REPORT

Tonkin + Taylor

Coastal Erosion Hazard Zone Assessment for Selected Northland Sites

2017 Update

Prepared for
Northland Regional Council

Prepared by
Tonkin & Taylor Ltd

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Exceptional thinking together

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Document Control

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10-2014	1	Report	T. Shand	P. Kench	R. Reinen-Hamill
12-2017	2	2017 Update	P. Knook	T. Shand	R. Reinen-Hamill

This original report has been updated in 2017 to include the following additional assessments and minor adjustments:

i Reassessment of CEHZ width for selected cliff coasts using site-specific DTM (Digital Terrain Model) and assumed stable angles rather than assumed cliff heights

ii CEHZs for shorelines protected by structures (termed CEHZ0)

iii Mapping of additional CEHZ that were included in T+T (2014) assessment, but were not mapped at that time

iv Revised Appendix A including component distribution and resulting CEHZ distribution histogram plots for each cell, and maps of historic shorelines shown on the latest aerial photograph for each site.

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Executive summary

Northland Regional Council (NRC) commissioned Tonkin & Taylor Ltd (T+T) to undertake a coastal erosion hazard zone (CEHZ) assessment for 31 sites within their administrative boundary. The NRC have previously assessed the CEHZ for the majority of sites over a number of different reports completed from 1988 to 2003. The NRC require a new set of CEHZ to be developed in line with the current state of scientific knowledge, relevant legislation and best practice guidelines.

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 three major coastal types:

- Beaches comprising unconsolidated sediments
- Cliff coasts
- Estuarine shorelines.

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

- 2015 Coastal Erosion Hazard Zone (Current): 2015 CEHZ
- 2065 Coastal Erosion Hazard Zone (50 years): 2065 CEHZ
- 2115 Coastal Erosion Hazard Zone (100 years): 2115 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, the CEHZ value with a 66% probability of being exceeded ($P_{66\%}$) at 2065 and the CEHZ value with a 5% probability of being exceeded ($P_{5\%}$) at 2115 have been adopted as prudent *likely* and *potential* CEHZ values (termed CEHZ1 and CEHZ2 respectively) to provide the required two hazard zones for Council's planning maps. 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 selected baseline, typically the 2013/2014 shoreline.

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. Therefore, mapping the extent of hazard is still applied to these areas as a dashed line.

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 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

Northland Regional Council (NRC) commissioned Tonkin & Taylor Ltd (T+T) to undertake a coastal erosion hazard zone (CEHZ) assessment for 31 sites within their administrative boundary (refer to Table 1-1 for site schedule and Figure 1-1).

The NRC have previously assessed the CEHZ for all sites, excluding Matauri Bay and Te Ti Bay Waitangi, 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. The 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	16	Ohawini Bay (& Parutahi Beach)
2	Waipu Cove	17	Oakura Bay
3	Ruakaka	18	Bland Bay
4	Marsden Point	19	Te Ti Bay Waitangi
5	Marsden Cove	20	Matauri Bay
6	One Tree Point	21	Te Ngaire Beach
7	Taiharuru	22	Tauranga Bay
8	Pataua Estuary and Pataua North	23	Taupo Bay
9	Whangaumu Beach (Wellingtons)	24	Hihi
10	Matapouri Estuary and Bay	25	Coopers Beach
11	Woolleys Bay	26	Cable Bay
12	Sandy Bay	27	Taipa
13	Whananaki Sandspit	28	Rangiputa
14	Teal Bay Beach (Ngawai Bay)	29	Tokerau Beach North
15	Helena Bay Beach (Te Mimiha)	30	Ahipara
		31	Omapere & Opononi

1.2 Study scope

The NRC professional services brief requires the following scope of works to develop CEHZ assessments for the 31 selected Northland sites:

- Provide two coastal hazard zones for each site, based on 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'.

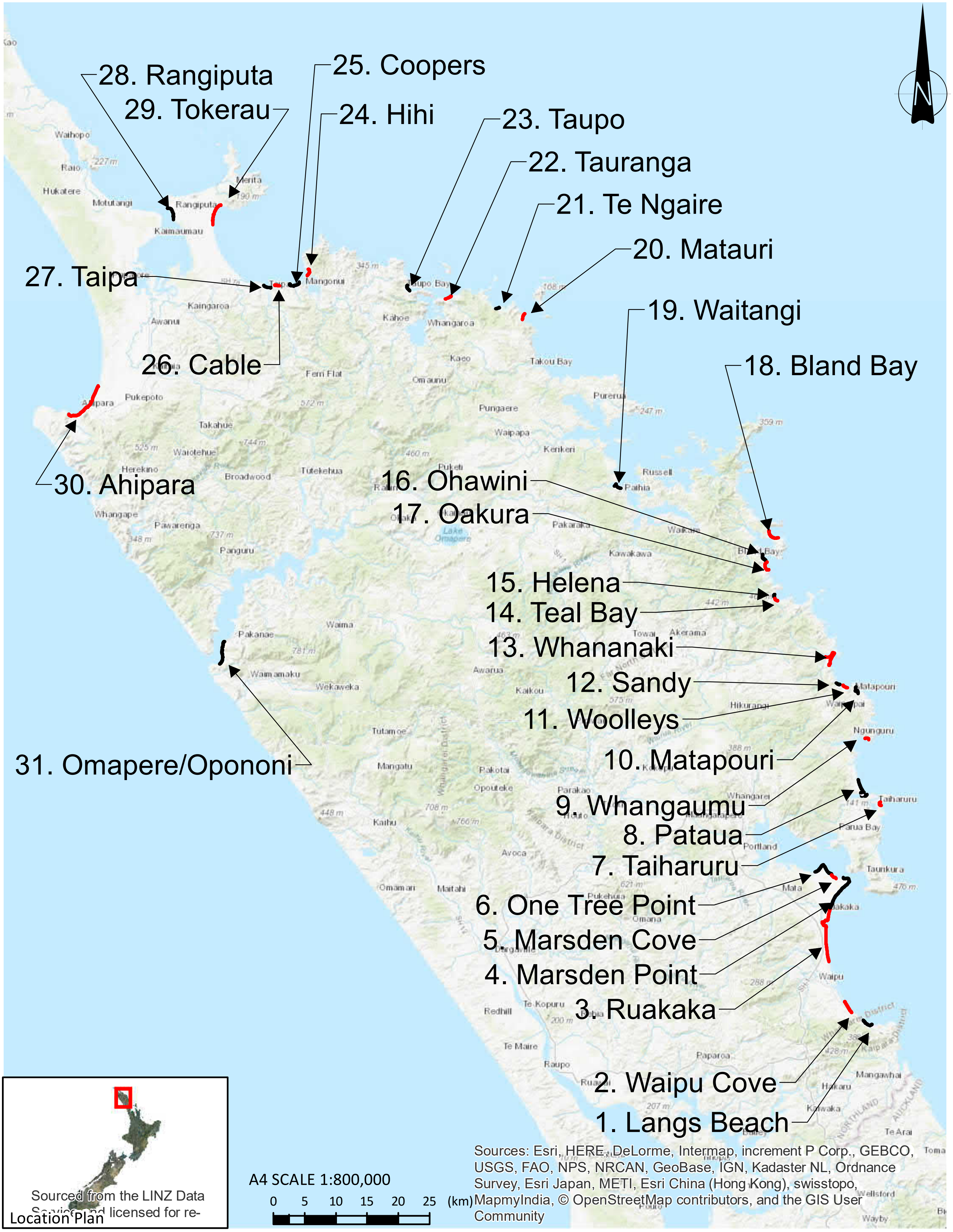
1.3 Report layout

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 A, 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 4.9.1 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 One Tree Point Vertical Datum 1964 (OTP64 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

Rev.
2

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, 1998: Review Of Coastal Hazard Zones for Eleven Selected beaches in Whangarei District Northland Region. Technical Report Prepared for Northland Regional Council, CR98/4.
- Gibb, 1998: 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.
- Tonkin & Taylor, 2012: Coastal Erosion Hazard Zone Review. Technical Report Prepared for Whangarei District 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 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 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 sites 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 1m. 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) 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 CRM that cover each site is listed 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
6	One Tree Point	n/a		
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
19	Te Ti Waitangi	n/a		
20	Matauri Bay	n/a		
21	Te Ngaire Beach	n/a		
22	Tauranga Bay	n/a		
23	Taupo Bay	n/a		
24	Hihi	2506/1	1988	1981
25	Coopers Beach	2506/2	1988	1981
26	Cable Bay	n/a		
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 LiDAR

LiDAR ground data was provided by NRC in post processed xyz format for all but two sites (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 ±0.1m, refer to Appendix C for the full LiDAR metadata report.

2.1.3 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 1km offshore for all but two sites (Te Ti Bay Waitangi and Matauri Bay). The offshore profiles will be 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
4	Marsden Point					
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

Site			Surveys			
ID	Name	Profile	No. of profiles	Start date	End date	Years
7	Taiharuru	n/a				
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
11	Woolleys Bay	n/a				
12	Sandy Bay	n/a				
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
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
20	Matauri Bay	n/a				
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

2.2 New data obtained

2.2.1 Site inspections

Site inspections were undertaken for all sites between 13 November 2013 and 13 January 2014 by Mark Ivamy (Senior Coastal Scientist, T+T) and Barney Brotherhood (River Management Engineer, NRC).

The following data was collected for each site during the site inspections:

- 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.

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

2.2.2 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 all sites (refer to Table 2-3).

Table 2-3 Aerial photographs available from NZAM to complete the shoreline data set

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

Site	Date Flown	Run Number	Scale
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.

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

2.2.3 LiDAR data

The dune crest elevation along each site is required for calculating the impact of sea level rise on shoreline retreat. The dune crest was captured in GIS based on the supplied LiDAR data. The LiDAR ground data was supplied for each site in xyz format. In order to effectively visualise and utilise the supplied LiDAR data it was translated into a digital elevation model (DEM) using ArcGIS (with 3D Analyst extension).

For each site the supplied data was batch translated from the xyz data files into las file format for use in ArcGIS. Note, this process changes the storage format only and does not change the core data. The output las files were organised into combined datasets in ArcGIS and used to create the DEM. The DEM was created using the average binning method, where each cell in the DEM is assigned the average elevation of all LiDAR points falling within the cell. The DEM has a square cell size of 2m based on the point density of the supplied data. Any voids in the data were filled using linear interpolation of the surrounding LiDAR points. The derivative slope raster was also created from the DEM for each site using ArcGIS.

The dune crest was digitised for each site within the LiDAR extent based on the DEM, slope raster and 2007 aerial image. This process resulted in a 2D GIS polyline of the dune crest alignment for each site. A set of points (sampling locations) were created along the 2D polylines (dune crests) at 1m spacing to extract the elevations for the dune crest. Each sample point was then assigned the elevation of the DEM cell it fell within. The output is a xyz point file of the dune crest for each site within the LiDAR extent (i.e. all sites except Sandys Bay and Woolleys Bay).

2.2.4 Profile data

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

Beach profiles were surveyed during the site inspection by NRC at existing beach profile benchmarks. For the purposes of this study, five additional new beach profile benchmarks were established at the following sites (bench mark 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 sites not covered under the existing NRC beach profile network.

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 four offshore locations (Figure 2-1) to provide representative offshore conditions for all sites. Data was obtained from a 34-year numerical wave hindcast (1979-2012) 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}).

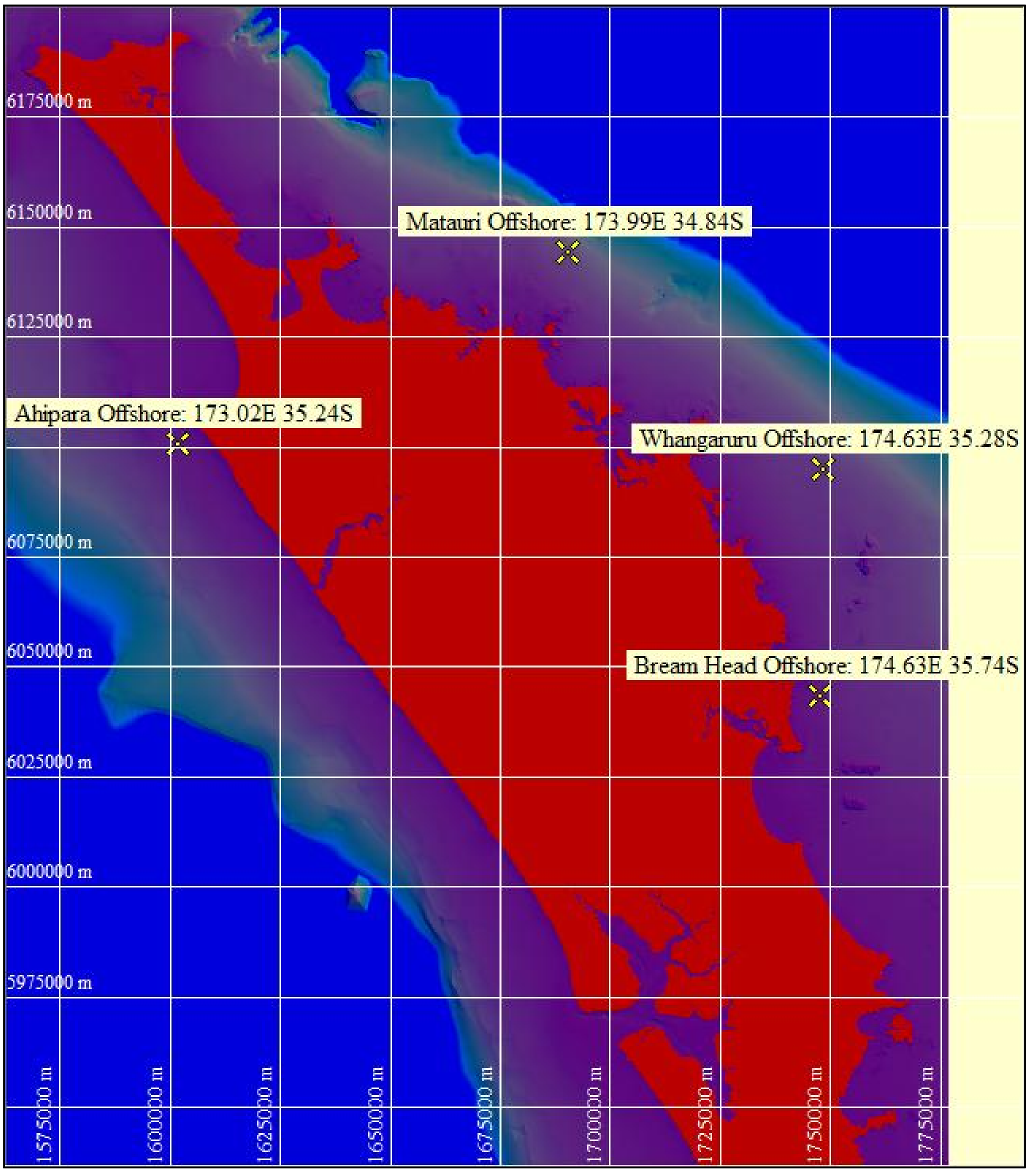

Figure 2-1 Locations of wave hindcast outputs supplied by MetOcean Solutions Ltd

2.2.7 Water level data

Tidal information for Marsden Point and secondary ports in Northland was obtained from the New Zealand Nautical Almanac 2013/14 (NZ 204: LINZ, 2013).

Additional one hour raw sea level data was provided by Northland Regional Council/LINZ for Marsden Point from August 1984 to September 2013. This data was not decomposed into tidal and non-tidal residual and was processed as a combined series to obtain extreme storm tide elevations.

2.3 Verification and quality control

2.3.1 Shoreline data

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

The existing 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 new 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 new GPS shoreline data was collected by T+T using differential GPS. The data 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:

$$E_{sum} = \sqrt{E_1^2 + E_2^2 + \cdots + E_n^2}. \qquad (2\text{-}1)$$

Table 2-5 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 2-5 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 (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 LiDAR data

The new dune crest data processed from LiDAR was verified against the source information by an independent operator (Mark Ivamy, T+T). Verification and quality control focused on accuracy of the 3D polyline representing the dune crest position as the highest point of the dune system. The dune crest elevation values was also cross checked against the beach profile data surveyed at each site.

2.3.3 Profile data

Both the existing beach and offshore profiles supplied by NRC were imported into the Beach Morphology Analysis Package (BMAP) software. The new beach profile data surveyed during the site inspections was also imported into BMAP and verified against the source information by an independent operator (Mark Ivamy, T+T).

2.3.4 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 (Mahurangi Limestone). Hihi and Coopers Beach also have sedimentary rock cliff shorelines comprising sandstone, mudstone and lignite conglomerate (Mangonui Formation).

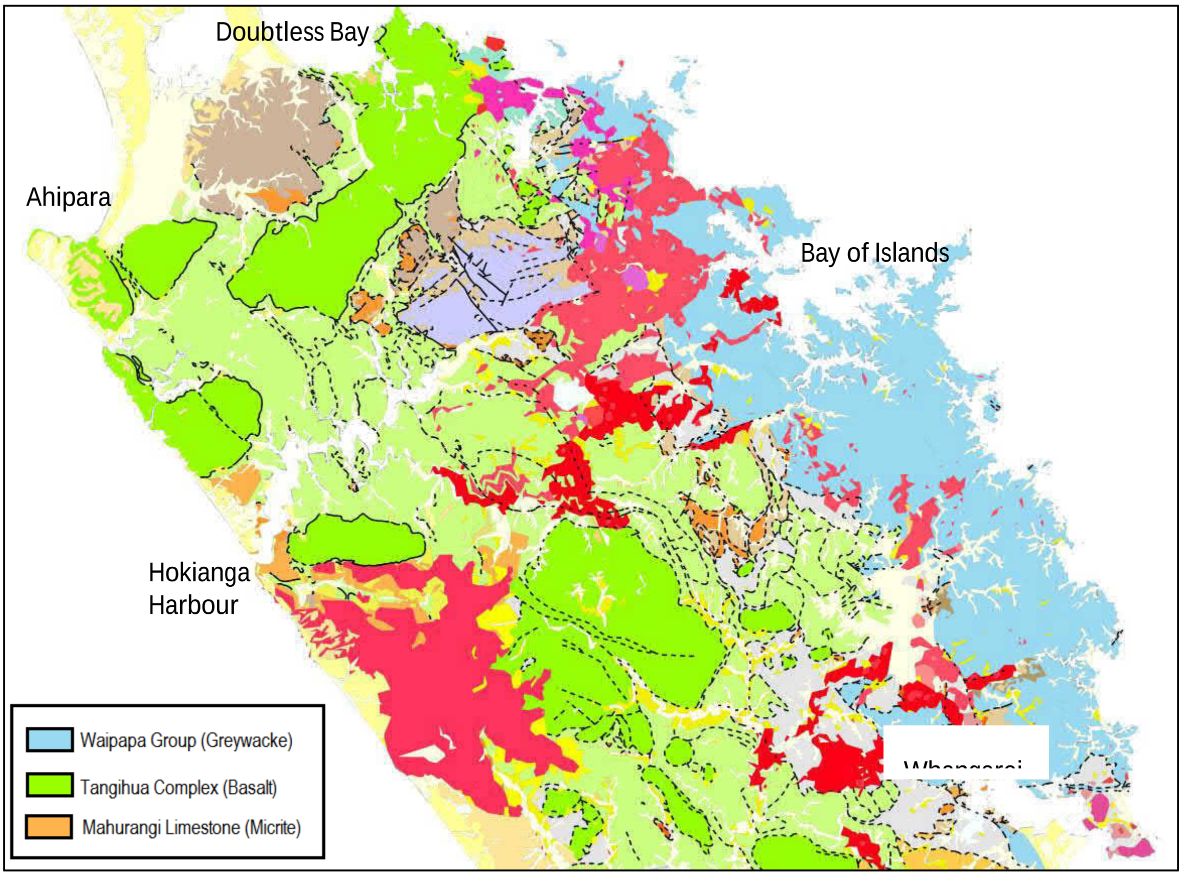

Figure 3-1 Northland Geology, known faults are represented by solid and dashed lines (source: GNS 1:250,000 Geological Units)

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).

