REPORT

Tonkin+Taylor

Coastal Erosion Hazard Assessment for Selected Sites 2019-2020

Prepared for
Northland Regional Council
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Executive summary

The NRC have previously assessed the coastal erosion hazard zone (CEHZ) for 31 sites within their administrative boundary over a number of different reports completed from 1988 to 2014 (T+T, 2014, 2017). The NRC require a new set of CEHZs to be developed in line with the current state of scientific knowledge, relevant legislation and best practice guidelines. This includes updating the assessments for 31 existing sites using the latest guidance on sea level rise (refer to MfE, 2017) and latest LiDAR data (i.e. from 2019), and 11 additional new sites.

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

The methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters with new techniques for defining and combining parameter ranges to allow for natural variation and uncertainty in individual parameters. The resulting distribution provides a probabilistic forecast of potential hazard zone width, improving on the previous methods that typically included the summation of single values for each component and one overall factor for uncertainty. The assessment method adopted for NRC produces a range of hazard zones corresponding to differing likelihoods. The benefit of this approach is that they can be used in risk-based assessments where the likelihood and the consequence of the hazard are considered as advocated by the NZCPS and supported by best practice guidelines.

The Northland region contains a range of coastal types. The processes controlling change along these different coastal types vary and therefore specific methods to determine CEHZ distances were applied to account for these differing processes. The expressions used to define CEHZ were developed for the two major coastal types:

- Beaches and coastal terraces comprising unconsolidated sediments
- Consolidated cliff coasts

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

- 2020 Coastal Erosion Hazard Zone (Current): 2020 CEHZ
- 2080 Coastal Erosion Hazard Zone (at least 50 years): 2080 CEHZ
- 2130 Coastal Erosion Hazard Zone (at least100 years): 2130 CEHZ.

Each site has been divided into coastal cells based on differences in shoreline physical characteristics and morphological behaviour, which can influence the resultant hazard. The appropriate expression was applied to each coastal cell to calculate the full probability distribution range of CEHZ distances.

Following consultation with Council, three CEHZs were produced for this assessment:

	Timeframe	Probability of exceedance	RCP scenario	Sea level rise[1]
CEHZ1	2080	66% *(likely)*	8.5M	0.33
CEHZ2	2130	5% *(potential)*	8.5M	0.85
CEHZ3	2130	5% *(potential)*	8.5H+	1.17

[1]Based on reference date of zero in 2019

The three scenarios represent different likelihoods, sea level rise magnitudes and time horizons that are suitable for updating planning maps. CEHZ1, with a 66% probability of being exceeded ($P_{66\%}$) at 2080 and CEHZ2 with a 5% probability of being exceeded ($P_{5\%}$) at 2130 have been adopted as prudent *likely* and *potential* CEHZ values. For both the CEHZ1 and the CEHZ2 the RCP8.5M was adopted as requested by NRC. It was further requested to assess a third hazard zone, similar to CEHZ2 (i.e. 5% probability of being exceeded at 2130) but instead using the RCP8.5H+, termed *CEHZ3*. Minimum set-back values have been adopted for each coastal type to account for potential uncertainties and limitations in data and methods. CEHZ lines have been mapped with respect to 2019 baseline.

Where land is protected by consented and competent erosion protection structures, it is acknowledged that these structures may provide a level of protection for a period of time. However, once these structures fail or are removed, the shoreline will likely return to its long-term stable position which may be well landward if the structure was maintaining the shoreline in a seaward position. CEHZs for shorelines protected by consented structures have been termed CEHZ0 and have been mapped to show the potential area affected by erosion immediately after failure of the structure.

There is additional uncertainty around stream mouths or where the backshore morphology and/or topography changes significantly from that assessed at the shoreline. The CEHZ lines around these features have been depicted by dashed lines to indicate where site-specific assessment is recommended.

The accuracy and refinement of these zones requires good baseline information. We recommend continuing to regularly monitor the shoreline position across the region to improve the length and quality of background data. We also recommend the adopted baselines and CEHZ values are reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

This study has assessed coastal erosion hazard at regional scale and may be superseded by local or site-specific assessment if undertaken by qualified and experienced practitioner using improved data from that presented in this report. This could include better site-specific geotechnical information to confirm subsurface soil conditions and better topographic data as well as site specific analysis and modelling of erosion.

1 Introduction

1.1 Background

The NRC have previously assessed the coastal erosion hazard zone (CEHZ) for 31 sites within their administrative boundary over a number of different reports completed from 1988 to 2014 (T+T, 2014, 2017). For this work, Northland Regional Council (NRC) commissioned Tonkin & Taylor Ltd (T+T) to update CEHZ assessments for all existing sites (IDs 1-31) using the latest guidance on sea level rise (refer to MfE, 2017) and available data (i.e. LiDAR data from 2019). In addition, NRC commissioned T+T to undertake CEHZ assessments at 13 new sites (IDs 32-44) that were not included in previous erosion assessments. A list of all sites is provided in Table 1.1 and a map of site locations is presented in Figure 1.1. At the request of NRC, CEHZ assessments were not completed for two sites (McLeods Bay and Taurikura/Urquharts; ID 43-44). A description of these sites and the rationales for not assessing CEHZ has been included in Appendix A.

Prior to 2014, NRC had assessed the CEHZ for 29 sites, excluding Matauri Bay (20) and Te Ti Bay Waitangi (19), over a number of different reports (refer to Section 2.1 for a list of previous reports). The previous reports were completed over a range of dates from 1988 to 2003. NRC require a new set of CEHZ to be developed in line with the current state of scientific knowledge and best practice guidelines.

Table 1.1: Site schedule

Site ID.	Site Name	Site ID.	Site Name
1	Langs Beach	23	Taupo Bay
2	Waipu Cove	24	Hihi
3	Ruakaka	25	Coopers Beach
4	Marsden Point	26	Cable Bay
5	Marsden Cove	27	Taipa
6	One Tree Point	28	Rangiputa
7	Taiharuru	29	Tokerau Beach North
8	Pataua Estuary and Pataua North	30	Ahipara
9	Whangaumu Beach (Wellingtons)	31	Omapere & Opononi
10	Matapouri Estuary and Bay	32	Mangawhai Heads
11	Woolleys Bay	33	Tamaterau
12	Sandy Bay	34	Woolleys Bay extension
13	Whananaki Sandspit	35	Moureeses
14	Teal Bay Beach (Ngawai Bay)	36	Long Beach
15	Helena Bay Beach (Te Mimiha)	37	Paihia
16	Ohawini Bay (& Parutahi Beach)	38	Whatuwhiwhi
17	Oakura Bay	39	Kaimaumau
18	Bland Bay	40	Baylys Beach
19	Te Ti Bay Waitangi	41	Glinks Gully
20	Matauri Bay	42	Whakapirau
21	Te Ngaire Beach	43	McLeods Bay
22	Tauranga Bay	44	Taurikua/Urquharts Bay

Grey highlighted cells indicate the 11 sites that were added since 2017 and for which CEHZ have been assessed

1.2 Study scope

The NRC professional services brief requires the following scope of works to develop CEHZ assessments for the 42 selected Northland sites:

- Provide three coastal hazard zones for each site, based on at least 50 year and 100 year planning horizons provided in ESRI ArcMap format.
- Provide comprehensive reporting to cover the CEHZ methodology, quantification and treatment of uncertainty and description of the coastal processes and coastal erosion hazard for each individual site.
- The CEHZ assessments will be undertaken in accordance with the principles of Policy 24: Identification of coastal hazards, of the New Zealand Coastal Policy Statement 2010 (NZCPS), where applicable to the coastal erosion hazard.
- The CEHZ assessments will be undertaken in accordance with good practice, and in general accordance with the guidance of the 2012 NIWA publication 'Defining coastal hazard zones and setback lines. A guide to good practice'.

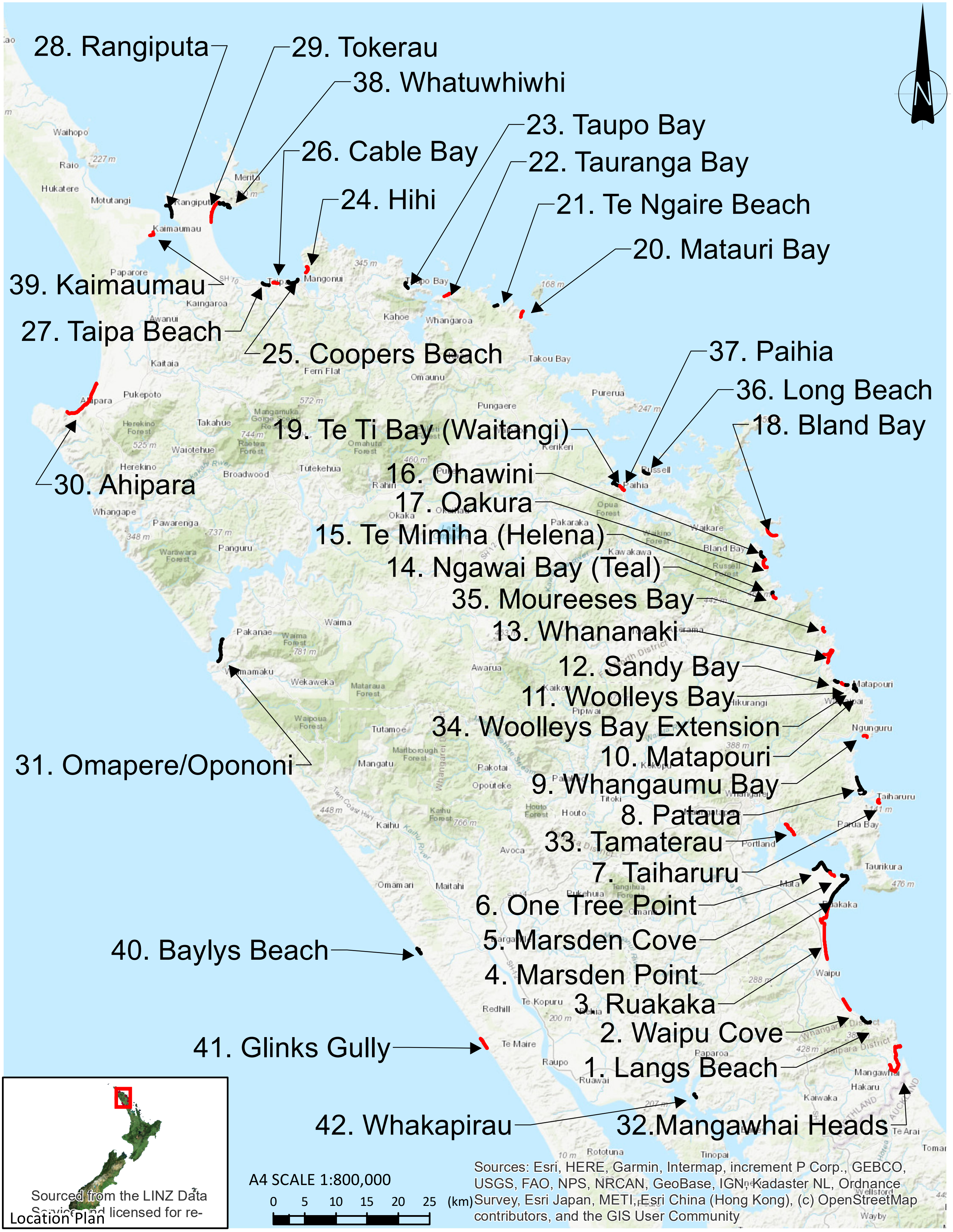
1.3 Report layout

In developing the methodology for this assessment, we have considered the existing information and data provided by NRC for each site and also any new data required to fill the gaps to enable a robust assessment to be made. Section 2 documents both the existing and new data gathered for the project, and outlines the data processing and quality control steps undertaken. A data schedule is included in Appendix C, which forms a summary record of the key data attributes. All digital data has also been provided to NRC.

Section 3 outlines the main coastal processes influencing coastal erosion and provides information on the techniques used to calculate the wave data required for analysis of short-term erosion modelling. The CEHZ methodology adopted for this study is described in Section 4 and Section 5 provides the CEHZ results for each site. Section 6 summaries the report and provides recommendations for future CEHZ reassessments.

1.4 Datums and coordinates

All elevations (levels) within this report are presented in terms of New Zealand Vertical Datum 2016 (NZVD2016 or Reduced Level). Coordinates are presented in terms of New Zealand Transverse Mercator (NZTM).



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NORTHLAND REGIONAL COUNCIL
CEHZ Assessment for Selected Northland Sites
Site Plan

FIGURE No. Figure 1.1

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2 Background data

2.1 Previous assessments and existing data

A number of previous CEHZ assessments have been completed within the Northland region. The following reports were supplied by NRC and have been reviewed and used as background information for this study:

- Gibb, 1988: Northland Regional Council 1988 Coastal Hazard Identification. Whangarei County Technical Publication No 1988/1
- Gibb, 1998a: Review Of Coastal Hazard Zones for Eleven Selected beaches in Whangarei District Northland Region. Technical Report Prepared for Northland Regional Council, CR98/4
- Gibb, 1998b: Coastal Hazard Zone Assessment for The One Tree Point Marsden Bay Area Whangarei Harbour. Technical Report Prepared for Whangarei District Council, CR98/8
- Gibb, 1999: Coastal Hazard Risk Zone Assessment for Pataua and Matapouri Bay Whangarei District. Ethnical Report Prepared for Whangarei District Council, CR97/7
- Geomarine International Limited, 2002: Identification of Coastal Hazard Zones at Nine Selected Northland Beaches. Technical Report Prepared for Northland Regional Council
- NRC, 2003: Identification of Coastal Hazard Zones at Ahipara & Te Ngaire. Addendum A to Geomarine International Limited, 2002
- T+T, 2012: Coastal Erosion Hazard Zone Review. Technical Report Prepared for Whangarei District Council
- T+T, 2014: Coastal Erosion Hazard Zone Assessment for selected Northland sites. Prepared for Northland Regional Council.
- T+T, 2017: Coastal Erosion Hazard Zone Assessment for selected Northland sites (2017 update). Prepared for Northland Regional Council.

NRC provided all available existing data collected from the previous studies including historic shorelines, LiDAR spot heights and beach profile surveys. Other data also supplied by NRC included a range of oblique and aerial photographs and resource consents for coastal activities that may influence coastal erosion (i.e. seawalls, groynes, beach nourishment). This existing data is described in the sections below.

2.1.1 Previously provided shorelines

Shoreline data is required to analyse both long-term and short-term shoreline movement using GIS based methods. The existing shoreline data provided by NRC is based on delineating the dune, cliff or embankment toe feature as the shoreline proxy and is characterised in to the following three data types:

- Surveyed GPS shoreline
- Digitised historic shoreline
- Mapped historic shoreline on Coastal Resource Maps (CRM).

The surveyed GPS shorelines were captured between 1998 and 2008 for all existing sites (i.e. ID 1- 31) except Taharuru, Sandy Bay, Te Ti Bay (Waitangi) and Matauri Bay. The number of shorelines captured over this time period ranges from 1 to 7 surveys per site. A hand-held Trimble differential GPS was used for the survey and the data was post-processed using standard differential correction methods giving a horizontal accuracy of between 0.5 and 1 m. The surveyed GPS shorelines were supplied by NRC as GIS polylines in shape file format.

Digitised historic shorelines have been provided by NRC for most sites covering a time period between 1940 and 2000. The number of shorelines recorded over this time period varies between 1 and 4 per site. The historic shorelines are based on digitising the shoreline proxy (i.e. the dune toe taken as the seaward edge of dune vegetation or cliff/embankment toe) from either geo-referenced historic aerial photographs or geo-referenced Coastal Resource Maps (CRM) to form a GIS polyline. The CRM were produced between 1986 and 1988 by the New Zealand Department of Survey and Land Information (Photogrammetric Branch). A schedule of the available CRMs is shown in Table 2.1. The CRM include mapped shorelines that are based on geo-referenced historic aerial photographs. Therefore, all historic shoreline data provided by NRC has in effect been based on geo-referenced historic aerial photographs.

Table 2.1: Coastal Resource Map schedule

Site No.	Site Name	CRM No.	CRM Date	Shoreline Dates
1	Langs Beach	1658/21	1986	1963, 1985
2	Waipu Cove	2163/19,20	1988	1963, 1985
3	Ruakaka	2163/14,15,16,17	1988	1950, 1961,1978, 1985
4	Marsden Point	2163/14,15,16,17	1988	1950, 1961,1978, 1985
5	Marsden Cove	2163/14	1988	1942
7	Taiharuru	1659/28	1986	1942, 1985
8	Pataua	1659/27	1986	1942, 1961, 1985
9	Whangaumu	1659/26	1986	1942, 1959
10	Matapouri	1659/25	1986	1942, 1959, 1985
11	Woolleys Bay	1658/5	1986	1942, 1985
12	Sandy Bay	1658/5	1986	1942, 1985
13	Whananaki	1659/24	1986	1942, 1959, 1985
14	Teal Bay	1659/23	1986	1950, 1961, 1985
15	Helena Bay	1659/23	1986	1950, 1961, 1985
16	Ohawini	1658/1	1986	1957, 1985
17	Oakura Bay	1658/1	1986	1957, 1985
18	Bland Bay	1659/22	1986	1953, 1955, 1959, 1985
24	Hihi	2506/1	1988	1981
25	Coopers Beach	2506/2	1988	1981
27	Taipa	2506/3	1988	1948, 1961, 1981
28	Rangiputa	2506/8,10	1988	1944, 1977, 1984
29	Tokerau North	2506/4,5,6,7	1988	1944, 1984
30	Ahipara	2506/9	1988	1950, 1981
31	Omapere & Opononi	1668A	1985-1986	1942, 1951, 1984

2.1.2 Previously provided LiDAR

LiDAR ground data was provided by NRC in post processed xyz format for all existing sites, except Sandy Bay and Woolleys Bay. The LiDAR data was captured between January and April 2007 by New Zealand Aerial Mapping (NZAM). LiDAR data is used to derive dune and cliff crest elevation, which is used for calculating the impact of sea level rise on shoreline retreat. NZAM converted the data from NZGD2000 ellipsoidal heights into One Tree Point 1964 vertical datum using the Land Information New Zealand (LINZ) NZGeiod05 separation and offset model. The stated vertical accuracy of the LiDAR data is ±0.1 m.

2.1.3 Previously provided profile data

NRC has collected beach profile data for the majority of sites between 1990 and 2013. Sites within Bream Bay have a larger survey period range dating back to 1976. This information is used to assess short-term shoreline movement. The beach profiles are surveyed from defined benchmarks at the back of the dune and extend seaward to at least the mean sea level elevation. The method of survey between 1990 and 2009 was by total station. The method of survey between 2010 and 2013 was by Real Time Kinematic (RTK) GPS survey. Both methods record sub-centimetre accuracy.

In addition to the beach profiles, NRC has supplied one offshore profile extending at least 1 km offshore for most of the existing sites (excluding Te Ti Bay Waitangi and Matauri Bay). The offshore profiles are used for calculating the closure depth and the impact of sea level rise on shoreline retreat. The survey method for the offshore profiles includes a depth sounder and differential GPS. NRC provided all beach profile data in Excel format. Table 2.2 provides a summary of the NRC beach profile data set made available for this project.

Table 2.2: NRC beach profile schedule

Site			Surveys			
ID	**Name**	**Profile**	**No. of profiles**	**Start date**	**End date**	**Years**
1	Langs Beach	LB1	4	25/07/2007	6/12/2013	6.4
2	Waipu Cove	Waipu South	36	24/08/1976	24/06/1983	6.8
		Lagoon	36	14/07/1976	24/06/1983	6.9
		Cove	57	13/07/1976	7/12/2013	37.4
3	Ruakaka	IT8E	55	14/07/1976	6/12/2013	37.4
		RM 11	42	17/07/1977	6/12/2013	36.4
		RM 13	46	13/07/1979	6/12/2013	34.4
		RM 15	44	31/07/1976	6/12/2013	37.4
		RM 17	66	23/08/1976	6/12/2013	37.3
5	Marsden Cove	MB1	8	18/11/2000	17/08/2005	4.7
		MB2	9	18/11/2000	6/06/2006	5.6
		MB3	9	18/11/2000	6/09/2006	5.8
6	One Tree Point	OTPW1	6	23/11/1998	12/08/2002	3.7
		OTPW2	4	23/11/1998	14/09/2000	1.8
		OTPW3	7	23/11/1998	12/08/2002	3.7
		OTPW4	4	23/11/1998	14/09/2000	1.8
		OTPW5	7	23/11/1998	12/08/2002	3.7
		OTPW6	6	23/07/1999	12/08/2002	3.1
8	Pataua	PT1	4	1/02/1998	5/12/2013	15.9
		PT2	4	1/02/1998	5/12/2013	15.9
9	Whangaumu	WANGAUMU1	9	10/03/1998	4/12/2013	15.7
10	Matapouri	M1	21	2/02/2001	4/12/2013	12.8
		M2a	25	2/02/1998	4/12/2013	15.8
		M3	21	2/02/2001	4/12/2013	12.8
		M4	21	2/02/2001	4/12/2013	12.8
13	Whananaki	WHAN1	6	16/08/2004	4/12/2013	9.3
		WHAN2	4	3/02/1998	4/12/2013	15.8
14	Teal Bay	NGAWAI1	6	10/05/1999	2/12/2013	14.6

Site			Surveys			
ID	Name	Profile	No. of profiles	Start date	End date	Years
15	Helena Bay	TM1	5	10/05/1999	16/03/2007	7.9
16	Ohawini	OHW1	4	3/02/1998	22/03/2005	7.1
		OHW2	3	22/03/2005	3/12/2013	8.7
17	Oakura Bay	OK1	5	3/02/1998	3/12/2013	15.8
18	Bland Bay	BB1	2	15/03/2007	3/12/2013	6.7
19	Te Ti Waitangi	TTB1	2	15/03/2007	2/12/2013	6.7
21	Te Ngaire Beach	TNG1	11	10/07/2002	2/12/2013	11.4
22	Tauranga Bay	TAURA1	12	4/07/2002	2/12/2013	11.4
23	Taupo Bay	TPO1	12	12/05/1999	14/11/2013	14.5
24	Hihi	HIHI1	9	13/05/1999	14/11/2013	14.5
25	Coopers Beach	COOP1	7	9/09/2003	14/11/2013	10.2
26	Cable Bay	CAB1	2	13/05/1999	4/11/2013	14.5
27	Taipa	TAI1	14	22/02/1990	14/11/2013	23.7
28	Rangiputa	Rangiputa A	7	25/05/1999	14/11/2013	14.5
		Rangiputa B	7	25/05/1999	14/11/2013	14.5
		Reef Lodge	7	25/05/1999	14/11/2013	14.5
29	Tokerau North	TOK1	6	10/02/1990	14/11/2013	23.8
30	Ahipara	AH1	3	23/02/1990	3/01/2002	11.9
31	Omapere & Opononi	OM1	10	26/01/2001	15/11/2013	12.8
		OM2	7	26/01/2001	30/09/2008	7.7
		OM3	8	26/01/2001	15/11/2013	12.8
		OM4	8	26/01/2001	15/11/2013	12.8
		OM5	6	26/01/2001	15/11/2013	12.8
		OM6	9	26/01/2001	15/11/2013	12.8
36	Long Beach	LB1	1	15/03/2007	15/03/2007	-
41	Glinks Gully	GL1	1	29/09/1994	01/08/2008	14

2.2 New data obtained

2.2.1 New site inspections

Site inspections were undertaken for existing sites between 13 November 2013 and 13 January 2014 by Mark Ivamy (Senior Coastal Scientist, T+T) and Barney Brotherhood (River Management Engineer, NRC). Site inspections for the additional 11 sites were undertaken between 3 and 7 February 2020 by Dr Eddie Beetham (Coastal Scientist, T+T), Matt de Boer (Natural Hazards Advisor, NRC) and Dr Terry Hume (External Peer Reviewer/Coastal Scientist, Hume Consulting Ltd).

The following data was collected for existing sites during the site inspections for the existing sites:

- GPS survey of current dune toe
- GPS survey of current dune crest (Woolleys Bay and Sandy Bay only)
- Beach profile survey (at existing benchmark locations)
- Sediment sample collected from the mid-beach slope (3 per site).

The current dune toe position is required to assess the latest shoreline movement trends and to provide a baseline for the coastal erosion hazard zone offset distances. The dune crest is required for calculating the impact of sea level rise on shoreline retreat. Both the dune toe and crest position were captured using a handheld differential GPS (Trimble GeoExplorer XH 6000 series). The GPS data was post processed using standard differential correction methods providing an accuracy of 0.1 to 0.5 m (vertical and horizontal).

All dune crest surveys and the majority of dune toe surveys were undertaken on foot. The dune toe survey was undertaken by vehicle for sections of Ahipara, Tokerau and sites within Bream Bay. The vehicle was driven at a set offset distance from the dune toe using the line of sight marker method, and the offset distance was checked at regular intervals of no more than 200 m.

The beach profile survey was completed at all existing NRC beach profile locations over the period of the site inspections and the data will be used to assess short-term shoreline movement. The survey was undertaken using RTK GPS in accordance with the standard NRC beach profile survey method adopted between 2010 and 2013. Sediment samples were collected for both existing sites and new sites.

Individual site characteristics are described within the site assessment (Appendix A).

2.2.2 New shoreline data

To assess long-term shoreline movement a maximum period of 20 years between survey dates is preferred. Based on cross checking the existing shoreline data provided by NRC against the New Zealand Aerial Mapping (NZAM) aerial image archives, we identified an additional 13 aerial photographs required across the 31 existing sites (refer to Table 2.3).

Table 2.3: Aerial photographs available from NZAM to complete the shoreline data set for 31 existing sites

Site	Date Flown	Run Number	Scale
Taupo Bay	28/10/1981	SN 5932	1:25000
Hihi	09/04/1948	SN 350	1:21000
Whangaumu Beach	13/12/1985	SN 8580	1:24000
Sandy Bay	05/02/1966	SN 1410	1:25000
Te Ti Bay	29/03/1951	SN 209	1:16000
Te Ti Bay	22/08/1971	SN 3406	1:16000
Te Ti Bay	04/01/1980	SN 5651	1:10000
Matauri Bay	12/10/1950	SN 350	1:21000
Matauri Bay	04/01/1980	SN 5651	1:10000
Taiharuru	10/01/1979	SN 5091	1:25000
Marsden Bay	13/12/1985	SN 8580	1:24000
One Tree Point	13/12/1985	SN 8580	1:24000
One Tree Point	05/06/1942	SN 411	1:16000

The aerial photographs listed in Table 2.3 were geo-referenced against the latest 2007 image and the dune toe was digitised to produce a GIS polyline.

NRC provided a full set of the geo-referenced CRM. The majority of the shorelines mapped on the CRM have been digitised in to GIS polylines (refer to Section 2.1.1). There were 13 shorelines mapped on the CRM that had not been digitised as GIS polylines by NRC (refer to Table 2.4). T+T digitised the shorelines listed in Table 2.4 to complete the historic shoreline dataset for the 31 existing sites.

Table 2.4: Shorelines shown on Coastal Resource Map that were not digitised by NRC

Site	Shoreline date
Taipa	1948, 1977, 1984
Teal Bay	1985
Oakura	1955, 1985
Whangaumu Beach	1942
Whananakai	1963
Matapouri	1966, 1979
Rangiputa	1944, 1984
Pataua	1979

Historic aerial photographs for the 11 new sites from before 2000 were sourced from Retrolens and photographs from after 2000 were sourced from LINZ. A minimum of three historic aerial photographs used for each site to digitise the historic shoreline position. The dates of the historic aerial photographs for the 11 new sites are shown in Table 2.5.

Table 2.5: Historic aerial photographs for 11 new sites used for analysis

Site	Aerial photograph date
Mangawhai Heads	1963, 1983, 2003
Tamaterau	1942, 1979, 2004
Woolleys Bay extension	1942, 1985, 2004
Moureeses Bay	1942, 1961, 1985, 2004
Long Beach	1951, 1971, 1981, 2000
Paihia	1951, 1977, 1981, 2000
Whatuwhiwhi	1944, 1984, 2000
Kaimaumau	1944, 1981, 2000
Baylys Beach	1952, 1979, 1991, 2014
Glinks Gully	1957, 1983, 1991, 2003
Whakapirau	1957, 1982, 2003

The aerial photographs sourced from Retrolens were geo-referenced against the latest 2014 image and the dune toe was digitised to produce a GIS polyline. The aerial photographs sourced from LINZ were already geo-referenced but were compared with the 2014 aerial photograph to verify the geo-referencing.

2.2.3 New LiDAR data

The 2019 LiDAR data for the entire Northland region was flown between January and November 2019. The data was provided by NRC in the form of a 1x1 m digital elevation model (DEM) in NZVD2016. The vertical accuracy of the DEM is 0.15 m and horizontal accuracy is 1 m.

2.2.4 New profile data

Offshore profile data was not available for Te Ti Bay and Matauri Bay, and the 11 new sites. Land Information New Zealand (LINZ) Nautical Charts were used to obtain the required offshore profile data for these sites (i.e. Charts NZ 51, NZ 5124, NZ5125 NZ 512, NZ52, NZ42 and NZ4265).

Beach profiles were surveyed during the site inspection of the 31 existing sites by NRC at existing beach profile benchmarks. For the purposes of the 2014 study, five additional new beach profile benchmarks were established at the following sites (benchmark coordinates provided in New Zealand Transverse Mercator projection):

- Matauri Bay (N6123100, E1683211)
- Sandys Bay (N6063218, E1736032)
- Wolleys Bay (N6063218, E1736032)
- Taiharuru Bay (N6045375, E1740276)
- Pautaua Estuary (N6047320, E1737470).

These additional profiles were surveyed to record the beach slope and backshore profile for existing sites that were not covered under the existing NRC beach profile network in 2014.

2.2.5 Sediment data

The sediment characteristics are required for modelling the shoreline response to storm events. At least 3 sediment samples were taken from the mid-beach slope along each site. The sediments were sampled from the top 300 mm of the beach face using a trowel and separately bagged for analysis. The sediment samples were analysed for grain size at the University of Waikato using the Rapid Sediment Analysis (RSA) method. Sediment size information is provided in Table 3.1 and has been used for numerical storm response modelling.

2.2.6 Wave climate data

Wave climate data was not available for the sites but is required to assist in understanding the coastal processes and quantifying potential short-term shoreline movement (storm cut).

MetOcean Solutions Ltd was commissioned to provide wave data at six offshore locations (Figure 2.1) to provide representative offshore conditions for all sites. Data was obtained from a 41-year numerical wave hindcast (1979-2020) run at 3 hourly intervals. The hindcast model for the Northland region has a spatial resolution of 0.05° by 0.05° (~5 km) is nested within a global wave model driven by CFSR wind forcing. Outputs include significant wave height (H_s), peak wave period (T_p) and mean direction at the peak frequency (D_{pm}).

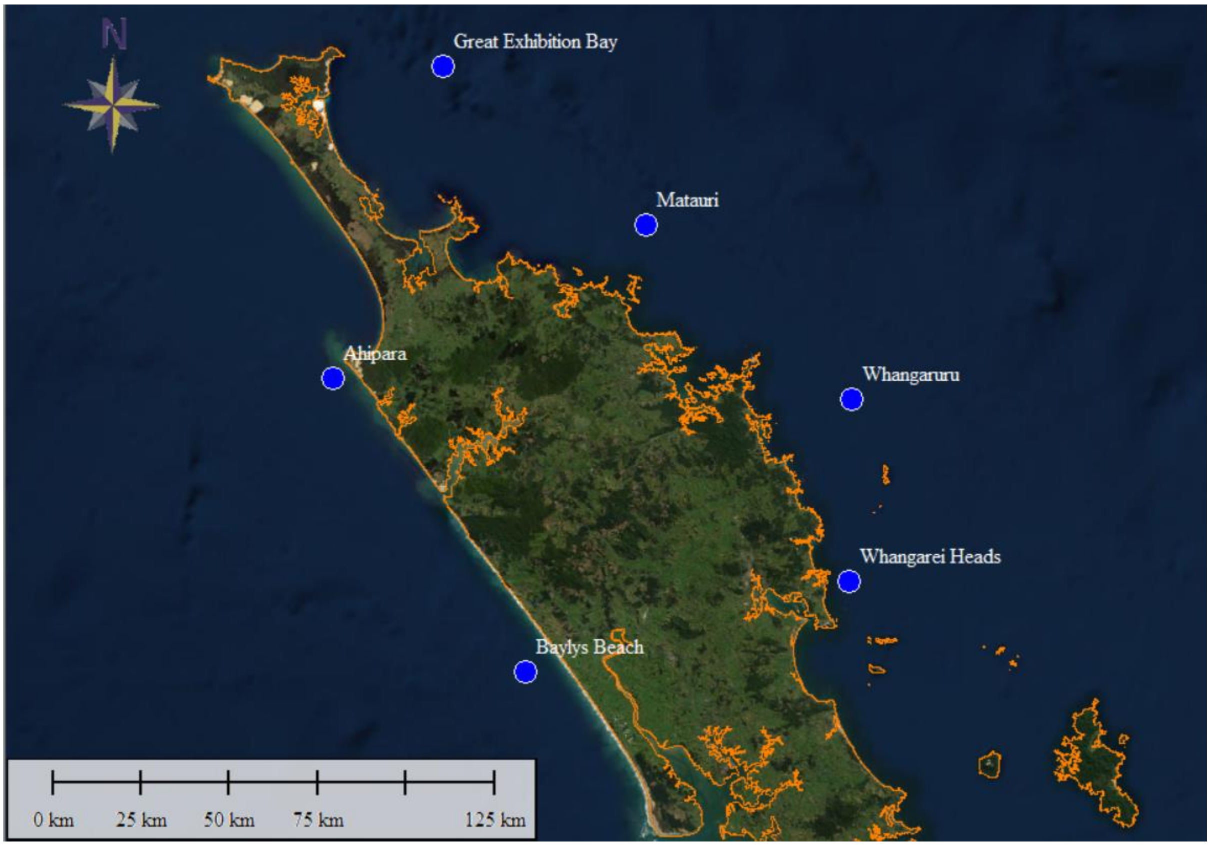


Figure 2.1: Locations of wave hindcast outputs supplied by MetOcean Solutions Ltd (aerial sourced from Esri)

2.3 Verification and quality control

2.3.1 Shoreline data

The historic shoreline data provided by NRC was verified against the source information where available (i.e. CRM and historic aerial photographs).

