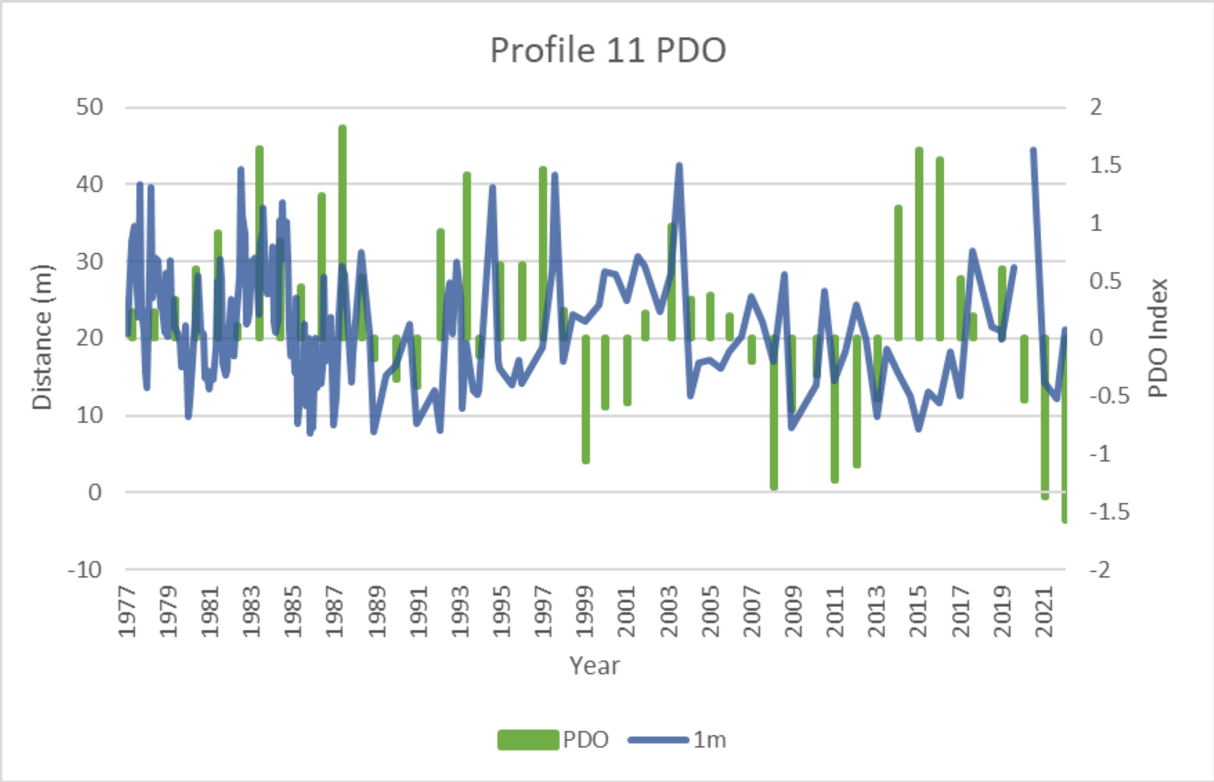

Figure 14.14: Profile 11 PDO chart.