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.

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

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, all sample results are presented.

Table 3-1 Beach Sediment summary

Site		Size Range (microns)			Description	
ID	Name	$D_{10\%}$	$D_{50\%}$	$D_{90\%}$	Wentworth Size Classification	
1	Langs Beach	167	291	496	Medium	Sand
2	Waipu	136	216	347	Fine	Sand
3	Ruakaka	146	246	428	Fine	Sand
4	Marsden Point	158	238	357	Fine	Sand
5	Marsden Cove	120	200	336	Fine	Sand
6	One Tree Point East	327	567	1012	Coarse	Sand
6	One Tree Point West	315	448	639	Medium	Sand
7	Taiharuru	216	326	497	Medium	Sand
8	Pataua North	272	587	1226	Coarse	Sand
8	Pataua Estuary	539	929	1487	Very Coarse	Sand
9	Whangaumu	220	356	595	Medium	Sand
10	Matapouri	201	320	517	Medium	Sand
11	Woolleys	217	408	772	Medium	Sand
12	Sandy Bay	170	255	385	Medium	Sand
13	Whananaki	167	296	557	Medium	Sand
14	Teal	224	708	1401	Coarse	Sand
15	Helena	190	814	1612	Coarse	Sand
16	Ohawini	90	139	214	Fine	Sand
17	Oakura	107	194	896	Fine	Sand
18	Bland	202	357	655	Medium	Sand
19	Waitangi	148	233	369	Fine	Sand
20	Matauri	123	186	281	Fine	Sand

Site		Size Range (microns)			Description
ID	Name	$D_{10\%}$	$D_{50\%}$	$D_{90\%}$	Wentworth Size Classification
21	Te Ngaire	118	206	463	Fine Sand
22	Tauranga	209	450	1127	Medium Sand
23	Taupo	164	328	795	Medium Sand
24	Hihi	134	214	342	Fine Sand
25	Coopers	142	225	364	Fine Sand
26	Cable	191	289	440	Medium Sand
27	Taipa	141	244	454	Fine Sand
28	Rangiputa	144	200	275	Fine Sand
29	Tokerau	117	173	255	Fine Sand
30	Ahipara	150	215	362	Fine Sand
31	Omapere Centre	235	441	1206	Medium Sand
31	Omapere North	208	691	1459	Coarse Sand
31	Omapere South	231	333	479	Medium Sand
31	Opononi Centre	295	867	1502	Coarse Sand
31	Opononi North	199	379	628	Medium Sand
31	Opononi South	158	250	401	Medium Sand

The relatively flat wider beaches of Tokerau, Ahipara, Matauri and Bream Bay tend to have finer sand characteristics. The finest sand beach sediment was sampled from relatively sheltered sites within harbour entrances at Oakura, Ohawini 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.

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:

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

3.3.1 Astronomical tide

Tidal levels for primary and secondary ports of New Zealand are provided by LINZ (2013) based on the average predicted values over the 18.6 year tidal cycle. Values for Marsden Point in terms of Chart Datum and OTP64 (RL) 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.

Table 3-2 Tidal levels given for Marsden Point (LINZ, 2012)

Tide state	Chart Datum (m)	OTP64 (RL)
Highest Astronomical Tide (HAT)	2.98	1.30
Mean High Water Springs (MHWS)	2.74	1.06
Mean High Water Neaps (MHWN)	2.32	0.64
Mean Sea Level (MSL)	1.57	-0.11[1]
Mean Low Water Neaps (MLWN)	0.83	-0.85
Mean Low Water Springs (MLWS)	0.40	-1.28
Lowest Astronomical Tide (LAT)	-0.05	-1.73

Source: LINZ Nautical Almanac 2012 – 13

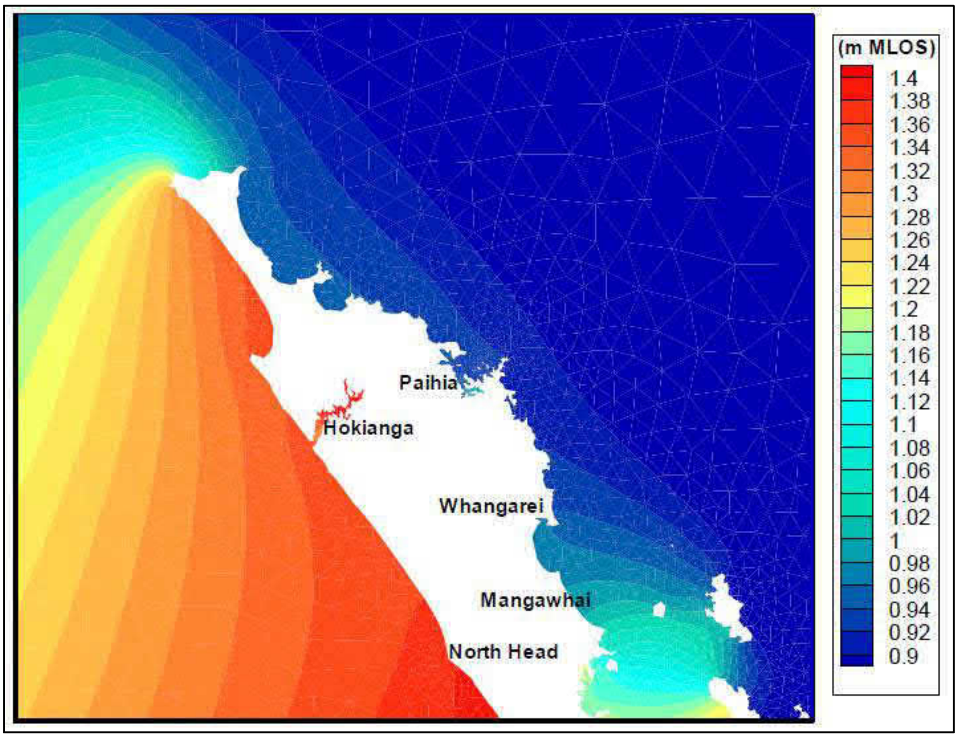

Figure 3-2 MHWS around the Northland Region (Bell and Gorman, 2003)

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).

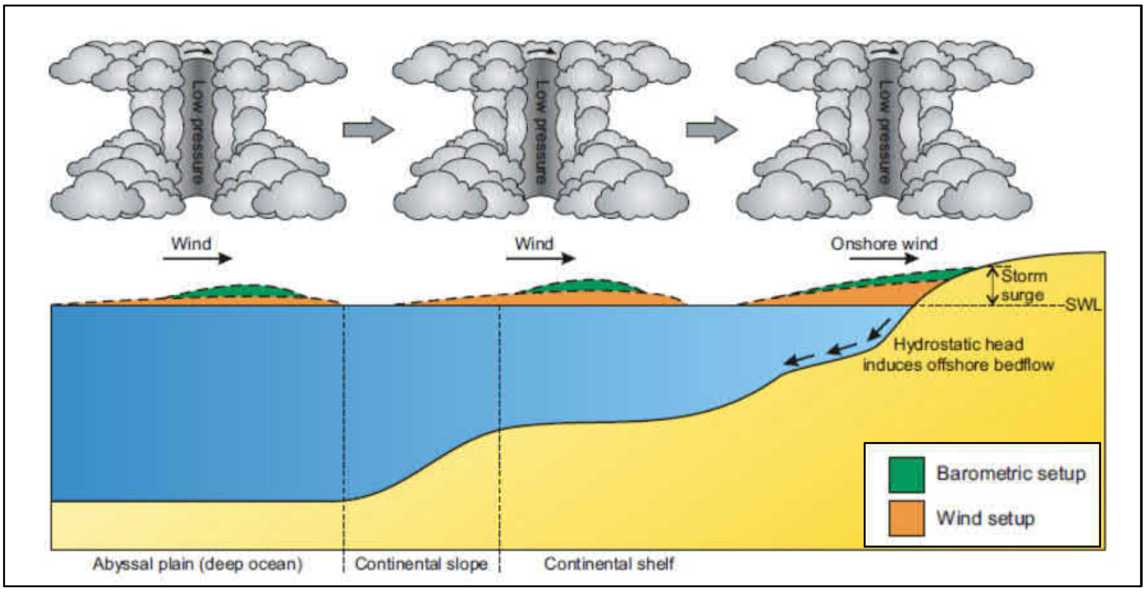

Figure 3-3 Processes causing storm surge (source: Shand, 2010)

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 (refer to Figure 3-4). The combined effect of these fluctuations may be up to 0.25 m (NIWA, 2011).

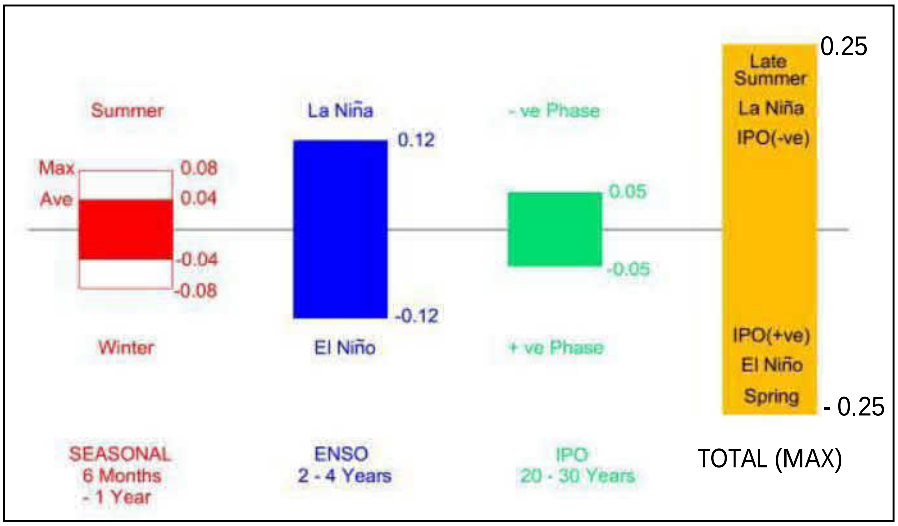

Figure 3-4 Components contributing to sea level variation over long term periods (source: Bell 2012)

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 3-5. 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.

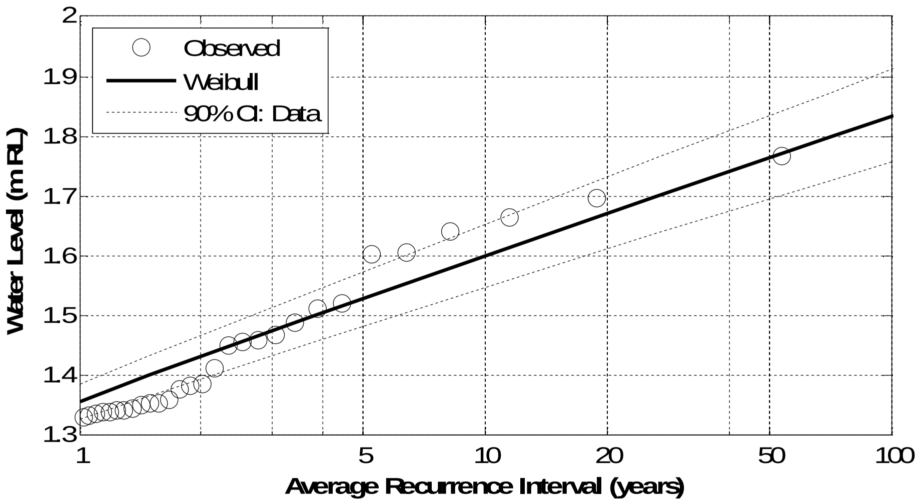

Figure 3-5 Extreme 1 hour averaged water level for Marsden Point (1984 - 2013)

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 and this higher rate and wider uncertainty may be due to the short record length.

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 Ministry of Environment (2008) guideline 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.

Modelling presented within the most recent IPCC report (AR5; IPCC, 2014) show predicted global sea level rise values by 2100 to range from 0.27 m, which is slightly above the current rate of rise, to 1 m depending on the emission scenario adopted. Extrapolating the RCP8.5 scenario to 2115 results in a sea level range from 0.27 to 0.47 m by 2065 and 0.62 to 1.27 m by 2115 (Figure 3-6). The RCP8.5 scenario assumes emissions continue to rise in the 21st century. Adopting this scenario is considered prudent until evidence of emission stabilising justify use of a lower projection scenario.

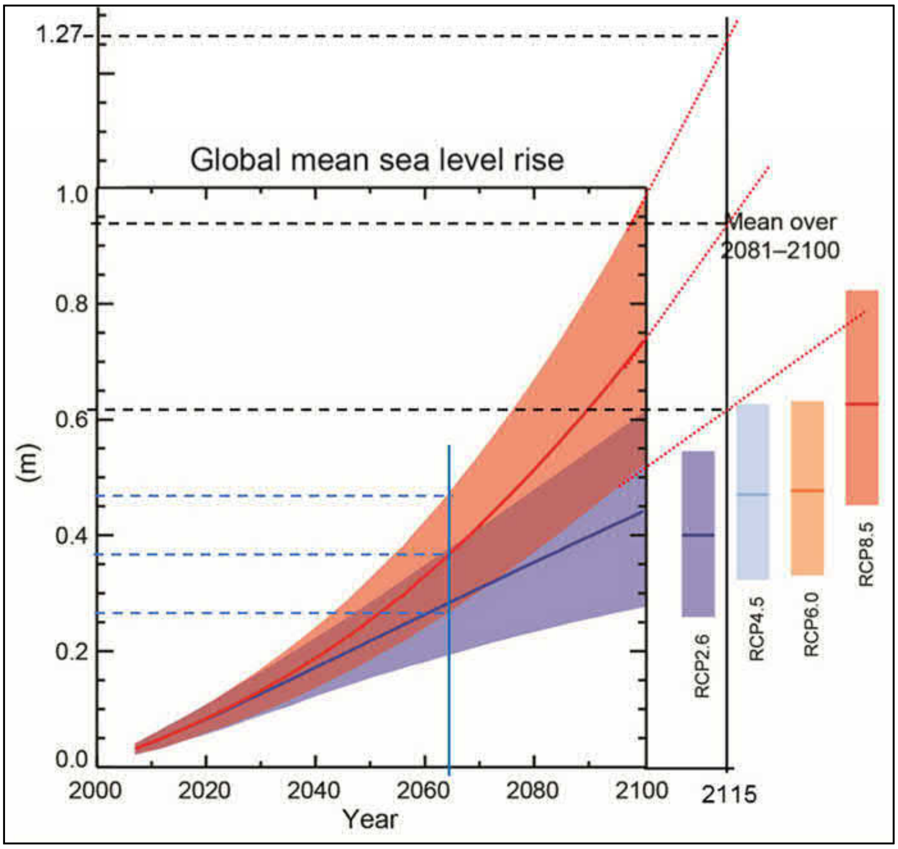

Figure 3-6 Projections of potential future sea level rise presented within IPCC AR5 (IPCC, 2014) with adopted values for this assessment at 2065 and extrapolated to 2115

3.4 Waves

Wave data from four offshore locations representative of the Northland Region was provided by MetOcean Solutions Ltd for this study (refer to Section 2.2.5).

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 3-7. These results show that offshore of Ahipara, 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 (2.5 m) and peak period (13.1 s) on the west coast is typically higher than on the east coast (1.2 to 1.5 m and 9.0 s). Refer to for a summary of the characteristic wave heights for the four Northland offshore locations.

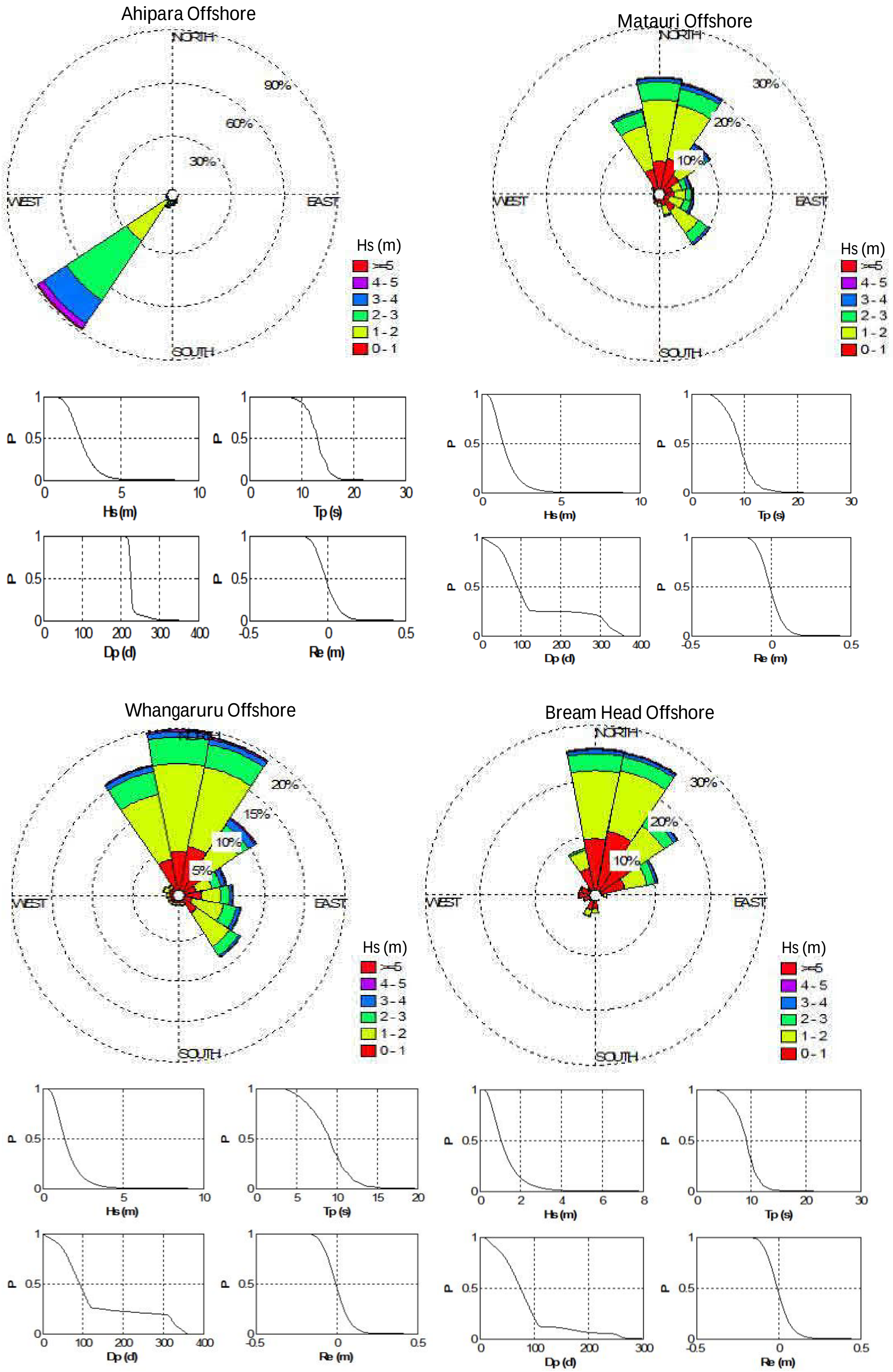

Figure 3-7 Wave roses and CDFs for each offshore buoy showing significant wave height (H_s), peak period (T_p), peak direction(D_p) and non-tidal residual(R_e)

Table 3-4 Characteristic wave heights for Northland offshore locations

Location	Coordinates		Mean			1% Exceedance		
	E (°)	S (°)	H_s (m)	T_p (s)	D_p (°)	H_s (m)	T_p (s)[1]	D_p (°)[1]
Ahipara	173.02	35.24	2.5	13.1	228.7	5.0	14.0	233.1
Matauri Bay	173.99	34.84	1.5	9.1	134.3	4.4	10.8	102.2
Whangaruru	174.63	35.28	1.5	9.0	132.1	4.4	10.8	99.8
Bream Head	174.63	35.74	1.2	9.0	84.1	3.9	10.5	62.8

[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 3-8) 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 3-9).