The GPS shoreline data provided by NRC was checked for anomalies and general alignment agreement. The NRC GPS data was processed by NRC using Trimble Pathfinder Office software including standard differential correction methods to achieve an accuracy of 0.5 to 1.0 m (horizontal) for areas with a clear view of the sky and 1.0 to 3.0 m (horizontal) for other areas with tree cover or at the cliff toe.

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

The GPS shoreline data collected by T+T in 2013 using differential GPS was processed using Trimble Pathfinder Office software including standard differential correction methods to achieve an accuracy of 0.1 to 0.5 m (vertical and horizontal) for areas with a clear view of the sky and 1.0 to 3.0 m (vertical and horizontal) for other areas with tree cover or at the cliff toe.

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

$$E_{sum} = \sqrt{E_1^2 + E_2^2 + \cdots + E_n^2}. \qquad (2.1)$$

Table 2.6 summaries the potential error for the range in shoreline data types collated for this project. Four potential measurement errors have been estimated for the different shoreline data types. The geo-referencing error (Er) represents the potential offset of an image from a known point based on ground control points collected during the geo-referencing process. This potential error does not apply to GPS data and increases with the age of the photograph due to scale and lower number of suitable ground control points.

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

Table 2.6: Shoreline data error summary

	Data Type						
Potential Measurement Error (metres)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Geo-referencing error (Er)	n/a	n/a	n/a	n/a	1	2	3
Digitising error (Ed)	n/a	n/a	n/a	n/a	1	1	1
GPS accuracy error (Eg)	0.5	3	1	3	n/a	n/a	n/a
Shoreline proxy error (Es)	0.5	0.5	1	1	2	3	3
Total potential error (Et) (metres)	0.71	3.04	1.41	3.16	2.45	3.74	4.36
Rounded	***1m***	***3m***	***1m***	***3m***	***2m***	***4m***	***4m***

Notes: Data type codes: A T+T GPS; B T+T GPS (cliff); C NRC GPS; D NRC GPS (cliff); E Aerial post 1990; F Aerial 1960 – 1990; G Aerial 1940 – 1960.

The GPS accuracy error (Eg) represents the potential error within the Trimble GPS unit, which is mainly based on the number of satellites the unit can access. The GPS data is less accurate for shorelines adjacent to cliffs and overhanging trees which restrict the GPS receivers satellite coverage. Therefore, the potential measurement error for GPS data is different for sites that contain cliff shorelines. For the purpose of estimating the potential measurement error, Taiharuru, Hihi, Coopers and Langs are considered to have cliff shorelines. The Trimble GPS unit used for the T+T site inspections of the 31 existing sites (XH GeoExplorer 6000) operates advanced technology compared to the GPS unit used by NRC, and has access to the GLONASS/GPS satellite system. Therefore, where no satellite restrictions occur, the T+T GPS data is more accurate than the NRC GPS data.

Shoreline proxy error (Es) is the estimated uncertainty in identifying the shoreline, which is more for black and white images. Example of features that cause shoreline proxy error include scale, shadow, overhanging trees and the uncertainty in identifying the correct dune vegetation edge based on black and white contrast.

2.3.2 Data quality control

A data quality control metadata sheet was maintained for all digital data at each site. The sheet documents the following metadata attributes over the life of the project:

- Site number
- Data type
- Data name
- Data source
- Processing steps
- Verification
- Versioning.

This metadata will be stored as part of each individual GIS file and a summary is provided in Appendix C for reference. The data quality control metadata spreadsheet is also provided electronically to Council in MS Excel format.

3 Coastal processes

3.1 Geology and geomorphology

The east coast of Northland is predominantly indented and rocky with Greywacke forming the main basement geology along the east coast (Waipapa Group). Refer to Figure 3.1 for a regional map of Northland's geology. The light blue colour represents the Waipapa Group Greywacke located along the east coast. The Waipapa Group Greywacke comprises sandstone, siltstone and argillite, with tectonically enclosed basalt. The majority of the rocky promontories within this area are relatively hard and unweathered Greywacke. However, the rocky cliff faces located within embayments are generally well weathered Greywacke with some forming soft clay. Ahipara and parts of southern Doubtless Bay have Basalt rock outcrops and nearshore reefs located along the shoreline. The Basalt rock is part of the Tangihua Complex and comprises mainly basalt pillow lava (shown as bright green).

Localised outcrops of relatively weak sedimentary rock also exist at some sites. Opononi is located within the Hokianga Harbour and the site has a muddy limestone cliff shoreline, similar to Baylys Beach (Mahurangi Limestone). Hihi and Coopers Beach also have sedimentary rock cliff shorelines comprising sandstone, mudstone and lignite conglomerate (Mangonui Formation).

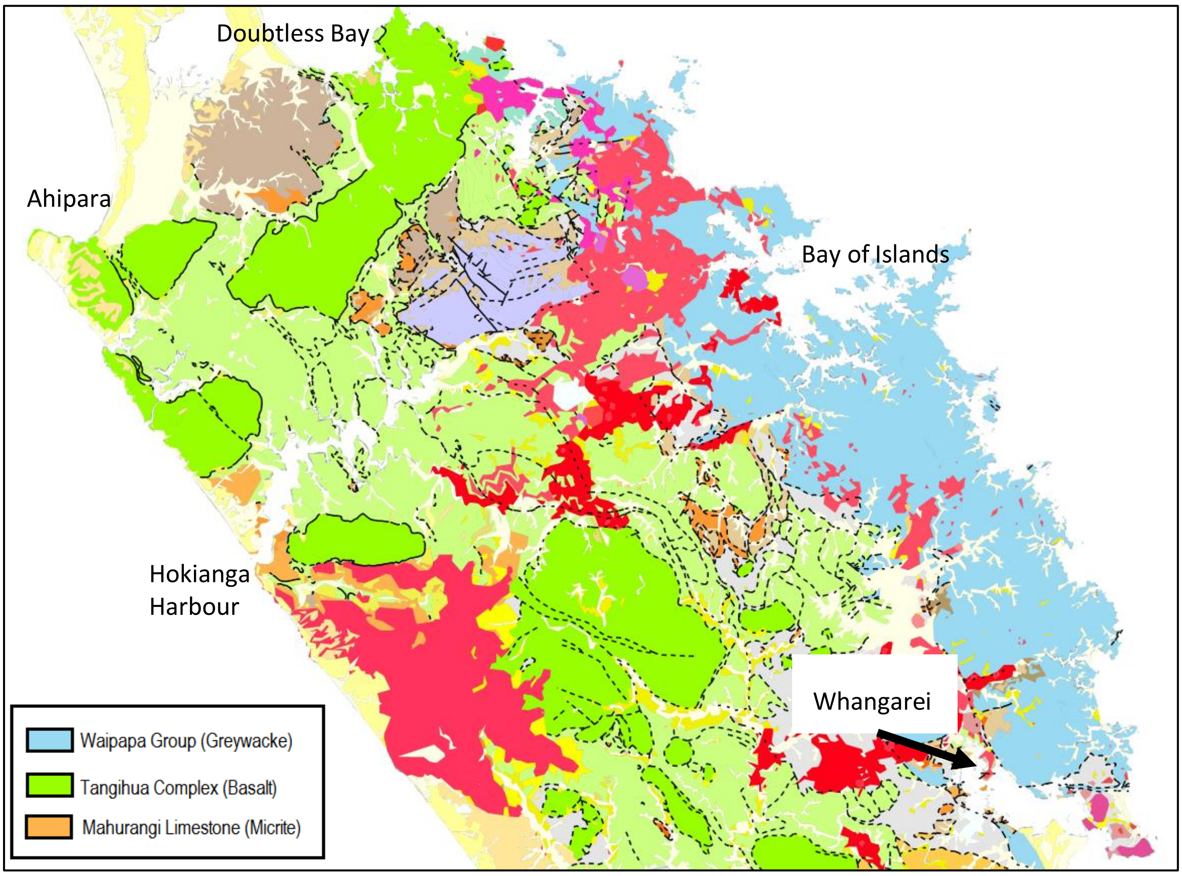


Figure 3.1: Northland Geology, known faults are represented by solid and dashed lines (source: GNS 1:250,000 Geological Units)

Due to the limited fluvial sediment supply compared to the west coast of the North Island, beaches on the east coast are restricted to defined compartments situated between rocky headlands and embayments. These compartments are generally located at river or stream mouths, where relatively small barrier beaches have formed over the Holocene period (last 10,000 years).

The majority of the sites are either partially attached barrier spits or fully attached foredune barriers. The barrier spits mostly have a single inlet located adjacent to the distal end of the sand spit with the other end fixed to a rocky headland. Some sites have barrier enclosed estuaries, where the sandy spit has built across the mouth of a drowned river valley (Whananaki, Matapouri).

The beach and backshore deposits of most sites are relatively flat Holocene coastal plains comprising unweathered Holocene sands and gravels. Older Pleistocene dunes are exposed at some locations which form higher dunes that are more consolidated and weathered (Marsden Point).

Further information on site descriptions are provided individually for each site within Appendix A.

3.1.1 Vertical land movement

Beavan and Litchfield (2012) have assessed vertical land movement around New Zealand's coastline. They find Northland to be tectonically stable utilising both long-term geological markers and shorter-term GPS markers with Kaitaia and Whangarei exhibiting -0.3 mm/year and +0.3 mm/year trends respectively. Therefore, vertical land movement has not been considered as part of this assessment.

3.2 Sediments

The beach sediment for all sites comprises predominately sand material, ranging from fine to very coarse in size. The results of the sediment size analysis undertaken by the University of Waikato is presented in Table 3.1 for representative samples. Where the sediment size characteristics changed along the site (e.g. from fine to medium sand), all sample results are presented. Note that no sediment sampling was undertaken at Tamaterau.

Table 3.1: Beach Sediment summary

Site		Size Range (mm)			Description	
ID	**Name**	**$D_{10\%}$**	**$D_{50\%}$**	**$D_{90\%}$**	**Wentworth Size Classification**	
1	Langs Beach	0.167	0.291	0.496	Medium	Sand
2	Waipu	0.136	0.216	0.347	Fine	Sand
3	Ruakaka	0.146	0.246	0.428	Fine	Sand
4	Marsden Point	0.158	0.238	0.357	Fine	Sand
5	Marsden Cove	0.120	0.200	0.336	Fine	Sand
6	One Tree Point East	0.327	0.567	1.012	Coarse	Sand
6	One Tree Point West	0.315	0.448	0.639	Medium	Sand
7	Taiharuru	0.216	0.326	0.497	Medium	Sand
8	Pataua North	0.272	0.587	1.226	Coarse	Sand
8	Pataua Estuary	0.539	0.929	1.487	Very Coarse	Sand
9	Whangaumu	0.220	0.356	0.595	Medium	Sand
10	Matapouri	0.201	0.320	0.517	Medium	Sand
11	Woolleys	0.217	0.408	0.772	Medium	Sand
12	Sandy Bay	0.170	0.255	0.385	Medium	Sand
13	Whananaki	0.167	0.296	0.557	Medium	Sand
14	Teal	0.224	0.708	1.401	Coarse	Sand
15	Helena	0.190	0.814	1.612	Coarse	Sand
16	Ohawini	0.090	0.139	0.214	Fine	Sand
17	Oakura	0.107	0.194	0.896	Fine	Sand
18	Bland	0.202	0.357	0.655	Medium	Sand

Site		Size Range (mm)			Description	
ID	Name	$D_{10\%}$	$D_{50\%}$	$D_{90\%}$	Wentworth Size Classification	
19	Waitangi	0.148	0.233	0.369	Fine	Sand
20	Matauri	0.123	0.186	0.281	Fine	Sand
21	Te Ngaire	0.118	0.206	0.463	Fine	Sand
22	Tauranga	0.209	0.450	1.127	Medium	Sand
23	Taupo	0.164	0.328	0.795	Medium	Sand
24	Hihi	0.134	0.214	0.342	Fine	Sand
25	Coopers	0.142	0.225	0.364	Fine	Sand
26	Cable	0.191	0.289	0.440	Medium	Sand
27	Taipa	0.141	0.244	0.454	Fine	Sand
28	Rangiputa	0.144	0.200	0.275	Fine	Sand
29	Tokerau	0.117	0.173	0.255	Fine	Sand
30	Ahipara	0.150	0.215	0.362	Fine	Sand
31	Omapere Centre	0.235	0.441	1.206	Medium	Sand
31	Omapere North	0.208	0.691	1.459	Coarse	Sand
31	Omapere South	0.231	0.333	0.479	Medium	Sand
31	Opononi Centre	0.295	0.867	1.502	Coarse	Sand
31	Opononi North	0.199	0.379	0.628	Medium	Sand
31	Opononi South	0.158	0.250	0.401	Medium	Sand
32	Mangawhai Heads	0.152	0.250	0.421	Medium	Sand
33	Tamaterau	N/A	N/A	N/A	N/A	N/A
34	Woolleys Bay extension	0.165	0.258	0.413	Medium	Sand
35	Moureeses Bay	0.172	0.263	0.402	Medium	Sand
36	Long Beach	0.115	0.172	0.259	Fine	Sand
37	Paihia	0.120	0.237	0.794	Fine	Sand
38	Whatuwhiwhi (Parakerake)	0.271	0.702	1.610	Coarse	Sand
38	Whatuwhiwhi (Waihapurua)	0.153	0.256	0.440	Medium	Sand
39	Kaimaumau	0.151	0.217	0.308	Fine	Sand
40	Baylys Beach	0.173	0.234	0.313	Fine	Sand
41	Glinks Gully	0.166	0.228	0.314	Fine	Sand
42	Whakapirau	0.188	0.450	1.240	Medium	Sand

The relatively flat wider beaches of Tokerau, Ahipara, Matauri, Bream Bay and West Coast tend to have finer sand characteristics. The finest sand beach sediment was sampled from relatively sheltered sites within harbour entrances at Oakura, Ohawini, Long Beach and Rangiputa. A number of sites have a wide range of sediment size across the beach face including sand and pebbles. These sites include Omapere, Opononi, Teal and Helena Bays, Whatuwhiwhi and Mangawhai Heads.

3.3 Water levels

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

Key components that determine water level are:

- Long-term changes in global mean sea level
- Astronomical tides
- Barometric and wind effects, generally referred to as storm surge
- Medium term fluctuations, including ENSO and IPO effects
- Variations in surf-zone water level due to wave transformation processes (wave setup and run-up.

3.3.1 Astronomical tide

Tidal levels for primary and secondary ports of New Zealand are provided by LINZ (2020) based on the average predicted values over the 18.6 year tidal cycle. Values for Marsden Point in terms of Chart Datum, One Tree Point Vertical Datum (OTP64) and New Zealand Vertical Datum (NZVD2016) are presented within Table 3.2. Mean High Water Springs (MHWS) levels around Northland calculated by Bell and Gorman (2003) are presented in Figure 3.2 and show that MHWS varies by less than 6 cm between Bream Bay and Doubtless Bay (0.94 to 0.98 m above the Mean Level of the Sea, MLOS). On the west coast, MHWS at Ahipara and the Hokianga Harbour Entrance is 1.34 m above MLOS, and at Glinks Gully and Baylys Beach 1.36 m above MLOS.

Table 3.2: Tidal levels given for Marsden Point (LINZ, 2020)

Tide state	Chart Datum (m)	OTP64 (m)	NZVD2016 (m)
Highest Astronomical Tide (HAT)	3.01	1.33	1.26
Mean High Water Springs (MHWS)	2.74	1.06	0.99
Mean High Water Neaps (MHWN)	2.31	0.63	0.56
Mean Sea Level (MSL)	1.60	-0.08	-0.15
Mean Low Water Neaps (MLWN)	0.9	-0.78	-0.85
Mean Low Water Springs (MLWS)	0.46	-1.22	-1.29
Lowest Astronomical Tide (LAT)	0.13	-1.55	-1.62

Source: LINZ Nautical Almanac 2019–20

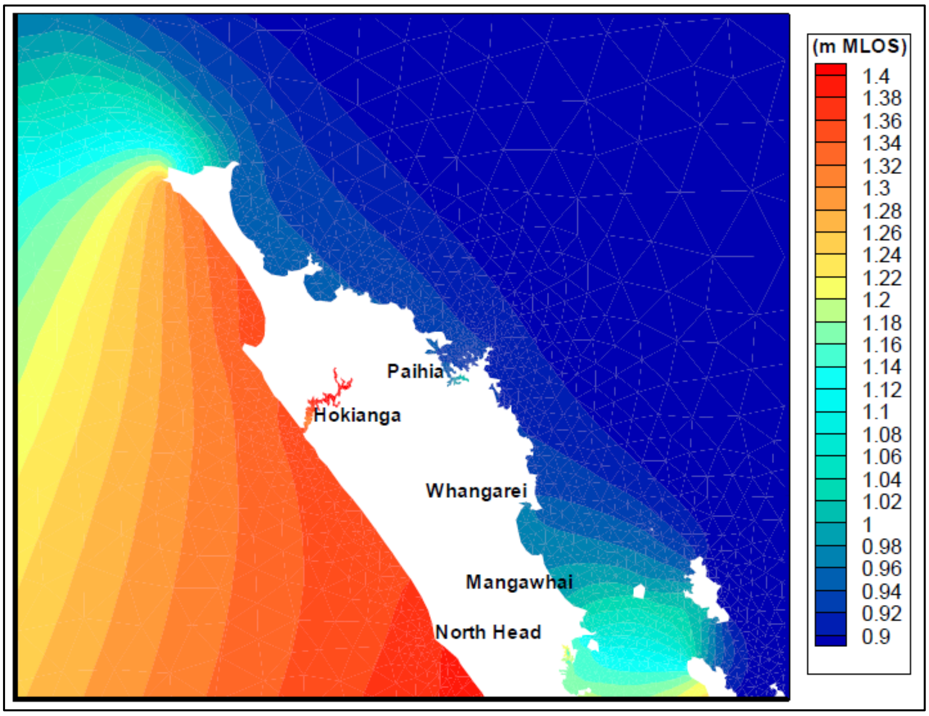


Figure 3.2: MHWS around the Northland Region (Bell and Gorman, 2003)

3.3.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide (Figure 3.3). Storm-surge applies to the general elevation of the sea above the predicted tide across a region but excludes nearshore effects of storm waves such as wave setup and wave run-up at the shoreline.

Previous studies of storm surge around New Zealand's coastline have concluded that storm surge appears to have an upper limit of approximately 1.0 m (Hay, 1991; Heath, 1979; Bell et. al, 2000). Given the perceived upper limit of storm surge for New Zealand, a standard storm surge of 0.9 m is considered representative of a return period of 80 to 100 years (MfE, 2004).

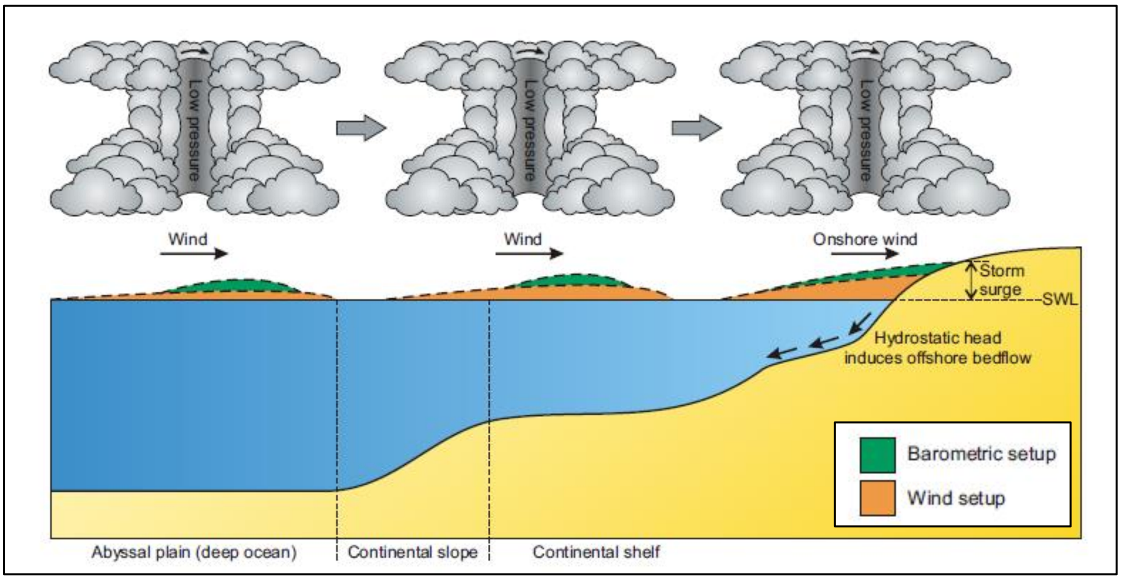


Figure 3.3: Processes causing storm surge (source: Shand, 2010)

3.3.3 Medium term fluctuations and cycles

Atmospheric factors such as season, El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) can all affect the mean level of the sea at a specific time. The combined effect of these fluctuations may be up to 0.25 m (NIWA, 2011).

3.3.4 Storm tide levels

The combined elevation of the predicted tide, storm surge and medium-term fluctuations is known as the storm tide. Results of an extreme value analysis of hourly sea level data for Marsden Point using a Weibull distribution and Gringorten plotting position formula are shown in Figure 3.4. On this basis, 10 and 100 year Average Recurrence Interval (ARI) storm tide levels utilised in storm response modelling are selected with a slight reduction in elevation for open coast Northland east coast beaches, and an increase for west coast sites to account for variation in astronomical tidal range based on LINZ (2013) secondary port tidal information and Bell and Gorman (2003) analysis.

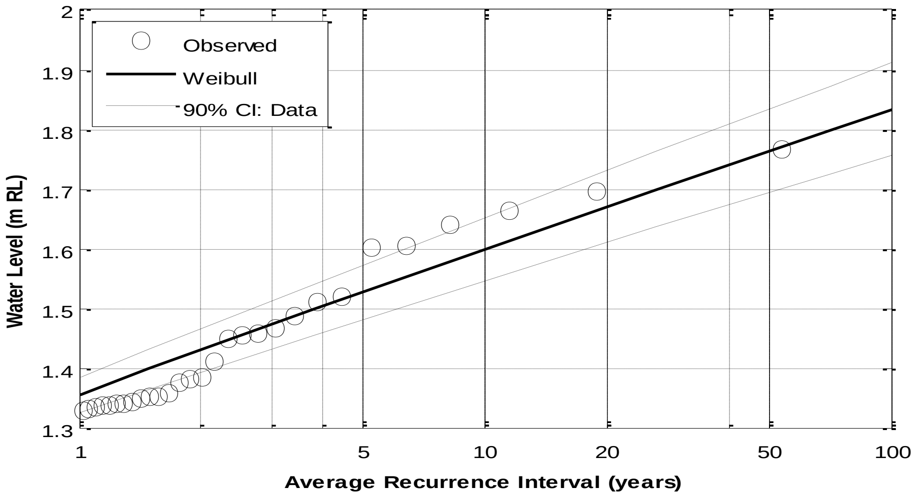


Figure 3.4: Extreme 1 hour averaged water level for Marsden Point (1984 - 2013)

Table 3.3: Storm tide level used in analysis

Site	Peak storm tide level (m RL)	
	10 year ARI	**100 year ARI**
Bream Bay	1.6	1.83
Bream Head to Doubtless Bay	1.55	1.75
Ahipara[1]	2.0	2.2

[1]Based on LINZ Secondary Port tidal information

3.3.5 Long-term sea levels

Historic sea level rise in New Zealand has averaged 1.7 ± 0.1 mm/year (Bell and Hannah, 2012) with Northland exhibiting a slightly higher rate of 2.2 ± 0.6 mm/year. Beavan and Litchfield (2012) found negligible vertical land movement in Northland. Therefore, the higher historic sea level rise rate and wider uncertainty may be due to the short record length (i.e. ~40 years) compared to the datasets used to calculate the New Zealand average rate (i.e. >70 years).

Climate change is predicted to accelerate this rate of sea level rise into the future. NZCPS (2010) requires that the identification of coastal hazards includes consideration of sea level rise over at least a 100 year planning period. Potential sea level rise over this time frame is likely to significantly alter the coastal hazard risk.

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

The most recent guideline released by the Ministry for the Environment (MfE, 2017) recommends four sea level rise scenarios to cover a range of possible sea-level futures. The scenarios are based on the most recent IPCC report (IPCC, 2013) (Figure 3.5).

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

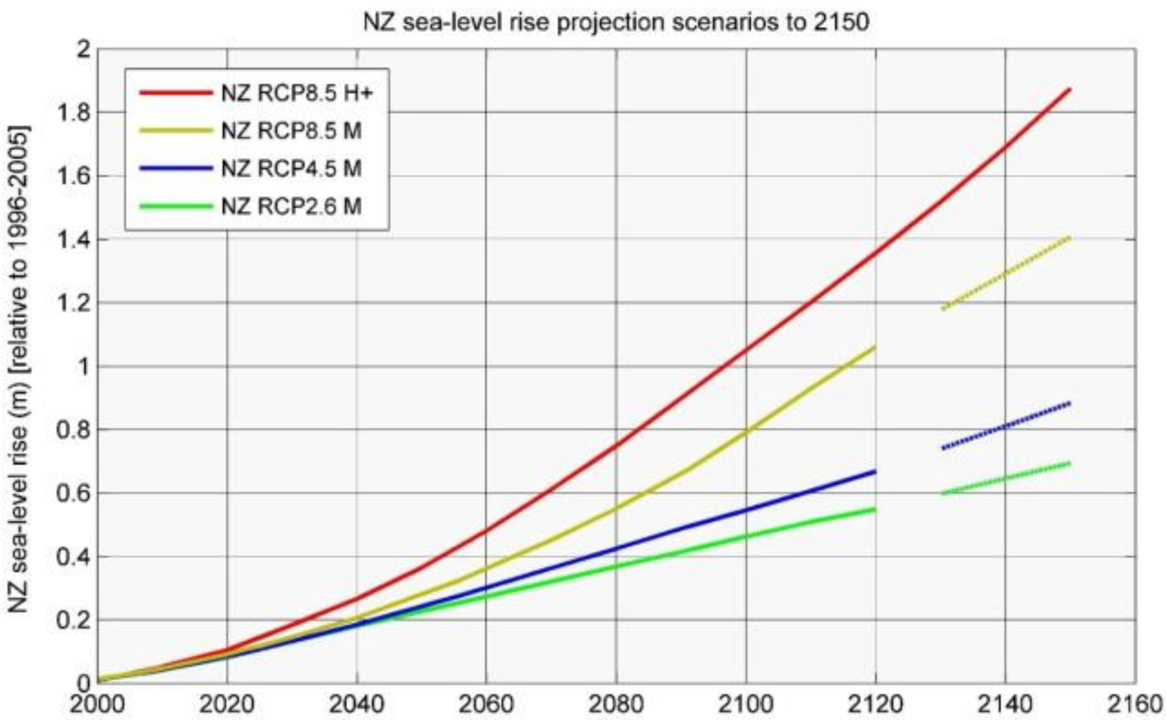


Figure 3.5: Projections of potential future sea level rise presented within MfE (2017) with adopted values for this assessment at 2080 and extrapolated to 2130

3.4 Waves

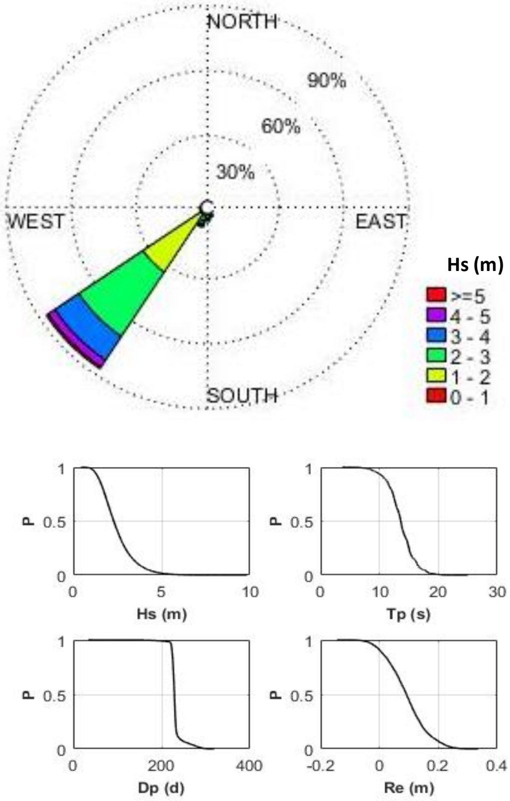
Wave data from six offshore locations representative of the Northland Region was provided by MetOcean Solutions Ltd for this study (refer to Section 2.2.6).

3.4.1 Offshore wave climate

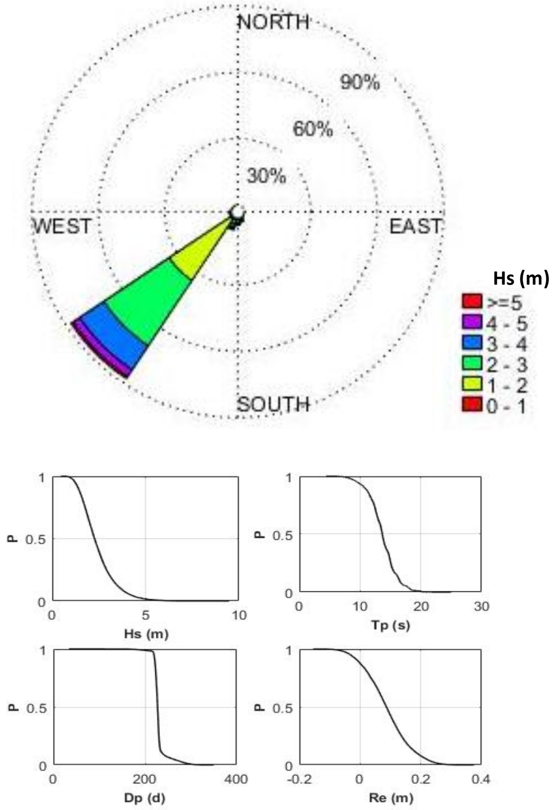
The wave climates of the east and west coast of Northland differ considerably. The majority of wave energy on the west coast is generated by mid latitude low pressure systems moving from west to east beneath Australia and New Zealand. This wave energy propagates into the Tasman Sea and reaches Northland as either swell from the southwest or combined sea-swell when wind streams extend sufficiently far north. Infrequent low pressure systems forming in the Tasman Sea or further north in the tropics induce northwest to north waves and winds. The east coast is sheltered from these predominant westerly systems and waves are dominated by infrequent easterly airflows generated by subtropical low pressure systems with ex-tropical cyclones and storms descending from the tropics during summer months.

Wave roses and cumulative distributions (cdf) of significant wave height, peak period, peak direction and non-tidal residual are shown for each offshore location in Figure 3.6. These results show that offshore of both Ahipara and Baylys Beach, waves arrive from a narrow directional range from the southwest. All east coast locations show similar predominantly north to northeast wave directions with less frequent southeast components. Mean significant wave height (2.4 to 2.5 m) and peak period (13.6 s) on the west coast is typically higher than on the east coast (1.3 to 1.6 m and 9.3 to 10 s). Refer to Figure 3.6 for a summary of the characteristic wave heights for the six Northland offshore locations.