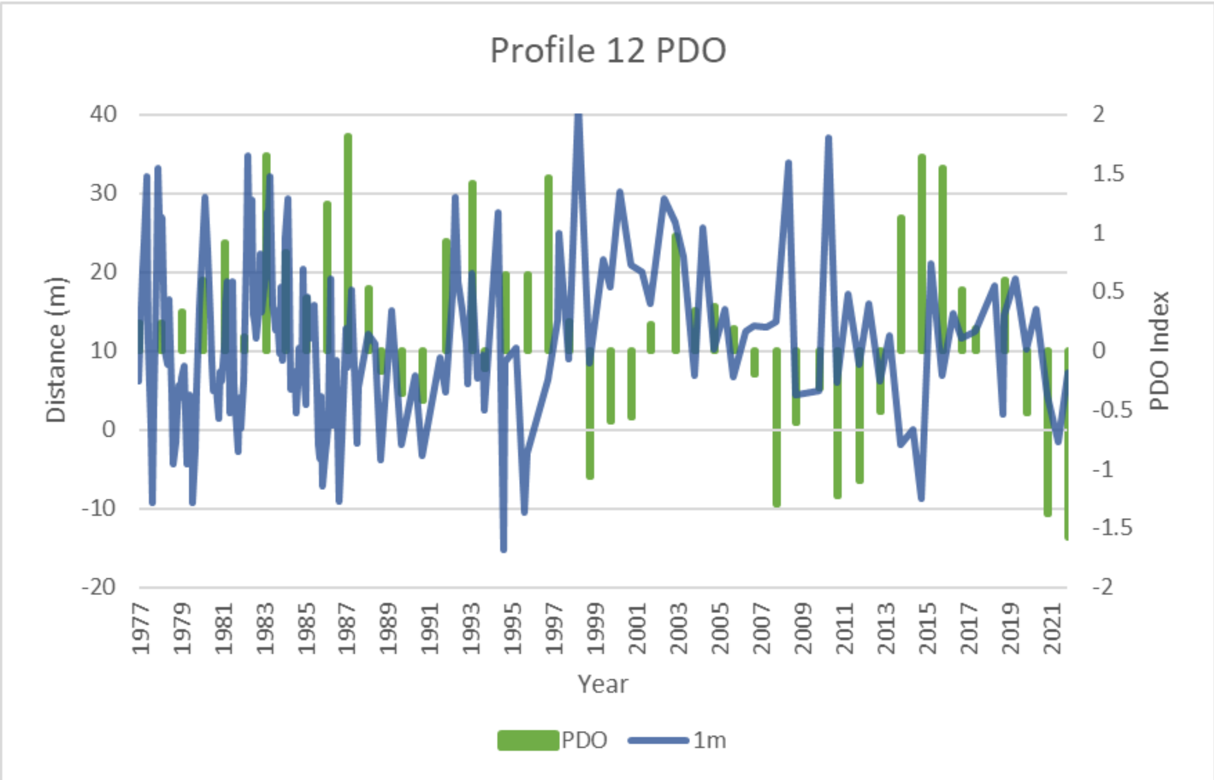

Figure 14.15: Profile 12 PDO chart.

