Pakiri Sand Extraction Consents

Assessment of Effects on Coastal Processes

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McCallum Bros Ltd

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Glossary

ADCP	ACOUSTIC Doppler Current Profiler
CD	Chart Datum
D_{50}	Medium grain size of a sediment sample (e.g. the 50^{th} percentile)
DGPS	Differential Global Positioning System
DSAS	Digital Shoreline Analysis System
EGM96	Earth Gravitational Model 1996
EDA	Excursion Distance Analysis
EOV	Edge of Vegetation
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HG	Harrison Grierson
H_s	Significant wave height (highest 1/3 of waves)
HWM	High Water Mark
KL	Kaipara Ltd
LAT	Lowest Astronomical Tide
LINZ	Land Information New Zealand
MBL	McCallum Brothers Ltd
mgs	mean grain size
MHWS	Mean High Water Spring Tide
MOSL	MetOcean Solutions Ltd
MPSS	Mangawhai-Pakiri Sand Study
MSL	Mean Sea Level
NZGD1949	New Zealand Geodetic Datum 1949
NZGD2000	New Zealand Geodetic Datum 2000
NZVD09	New Zealand Vertical Datum 2009
AUP	Auckland Unitary Plan
RNZN	Royal New Zealand Navy

RTK	Real Time Kinematic
SWAN	Simulating Waves Nearshore
UAV	Unmanned Aerial Vehicle
T_m	Mean wave period
T_p	Peak wave period (period associated with most energetic waves in the total wave spectrum)
T_s	Significant wave period (highest 1/3 of waves)
WRF	Weather Research and Forecasting

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to describe the coastal processes operating within the Mangawhai-Pakiri embayment and to identify the scale of any effects to these processes from the past or continued inshore extraction of sand from the embayment in accordance with the scope of services set out in the contract between Jacobs and McCallum Bros Ltd ('the Client'). That scope of services, as described in this report, was developed with the Client.

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1. Introduction

1.1 Background

The Mangawhai-Pakiri embayment is situated in the northern Hauraki Gulf, and contains 25 km of sandy beaches between the rocky headlands of Bream Tail and Cape Rodney (Figure 1.1).

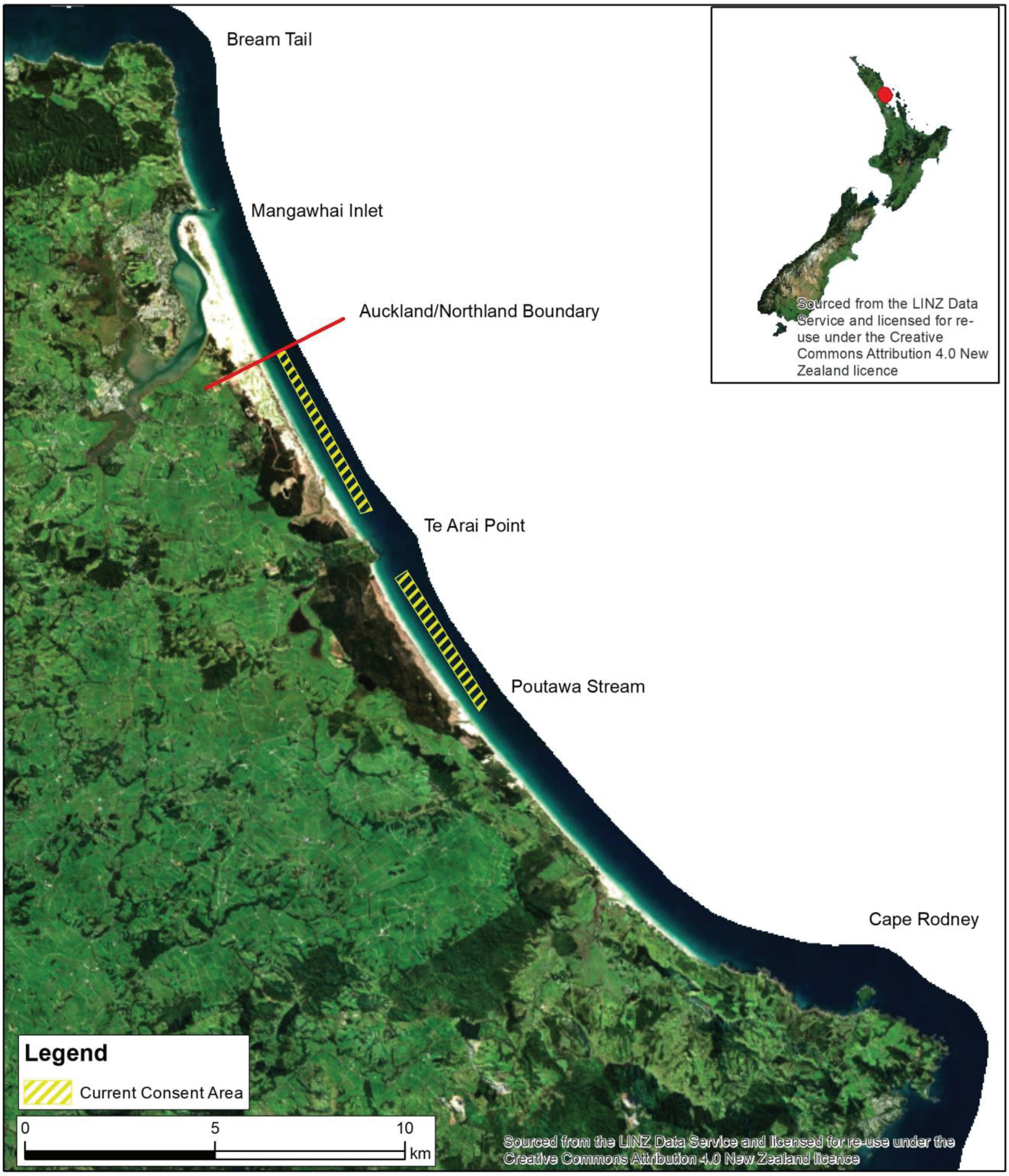

Figure 1.1: Mangawhai-Pakiri Embayment showing the proposed renewal consent area for McCallum Bros Ltd Inshore Sand Extraction.

On shore the beaches are backed by a dune field extending up to 2 km landward in the centre of the embayment and tapering to around 200m wide at the ends, with dunes up to 40 m in height. Much of this dune field was stabilised in the 1960's by the planting of pine trees, but in recent years sections of the forestry have been cleared for golf course and rural-residential developments. Offshore, the sandy seabed slopes gently to the middle continental shelf about 4km offshore, where it flattens and becomes muddy in water depths of 50-60 m (Hume et al, 1999). The embayment is exposed to Pacific Ocean swells from north to southeast.

McCallum Brothers Ltd (MBL) have been extracting sand from the nearshore of the Mangawhai-Pakiri embayment for more than 75 years. The current coastal permits (ARC28165, ARC28172, ARC28173 & ARC28174) were granted by the Environment Court in May 2006 for a 14-year period to 6th September 2020, which allows MBL to extract sand at volumes up to 76,000 m^3/year from the inshore area between the 5 m and 10 m water depths (Chart Datum[1], CD) between the Auckland/Northland regional boundary and the Poutawa Stream as shown in Figure 1.1.

In preparation for an application to renew these consents, Jacobs have been commissioned to report on the physical coastal processes' environment in the consent area and to assess the potential effect of proposed MBL sand extraction operation on these coastal processes.

There are also other sand extraction consents within the embayment, which have also been operative for a number of years, notably those held by Kaipara Limited (KL) since 2003 to extract up to 2 million m^3 of sand over a 20-year period from deeper than 25 m (CD) water depth or 2 km from MHWS, whichever is furthest.

1.2 Scope of Report

The scope of this assessment includes the following components:

- Review of previous studies and Environment Court hearing (ENV A104/05 and 105/05) evidence and decision on coastal processes.
- Outline of the field and desktop investigation methods used to define the coastal process environment and potential effects of MBL sand extraction operation, including: seabed bathymetry and morphology, seabed sand properties, waves and currents, sediment supply and transport, dredge trench infilling, shoreline position and beach volume change.
- Description of the current coastal processes' environment within the wider Mangawhai and Pakiri embayment in general, and the consent area in particular.
- Assessment of the potential effects of the renewal of the current extraction consent on the coastal process environment, in particular the effects on coastal erosion, seabed disturbance, and sustainability of the extraction activity. This assessment of effects has been made taking into account previous studies, monitoring of the dredging operation during the present consent, and recent investigations undertaken for the purpose of this assessment.

1.3 Description of the Extraction Activity

1.3.1 Renewal Consent

MBL is seeking consent to continue to extract sand at the same location as currently consented under coastal permits ARC28165, ARC28172, ARC28173 & ARC28174, as shown in Figure 1.1. The landward and seaward boundaries of the current consent are defined by water depths, being the 5 m[2] and 10 m depths mapped on the LINZ Bathymetric Chart NZ522 as shown in Figure 1.2.

[1] Chart datum (CD), which has a zero depth at Lowest Astronomical Tide (LAT).
[2] The landward limit of extraction is also to be no closer than 100 m seaward of the crest of the nearshore bar.