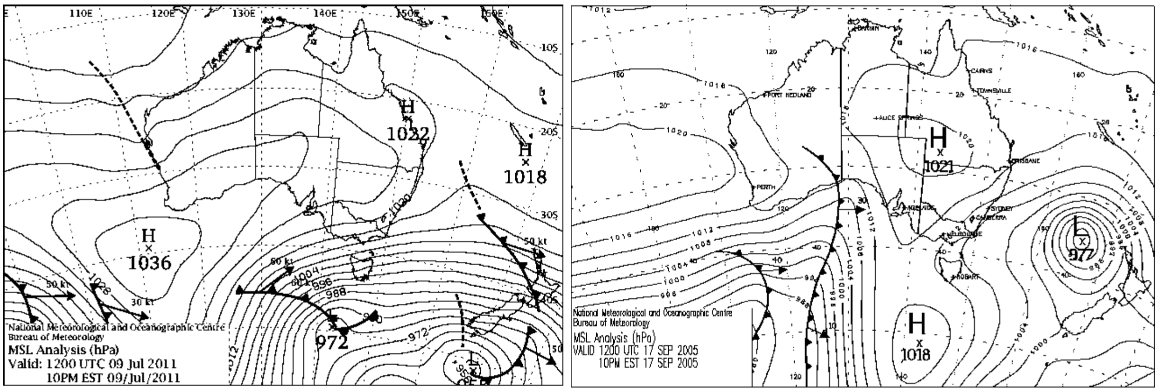

Figure 3-8 Typical storm systems affecting the west coast of Northland with a large mid-latitude cyclone in July 2011 (A) and an East coast low in September 2005 (B)

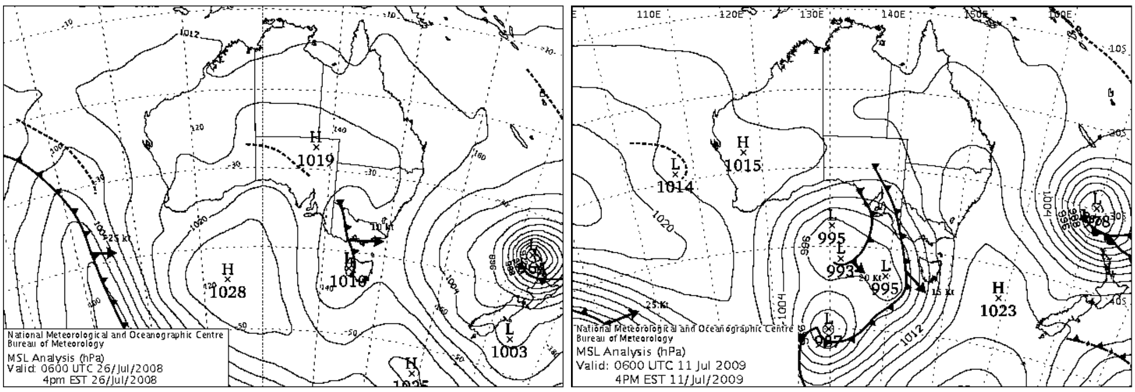

Figure 3-9 Sub-tropical storm systems causing large waves on the Northland east coast in July 2008 (A) and July 2009 (B)

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 3-10 and Figure 3-11) 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.

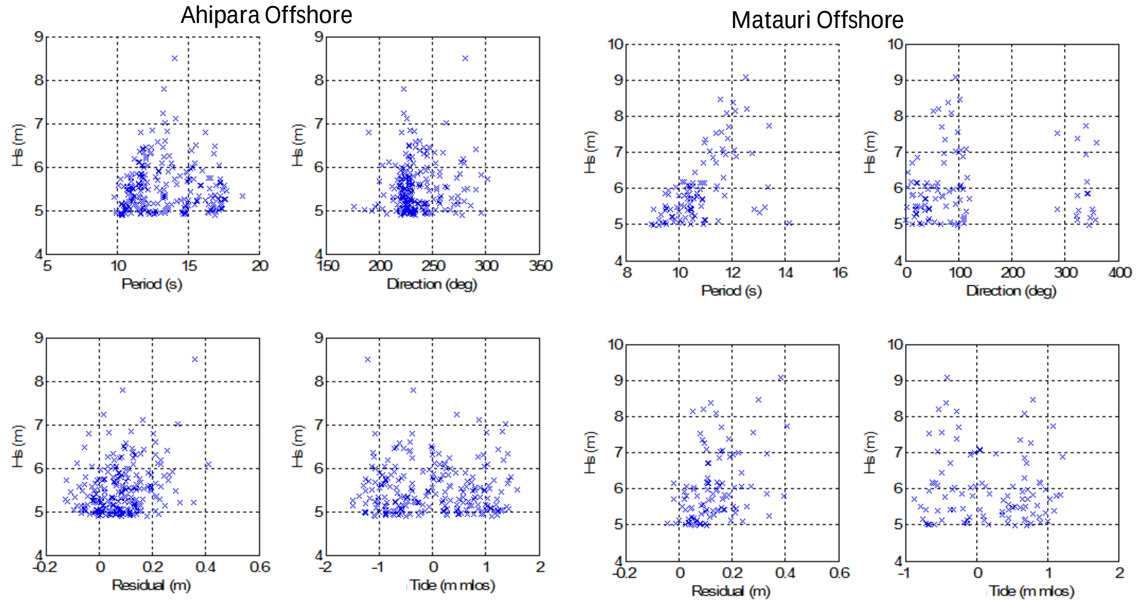

Figure 3-10 Storm peak characteristics for Ahipara and Matauri relating wave height to wave period, direction, non-tidal residual (storm surge) and tide.

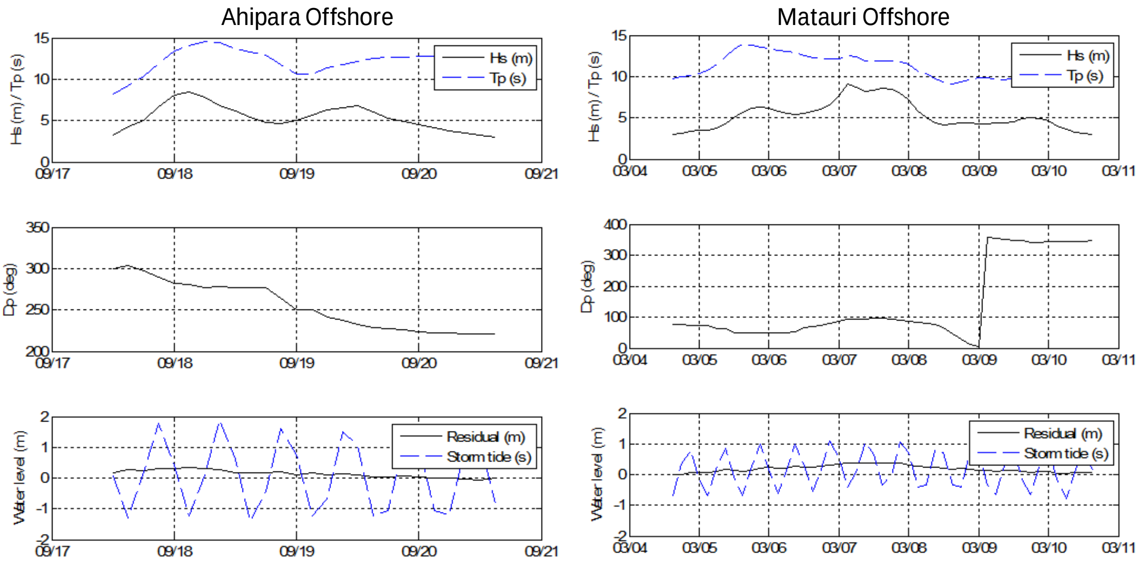

Figure 3-11 Time series of maximum storm on record for the Ahipara offshore site (September 2005) and for the Matauri and Whangaruru sites (March 1988)

The clustering of storm events can result in greater beach erosion than would occur for singular storm events as the beach 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 3-12 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.

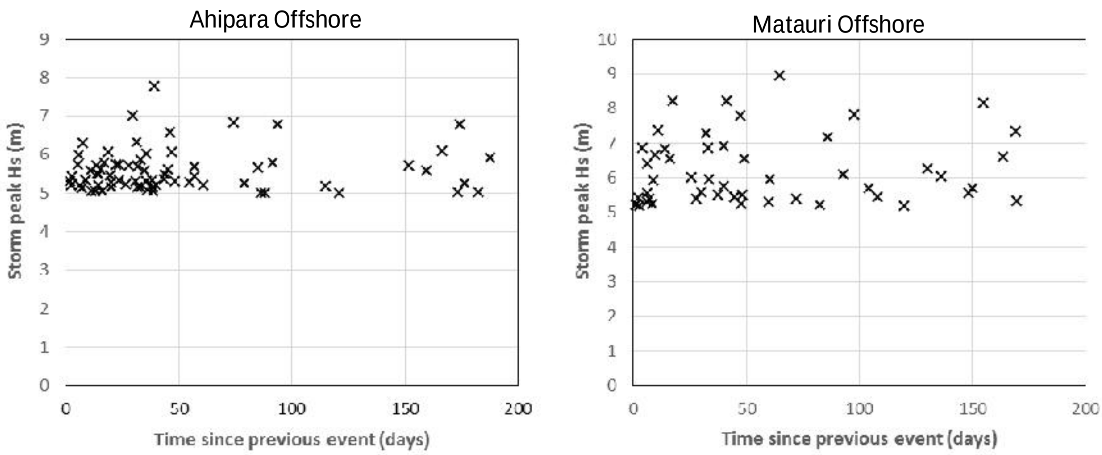

Figure 3-12 Storm peak wave height as a function of time since the previous storm event

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 3-13 and a complete description of the wave modelling process and results provided in Appendix B.

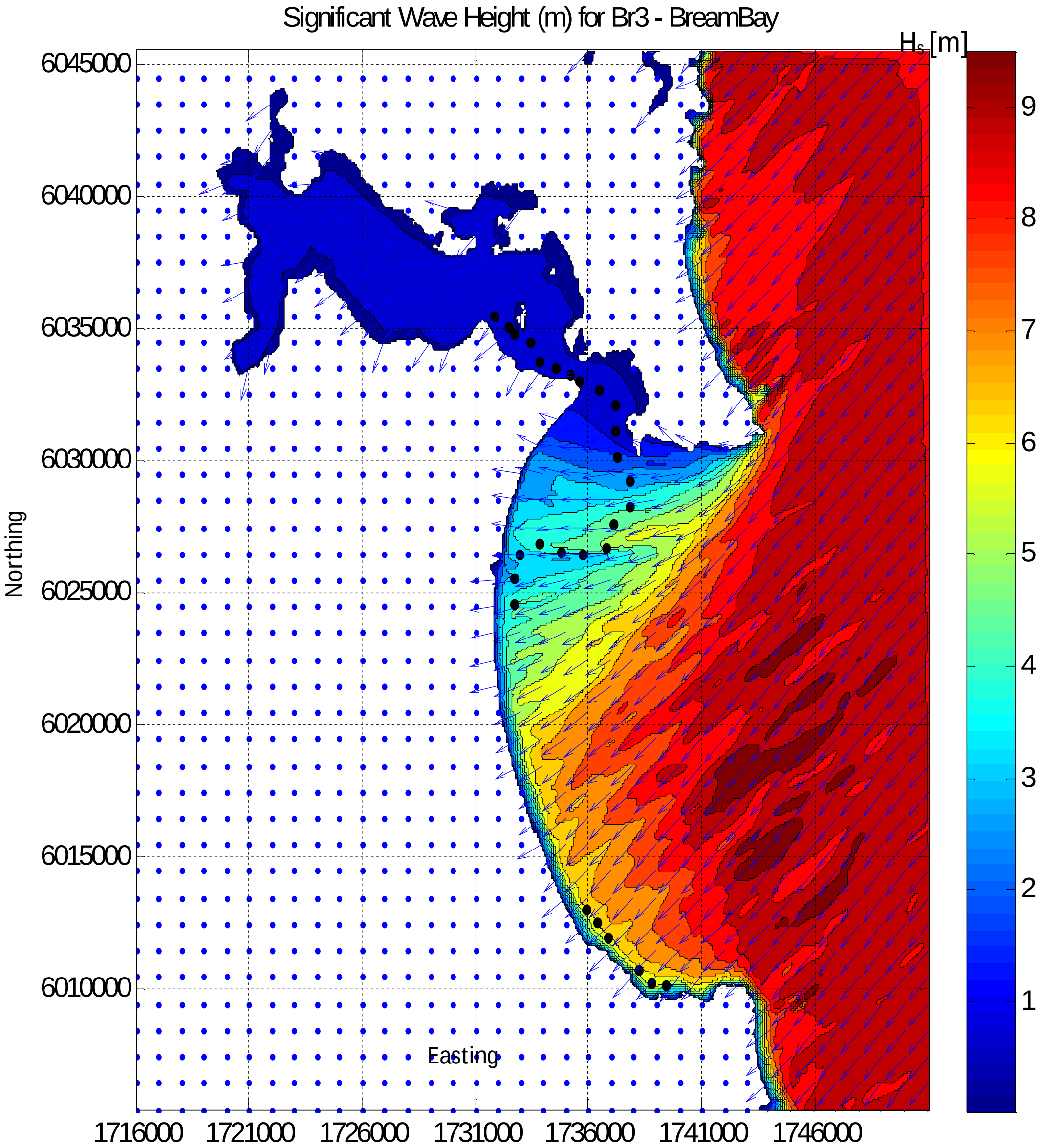

Figure 3-13 Example of SWAN output of significant wave height for Bream Bay during 100 year ARI storm event from the Northeast

4 Methodology

4.1 Statutory considerations

The New Zealand Coastal Policy Statement (NZCPS) 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) 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
>
> 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 private vehicular access routes for proposed new lots is considered when assessing subdivision proposals.

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 and land use within high risk coastal hazard areas

7.1.4 New Subdivision and development within other coastal hazard areas

7.1.5 Existing development in known hazard-prone areas

7.1.6 Regionally significant infrastructure and critical infrastructure

7.1.7 Climate change and development

7.1.8 Statutory plans and strategies

7.1.9 Monitoring and information gathering

7.1.10 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 of occurring (63%) and a 1,000 year ARI event has a probability of occurring 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.

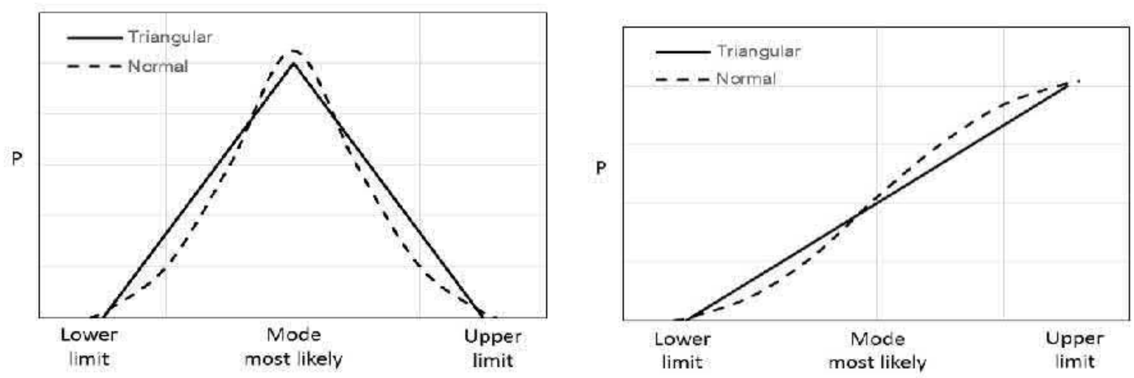

Figure 4-1 Example triangular and normal pdf (A) and cdf (B)

4.4 Defining coastal behaviour cells

Each coastal compartment (designated 1 to 31) 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 beach shoreline

The method for unconsolidated beach shorelines is expressed in Equation 4-1 and will be applied to uniform, non-consolidated coastlines not influenced by streams, estuaries or distal spit migrations. The CEHZ will be established from the cumulative effect of four main parameters (Figure 4-2):

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

Where:

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

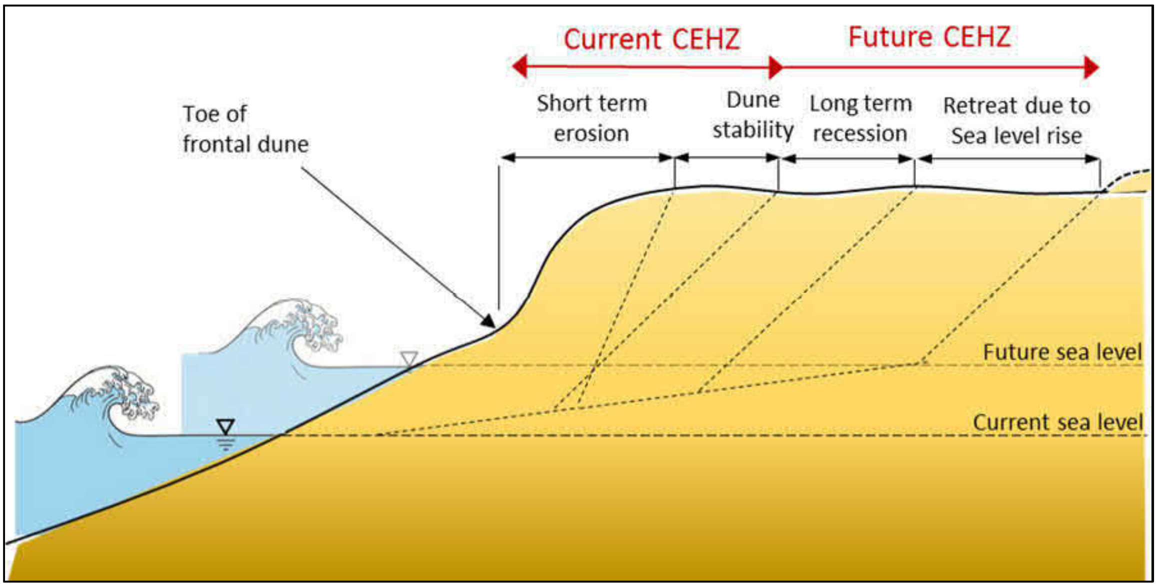

Figure 4-2 Definition sketch for open coast CEHZ

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 Cliff shoreline

This section applies to sea cliffs and coastal hill slopes 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 cliffs will be established from the cumulative effect of the long-term retreat and slope instability (Figure 4-3) as outlined in Equation 4-2.

$$CEHZ_{Cliffs} = \left(\frac{H_C}{\tan \alpha}\right) + \left(LT_H \times LT_F\right) \times T \qquad (4\text{-}2)$$

Where:

HC	=	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
a	=	The characteristic composite stable angle of repose
LTH	=	Historic long-term retreat (regression rate), m/yr, based on historic aerial photo analysis
LTF	=	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.