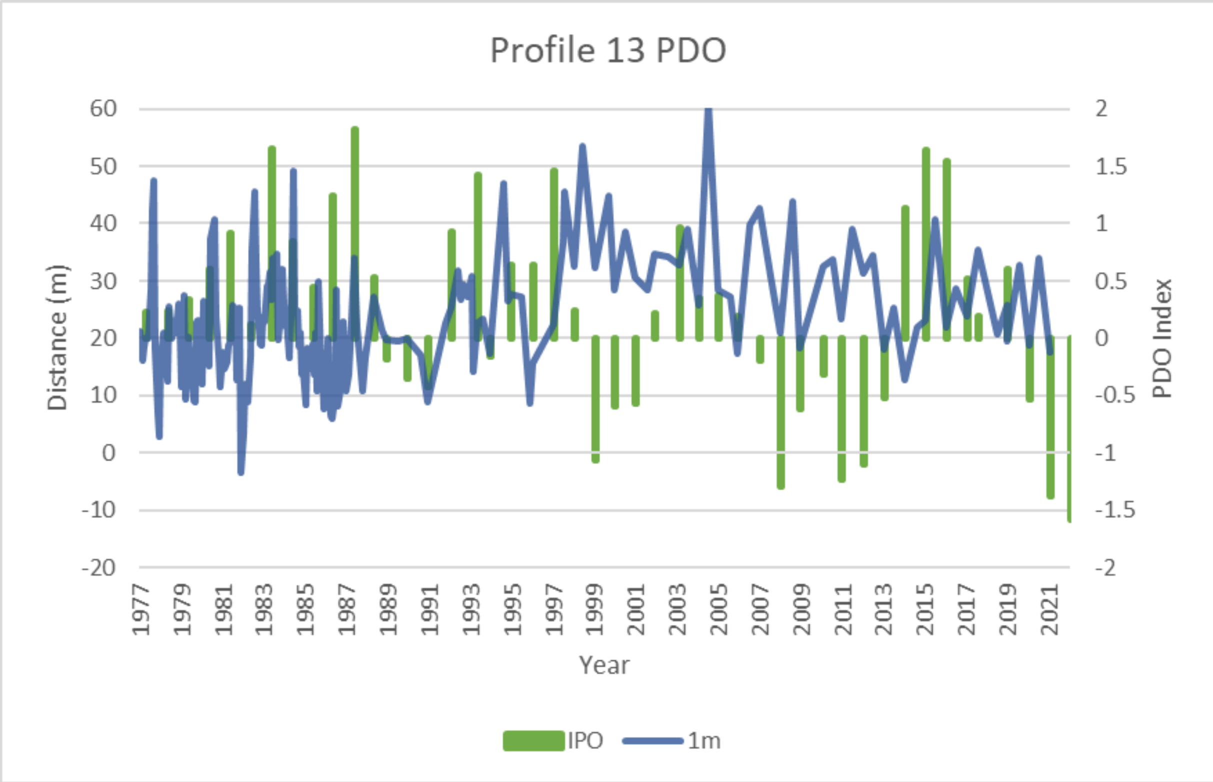

Figure 14.16: Profile 13 PDO chart.

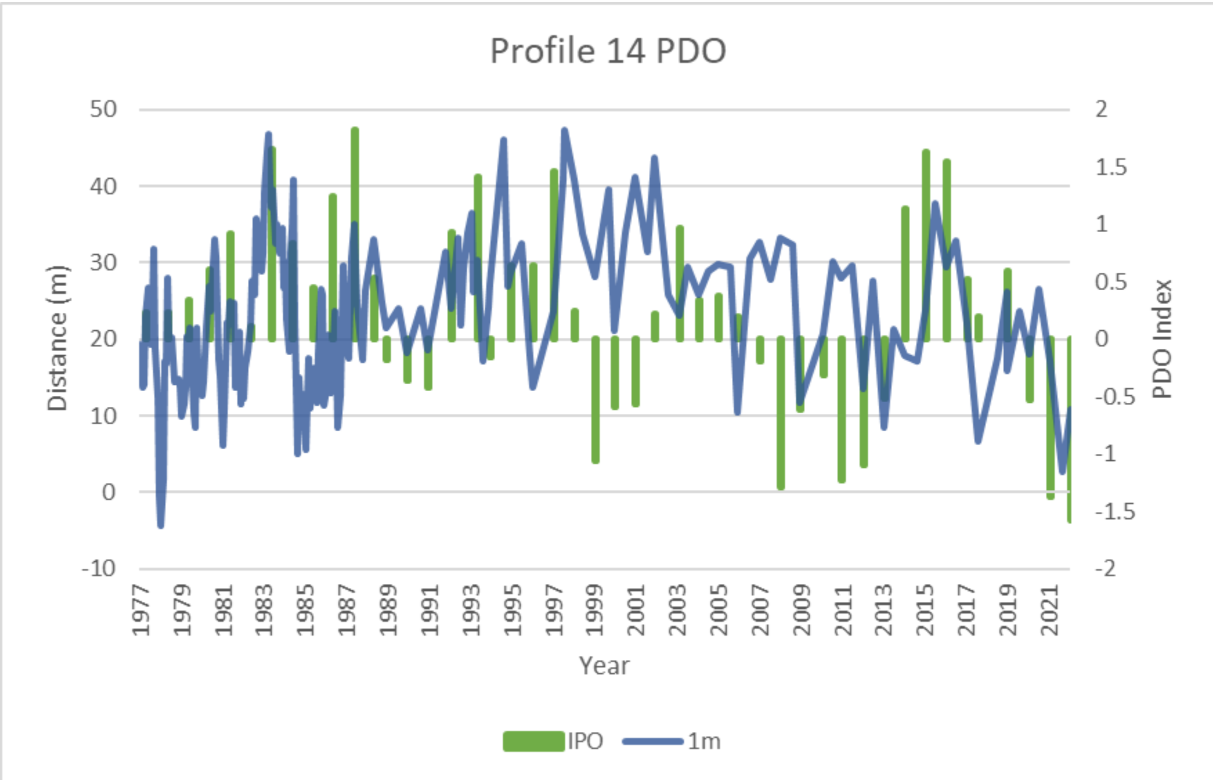

Figure 14.17: Profile 14 PDO chart.