Baylys Beach Offshore



Ahipara Offshore



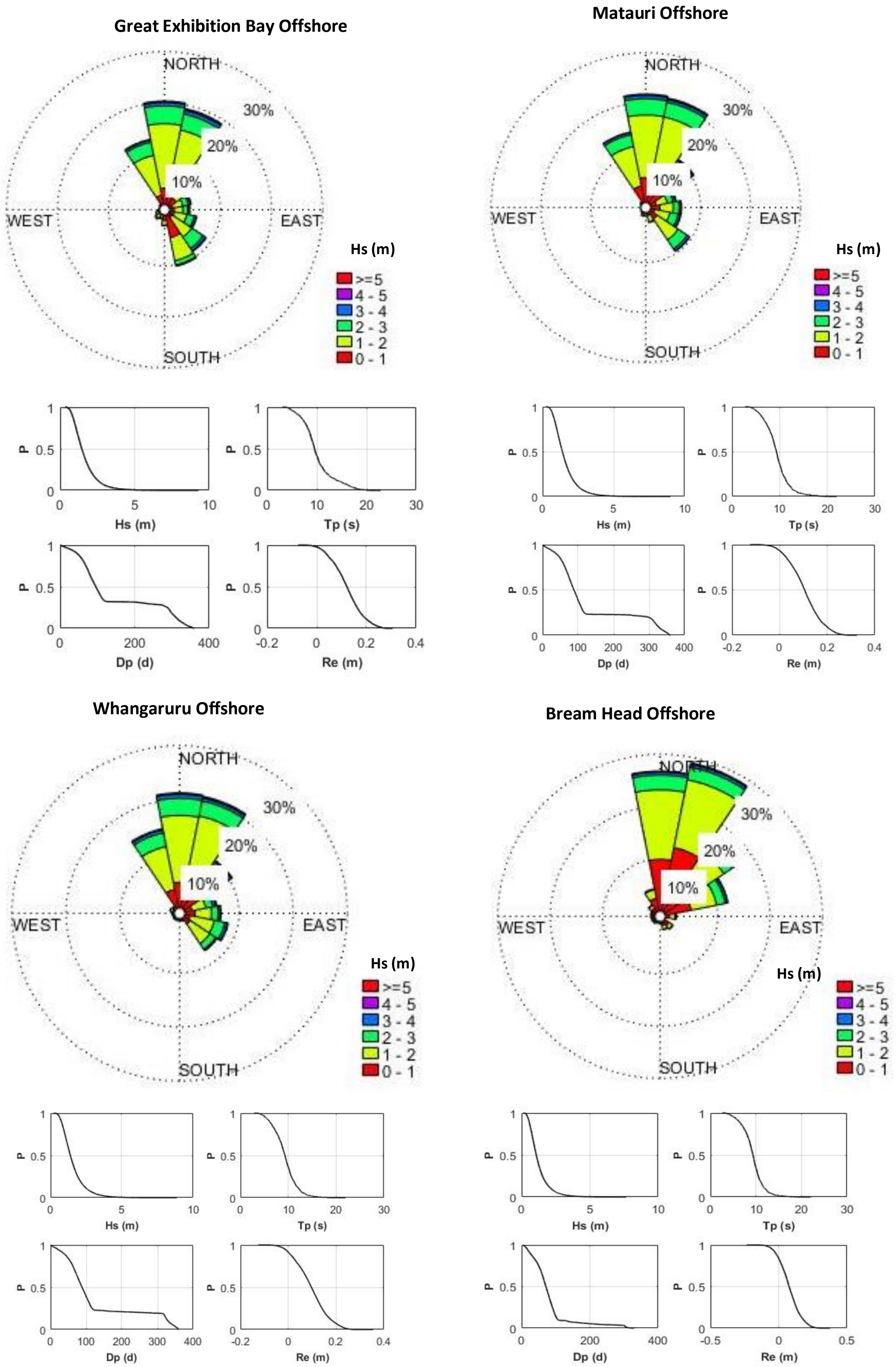


Figure 3.6: Wave roses and CDFs for each offshore buoy showing significant wave height (H_s), peak period (T_p), peak direction(D_p) and non-tidal residual(R_e)

Table 3.4: Characteristic wave heights for Northland offshore locations

	Coordinates		Mean			1% Exceedance		
Location	**E (°)**	**S (°)**	**H_s (m)**	**T_p (s)**	**D_p (°)**	**H_s (m)**	**T_p (s)[1]**	**D_p (°)[1]**
Baylys Beach	173.62	35.98	2.5	13.6	231.3	5.4	14.3	235.4
Ahipara	173.02	35.24	2.4	13.6	230	5.3	14.4	234.5
Great Exhibition Bay	173.36	34.44	1.6	10	147.8	4.4	11.1	108.8
Matauri Bay	173.99	34.84	1.6	9.4	130	4.4	11	108
Whangaruru	174.63	35.28	1.6	9.3	128.4	4.4	10.9	103.7
Bream Head	174.63	35.74	1.3	9.3	79.7	3.9	10.6	60.7

[1]Wave period and direction for 1% exceedance H_s conditions

3.4.2 Storm climatology

Northland is affected by storm events from a range of sources. On the west coast these include large mid latitude low pressure systems occurring between 50 and 60° S propagating into the Tasman Sea (Figure 3.7) and low pressure systems forming off the east coast of Australia (i.e. East Coast lows). The east coast is affected by similar sub-tropical lows and by systems of tropical origin descending towards the north of New Zealand as tropical or ex-tropical cyclones (Figure 3.8).

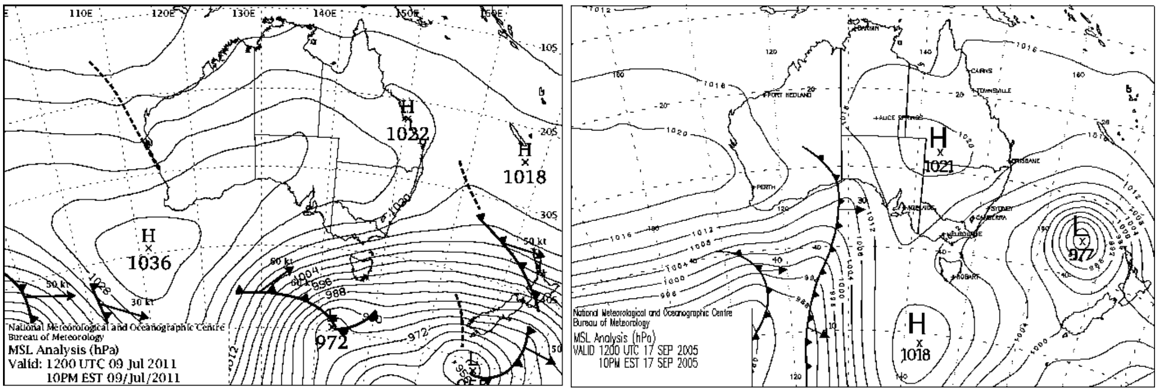


Figure 3.7: Typical storm systems affecting the west coast of Northland with a large mid-latitude cyclone in July 2011 (A) and an East coast low in September 2005 (B)

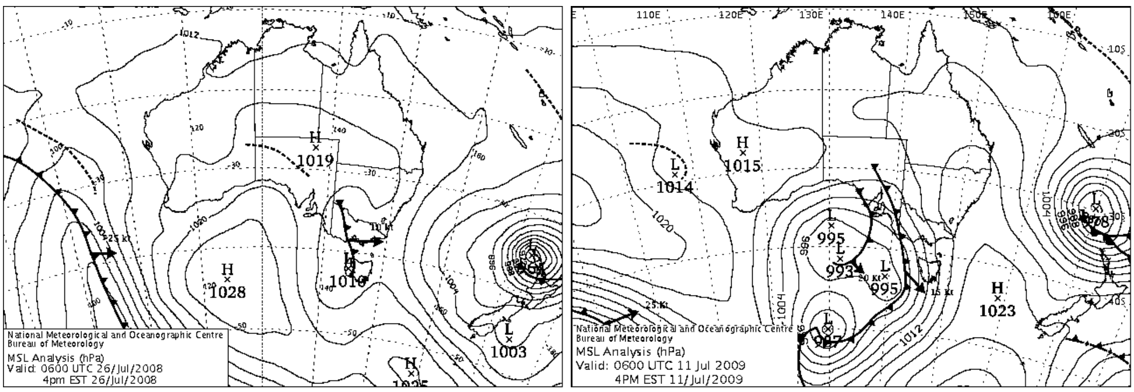


Figure 3.8: Sub-tropical storm systems causing large waves on the Northland east coast in July 2008 (A) and July 2009 (B)

Significant storm events have been identified for each offshore dataset using a peaks-over-threshold (PoT) method based on a 1% exceedance height threshold and incorporating a minimum duration threshold between storms to ensure event independence. Results (Figure 3.9 and Figure 3.10) show that for both east and west coast sites, wave period tends to increase with storm peak wave heights, although longer periods are observed for smaller waves on both coasts.

On the west coast, the largest storms may arrive from directions 220 to 280° and on the east coast from 40 to 100°. Non-tidal residual (storm surge) appears highly scattered compared to more typical (lower) storm events on both coasts, but the largest events do coincide with largest tidal residual indicating high dependence in extreme events. This is similar to findings on the east coast of Australia (Shand et al., 2011) where asymptotic dependence between wave height and non-tidal residual was noted.

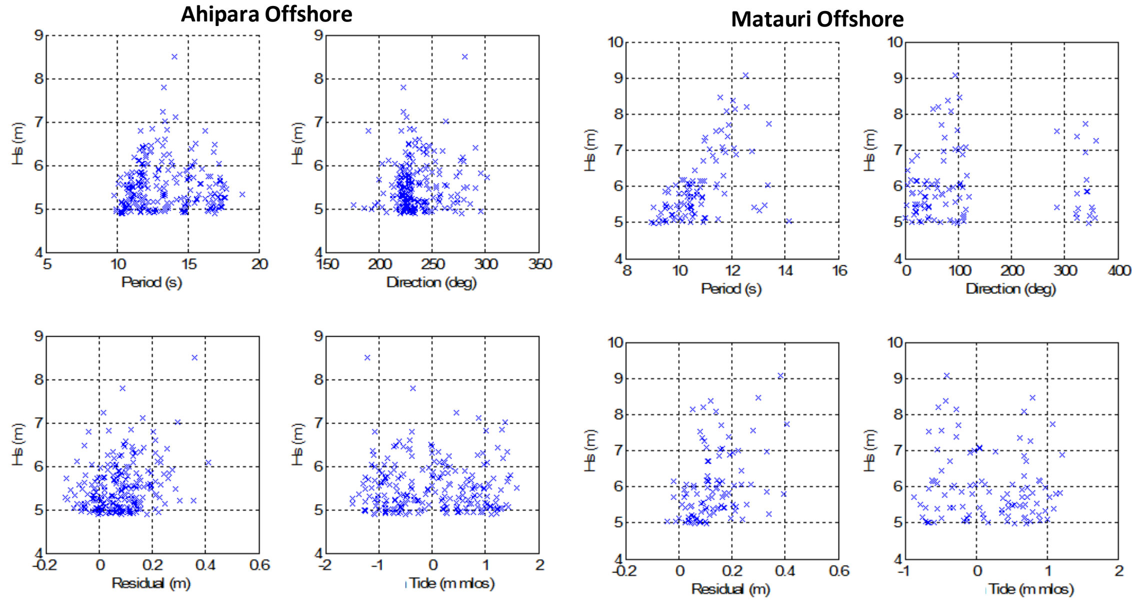


Figure 3.9: Storm peak characteristics for Ahipara and Matauri relating wave height to wave period, direction, non-tidal residual (storm surge) and tide.

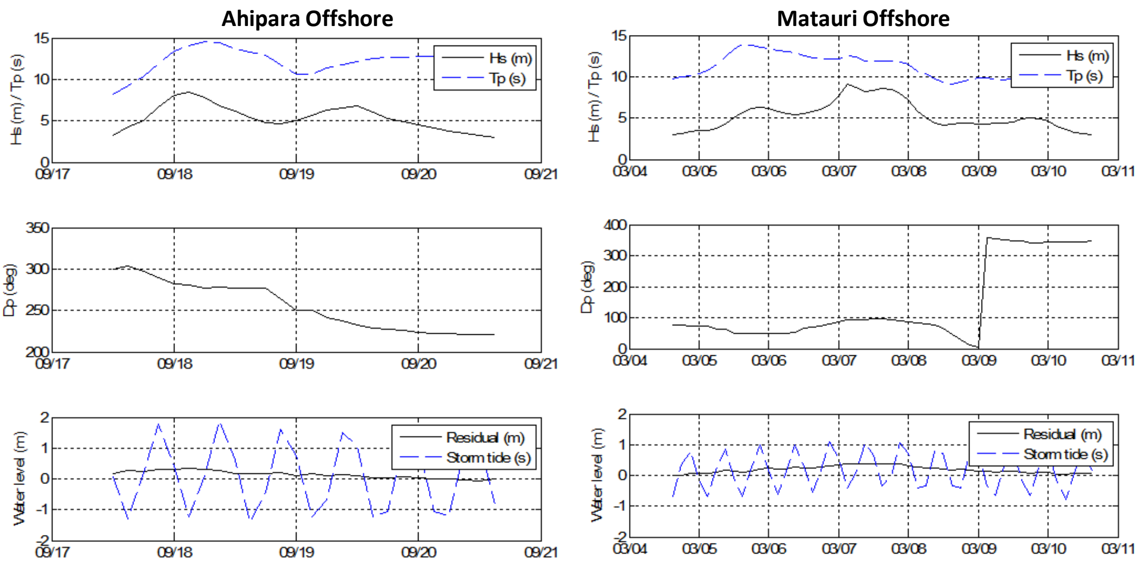


Figure 3.10: Time series of maximum storm on record for the Ahipara offshore site (September 2005) and for the Matauri and Whangaruru sites (March 1988)

The clustering of storm events can result in greater beach erosion than would occur for singular storm events as the beach does not have time to recover between events. Such storm clustering is known to occur along the New Zealand east coast. For example, Tropical Cyclones Fergus, Drena and Gavin made landfall between December 1996 and March 1997. De Lange (2000) found the phase of inter-decadal Pacific Oscillation (IPO) to cause changes in sea level, prevailing wind direction, storm frequency and wave climate with more events (and increased erosion on the northeast coast of New Zealand) occurring during negative phases (i.e. 1948 to 1974) than during positive phases (i.e. 1976 to 1998).

Figure 3.11 shows the time interval since previous events as a function of wave height for the Ahipara and Matauri offshore sites. Event interval is negatively skewed for both sites indicating some tendency for clustering, although not necessarily for the largest events which lie at a median interval for both sites. The use of multiple back-to-back events is common in Australian hazard assessments to ensure fully developed storm erosion conditions are reached and this approach is applied for this study.

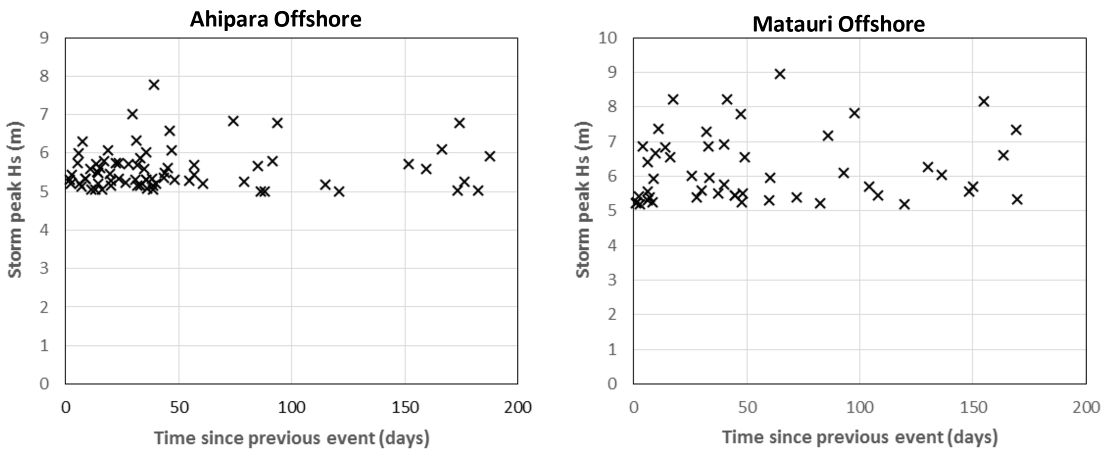


Figure 3.11: Storm peak wave height as a function of time since the previous storm event

3.4.3 Design storm events

Design storm events have been derived for use in beach erosion modelling by the following process:

1. Analysing wave data to define the Average Recurrence Interval (ARI) for storm peak wave height
2. Construct synthetic design storm time series for each wave output location using methods described in Carley and Cox (2003)
3. Constructing SWAN wave model domains covering all open coast cells
4. Simulate 10 year and 100 year ARI wave events from critical directions for each model domain and obtain nearshore wave height for each coastal cell
5. Modify previously-defined Synthetic Design Storms based on wave height transformation factors to provide boundary conditions for cell-specific beach erosion modelling.

An example wave output for Bream Bay during a 100 year ARI NE wave event is presented in Figure 3.12 and a complete description of the wave modelling process and results provided in Appendix B.

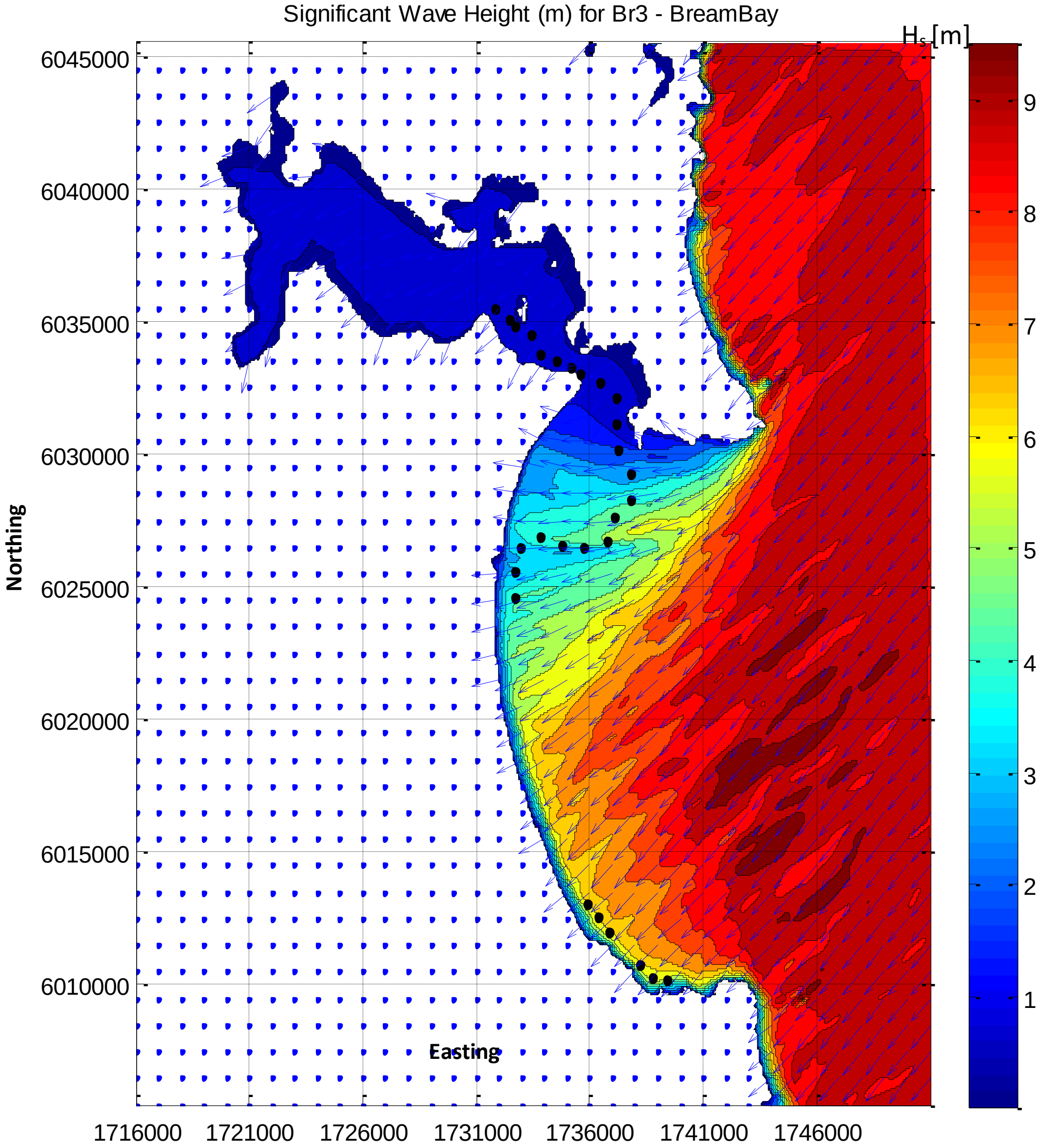


Figure 3.12: Example of SWAN output of significant wave height for Bream Bay during 100 year ARI storm event from the Northeast

4 Methodology

4.1 Statutory considerations

The New Zealand Coastal Policy Statement (NZCPS) 2010 is a national policy statement under the Resource Management Act 1991. The NZCPS states policies in order to achieve the purpose of the Act in relation to the coastal environments of New Zealand. Regional policy statements and plans must give effect to (be consistent with) the NZCPS.

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

- Policy 3, which requires a precautionary approach in the use and management of coastal resources potentially vulnerable to effects from climate change so that avoidable social and economic loss and harm to communities does not occur.
- Policy 24, which requires identification of areas in the coastal environment that are potentially affected by coastal hazards (including Tsunami) giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, should be assessed having regard to:
  - physical drivers and processes that cause coastal change including sea level rise
  - short-term and long-term natural dynamic fluctuations of erosion and accretion
  - geomorphological character
  - cumulative effects of sea level rise, storm surge and wave height under storm conditions
  - anthropogenic influences
  - extent and permanence of built development
  - effects of climate change on the above matters, on storm frequency and intensity and on natural sediment dynamics.

  These should take into account natural guidance and the best available information on the likely effects of climate change for each region.
- Policy 25 which promotes avoiding increasing the risk of social, environmental and economic to erosion hazard in areas potentially affected by coastal hazards over at least the next 100 years.
- Policy 27 which promotes reducing hazard risk in areas of significant existing development likely to be affected by coastal hazards.

NRC's Regional Policy Statement (RPS) 2016 (updated May 2018) gives effect to the policies of the NZCPS, particularly with regard to their natural hazard policies 7.1.1 to 7.1.10, where the overall approach is informed by policy 7.1.1:

> 7.1.1 General risk management approach
>
> Subdivision, use, and development of land will be managed to minimise the risks from natural hazards by:
>
> a) Seeking to use the best available information, including formal risk management techniques in areas potentially affected by natural hazards
>
> b) Minimising any increase in vulnerability due to residual risk

c) Aligning with emergency management approaches (especially risk reduction)

d) Ensuring that natural hazard risk to vehicular access routes and building platforms for proposed new lots is considered when assessing subdivision proposals

e) exercising a degree of caution that reflects the level of uncertainty as to the likelihood or consequences of a natural hazard event.

Where there is uncertainty in the likelihood or consequences of a natural hazard event, decision-makers will adopt a precautionary approach.

The remaining natural hazard policies in the RPS cover:

7.1.2 New subdivision and land use within 10 year and 100 year flood hazard areas

7.1.3 New subdivision, use and development within areas potentially affected by coastal hazards (including high risk coastal hazard areas)

7.1.4 Existing development in known hazard-prone areas

7.1.5 Regionally significant infrastructure and critical infrastructure

7.1.6 Climate change and development

7.1.7 Statutory plans and strategies

7.1.8 Monitoring and information gathering

7.1.9 Advocacy and education.

4.2 Risk-based approach

A risk-based approach to managing coastal hazard is advocated by the NZCPS and endorsed by NRC's RPS, with both the likelihood and consequence of hazard occurrence requiring consideration. For example, the policy statement suggests consideration of areas both 'likely' to be affected by hazard and areas 'potentially' affected by hazard. While the term 'likely' may be related to a likelihood over a defined timeframe based on guidance provided by MfE (2008), i.e. probability greater than 66% as shown in Table 4.1, the term 'potential' is less well defined. This assessment therefore aims to derive a range of hazard zones corresponding to differing likelihoods which may be applied to risk assessment.

Table 4.1: Likelihood of scenario occurring within the selected planning horizon

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

The probability of event occurrence over a timeframe of interest is provided in Table 4.2. This table shows that over a timeframe of 100 years, an event with an ARI of 100 years has a probability occurrence of 0.63 (63%) and a 1,000 year ARI event has an occurrence probability of 0.1 (10%). However, when combining several independent components to determine a final product (i.e. a hazard distance), the combined likelihood is typically substantially lower. This combined likelihood is difficult to quantify using the standard deterministic approach to hazard assessment where single low-probability values are determined for each component and combined, often giving very conservative results. A stochastic forecast method has therefore been implemented to include both the range of probabilities for each component but also uncertainties inherent in such assessment.

Table 4.2: Probability of event occurrence within a specified timeframe

	ARI (years)	AEP (%)	Probability (%) of event occurrence within					
			1 year	5 years	10 years	20 years	50 years	100 years
Design Event Occurrence	**1**	**63**	63.2	99.3	100	100	100	100
	5	**18**	18.1	63.2	86.5	98.2	100	100
	10	**9.5**	9.5	39.3	63.2	86.5	99.3	100
	20	**5**	4.9	22.1	39.3	63.2	91.8	99.3
	50	**2**	2.0	9.5	18.1	33.0	63.2	86.5
	100	**1**	1.0	4.9	9.5	18.1	39.3	63.2
	1,000	**0.1**	0.1	0.5	1.0	2.0	4.9	9.5

4.3 Stochastic forecast approach

The methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters (Gibb, 1978; T+T, 2004; 2006; 2012; CSL, 2008, 2012) but rather than including single values for each component and a factor for uncertainty, parameter bounds are specified for each parameter and combined by stochastic simulation. The resulting distribution is a probabilistic forecast of potential hazard zone width.

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

The stochastic method is described in Cowell et al. (2006). The methods used to define probability distribution functions (pdfs) for each parameter are described within the parameter descriptions below. Where pdfs are not defined empirically (i.e. based on data or model results), simple triangular distributions have been assumed with bounding (minimum and maximum) and modal parameters. These triangular distributions can be constructed with very little information yet approximate a normal distribution (Figure 4.1) and permit flexibility in defining range and skewed asymmetry. Figure 4.1 also shows the output displayed in cumulative distribution format (cdf).

Comparisons using triangular and normal distributions have been undertaken and show little actual difference (<6 m) in mean CEHZ values derived using the different distributions. For exceedance probabilities less than 50% considering a 100 year time frame the resultant CEHZ values typically increase up to 13%. The full assessment including results is shown in Appendix D. Based on this assessment NRC decided to adopt triangular distributions for this study.

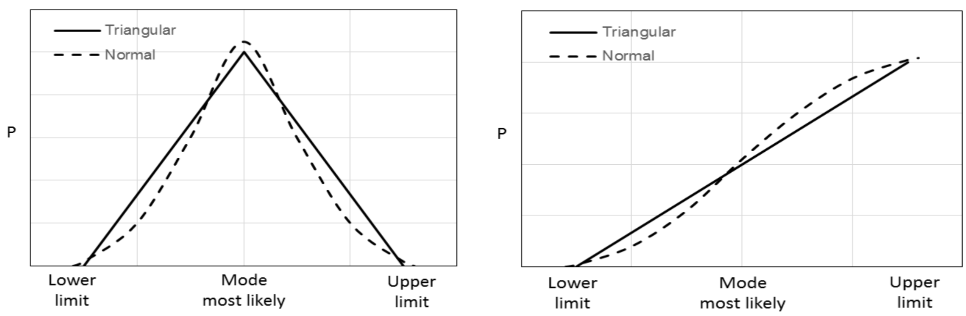


Figure 4.1: Example triangular and normal pdf (A) and cdf (B)

4.4 Defining coastal behaviour cells

Each coastal compartment (designated 1 to 42) has been divided into coastal cells based on shoreline composition and behaviour which can influence the resultant hazard. Factors which may influence the behaviour of a cell include:

- cell morphology and lithology
- exposure
- profile geometry
- backshore elevation
- historical shoreline trends.

4.5 Coastal erosion hazard methodologies

The Northland region contains a range of coastal types. The processes controlling erosion along these different coastal types vary and therefore the methods used to determine coastal erosion hazard zone distances must also vary to account for these differing processes. The expressions used to define CEHZ's for the three major coastal types are presented below.

4.5.1 Unconsolidated shoreline

The method for unconsolidated shorelines is expressed in Equation 4.1 and will be applied to uniform, non-consolidated shorelines (e.g. open coast beaches or coastal terraces typically situated within larger estuaries), which are not influenced by streams, smaller scale estuaries or distal spit migrations. The CEHZ will be established from the cumulative effect of four main parameters (Figure 4.2):

$$CEHZ_{Beach} = ST + DS + (LT \times T) + SL \tag{4.1}$$

Where:

ST	=	Short-term changes in horizontal shoreline position related to storm erosion due to singular or a cluster of storms events or fluctuations in sediment supply and demand, beach rotation and cyclical changes in wave climate (m)
DS	=	Dune stability allowance. This is the horizontal distance from the base of the eroded dune to the dune crest at a stable angle of repose, (m)
LT	=	Long-term rate of horizontal coastline movement (m/yr)
T	=	Timeframe (years)
SL	=	Horizontal coastline retreat due to the effects of increased mean sea level (m).

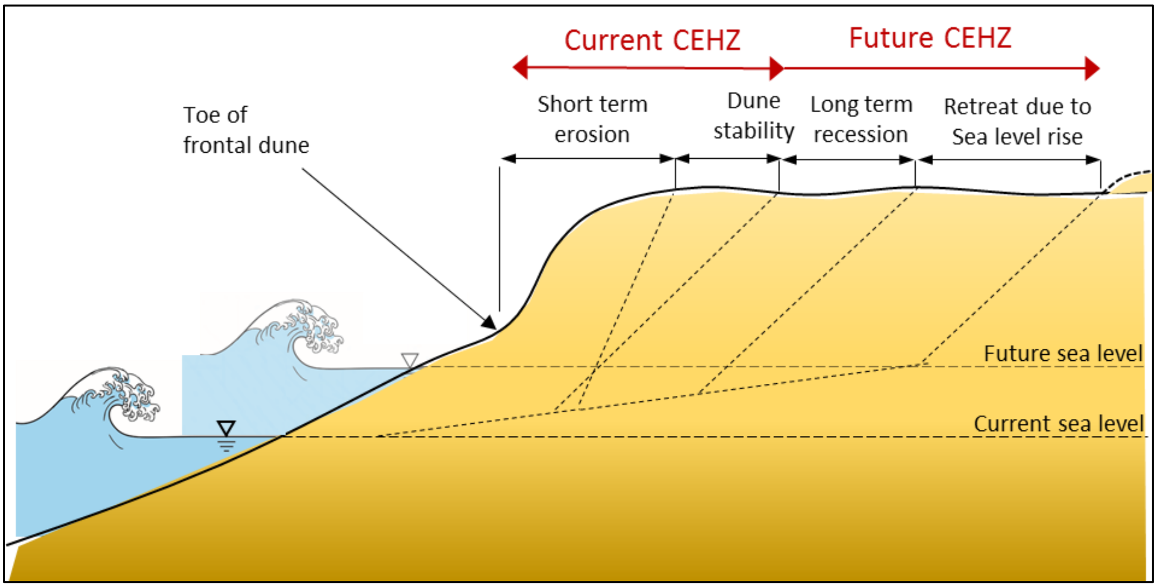


Figure 4.2: Definition sketch for CEHZ on unconsolidated shoreline

The $CEHZ_{Beach}$ baseline to which values are referenced is the most recent dune toe derived from site survey data or LiDAR, except in some cases of dynamic inlets or spits where the maximum inland extent of fluctuation (envelope) may be adopted (i.e. Shand, 2012). This has been considered on a site-by-site basis and will be discussed within the site-specific assessments.

4.5.2 Consolidated shoreline

This section applies to sea cliffs, coastal hill slopes and consolidated coastal terraces that are directly affected by coastal erosion. This will primarily be considered for One Tree Point and Coopers Beach and any part of the other beach areas where the backshore is shown to be rock rather than alluvium. The CEHZ for unconsolidated shorelines will be established from the cumulative effect of the long-term retreat and slope instability (Figure 4.3) as outlined in Equation 4.2.

$$CEHZ_{Cliffs} = \left(\frac{H_C}{\tan\alpha}\right) + \left(LT_H \times LT_F\right) \times T \quad (4.2)$$

Where:

H_C = Height (m) of cliff from LiDAR or survey data. Note that as the active cliff recedes landward, the effective height may increase if the backshore slopes up

α = The characteristic composite stable angle of repose

LT_H = Historic long-term retreat (regression rate), m/year, based on historic aerial photo analysis

LT_F = Factor for the potential increase in future long-term retreat due to sea level rise effects

T = Timeframe (years).

The $CEHZ_{Cliffs}$ baseline to which values are referenced is the most recent cliff toe location derived from LiDAR or site survey data.

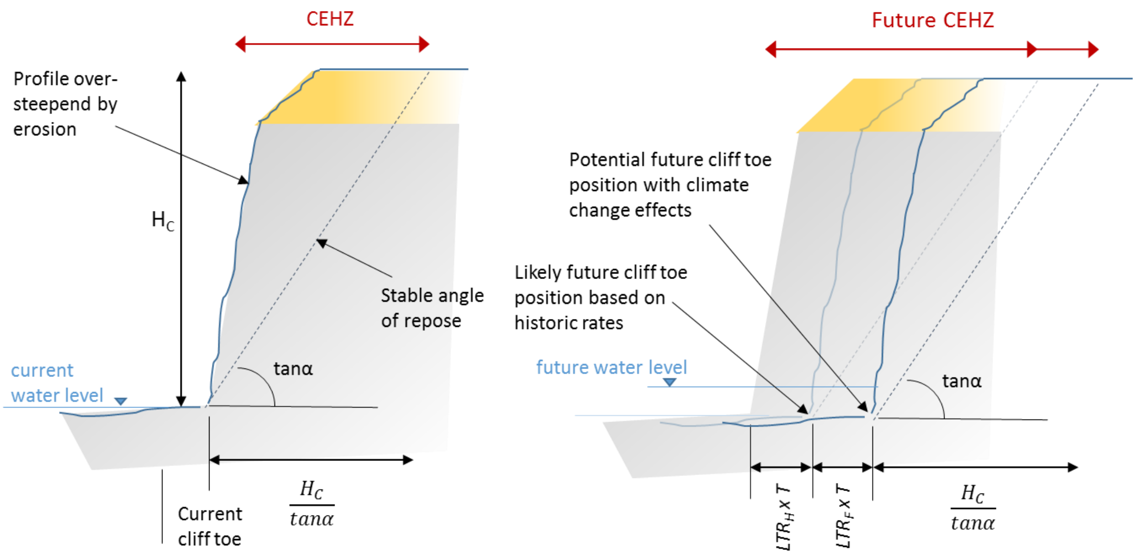


Figure 4.3: Definition sketch for CEHZ on consolidated shoreline

4.5.3 Inlets

Sections of shoreline that are situated within or in the vicinity of inlets, such as estuary, river or stream inlets, or distal spits may be more dynamic than uninterrupted, uniform shorelines. These shorelines typically move landward and seaward on a more regular basis depending on the sediment supply and inlet dynamics. These shorelines are typically unconsolidated, however, in some cases may be comprised of sediment deposited in front of consolidated cliffs.