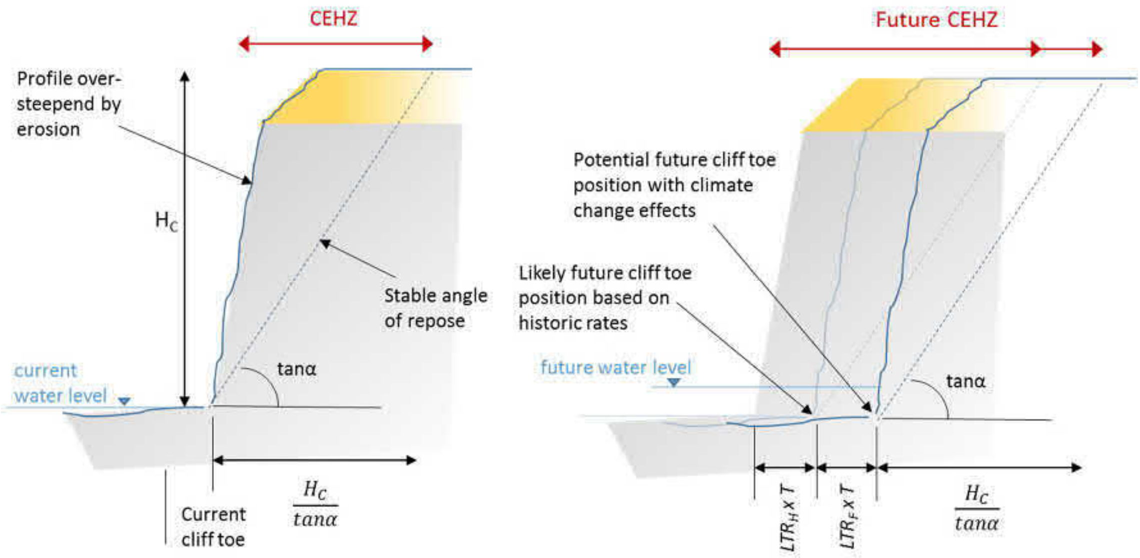

Figure 4-3 Definition sketch for cliff shore CEHZ

4.5.3 Estuarine soft-shore

Estuarine shorelines are typically low-lying with backshore comprised of weakly consolidated material. Material lost from the system during storms is not generally replenished and erosion of the bank is a one-way process. The short-term component (ST) related to beach rebuilding on the open coast is therefore not applicable to estuarine shorelines and is omitted. A modified technique to assess the CEHZ for these regions is proposed below:

$$CEHZ_{Estuary} = \frac{H_B}{\tan a} + (LT_H \times LT_F) \times T + I_{SLR} \quad (4\text{-}3)$$

Where:

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

a = The characteristic composite stable angle of repose of the weakly consolidated bank material

LT_H = Historic long-term retreat (regression rate), m/yr, 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)

I_{SLR} = Landward translation of the mean high water line due to inundation by increased future sea level (m). Note that this term is applicable only if the future mean high water exceeds the bank height or for very gently sloping estuary margins where a future long-term rate, LTF, is not applicable.

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

Where the estuarine shoreline is comprised of non-consolidated sandy material the methods for $CEHZ_{Beach}$ have been adopted with a modified term for coastline retreat due to the effects of sea level rise.

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:

- 2015 Coastal Erosion Hazard Zone (Current): 2015 CEHZ
- 2065 Coastal Erosion Hazard Zone (50 years): 2065 CEHZ
- 2115 Coastal Erosion Hazard Zone (100 years): 2115 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 (1997) 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 4-4) described by the following relationship.

$$\Delta E_{max} = \frac{(WL - H_J) + \Delta BL}{\tan\theta} \tag{4-4}$$

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.

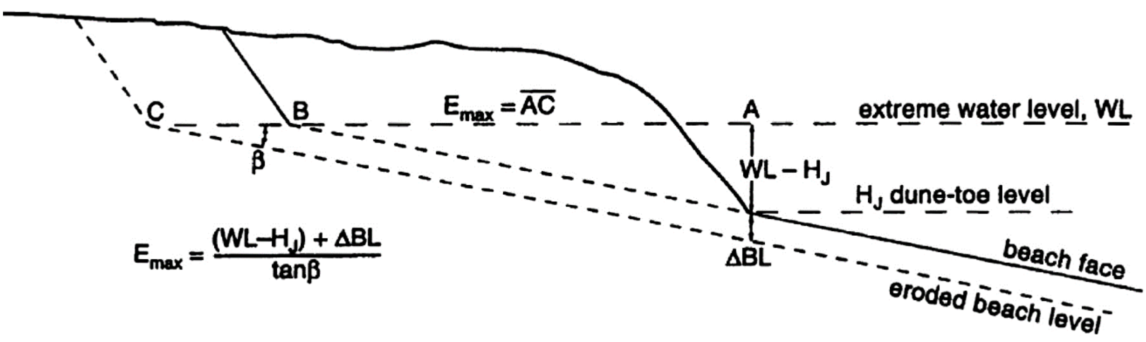

Figure 4-4 Geometric model used to evaluate the maximum potential erosion during an erosion event (Komar, 1997)

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 (1997) 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 -10m RL contour.

Design storm nearshore time series including wave height, period and water level are applied at the outer profile boundary (i.e. Figure 4-5 for Waipu Cove). Design storms for 10 yr, 100 yr and 2x100 yr events are simulated with the later allowing for potential clustering of storms. Such clustering may result in greater erosion as the first event lowers the beach height and relatively greater wave energy may reach the backshore in subsequent events.

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

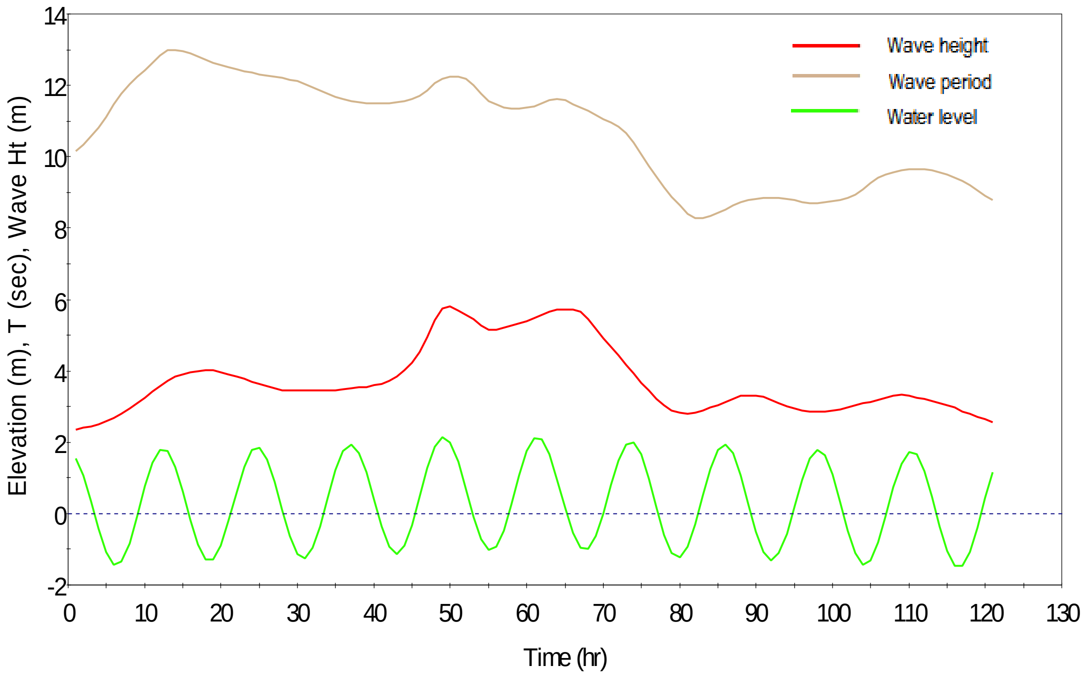

Figure 4-5 Example synthetic 100yr design storm input for Waipu Cove

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 4-6 shows the initial and equilibrium profiles formed due to 10, 100 and 2x100 year 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 15m respectively.

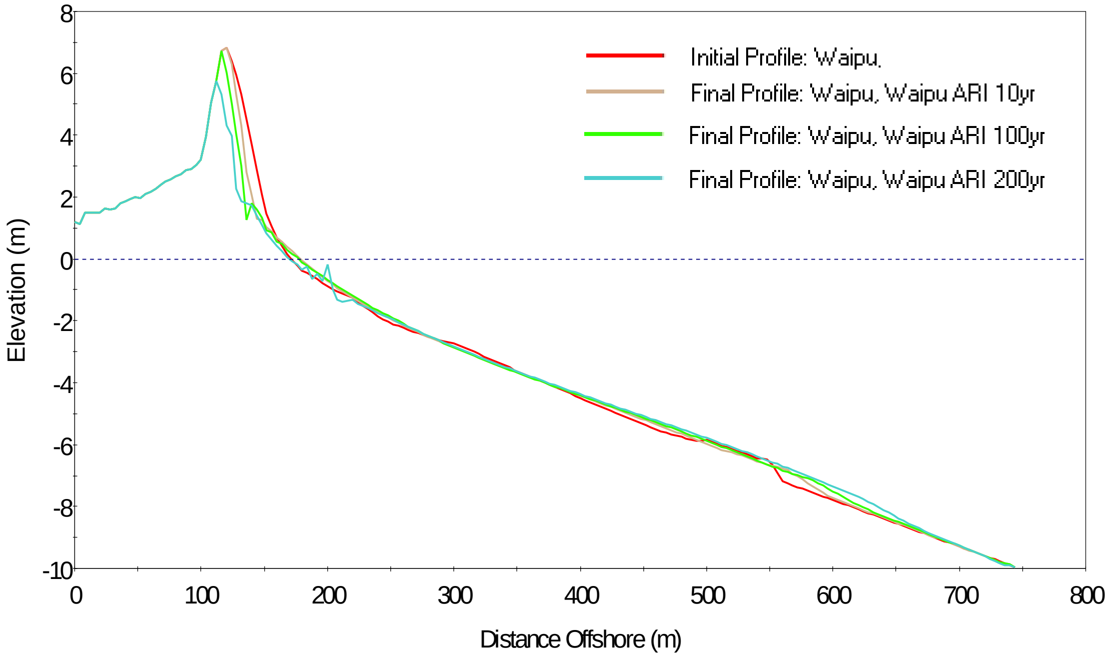

Figure 4-6 Example SBEACH results for Waipu Cove

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	4 m	5.5 m	8.5 m

Numerical storm cut distances of 4 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 4-7 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 4-8). 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 4-9).

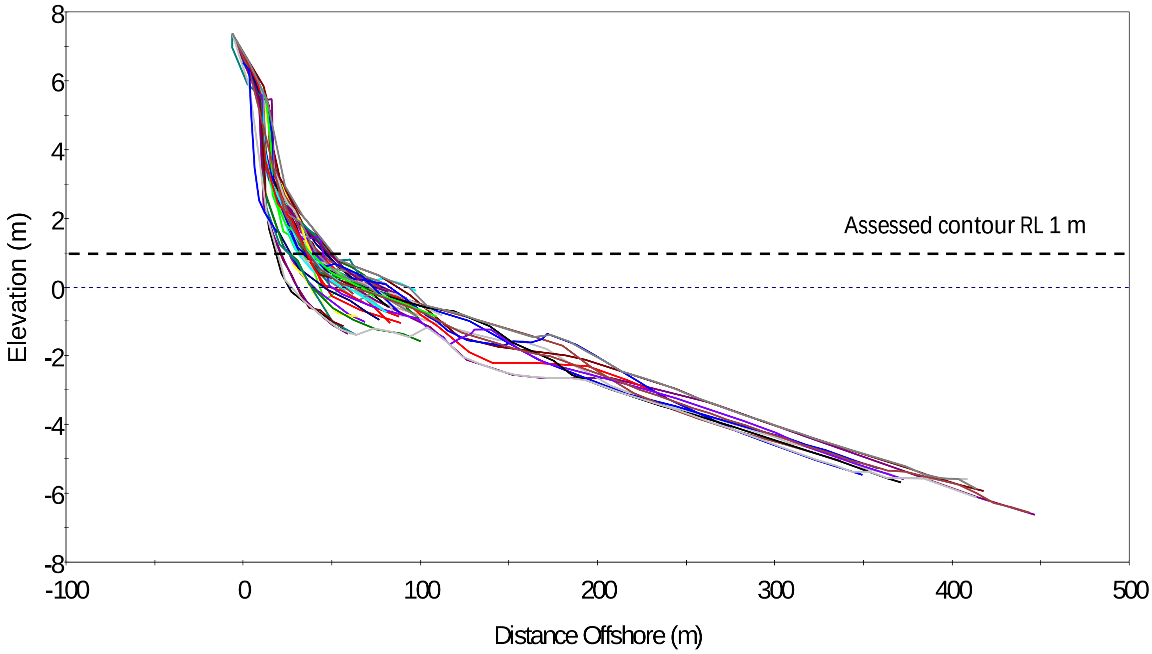

Figure 4-7 Example beach profiles for Waipu Cove

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.

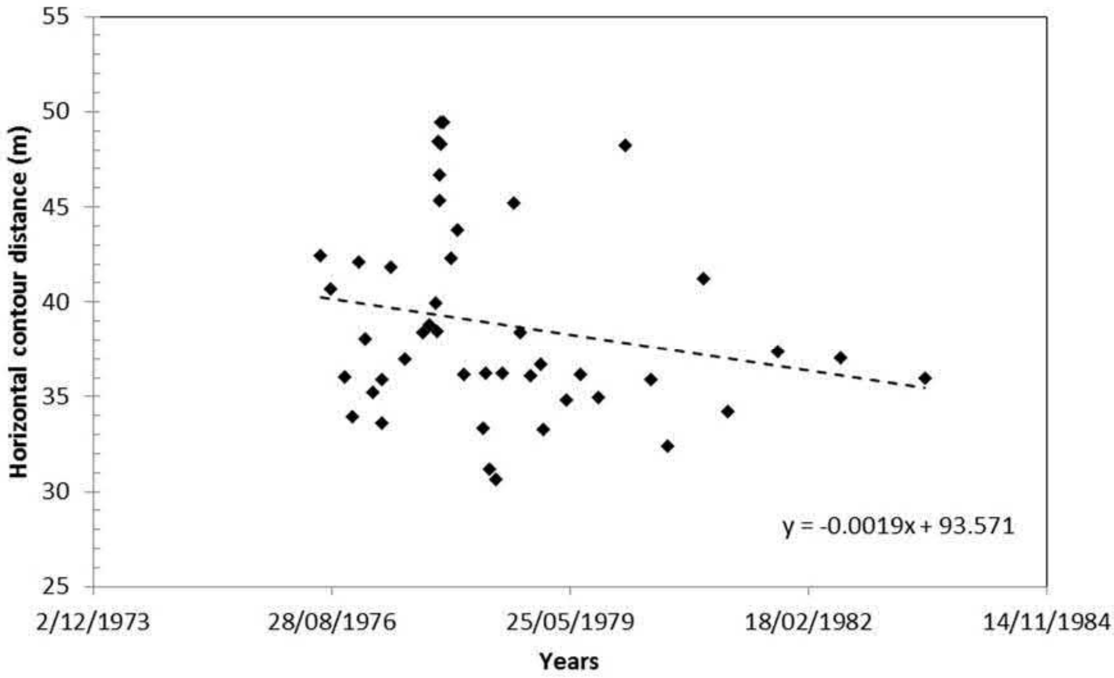

Figure 4-8 Example Linear Regression for Waipu Cove

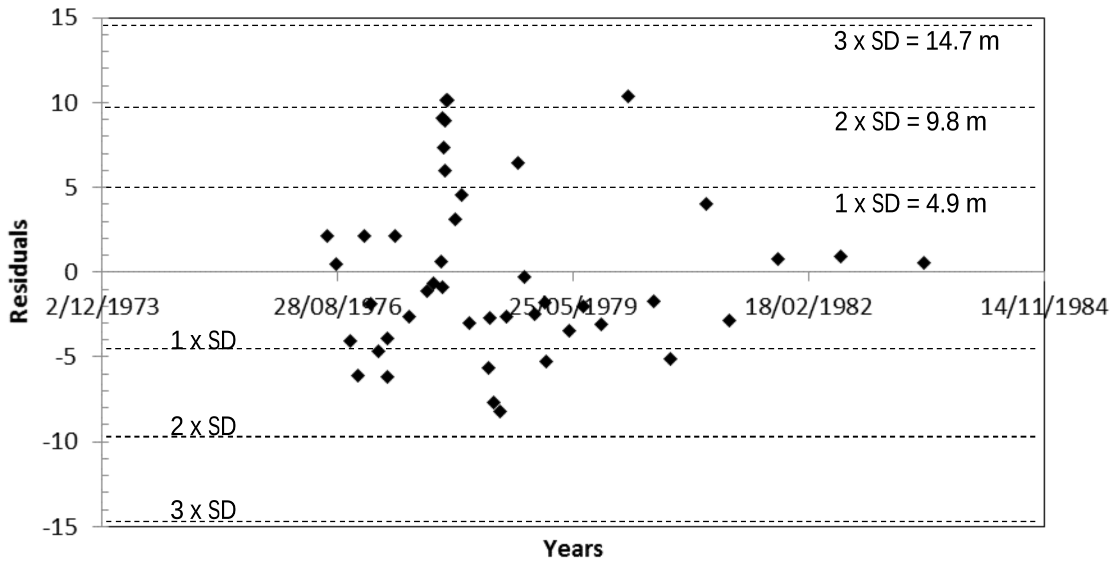

Figure 4-9 Example contour excursion residuals (de-trended) for Waipu Cove

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. 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 – 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, 1997) 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 2 x 100 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:

$$DS = \frac{H_{dune}}{2(\tan a_{sand})} \tag{4-5}$$

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 the first phase of this study.

The shoreline data has be analysed using the GIS-based DSAS model. DSAS processes the shoreline data and calculates shoreline change statistics at 5 m intervals along each site. Figure 4-10 and Figure 4-11 presents 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.