15 APPENDIX F

INUNDATION HAZARD

This appendix includes all of the figures for MHWS and STE100 under current and future climates, as well as the Central Beach section, Hamanatua Stream section and northern Section for ESL100 under current and future climates.

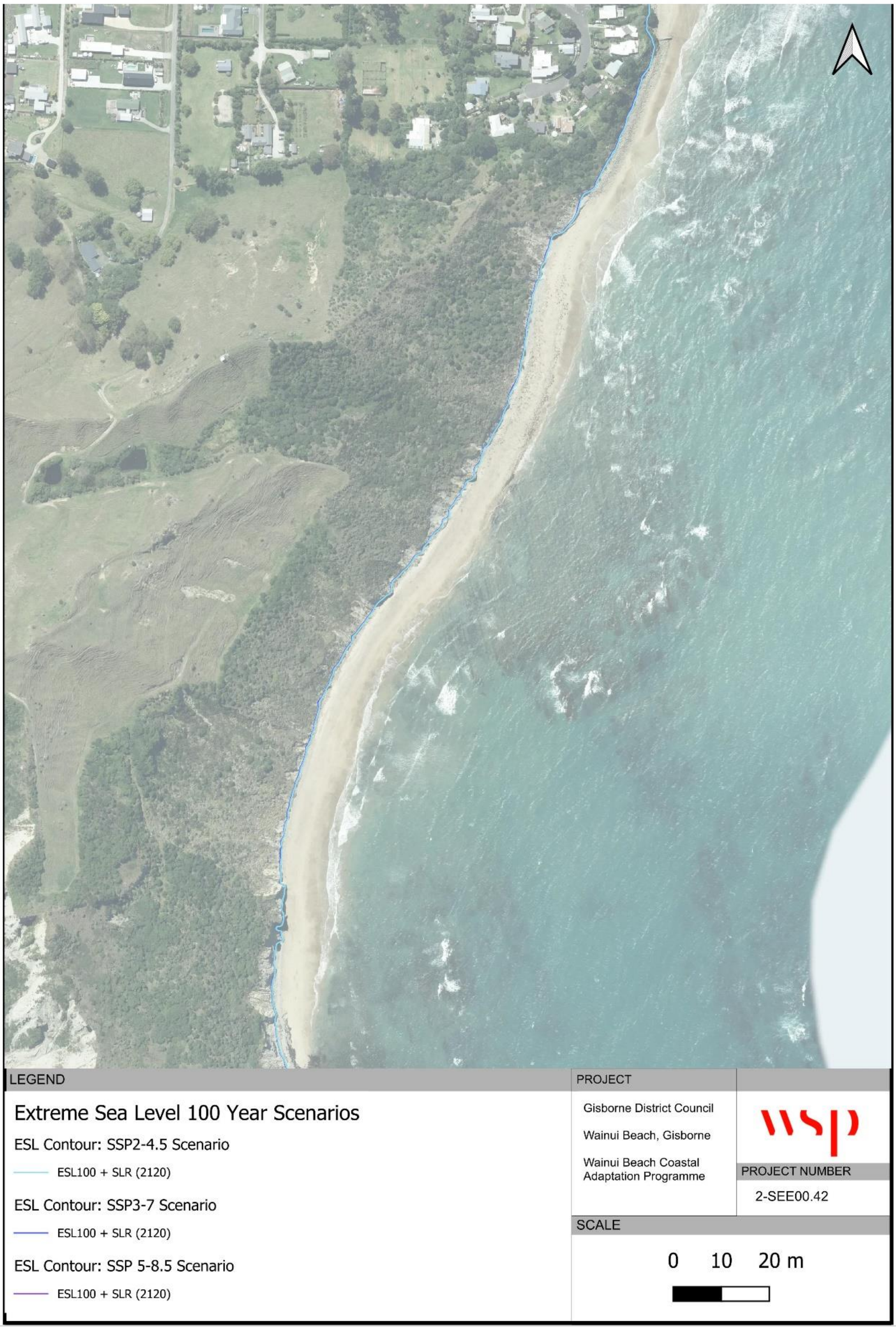

Figure 15.1: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Southern Beach Section A