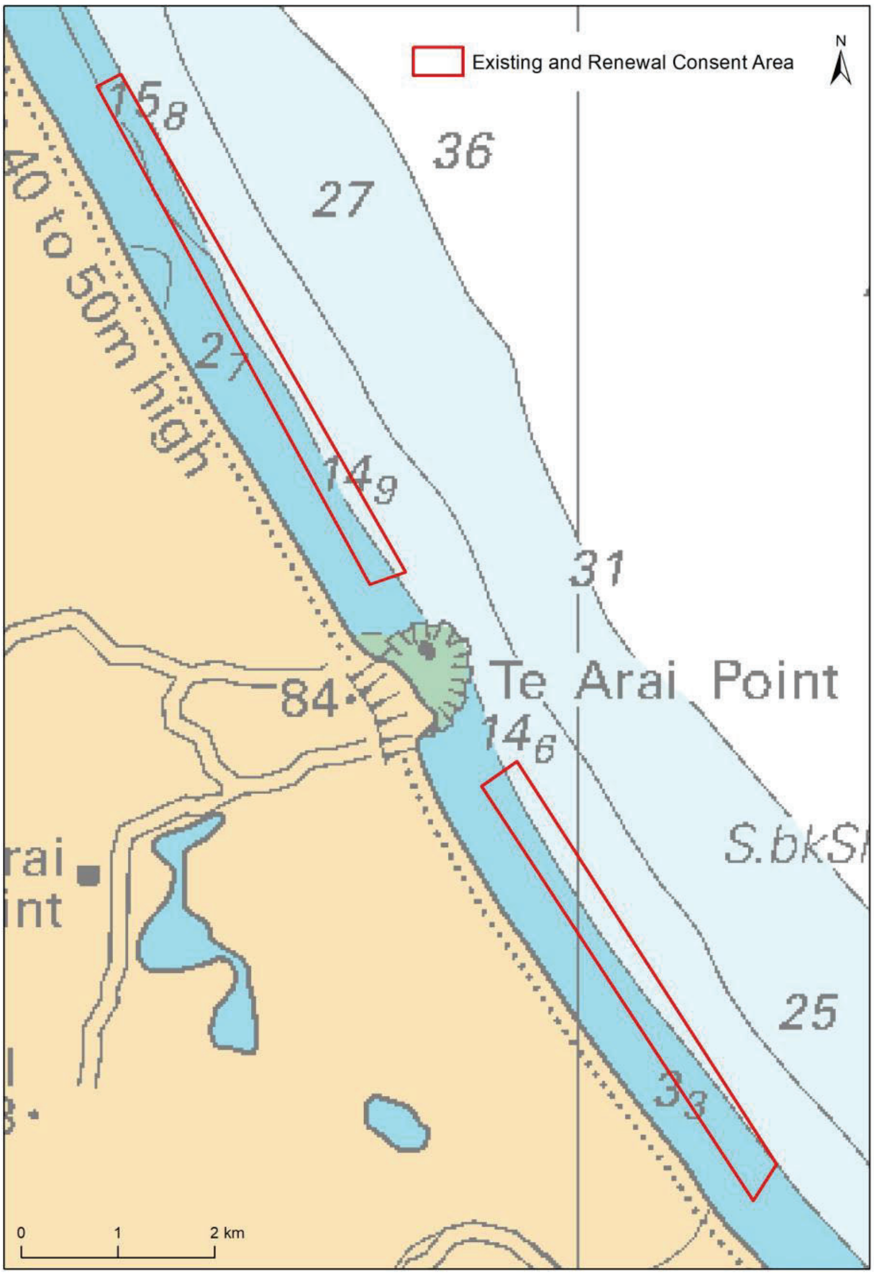

Figure 1.2: McCallum Bros Ltd Pakiri Sand Extraction existing and renewal consent area on overlay of Bathymetric Chart NZ522 water depth contours.

These depth contours are in terms of chart datum (CD), which is a different datum than the bathymetry collected for this assessment, being in terms of MSL in Mt. Eden Datum so that they are in the same datum as the beach surveys. MSL in Mt. Eden Datum is 1.9 m above the zero base of CD for Auckland, therefore the seabed contours presented in the AEE from the recent bathymetric surveys undertaken for this assessment are in the order of 2 m deeper than on Hydrographic Chart NZ522. For simplicity and to avoid ambiguity, it is proposed that the renewal consent area be demarcated solely by the coordinates given in Table 1.1 without reference to the water depths.

The proposed extraction area is spilt into two areas located north ('northern area') and south ('southern area') of Te Arai Point. The total extraction area covers 2.57 km^2, extending a total length of 8.9 km alongshore broken by the 1.9 km long exclusion area around Te Arai Point. The width of the extraction area varies from 230 m to 345 m.

Table 1.1: Co-ordinates of renewal consent area.

Northern Area		Southern Area	
NZTM2000 Projection	**NZGD2000 Projection**	**NZTM2000 Projection**	**NZGD2000 Projection**
1745987.4, 6001965.8	36 06 58S 174 37 20E	1749100.9, 5996074.1;	36 10 07S 174 39 28E
1746186.8, 6002065.1	36 06 54S 174 37 27E	1749400.1, 5996274.4	36 10 00S 174 39 40E
1748196.6, 5997771.1	36 09 13S 174 38 51E	1751308.1, 5992579.6	36 11 59S 174 40 59E
1748496.4, 5997872.1	36 09 09S 174 39 03E	1751507.5, 5992879.9	36 11 49S 174 41 07E

MBL is seeking consent to continue to extract sand at the same rate as the current consents, being 76,000 m^3/per consecutive 12-month period, with the extraction to be in approximately equal volumes from each of the northern and southern extraction areas balanced over any 12-month period.

Under the new consent MBL propose to undertake all sand extraction by trailing suction dredges, with stationary dredging have been phased out. MBL has recently introduced a new purpose built trailing suction dredge vessel, the 'William Fraser', to the sand extraction operation as a replacement for its previous vessel, the "Coastal Carrier". In terms of the physical coastal process effects of relevance are that this new vessel has a larger draghead, larger hopper capacity, and better dredge efficiency, and therefore to obtain the same volume of sand requires less dredge area and less seabed disturbance.

1.3.2 Historical Extraction Volumes

MBL have been extracting sand from the nearshore of the Mangawhai-Pakiri embayment for around 75 years (i.e. since post World War 2) to supply the Northland-Auckland region with a high-quality sand product that requires minimum processing for use in the concrete industry. MBL are one of a number of companies who have been engaged in extraction activities from the Mangawhai-Pakiri embayment, with ARC historical records indicating that sand extraction from the embayment has been occurring since the 1920's. Although exact records are not available, it is estimated that the extraction volumes prior to 1966 could have been in the order of 2 million m^3. A summary of the sand extraction volumes identified from available data is presented in Table 1.2, which shows that a total of around 5.4 million m^3 of sand has been extracted from the Mangawhai-Pakiri embayment since 1966.

Table 1.2: Mangawhai-Pakiri sand extraction volumes 1966-2019 (volumes rounded to 100 m^3)

Period	Mangawhai Inlet Ebb Tide Delta Extraction volume (m^3)	Inshore Extraction volume (m^3)	Offshore Extraction volume (m^3)	Total Extraction volume (m^3)
1966-1987	200,000	1,300,000	0	1,500,000
1988-1992	61,900	266,100	0	328,000
1992-1997	102,700	405,500	0	508,200
1997-2003	253,000$^{(1)}$	590,000$^{(1)}$	0	843,000
2003-2019	0	677,600	1,572,500	2,250,000
1966-2019	**617,600**	**3,239,200**	**1,572,500**	**5,429,200**
Note (1) volumes extracted from each area assumed as pro-rata percentage of the consented volumes				

Hilton (1989) reported that the 1.5 million m^3 that was extracted between 1966 and 1987 was largely sourced from the nearshore at depths of 4-10 m. It is assumed that majority of this was from a similar area as the current MBL inshore extraction as only 200,000 m^3 is reported as being extracted from the ebb tide of the Mangawhai Inlet up to 1979 when extraction in that area was suspended following breaching of the barrier spit during a major storm in 1978, and only resumed in 1989.

Under the RMA 1991, coastal permits were granted by the Minister of Conservation in 1992/93 for 10 years to five companies, including MBL and KL, for the combined extraction of 50,000 m^3/yr from the Mangawhai entrance and 115,000 m^3/yr from the current extraction area. The data presented in MPSS Module 3 from these extractions up to 1997 were supplied by Northland and Auckland Regional Councils and shows that the extraction rates were less than the maximum allowed under the consents, averaging 81,000 m^3/yr from the inshore area. The majority of the inshore extraction over this period (at least 65%) occurred from south of Te Arai Point, of which the most (43%) was from the zone immediately north of the Poutawa Stream.

Extraction volumes from 1997 to 2003 can be deduced from the information presented in MPSS Module 3 as being 0.843 million m^3. The distribution of this extraction between the entrance to Mangawhai Inlet and the inshore extraction area is not known. However, assuming a pro-rata percentage extraction from each area as per the consented volumes (e.g. 70% from the inshore area), gives an estimate of 590,000 m^3 from the inshore area and 253,000 m^3 from the Mangawhai Inlet over this 6-year period.

In the early 2000's, when the original Coastal Permits were due to expire, KL applied for and were granted in 2003 a coastal permit to extract from offshore areas at depths greater than 25 m CD. As a result, they surrendered their consent for extracting up to 45,000 m^3/yr from the inshore area. Their new offshore consent allowed for extraction of up to 2 million m^3 over a 20-year term to 2023. In 2006, MBL and Sea Tow Ltd were granted MBL's current coastal permits. Consents for extraction from the Mangawhai Inlet entrance were not renewed.

Extraction volumes since 2003 have been supplied by MBL for both the inshore and offshore areas[3] from their extraction records and are presented in Table 1.3. The data shows a combined total of 2.25 million m^3 has been extracted over the 17 years, of which 677,500 m^3 has been from the MBL inshore consent area and 1.57 million m^3 from the KL offshore consent area. MBL extraction records show that approximately 35% of the extraction from the KL area has been from water depths less than 30 m CD. This implies an average annual combined extraction rate from less than the -30 m CD contour is in the order of 77,000 m^3/yr. However, on an annual basis the combined extraction volume has varied by over 119,000 m^3/yr, with a minimum extraction of 98,800 m^3 in 2011 and a maximum of 218,300 m^3 in 2019. Further details on the monthly variations in the extraction volumes since 2003 from the extraction inshore and offshore areas are presented in **Appendix A**.

Table 1.3: Mangawhai-Pakiri annual sand extraction volumes 2003-2019. (Data supplied by MBL from extraction records)

Annual Extraction Volumes 2003-2019 (m^3)			
Year (1)	**Inshore sand**	**Offshore sand**	**Combined Volume**
2003	53,000		53,000
2004	62,305	97,354	159,659
2005	79,250	72,980	152,230
2006	65,450	60,834	126,284
2007	62,900	55,982	118,882
2008	43,510	84,105	127,615
2009	19,240	83,168	102,408
2010	22,540	84,970	107,510
2011	23,460	75,395	98,855
2012	22,758	79,216	101,974
2013	16,560	82,653	99,213
2014	13,406	116,336	129,742
2015	14,700	127,190	141,890
2016	18,270	128,400	146,670
2017	13,890	162,035	175,925
2018	71,600	118,320	189,920
2019	74,720	143,550	218,270
TOTAL	**677,559**	**1,572,488**	**2,250,047**

Note (1) The year is the extraction return year running from Sept of the preceeding year to Aug of the year given

[3] As well as their inshore area, MBL extract all the sand from the KL offshore area under licence.

2. Investigation Methods

2.1 Relevant Previous studies

The coastal processes and shoreline changes within the Mangawhai-Pakiri embayment have been the subject of numerous studies during the 1990's to mid 2000's, including the extensive MPSS from 1996-2000, with the focus of a large number of the investigations being to assess the sustainability of the sand extraction activities being undertaken within the embayment. This body of work provides background scientific knowledge of the coastal processes operating within the embayment. The following work has been reviewed.