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

A4 SCALE 1:7,500

0 50 100 150 200 250 300 Meters

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DRAWN	PPK	Dec.17
CHECKED	TDS	Dec.17
APPROVED	RRH	Dec.17

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PROJECT No. 1001049

NORTHLAND REGIONAL COUNCIL

CEHZ Assessment for Selected Northland Sites
Bland Bay DSAS results

FIGURE No. Figure 1.10

Rev. 2

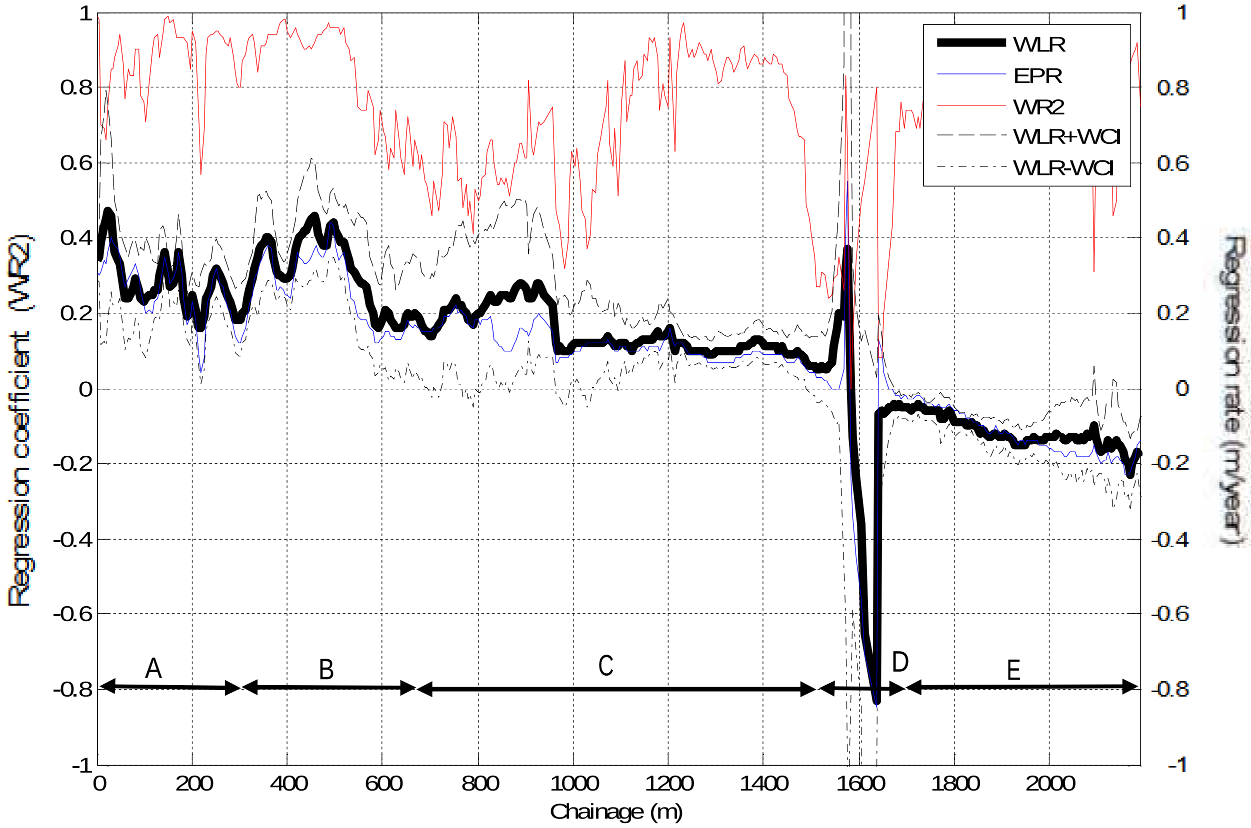


Figure 4-11 Results of weighted linear regression (WLR —) analysis of historic shoreline positions for Bland Bay from North to South with coastal cells indicated by letters A to E. The 90% confidence intervals for the WLR are also presented (- -) together with WLR R2 value indicating goodness of fit (—) 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 two required timeframes (i.e. 50 and 100 years) which conform to guidance provided within MfE (2008) but also take into account new model results presented in the IPCC 5th Assessment Report (IPCC, 2013).

Utilising the most recent projections (IPCC, 2013) and adopting a precautionary approach required by NZCPS (2010) and in keeping with recommendations in MfE (2008), this assessment has adopted sea level rise values projected for the *RCP8.5 scenario - emissions continue to rise in the 21st century*. This is considered prudent until evidence of emission stabilising justify use of a lower projection scenario. These sea levels range from 0.27 to 0.47 m by 2065 and 0.62 to 1.27 m by 2115 (refer to Section 3.3.5).

An average historic rate of sea level rise of 1.7 mm/year has been deducted from the adopted SLR values for use in assessment on the basis that the existing long term trends and processes already incorporate the response to the historic situation. Table 4-7 presents the sea level rise values used in this present assessment.

Table 4-7 Sea level rise values (m) utilised in assessment

Time frame	Min	Mode	Max
2065	0.19	0.29	0.39
2115	0.45	0.77	1.1

Note these values include a discount of 1.7 mm/year based on average historical trends as presented in Section 3.3.5

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 4-12). The most well-known of these geometric response models is that of Bruun (Bruun, 1962, 1988) which proposes that with increased sea level, material is eroded from the upper beach and deposited offshore to a maximum depth, termed closure depth. The increase in sea bed level is equivalent to the rise in sea level and results in landward recession of the shoreline. The model may be defined by the following equation:

$$SL = \frac{L_*}{B + d_*} S \qquad (4\text{-}6)$$

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.

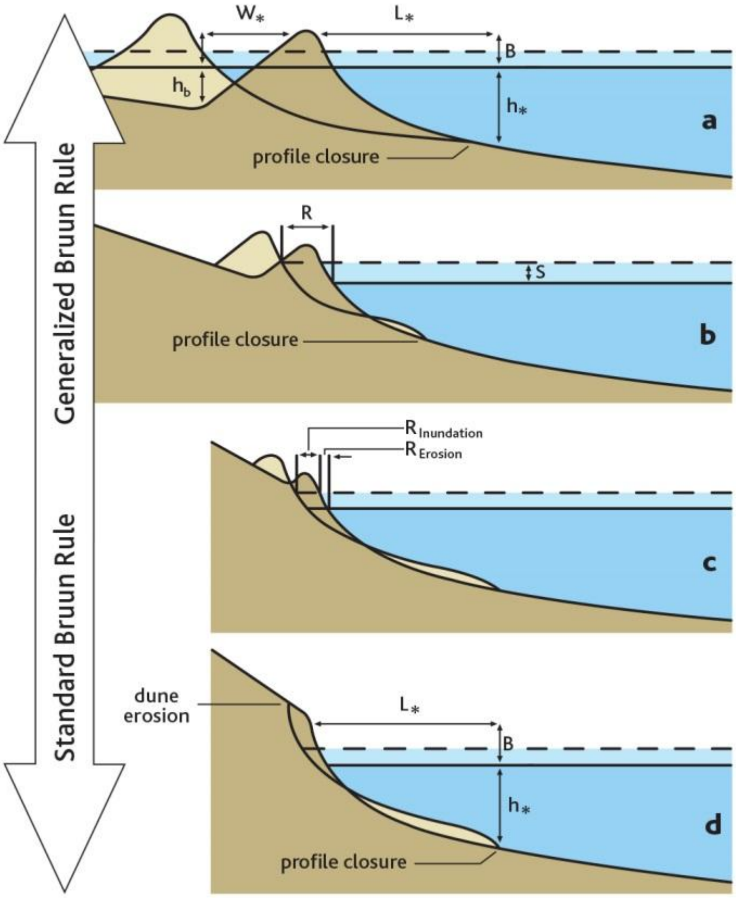


Figure 4-12 Schematic diagrams of the Bruun model modes of shoreline response (after Cowell and Kench, 2001)

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

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

Shand et al. (2013) argue that as sea-level rise is expected to be ongoing, then the outer limit of profile adjustment is likely to be 'left behind' before it can reach equilibrium. The closure depth can therefore be more realistically defined as the point at which the profile adjustment can 'keep up' with sea-level change and becomes a calibration parameter in lieu of an adequate depth-dependent lag parameter. Shand et al. (2013) tested a range of closure depth definitions against a non-equilibrium model calibrated using 30 years of beach data (Ranasinghe et al., 2011). Results (Figure 4-13) show the various definitions of closure to predict Recession/SLR values straddling the entire probabilistic (2 – 99%) range predicted by the Ranasinghe's probabalistic model.

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

$$d_l = 2.28H_{s,t} - 68.5(H_{s,t}^2 / gT_s^2) \cong 2 \times H_{s,t} \quad (4\text{-}7)$$

$$d_i = 1.5 \times d_l \quad (4\text{-}8)$$

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.

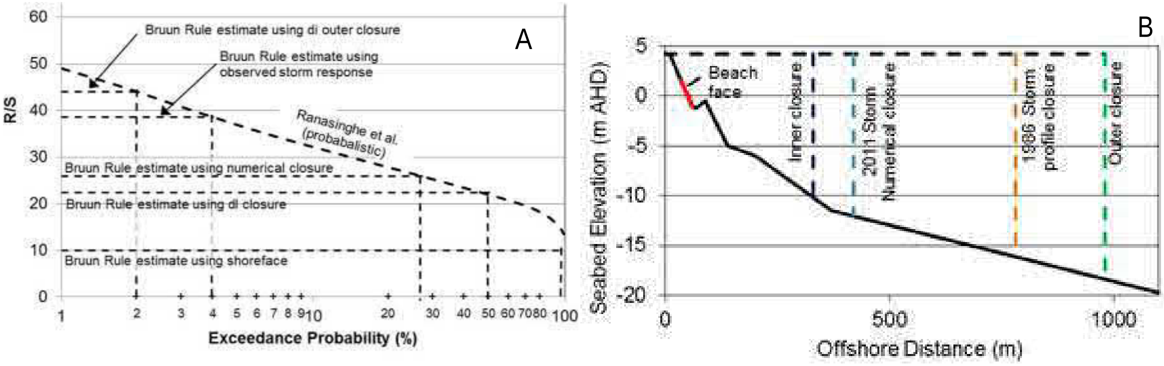


Figure 4-13 Probabilistic estimate of relative coastal recession at Narrabeen Beach (from Ranasinghe et al., 2011) with Bruun Rule estimates (A) using a variety of closure estimators (B).

An exception to this are the non-consolidated shorelines within estuaries or beaches perched on rock platforms 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 (Stephens and Giles, 2010).

4.6.5.3 Cliff response

Erosion of consolidated coastlines 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).

$$LT_F = LT_H \times \frac{S_F}{S_H} \tag{4-9}$$

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.

$$LT_F = LT_H \sqrt{\frac{S_F}{S_H}} \tag{4-10}$$

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.

Aston et al. (2011) propose a generalised expression for future recession rates of cliff coastlines shown in Equation 4-11 and Figure 4-14 where the coefficient m is determined by the response system. 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 → 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.

$$R_2 = R_1 \left(\frac{S_2}{S_1} \right)^m \qquad (4\text{-}11)$$

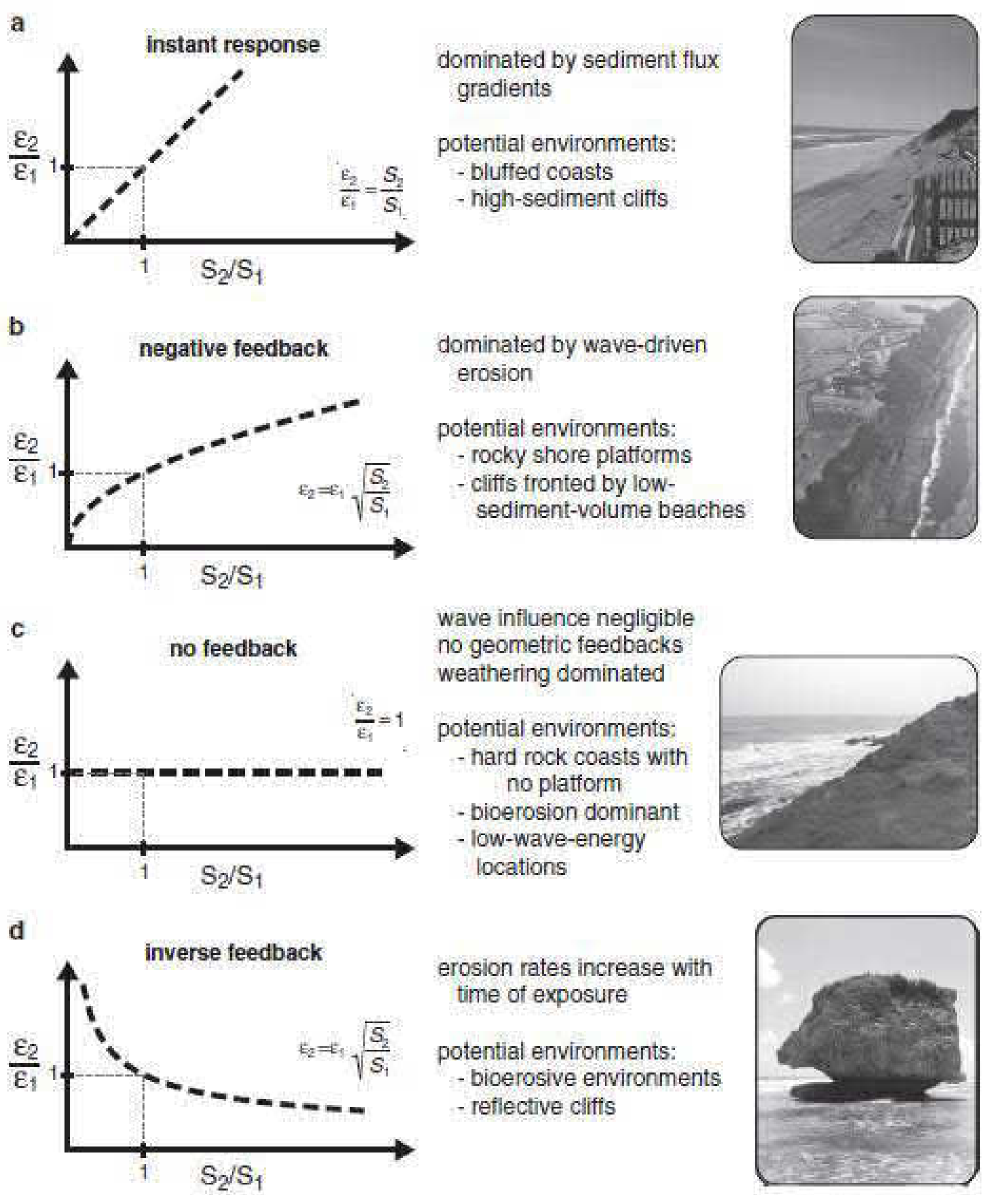


Figure 4-14 Possible modes of cliff response to SLR (adapted from Ashton et al., 2011)

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. For soft, weakly consolidated cliff and banks (i.e. Tauranga and Awhitu Group sediments and completely weathered rock) shoreline response between negative feedback (m = 0.5) and instant response (m = 1) are assumed. For harder cliffs (unweathered sedimentary or volcanic) or material not exposed to wave action (i.e. weathered cover material), response types between no feedback (m = 0) and negative feedback response (m = 0.5) are assumed.

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 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.

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 4-8. 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 4-8 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/yr)		-90% CI of smallest trend in cell	Mean regression trend	+90% CI of largest trend in cell
SLR (m)[1]		lower 95% SLR value for RCP8.5 scenario minus historic trend	50% SLR value for RCP8.5 scenario minus historic trend	upper 95% SLR value for RCP8.5 scenario minus historic trend
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	Hard cliff	No response		Negative feedback
	Soft shore	Negative feedback		Instant response

[1]SL component is a function of SLR and active beach slope parameters

Figure 4-15 presents an example component and CEHZ histogram cumulative distribution functions for Waipu Cove at 2115. Results show the possible CEHZ to range from 27 to 77 m, with a $P_{50\%}$ (50% probability of exceedance) value of 48 m. The $P_{5\%}$ is 61 m, which is substantially below the maximum extent and the $P_{66\%}$ is 45 m.

4.9 Mapping of the CEHZ

Coastal erosion hazard zone distances are mapped as offsets to the existing baseline. Figure 4-16 shows the range of CEHZ values for Waipu Cove at 2115. 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.

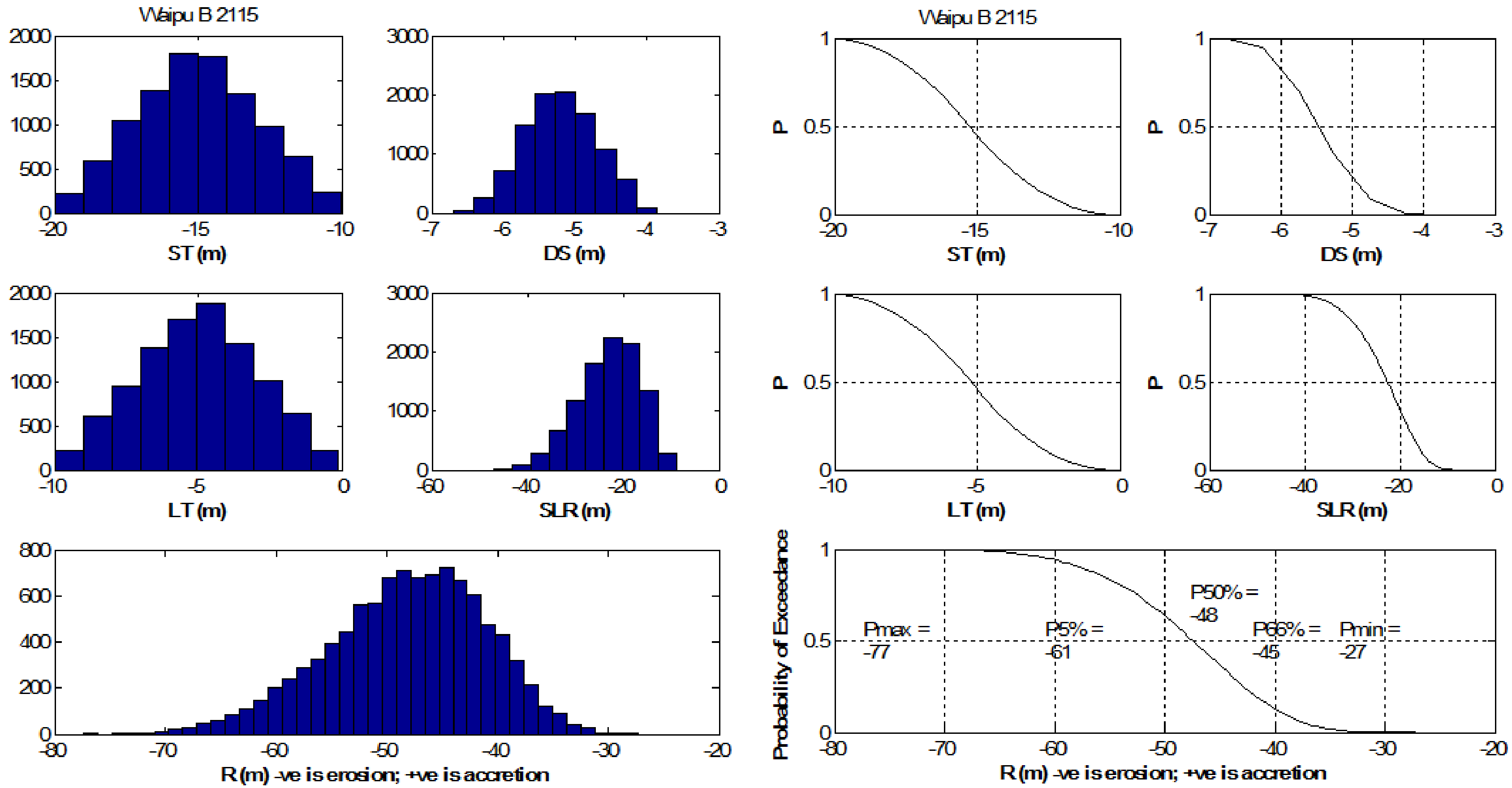
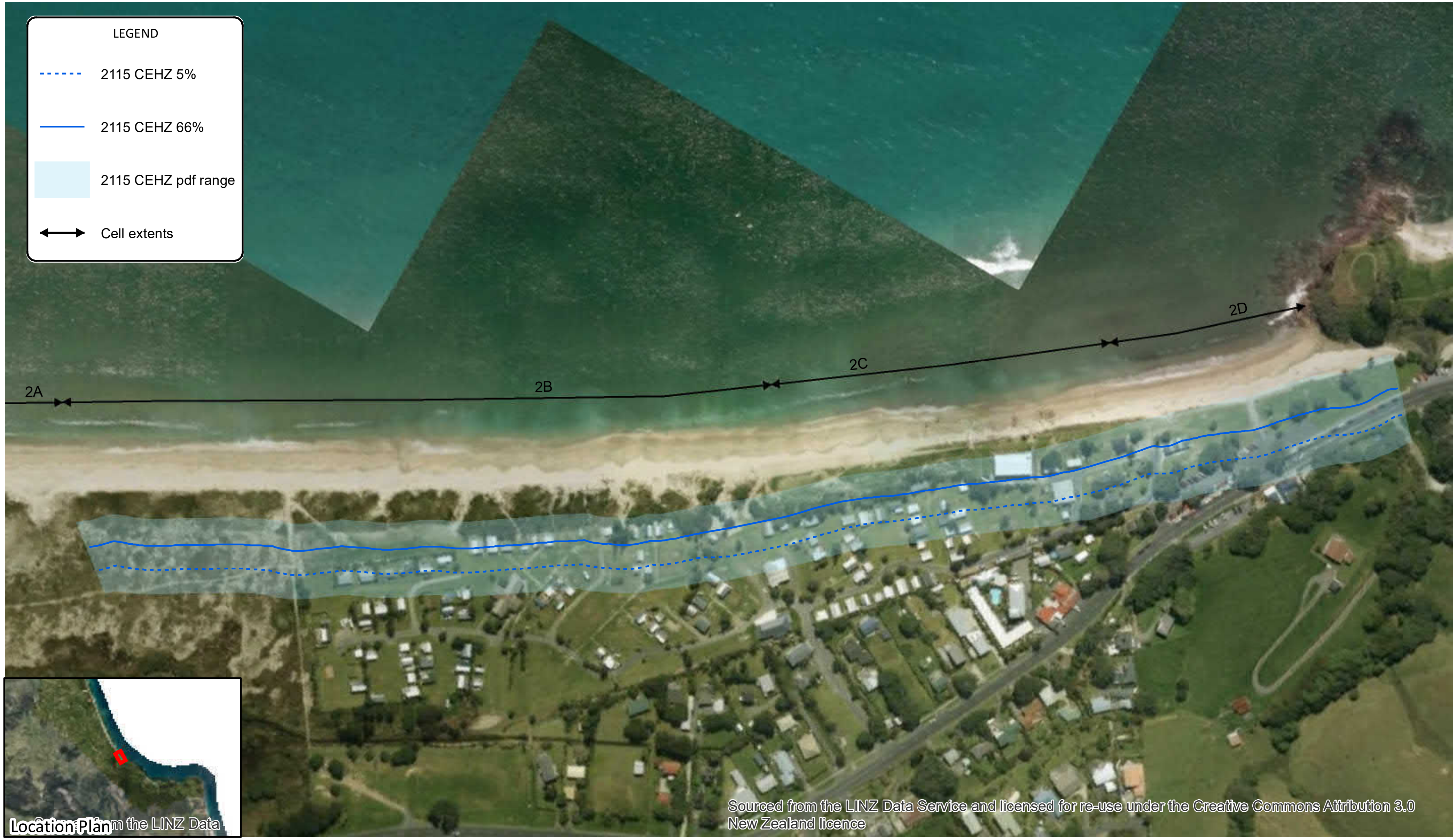