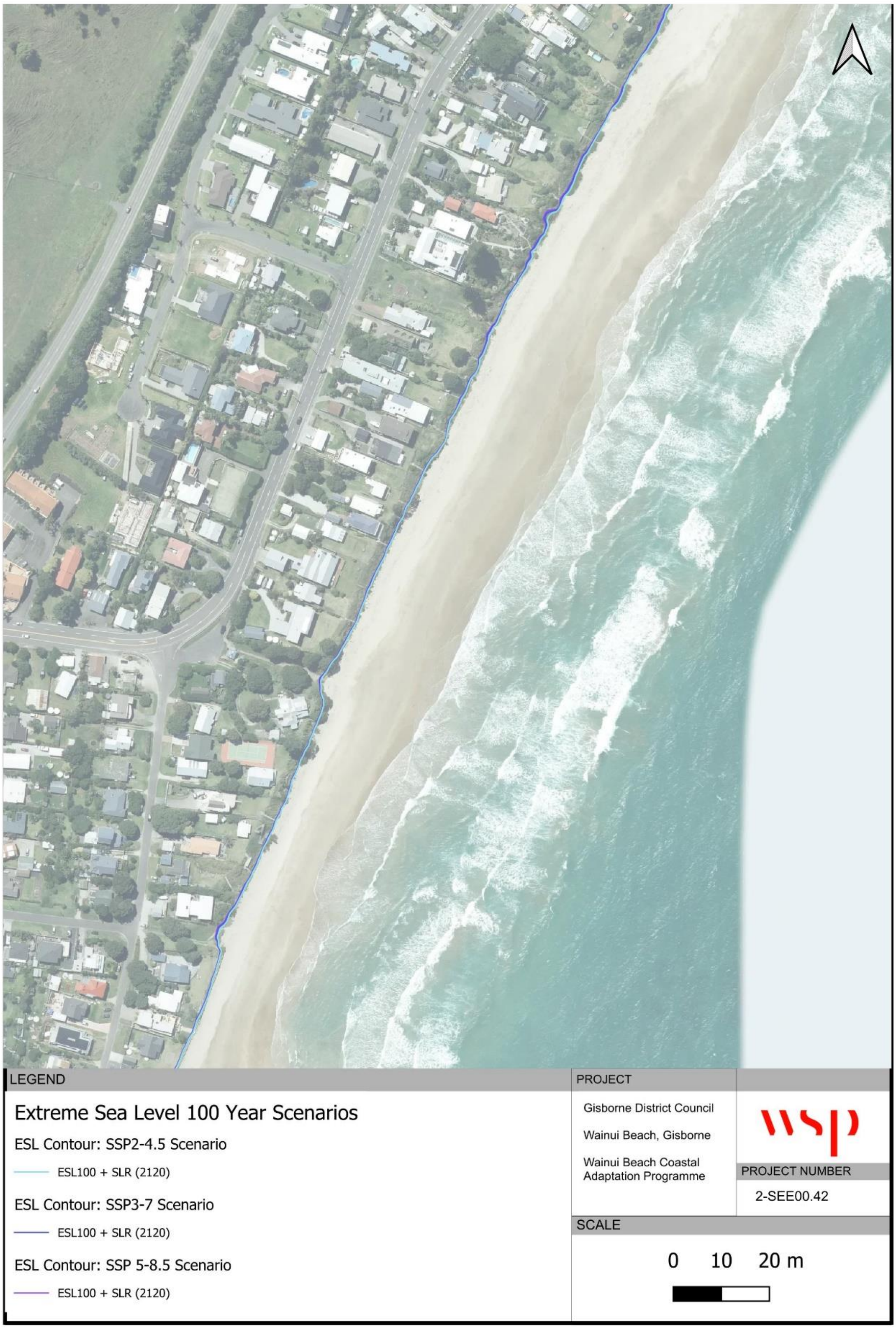

Figure 15.2: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Central Beach A section a.

Figure 15.3: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Central Beach B section b.

Figure 15.4: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Hamanatua Stream section .

Figure 15.5: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Northern Beach A section a.

Figure 15.6: Extreme Sea Level (ESL100) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Northern Beach B section.