For unconsolidated inlet shorelines, the short-term component is based on the observed fluctuation of the shoreline instead of due to storm erosion. For consolidated shorelines that are fronted by dynamic sedimentary deposits an additional component is added to Equation 4.2 to account for the dynamic shoreline fluctuations. The baseline for these types of shoreline is the toe of the unconsolidated coastal terrace (see schematisation of inlet shoreline in Figure 4.4).

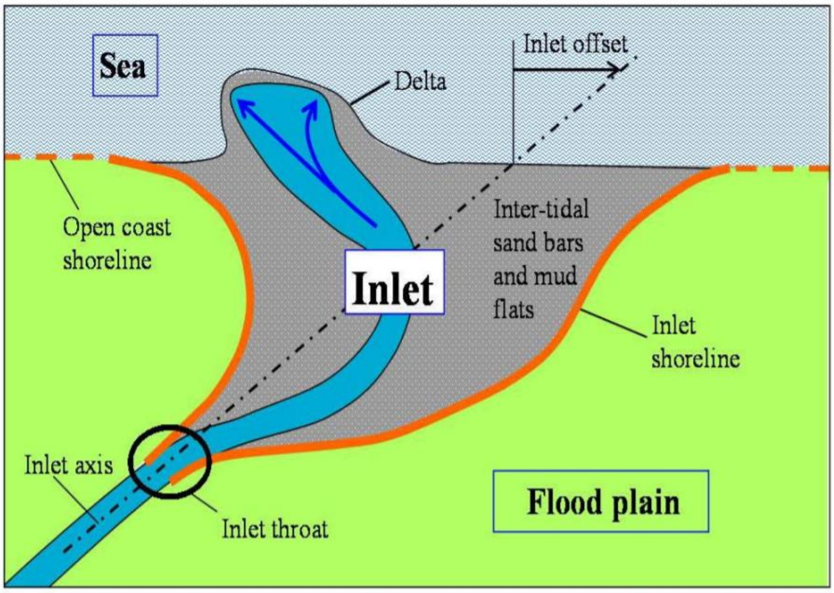


Figure 4.4: Morphology of an inlet including schematisation of inlet shoreline (source: Shand, 2012)

4.6 Component derivation

4.6.1 Planning timeframe (T)

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

- 2020 Coastal Erosion Hazard Zone (Current): 2020 CEHZ
- 2080 Coastal Erosion Hazard Zone (at least 50 years): 2080 CEHZ
- 2130 Coastal Erosion Hazard Zone (at least 100 years): 2130 CEHZ.

4.6.2 Short-term (ST)

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

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

1 existing information sources such as previous reports and anecdotal evidence
2 simple geometric models for beach response
3 statistical analysis of shoreline position obtained from aerial photographs or beach profile analysis
4 numerical assessment of storm erosion potential.

4.6.2.1 Anecdotal or experience-based

Existing information presented within previous studies has often been derived based on anecdotal or field evidence or experience. Where no better information is available, these existing values may be retained.

Maximum erosion excursions of up to 40 m have been reported (Gibb, 1998) on some east coast beaches, although these are generally considered at the upper end of potential storm cut. For west coast beaches, NRC (2003) adopted values of 10 to 30 m, although larger 50 m values were adopted for the more active sand spit at Ahipara.

4.6.2.2 Geometric models

Geometric methods predict the final response state of a beach without simulating the processes occurring. Such methods are often based on theoretical relations and/or observed response at particular sites and therefore require calibration and careful interpretation of results.

An example of such a model is the Komar Geometric Model of Foredune Erosion (1999) which was developed primarily as an alternative to process-based models (i.e. SBEACH) in determining storm erosion during periods of elevated water level on the United States West Coast. The model is a based on a simple two-dimensional geometric relationship which assumes the active beach is translated landward in response to elevated water level (Figure 4.5) described by the following relationship.

$$DE_{\max} = \frac{(WL - H_J) + \Delta BL}{\tan\theta} \qquad (4.4)$$

Where WL-H_J is the elevation of the total water level including storm tide and run-up (WL) above the dune toe level (H_J), ΔBL is the potential lowering of the profile due to storm erosion and tanϑ is the slope of the beach face.

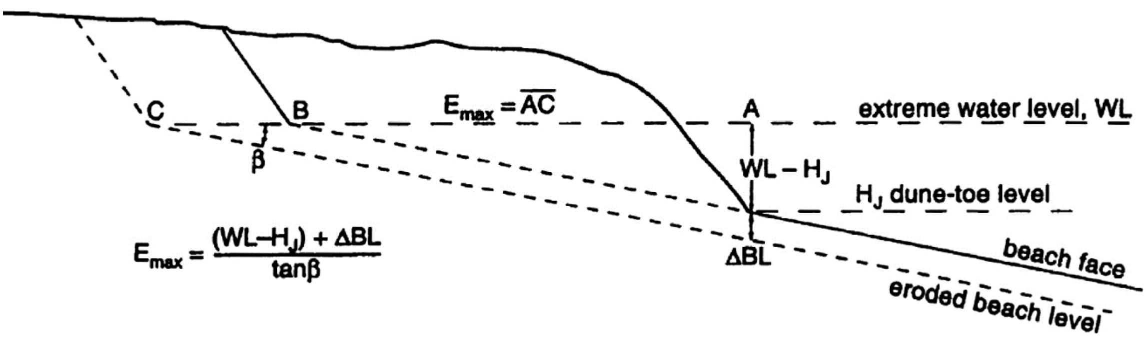


Figure 4.5: Geometric model used to evaluate the maximum potential erosion during an erosion event (Komar et al., 1999)

The model does not include a term for storm duration or response (erosion) speed and therefore assumes that the maximum possible erosion extent occurs for a particular extreme water level. However, in New Zealand the maximum storm tide level generally occurs only over a high tide period limiting the time available for the beach to fully respond (erode). Ramsey et al. (2012) note that the method is therefore generally considered to be precautionary given that most storms are of limited duration.

Example storm cut distances calculated for 10 year ARI storm events at three Northland beaches. Maximum water level was calculated using wave run-up based on empirical formula (Hedges and Mase, 2004 and Stockton et al., 2006) which were shown by Shand et al. (2011) to provide best agreement with storm wave runup elevation. Results are presented in Table 4.3 and show values of 56 to 58 m on east coast beaches and 74 m for Ahipara. These values exceed those used in existing assessments which typically range from 10 to 30 m on the east coast (Gibb, 1998, 1999; Geomarine, 2002; NRC, 2003) and 10 to 50 m on the west coast (NRC, 2003) and are therefore likely over-conservative without further calibration.

Table 4.3: Storm cut for 10 year ARI event assessed using Komar et al. (1999) geometric model of foredune erosion

Site	Total water level (WL, m)	Dune toe level (H_j, m)	Vertical erosion depth (ΔBL, m)	Beach face slope	Maximum excursion distance (DE_{max}, m)
Ahipara (profile AH1)	4.3	2.5	0	0.024	74
Taipa	4.2	2.0	0	0.0375	58
Waipu	5.5	2.5	0	0.053	56

4.6.2.3 Semi process-based methods

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

Semi process-based model description

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

Model input

A representative cross-shore profile from the dune crest to the RL -10 m contour was assessed for each coastal cell based on average profile surveys information, although often only one representative profile was available for each beach. Beach profile information was supplemented by LiDAR data landward of the dune crest and LINZ bathymetric charts where surveyed profiles do not extend to the RL -10 m contour.

Design storm nearshore time series including wave height, period and water level are applied at the outer profile boundary (i.e. Figure 4.6 for Waipu Cove). Design storms for 10 year, 100 year and 2x100 year ARI events are simulated with the later allowing for potential clustering of storms. Such clustering may result in greater erosion as the first event lowers the beach height and relatively greater wave energy may reach the backshore in subsequent events.

Grain size characteristics are included for each profile based on the results of grain size analysis undertaken by the University of Waikato.

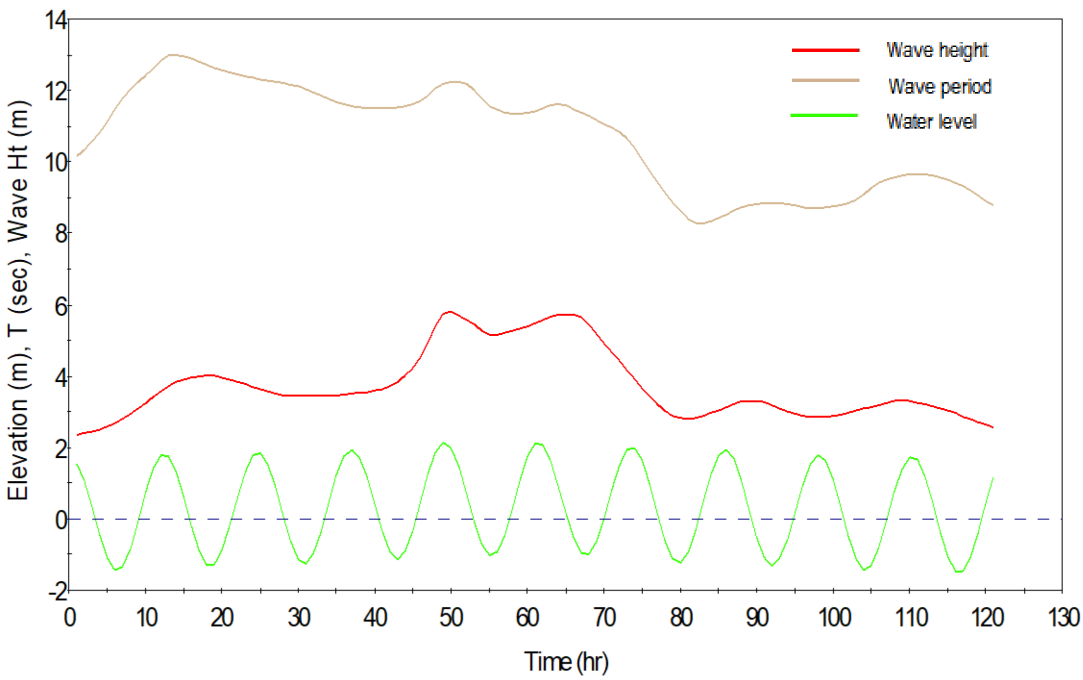


Figure 4.6: Example synthetic 100 yr design storm input for Waipu Cove

Model results

SBEACH assumes an equilibrium profile concept which instantly responds to the present wave forcing conditions and calculates an equilibrium profile based on that forcing. Figure 4.7 shows the initial and equilibrium profiles formed due to 10, 100 and 2x100 year ARI storms for Waipu Cove. Changes in horizontal shoreline position at a predefined contour (i.e. the dune toe) provide information on short-term erosion distances. For Waipu Cove, which is partially sheltered from the design storm wave height, these distances are 5, 10 and 15 m respectively.

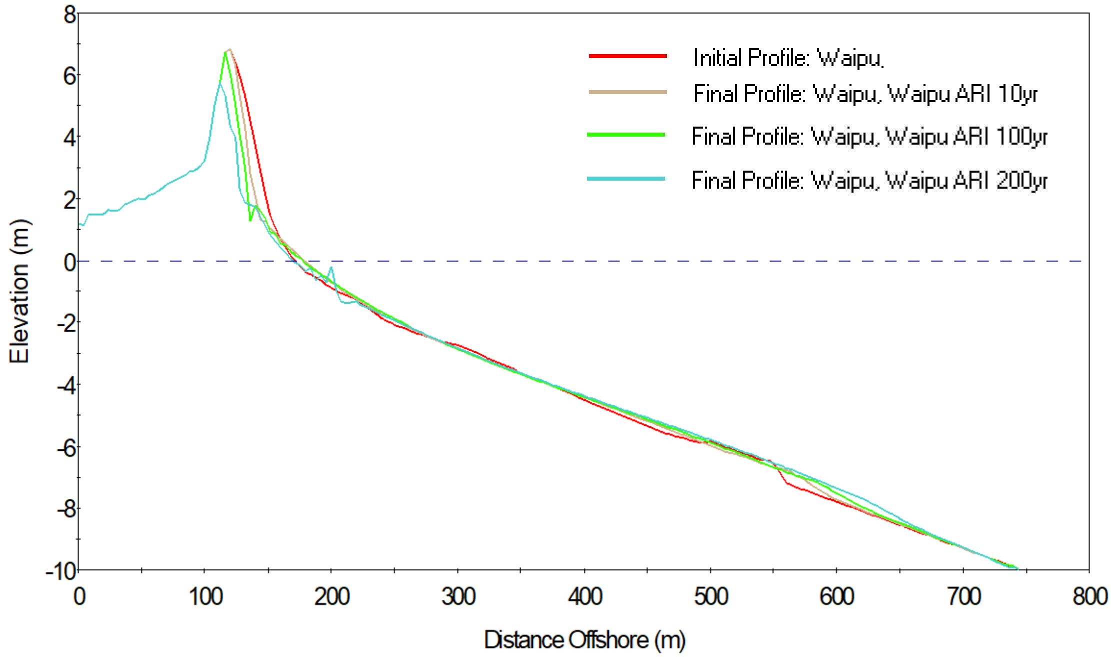


Figure 4.7: Example SBEACH results for Waipu Cove

The range of shoreline excursion distances calculated by SBEACH for open coast Northland Beaches is shown in Table 4.4. Results show average shoreline excursion on east coast beaches to range from 11 to 21 m for the different storm magnitudes, although values for specific beaches range considerably depending on exposure, offshore profile and sediment characteristics.

Table 4.4: Storm excursion distances calculated by SBEACH for east and west coast beaches

Storm	10 year	100 year	2 x 100 year
Open East coast	11 m (1.5 to 25m)	16 m (5 to 35 m)	21 m (9 to 50 m)
Open West coast	3 m (1.5 to 4 m)	4 m (2.5 to 5.5 m)	8.5 m (5.5 to 8.5 m)

Numerical storm cut distances of 3 to 8.5 m were found for west coast beaches. However, we consider that this model likely underestimates storm cut on dissipative west coast beaches as it does not include the effects of infra-gravity waves which dominate swash motions and sediment transport on dissipative beaches. Alternative methods such as statistical or anecdotal measures are therefore considered more reliable in these locations and were adopted in preference.

4.6.2.4 Statistical methods

The horizontal position of shorelines derived from aerial photographs or contours (typically MHWS) extracted from profile analysis can be used where available to assess short-term fluctuation.

The Beach Morphology Analysis Package (BMAP) has been used to calculate the change in horizontal shoreline position per surveyed beach profile. BMAP is an integrated set of computer analysis routines compiled at the U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center (CERC) for analysing beach profile morphology and its change (Larson and Kraus 1992).

Figure 4.8 shows an example of the available (45 surveyed) beach profiles for Waipu Cove. The excursion of the RL 1m contour, which is approximately high tide, has been assessed in BMAP to provide a plot of contour position over time (Figure 4.9). While this plot provides some information on trends the data sets are generally too short to inform the long-term components. The data is therefore de-trended to remove any long-term effects leaving residual excursion distances (Figure 4.10).

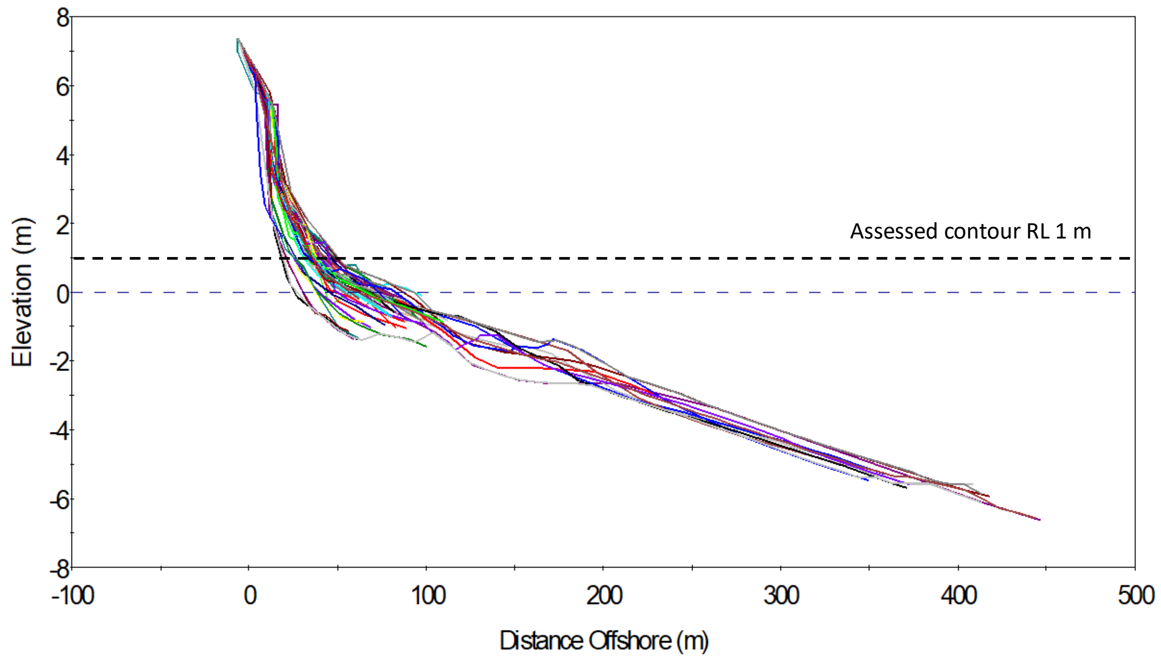


Figure 4.8: Example beach profiles for Waipu Cove

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

With sufficient data, these may be interpreted as the bounding and modal parameters of the short-term fluctuation parameter. However, without frequent survey data, particularly immediately following storm events, it is likely that the maximum impact of storms is omitted as some beach recovery will occur before the next regular survey or aerial photographic record. On the other hand a series of storms may occur between two consecutive surveys, with survey data showing the shoreline retreat due to multiple storms.

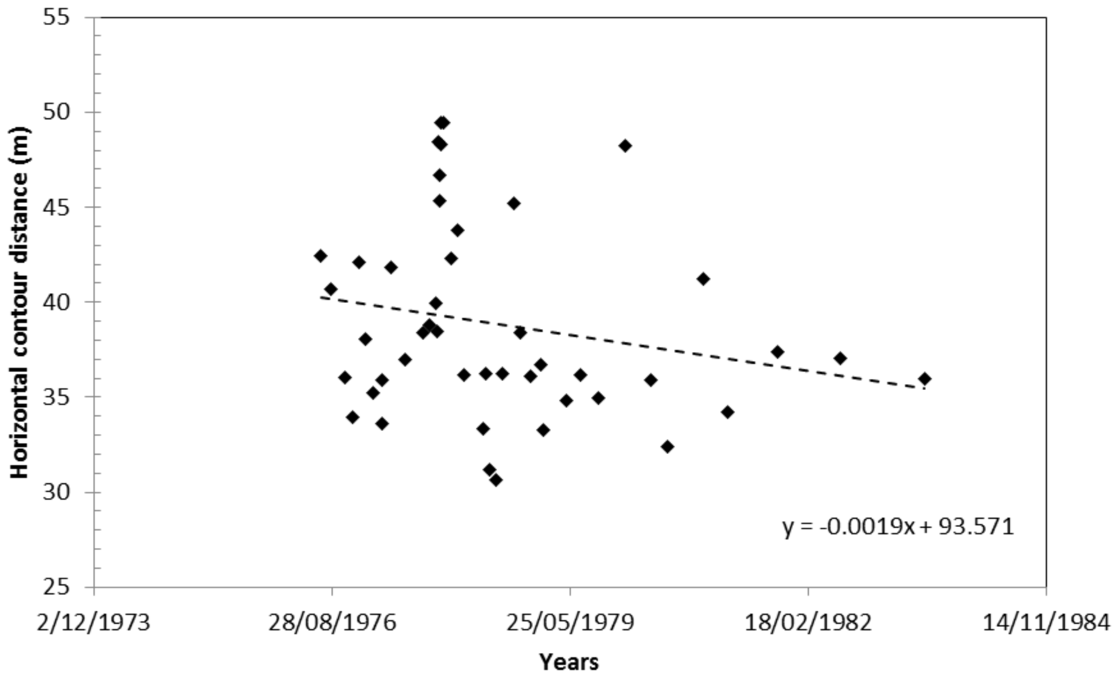


Figure 4.9: Example Linear Regression for Waipu Cove

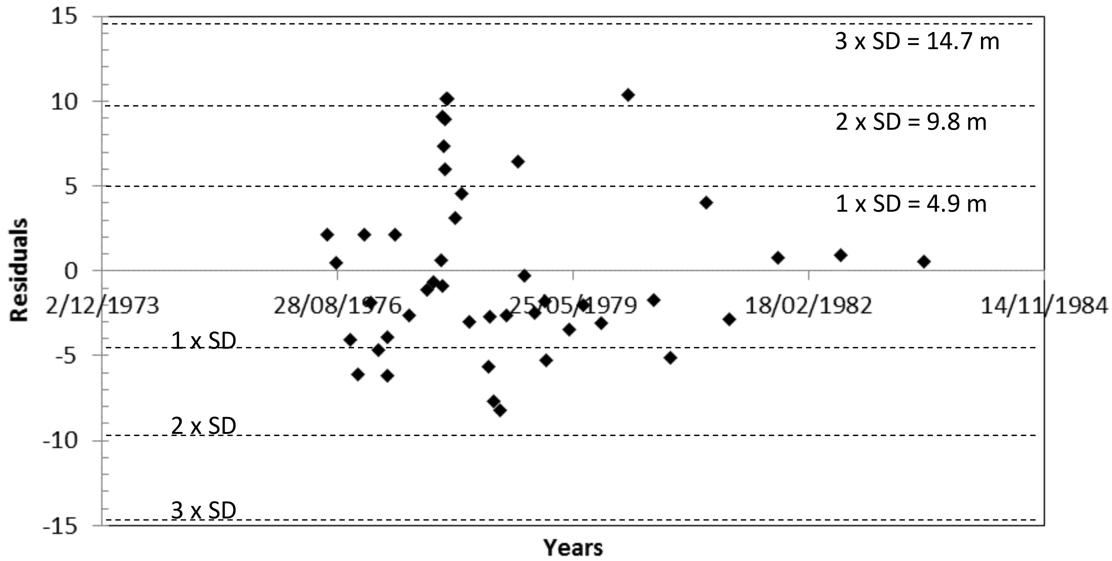


Figure 4.10: Example contour excursion residuals (de-trended) for Waipu Cove

Table 4.5 shows the average statistical measures of shoreline excursion for Northland Beaches. These results show that for open east coast beaches average 1 x 2 x and 3 x the SD values are 4.2, 8.4 and 12.6 m respectively, or around half the value found by the process based SBEACH modelling and significantly less than the values derived from the geometric model. Excursion distances for estuarine shorelines were significantly smaller at 1 to 5 m and beach profile data was insufficient at open west coast beaches to allow analysis (i.e. only 1 profile). Previous work by Tonkin + Taylor (2006) has analysed profiles on similar beaches at Muriwai and Piha and found average values of 6.8, 13.6 and 20.5 m.

Table 4.5: Average statistical measures of shoreline excursion of Northland Beaches

Storm	1 x Std Dev	2 x Std Dev	3 x Std Dev
Open East coast	4.2 m (0.3 to 15 m)	8.4 m (0.6 to 30 m)	12.6 m (0.9 to 45 m)
Estuarine East coast[1]	1 m (0.4 to 1.5 m)	2 m (0.8 to 3 m)	3 m (1.2 to 4.5 m)
Open West coast[2]	6.8 m (4.7 to 10 m)	13.6 m (9.3 to 20 m)	20.5 m (14 to 30 m)
Estuarine West coast[3]	1.6 m (0.9 to 2.5 m)	3.2 m (1.8 to 5 m)	4.8 m (2.7 to 7.5 m)

[1]Profiles for Marsden Cove only

[2]Profiles for Piha/Muriwai at 3 m contour as reported in Tonkin & Taylor (2006) as insufficient data exists for Northland west coast sites

[3]Profiles for Omapere and Opononi

4.6.2.5 Adopted values

Different coastal types are influenced to varying degrees by different causes of shoreline movement. Steeper, pocket beaches on the east coast with generally low wave climates periodically impacted by high energy storms or series of storms are likely to be controlled by storm cut, while low gradient, dissipative west coast beaches are expected to be controlled more by fluctuations in sediment supply and seasonal changes in wave climate and water level.

With sufficient data, statistical analysis of profile datasets would provide adequate information to derive short-term effects. Values obtained from the simple geometric model (Komar et al., 1999) were deemed to be based on non-realistic assumptions for these coastlines and overly conservative and have therefore not been used. For the present assessment, both statistical and numerical methods have been used to derive short-term components. Results have been compared and a combined distribution constructed based on quality of data and the resultant values. While the exact combination is site-specific, typical values are provided in Table 4.6.

Table 4.6: Typical short-term erosion component values

Site	Wave climate	Typical adopted short-term erosion values	Evidence
East coast open coast	Low wave climate	5 to 10 m	Generally based on SBEACH model results for 10, 100 and 2x100 year ARI design storms supplemented with statistical values where sufficient data exists
	Moderate wave climate	10 to 20 m	
	High wave climate and/or dynamic shoreline	10 to 30 m	
Estuarine shoreline	Sheltered	2 to 6 m	Based on analysis of profile data and previous studies such as T+T (2012)
	Exposed	5 to 10 m	
West coast	Moderate wave climate	5 to 15 m	Based on statistical analysis of profile data for similar west coast beaches (Piha and Muriwai reported in T+T, 2006)
	High wave climate	10 to 20 m	

4.6.3 Dune and cliff stability

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

$$DS = \frac{H_{dune}}{2(\tan \alpha_{sand})} \qquad (4.5)$$

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

Along cliff and soft shore banks, the stable angle is dependent on a range of factors such as geological type, weathering profile, local bedding and faulting characteristics, groundwater level, overland flow paths and vegetation cover. Furthermore, if a slope comprises multiple rock types (for example a competent underlayer and weathered cover material), composite angles incorporating stable angles of repose for each material must be derived.

Characteristic composite stable angles of repose have been derived for each cliff site by Geologists from T+T based on previous experience and local studies.

4.6.4 Long-term trends (LT)

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

Long-term trends have been evaluated by the analysis of the historic shoreline positions. These have been derived from geo-referenced historic aerial photographs, augmented with cadastral surveys and surveyed dune, cliff, or bank toe data obtained in 2014.

The shoreline data has been analysed using the GIS-based DSAS model. DSAS processes the shoreline data and calculates shoreline change statistics at a specified (e.g. 5 m) intervals along each site. Figure 4.11 and Figure 4.12 present examples of DSAS results for Bland Bay based on 5 aerial photographs between 1955 and 2013 with results displayed spatially and graphically respectively. Rates of long-term shoreline movement are derived using weighted linear regression analysis with the 90% confidence intervals providing bounding values for the parameter distribution (WCI). In a weighted linear regression, more reliable data (lower error values) are given greater emphasis or weight towards determining a best-fit line. By calculating trends along the entire shoreline, rather than at a low number of discrete points, alongshore variation in trends can be determined and either used to inform parameter bounds or separated into separate coastal behaviour cells.

Notes: Background aerial from Esri database.
DSAS output taken as Weighted Linear Regression (WLR)

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CEHZ Assessment for Selected Northland Sites
Bland Bay DSAS results

FIGURE No. Figure 4.11

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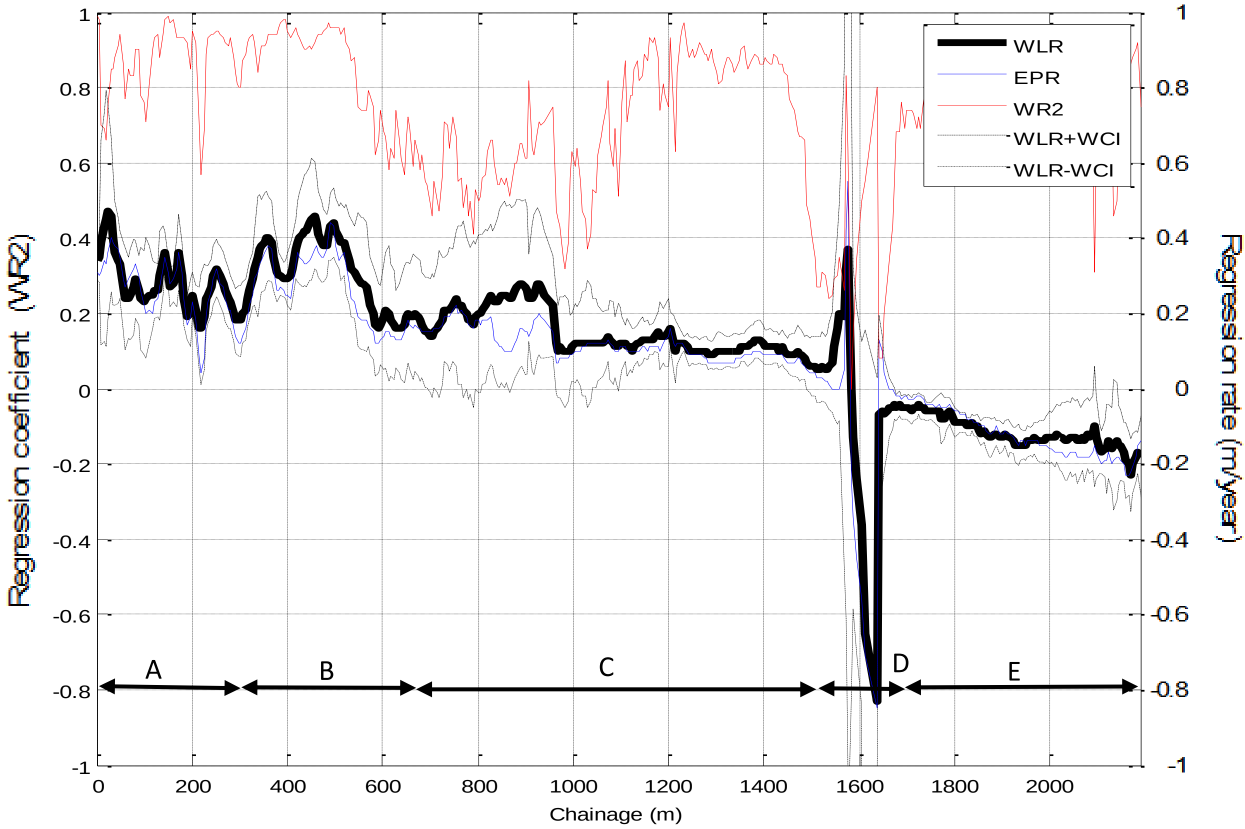

Figure 4.12: Results of weighted linear regression (WLR ▬) analysis of historic shoreline positions for Bland Bay from North to South with coastal cells indicated by letters A to E. The 90% confidence intervals for the WLR are also presented (- -) together with WLR R2 value indicating goodness of fit (—) and, for comparison, the end point rate (—)

4.6.5 Effects of sea level rise (SLR)

4.6.5.1 Adopted SLR values

We have adopted a range of sea level rise values over the required timeframes of at least 50 years (2080) and 100 years (2130). These values conform to guidance provided within MfE (2017), which is based on the IPCC 5th Assessment Report (IPCC, 2013).

Sea level rise projections included in MfE (2017) are relative to a baseline of zero between 1986-2005 (see third column in Table 4.7). An adjustment is required to make these sea level rise predictions relative to the 2019 shoreline that we use as a baseline for this assessment. This has been done by subtracting the amount of ‘projected’ sea level rise between 1995 (median of 1986-2005) and 2019 from the 2080 and 2130 values (see resulting values in fourth column of Table 4.7). These adjusted sea level rise values have been used to assess sea level rise effects for consolidated cliff shorelines (refer to Section 4.6.5.3).

An additional adjustment of sea level rise values has been undertaken for unconsolidated beach sites. The projected sea level rise values included in MfE (2017) incorporate the historic sea level rise rates (i.e. 2.2 mm/year). As the derived long-term shoreline rates already include the effect of the historic sea level rise, the historic sea level rise should be discounted from the projected sea level rise values to avoid double-counting the effect of historic sea level rise. Therefore, the historic sea level rise is subtracted from the 2080 and 2130 SLR values (for each year since 2019) (see resulting values in fifth column of Table 4.7).

A summary of the adjusted sea level rise used in CEHZ calculations is presented in Table 4.7 (highlighted grey), with the 2080 RCP8.5 scenario representing CEHZ1, 2130 RCP8.5 representing CEHZ2 and 2130 RCP8.5H+ representing CEHZ3.