- Hilton M. J. 1990 Process of sedimentation on the shoreface and continental shelf and the development of facies, Pakiri, New Zealand (Unpublished Ph.D thesis, University of Auckland).
- Hilton, M. J. (1995). Sediment facies of an embayed coastal sand body, Pakiri, New Zealand. Journal of coastal research.
- Hilton, M. J., & Hesp, P. (1996). Determining the limits of beach-nearshore sand systems and the impact of offshore coastal sand mining. Journal of Coastal Research.
- Hume, T. M., et al. (1996-2000) Mangawhai-Pakiri Sand Study: Modules 1-5 (Technical Reports) and Module 6 (Final Report).
- Hume, T. M., et al. (2000). Sediment facies and pathways of sand transport about a large deep water headland, Cape Rodney, New Zealand. New Zealand Journal of Marine and Freshwater Research.
- Riddle, B. B. (2000). Sidescan Sonar Mapping of surficial Sea Floor Sediments in the Outer Hauraki Gulf (Unpublished Masters Thesis), University of Waitako).
- Hicks, D. M., Green, M. O., Smith, R. K., Swales, A., Ovenden, R., & Walsh, J. (2002). Sand volume change and cross-shore sand transfer, Mangawhai Beach, New Zealand. Journal of Coastal Research.
- Evidence and Decisions for 2003 Kaipara Ltd sand extraction application.
- NIWA (2004) Beach Profile change along Mangawhai-Pakiri Embayment 1978-2003.
- Todd D., et al (2004). Interpretation of NIWA 2004 Report with Respect to Sand Extraction at Te Arai Point.
- Environment Court Evidence and Decision on 2006 McCallum Bros Ltd sand extraction appeal.

2.2 Existing MBL Consent Monitoring

As required by its current consent, MBL has undertaken six monthly beach surveys and three yearly bathymetry surveys. The information from the MBL consent monitoring is used in this assessment, with the data collection methods being outlined below.

2.2.1 Beach Surveys

Topographic surveys of 20 km of the beach along the Mangawhai-Pakiri embayment from approximately 300 m north of the extraction zone to south of the Pakiri River have been undertaken every six months. The inclusion of the beach 6.5 km south of the MBL extraction area to the Pakiri River mouth allows this southern area to be treated as a control area for the assessment of extraction effects on shoreline changes.

From April 2007 to March 2017 these surveys were carried out by Harrison Grierson (HG) using GNSS[4] survey technology in Real Time Kinematic (RTK) mode to collect survey data by beach vehicle and walking from the top of the seaward dune scarp to low tide water level. The horizontal datum used in the surveys was Geodetic 2000 with Mount Eden Circuit projection, with a base station established at LINZ Trig A9J7 located on Te Arai Point. The height datum used was 'Mean Sea Level (MSL)', with a published reduced level of 84.55m at Trig A9J7 used as the origin of the levels. The geoid model NZVD09 published by LINZ has been used since the

[4] Global Navigation Satellite System

2010 surveys to accurately “convert” the GNSS observed heights to elevations of the beach relative to the level datum. For surveys prior to 2010, no geoid model was used, and the outputs supplied by HG accommodated this change.

From October 2017 onwards the beach survey method changed to be undertaken by Survey-Worx using UAV (e.g. Drone) mounted integrated aerial photograph and GNSS technology. This beach survey method has the ability to capture topographic data more efficiently and quickly, particularly in the dune areas. The bearing and co-ordinate datum for this survey was retained as Geodetic 2000 with Mt. Eden circuit projection, and the level datum retained as MSL with the same origin at Trig A9J7 (84.55m).

Eleven historical beach profile lines, some of which were first established in 1978 by the Auckland Regional Water Board following severe erosion events in 1978 and reported in the Mangawhai-Pakiri Sand Study (MPSS), are interpolated from the topography survey data to continue the excursion distance and volume change analysis of this historical data set. The location of these beach profiles are shown in Figure 2.1.

Figure 2.1: Location of historical beach profiles used in shoreline position/volume and bathymetry change monitoring under existing MBL extraction consents

2.2.2 Bathymetry surveys

Three yearly bathymetry surveys have been carried out by either Ports of Auckland or Discovery Marine on 4 occasions since the granting of the consent, being April or March 2007, 2010, 2013, and 2016. The surveys are concentrated around the extension of the 11 historical beach profile sites in Figure 2.1, and were surveyed from the surf zone (depth 1.5-2 m) to around the 35 m depth contour. All surveys were undertaken as far as possible at high water to maximise overlap with beach surveys.

All surveys were undertaken with an integrated digital survey outfit comprising of a digital echo sounder, a DGPS positioning system, motion sensor and laptop computer. For the 2007 survey, horizontal survey control was based on NZGD1949, with subsequent surveys being based on the Mount Eden 2000 Grid (NZGD2000). The Geoid model used in all surveys was EGM96 (Global). For vertical survey control, two depth reduction methods have been used. For 2007, 2013 and 2016 surveys, raw survey data was reduced for tide using a co-tidal model developed from observed tides at Auckland and Marsden Point, with data presented relative to the local Pakiri Sounding Datum; 1.33 m below MSL. For the 2010 survey, the survey RTK positioning was used to provide a tidal correction to reduce soundings to MSL. For all surveys, depth accuracy was assessed as being better than +/- 0.25m.

The latest three yearly bathymetric profile survey in March 2019 was undertaken as part of a wider bathymetric survey of the embayment nearshore area carried out for this assessment and described below as part of the recent field investigations.

2.3 Recent MBL Field Investigations

In addition to the work discussed above, a number of field investigations have been undertaken to provide further information for this assessment. The methods employed in these investigations are outlined in the following sections.

2.3.1 Bathymetry

A hydrographic survey of the nearshore area within the 20 m water depth contour from the Mangawhai River mouth to the Pakiri River was largely undertaken in March 2019, with the survey area in the vicinity of the extraction area extended seaward to around the 30 m depth contour during a subsequent survey in October 2019. The areas covered in these surveys is shown in **Appendix B**. All surveys were undertaken under the supervision of Survey Worx Ltd, registered professional surveyors. The equipment, methodology and accuracy of the survey is given in **Appendix C**.

The mapping of the 2019 bathymetric surveys in terms of depth below MSL is presented in **Appendix G,** and reporting of the survey results are presented in section 3.2.2.

A small bathymetric survey was also undertaken off Bream Tail at the northern end of the Mangawhai-Pakiri embayment. The purpose of this survey was to help determine the potential pathway of sand entering the embayment from the north for the sediment budget calculations.

2.3.2 Seabed Sediment Sampling

To determine the distribution of seabed sediment particle size in the proposed renewal consent area and the nearshore environment to a water depth of 30 m MSL, 121 samples were collected by a box dredge as shown in Figure 2.2 from the locations shown in **Appendix D**. The sampling was part of the benthic fauna investigations by Bioresearches (2019a). The methodology used and detailed results are reported in Bioresearches (2019a).

A further four sediment samples were collected from the seabed off Bream Tail as part of the investigations for longshore sediment transport into the Mangawhai-Pakiri embayment.

Results of the sediment size distributions are presented in terms of mean grain size (mgs) from the Wentworth scale and sorting calculated using the Inclusive Graphic Standard Deviation as shown in Table 2.1

Table 2.1: Sediment size and sorting descriptions

Mean Gain Size (mgs)		Sorting	
Size range (mm)	**Aggregate name (Wentworth class)**	**Inclusive Graphic Standard Deviation (mm)**	**Description**
1.0 – 2.0	Very Coarse Sand	$\sigma_I > 0.78$	Very well sorted
0.5 – 1.0	Coarse Sand	$0.71 < \sigma_I < 0.78$	Well sorted
0.25 – 0.5	Medium Sand	$0.5 < \sigma_I < 0.71$	Moderately sorted
0.125 – 0.25	Fine Sand	$0.25 < \sigma_I < 0.5$	Poorly sorted
0625 – 125	Very Fine Sand	$0.0625 < \sigma_I < 0.25$	Very poorly sorted
< 62.5 µm	Silt	$\sigma_I < 0.0625$	Extremely poorly sorted

2.3.3 Seabed micro-topography

Seabed micro-topography, being the presence of sand ripples was sampled by drop cameras photographing the seabed at approximately 1 m depth intervals from the -5 m to at least -25 m MSL contour along four transects located near the northern and southern ends of each extraction zone as shown in **Appendix D**. A fifth photograph transect was taken off Bream Tail in water depth from 14 m to 30 m (locations shown in Figure 3.15). At each site a single drop camera photograph of a 1 m² area of seabed was recorded with a compass reference. The cameras were set to record images at 2 second intervals and the best images selected, with coordinates, water depth and time recorded at each site.

Photos of sand ripple formations were also taken by divers during dredge infill measurements (described in section 2.3.5).

2.3.4 Ocean Currents

A downward-facing RDI Sentinel V50 500kHz Acoustic Doppler Current Profiler (ADCP) mounted to the base of a surface buoy located in 33 m water depth at the site shown in **Appendix B** was deployed by Cawthron Institute for two months during May to July 2019. This deployment also included a WETlabs WQM water quality recording instrument attached via a 20 m line, which is discussed in the Water Quality Technical Report (Jacobs, 2019). The purpose of the current recordings was to provide data on the ambient conditions during other investigations such as the dredge trench infill and for validation of the ocean current modelling undertaken by MetOcean Solutions Ltd (MOSL) (see section 2.4.1). Unfortunately, the ADCP did not function for the later part of the deployment, restricting the current recordings to 13 days from 20th May to 1 June 2019.

2.3.5 Dredge Trench Infill

Repeated measurements of different dredge tracks at approximately 10 m water depth in the MBL consent area and in 25-30 m water depth in the KL consent area were undertaken by MBL divers several times over the period from October 2018 to November 2019. The methodology involved measurements of the width and depth of the dredge trench at the same location over a period of days and weeks until the trench was no longer visible on the seabed. The purpose of measurements was to determine the rate of trench infill, establish the duration of evidence of sea bed disturbance within the consent area, and to assess the volumes moving across a theoretical closure depth at around the 25 m CD water depth contour. Analysis of infill rates included consideration of waves and currents between measurements provided by a 3 hourly time series of modelled data at Mangawhai-Pakiri P1 site in 30 m of water depth provided by MOSL for the period from November 2018 to June 2019.

Examples of infill measurement methodology are shown in Figure 2.2, with the locations of the measurements being shown in Figure 2.3, and the measurement dates in Table 2.2. It is noted that additional dives on trenches were undertaken where the trench was not able to be detected on the seabed. The results of the trench infill analysis are presented in sections 3.6.3.2 and 4.3.2.