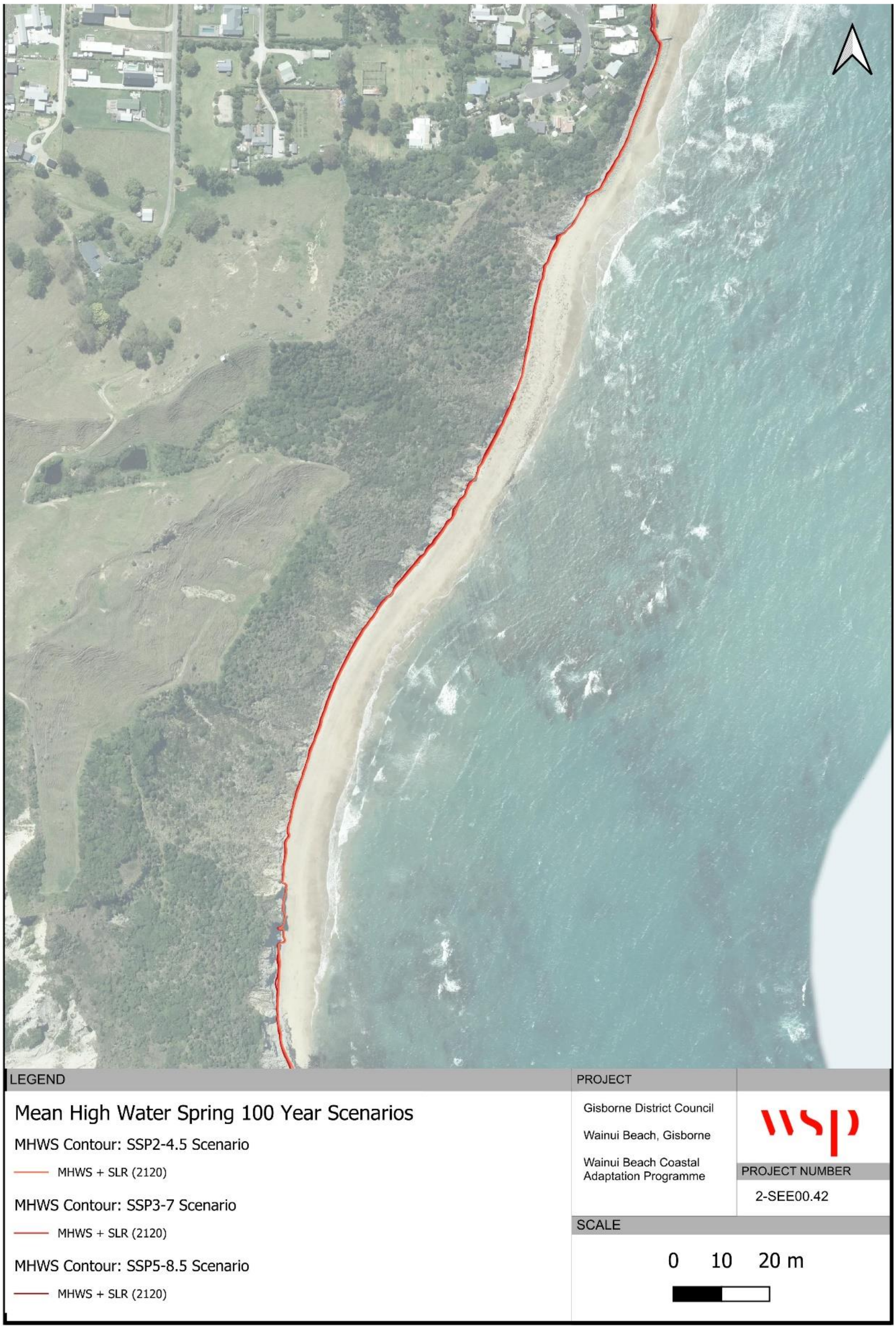

Figure 15.7: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Southern Beach A section.

Figure 15.8: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Southern Beach B section.

Figure 15.9: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Haumatua Stream Section

Figure 15.10: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Central Beach A section.

Figure 15.11: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Central Beach B section.

Figure 15.12: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Haumanatua Stream section

Figure 15.13: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Northern Beach A section.

Figure 15.14: Mean High Water Spring (MHWS) 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Northern Beach B section.

Figure 15.15: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Southern Beach A section.

Figure 15.16: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Southern Beach B section

Figure 15.17: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Wainui Stream section

Figure 15.18: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Central Beach A section.