Figure 4-15 Example histogram (A) and cumulative distribution functions (B) of parameter samples and the resultant CEHZ distances for Waipu Cell B 2115



Notes: Background aerial from Esri database.

A4 SCALE 1:3,500

0 50 100 150 Meters

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105 Carlton Gore Rd, Newmarket, Auckland
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DRAWN	PPK	Dec.17
CHECKED	TDS	Dec.17
APPROVED	RRH	Dec.17

ARCFILE CEHZFigure4_17.mxd

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PROJECT No. 1001049

NORTHLAND REGIONAL COUNCIL
CEHZ Assessment for Selected Northland Sites
Waipu Cove CEHZ 2115

FIGURE No. Figure 4.16

Rev. 2

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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 terrain model (DTM) based on available LiDAR data
- 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) back into each DTM 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.

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 bank), 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 4-17). In these cases the CEHZ has been determined by the following methodology:

- For each cliff section, construct a digital terrain model (DTM) based on available LiDAR data
- Digitise the current cliff toe position based on the constructed DTMs and aerial photographs
- Project stable cliff angles back into each DTM 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 4-17 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.

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.

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 2065 (CEHZ value with a 66% probability of being exceeded by 2065) and the $P_{5\%}$ value for 2115 (5% probability of being exceeded by 2115) were adopted as prudent *likely* and *potential* coastal erosion hazard zones values termed the *CEHZ1* and *CEHZ2* respectively. Where the current $P_{66\%}$ value exceeds the 2065 (i.e. the current erosion width is larger due to future accretion) then the current value is adopted. CEHZs for shorelines protected by consented structures have been termed CEHZ0.

For cliff coasts where the methodology as set out in Section 0 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 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 and in the data and modelling techniques. These judgement-based minimum values correspond to the average of the lowest 1/3 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 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
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 and values are mapped with respect to the adopted 2013/2014 baseline. These lines are presented in individual site assessments within Appendix A and are provided in digital form. 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. Future shoreline distances are presented in Table 5-2 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 time frame. This has been checked for all sites based on analysis of the 2 m RL contour taken as the potential high tide level in 100 years' time (MHWS of 1.06 m RL plus 100 year SLR of 1.0 m ≈ 2 m RL). Where the 2 m RL contour is further landward than the calculated 2115 CEHZ2, 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[1]

Site			CEHZ1 (m)	CEHZ2 (m)	Site			CEHZ1 (m)	CEHZ2 (m)
Name	No.	Cell	2065$_{P66\%}$	2115$_{P5\%}$	Name	No.	Cell	2065$_{P66\%}$	2115$_{P5\%}$
Langs	1	A	-3*	-13*	Marsden Cove[2]	5	D	-4*	-17*
Langs	1	B	-20	-52	One Tree Point	6	A	-12	-41
Langs	1	C	-23	-57	One Tree Point	6	B	-7*	-25*
Langs	1	D	-4*	-10*	One Tree Point	6	BB	-3*	-14*
Langs	1	E	-15[3]	-38	One Tree Point	6	C	-5*	-21*
Langs	1	F	-7*	-27*	One Tree Point	6	D	-7*	-24*
Waipu[2]	2	A	-36	-73	Taiharuru	7	A	-6*	-22*
Waipu	2	B	-30	-61	Taiharuru	7	B	-26	-57
Waipu	2	C	-21	-50	Taiharuru	7	C	-9*	-40*
Waipu	2	D	-16	-42	Pataua	8	A	-26	-56
Ruakaka	3	A	-24[4]	-42	Pataua	8	B	-33	-65
Ruakaka	3	B	-21[4]	-39	Pataua	8	C	-31	-66
Ruakaka	3	C	-26	-69	Pataua	8	D	-15	-31
Ruakaka[2]	3	CC	-8*	-32*	Pataua	8	DD	-11	-27
Ruakaka	3	D	-24	-53	Pataua[2]	8	E	-12	-26
Ruakaka	3	E	-25	-55	Pataua[2]	8	F	-10[3]	-25[3]
Marsden Point[2]	4	A	-13[4]	-25[3]	Pataua[2]	8	G	-10[3]	-25[3]
Marsden Point	4	AA	-23	-93	Pataua[2]	8	H	-10[3]	-25[3]
Marsden Point	4	B	-65	-162	Whangaumu	9	A	-19[5]	-36[5]
Marsden Point	4	C	-58	-136	Whangaumu	9	B	-15[3]	-35[3]
Marsden Point	4	D	-29	-79	Whangaumu	9	C	-16	-36
Marsden Point	4	E	-41	-101	Matapouri	10	A	-27	-58
Marsden Point	4	F	-34	-88	Matapouri	10	B	-26	-49
Marsden Cove[2]	5	A	-16	-37	Matapouri	10	C	-24	-48
Marsden Cove[2]	5	B	-14	-35	Matapouri	10	D	-26	-50
Marsden Cove[2]	5	C	-16	-38	Matapouri	10	E	-16	-35

[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 1.0 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

[4]Current $P_{66\%}$ value has been adopted for CEHZ1 as it is larger than 2065 $P_{66\%}$ values and therefore present greater hazard.

[5]Modified from the original T+T (2014) assessment to better represent topography. Maximum distance has been tabulated.

*Updated using cliff projection methodology, so future shoreline distances have been tabulated.

Site			CEHZ1 (m)	CEHZ2 (m)	Site			CEHZ1 (m)	CEHZ2 (m)
Name	No.	Cell	2065$_{P66\%}$	2115$_{P5\%}$	Name	No.	Cell	2065$_{P66\%}$	2115$_{P5\%}$
Matapouri[2]	10	F	-12	-28	Oakura	17	A	-26	-74
Matapouri	10	G	-13	-31	Oakura	17	B	-28	-76
Woolleys	11	A	-17[6]	[6]	Oakura	17	BB	-25	-71
Woolleys	11	B	-17	-33	Oakura	17	C	-26	-72
Woolleys	11	C	-19	-40	Oakura	17	D	-28	-75
Woolleys	11	D	-17	-33	Oakura	17	E	-10	-25
Sandy	12	A	-34	-93	Oakura	17	F	-23	-37
Sandy	12	AA	-34	-94	Bland	18	A	-21	-52
Sandy	12	B	-46	-113	Bland	18	B	-17	-47
Sandy	12	C	-45	-111	Bland	18	C	-22	-63
Sandy	12	D	-51	-70	Bland	18	D	-29	-75
Whananaki	13	A	-13	-34	Bland	18	E	-15	-46
Whananaki	13	B	-45	-105	Waitangi	19	A	-4*	-20*
Whananaki	13	C	-43	-90	Waitangi	19	B	-10[3]	-25[3]
Whananaki	13	D	-28	-60	Waitangi	19	C	-29	-106
Whananaki	13	E	-33	-70	Waitangi	19	D	-24	-96
Teal	14	A	-49	-69	Waitangi	19	E	-20	-44
Teal	14	B	-20	-59	Matauri	20	A	-26	-68
Teal	14	C	-24	-70	Matauri	20	B	-33	-109
Teal	14	D	-13	-38	Matauri	20	BB	-29	-102
Helena[2]	15	A	-10[3]	-25[3]	Matauri	20	C	-27	-95
Helena	15	B	-24	-61	Te Ngaire	21	A	-26	-73
Helena	15	C	-20	-45	Te Ngaire	21	B	-21	-62
Ohawini	16	A	-17	-55	Te Ngaire	21	C	-23	-67
Ohawini	16	B	-17	-55	Tauranga	22	A	-16	-37
Ohawini	16	C	-17	-55	Tauranga	22	AA	-19	-42
Ohawini	16	D	-20	-28	Tauranga	22	B	-25	-54
Ohawini	16	E	-18	-56	Tauranga	22	C	-32	-65
Ohawini	16	F	-11	-25	Taupo	23	A	-24	-58
Ohawini	16	G	-18	-58	Taupo	23	B	-24	-55
Ohawini	16	H	-10	-25	Taupo	23	C	-26	-69

[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 1.0 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

[4]Current $P_{66\%}$ value has been adopted for CEHZ1 as it is larger than 2065 $P_{66\%}$ values and therefore present greater hazard.

[6]Modified in consultation with NRC from the original T+T (2014) assessment, so width varies.

*Updated using cliff projection methodology, so future shoreline distances have been tabulated.

Site			CEHZ1 (m)	CEHZ2 (m)	Site			CEHZ1 (m)	CEHZ2 (m)
Name	No.	Cell	$2065_{P66\%}$	$2115_{P5\%}$	Name	No.	Cell	$2065_{P66\%}$	$2115_{P5\%}$
Taupo	23	D	-26	-69	Tokerau	29	B	-26	-92
Hihi	24	A	-2*	-10*	Tokerau	29	C	-27	-95
Hihi	24	B	-4*	-20*	Tokerau	29	D	-33	-105
Hihi	24	C	-19	-34	Tokerau	29	E	-28	-94
Hihi	24	D	-26	-58	Ahipara	30	A	-24	-112
Hihi	24	E	-27	-59	Ahipara	30	B	-11	-28
Hihi	24	F	-18*	-81*	Ahipara	30	C	-13	-29
Coopers	25	A	-4*	-20*	Ahipara	30	D	-10[3]	-15[3]
Coopers	25	B	-4*	-20*	Ahipara	30	E	-23	-107
Coopers	25	C	-4*	-20*	Ahipara	30	F	-10[3]	-15[3]
Coopers	25	D	-4*	-20*	Ahipara	30	G	-42	-142
Coopers	25	E	-8*	-32*	Ahipara	30	H	-47	-147
Coopers	25	F	-8*	-32*	Ahipara	30	I	-32	-137
Coopers	25	G	-8*	-32*	Ahipara	30	J	-37	-146
Cable	26	A	-16	-38	Ahipara	30	K	-52	-161
Cable	26	B	-17	-39	Omapere	31	A	-11	-25[3]
Cable	26	C	-21	-46	Omapere	31	B	-10[3]	-25[3]
Cable	26	D	-15	-26	Omapere	31	BB	-13	-26
Cable	26	E	-25	-48	Omapere	31	C	-16	-36
Cable	26	F	-29	-57	Omapere	31	D	-10[3]	-25[3]
Taipa	27	A	-15	-55	Omapere	31	E	-15	-38
Taipa	27	B	-16	-55	Omapere	31	F	-24	-48
Taipa	27	C	-17	-64	Omapere	31	G	-19	-40
Rangiputa	28	A	-14	-30	Omapere	31	H	-12	-27
Rangiputa	28	B	-24	-48	Omapere	31	I	-24	-56
Rangiputa	28	C	-13	-25[3]	Omapere	31	J	-18	-50
Tokerau	29	A	-31	-102					

[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 1.0 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

[4]Current $P_{66\%}$ value has been adopted for CEHZ1 as it is larger than 2065 $P_{66\%}$ values and therefore present greater hazard.

*Updated using cliff projection methodology, so future shoreline distances have been tabulated.

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, inlets and high cliffs. However, the largest CEHZ2 values are dominated by unconsolidated coast beaches and inlets 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.

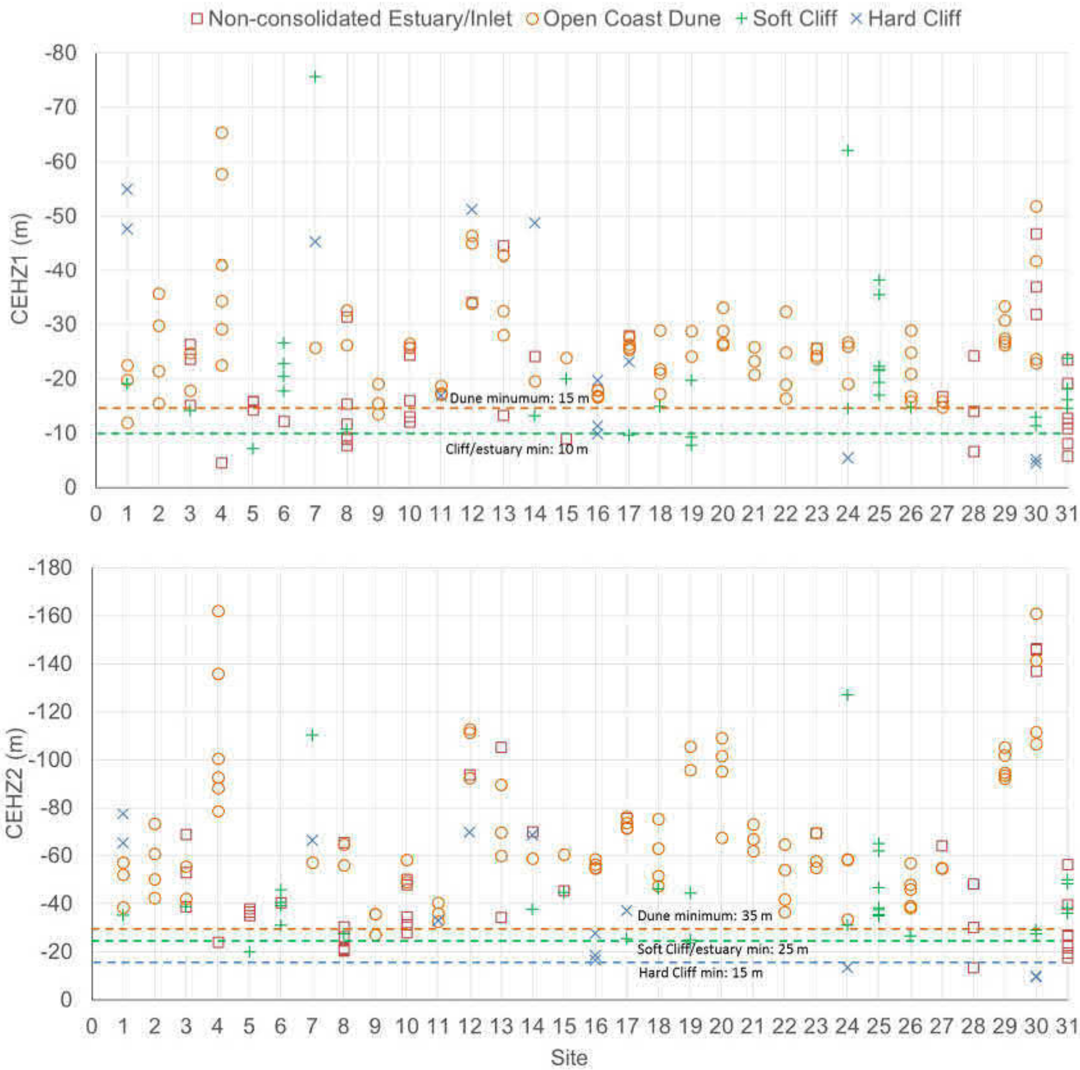

Figure 5-1 CEHZ widths for individual Northland sites (including original CEHZ widths (T+T, 2014) for sites for which the cliff projection method has been adopted)

5.3 CEHZ maps (2017 update)

5.3.1 Cliff coasts CEHZ

Table 5-3 shows the cliff coasts sites/cells for which the CEHZs have been reassessed since the T+T (2014) study using the cliff projection methodology described in Section 0. The CEHZ lines for sites/cells tabulated in Table 5-3 have been mapped in Appendix A.

The future cliff toe/shoreline distances for both the 50 year and 100 year time frames are tabulated in the Coastal Erosion Hazard Zone Widths tables in Appendix A instead of the CEHZ1 and CEHZ2. These have been indicated with an asterisk.

Table 5-3 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)

5.3.2 CEHZ0 behind structures

Table 5-4 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 and CEHZ2.

Table 5-4 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
Omapere/Opononi	31	A, C, E, F, G, I, J

5.3.3 Additional and modified CEHZ mapping

CEHZs were assessed for several cells in the original T+T (2014) study but were not mapped due to lack of LiDAR or other necessary data. Table 5-5 shows the sites/cells for which the CEHZs have been mapped in addition to those mapped in T+T (2014). The CEHZs for these sites/cells have been mapped in the revised Appendix A.

Table 5-5 Sites/cells for which CEHZs have been mapped in addition to T+T (2014)

Site name	Site number	Cell
Matapouri	10	A
Teal Bay	14	A
Oakura	17	A
Tokerau	29	A

The CEHZ1 and CEHZ2 for cell 9A at Whangaumu have been modified to better represent the increase in dune height at the western end of the coastal cell. The dune elevation is approximately 5 m higher at the western end of cell 9A with respect to remaining shoreline of cell 9A. Table 9-2 in Appendix A has been updated accordingly to show the maximum measured CEHZ width from the coastal edge within cell 9A for both the CEHZ1 and CEHZ2. These maximum values are indicative only and do not supersede the mapped CEHZ1 and CEHZ2 lines. The updated CEHZ1 and CEHZ2 with the maximum value have been indicated with an asterisk.