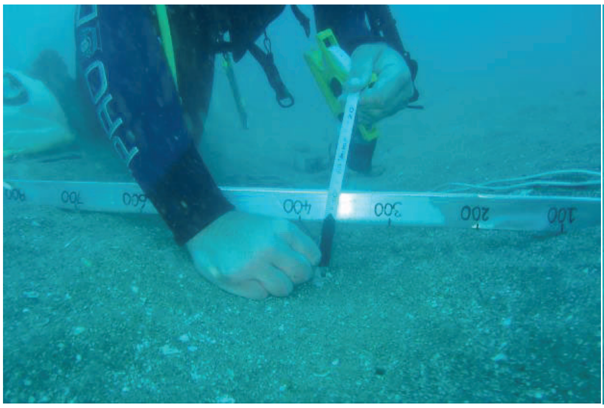

Figure 2.2: Dredge trench infill measurement methodology

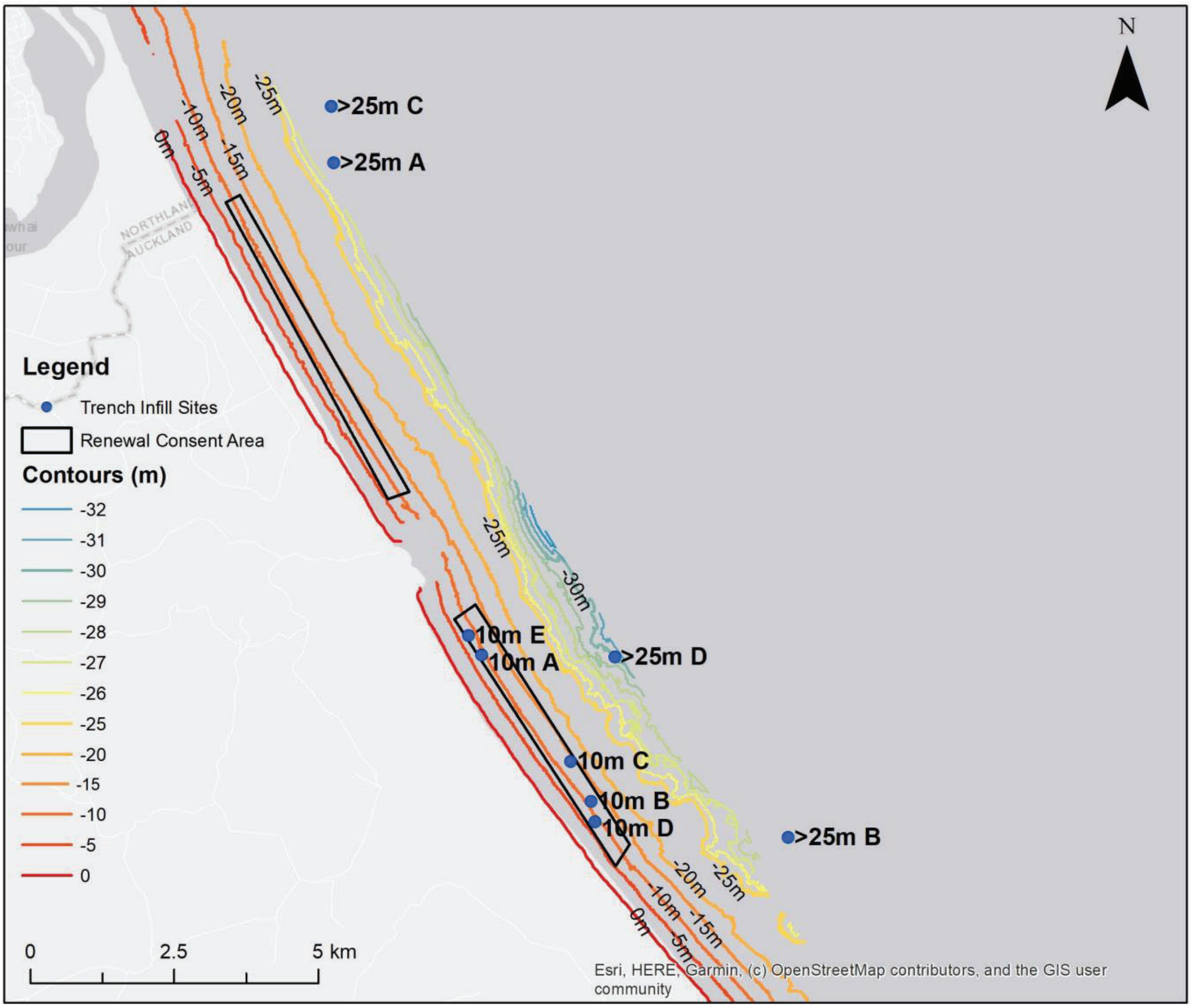

Figure 2.3: Location of dredge trench infill measurements. Depth contours in terms of MSL.

Table 2.2: Dates of dredge trench infill measurements

Trench	Dredge date	Initial measure date	1st re-measure date	2nd re-measure date	3rd re-measure date
10 m Trench A	29/10/2018	29/10/2018	30/10/2018	7/11/2018	13/11/2018
10 m Trench B	28/11/2018	29/11/2019	7/12/2019		
10 m Trench C	2/4/2019	16/4/2019			
10 m Trench D	17/6/2019	18/6/2019			
10 m Trench E	28/11/2019	15/12/2019			
>25 m Trench A	29/10/2018	30/10/2018	7/11/2018	13/11/2018	
>25 m Trench B	19/11/2018	19/11/2018	20/11/2018	29/11/2018	7/12/2019
>25 m Trench C	14/4/2019	14/4/2019	16/4/2019	2/5/2019	
>25 m Trench D	27/11/2019	27/11/2019	28/11/2019	5/12/2019	

2.4 Desktop studies

2.4.1 Wind, Wave, Currents (Metocean Conditions)

MetOcean Solutions Ltd (MOSL) undertook numerical hindcast modelling of wind, wave and current conditions to provide data on long-term conditions and the conditions during the field investigations programme from November 2018 to June 2019. All data was presented for representative sites P1 and P2 in 29 m and 32 m water depths at the locations shown in Figure 2.4. The results for the field investigations period were compared to the long-term conditions to assess the representativeness of the conditions during the field investigations period.

Figure 2.4: Location of ADCP sites (ADCP4 & ADCP0) used in validation of hydrodynamic modelling of ocean currents at sites P1 and P2.

Details of methodologies used in the modelling of each metocean parameter are given in MOSL report in **Appendix E** and are briefly summarised below.

- Hourly near surface marine wind data produced from the 40-year WRF (Weather Research and Forecasting) model from 1979 to 2018.
- Three-hourly directional wave data produced from high-resolution nested SWAN (Simulating Waves Nearshore) wave hindcast produced from the above WRF winds, with the final Hauraki Gulf model having a resolution of approximately 800m. Model results are presented for a 40-year period from 1979 to 2018.
- A 19 year (Jan 2000 – Jun 2018) hindcast of tidal and residual current data produced from nested ROMS hydrodynamic model (version 3.7) with the final domain covering the northern Hauraki Gulf at a resolution of 350 m to produce accurate local wind driven and tidal circulations at 3-hourly intervals. The final hydrodynamic hindcast product was validated against co-temporal current time series obtained from measured data from ADCP4 and ADCP0 sites shown in Figure 2.4. ADCP4 was a two-month deployment in 2016 in Bream Bay for the Refining New Zealand Dredging consents application (MetOcean Solutions, 2017) and ADCP0 being the short 13 day record from the downward facing instrument deployed for this study as discussed in section 2.3.4.

The results of the MOSL wave and current modelling is presented in Section 3.4.1.2 and 3.4.2.2 respectively.

Wave data from 2007 to 2019 collected by the Northport TriAxys directional waverider buoys located off Marsden Point, around 26 km north of the MBL extraction area (location shown in Figure 2.4), has also been used to provide metocean conditions for the assessment of shoreline change from the MBL beach monitoring surveys. The summary statistics of this 12 years of wave data is presented in section 3.4.1.3 and a summary of storm events in section 3.4.1.4.

2.4.2 Digital Shoreline Analysis from Aerial Photographs

Long-term shoreline movements were determined from aerial photographs captured on the following dates:

- 12th September 2018
- 27th January 2008
- 19th January 2007
- 2nd July 1982
- 11th October 1963
- 20th March 1961

The coverage from each of these imagery dates as presented in Figure 2.5, shows that there is relative full coverage of the consent area and the control area to the south within the four time periods of early 1960's, 1982, late 2000's, and 2018.

The analysis involved georeferencing the imagery and digitizing the seaward dune edge as the shoreline reference position. This location was determined from dune form and vegetation limit, which is considered to be an appropriate reference for shoreline change as it is recognisable on the majority of the imagery, and is also a good indicator of both landward (erosion) and seaward (accretion) shoreline movements. The dune edge extent for the entire shoreline within each set of images was digitized manually and captured in a geo-database using ArcGIS.

In some instances, poor image quality made it difficult to accurately interpret the shoreline extent due to low image resolution and high light exposure, in particular the 1961-1963 black and white images with an un-vegetated dune field pre forestry planting (Figure 2.6a), and the 2018 imagery with high exposure in the foredune area (Figure 2.6b). Despite these difficulties, the resulting expected confidence interval of the digitised dune edge position is considered to be in the order of ± 5 m.

The GIS based DSAS (Digital Shoreline Analysis System) was used to calculate net shoreline change and linear regression rates of shoreline movements at 100 m spaced transects from a common baseline position on each set of imagery since 1961-1963. A total of 165 transects were generated along the 17 km of shoreline analysed from the regional boundary to the Pakiri River.

The results of the DSAS analysis is presented in section 3.5.2.

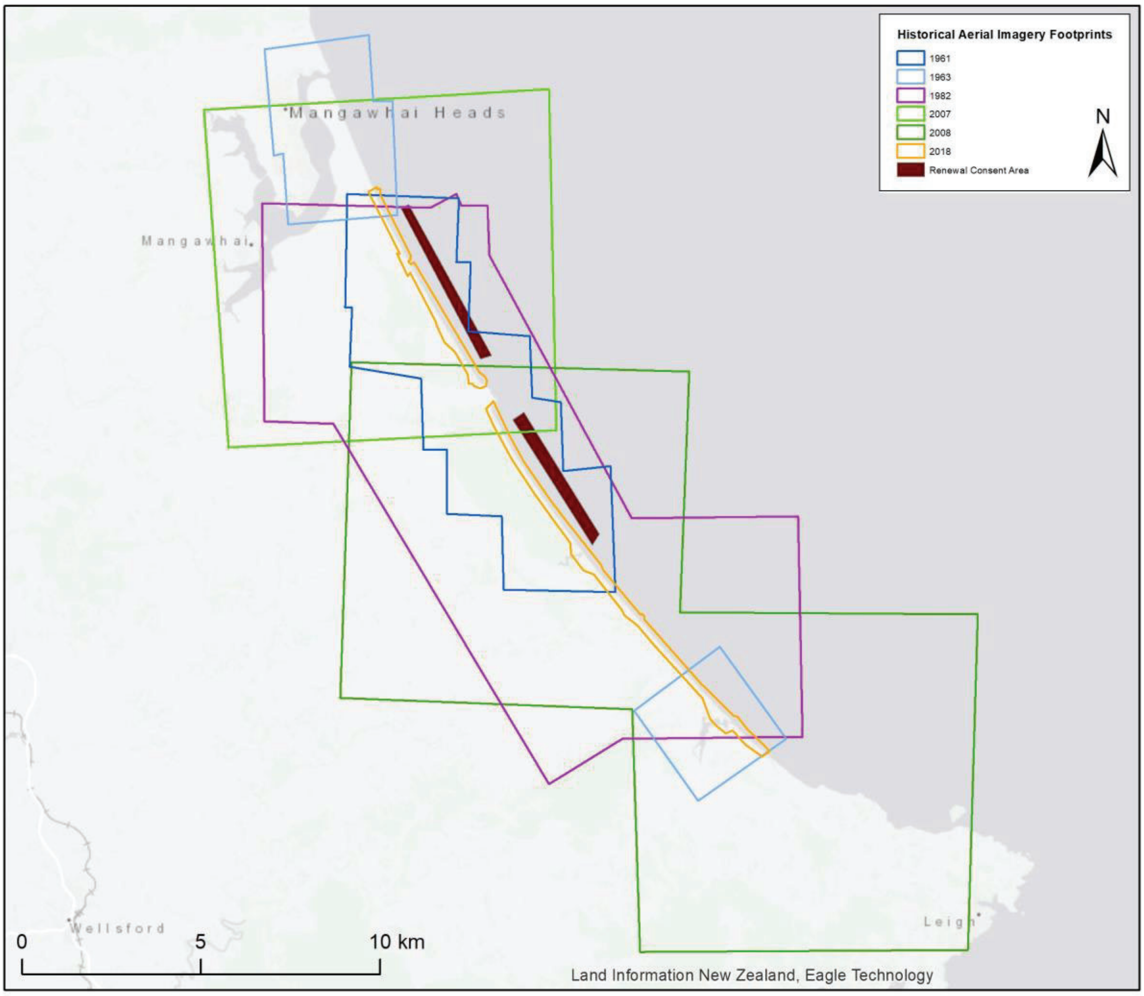

Figure 2.5: Coverage of aerial imagery used in the Digital Shoreline Analysis System