Table 4.7: Sea level rise (SLR) values (m) utilised in assessment

Timeframe	SLR scenario	Projected SLR relative to 1986-2005 basline[1]	SLR from present day (2019) baseline[2]	'Effective' SLR from present day baseline[2,3]
CEHZ application			Consolidated cliff shorelines	Unconsolidated beach shorelines
2080	RCP2.6	0.37	0.29	0.16
	RCP4.5	0.42	0.34	0.21
	RCP8.5	0.55	0.46	0.33
	RCP8.5H+	0.75	0.64	0.51
2130	RCP2.6	0.6	0.52	0.28
	RCP4.5	0.74	0.66	0.42
	RCP8.5	1.18	1.09	0.85
	RCP8.5H+	1.52	1.41	1.17

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

[2] Correction applied to adjust from 1986-2005 (taken to be 1995) to 2019 (base shoreline derived from 2019 LiDAR DEM)

[3] Subtract historic rate of 2.2 mm/year (Hannah & Bell, 2012) to avoid double-counting erosion response

4.6.5.2 Beach response

Geometric response models propose that as sea level is raised, the equilibrium profile is moved upward and landward conserving mass and original shape (Figure 4.13). The most well-known of these geometric response models is that of Bruun (Bruun, 1962, 1988) which proposes that with increased sea level, material is eroded from the upper beach and deposited offshore to a maximum depth, termed closure depth. The increase in seabed level is equivalent to the rise in sea level and results in landward recession of the shoreline. The model may be defined by the following equation:

$$SL = \frac{L_*}{B + d_*} S \quad (4.6)$$

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

The rule is governed by simple, two-dimensional conservation of mass principles and assumes no offshore or onshore losses or gains and an instantaneous profile response following sea-level change. The rule assumes an equilibrium beach profile where the beach may fluctuate under seasonal and storm-influences but returns to a statistically average profile (i.e. the profile is not undergoing long-term steepening or flattening). Losses or gains to the system and changes to the equilibrium profile are likely accounted for within the long-term change parameter and therefore are not likely to introduce additional uncertainty. The definition of a closure depth (maximum seaward extent of sediment exchange) and the lag in response of natural systems have been cited as significant limitations in the method (Hands, 1983).

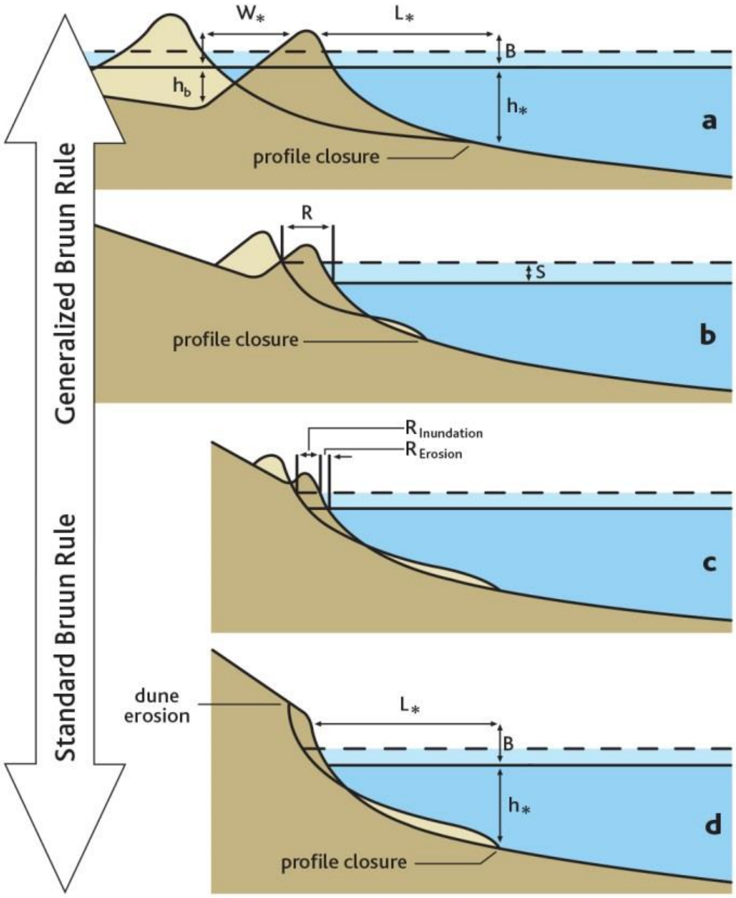

Figure 4.13: Schematic diagrams of the Bruun model modes of shoreline response (after Cowell and Kench, 2001)

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

Shand et al. (2013) argue that as sea-level rise is expected to be ongoing, then the outer limit of profile adjustment is likely to be 'left behind' before it can reach equilibrium. The closure depth can therefore be more realistically defined as the point at which the profile adjustment can 'keep up' with sea-level change and becomes a calibration parameter in lieu of an adequate depth-dependent lag parameter. Shand et al. (2013) tested a range of closure depth definitions against a non-equilibrium model calibrated using 30 years of beach data (Ranasinghe et al., 2011). Results (Figure 4.14) show the various definitions of closure to predict Recession/SLR values straddling the entire probabilistic (2–99%) range predicted by the Ranasinghe's probabilistic model.

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

$$d_l = 2.28 H_{s,t} - 68.5(H_{s,t}^2 / gT_s^2) \cong 2 \times H_{s,t} \quad (4.7)$$

$$d_i = 1.5 \times d_l \quad (4.8)$$

Where d_l is the closure depth below *mean low water spring,* $H_{s,t}$ is non-breaking significant wave height exceeded for 12 hours in a defined time period, nominally one year, and T_s is the associated period. Table 4.8 shows the resulting closure slopes for different environments.

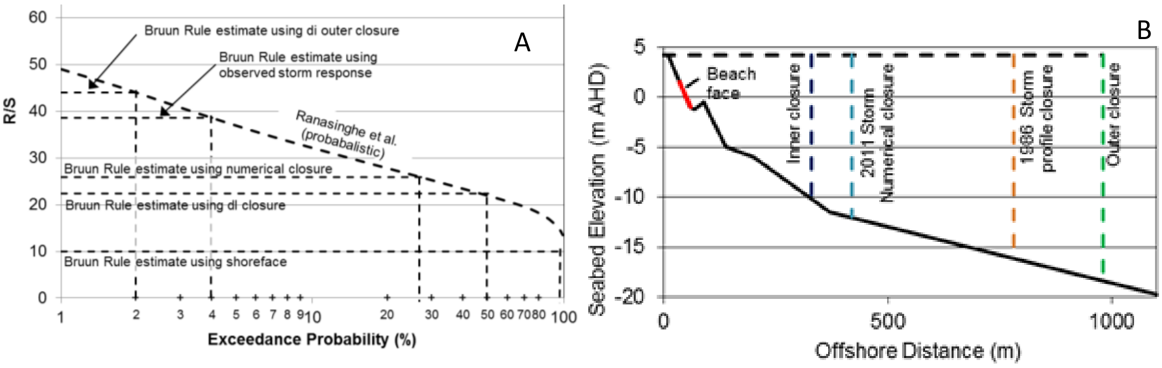

Figure 4.14: Probabilistic estimate of relative coastal recession at Narrabeen Beach (from Ranasinghe et al., 2011) with Bruun Rule estimates (A) using a variety of closure estimators (B).

Table 4.8: Summary of resulting closure slopes for different environments

	Closure slope ranges		
Site	**Min**	**Mode**	**Max**
East coast open coast	0.750 to 0.013	0.50 to 0.009	0.250 to 0.007
Estuarine shoreline	1.353 to 0.032	1.275 to 0.080	1.196 to 0.006
West coast	0.044 to 0.020	0.03 to 0.008	0.040 to 0.006

Exceptions to this are the non-consolidated shorelines within estuaries, such as coastal terraces, or beaches perched on rock platforms or intertidal flats where the beach and fronting material do not interact. In this case, the beach slope above the intersection of the beach and fronting platform is adopted. This is consistent with the principles described in the eShorance estuary shoreline response model (Stevens and Giles, 2010).

4.6.5.3 Cliff response

Erosion of consolidated shorelines is a one-way process which typically has two components; a gradual recession caused by weathering and coastal processes, and episodic failures due to cliff lithology and geologic structure.

Gradual recession due to weathering is a function of climatic conditions, exposure and cliff material. Marine hydraulic processes affect cliffs either by wave action causing erosion at the toe, or by removing slope debris deposited at the toe following subsequent cliff-face collapse. Sea level rise increases the amount of wave energy able to propagate over a fronting platform or beach to reach a cliff toe, removing talus more effectively and increasing the potential for hydraulic processes to affect erosion and recession, however, in some locations, the talus may be self-armouring, and may slow cliff recession due to waves.

DEFRA (2002) propose a simple method to evaluate recession in soft-cliff environments by assuming that future recession (LT_F) will be proportional to historic rates (LT_H) multiplied by the ratio of future

(S_F) to historic sea-level rise (S_H). The model shown in Equation 4.9 below assumes, however, that the profile will respond instantaneously and that all recession that has occurred historically was a function of historic sea-level rise (i.e. marine processes).

$$LT_F = LT_H \times \frac{S_F}{S_H} \quad (4.9)$$

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

$$LT_F = LT_H \sqrt{\frac{S_F}{S_H}} \quad (4.10)$$

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

Ashton et al. (2011) propose a generalised expression for future recession rates of cliff coastlines shown in Equation 4.11 and Figure 4.15 where the coefficient *m* is determined by the response system. S_1 and S_2 relate to the S_H (historic sea level rise) and S_F (future sea level rise) respectively. An instantaneous response (m = 1) equates to Equation 4.11 where the rate of future recession is proportional to the increase in SLR. A negative/damped feedback system occurs where rates of recession are slowed by development of a shore platform or fronting beach. No feedback ($m \rightarrow 0$) indicates that wave influence is negligible, and weathering dominates. They suggest an additional case of inverse feedback when $m < 0$ indicating a reduction in recession with increasing sea levels. They suggest this could occur when erosion is controlled by bio-erosion which may reduce with additional submergence. This approach is conceptually plausible and has the potential to predict recession rates on a wide variety of rock types with further analysis.

$$R_2 = R_1 \left(\frac{S_2}{S_1} \right)^m \quad (4.11)$$

This generalised expression has been adopted for the present assessment in locations where the fronting beach volume is less than approximately 20 m^3/m. Given the uncertainties in deriving response type without detailed site-specific modelling and analysis, a range of response types have been adopted as parameter bounds. Material erosion susceptibility (i.e. hardness) and wave exposure are the two main factors which contribute to cliff shoreline response. Without any other data available to derive response factor, the SLR response factors have been derived based on relative material susceptibility and wave exposure for the adopted main types of geology for the Northland region using the negative/damped feedback system (m = 0.5) as a basis/upper bound.

For soft, weakly consolidated cliff and coastal terraces (i.e. Tauranga and Awhitu Group sediments and completely weathered rock) m = 0.5 was adopted as an upper bound value, with m = 0.3 and m = 0.4 as lower and modal bounds respectively. The response to SLR factors are the same for any wave exposure as lower *m* values would not be appropriate for these soft cliffs and higher values not realistic based on Ashton et al. (2011). The Dacite lave was observed within the Mangawhai Estuary and was assessed by an engineering geologist as highly susceptible and therefore has the same SLR response factors as the soft cliffs.

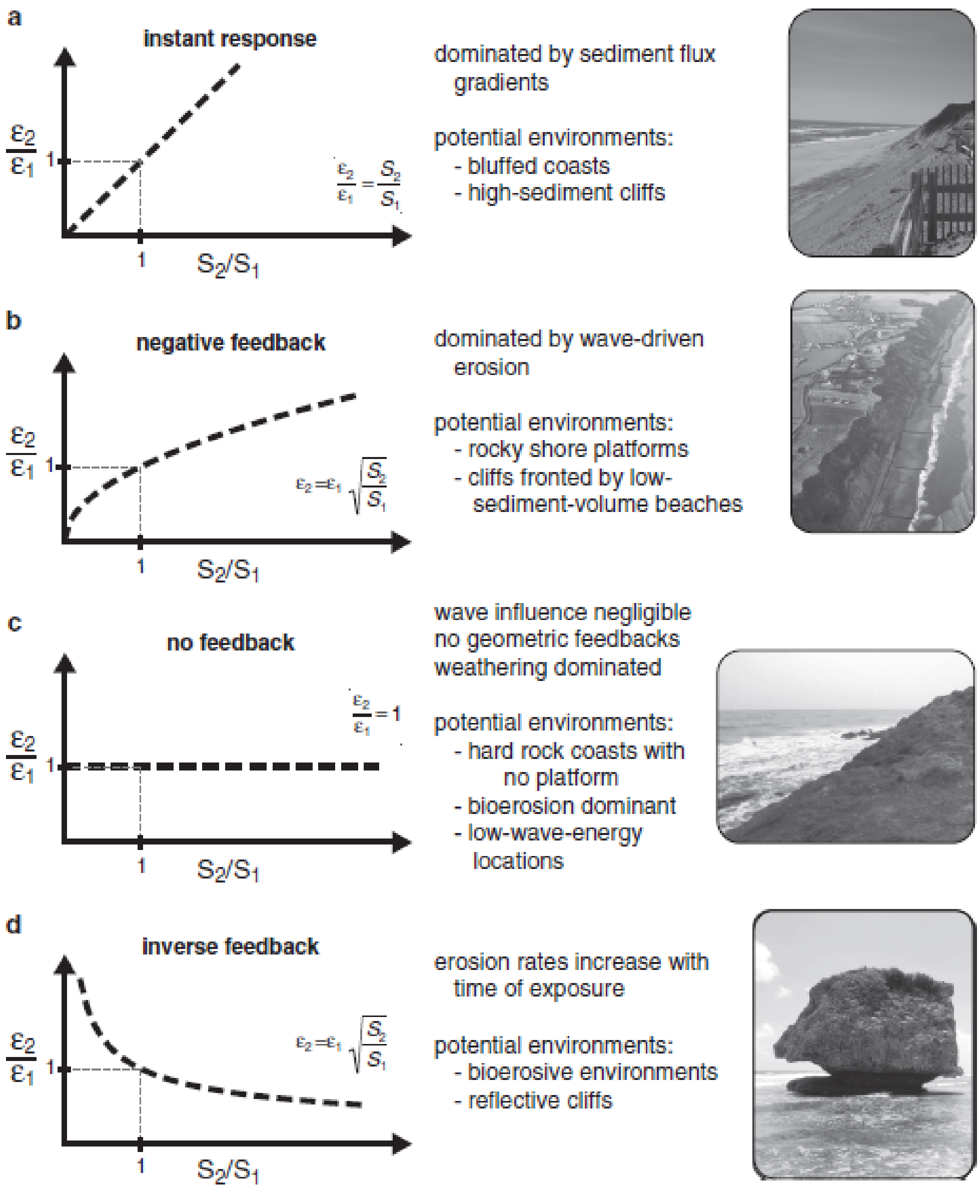

Figure 4.15: Possible modes of cliff response to SLR (adapted from Ashton et al., 2011)

Waipapa Greywacke is typically less susceptible and therefore lower *m* values were adopted that vary based on wave exposure. For high wave exposure *m* values range from 0.2 to 0.4 and for low wave exposure *m* values range from 0 to 0.2. For hard cliffs such as basalt, a no feedback response (*m* = 0) was assumed as a basis, with *m* values range from 0 and 0.1.

Table 4.9: Adopted SLR response factors for unconsolidated shorelines (*m* values)

Geological unit	Material susceptibility	Exposure	Min	Mode	Max
Basalt	Low	Any	0	0.05	0.1
		Low	0	0.1	0.2
		Med	0.1	0.2	0.3
Waipapa Greywacke	Med	High	0.2	0.3	0.4
Decite Lava	Med-High	Any	0.3	0.4	0.5
Mudstone/Limestone Weakly cemented sediment Weakly consolidated colluvium	High	Any	0.3	0.4	0.5

4.6.5.4 Estuarine response due to inundation

In low-lying estuarine environments increased future sea level may result in inundation of the backshore. While this is not technically erosion (loss of material), the net result is the same with the mean shoreline position being translated inland. This term has therefore been assessed separately in low-lying environments where recession by the Bruun Rule or cliff erosion methods are not applicable. This component has been assessed on a case-by-case basis and parameter bounds are due to uncertainties in sea level rise as described earlier.

4.7 Anthropogenic effects

The human influences on coastal erosion hazard assessments include:

- construction of land protection works (seawalls/revetments, etc.)
- mining and removal of beach sand, or nourishment
- concentration of storm water and surface flows down cliff and bank faces
- modification of dune vegetation.

The effects of historic removal or addition of beach sand on the sediment budget cannot be quantified due to lack of data and targeted monitoring. As these activities have generally ceased along Northland Beach, they are expected to influence the derived future erosion hazard zones but any future applications to undertake such activities should consider the effects on sediment budget and erosion hazard.

Modifications to natural dune vegetation (e.g. Glinks Gully) can alter dune recovery patterns following storm events. An example of this is at Tokerau Beach where degradation of the dune vegetation has limited the ability of the dune system to recover following storm events (Howse, pers. comm., Feb 2014) and could potentially affect long-term rates of erosion. While this is possible, the quality of available data (survey or aerial photograph) has not allowed assessment to this level of detail. Ongoing profile monitoring will assist in quantification of any changes to long-term trends as a result of such modifications.

While properly designed coastal protection works along beach or cliff toes can reduce erosion rates while in place, the shoreline position is generally returned to its long-term equilibrium position rapidly once the structure fails or is removed. We have therefore evaluated the hazard extent excluding the effects of any structures. This identifies the potential land area that could be affected, or the area that is benefitting with the structure. Informed decision around the future maintenance or re-consenting of structures can then be made. For shorelines that have been reclaimed a nominal long-term rate of 0 ±0.1 m/year have been adopted. For shorelines that have been protected for a long period and unable to derive a long-term rate, the same nominal long-term rate or the long-term rate from the adjacent cells if the same exposure and morphology was adopted.

4.8 Combination of parameter components to derive CEHZ

For each coastal cell, the relevant parameters influencing the CEHZ and parameter bounds have been defined according to the methods described above as summarised in Table 4.10. Probability distributions constructed for each parameter are randomly sampled and the extracted values used to define a potential CEHZ distance. This process is repeated 10,000 times using a Monte Carlo technique and probability distribution of the resultant CEHZ width is forecast.

Table 4.10: Theoretical erosion hazard parameter bounds

Parameter	Lower bound	Mode	Upper Bound
ST (m)	10% AEP storm cut or 1 x standard deviation (SD) of contour excursion	1% AEP storm cut or 2 x SD	2 x 1% AEP cut or 3 x SD or existing ST value
DS (m)	H_{max} & α_{min}	H_{mean} & α_{mean}	H_{min} & α_{max}
LT (m/year)	-90% CI of smallest trend in cell	Mean regression trend	+90% CI of largest trend in cell
SLR (m)[1]	Values shown for 'Effective SLR' in in Table 4.7		
Closure slope[1]	Slope across active beach face to typical swash excursion	Slope from dune crest to inner Hallermeier depth	Slope from dune crest to outer Hallermeier closure depth
LT_F	Values shown in Table 4.9		

[1]SL component is a function of SLR and active beach slope parameters. Note that for coastal terraces the slopes between the coastal edge toe and intersection between beach and intertidal flat/rock platform is used instead of closure slopes.

Figure 4.16 presents an example component and CEHZ histogram cumulative distribution functions for Waipu Cove at 2130. Results show the possible CEHZ to range from 23 to 46 m, with a $P_{50\%}$ (50% probability of exceedance) value of 34 m for the RCP2.6 scenario (lowest SLR scenario). For the highst SLR scenario (RCP8.5H+) the possible CEHZ ranges from 40 to 84 m, with $P_{50\%}$ value of 60 m. The $P_{5\%}$ is 40 and 74 m for respectively the RCP2.6 and RCP8.5H+ scenarios, which is substantially below the maximum extents, and the $P_{66\%}$ is 33 and 56 m respectively.

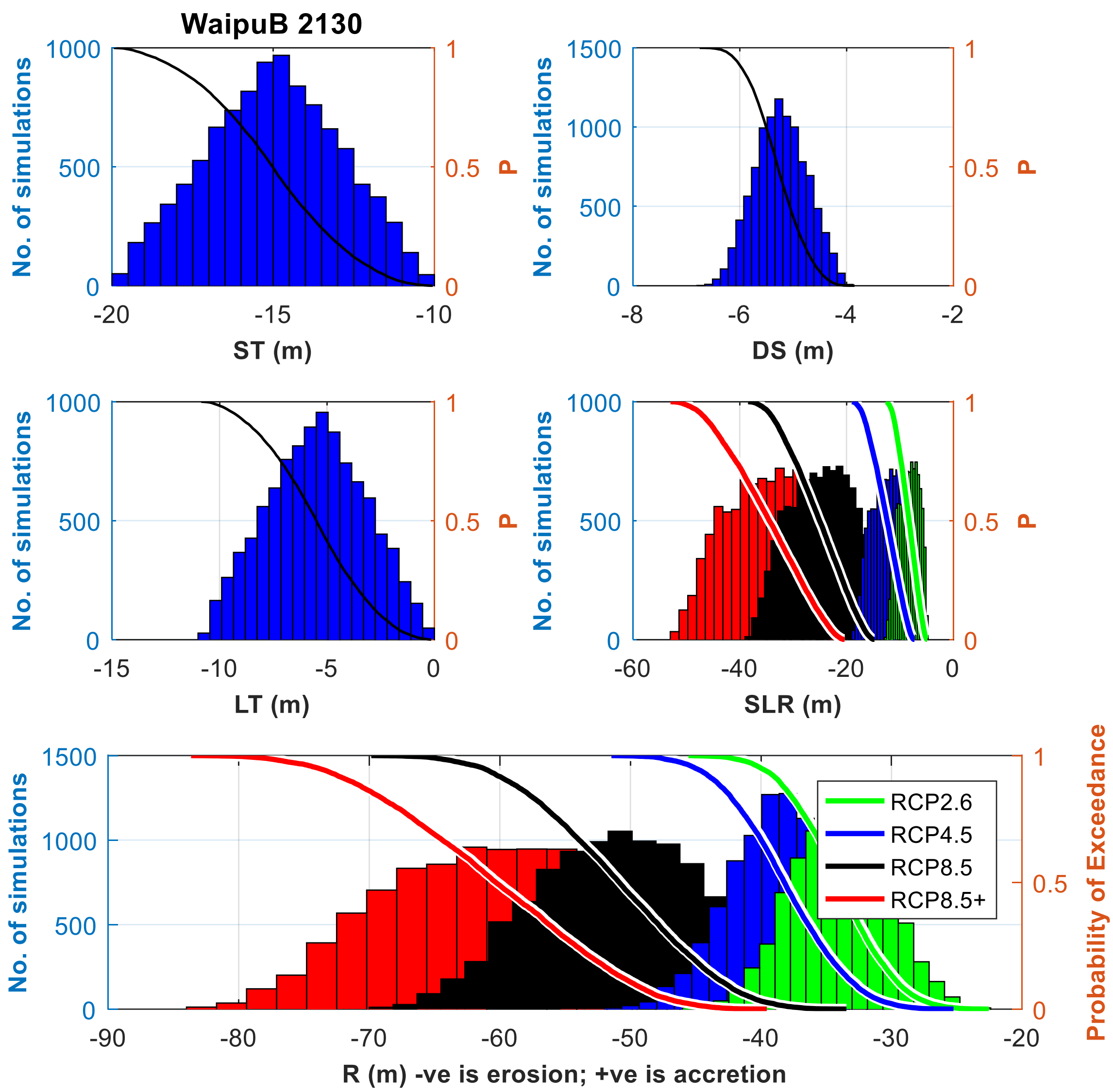

Figure 4.16: Example histograms and cumulative distribution functions of parameter samples and the resultant CEHZ distances for Waipu Cell B 2130

4.9 Mapping of the CEHZ

Coastal erosion hazard zone distances are mapped as offsets to the existing baseline and represent areas potentially susceptible to coastal erosion (i.e. not future shoreline). Figure 4.17 shows a cross-shore schematisation of the current and future CEHZs including the current and future shorelines for a cliff shoreline.

Figure 4.18 shows the range of CEHZ values for an unconsolidated shoreline at Waipu Cove at 2130. Where the hazard values differ between adjacent coastal cells, the mapped CEHZ is merged over a distance of at least 10 times the difference between values providing smooth transitions or along contours or material discontinuities where these are present. For example, transitioning from a cliff to a dune morphology would generally follow the contour line. Specific refinements of the mapping for cliff coasts and where consented seawalls are present are discussed below.

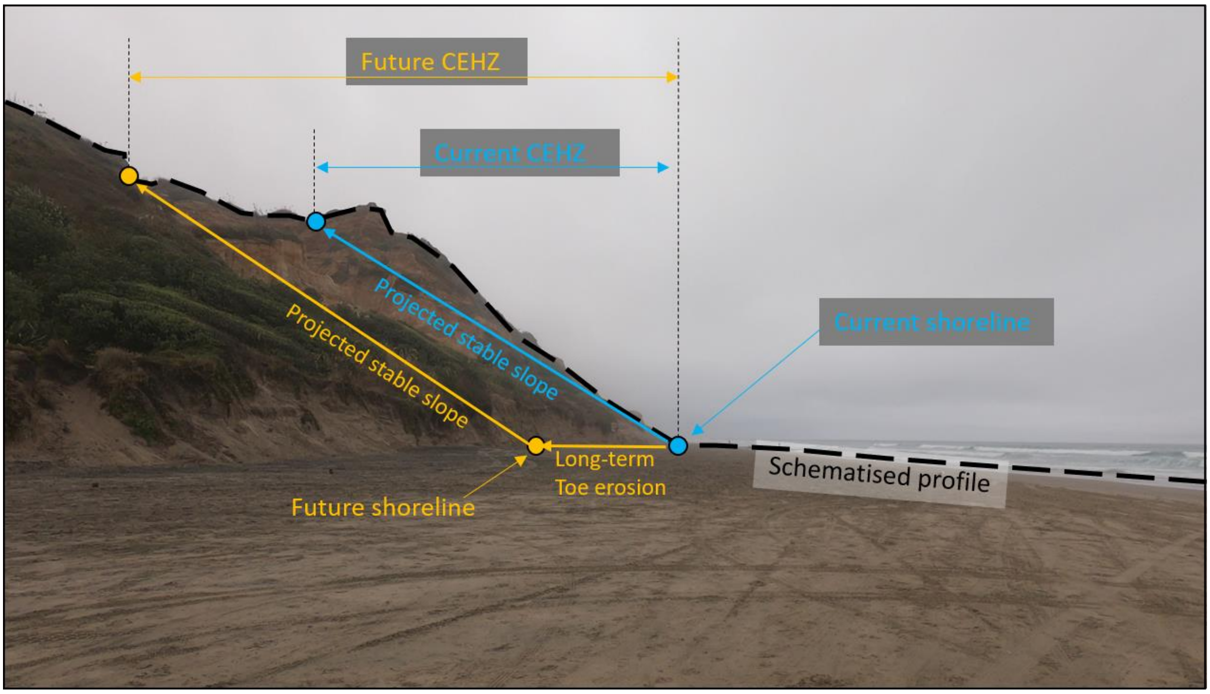

Figure 4.17: Schematisation of current and future CEHZs for a cliff shoreline including current and future shoreline positions

Notes: Background aerial from Esri database.

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PROJECT No. 1012360

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CEHZ Assessment for Selected Northland Sites
Waipu Cove CEHZ 2130

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4.9.1 Cliff CEHZs

CEHZs for cliff coasts ($CEHZ_{cliff}$) include a range of cliff heights and are combined with stable angles and future cliff toe positions (see Equation 4.2). However, for some sites the cliff height may vary significantly along coastal cells resulting in both conservative and non-conservative estimates of hazard width. The following method (termed cliff projection method) has therefore been adopted to map the cliff CEHZs which takes into account cliff topography more accurately:

- For each selected cliff section, construct a digital elevation model (DEM) based on available LiDAR data that includes ground points only (i.e. excluding vegetation etc.)
- Re-run Monte-Carlo simulations to determine the future cliff toe position based on the long-term erosion value and sea level rise
- Project stable cliff angles (maximum for CEHZ1 and modal for CEHZ2 and CEHZ3) back into each DEM from the future cliff toe positions at <2 m intervals. The resultant hazard zone is the intersection of the above land and the stable slope
- Combine the intersection points alongshore and map the cliff CEHZs.

By re-running the Monte-Carlo simulations a probabilistic future cliff toe position is obtained which is in keeping with the risk-based approach. However, deterministic stable slopes are adopted to project the resultant hazard.

This method has been applied to all cliff sites/cells except where the backshore has a slope close to the stable angle. In these locations the resulting CEHZs can be very large and is deemed unrealistic. In these circumstances, the original CEHZ method assuming a range of representative cliff heights yield more reasonable results and have been adopted in preference.

Table 4.11 shows the cliff coasts sites/cells for which the cliff projection methodology was used. The future cliff toe/shoreline distances for both at least 50 year and at least 100 year time frames are tabulated in the Coastal Erosion Hazard Zone Widths tables in Appendix A instead of the CEHZ1, CEHZ2 and CEHZ3. These have been indicated with an asterisk.

Table 4.11: Cliff coast sites/cells for which the CEHZ have been reassessed

Site name	Site number	Cell
Langs Beach	1	A, D, F
Ruakaka	3	CC
Marsden Cove	5	D
One Tree Point	6	B, BB, C, D
Taiharuru	7	A, C
Waitangi	19	A
Hihi	24	A, B, F
Coopers	25	A - G (all)

4.9.2 Shorelines protected by structures

CEHZs for shorelines protected by consented structures (CEHZ0) have been assessed to reflect the protection potentially offered by these structures while they remain functional. Where the structure extends to the crest of the backshore (i.e. along a beach or low coastal terrace), the CEHZ is at the structure crest. However, where the structure protects the toe only, the unprotected backshore above the structure will flatten to form a stable angle (Figure 4.19). In these cases the CEHZ has been determined by the following methodology:

- For each cliff section, construct a digital elevation model (DEM) based on available LiDAR data
- Digitise the current cliff toe position based on the constructed DEMs and aerial photographs
- Project stable cliff angles back into each DEM from the current cliff toe position. The resultant hazard zone is the intersection of the above land and the stable slope
- Combine the intersection points alongshore and map the CEHZ.

Note that this assessment has not considered the current condition of coastal structures and does not provide any opinion as to the expected remaining structure life. The CEHZ values will only be valid as long as the structures remain effective. Protective structures may fail as a result of lack of maintenance, subsidence, overtopping by waves, or lateral erosion from adjacent unprotected shorelines and the shoreline rapidly adjust to an eroded location that would have occurred if no erosion protection was present.

Figure 4.19: Example of protected and non-protected cliffs at One Tree Point, with the upper parts of the protected cliffs flattening to achieve a stable angle and becoming vegetated

4.10 Uncertainties and limitations

Uncertainty may be introduced to the assessment by:

- an incomplete understanding of the parameters influencing the coastal erosion hazard zone
- an imprecise description of the natural processes affecting, and the subsequent quantification of each individual parameter
- errors introduced in the collection and processing of data
- variance in the processes occurring within individual coastal cells
- other hazards such as land based geotechnical instability, or planning and landscape impacts, etc. are not accounted for within the CEHZ.

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

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

Similarly, numerical models are beginning to better resolve the physical processes responsible for coastal erosion. However, complex coupled models are computationally expensive and heavily reliant on quality, long-term data. Without such data, complex model results are largely meaningless. We have attempted to balance the use of numerical modelling where useful (wave and beach response) with analytical and empirical assessment to ensure results are robust and sensible.

Uncertainty in individual parameter is incorporated into the present assessment within the individual parameter bounds. Greater uncertainty (i.e. around stream mouths) utilises wider parameter bounds while less uncertainty utilises narrower bounds. This allows independent uncertainty terms to be combined within the probabilistic framework rather than utilising a single factor or adding uncertainty to each term as has been done previously.

Uncertainties in individual parameter components will reduce as better and longer local data is acquired, particularly around rates of short- and long-term shoreline movement and shoreline response to SLR. Data collection programmes such as beach profiling are essential to reducing this uncertainty and should be continued. In the interim, we recommend that conservative, lower probability CEHZ values are selected for implementation.

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

5 Erosion hazard assessment

5.1 Component values

Components have been assessed for each coastal cell based on the data and methodologies described in the preceding sections. Adopted components are presented for each site within the individual site assessments included in Appendix A.

5.2 CEHZ values

For each coastal cell a range of CEHZ probabilistic values are calculated and presented within the individual site assessments within Appendix A. Following consultation with Council, the $P_{66\%}$ value for 2080 (CEHZ value with a 66% probability of being exceeded by 2080) and the $P_{5\%}$ value for 2130 (5% probability of being exceeded by 2130) were adopted as prudent *likely* and *potential* coastal erosion hazard zones values termed the *CEHZ1* and *CEHZ2* respectively. For both the CEHZ1 and the CEHZ2 the RCP8.5M was adopted as requested by NRC. It was further requested to assess a third hazard zone, similar to CEHZ2 but instead using the RCP8.5H+, termed *CEHZ3*. CEHZs for shorelines protected by consented structures have been termed CEHZ0.

For consolidated shorelines where the methodology as set out in Section 4.5.2 have been adopted the likely ($P_{66\%}$) and potential ($P_{5\%}$) future cliff toe positions have been determined. The minimum and modal stable cliff angles (refer to Appendix A) have been used to determine the resultant future hazard zones (CEHZ1 and CEHZ2/CEHZ3 respectively).