The CEHZ2 line for cell 11A at Woolleys Bay has been removed as requested by NRC and the CEHZ2 value in Table 5-2 has been deleted.

It should further be noted that for all sites, where $2015_{P66\%}$ exceeds the $2065_{P66\%}$ (i.e. where potential accretion dominates), then the 2015 value has been mapped as the CEHZ1. This approach has been taken to ensure adequate conservatism when these lines are applied between 2015 and 2065.

The cell boundary between Ahipara cell 30D and 30E have been re-assessed taking into account local geology. It has been observed during a site visit that the cliff at the cell boundary between 30D and 30E starts to transition into an unconsolidated beach shoreline (cell 30E). However, an offshore reef is present that intersects with the shoreline approximately 30m east of the original cell split. This indicates that the backshore geology is likely to be basalt and that the cell split is likely better located at this intersection. The cell boundary has therefore been adjusted (see Figure 5-2 and Appendix A)

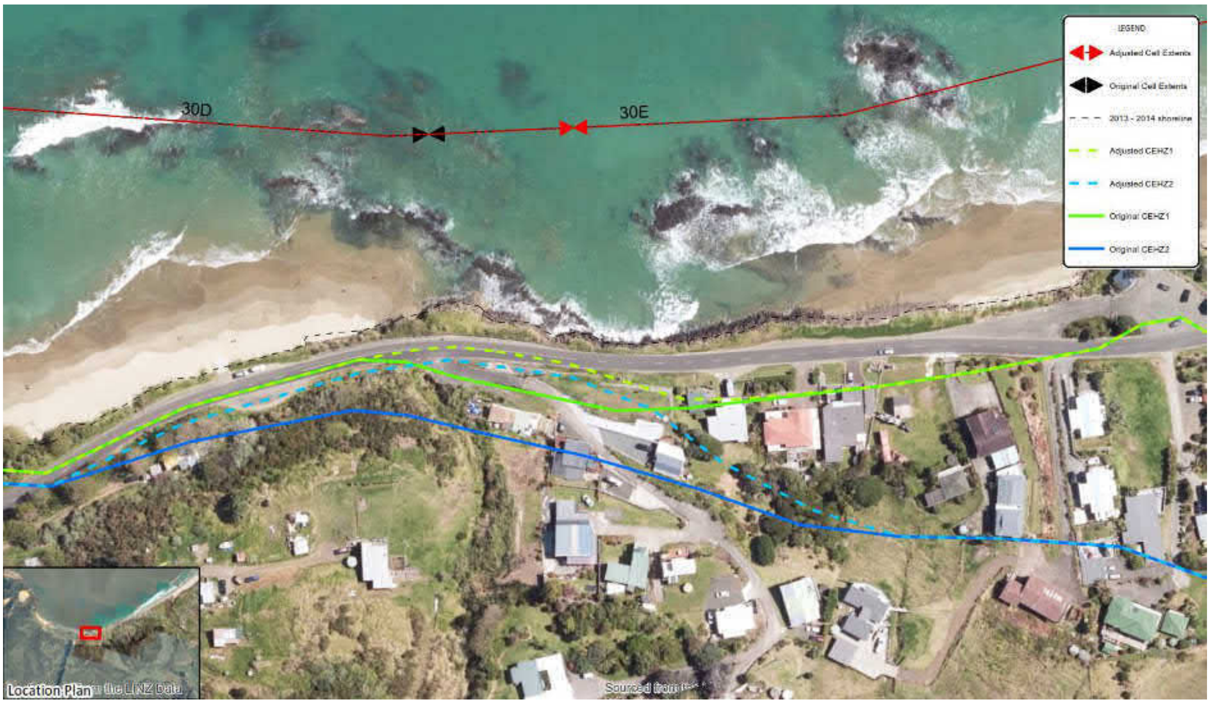

Figure 5-2 Cell boundary adjustment at Aphipara between cell 30D and 30E.

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 5-6. 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 2065 being the CEHZ1 value and the 5% exceedance value at 2115 being the CEHZ2 value.

Results show that CEHZ distributions range widely for each coastal type with the current CEHZ for open coast sites ranges from 5 to 40 m with an average of 10 to 22 m. This range tends to increase at 2065 and 2115, particularly for west coast open coast sites (i.e. Ahipara) 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 (1.3 m) occurring together with maximum long-term recession rates and a large storm cut value is low and therefore the P5% value tends to be significantly lower (140 to 160 m at 2115) than the maximum potential value (230 m at 2115).

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. at northern Marsden Point and Omapere). 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 CEHZ1 and CEHZ values 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 Taiaharuru, 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.

Table 5-6 Summary of CEHZ values for Northland Coastal Types

		CEHZ (% Exceedance)				CEHZ 2065 (% Exceedance)				CEHZ 2115 (% Exceedance)			
Coastal Type		100 %	66%	5%	0%	100 %	66% CEHZ1	5%	0%	100 %	66%	5% CEHZ2	0%
Open coast-East	Max	-19	-26	-35	-39	-49	-65	-82	-111	-87	-123	-162	-221
	Mean	-10	-15	-20	-22	-14	-26	-36	-47	-20	-42	-67	-95
	Min	-5	-8	-10	-11	2	-12	-19	-22	10	-18	-27	-34
Open coast - west	Max	-14	-18	-22	-25	-34	-52	-77	-104	-54	-93	-161	-231
	Mean	-11	-15	-19	-21	-19	-35	-60	-85	-30	-62	-130	-196
	Min	-8	-10	-13	-14	-6	-23	-48	-72	-7	-40	-107	-166
Inlet/ Estuary	Max	-17	-22	-31	-35	-31	-47	-74	-104	-48	-78	-147	-217
	Mean	-6	-10	-13	-15	-9	-19	-27	-35	-13	-31	-50	-66
	Min	-2	-4	-4	-5	10	-5	-12	-14	28	0	-14	-21
Soft Cliff[1]	Max	-52	-65	-78	-90	-59	-76	-90	-107	-66	-88	-127	-177
	Mean	-10	-14	-18	-22	-14	-21	-28	-35	-18	-29	-43	-60
	Min	-2	-3	-4	-4	-4	-7	-10	-14	-5	-12	-20	-29
Hard Cliff[1]	Max	-40	-47	-59	-67	-44	-55	-64	-74	-48	-63	-78	-93
	Mean	-17	-23	-29	-34	-19	-26	-33	-40	-21	-31	-39	-49
	Min	-1	-3	-5	-7	-2	-5	-7	-10	-2	-6	-10	-13

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

The relationship between the Coastal Erosion Hazard Zone 1 and 2 values and the individual parameter mean values are presented for open coast beaches and cliff coasts in the Northland Region in Figure 5-3 and Figure *5-4*. Results show that at 2065, the CEHZ1 values for beaches is not significantly influenced by any one parameter, although by 2115 the CEHZ2 value is more significantly influenced by closure slope which predicts response to sea level rise and by long-term trends when these are large.

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 2115 for the CEHZ2, particularly for soft cliff where sea level rise is expected to more notably affect erosion rates.

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 (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.

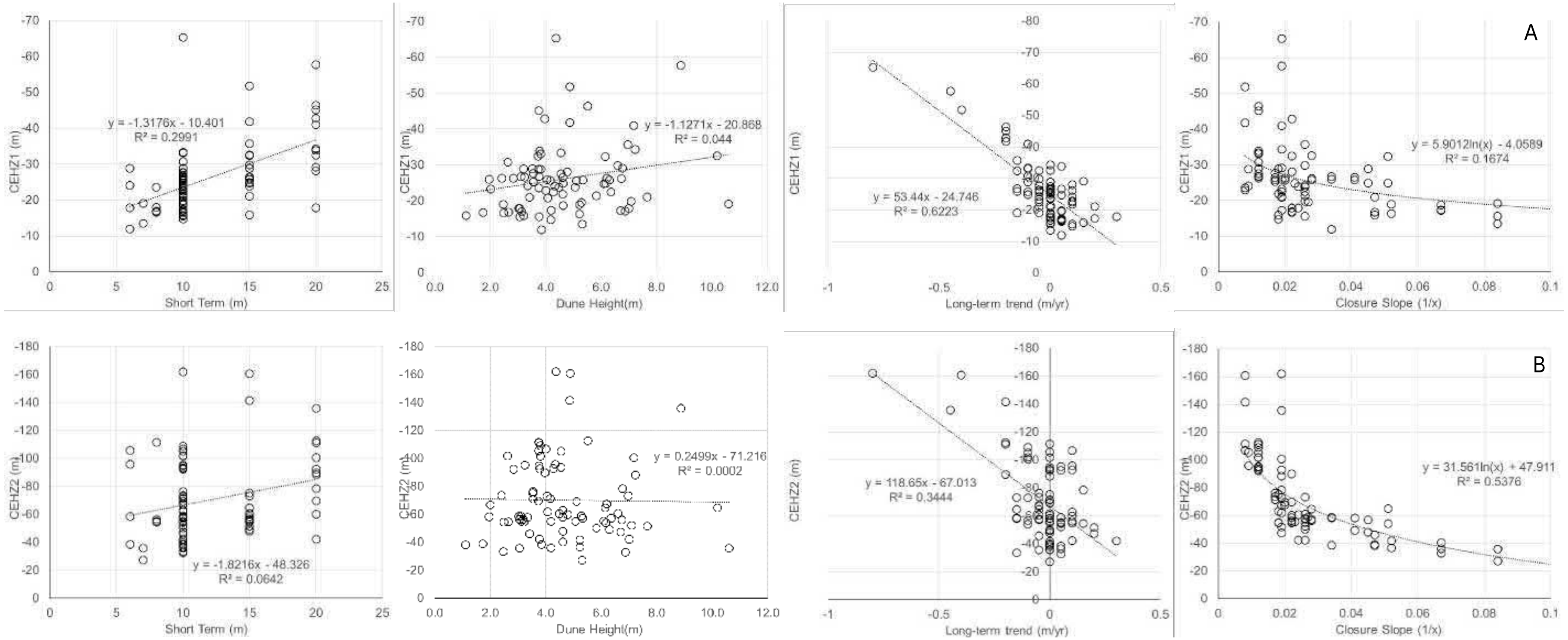

Figure 5-3 Relationship between CEHZ1 (A) and CEHZ2 (B) distance and individual parameters (mean value) for open coast beaches in the Northland Region

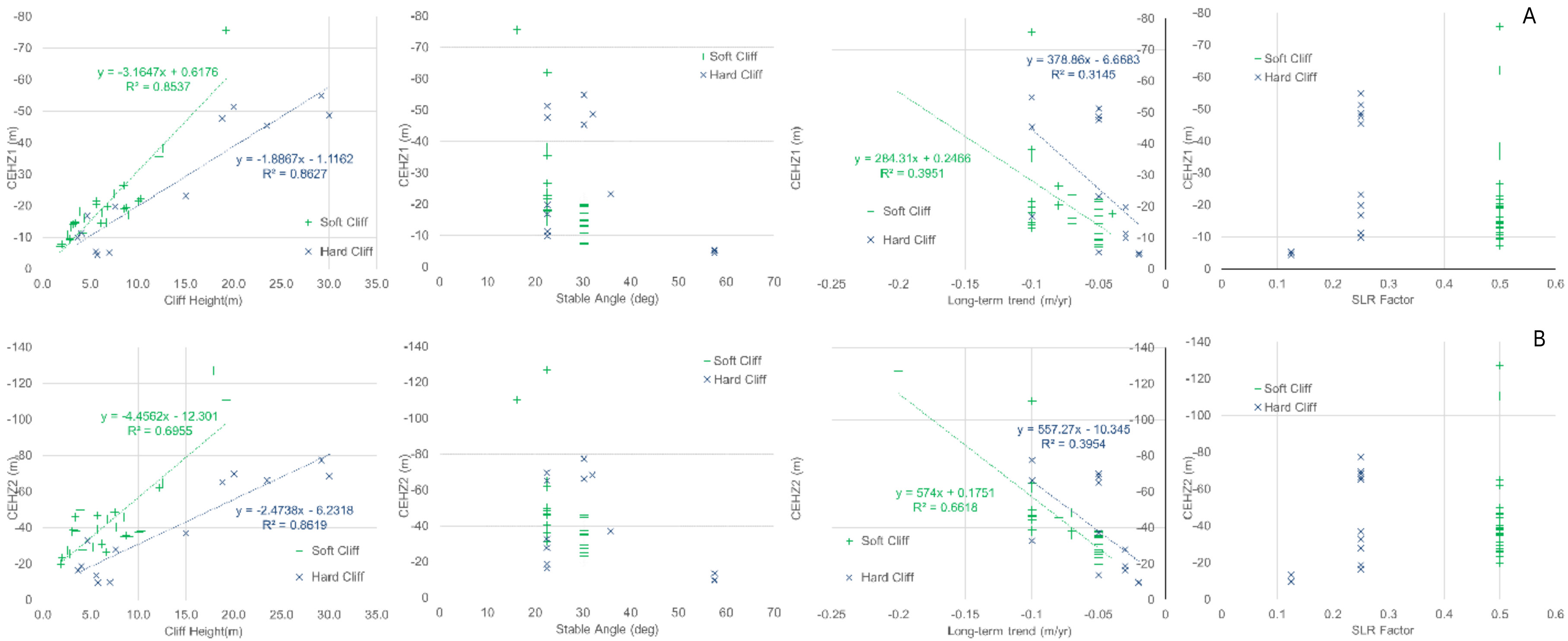

Figure 5-4 *Relationship between CEHZ1 (A) and CEHZ2 (B) distance and individual parameters (mean value) for cliff coasts in the Northland Region (excluding the CEHZ widths for sites for which the cliff projection method has been adopted)*

6 Summary and recommendations

The NRC have previously assessed the coastal erosion hazard zone (CEHZ) for the majority of settlements within their administrative boundary over a number of different reports completed from 1988 to 2003. The NRC require a new set of CEHZ for 31 sites to be developed in line with the current state of scientific knowledge, relevant legislation and best practice guidelines.

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 three major coastal types:

- Beaches comprising unconsolidated sediments
- Cliff coasts
- Estuarine shorelines.

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

- 2015 Coastal Erosion Hazard Zone (Current): 2015 CEHZ
- 2065 Coastal Erosion Hazard Zone (50 years): 2065 CEHZ
- 2115 Coastal Erosion Hazard Zone (100 years): 2115 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 2065 and the CEHZ value with a 5% probability of being exceeded ($P_{5\%}$) at 2115 have been adopted as prudent *likely* and *potential* CEHZ values (termed CEHZ1 and CEHZ2 respectively) to provide the required two hazard zones for Council's planning maps. 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 selected baseline, typically the 2013/2014 shoreline.

Results show that CEHZ1 values for open coast beaches range from 15 to 65 m and CEHZ2 values range from 30 to 160 m on east coast beaches and from 100 to 160 m on west coast beaches. The larger 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 10 to 75 m and CEHZ2 values from 25 to 130 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 estuaries and inlets may be large where inlets are unstable 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. Therefore, mapping the extent of hazard is still applied to these areas as a dashed line.

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.

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The methodology set out in this report has been reviewed by Professor Paul Kench (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 Table B-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.

Table B-1 Extreme wave heights for Northland offshore locations

	Coordinates		H_s (m) ± 90% CI			
Location	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)

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 (Table B-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 B-1.

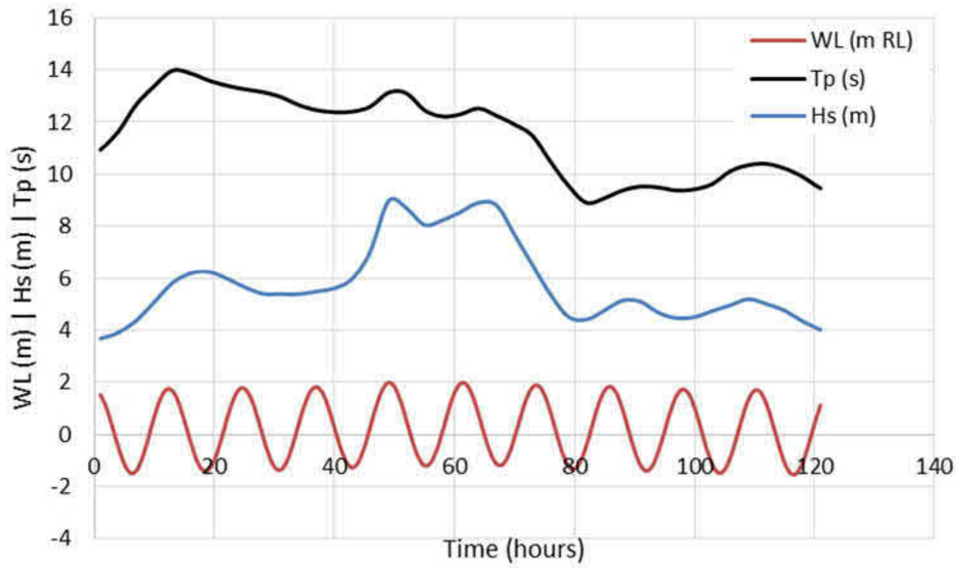

Figure B-1 Example 100 year ARI synthetic design storm for the west coast

Table B-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 B-2). A total of six local model domains (see Table B-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.