Figure 15.19: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Central Beach B section

Figure 15.20: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Hamanatua Stream section

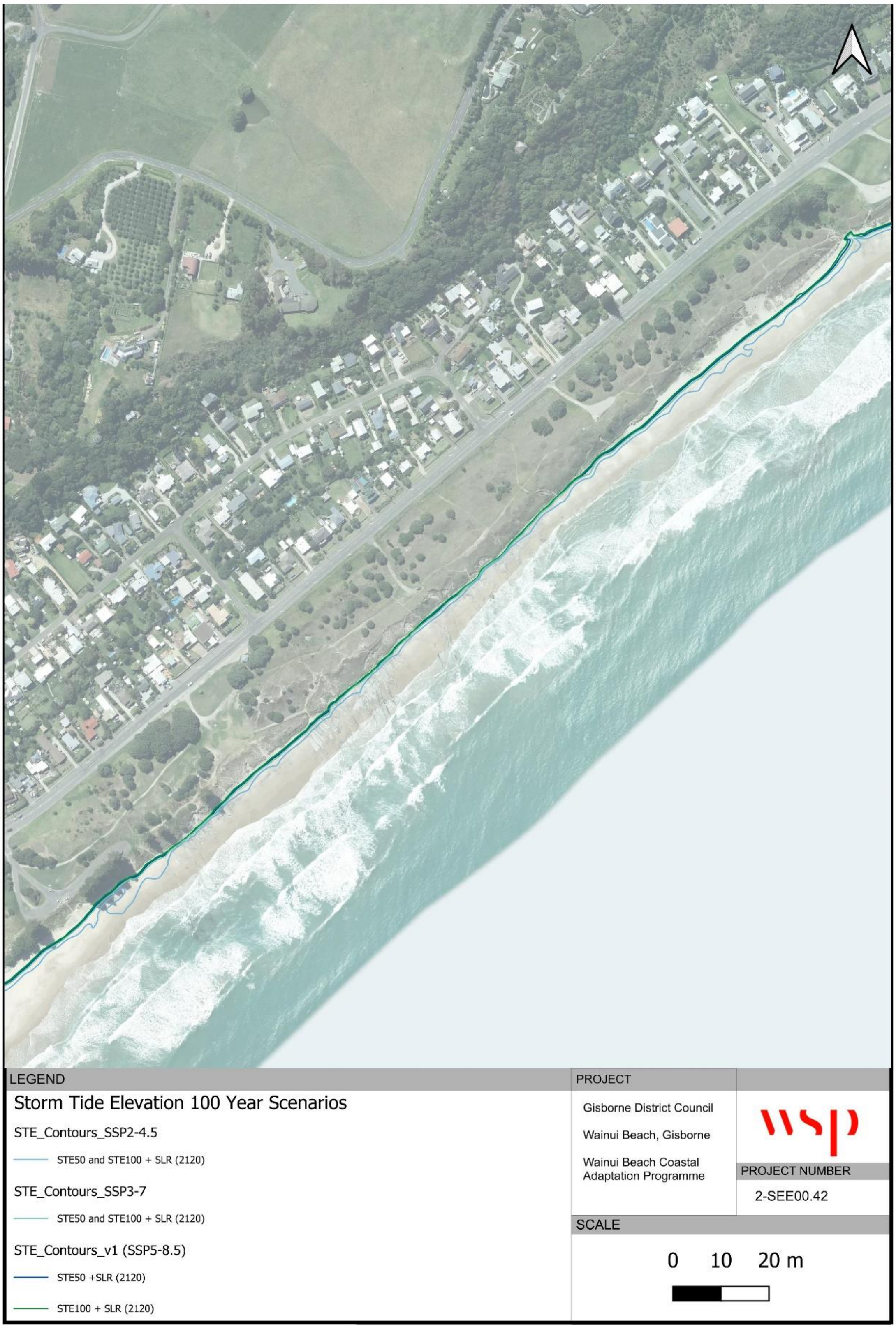

Figure 15.21: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Northern Beach A section

Figure 15.22: Storm Tide Elevation (STE) for the 50-year and 100-year ARI with the 100 year sea level rise inundation scenarios using SSP2-4.5, SSP3-7, and SSP5-8.5 for Northern Beach B section

16 APPENDIX G

POTENTIAL FUTURE EROSION HAZARD

This appendix includes all of the figures for the potential erosion zones for the Northern Beach section.