Minimum set back values have been developed for each coastal type to take into account limitations and uncertainties in our current understanding of processes that drive erosion hazard, limitations in data and modelling techniques. These judgement-based minimum values as derived by T+T (2014) correspond to the average of the lowest one-third of values for each of the coastal types and are presented in Table 5.1. For beaches this corresponds to 15 m and 35 m for the CEHZ1 and CEHZ2/CEHZ3 respectively, for soft cliffs and estuary banks to 10 m and 25 m and for hard cliffs such as basalt and greywacke where the effects of sea level rise are minimal, to 10 and 15 m. Utilising these minimum values provides a targeted precautionary approach as advocated in the NZCPS without applying overly conservative factors of safety for sites with sufficient hazard zone widths.

Table 5.1: Adopted minimum CEHZ values

Coastal type	Minimum CEHZ1	Minimum CEHZ2/CEHZ3
Open coast beach	15	35
Inlet/estuary	10	25
Soft cliff	10	25
Hard cliff	10	15

A summary of the CEHZ values is presented in Table 5.2, with future shoreline distances for cells for which the cliff projection method has been adopted.

Low-lying sites may experience passive shoreline erosion due to sea level rise as the high tide elevation exceeds the crest of the dune of bank edge over a 100 year timeframe. This has been checked for all sites based on analysis of the 2 m NZVD2016 contour taken as the potential high tide level in 100 years' time (MHWS of 0.99 m NZVD2016 plus 100 year SLR of 1.0 m ≈ 2 m NZVD2016). Where the 2 m NZVD2016 contour is further landward than the calculated CEHZ2 or CEHZ3, the shoreline position is more likely to be controlled by the new tidal regime than by wave and storm surge induced coastal erosion.

Table 5.2: Adopted coastal erosion hazard zone values (m)[1]

Name	No.	Cell	CEHZ1	CEHZ2	CEHZ3	Name	No.	Cell	CEHZ1	CEHZ2	CEHZ3
Langs	1	A	-4*	-15*	-17*	Pataua	8	DD	-11	-24	-27
Langs	1	B	-21	-55	-69	Pataua[2]	8	E	-13	-27	-32
Langs	1	C	-24	-59	-74	Pataua[2]	8	F	-9	-21	-26
Langs	1	D	-5*	-17*	-20*	Pataua[2]	8	G	-10	-22	-26
Langs	1	E	-12	-40	-51	Pataua[2]	8	H	-8	-21	-25
Langs	1	F	-9*	-30*	-34*	Whangaumu	9	A	-20	-37	-41
Waipu[2]	2	A	-39	-76	-88	Whangaumu	9	B	-14	-28	-32
Waipu	2	B	-32	-61	-74	Whangaumu	9	C	-14	-35	-39
Waipu	2	C	-23	-51	-64	Matapouri	10	A	-27	-60	-68
Waipu	2	D	-16	-43	-55	Matapouri	10	B	-27	-50	-59
Ruakaka	3	A	-16	-41	-55	Matapouri	10	C	-25	-49	-58
Ruakaka	3	B	-14	-38	-51	Matapouri	10	D	-28	-52	-59
Ruakaka[2]	3	C	-30	-74	-81	Matapouri	10	E	-18	-35	-41
Ruakaka[2]	3	CC	-9*	-27*	-31*	Matapouri[2]	10	F	-12	-28	-34
Ruakaka	3	D	-24	-53	-66	Matapouri[2]	10	G	-14	-32	-38
Ruakaka	3	E	-25	-56	-70	Woolleys[2]	11	A	-18	-36	-44
Marsden Point[2]	4	A	-3	-24	-31	Woolleys	11	B	-17	-34	-41
Marsden Point	4	AA	-24	-98	-120	Woolleys	11	C	-19	-42	-49
Marsden Point	4	B	-75	-174	-200	Woolleys	11	D	-19	-35	-37
Marsden Point	4	C	-63	-144	-169	Sandy	12	A	-36	-95	-120
Marsden Point	4	D	-30	-80	-105	Sandy	12	AA	-36	-97	-124
Marsden Point	4	E	-44	-107	-133	Sandy	12	B	-50	-117	-142
Marsden Point	4	F	-36	-93	-118	Sandy	12	C	-49	-116	-141
Marsden Cove[2]	5	A	-18	-39	-42	Sandy	12	D	-52	-72	-74
Marsden Cove[2]	5	B	-16	-38	-41	Whananaki	13	A	-14	-35	-43
Marsden Cove[2]	5	C	-18	-41	-45	Whananaki	13	B	-50	-114	-121
Marsden Cove[2]	5	D	-4*	-14*	-17*	Whananaki	13	C	-46	-93	-109
One Tree Point[2]	6	A	-13	-44	-47	Whananaki	13	D	-29	-60	-77
One Tree Point	6	B	-8*	-20*	-23*	Whananaki	13	E	-34	-71	-87
One Tree Point	6	BB	-4*	-13*	-14*	Teal	14	A	-50	-70	-71
One Tree Point	6	C	-5*	-18*	-20*	Teal	14	B	-20	-62	-81
One Tree Point	6	D	-7*	-19*	-22*	Teal	14	C	-26	-73	-92
Taiharuru	7	A	-8*	-24*	-26*	Teal[2]	14	D	-14	-33	-37
Taiharuru	7	B	-28	-58	-70	Helena[2]	15	A	-10	-48	-64
Taiharuru	7	C	-9*	-30*	-34*	Helena	15	B	-25	-64	-80
Pataua	8	A	-27	-57	-69	Helena	15	C	-20	-40	-44
Pataua	8	B	-34	-66	-77	Ohawini	16	A	-18	-56	-74
Pataua	8	C	-33	-67	-80	Ohawini	16	B	-18	-56	-75
Pataua	8	D	-17	-31	-36	Ohawini[2]	16	C	-18	-56	-75

Name	No.	Cell	CEHZ1	CEHZ2	CEHZ3	Name	No.	Cell	CEHZ1	CEHZ2	CEHZ3
Ohawini	16	D	-20	-28	-28	Hihi	24	D	-29	-60	-71
Ohawini	16	E	-19	-58	-77	Hihi[2]	24	E	-29	-60	-71
Ohawini	16	F	-12	-18	-19	Hihi	24	F	-19*	-70*	-80*
Ohawini	16	G	-20	-60	-79	Coopers	25	A	-5*	-17*	-20*
Ohawini	16	H	-10	-16	-17	Coopers	25	B	-5*	-17*	-20*
Oakura	17	A	-22	-65	-79	Coopers	25	C	-5*	-18*	-20*
Oakura	17	B	-23	-65	-80	Coopers	25	D	-5*	-18*	-20*
Oakura	17	BB	-24	-55	-69	Coopers	25	E	-9*	-28*	-32*
Oakura	17	C	-24	-56	-69	Coopers	25	F	-9*	-28*	-32*
Oakura	17	D	-27	-78	-101	Coopers	25	G	-9*	-28*	-32*
Oakura	17	E	-10	-23	-25	Cable	26	A	-17	-39	-48
Oakura	17	F	-29	-48	-50	Cable	26	B	-18	-40	-49
Bland	18	A	-21	-50	-68	Cable	26	C	-23	-47	-57
Bland	18	B	-17	-46	-63	Cable	26	D	-15	-25	-26
Bland	18	C	-23	-63	-85	Cable	26	E	-26	-48	-59
Bland[2]	18	D	-31	-77	-99	Cable	26	F	-31	-59	-69
Bland[2]	18	E	-16	-41	-46	Taipa	27	A	-15	-56	-77
Waitangi[2]	19	A	-5*	-17*	-20*	Taipa	27	B	-16	-56	-77
Waitangi	19	B	-10	-23	-25	Taipa	27	C	-19	-68	-89
Waitangi	19	C	-32	-106	-142	Rangiputa	28	A	-15	-31	-36
Waitangi	19	D	-26	-96	-131	Rangiputa	28	B	-27	-51	-56
Waitangi	19	E	-18	-33	-34	Rangiputa	28	C	-5	-12	-17
Matauri	20	A	-28	-70	-87	Tokerau	29	A	-34	-105	-136
Matauri	20	B	-36	-114	-147	Tokerau	29	B	-29	-95	-126
Matauri[2]	20	BB	-31	-105	-138	Tokerau[2]	29	C	-29	-96	-127
Matauri[2]	20	C	-29	-98	-131	Tokerau	29	D	-37	-110	-141
Te Ngaere	21	A	-28	-75	-94	Tokerau	29	E	-30	-97	-128
Te Ngaere[2]	21	B	-22	-63	-82	Ahipara	30	A	-26	-118	-158
Te Ngaere[2]	21	C	-25	-69	-88	Ahipara	30	B	-12	-25	-27
Tauranga	22	A	-17	-38	-48	Ahipara	30	C	-13	-27	-29
Tauranga	22	AA	-20	-44	-54	Ahipara	30	D	-5	-9	-9
Tauranga	22	B	-27	-58	-69	Ahipara	30	E	-22	-79	-106
Tauranga	22	C	-35	-68	-80	Ahipara	30	F	-5	-10	-10
Taupo	23	A	-26	-58	-72	Ahipara	30	G	-44	-116	-143
Taupo	23	B	-26	-54	-68	Ahipara	30	H	-49	-123	-151
Taupo	23	C	-28	-70	-90	Ahipara	30	I	-35	-113	-140
Taupo	23	D	-28	-70	-90	Ahipara	30	J	-41	-124	-151
Hihi	24	A	-3*	-10*	-10*	Ahipara	30	K	-56	-139	-167
Hihi	24	B	-5*	-18*	-20*	Omapere	31	A	-12	-24	-26
Hihi	24	C	-21	-35	-36	Omapere	31	B	-5	-19	-20

Name	No.	Cell	CEHZ1	CEHZ2	CEHZ3	Name	No.	Cell	CEHZ1	CEHZ2	CEHZ3
Omapere	31	BB	-14	-28	-30	Long Beach	36	B	-25	-56	-68
Omapere	31	C	-17	-33	-36	Long Beach	36	C	-21	-49	-61
Omapere	31	D	-8	-21	-22	Long Beach	36	D	-22	-50	-62
Omapere	31	E	-15	-35	-38	Paihia	37	A	-7*	-23*	-24*
Omapere	31	F	-24	-45	-49	Paihia	37	B	-14*	-38*	-44*
Omapere	31	G	-21	-42	-44	Paihia	37	C	-11	-24	-25
Omapere	31	H	-12	-29	-29	Paihia	37	D	-5*	-19*	-20*
Omapere	31	I	-27	-61	-62	Paihia	37	E	-12	-42	-54
Omapere	31	J	-19	-44	-49	Paihia	37	F	-11	-41	-54
Mangawhai Heads	32	A	-1*	-8*	-9*	Whatuwhiwhi	38	A	-3*	-15*	-15*
Mangawhai Heads	32	B	-10*	-36*	-41*	Whatuwhiwhi	38	B	-26	-76	-94
Mangawhai Heads	32	C	-3*	-9*	-10*	Whatuwhiwhi	38	C	-3*	-15*	-15*
Mangawhai Heads[2]	32	D	-6	-20	-22	Whatuwhiwhi	38	D	-9	-47	-65
Mangawhai Heads[2]	32	E	-11	-25	-28	Whatuwhiwhi	38	E	-19	-65	-83
Mangawhai Heads	32	F	-4*	-17*	-20*	Whatuwhiwhi	38	F	-3*	-15*	-15*
Mangawhai Heads[2]	32	G	-12	-36	-42	Whatuwhiwhi	38	G	1*	-7*	-8*
Mangawhai Heads	32	H	-6	-15	-17	Whatuwhiwhi	38	H	-3*	-14*	-15*
Mangawhai Heads	32	I	-2*	-8*	-10*	Kaimaumau	39	A	-12*	-37*	-43*
Mangawhai Heads[2]	32	J	-7	-19	-21	Kaimaumau	39	B	-4*	-17*	-20*
Mangawhai Heads	32	K	-4*	-17*	-20*	Baylys	40	A	-9*	-27*	-31*
Mangawhai Heads[2]	32	L	-12	-30	-36	Baylys	40	B	-3*	-14*	-15*
Tamaterau[2]	33	A	-12	-28	-32	Baylys	40	C	-12*	-37*	-42*
Tamaterau[2]	33	B	-11	-26	-30	Baylys	40	D	-4*	-17*	-20*
Tamaterau[2]	33	C	-13	-33	-36	Baylys	40	E	-3*	-10*	-10*
Tamaterau[2]	33	D	-11	-24	-28	Baylys	40	F	-4*	-17*	-20*
Tamaterau	33	E	-12	-28	-32	Glinks	41	A	3	-17	-29
Woolleys Ext	34	A	-3*	-12*	-13*	Glinks	41	B	15	-9	-20
Woolleys Ext	34	B	-14	-31	-39	Glinks	41	C	-26	-56	-69
Woolleys Ext	34	C	-6*	-16*	-18*	Glinks	41	D	4	-16	-28
Moureeses	35	A	-12*	-33*	-36*	Whakapirau	42	A	-11	-23	-25
Moureeses	35	B	-2*	-9*	-10*	Whakapirau	42	B	-2*	-10*	-12*
Moureeses	35	C	-2*	-7*	-8*	Whakapirau	42	C	-7	-19	-22
Moureeses	35	D	-1*	-8*	-9*	Whakapirau[2]	42	D	-10	-21	-23
Long Beach	36	A	-21	-54	-66						

[1]Distance applied from the adopted baseline which may or may not correspond to the most recent shoreline

[2]Sites have low-lying backshore areas that could potentially be inundated by >1 m of sea level rise over a 100 year timeframe and should be separately assessed within a flood assessment

[3]Minimum values have been adopted for CEHZ. Original values are provided within individual site assessments in Appendix A

*Cliff projection methodology used, so future shoreline distances have been tabulated with the cliff project distances additional and shown in mapping.

The range of CEHZ widths as a function of coastal type (excluding sites for which the cliff projection method has been adopted) are presented in Figure *5.1*. These plots show that the largest CEHZ1 values are a mixture of unconsolidated open coast beaches, non-consolidated coastal terraces and high cliffs. However, the largest CEHZ2 and CEHZ3 values are dominated by unconsolidated coast beaches and non-consolidated coastal terraces as the effects of sea level rise over a 100 years period begin to dominate. The dashed lines show the adopted minimum values with values below being rounded up to these minimums.

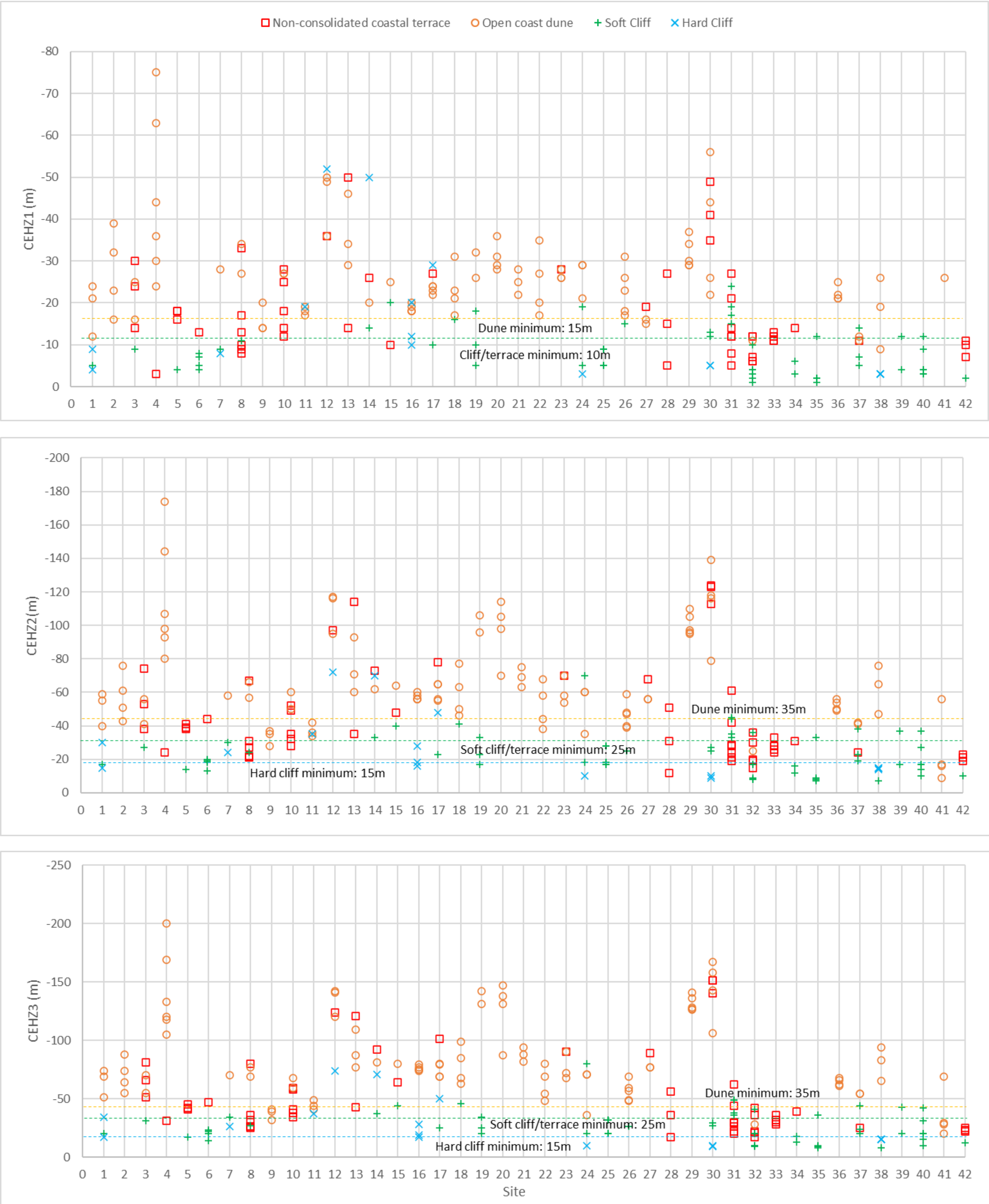

Figure 5.1: *CEHZ distances for individual Northland sites*

5.2.1 Modified CEHZ values for existing sites

Some component values for several existing sites have been refined in addition to the SLR values since the T+T (2017) assessment. This means that the resulting CEHZ values for the respective sites have been updated.

For Ahipara the closure slopes have been reviewed and refined to be more realistic as it was found that the previously adopted closure slopes were conservative. For the remaining open coast beach sites the closure slopes were considered to be realistic and have not been changed.

For cliff shorelines of existing sites the sea level rise response factors (*m* values) have been refined based on the recent work T+T have undertaken for other regions, such as Auckland and Tauranga. Previously an upper bound of 0.75 was adopted and this has been refined to 0.5 based on a better understanding of the Ashton et al. (2010) paper and physical upper bound limit of 0.5 for coastal cliffs in New Zealand.

5.3 CEHZ maps

CEHZs are mapped with respect to the adopted 2019 baseline and represent areas susceptible to coastal erosion (i.e. not the future shoreline). CEHZ lines have been dashed where the backshore morphology and/or topography changes significantly from that assessed or around stream mouths. This is to reflect the additional uncertainty around these features and to indicate where site-specific assessment is recommended. The transitions of CEHZs between adjacent cells have been mapped as described in Section 0. The mapped CEHZs are presented in individual site assessments within Appendix A and provided in digital form.

Modifications to CEHZ maps as discussed in Section 5.3.3 in T+T (2017), including modification of CEHZ1-3 for cell 9A at Whangaumu, removal of CEHZ2-3 at cell 11A at Woolleys Bay and shift in cell boundary position between cell 30D and 30E at Ahipara, have been incorporated for this study.

5.3.1 CEHZ0 behind structures

Table 5.3 shows the sites/cells that include coastal protection structures and for which CEHZ0 have been derived. The CEHZ0 lines for these sites/cells have been mapped in Appendix A along with potential CEHZ1, CEHZ2 and CEHZ3.

Table 5.3: Sites/cells including coastal protection structures and for which CEHZ0 have been assessed

Site name	Site number	Cell
Langs Beach	1	C
One Tree Point	6	B, BB, C, D
Taiharuru	7	B
Whangaumu	9	A
Helena Bay	15	C
Ohawini	16	E
Waitangi	19	C
Matauri	20	A
Hihi	24	C, D, E
Rangiputa	28	A, B
Ahipara	30	F

Site name	Site number	Cell
Omapere/Opononi	31	A, C, E, F, G, I, J
Mangawhai Heads	32	D
Woolleys Extension	34	A
Moureeses Beach	35	C
Paihia	37	B, E
Glinks Gully	41	C
Whakapirau	42	B, C

5.4 Discussion

Results of the probabilistic CEHZ assessment (excluding the CEHZ widths derived for sites for which the cliff projection method has been adopted) are summarised in Table 5.4. For each coastal type, the range and mean of the 0%, 5%, 66% and 100% exceedance values across all coastal cells are presented with the 66% exceedance value at 2080 being the CEHZ1 value and the 5% exceedance value at 2130 being the CEHZ2 and CEHZ3 values.

Results show that CEHZ distributions range widely for each coastal type with the current CEHZ for open coast sites ranges from 3 to 40 m with an average of 10 to 21 m. This range tends to increase at 2080 and 2130, particularly for open west coast sites (i.e. Ahipara and Glinks Gully) where very flat offshore profiles can result in large recession values due to sea level rise. However, the likelihood of the highest potential future sea level rise (1.41 m for RCP 8.5+ to 2130, refer to Table 4.7) occurring together with maximum long-term recession rates and a large storm cut value is low and therefore the $P_{5\%}$ value tends to be significantly lower (up to 167 m at 2130 RCP 8.5+) than the maximum potential value (218 m at 2130 RCP 8.5+).

While the CEHZ values are generally higher for future cases, some exceptions occur where long-term accretion trends exceed predicted recession due to sea level rise resulting in some low likelihood (less than 66%) CEHZ values being seaward of the current shoreline position (i.e. Glinks Gully). However, more likely (>66%) values show that sea level rise-induced recession tends to dominate and erosion landward of the current shoreline occurs for the CEHZ2 and CEHZ3 for all cells.

The current CEHZ values for high cliffs tend to exceed those for open coast sites due to the larger hazard widths applicable to high cliffs (i.e. at Taiharuru, Southern Sandy Bay and Teal Bay). However, as cliff coastlines are less affected by the effects of sea level rise than open coast beaches, future CEHZ widths tend to be lower for cliff coasts.

The relationship between the CEHZ 1, 2 and 3 values and the individual parameter mean values are presented for open coast beaches, non -consolidated coastal terraces and cliff coasts in the Northland Region in Figure 5.2, Figure 5.3.and Figure 5.4 respectively. Results show that at 2080, the CEHZ1 values for beaches are not significantly influenced by any one parameter, although by 2130 the CEHZ2 and CEHZ3 values are more significantly influenced by closure slope which predicts response to sea level rise and by long-term trends when these are large.

CEHZ values for non-consolidated coastal terraces follow a similar parametric trend to values for open coast beaches, with closure slope having a larger influence by 2130. Hazard zone values width for cliff coasts is highly influenced by cliff height with higher cliffs exhibiting larger hazard widths as expected. The CEHZ1 value is moderately affected by long-term trends, although this becomes more pronounced by 2130 for the CEHZ2 and CEHZ3, particularly for soft cliff where sea level rise is expected to affect erosion rates more notably.

Coastal processes and future shoreline positions are difficult to forecast over a 100 year timeframe at some sites due to their dynamic nature, interrelationships with other systems (i.e. ebb tide deltas, rivers or offshore reefs) and the potential for morphological feedbacks to slow or increase the rates of historic trends. These forecasts become more uncertain when considering the effect of potential sea level rise. Marsden Point is an example of a complex site where the offshore ebb tide delta (the Mair Bank) at the mouth of the Whangarei Harbour has a significant control on the inshore and adjacent shoreline position. Assessment of historic aerial photographs has shown large variations in shoreline position of up to 80 m have occurred in this area over the last 60 years. Such changes are likely controlled by the shape and locations of the offshore ebb delta with Morgan et al. (2011) finding that the seaward (southern) margin of the bar has moved significantly since 1955 while the northern margin has remained stable over this period. Future changes to the ebb tide delta, particularly under an increase sea level regime, may result in relatively rapid changes to shoreline position in this area, which may vary from historic trends.

The distal ends of spits are also very dynamic areas where accurately forecasting future shoreline positions is problematic. We have represented the shoreline movement as a result of sea level rise as a fairly linear retreat along the spit. However, we are aware that a number of alternative morphological responses may occur due to a variety of drivers. For example, at Oakura where the stream position is constricted by the southern cliff shoreline, the stream may breach the spit where the spit width is reduced over time. At other sites, low lying areas landward of the spit feature may become exposed to greater levels of wave induced storm cut if the spit breaches as a result of sea level rise induced shoreline retreat (e.g. Ahipara, Langs Beach).

Where land is protected by consented and competent erosion protection structures, the structures may provide a level of protection for a period of time. However, once these structures fail or are removed, the shoreline will likely return to its long-term stable position which may be well landward if the structure was maintaining the shoreline in a seaward position.

Due to the level of development at the sites, most areas have a relatively narrow area of dune vegetation. Some sites have areas with no dune vegetation where backshore areas comprise farmland, grass reserve or private development. We expect dune recovery to be negatively affected where native dune vegetation has been removed, which could result in a greater erosion response in both the long-term and short-term than historically experienced. We recommend continuing to monitor the shoreline position in these dynamic areas by mapping shoreline positions from aerial photographs or GPS surveys. The shoreline mapping will provide background data to help resolve these uncertainties for future CEHZ reassessments.

Some low-lying sites may experience passive shoreline erosion due to sea level rise as the high tide elevation exceeds the crest of the dune of the backshore bank over a 100 year timeframe. At sites with relatively flat backshore areas, the high tide line could move significantly further inland than the calculated CEHZ over a 100 year timeframe. This has been highlighted for a number of sites mainly located in estuary environments.

Table 5.4: Summary of CEHZ values for Northland Coastal Types

Coastal Type		Current CEHZ (% Exceedance)				2080 CEHZ RCP8.5 (% Exceedance)				2130 CEHZ RCP8.5 (% Exceedance)				2130 CEHZ RCP8.5+ (% Exceedance)			
		Min	**66%**	**5%**	**Max**	**Min**	**66% CEHZ1**	**5%**	**Max**	**Min**	**66%**	**5% CEHZ2**	**Max**	**Min**	**66%**	**5% CEHZ3**	**Max**
Open East Coast	Max	-19	-26	-35	-40	-56	-75	-93	-112	-100	-135	-174	-217	-107	-147	-200	-255
	Mean	-10	-14	-19	-21	-14	-26	-37	-46	-23	-42	-63	-81	-29	-51	-80	-102
	Min	-3	-5	-7	-7	5	-9	-19	-23	15	-9	-19	-23	7	-12	-20	-25
Open West Coast	Max	-13	-18	-23	-26	-38	-56	-74	-91	-60	-97	-139	-179	-68	-110	-167	-218
	Mean	-11	-16	-20	-23	-3	-19	-37	-52	-9	-33	-65	-90	-16	-43	-84	-115
	Min	-8	-10	-13	-14	35	15	-8	-23	35	15	-8	-23	29	9	-15	-31
Non-consolidated coastal terraces	Max	-17	-22	-31	-35	-34	-50	-68	-89	-57	-82	-124	-169	-64	-95	-151	-209
	Mean	-6	-9	-11	-13	-9	-17	-25	-31	-14	-27	-40	-50	-18	-32	-48	-59
	Min	-2	-2	-2	-3	13	-3	-10	-13	26	2	-10	-13	19	-5	-11	-14
Soft Cliff	Max	-11	-17	-23	-29	-15	-24	-33	-40	-20	-31	-45	-55	-21	-33	-49	-63
	Mean	-6	-8	-11	-13	-9	-15	-20	-25	-13	-22	-32	-39	-14	-24	-35	-43
	Min	-3	-4	-5	-6	-6	-10	-13	-16	-8	-15	-23	-27	-9	-16	-25	-30
Hard Cliff	Max	-40	-46	-59	-68	-43	-52	-64	-72	-45	-58	-72	-84	-45	-59	-74	-87
	Mean	-13	-18	-24	-28	-16	-22	-29	-34	-18	-26	-34	-41	-18	-27	-35	-42
	Min	-1	-3	-6	-7	-2	-5	-7	-10	-3	-6	-9	-13	-3	-6	-9	-13

[1]Note: the CEHZ widths have been excluded for sites for which the cliff projection method has been adopted

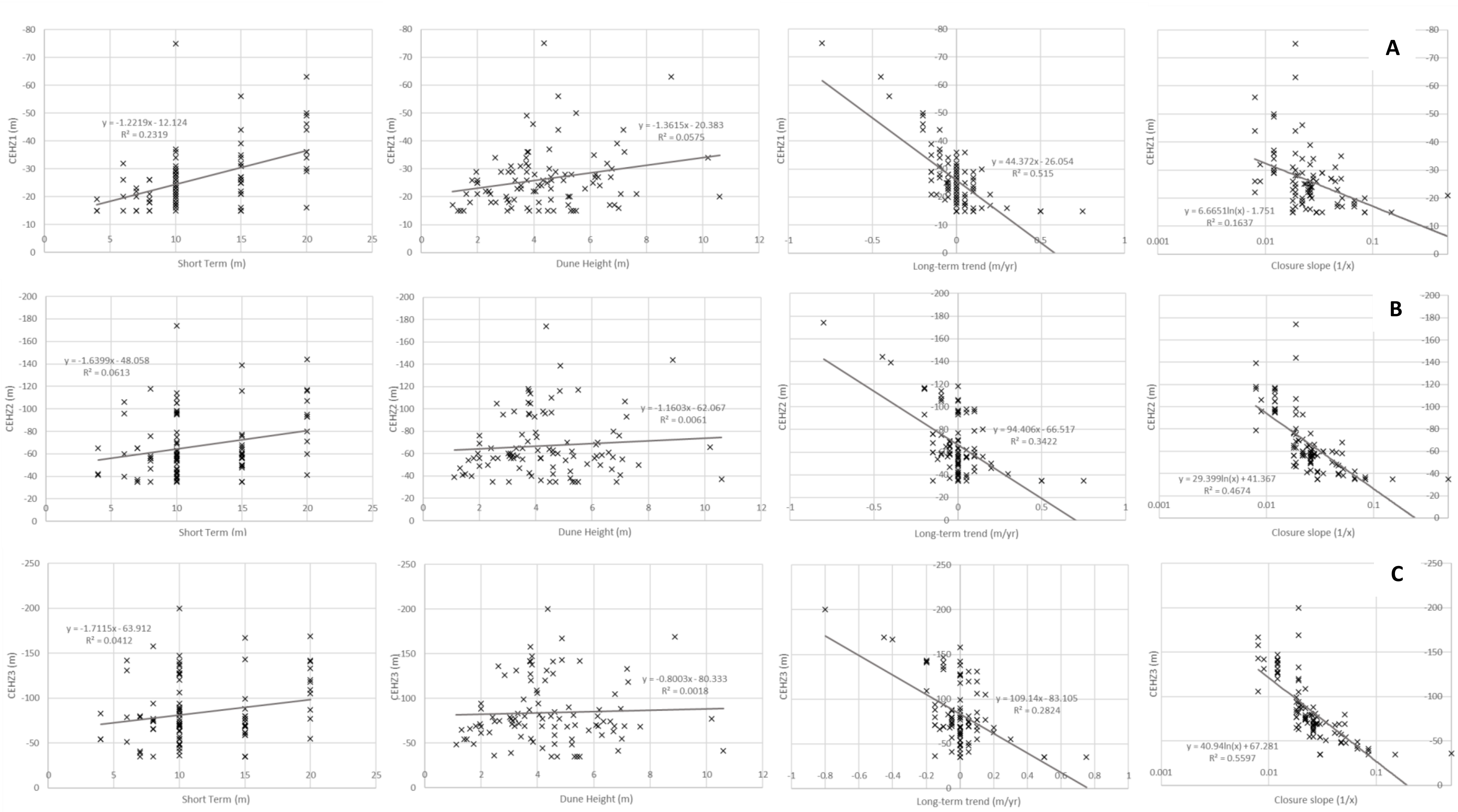

Figure 5.2: Relationship between CEHZ1 (A), CEHZ2 (B) and CEHZ3 (C) distance and individual parameters (mean value) for open coast beaches in the Northland Region