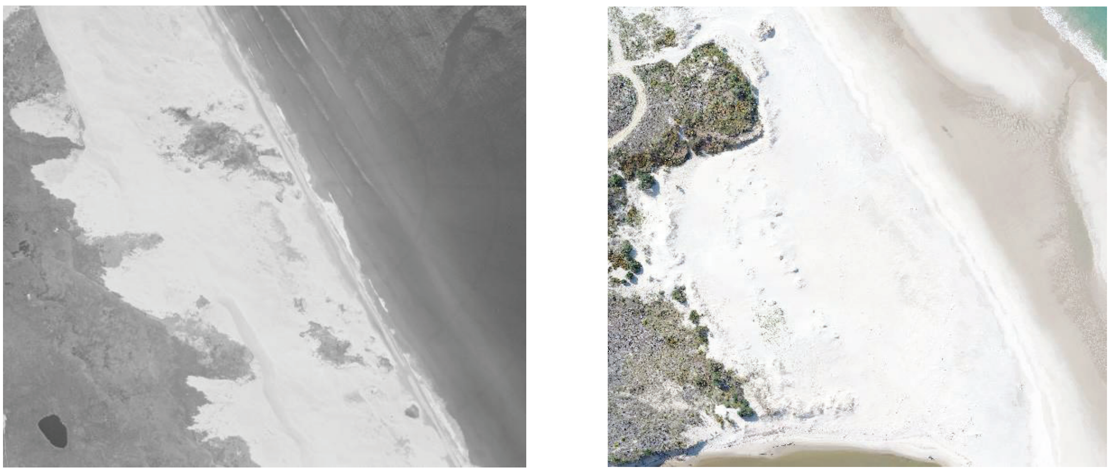

Figure 2.6: Examples of poor aerial imagery quality; a) 1963 black and white image, b) 2018 over-exposed image.

2.4.3 Sediment Budget

The sediment budget for the Mangawhai-Pakiri embayment, particularly around the potential supply to the inner shoreface (e.g. consent area) depends on sand supply from a number of sources including from biogenic sources, from alongshore around Bream Tail, and cross shore from deeper water (diabathic transport). As part of this coastal process assessment, each of these sediment supply components of the budget were examined. A summary of the methods undertaken in each assessment are provided below.

Biogenic Sand Supply

A biogenic sand production assessment was undertaken by Bioresearches Ltd (Bioresearches, 2019b), which is presented in **Appendix F**.

Cross shore sediment supply (diabathic transport)

The modelled metocean current and wave data, along with trench infill measurements were used to infer sediment transport across the previously accepted depth of closure of 27m below MSL within the Mangawhai-Pakiri embayment.

Longshore Sediment Supply – Bream Tail

Sediment samples, photographic surveys and diver observations have been undertaken to investigate sediment transport around this headland to the Mangawhai-Pakiri embayment.

3. Description of Coastal Process Environment

3.1 General Geomorphology

It is important to understand the general geomorphology of the Mangawhai-Pakiri embayment to put the long-term sand extraction activity into context of the whole coastal process environment. As stated in the MPSS Final Module 6 report (Hume et al. 1999), the Mangawhai-Pakiri sand body is a wedge of sediment comprising the dunes, beach and seabed sands extending seaward to about the 40-m depth as shown in Figure 3.1. It should be noted that reference to water depths are from LAT (same as CD) and should be taken as approximate boundaries between morphological features rather than absolute boundary locations.

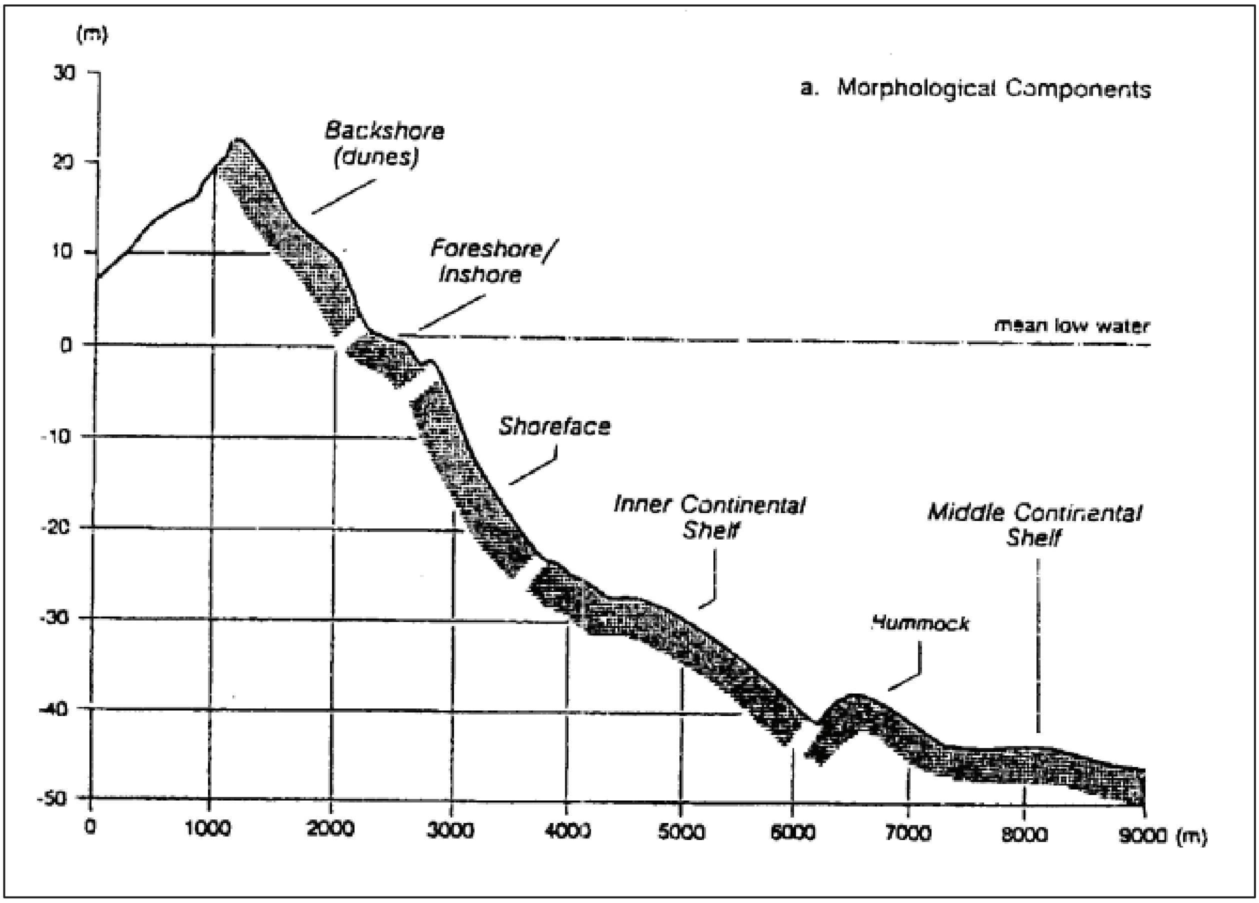

Figure 3.1: Morphological components of the Mangawhai-Pakiri embayment after Hilton (1990, p65)

The sand body is primarily made up of recent modern Holocene quartz-feldspathic sands with a portion of calcareous material from local shell production, that overlie older iron-stained consolidated Pleistocene sediments. The volume of this Holocene sand within the Mangawhai-Pakiri dunes, beach and mantling the seabed to the 40 m depth was estimated in the MPSS as being in the range 174-694 million m^3, of which 82-142 million m^3 was estimated to be located offshore with 85% of this (e.g. 70-120 million m^3) being located on the shoreface at water depths less than approximately 25 m CD.

Geologically the source of the Mangawhai-Pakiri sand is considered to be from the ancestral Waikato River, flowing east into the Hauraki Gulf during periods of considerably lower sea level (e.g. approximately 120 m lower than present) during Pleistocene glaciation periods, and then being “combed-up’ by wave action during the Holocene sea level transgression (up to 6500 years ago) to infill the Mangawhai-Pakiri embayment. The MPSS estimated that over the last 6,000 years of Holocene relatively stable sea levels, the shoreline of the Mangawhai-Pakiri embayment prograded (e.g. built seaward) by 150-200 m at the most (Hume at. el. 1999).

In more recent times (i.e. since the 1920's), which include sand extraction activities over the total period, Hume et al. (1999) reported that the MPSS found that the shoreline position as referenced by the HWM (High Water Mark) had fluctuated back and forth by up to 40 m with no fixed trend or pattern, and that the movements of the dune vegetation/toe line were less than 10 m over the same period. Similarly, over the 20 years from 1978 to 1997, beach profiles show that shoreline position and sand storage fluctuated primarily in response to wave events with substantial swapping of sand between the foredune-beach – nearshore being possible (Hume et al. 1999). Further analysis of historic and recent shoreline movements since the MPSS is presented in section 3.5.

3.2 Seabed Bathymetry

3.2.1 From Literature Review

Module 3 of the MPSS (Hume et al., 1998, p11) reported that the RNZN[5] conducted intensive hydrographic surveys of the offshore region of the embayment over the 1962-1964 period, with the fairsheet data being the source from which the hydrographic charts (NZ52 and NZ522) were prepared in the 1970's. Although these hydrographic charts were updated by LINZ in 1992, the data for the Mangawhai-Pakiri embayment continues to be from these 1960's surveys.