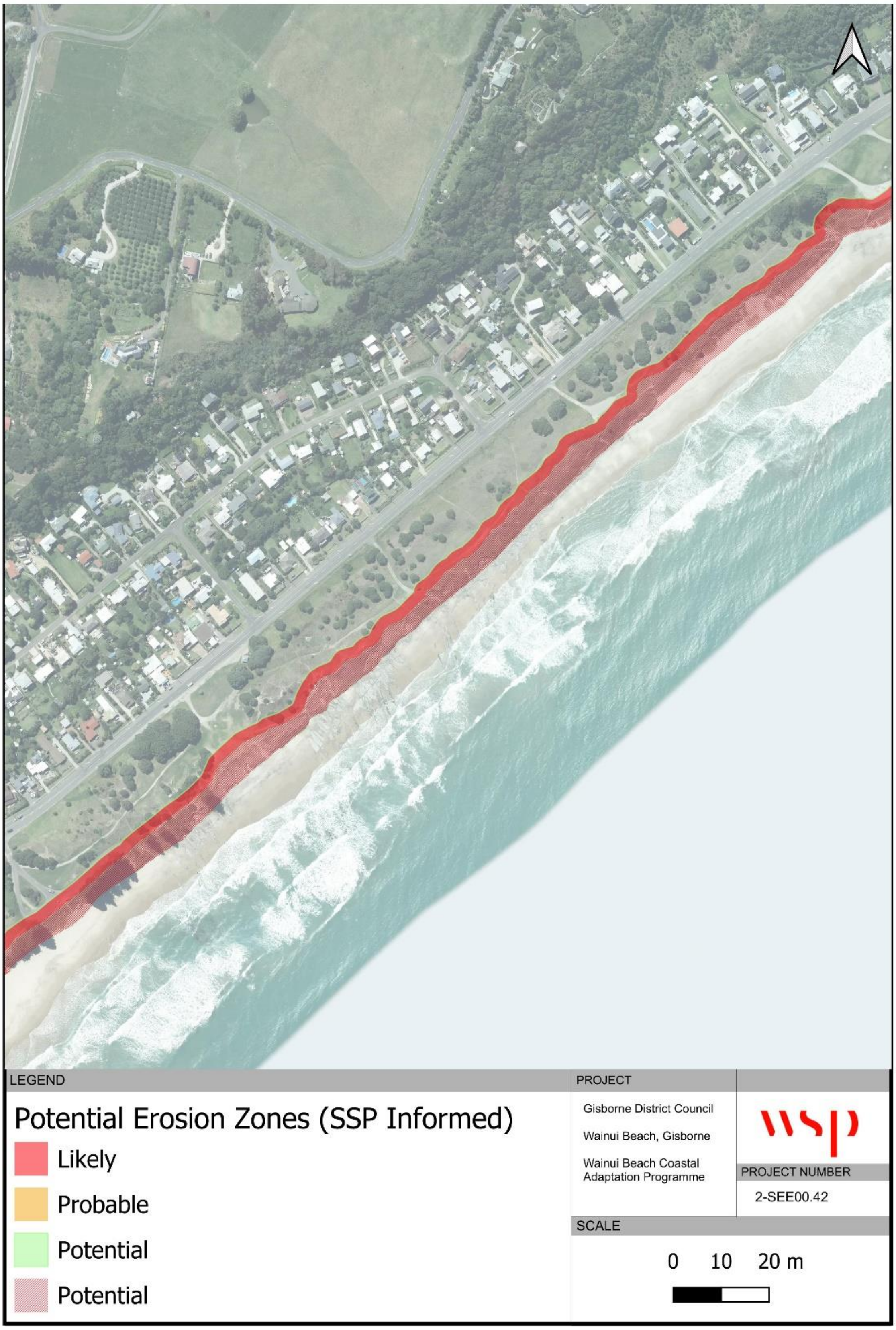

Figure 16.1 Potential erosion hazard zone along the Northern Beach B section of Wainui Beach

Figure 16.2 Potential erosion hazard zone along the Northern Beach A section of Wainui Beach