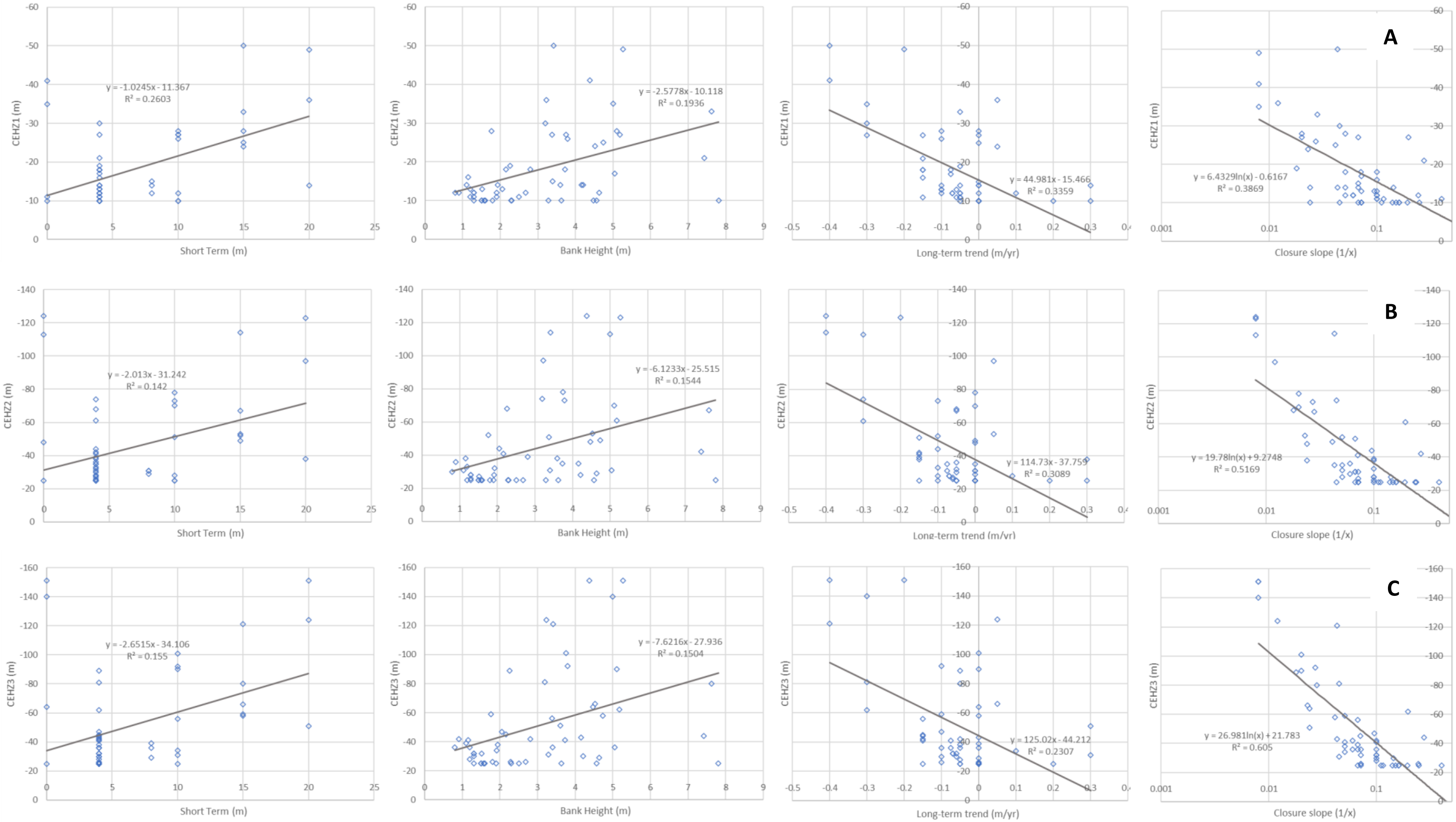

Figure 5.3: *Relationship between CEHZ1 (A), CEHZ2 (B) and CEHZ3 (C) distance and individual parameters (mean value) for inlet and estuary bank sites in the Northland region*

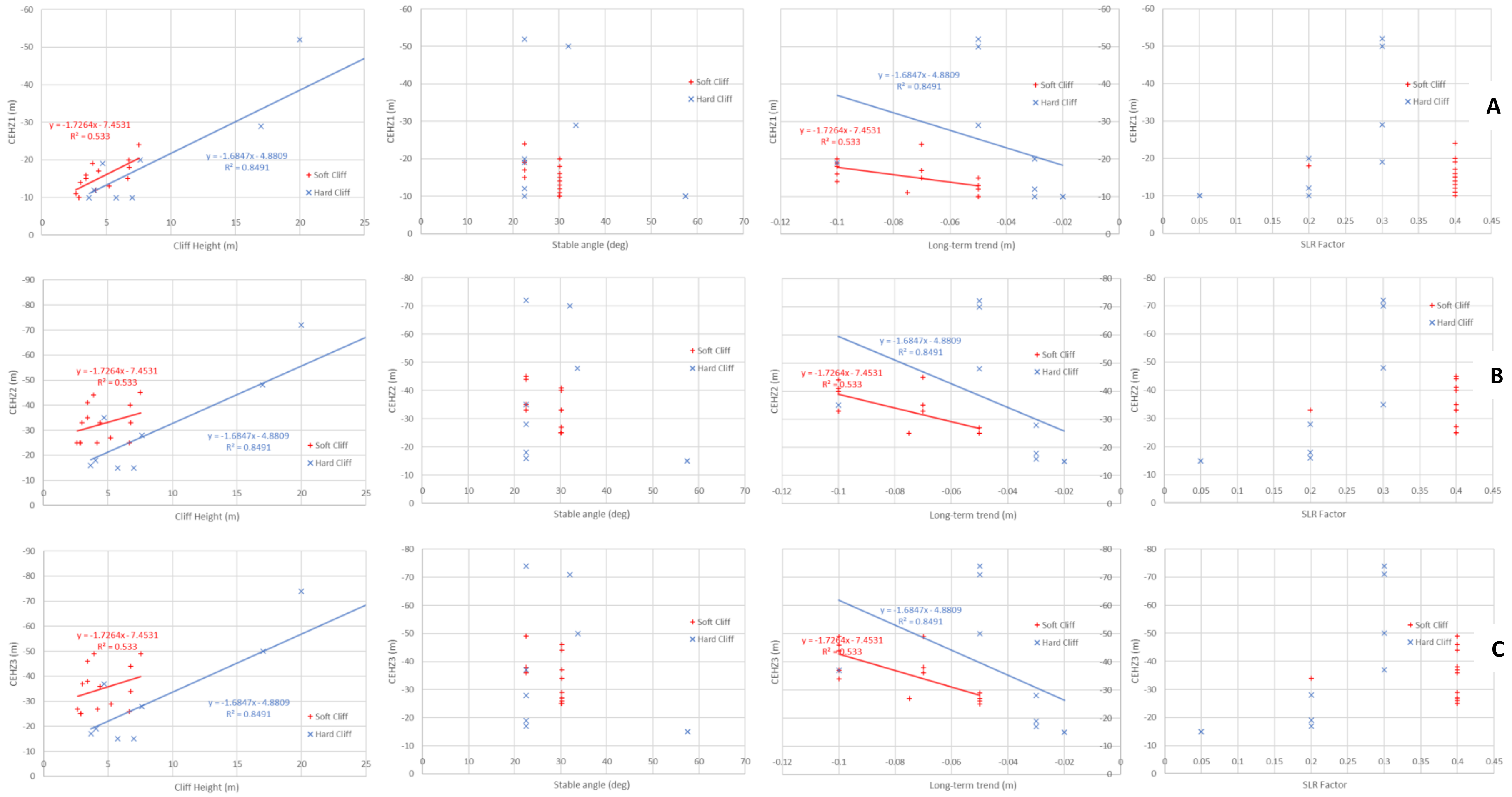

Figure 5.4: Relationship between CEHZ1 (A) and CEHZ2 (B) distance and individual parameters (mean value) for cliff coasts in the Northland Region (excluding the CEHZ widths for sites for which the cliff projection method has been adopted)

6 Summary and recommendations

The NRC have previously assessed the coastal erosion hazard zone (CEHZ) for 31 sites within their administrative boundary over a number of different reports completed from 1988 to 2014. The NRC require a new set of CEHZ for 42 sites to be developed in line with the current state of scientific knowledge, relevant legislation and best practice guidelines. This includes updating the assessments for 31 existing sites using the latest guidance on sea level rise (refer to MfE, 2017) and latest LiDAR data (i.e. from 2019), and 11 additional new sites.

The New Zealand Coastal Policy Statement (NZCPS) is a national policy statement under the Resource Management Act 1991. The NZCPS states policies in order to achieve the purpose of the Act in relation to the coastal environments of New Zealand and NRC's RPS gives effect to the NZCPS. The CEHZ methodology used for this project has been developed in accordance with the Objectives and Policies of the NZCPS directly relevant to the assessment of coastal erosion hazard.

The methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters with new techniques for defining and combining parameter ranges to allow for natural variation and uncertainty in individual parameters. The resulting distribution provides a probabilistic forecast of potential hazard zone width, improving on the previous methods that typically included the summation of single values for each component and one overall factor for uncertainty. The assessment method adopted for NRC produces a range of hazard zones corresponding to differing likelihoods. The benefit of this approach is that they can be used in risk-based assessments where the likelihood and the consequence of the hazard are considered as advocated by the NZCPS and supported by best practice guidelines.

The Northland region contains a range of coastal types. The processes controlling change along these different coastal types vary and therefore specific methods to determine CEHZ distances were applied to account for these differing processes. The expressions used to define CEHZ were developed for the two major coastal types:

- Beaches and coastal terraces comprising unconsolidated sediments
- Consolidated cliff coasts

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

- 2020 Coastal Erosion Hazard Zone (Current): 2020 CEHZ
- 2080 Coastal Erosion Hazard Zone (at least 50 years): 2080 CEHZ
- 2130 Coastal Erosion Hazard Zone (at least 100 years): 2130 CEHZ.

Each site has been divided into coastal cells based on differences in shoreline physical characteristics and morphological behaviour, which can influence the resultant hazard. The appropriate expression was applied to each coastal cell to calculate the full probability distribution range of CEHZ distances.

Results showed that the potential CEHZ values for each cell can range significantly, particularly at future times where the uncertainties surrounding the magnitude and effects of sea level rise is large. Following consultation with Council, the CEHZ value with a 66% probability of being exceeded ($P_{66\%}$) at 2080 and the CEHZ value with a 5% probability of being exceeded ($P_{5\%}$) at 2130 have been adopted as prudent *likely* and *potential* CEHZ values (termed CEHZ1 and CEHZ2 respectively) to provide the required hazard zones for Council's planning maps. It was further requested to assess a third hazard zone, similar to CEHZ2 but instead using the RCP8.5H+, termed *CEHZ3*. Minimum set-back values have been adopted for each coastal type to account for potential uncertainties and limitations in data and methods. CEHZ lines have been mapped with respect to the 2019 baseline.

Results show that CEHZ1 values for open coast beaches range from 9 to 75 m and CEHZ2 values range from 19 to 174 m on east coast beaches and from 8 to 139 m on west coast beaches. The CEHZ3 values go up to 200 m and 167 m for east and west coast beaches respectively. The largest east coast and west coast values are high due to long-term erosive tendencies and very flat offshore profiles which are highly susceptible to the effects of sea level rise. For cliff coasts, CEHZ1 values range from 5 to 52 m and CEHZ2 values from 9 to 72 m (excluding sites for which the cliff projection method has been applied). Larger values occur where cliffs are high with low stable angles of repose resulting in wide hazard zones and where material is soft and susceptible to increased rates of erosion due to sea level rise. CEHZ widths for coastal terraces may be large where inlets are influencing the shoreline dynamics and subject to large-scale shifts in position, or where the adjacent shoreline is in an erosive state.

Where land is protected by consented and competent erosion protection structures, it is acknowledged that these structures may provide a level of protection for a period of time. However, once these structures fail or are removed, the shoreline will likely return to its long-term stable position which may be well landward if the structure was maintaining the shoreline in a seaward position. CEHZs for shorelines protected by consented structures have been termed CEHZ0 and have been mapped to show the potential area affected by erosion immediately after failure of the structure.

There is additional uncertainty around stream mouths or where the backshore morphology and/or topography changes significantly from that assessed at the shoreline. The CEHZ lines around these features have been depicted by dashed lines to indicate where site-specific assessment is recommended.

As a result of this study we recommend:

1. That regular monitoring of the shoreline position across the region is continued to improve the length and quality of background data. This should include overlaying of successive LiDAR surveys, continuation of beach profile monitoring at established sites, and digitising of shorelines as aerial imagery becomes available or by GPS survey.
2. That site-specific assessment is undertaken as required in locations of additional uncertainty such as around stream mouths or at the transition between beach and cliff.
3. That the adopted baselines and CEHZ values are reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

This study has assessed coastal erosion hazard at regional scale and may be superseded by local site-specific assessment if undertaken by qualified and experienced practitioner using improved data from that presented in this report. This could include better site-specific geotechnical information to confirm subsurface soil conditions and better topographic data as well as site specific analysis and modelling of erosion.

7 Applicability

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

Tonkin & Taylor Ltd

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The methodology and site assessments for sites 1-31 have been reviewed by Professor Paul Kench in 2014, and the site assessments for sites 32-44 reviewed by Dr Terry Hume in 2020 (refer to Appendix F).

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Appendix A: Site assessments

Appendix B: SWAN wave modelling to derive design storm events

B1 Design storm events

Large, low probability wave events are generally defined in terms of an Average Recurrence Interval (ARI). The commonly used approach to derive extreme wave height for a particular ARI is to fit a theoretical distribution to historical storm wave data. The 3 parameter Weibull distribution (Equation B-1) has been adopted for the present study as it has been found to provide best agreement with storm wave data on the east Australian coast resulting from similar storm systems (Shand et al., 2010).

$$F_{(x)} = 1 - \exp\left[-\left(\frac{x-B}{A} \right)^{-k} \right] \qquad \text{(B-1)}$$

Where F(x) is the distribution function and A, B and k are scale, location and shape parameters optimised to each distribution. Results for each offshore site including the 90% confidence interval are presented in Appendix B Table 1 and show similar extreme values for both coasts at lower recurrence intervals, although the east coast values are higher at high recurrence interval. This is presumably due to the climatology of extreme storm events and the potential for more intense storm systems with an easterly fetch to the north of New Zealand.

Appendix B Table 1: Extreme wave heights for Northland offshore locations

Location	Coordinates		H_s (m) ± 90% CI			
	E (°)	**S (°)**	**1 yr ARI**	**10 yr ARI**	**50 yr ARI**	**100 yr ARI**
Ahipara	173.02	35.24	6.1 (± 0.1)	7.3 (± 0.3)	8.1 (± 0.4)	8.4 (± 0.5)
Matauri Bay	173.99	34.84	6.1 (± 0.2)	7.5 (± 0.5)	9.3 (± 0.8)	9.9 (± 0.9)
Whangaruru	174.63	35.28	6.3 (± 0.2)	8.2 (± 0.5)	9.4 (± 0.8)	9.9 (± 0.8)
Bream Head	174.63	35.74	5.6 (± 0.2)	7.3 (± 0.5)	8.4 (± 0.8)	8.8 (± 0.9)
Gr. Exh. Bay	173.36	34.44	6.0 (± 0.2)	8.2 (± 0.5)	9.4 (± 0.9)	9.9 (± 1.1)
Baylys Beach	173.62	35.98	6.5 (± 0.1)	8.3 (± 0.5)	9.6 (± 0.9)	10.2 (± 1.0)

B2. Synthetic design storms

A synthetic design storm provides time series information of wave height and period during an entire storm event. Such an approach was presented by Carley and Cox (2003) and is useful in the assessment of erosion where temporal processes such as storm duration and the joint occurrence of extreme wave height with elevated water level is important.

Synthetic design storm events have been generated for 10 year and 100 year ARI storm events for both the west coast and east coast offshore sites (Appendix B Table 2). These synthetic storms incorporate storm duration, storm shape and peak wave height, wave period evolution and water level including astronomical tide and storm surge. An example of the 100 year ARI synthetic design storm for the west coast is presented in Figure Appendix B.1.

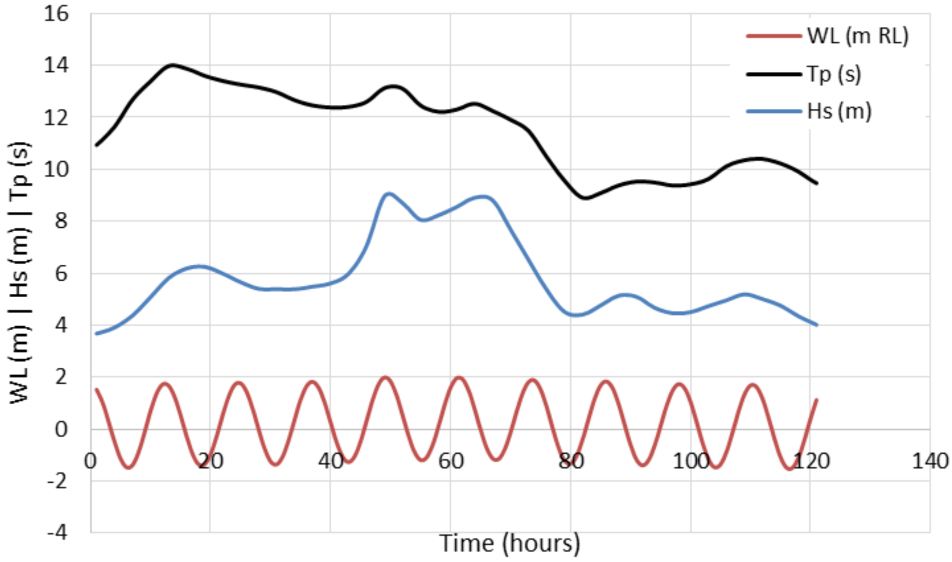

Figure Appendix B.1: Example 100 year ARI synthetic design storm for the west coast

Appendix B Table 2: Parameters for synthetic design storm generation

Synthetic Design Storm	Duration (hours)	Peak H_s (m)	Peak T_p (s)	Peak WL (m RL)
10yr ARI West	61 hours	7.3 m	12 s	1.55 m
100yr ARI West	121 hours	8.4 m	13 s	1.75 m
10yr ARI East	61 hours	7.5 m	14 s	2.0 m
100yr ARI East	121 hours	7.9 m	14 s	2.2 m

B3. Wave transformation modelling

Numerical wave transformation modelling has been undertaken to transform wave characteristics described above into nearshore wave conditions for each site.

B3.1 Model description

The numerical model SWAN (Simulating WAves Nearshore) has been used to undertake wave transformation modelling. SWAN is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters by solving the spectral action balance equation without any restrictions on the wave spectrum evolution during growth or transformation. The SWAN model accommodates the process of wind generation, white capping, bottom friction, quadruplet wave-wave interactions, triad wave-wave interactions and depth induced breaking. SWAN is developed at Delft University of Technology in the Netherlands and is widely used by government authorities, research institutes and consultants worldwide. Further details of SWAN can be found in Booij et al. (1999).

B3.2 Model domain

The regional model domain encompassing all of Northland was constructed using bathymetry sourced from the LINZ Nautical Charts (Figure Appendix B.2). A total of eight local model domains (see Appendix B Table 3) have been generated incorporating all coastal cells being assessed except for Omapere. Omapere is subject to only limited offshore wave energy due to the presence of the Hokianga Bar and the narrow inlet throat.

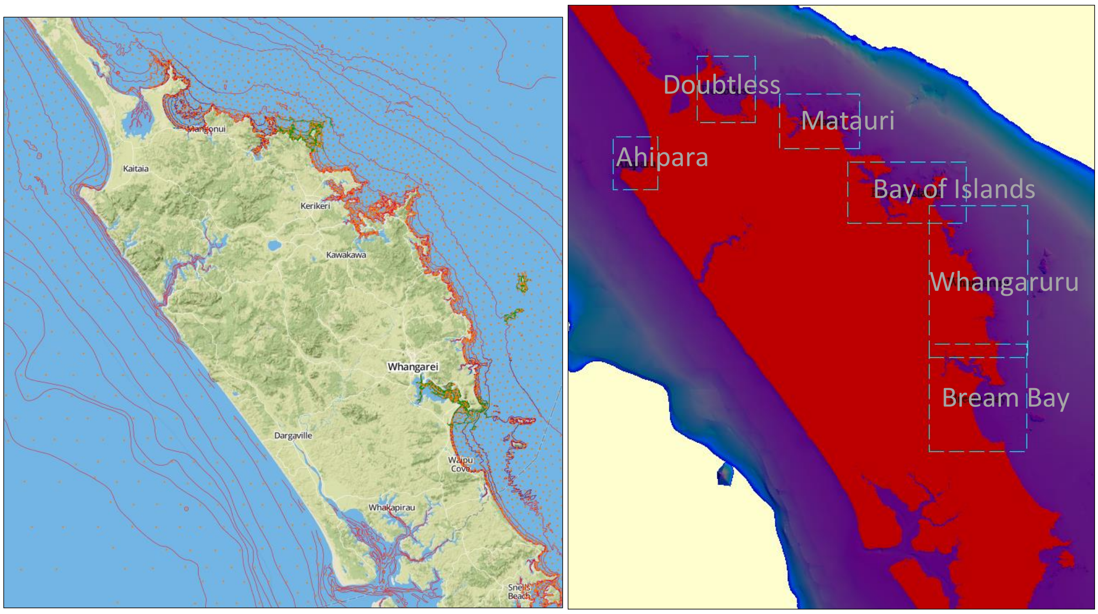

Figure Appendix B.2: Bathymetric contours and spot heights from LINZ database and SWAN model domains (dashed boxes)

Appendix B Table 3: Model domains

Model domain	Coordinates (lower left corner) [X,Y] NZTM2000	Domain size [X,Y]	Grid resolution
Ahipara	(1602000,6101000)	20x20km^2	50mx50m
Doubtless	(1632500,6125000)	20x25km^2	50mx50m
Matauri	(1662000,6116000)	30x20km^2	50mx50m
Bay of Islands	(1687000,6086500)	40x25km^2	50mx50m
Whangaruru	(1716100,6040500)	35x55km^2	50mx50m
Bream Bay	(1716000,6005500)	35x40km^2	50mx50m

B3.3 Storm event modelling

Wave modelling was undertaken to transform wave conditions offshore to the nearshore where they are used to drive beach erosion models. The peak significant wave height during the design events (10 and 100 year ARI from multiple directions) are transformed from offshore to 10 m water depth using the local SWAN models while applying a corresponding extreme wind (i.e. 100 year ARI wind during the 100 year ARI wave event). This check ensures that wave energy gained by wind forcing is allowed for as well as losses due to refraction, friction and breaking. Figure Appendix B.3 to Figure Appendix B.8 show example results of the significant wave height during a 100 year ARI storm from the northeast (east coast) or from the west (west coast) for each model domain.

B4. Nearshore synthetic design storms

The offshore synthetic design storms derived previously for offshore locations are transformed to each specific coastal cell based on the results of wave transformation modelling to enable beach erosion modelling to be undertaken for each specific coastal cells utilising appropriate storm wave climates

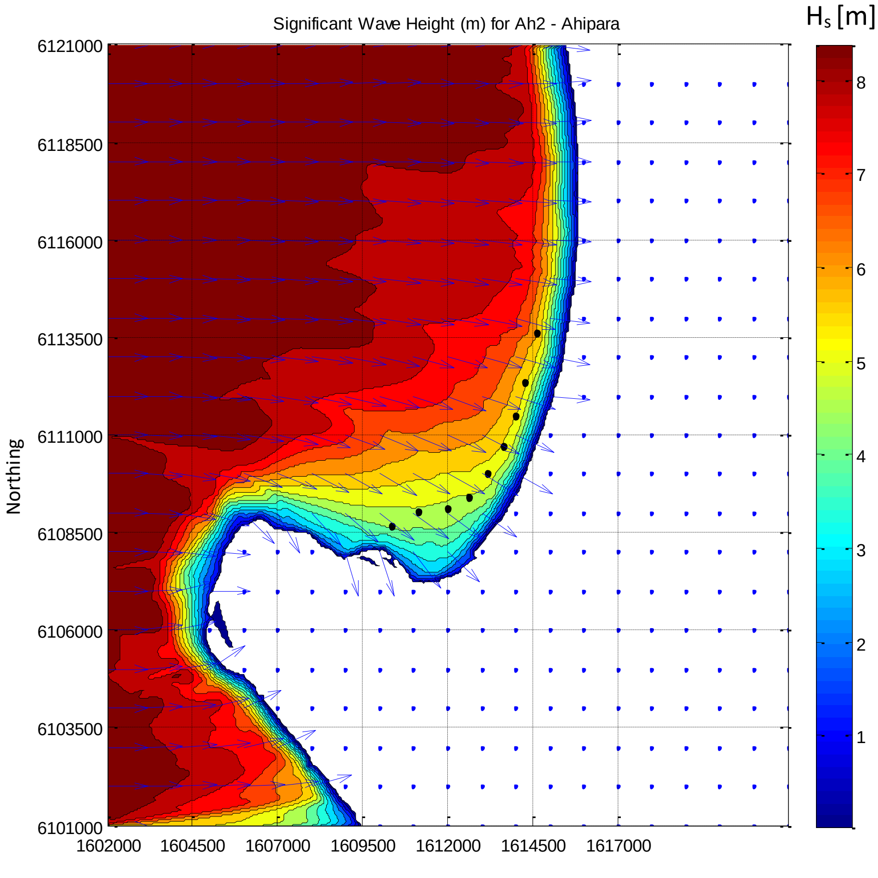

Figure Appendix B.3: SWAN model results for the Ahipara domain – Significant wave height and direction during a 100 year ARI storm from the west

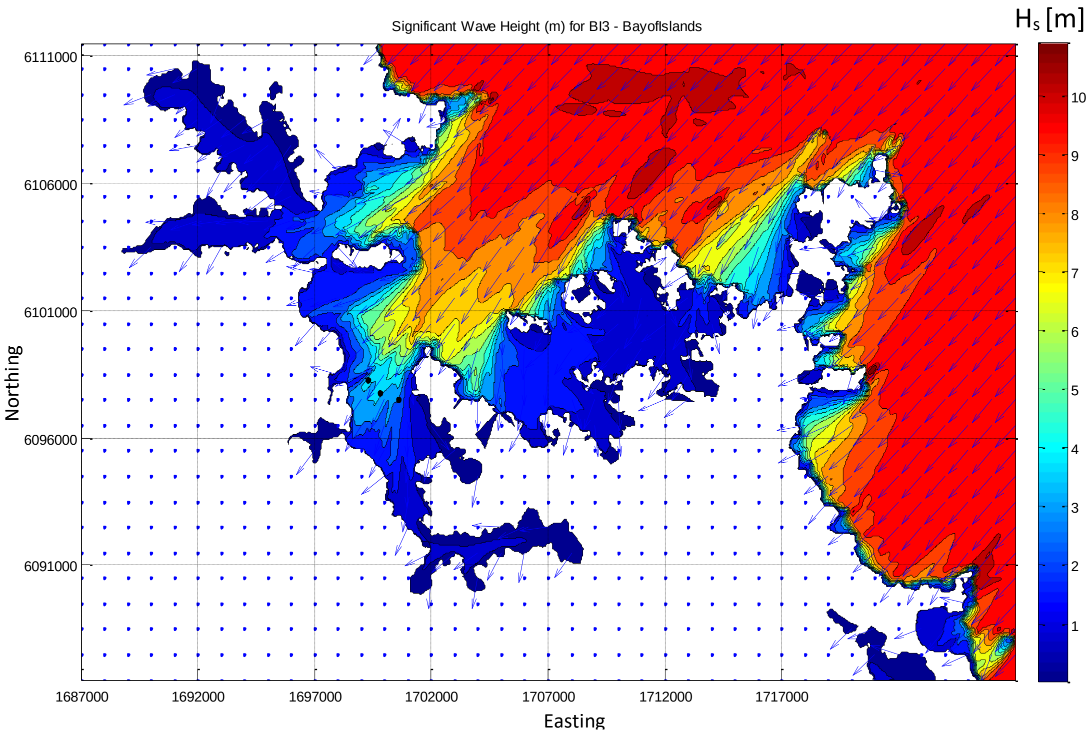

Figure Appendix B.4: SWAN model results for the Bay of Islands model domain – Significant wave height and direction during a 100 year ARI storm from the Northeast

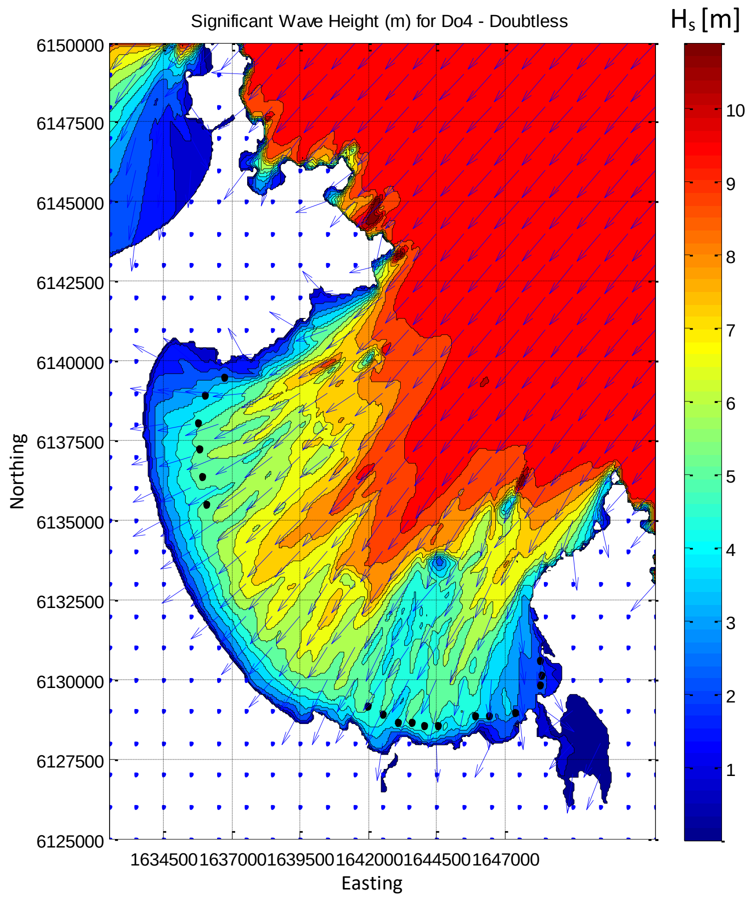

Figure Appendix B.5: SWAN model results for the Doubtless model domain – Significant wave height and direction during a 100 year ARI storm from the Northeast

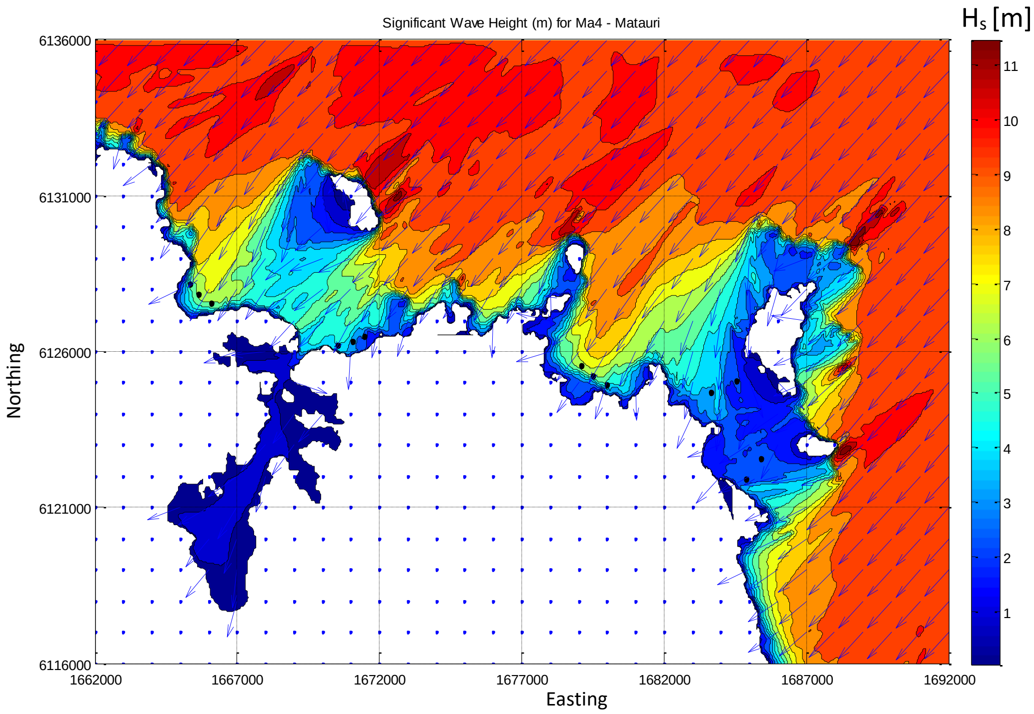

Figure Appendix B.6: SWAN model results for the Matauri model domain – Significant wave height and direction during a 100 year ARI storm from the Northeast