3.2.2 2019 Bathymetry

The current bathymetric maps of the shoreface as determined from hydrographic surveys in March and October 2019 are presented in **Appendix G**. As noted in Section 2.3.1, the contours are in terms of metres below MSL, rather than water depths below CD (i.e. LAT) as in the LINZ hydrographic charts. As shown on the maps in Appendix G, the 2019 bathymetric surveys undertaken with multibeam sonar did not include the area shallower than -5 m MSL due to vessel draft constraints, hence do not include the nearshore bar in the coverage. Also included in Appendix G are the beach and offshore profiles from the 2019 survey for each of the historical profile positions referred to above, with the section of missing nearshore profile being shown as a dashed surface, but not including any interpolation of the nearshore bar profile. The position of the existing MBL inshore extraction area is shown on the profiles that pass through the extraction area (e.g. P2, P2B, P3, P4), which shows that the extraction area generally range from -6 to -8 m below MSL to -14 m to -16 m below MSL.

As can be seen from the maps in Appendix G, and the following Table (3.1) the shoreface bathymetry is generally similar along the length of the embayment, with very little longshore variation in seabed slope from the -5 m to the -20 m MSL contour, with slopes generally in the range 1:40 to 1:50. Seaward of the -20 m MSL contour the seabed is considerably flatter out to the limit of the survey, which ranges from the -25 m to -30 m MSL contour, with slopes generally in the order of 1:90 to 1:110.

Three yearly hydrographic surveys of the same profiles between 2004 and 2019 (e.g. 2004, 2007, 2010, 2013, 2016, 2019) are presented in Section 4.2.1 for the assessment of effects of the current extraction activity on seabed levels.

Table 3.1: Seabed Slopes from 2019 bathymetric survey

Profile	Seabed slope -5 m to -20 m (MSL) contour	Seabed slope <-20 m (MSL) contour
P1	1:52	1:102 (To -27m contour)
P2	1:46	1:109 (to -29m contour)
P2b	1:51	1:108 (to -28m contour)
P2a	1:51	1:104 (To -30m contour)
P3	1:49	1:106 (To -30m contour)
P4	1:41	1:126 (To -28m contour)
P5	1:44	1:110 (To -30m contour)

[5] Royal New Zealand Navy

P6	1:49	1:96 (To -26m contour)
P7	1:48	1:87 (To -23m contour)

3.2.3 Inshore Trench Exposure Durations

As described in Section 2.3.5, a series of trench infill measurements were undertaken for a number of trenches located in the MBL inshore consent area (locations Figure 2.3) to assess the rate of infill and the duration before the disturbance on the seabed is no longer evident. One of the purposes of this work was to determine whether dredging might have localised long term effects on the contour of the seabed. The results of this assessment are presented in Tale 3.2.

Table 3.2: Extraction Trench Infill Rates and Durations in the MBL Extraction Area

Trench	Start Date	Final Obs date	Days to infill	Infill Rate (m^3/m/day)	Notes
Trench A 10 m	30/10/2018	13/11/2018	14	0.0083	Track almost gone by 13/11 following first reasonable swell after a prolonged period of calm. There was a lot of movement on the bottom with layer of sand moving in line with the swell.
Trench B 10 m	28/11/2018	7/12/2018	9	0.0128	No sign of this track on 7/12. Quite a strong surge and a lot of sand moving over the bottom at time of observation.
Trench C 10 m	2/04/2019	16/04/2019	14	0.0083	No sign of track on 16/4. Reasonable surge due to the swell at time of observation with some larger ripple bedforms 200 mm wide and 30 – 40 mm deep present suggesting that conditions prior to arrival sufficient for large scale sediment transport.
Trench E 10 m	28/11/2019	15/12/2019	17	0.0068	Depressions present along the old track on the 5/12, but could not be certain whether this is from extraction or wave activity. Based on the swell surge anything left of the track would have been gone by the next day
Note: Volume to infill trench: 0.12 m^3/m. Trench D not included as only one observation was taken the day after it was dredged.					

It is noted that there were also other observations when dives were made 1-2 days following extraction, and trenches were not found due to being totally infilled.

These results show that extraction trenches within the MBL inshore extraction area in water depths between -6 m and -16 m MSL infill rapidly, sometimes in a matter of days, and generally less than two weeks. This emphasises the substantial rates of sand transport occurring between the beach/dunes and the nearshore under most conditions, driven by waves and wave driven currents.

These results show that the shallow extraction trenches are short lived, and by spacing out the interval between re-dredging the same track the formation of permanent trenches, holes or pits which could alter wave patterns approaching the nearshore bar and beaches will not occur.

3.3 Surficial Seabed Sediment Characteristics

3.3.1 From Literature Review

Information on the surficial seabed sediment size distribution and bedform micro-topography of the Mangawhai-Pakiri embayment has been presented by McCabe (1985), Hilton (1990), Module 2 of the MPSS (Healy et al. 1996), and Riddle (2000) from a combination of sampling and sidescan sonar surveys. There is a reasonable consistency between the data obtained in each of the studies, with the following general patterns being found:

- Foreshore sediments comprise of well to moderately sorted medium sands (mean grain size (mgs)) 0.44 – 0.27 mm),
- Nearshore sediments (0-15 m water depths) are very well sorted fine sands (mgs 0.25 mm) which get finer as water depth approaches 15 m,
- Medium to coarse sands (mgs 0.71-1.0mm) are found on the inner continental shelf, which end abruptly at water depths of around 40 m,
- Very coarse sands (mgs >1 mm) containing granules and pebbles are found around the 40 m water depth,
- Muddy fine sands (mgs 0.18 mm) with mud content of 10-15% are found on the middle continental shelf (e.g. depths > 40 m).

Sediment cores taken from south of Te Arai Point during the MPSS showed that the thickness of Holocene sand on the foreshore and nearshore to around the -6 m contour generally ranged from 2 m to 8 m, and from 0.1 m to 2 m seaward to around the -40 m (CD) contour.

3.3.2 2019 Sediment Sampling Results

The sediment size distributions along with the mean gain size (mgs) and sorting classification of the 121 sediment samples taken by MBL in March 2019 are presented in **Appendix H** for contour bands of 0 to -15 m (MSL), -15 to -25 m (MSL) and > -25 m below MSL. The spatial distribution of the mgs from these samples along with an additional 300 samples presented in Bioresearches (2017) for the shoreface from between the -30 m and -45 m contour are also presented in **Appendix H**. The resulting sediment size distributions are similar to those presented above from the literature and can be summarised as follows:

- 0 m to -15 m contour (27 MBL samples), which includes the MBL extraction consent renewal area: Very well sorted Fine to Medium sand with sample mgs in the range 0.22 mm to 0.48 mm and average mgs across all samples of 0.26 mm. The Fine sand samples are scattered along the embayment, with a small concentration in the vicinity of Te Arai Stream. No samples contained material finer than 0.075 mm, or had more than 5% coarser than 1.18 mm. The average medium grain size (D_{50}) was 0.25 mm. There does not appear to be any differences in the sediment size distributions between the extraction areas and the southern control area.

- -15 m to -25 m contour (49 MBL samples): Still a very well sorted sand but with a slightly coarser mgs of predominantly Medium sand (38 samples) with areas of fine sand off the mouths of Te Arai and Poutawa Streams (combined 11 samples). Across all samples in this contour band the mgs had a similar range (0.22 mm to 0.47 mm) but with a slightly higher average mgs of 0.32 mm. Again, no samples contained material finer than 0.075 mm, or had more than 5% coarser than 1.18 mm. The average medium grain size (D_{50}) was 0.33 mm.

- -25 m to -35 m contour (40 MBL samples): The MBL samples were predominantly very well sorted Medium sands (90% of samples), with the remainder being well sorted coarse sand mostly located off the Te Arai Point headland. Across all samples in this contour band the mgs had a range of 0.28 mm to 0.84 mm, with an average mgs of 0.46 mm. Again, no samples contained material finer than 0.075 mm, or had more than 5% coarser than 1.18 mm. The average medium grain size (D_{50}) was 0.43 mm. The samples presented by Bioresearches (2017) from this depth band tended to be coarse sand to the north of Te Arai Point, fine sand offshore of the southern extraction area, and a combination of both size classes in the southern control area.

- -35 m to -45 m contour: The Bioresearches (2017) samples from this contour band predominantly had mgs in the Coarse sand class.

From MBL sampling of extraction sand as part of the concrete industry quality control, the carbonate content of samples from both the MBL inshore and the KL offshore consent is in the range of 2-5%, the same as determined by Hilton (1990).

3.3.3 2019 Bedform Micro-topography

Images from the seabed photograph transects within the proposed renewal consent area and descriptions of the micro-topography are presented in Bioresearches (2019a), which summarised the bedform patterns as follows:

- fine sand with irregular small or no ripples inshore of the MBL sand extraction areas,
- increasing sand size with shell debris and ripple size with depth, across the MBL extraction area,
- larger ripples but low or flat shape in the area seaward of the MBL extraction area.

Examples of the images with ripples from the consent renewal area at depths 9-10 m are presented in Figure 3.2 a & b.

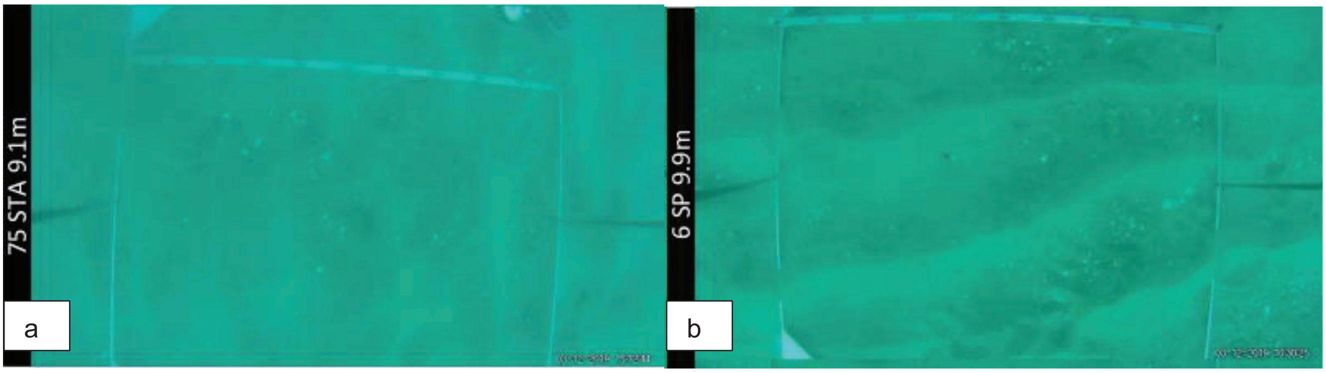

Figure 3.2: Images of sand ripple bedforms: a) South Te Arai Transect at 9.1 m depth; b) South Pakiri Transect at 9.9 m depth,

Large sand ripples were also found by divers in greater water depths of 26 -31 m when undertaking the trench infill measurements. These ripples had amplitudes in the order 50mm and wave lengths in the order of 250 mm. Images of these ripples are shown in Figure 3.3.