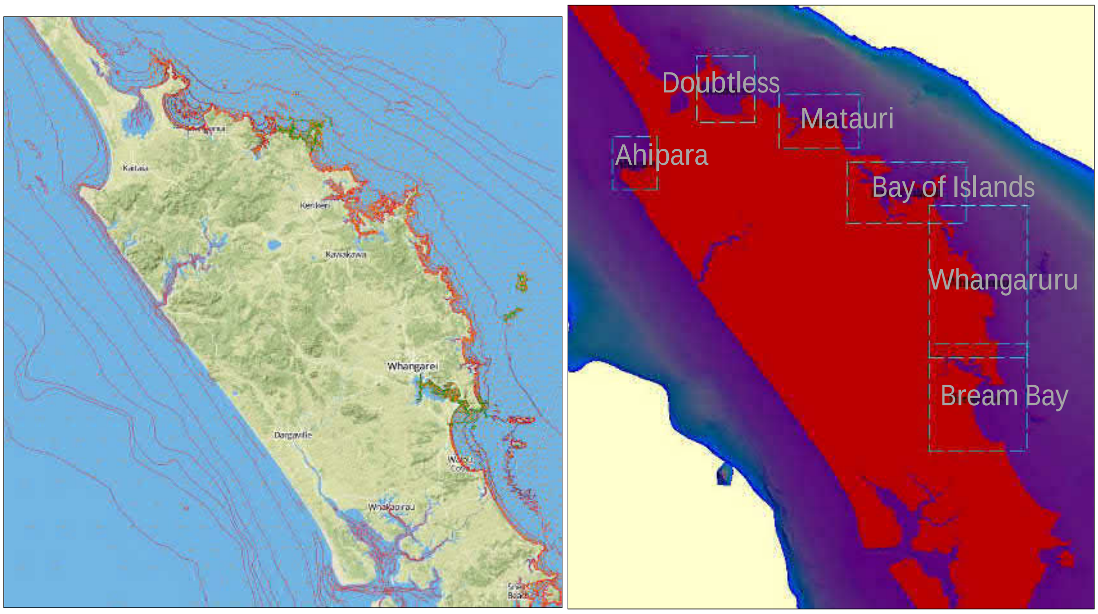

Figure B-2 Bathymetric contours and spot heights from LINZ database (A) and derived bathymetry map model (B) used to construct SWAN model domains (dashed boxes)

Table B-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. Figures B-3 A-F 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

H_s [m]

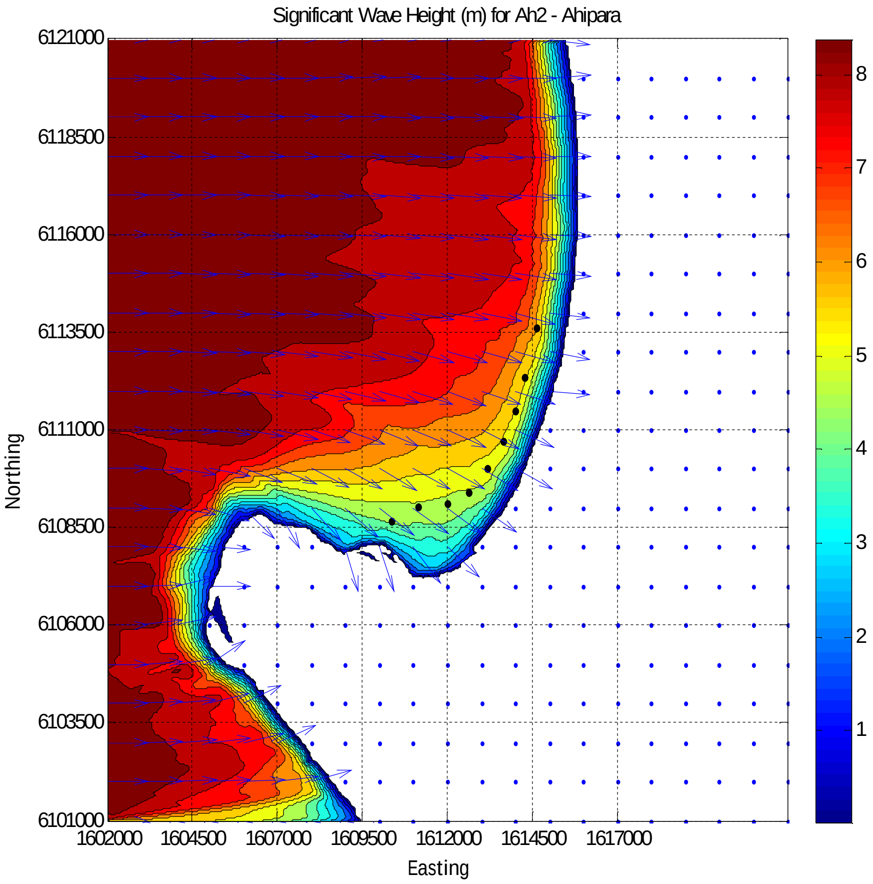

Figure B-3 A SWAN model results for the Ahipara domain – Significant wave height and direction during a 100 year ARI storm from the west

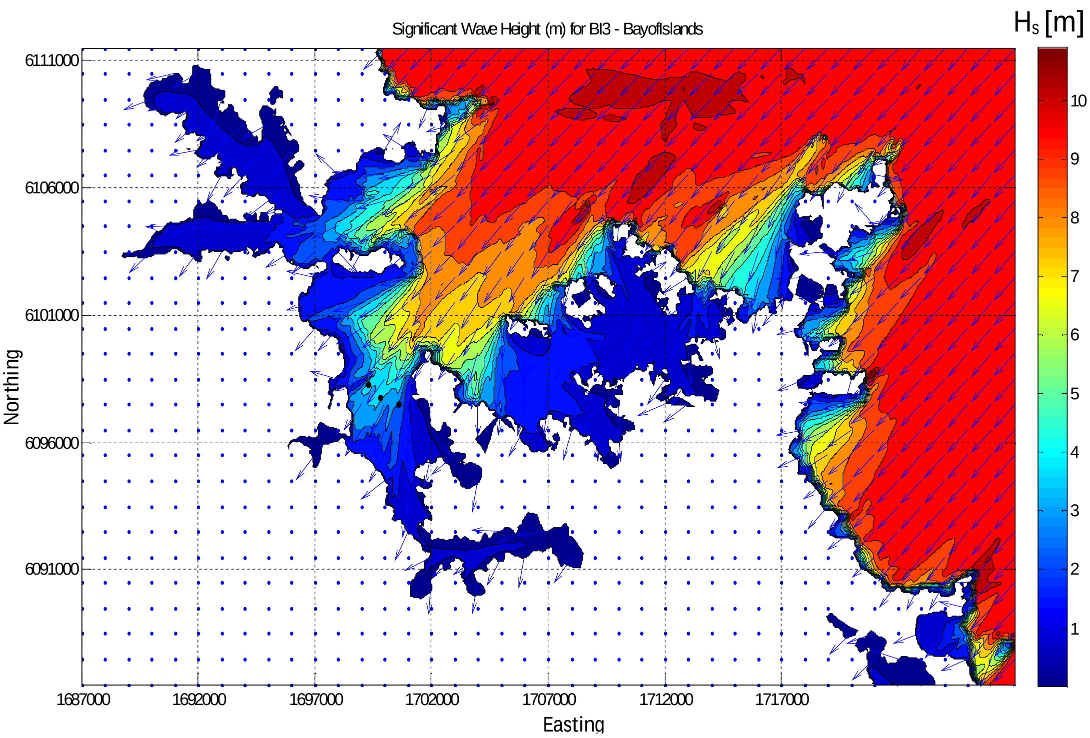

Figure B-3B SWAN model results for the Bay of Islands model domain – Significant wave height and direction during a 100 year ARI storm from the Northeast

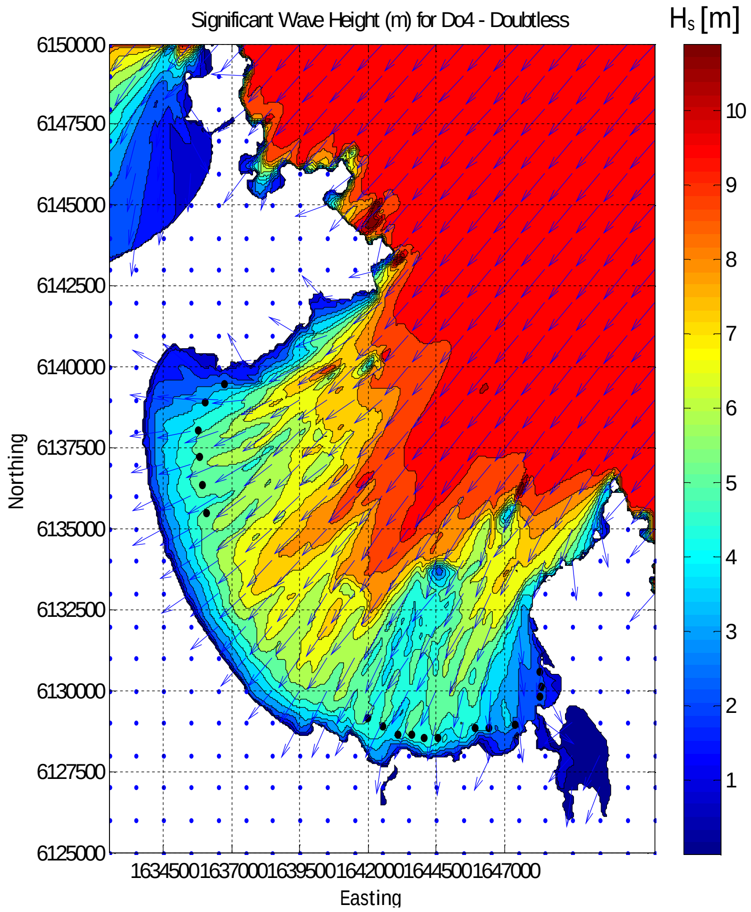

Figure B-3C SWAN model results for the Doubtless model domain – Significant wave height and direction during a 100 year ARI storm from the Northeast

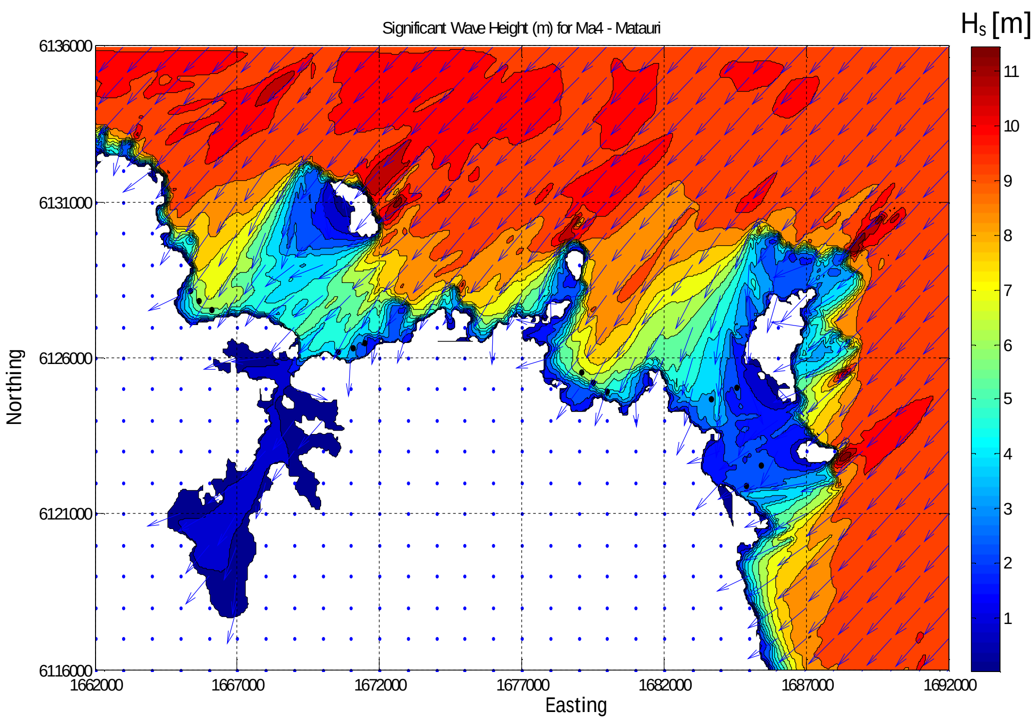

Figure B-3D SWAN model results for the Matauri model domain – Significant wave height and direction during a 100 year ARI storm from the Northeast

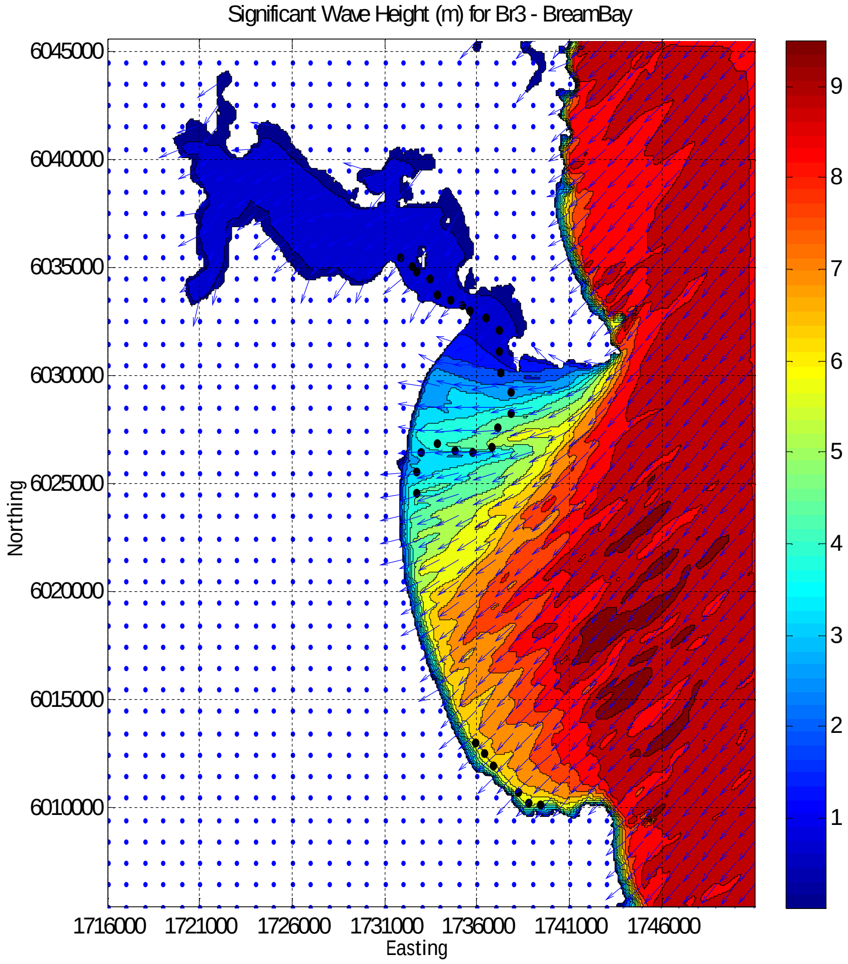

Figure B-3E SWAN model results for the Bream Bay model domain – Significant wave height and direction during a 100 year ARI storm from the northeast

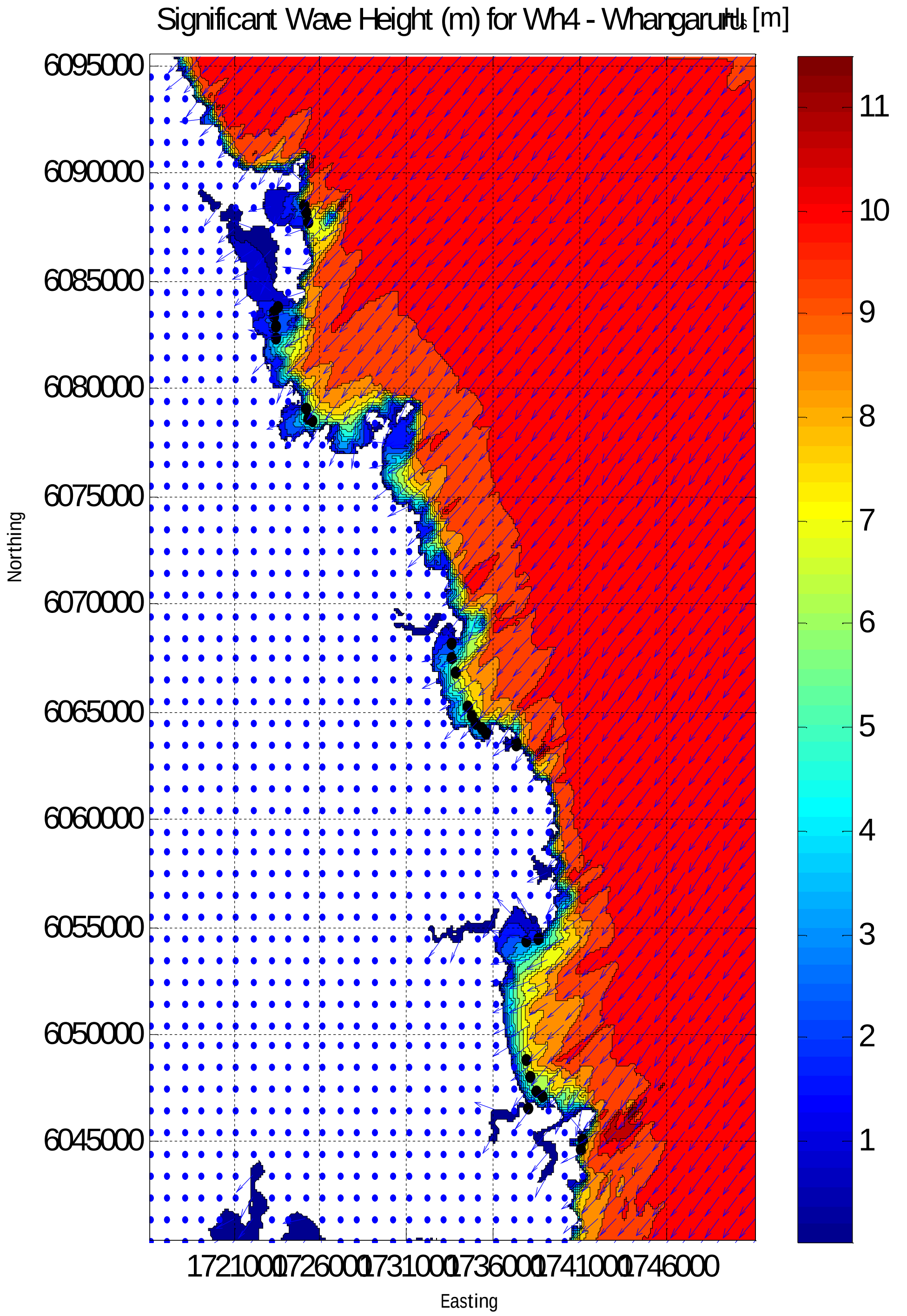

Figure B-3F SWAN model results for the Whangaruru model domain – Significant wave height and direction during a 100 year ARI storm from the northeast

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
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
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
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
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

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
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
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
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
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
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
8	Pataua	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	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

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
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
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
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
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
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
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

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
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
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
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
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
18	Bland	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
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
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
20	Matauri	Dune Crest	2007 dune crest	LiDAR	Digitise dune crest polyline based on LiDAR derived DTM.	James Lyth	Mark Ivamy	A
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
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
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

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
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
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
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
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
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

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
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
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
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
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
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

Site Number	Site Name	Data Type	Data Desc	Data Source	Processing Steps	Processed By	Verification	Versioning
29	Tokerau	Shoreline	2013 shoreline	GPS	GPS shoreline captured by TT during site inspection.	Mark Ivamy	Mark Ivamy	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
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
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

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.

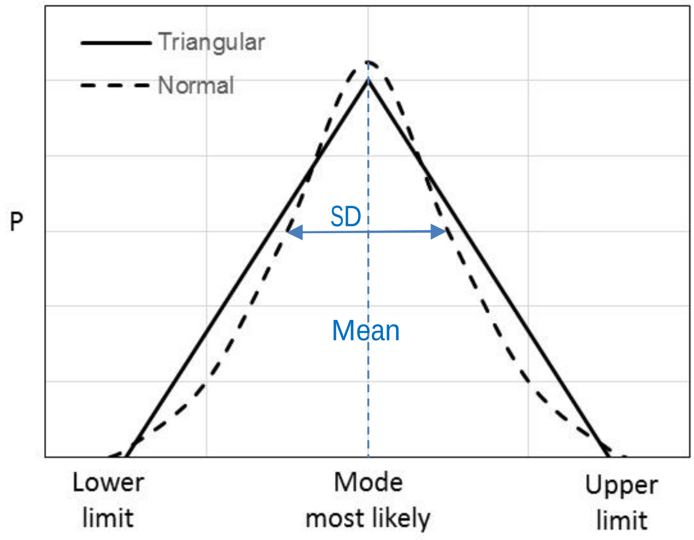

Figure 2.1: Example of triangular distribution and normal distribution

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
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Appendix E : Undertaking site-specific CEHZ assessment 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:

1 Determine the future cliff toe position (2065 or 2115) 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 ($H/\tan\alpha$)

5 Offset the calculated distance from future cliff toe.

The distance between the present day cliff toe and the offset line from the 2065 or 2115 future cliff toe represents the CEHZ1 and CEHZ2 respectively. These steps should be repeated if the stable cliff angle or cliff height vary alongshore.

Appendix F : Letter of peer review

SCHOOL OF ENVIRONMENT
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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

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