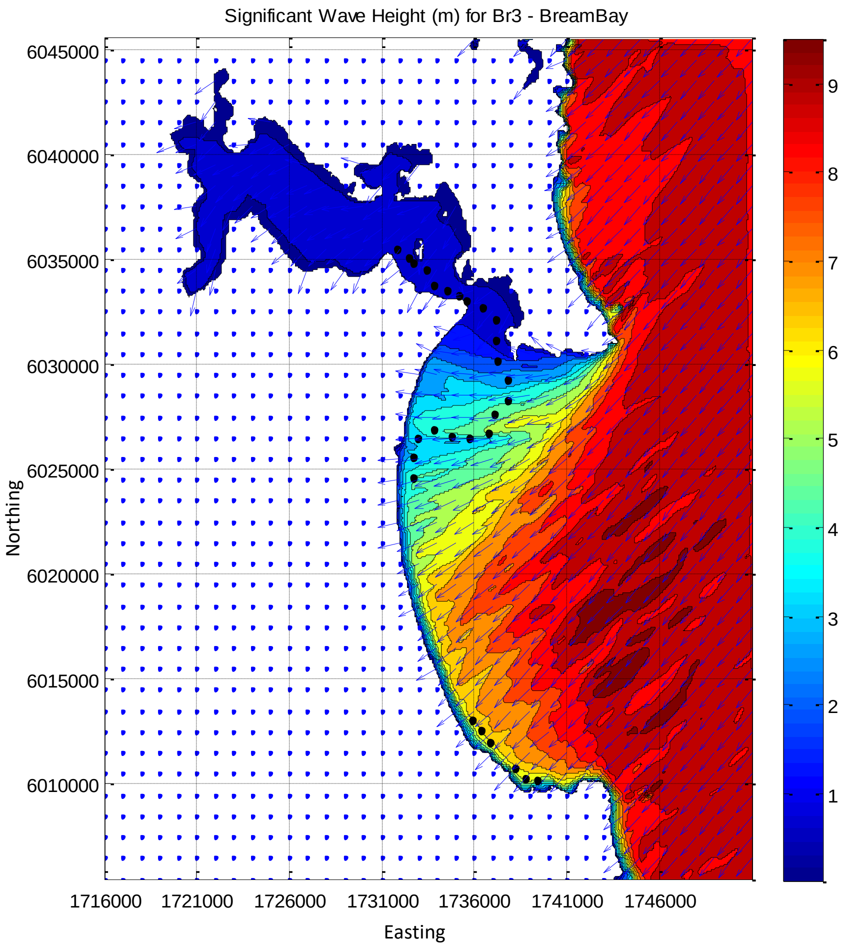

Figure Appendix B.7: SWAN model results for the Bream Bay model domain – Significant wave height and direction during a 100 year ARI storm from the northeast

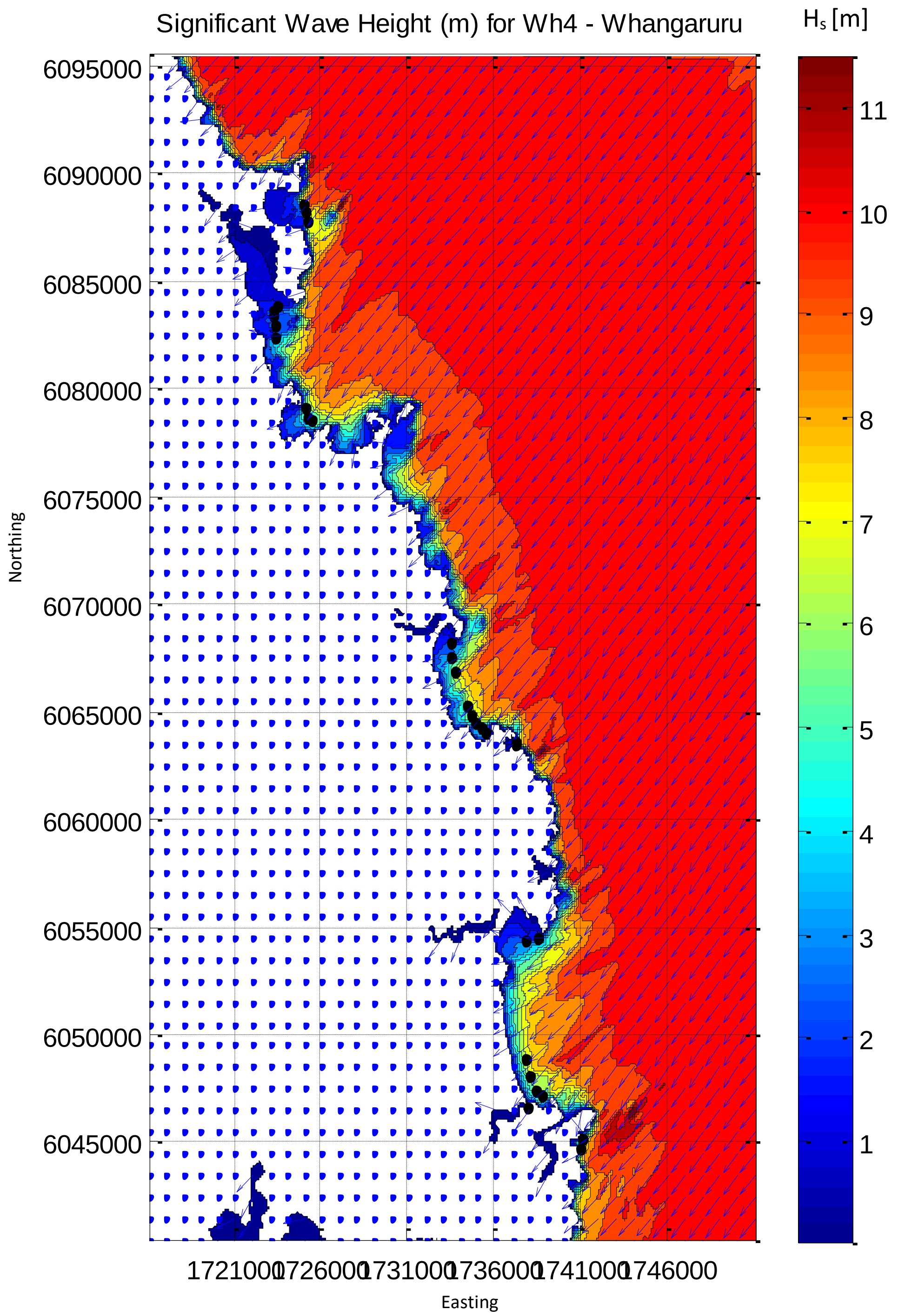

Figure Appendix B.8: SWAN model results for the Whangaruru model domain – Significant wave height and direction during a 100 year ARI storm from the northeast

Appendix C: Data schedule

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
1	Langs	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
1	Langs	Shoreline	1963 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
1	Langs	Shoreline	1972 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
1	Langs	Shoreline	1985 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
1	Langs	Shoreline	1998 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
1	Langs	Shoreline	2002 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
1	Langs	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
1	Langs	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
1	Langs	Shoreline	2014 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
1	Langs	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
1	Langs	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
2	Waipu	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
2	Waipu	Shoreline	1963 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
2	Waipu	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
2	Waipu	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
2	Waipu	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
2	Waipu	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
2	Waipu	Shoreline	2008 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
2	Waipu	Shoreline	2014 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
2	Waipu	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
2	Waipu	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
3	Ruakaka	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
3	Ruakaka	Shoreline	1950 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
3	Ruakaka	Shoreline	1961 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
3	Ruakaka	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
3	Ruakaka	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
3	Ruakaka	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
3	Ruakaka	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
3	Ruakaka	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
3	Ruakaka	Shoreline	2014 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
3	Ruakaka	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
3	Ruakaka	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
4	Marsden Point	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
4	Marsden Point	Shoreline	1950 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	1961 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
4	Marsden Point	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
4	Marsden Point	Shoreline	2014 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
4	Marsden Point	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
4	Marsden Point	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
5	Marsden Cove	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
5	Marsden Cove	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
5	Marsden Cove	Shoreline	1985 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
5	Marsden Cove	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
5	Marsden Cove	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
5	Marsden Cove	Dune/Cliff crest	2019 Crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
6	One Tree Point	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
6	One Tree Point	Shoreline	1942 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
6	One Tree Point	Shoreline	1985 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
6	One Tree Point	Shoreline	2007 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
6	One Tree Point	Shoreline	2014 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
6	One Tree Point	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
6	One Tree Point	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
7	Taiharuru	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
7	Taiharuru	Dune Crest	2013 dune crest	GPS	Dune crest surveyed with robotic RTK GPS by Barney Brotherhood.	Barney Brotherhood	Mark Ivamy	A
7	Taiharuru	Shoreline	1942 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
7	Taiharuru	Shoreline	1979 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
7	Taiharuru	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
7	Taiharuru	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
7	Taiharuru	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
7	Taiharuru	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
8	Pataua	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
8	Pataua	Shoreline	1942 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
8	Pataua	Shoreline	1961 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
8	Pataua	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
8	Pataua	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
8	Pataua	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
8	Pataua	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
8	Pataua	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
8	Pataua	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
8	Pataua	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
9	Whangaumu	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
9	Whangaumu	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
9	Whangaumu	Shoreline	1959 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
9	Whangaumu	Shoreline	1985 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
9	Whangaumu	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
9	Whangaumu	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
9	Whangaumu	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
9	Whangaumu	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
9	Whangaumu	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
9	Whangaumu	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
9	Whangaumu	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
10	Matapouri	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
10	Matapouri	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
10	Matapouri	Shoreline	1959 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
10	Matapouri	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
10	Matapouri	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
10	Matapouri	Shoreline	2000 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
10	Matapouri	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
10	Matapouri	Shoreline	2004 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
10	Matapouri	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
10	Matapouri	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
10	Matapouri	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
10	Matapouri	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
11	Woolleys	Dune Crest	2013 dune crest	GPS	Dune crest surveyed with robotic RTK GPS by Barney Brotherhood .	Barney Brotherhood	Mark Ivamy	A
11	Woolleys	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
11	Woolleys	Shoreline	1966 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
11	Woolleys	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
11	Woolleys	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
11	Woolleys	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
11	Woolleys	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
11	Woolleys	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
12	Sandy	Dune Crest	2013 dune crest	GPS	Dune crest surveyed with robotic RTK GPS by Barney Brotherhood.	Barney Brotherhood	Mark Ivamy	A
12	Sandy	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
12	Sandy	Shoreline	1966 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
12	Sandy	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
12	Sandy	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
12	Sandy	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
12	Sandy	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
13	Whananaki	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
13	Whananaki	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
13	Whananaki	Shoreline	1959 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
13	Whananaki	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
13	Whananaki	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
13	Whananaki	Shoreline	2008 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
13	Whananaki	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
13	Whananaki	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
13	Whananaki	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
14	Teal	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
14	Teal	Shoreline	1950 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
14	Teal	Shoreline	1961 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
14	Teal	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
14	Teal	Shoreline	1999 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
14	Teal	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
14	Teal	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
14	Teal	Shoreline	2008 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
14	Teal	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
14	Teal	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
14	Teal	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
15	Helena	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
15	Helena	Shoreline	1950 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
15	Helena	Shoreline	1961 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
15	Helena	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
15	Helena	Shoreline	1999 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
15	Helena	Shoreline	1999 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
15	Helena	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
15	Helena	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
15	Helena	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
15	Helena	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
15	Helena	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
16	Ohawini	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
16	Ohawini	Shoreline	1957 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
16	Ohawini	Shoreline	1985 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
16	Ohawini	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
16	Ohawini	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
16	Ohawini	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
16	Ohawini	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
16	Ohawini	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
16	Ohawini	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
17	Oakura	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
17	Oakura	Shoreline	1957 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
17	Oakura	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
17	Oakura	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
17	Oakura	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
17	Oakura	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
17	Oakura	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
17	Oakura	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
18	Bland	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
18	Bland	Shoreline	1955 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
18	Bland	Shoreline	1953 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
18	Bland	Shoreline	1971 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
18	Bland	Shoreline	1981 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
18	Bland	Shoreline	1985 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
18	Bland	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
18	Bland	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
18	Bland	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
18	Bland	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
18	Bland	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
19	Waitangi	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
19	Waitangi	Shoreline	1951 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
19	Waitangi	Shoreline	1971 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
19	Waitangi	Shoreline	1980 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
19	Waitangi	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
19	Waitangi	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
19	Waitangi	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
20	Matauri	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
20	Matauri	Shoreline	1950 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
20	Matauri	Shoreline	1980 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
20	Matauri	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
20	Matauri	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
20	Matauri	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
21	Te Ngaire	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
21	Te Ngaire	Shoreline	1948 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	1959 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	1976 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	1981 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
21	Te Ngaire	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
21	Te Ngaire	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
21	Te Ngaire	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
22	Tauranga	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
22	Tauranga	Shoreline	1948 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
22	Tauranga	Shoreline	1961 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
22	Tauranga	Shoreline	1981 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
22	Tauranga	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
22	Tauranga	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
22	Tauranga	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
22	Tauranga	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
22	Tauranga	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
22	Tauranga	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
23	Taupo	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
23	Taupo	Shoreline	1948 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
23	Taupo	Shoreline	1981 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
23	Taupo	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
23	Taupo	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
23	Taupo	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
23	Taupo	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
23	Taupo	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
23	Taupo	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
24	Hihi	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
24	Hihi	Dune Crest	2013 dune crest	GPS	Dune crest surveyed with robotic RTK GPS by Barney Brotherhood.	Barney Brotherhood	Mark Ivamy	A
24	Hihi	Shoreline	1948 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
24	Hihi	Shoreline	1981 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
24	Hihi	Shoreline	1998 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
24	Hihi	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
24	Hihi	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
24	Hihi	Shoreline	2006 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
24	Hihi	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
24	Hihi	Shoreline	2008 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
24	Hihi	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
24	Hihi	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
25	Coopers	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
25	Coopers	Shoreline	1948 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
25	Coopers	Shoreline	1960 shoreline	NZAM-AERIAL	Georeference image and digitise shoreline	Patrick Knook	Mark Ivamy	A
25	Coopers	Shoreline	1966 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
25	Coopers	Shoreline	1981 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
25	Coopers	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
25	Coopers	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
25	Coopers	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
25	Coopers	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
25	Coopers	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
26	Cable	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
26	Cable	Shoreline	1948 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
26	Cable	Shoreline	1966 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
26	Cable	Shoreline	1981 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
26	Cable	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
26	Cable	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
26	Cable	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
26	Cable	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
26	Cable	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
26	Cable	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
26	Cable	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
27	Taipa	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
27	Taipa	Shoreline	1948 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
27	Taipa	Shoreline	1961 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A

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27	Taipa	Shoreline	1981 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
27	Taipa	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
27	Taipa	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
27	Taipa	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
27	Taipa	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
27	Taipa	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
27	Taipa	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
28	Rangiputa	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
28	Rangiputa	Shoreline	1944 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
28	Rangiputa	Shoreline	1977 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
28	Rangiputa	Shoreline	1984 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
28	Rangiputa	Shoreline	1999 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
28	Rangiputa	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
28	Rangiputa	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
28	Rangiputa	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
28	Rangiputa	Shoreline	2008 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
28	Rangiputa	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
28	Rangiputa	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
28	Rangiputa	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
29	Tokerau	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
29	Tokerau	Shoreline	1944 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	1970 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	1976 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	1977 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	1984 shoreline	CRM	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
29	Tokerau	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
29	Tokerau	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
29	Tokerau	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
30	Ahipara	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
30	Ahipara	Shoreline	1950 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	1960 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	1977 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	1981 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
30	Ahipara	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	2007 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	2008 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
30	Ahipara	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
30	Ahipara	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
30	Ahipara	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
31	Omapere	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
31	Omapere	Shoreline	1942 shoreline	CRM	Digitise from CRM Plan at maximum 1:1000 scale.	Patrick Knook	Mark Ivamy	A
31	Omapere	Shoreline	1961 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
31	Omapere	Shoreline	1968 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
31	Omapere	Shoreline	1977 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
31	Omapere	Shoreline	1984 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2000 shoreline	NRC-AERIAL	Historic shoreline supplied by NRC as shape file	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2002 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2003 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2004 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2005 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2007 shoreline	GPS	GPS shoreline supplied by NRC.	NRC	Mark Ivamy	A
31	Omapere	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	A
31	Omapere	Shoreline	2019 shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
31	Omapere	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
32	Mangawhai Heads	Shoreline	1963 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
32	Mangawhai Heads	Shoreline	1983 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
32	Mangawhai Heads	Shoreline	2003 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
32	Mangawhai Heads	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
32	Mangawhai Heads	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
33	Tamaterau	Shoreline	1942 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
33	Tamaterau	Shoreline	1979 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
33	Tamaterau	Shoreline	2004 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
33	Tamaterau	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
33	Tamaterau	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
34	Woolleys Bay Ext	Shoreline	1942 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
34	Woolleys Bay Ext	Shoreline	1985 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
34	Woolleys Bay Ext	Shoreline	2004 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
34	Woolleys Bay Ext	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
34	Woolleys Bay Ext	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
35	Moureeses Bay	Shoreline	1942 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
35	Moureeses Bay	Shoreline	1961 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
35	Moureeses Bay	Shoreline	1985 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
35	Moureeses Bay	Shoreline	2004 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
35	Moureeses Bay	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
35	Moureeses Bay	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
36	Long Beach	Shoreline	1951 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
36	Long Beach	Shoreline	1971 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
36	Long Beach	Shoreline	1981 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
36	Long Beach	Shoreline	2000 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
36	Long Beach	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
36	Long Beach	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
37	Paihia	Shoreline	1951 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
37	Paihia	Shoreline	1971 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
37	Paihia	Shoreline	1981 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
37	Paihia	Shoreline	2000 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
37	Paihia	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
37	Paihia	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
38	Whatuwhiwhi	Shoreline	1944 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
38	Whatuwhiwhi	Shoreline	1984 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
38	Whatuwhiwhi	Shoreline	2000 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
38	Whatuwhiwhi	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
38	Whatuwhiwhi	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
39	Kaimaumau	Shoreline	1944 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
39	Kaimaumau	Shoreline	1981 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
39	Kaimaumau	Shoreline	2000 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
39	Kaimaumau	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
39	Kaimaumau	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
40	Baylys Beach	Shoreline	1952 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
40	Baylys Beach	Shoreline	1979 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
40	Baylys Beach	Shoreline	1991 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
40	Baylys Beach	Shoreline	2014 Shoreline	Aerial	Digitised shoreline ployline based on 2014-2016 LINZ Aerials	Josh Joubert	Patrick Knook	A
40	Baylys Beach	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
40	Baylys Beach	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
41	Glinks Gully	Shoreline	1957 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
41	Glinks Gully	Shoreline	1983 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
41	Glinks Gully	Shoreline	1991 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
41	Glinks Gully	Shoreline	2003 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
41	Glinks Gully	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
41	Glinks Gully	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
42	Whakapirau	Shoreline	1957 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
42	Whakapirau	Shoreline	1982 Shoreline	Aerial	Digitised shoreline ployline based on historic aerials sourced from Retrolens.nz	Josh Joubert	Patrick Knook	A
42	Whakapirau	Shoreline	2003 Shoreline	Aerial	Digitised shoreline ployline based on 2000-2004 LINZ Aerials	Josh Joubert	Patrick Knook	A
42	Whakapirau	Shoreline	2019 Shoreline	LiDAR	Digitised shoreline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A
42	Whakapirau	Dune/Cliff crest	2019 crestline	LiDAR	Digitised crestline polyline based on LiDAR derived DTM	Josh Joubert	Patrick Knook	A

Appendix D: Assessment of replacing triangular distributions with normal distributions

Memo

To:	Toby Kay	Job No:	1001049
From:	Patrick Knook	Date:	16 June 2017
cc:	Tom Shand		
Subject:	Assessment of replacing triangular distribution with normal distribution for Short-Term and Long-Term components		

1 Objective

Previous coastal erosion hazard zones (CEHZ) for selected sites within Northland were assessed using a probabilistic approach (T+T, 2014). Triangular input distributions were adopted with parameter bounds (min, mode and max) defined for each component. A Monte Carlo technique was then used to derive probability distributions for each component and resultant CEHZ width.

Following the peer review recommendation for the Christchurch hazard assessment to evaluate the potential to use normal distributions for both the short-term (storm cut) and long-term component, Northland Regional Council (NRC) have requested to undertake a similar assessment for Northland.

This memo sets out a comparison of resultant CEHZs for two selected sites by replacing the triangular distributions with normal distributions for the short-term (ST) and/or long-term (LT) components, while keeping the triangular distribution for the remaining components (Dune Stability and Sea Level Rise) as requested by NRC.

2 Assessment

Waipu Cove (cell 2C) and Marsden Point (cell 4C) have been selected to review the resultant CEHZs by replacing the triangular distributions with normal distributions for ST and LT. These sites were selected because of the availability of extensive beach profile datasets (40+ profiles), which were used to derive parameter bounds for ST. For both the ST and LT the datasets previously used in T+T (2014) have been used to derive normal distributions.

A normal distribution is a probability distribution that plots all of its values symmetrically around the mean, with most of the results situated around the mean. The probability density of the normal distribution includes a mean and a standard deviation (SD), with the SD quantifying the amount of variation of the dataset. Figure 2.1 shows and example of a normal distribution including a comparison with a triangular distribution.

For this assessment the same mean/modal value has been adopted in order to compare a normal distribution with a triangular distribution. The SD have been derived from the previously used datasets.

2.1 Short-Term (ST)

The triangular distributions for the ST component were based on a combination of SBEACH results and statistical analysis results for the previous study (refer T+T, 2014). With sufficient data, statistical analysis of profile datasets provide adequate information to derive short-term effects.

Both at Waipu Cove 2C and Marsden Point 4C beach profile datasets including more than 40 surveys are available and these have been used to derive input parameters for the normal distributions. The modal values for cell 2C and 4C were found to be 10 m and 20 m respectively. The SD have been derived from beach profile residuals (de-trended contour excursion distances; refer to T+T (2014) for methodology). The SD for cell 2C and 4C are 4.96 m and 6.9 m respectively. Table 2.1 shows a summary of input values for both the triangular distribution and normal distribution for the two selected site.

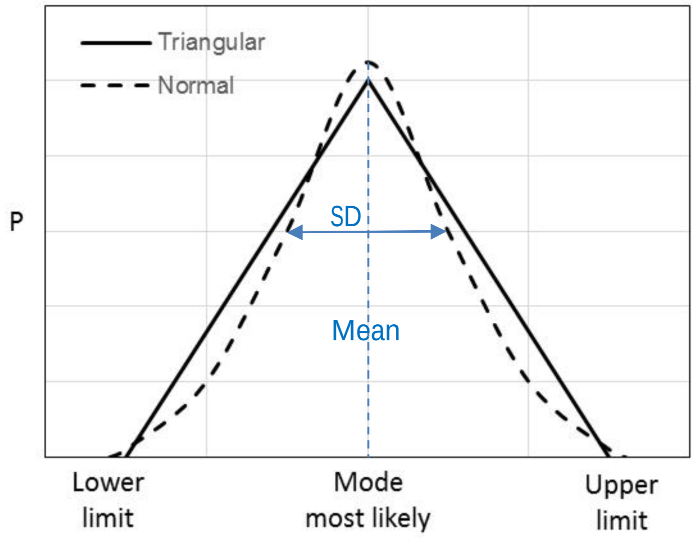

Figure 2.1: Example of triangular distribution and normal distribution

2.2 Long-Term (LT)

The GIS-based model DSAS was previously used to derive the long-term shoreline change statistics at 5 m intervals along each site. The shoreline change statistics include weighted linear regression rates and 90% confidence intervals, and were used to assess bounding values for the triangular distributions (refer to T+T, 2014).

The modal values for cell 2C and 4C were found to be 0 m/yr and -0.45 m/yr. The SD has been derived taking into account all linear regression rate values within each cell. The SD for cell 2C and 4C are 0.078 m/yr and 0.188 m/yr respectively (see Table 2.1).

Table 2.1: Input values for ST and LT for triangular and normal distributions

Site	Waipu Cove 2C					Marsden Point 4C				
Distribution	Triangular			Normal		Triangular			Normal	
Parameter	Min	Mode	Max	Mean	SD[1]	Min	Mode	Max	Mean	SD[1]
ST (m)	5	10	15	10	4.98	10	20	30	20	6.9
LT (m/yr)	-0.075	0	0.1	0	0.078	-0.6	-0.45	-0.15	-0.45	0.188

[1]Standard Deviation

2.3 Resultant CEHZs

The constructed normal distributions using the values as set out in Table 2.1 for both the ST and LT components have been randomly sampled and the extracted values are then used to define a potential CEHZ distance. This process is repeated 10,000 times using a Monte Carlo technique and probability distribution of the resultant CEHZ width is forecast. We have run the scenarios as set out in Table 2.2.

Table 2.2: Distribution scenarios assessed

Scenario	ST	LT
1	Triangular Distribution	Triangular Distribution
2	Normal Distribution	Triangular Distribution
3	Triangular Distribution	Normal Distribution
4	Normal Distribution	Normal Distribution

The resulting ST, LT and resultant CEHZ histograms and probability curves for both sites for a 100 year time frame are shown in Appendix A and are summarised in Table 2.3. It can be seen from Table 2.3 that the maximum CEHZ distances typically increase when a normal distribution is and the minimum CEHZ values typically decrease. The average CEHZ (P50%) is roughly the same (<1 m difference) for each assessed scenario at Waipu Cove 2C, but is up to 6 m larger at Marsden Point 4C when a normal distribution is adopted for both components.

The 100 year P5% CEHZ (i.e. a 5% probability of exceedance at 2115) was previously adopted by NRC as the CEHZ2 distance. The 2115 resultant CEHZ widths for Waipu Cove 2C and Marsden Point 4C are shown in Table 2.3. It can be seen from Table 2.3 that the CEHZ2 width increases from -52 m to -58 m at Waipu Cove 2C (11.5% increase) and from -130 m to -147 m at Marsden Point 4C (13% increase).

Table 2.3: 2115 resultant CEHZ widths (m)

	Waipu Cove 2C				Marsden Point 4C			
	Probability of exceedance				Probability of exceedance			
Scenario	Max	5%	50%	Min	Max	5%	50%	Min
1	-69	-52	-37	-12	-165	-130	-101	-56
2	-73	-54	-37	-7	-184	-132	-101	-46
3	-84	-57	-38	-4	-201	-146	-106	-10
4	-82	-58	-38	0	-210	-147	-107	-12

3 Conclusions

The results of this assessment show that in case a normal distribution is adopted for either the ST or LT component or both, the 2115 resultant CEHZ width typically increases for an exceedance probability less than 50% (i.e. between P50% and maximum). For exceedance probabilities larger than 50% the 2115 resultant CEHZ width is typically less. The CEHZ2 increases 11.5% - 13%.

16-Jun-17
p:\1001049\workingmaterial\distribution analysis\20170608.distributionanalysis.r1.docx

Appendix E: Undertaking site-specific CEHZ assessments for cliff coasts

To determine a site-specific CEHZ for a cliff coast, the following steps should be undertaken by a qualified and experienced practitioner (see sketch in Figure Appendix E.1):

1 Determine the future cliff toe position (2080 or 2130) using Council GIS
2 Determine cliff height (H) above the cliff toe using Council LiDAR or site-specific topographic survey
3 Assessment of the stable cliff angle (by qualified geologist)
4 Divide cliff height by stable cliff angle (H/tanα)
5 Offset the calculated distance from future cliff toe.

The distance between the present-day cliff toe and the offset line from the 2080 or 2130 future cliff toe represents the CEHZ1 and CEHZ2/CEHZ3 respectively. These steps should be repeated if the stable cliff angle or cliff height vary alongshore.

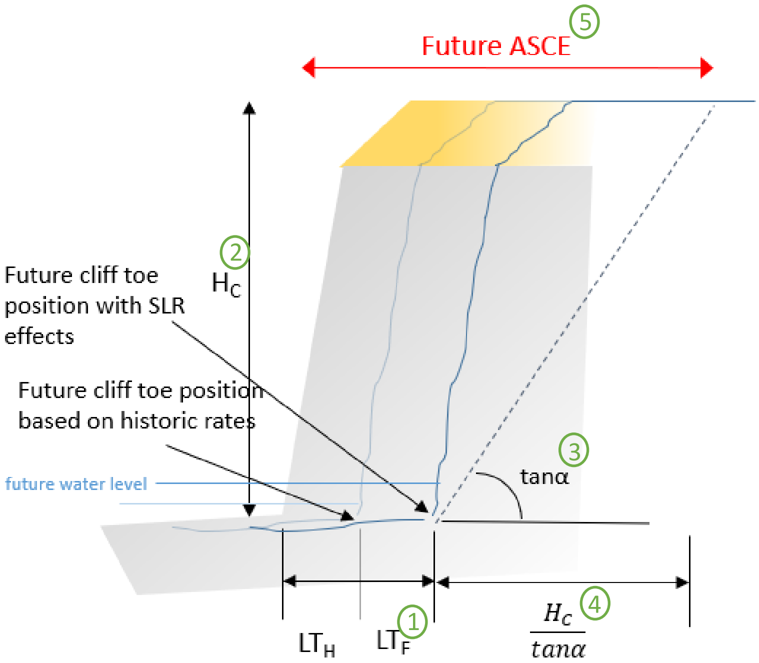

Figure Appendix E.1: Definition sketch of cliff coast CEHZ (green numbers relate to steps above)

Appendix F: Peer review letters

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Dr Tom Shand
Tonkin & Taylor Ltd.

15 September 2014

REVIEW: Northland Regional Council
Coastal Erosion Hazard Zone Assessment for Selected Northland Sites

In September 2014 I reviewed the coastal hazard report prepared by Tonkin & Taylor Ltd. for Northland Regional Council. The report contains an updated analysis of coastal erosion hazard zones for the basis of hazard management and planning by Council. Having been involved with a number of hazard analyses around New Zealand over the past 15 years and recently appointed as expert member of a panel appointed to review the coastal erosion hazard assessment for the Kapiti coast I believe I am well-placed to comment on the approach and outcomes of the report. I make the following general comments of the report.

1. The report is well written and logically presented.

2. The report adopts leading and robust methodological approaches to evaluate the coastal erosion hazards in Northland. In particular, the report recognizes the spatial variability in physical and oceanographic characteristics of the Northland coast and develops different models to use on these different types of coast. Furthermore, the report adopts a probabilistic approach to assessing the erosion hazards along the coast. Such an approach has been advocated for more than a decade and this report is among the first in New Zealand to operationalize this approach.

3. I have made a number of detailed comments on the report and forwarded these to Tonkin & Taylor Ltd. for their consideration in revising the report. In particular, I recommended greater exploration of the hazard results provide improved context for Northland Regional Council in supporting their future deliberations for hazard management.

4. I believe the report and its findings are robust given the current state of knowledge of coastal science and the methodological tools available to evaluate erosion hazards. As acknowledged in the report the erosion hazards should be re-evaluated on a periodic basis as improved information and assessment tools become available.

Yours sincerely

Professor Paul Kench

Head of School
School of Environment

HCL
Hume Consulting Ltd

3 July 2020

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Peer review of coastal erosion hazard assessment for selected sites in Northland

Dear Patrick

HCL were contracted by T+T to undertake a peer review of a coastal erosion hazard assessment for 12 selected sites in Northland, and specifically of the Site Assessments component of the work. The overall methodology being used to derive the coastal erosion hazard distances had been reviewed previously and is outside of the scope of this peer review.

The HCL review proceeded as:

- A site visit accompanying a T+T staff member making on-site assessments of the 12 sites over 5 days (20-24 January 2020).
- A review was undertaken (21 April) of an early draft of the site assessments report to check/confirm the rational for the adopted component values and cell splits for calculating coastal erosion hazard zones for the sites and shoreline change history from DSAS. This confirmation was required prior to the next step of calculation of the hazard distances.
- A review was undertaken (24 June) of the completed report “T+T (2020). Coastal Erosion Hazard Assessment for Selected Northland Sites Appendix A2: Site Assessments. Draft report for NRC. 147p”. The main document and Appendix A1 were not part of the scope for peer review but were read through for background information.

Site visit

This provided the reviewer with a first-hand knowledge of the sites and the opportunity to assess the thoroughness with which the on-site assessments were being made.

April review

My review of component values confirmed the site descriptions, cell splits and shoreline change history from DSAS. Checks were made of the cell data in the text for consistency with that in the table. Suggestions were made clarify and simplify the text in places, consider changing in some of the terminology (e.g., replace embankment with coastal terrace) and to standardise the site descriptions to a greater degree, including adding beach sediment type descriptions for each cell.

All my suggested changes were made by T+T and incorporated into the June version.

June review
The T+T 2020 report is huge overall, when the main report and the appendices are considered. Given that the various parts split up may be used separately, I suggest that the Appendices A1 and A2 are made more standalone, by adding upfront a page with a paragraph or two describing how the Appendix links with the main report. This would include copying in Figure 1 from the main report (CEHZ Assessment for Selected Northland Sites Site Plan) which I found myself referring to while using the appendix.

In my review of the 12 site descriptions I identified a number of small editorial issues (e.g., standardising terms such as short-term vs short term, improvement to the headings in key tables) along with small editorial matters – all easily corrected. I also identified several of editorial matters in the main report - easily corrected.

The hazard distances calculated all looked reasonable except for the CEHZ distances for some of the cliff cells. The CEHZ distances for cliff cells for CEHZ2 and CEHZ3, for Woolleys Bay, Moureeses Bay and Bayleys Beach looked to be very large. There was mention of issues with calculating CEHZ distances for cliff cell in the main report, and I understand that all the CEHZ distances have been calculated in a consistent manner. If the lines are taken as surrogates for future shorelines, then in interpreting the lines some consideration would need to be given to how the shoreline might reshape itself in the future. At Bayleys, on the open west coast, one might expect the future shoreline to be sub parallel to the existing shoreline. At Wooleys, a pocket beach, it might straighten out only to a certain degree as the sandy beach develops and protects the cliff from further erosion? At Moureeses, a pocket beach, the reef in the central bay will serve to act as an offshore breakwater (even with high sea level) and sand may accumulate as a salient in behind the reef? I suggest some text be added to address this issue.

Overall
Appendix A2 is a very comprehensive, well- structured and illustrated document. It demonstrates that the hazard mapping was soundly ground-truthed. While a consistent methodology was applied to each site, it was notable that small adjustments in methodology were made at sites where the local conditions necessitated that. I note too that the main report and Appendix 1 use methodology that follow MFE (2017) guidance for local authorities in terms of using a stochastic/probabilistic methodology and choice of sea level rise scenarios has been updated with latest information.

Appendix A2 does a good job in underpinning the main report.

Dr Terry M. Hume

Managing Director
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