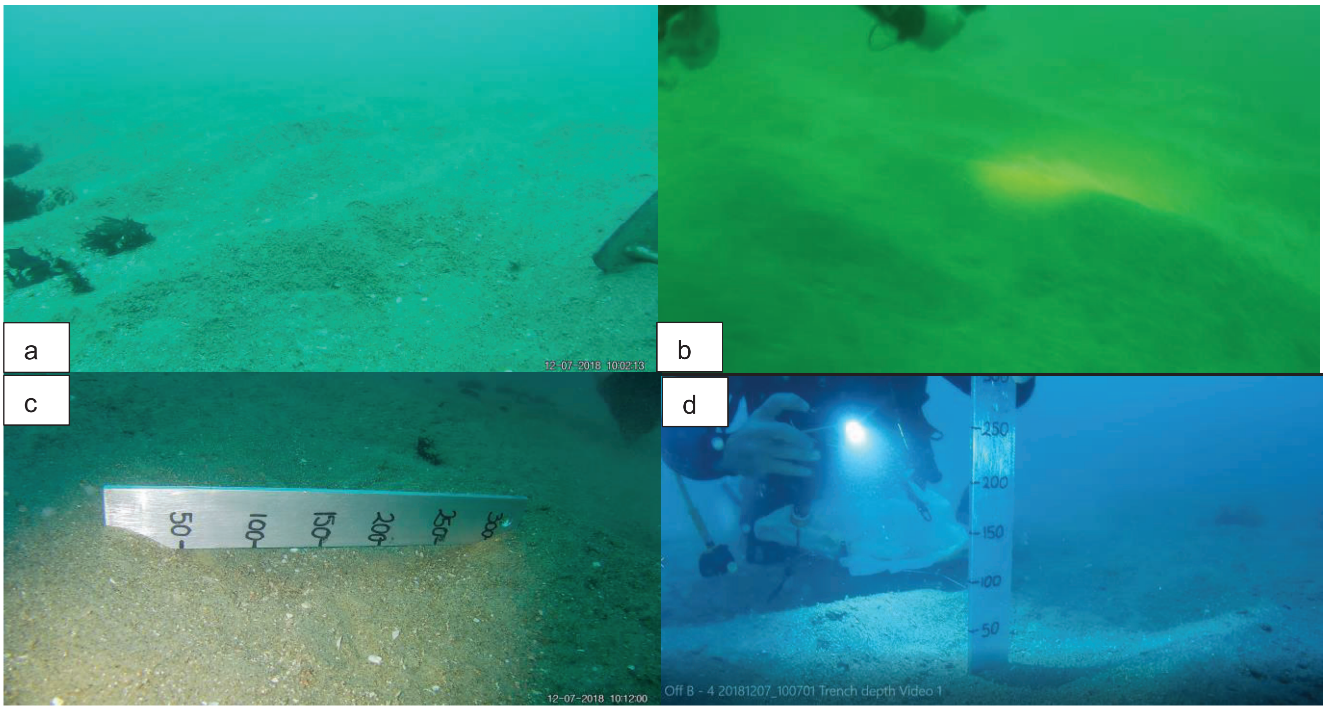

Figure 3.3: Images of sand ripple bedforms in water depths greater than 25 m: a) 26-27 m water depth adjacent to trench infill B; b) 31 m water depth adjacent to trench infill C; c) wave length of ripples in 26-27 m water depth; d) amplitude of ripples in 26-27 m water depth

The limited interpretation of backscatter mosaics from the multi-beam surveys appeared to confirm the findings of the MPSS side scan sonar that fingers of fine sand overlay shore-normal bands of coarser sediment in water depths approaching 25 m CD as shown in Figure 3.4.

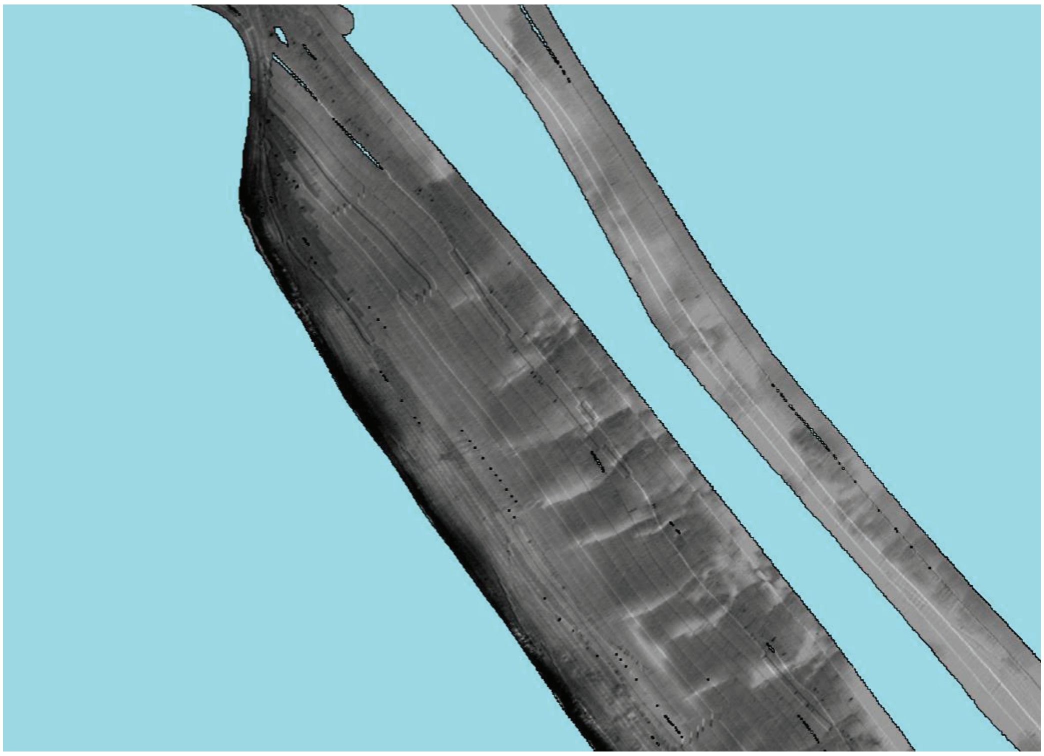

Figure 3.4: Backscatter mosaic from multibeam survey south of Te Arai Point showing fingers of fine sand overlaying shore-normal bands of coarser sand.

3.4 Wave and Currents

3.4.1 Waves

3.4.1.1 From Literature Review

The MPSS (Module 4; Bell et at. 1997) reports the wave climate recorded by a directional wave buoy located in 35 m water depth off Mangawhai for an 18-month period from March 1995 to August 1996 as part of the investigations programme. It is noted that this is a relatively short data set that may not be representative of the long-term wave climate.

3.4.1.2 Modelled Mangawhai-Pakiri Waves 1979-2018

Tables of the monthly and annual summaries of the 40 years (1979-2018) modelled three-hourly directional wave data for locations P1 and P2 in Mangawhai-Pakiri embayment (see Figure 2.4 for location) are presented in MetOcean Solutions (2019, chapter 4 – p58-99), which is reproduced in **Appendix E**. The direction and height wave roses for P1 and P2 are reproduced in Figure 3.5. The modelled wave climate can be summarised as follows:

- Modelled significant wave Height (H_s) statistics were very similar at P1 and P2, indicating a very similar wave climate on either side of Te Arai Point. The modelled mean H_s at both sites was of 0.93 m, being 0.2 m higher than recorded at similar location and depth as P1 in the MPSS. However, maximum modelled H_s over the 40 years hindcast (6.37 m at P1, 6.31 m at P2) was significantly less than the 8.06 m recorded in the MPSS.

- The modelled H_s was less than 1 m for 67% of the 40-year period, exceeded 2 m 6% of the time, and 3 m 1.3% of the time. This distribution had more larger waves than reported over the 18-month period recorded in the MPSS.

- The modal peak wave period (T_p) was 8-10 seconds (38%), with 75% of waves having T_p in the range 6-12 seconds. This was a similar range of peak periods as recorded in the MPSS.

- On an 8-point compass, the majority of waves (66%) arrived from a NE direction (22.5-67.5^0), with a further 20% arriving from the East (67.5. -112.5^0). This is a similar directional window as recorded in the MPSS. It is noted that the predominant NE wave approach would produce southerly sediment transport in the surf zone due to the beach orientation being ENE, particularly for the shoreline north of Te Arai Point.

- Winter and summer wave distributions were very similar having the same mean H_s (0.97 m), but with winter having slightly more higher waves (1 percentile Hs = 3.65 m compared to 2.85 m in summer).

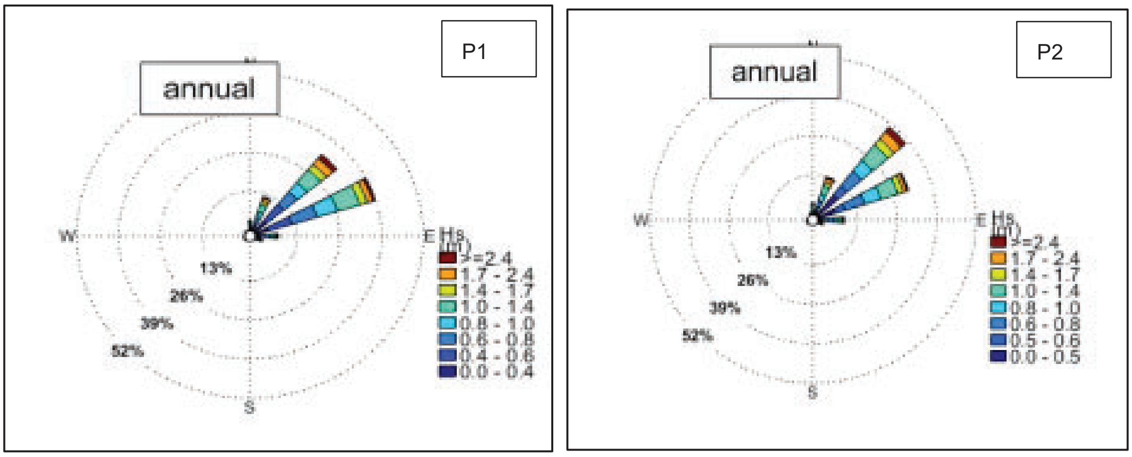

Figure 3.5: Wave direction-height roses for sites P1 and P2 from modelling of wave climate 1979-2018. Source MetOcean Solutions (2019)

From the distribution of wave periods over the 40-year wave record, it was calculated that for around 80% of the waves (e.g. those with T_p>6 sec) the wave motion would have penetrated to the seabed at the 30 m depth. Maximum orbital velocities within these waves were calculated[6] to be up to 0.5 m/s (for H_s >5 m & T_p ≥12 seconds), which were higher than reported in the MPSS for similar depths. However, the orbital velocities were only sufficient to entrain the sand grain size found at this depth for around 10% of the time, which was a similar result to what was found from the MPSS modelling.

3.4.1.3 Recorded Marsden Point Waves 2007-2019

Hourly time series of wave data from the Northport Marsden Point wave buoys located at the northern end of Bream Bay (location 26 km north of MBL extraction area as shown in Figure 2.4) have been used since 2007 to provide indicative metocean conditions for the interpretation of six monthly shoreline changes recorded by the MBL beach monitoring surveys required under the current consent conditions. Although it is recognised that this data is not likely to be representative of wave direction within the Mangawhai-Pakiri embayment, it was the only time series data set available and considered to be indicative of wave heights and periods in the embayment.

[6] Orbital velocities calculated by the Soulsby Exponential Approximation from Soulsby (2006)

The summary wave statistics from the 12 years of time series data are presented in Table 3.3 and Figure 3.6 to 3.8, with the key points and comparison with the modelled wave climate at Mangawhai-Pakiri being as follows:

- The mean significant wave height (H_s) over the 12-year record was 0.74 m, which is 0.2 m lower than the 40-year modelled record from the Mangawhai-Pakiri embayment.
- The recorded H_s was less than 1 m for 78% of the 12-year period, exceeded 2 m 3% of the time, and 3 m 0.5% of the time. This indicates less frequency of large waves than the modelled record, reflected in the Marsden recorded 1 percentile H_s being 2.59 m compared to 3.14 m for the Mangawhai-Pakiri modelled data.
- The maximum recorded H_s of 6.37 m (8/7/2014) was the same as the maximum modelled H_s at P1, however although they both occurred in July, it is unknown whether they were from the same event.
- The average mean wave period (T_m) was 6.13 seconds, with the highest frequencies being in the 4-7 second range, 90% being less than 9.1 seconds, and only 1% being greater than 11.5 seconds (see Figure 3.7). This distribution is not directly comparable to the modelled record which recorded peak wave period (T_p).
- On an 8-point compass, the majority of waves (65%) arrived from an East approach direction (67.5. - 112.5^0), and 81 % from between NE to SE directions (22.5 – 157.5^0). When broken into a 16-point compass, the modal wave approach directions are from the East (42%) and ENE (21%) (See Figure 3.8). This recorded approach window at Marsden Point is further East than the modelled Mangawhai-Pakiri data, probably due to the blocking effect of Bream Head on northerly waves at Marsden Point, and the reduced blocking effect of Great Barrier Island on easterly waves.
- Winter and summer wave distributions were very similar having the same mean H_s (0.74 m), but with winter having slightly more higher waves (3.9% > 2 m compared to 2.5% in summer), more slightly longer wave periods (1 percentile Tm = 11.80 seconds in winter compared to 11 seconds in summer), and slightly less waves from ENE-East directions (60% in winter compared to 66% in summer). This was a similar result to the modelled wave data for Mangawhai -Pakiri.

Table 3.3: Summary wave statistics from Northport wave buoys at Marsden Point January 2007 to March 2019.

Parameter	Total Record 2007-2019	Winter Record	Summer Record
Max Significant Wave Height (Max Hs)	6.37 m	6.37 m	5.45 m
Mean Significant Wave Height (mean Hs)	0.74 m	0.74 m	0.74 m
Median Significant Wave Height (median Hs)	0.58 m	0.56 m	0.60 m
1 percentile Hs	2.59 m	2.76 m	2.45 m
0.1percentile Hs	4.15 m	4.85 m	3.45 m
% Hs ≤ 1m	78.4%	77.6%	79.2%
% Hs > 2 m	3.2%	3.9%	2.5%
% Hs > 3 m	0.5%	0.7%	0.2%
Average Mean Wave Period (mean Tm)	6.13 sec	6.16 sec	6.10 sec
Median Mean Wave Period (median Tm)	6.0 sec	5.9 sec	6.0 sec
10 percentile Tm	9.1 sec	9.3 sec	8.8 sec
1 percentile Tm	11.5 sec	11.8 sec	11.0 sec

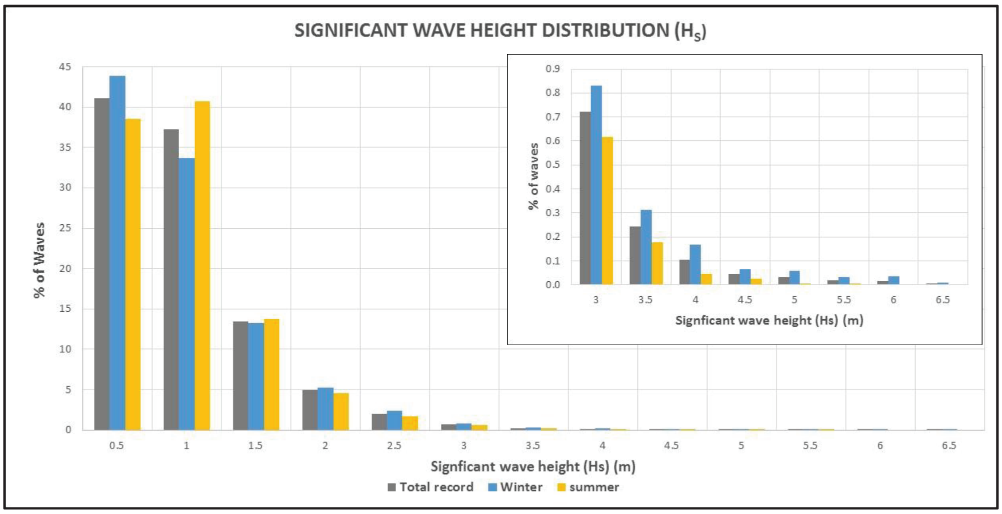

Figure 3.6: Significant wave height (Hs) distribution from Marsden Point wave buoys 2007-2019.

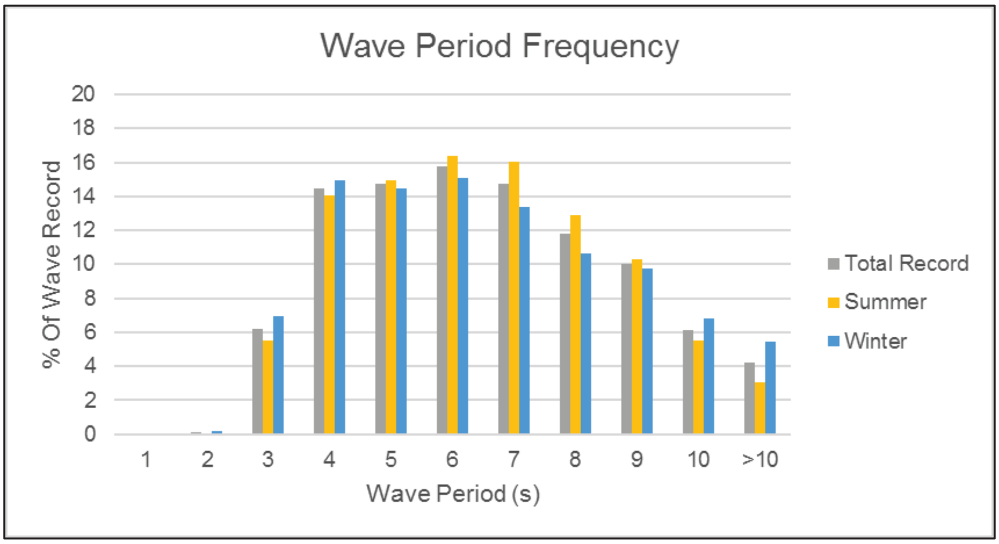

Figure 3.7: Mean wave period (Tm) distribution from Marsden Point wave buoys 2007-2019.

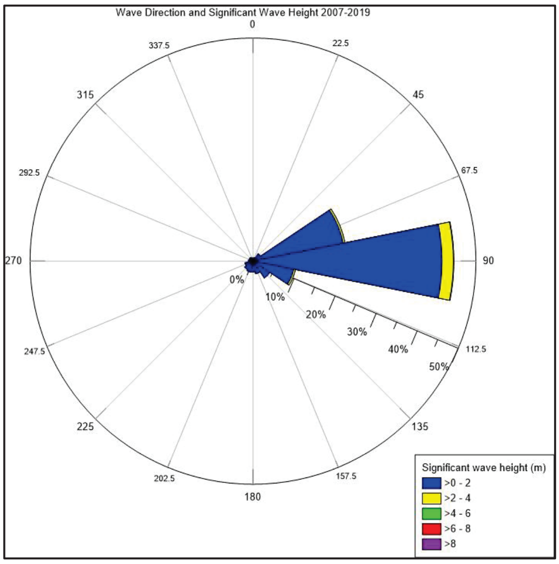

Figure 3.8: Wave direction distribution from Marsden Point wave buoys 2007-2019.

From the above comparisons, it is considered that the Marsden Point recorded wave data provides a good approximation of the wave heights in the Mangawhai-Pakiri embayment, however wave directions are more easterly than experienced in the embayment.

3.4.1.4 Marsden Point Storm Events 2007-2019

For the purpose of this analysis, storm events have been defined as periods when H_s exceeded the 1 percentile H_s of 2.59 m (total record) for longer than 3 consecutive hours. Applying this criteria, 57 storm events occurred over the 12-year recording period. The dates and wave conditions in each of these events are also presented in **Appendix I**. The majority of these storm events (44) were from an east direction window (78^0 to 101^0), with the remainder being from ESE or ENE directions. However, as discussed in section 3.4.1.2, a number of these storms are likely to have a more northerly approach within the Mangawhai-Pakiri embayment.

Storm events were generally of a short duration, with only 11 storms having durations of longer than 24 hours, and the maximum duration being 89 hours (July 2014). The event in July 2014 also had the largest wave height on record, with maximum Hs of 6.37 m and a Tm of 10.8 seconds. The only other storm with maximum H_s greater than 6 m was in July 2009, with a duration of 35 hours and a Tm of 10.3 seconds. A further four events had significant wave heights greater than 5 m. However, one of these events was 10 July 2007 (max H_s = 5.76 m, duration 15 hrs), in which the wave buoy suffered a power failure for four days from the 10th July, and is unlikely to have recorded the total storm duration or largest wave height. Other records[7] note that the event occurred in association with a severe wind event in which gusts of 180 km/hr were reported offshore north of Auckland, and the largest beach erosion recorded by the consent monitoring since 2007 occurred in the 6-month period containing this storm. Therefore it is considered that this event was much more significant than indicated by the wave buoy records.

In terms of monthly distribution, the highest frequency of storms occurred in March, June and July (8-9 storms over the 12-year record), with the least being in October and November (nil to one storm).

In terms of seasonality, more storms (35) occurred in the winter six months from April to September, than in the summer (22) from October to March, with winter storms generally had larger wave heights and longer durations. The greatest number of storms in one winter was five, occurring in four different years (2007, 2011,2012 & 2014), and the greatest number of summer storms (three) occurred in 2008, 2012, and 2014. In terms of annual distribution, the greatest number of storm events occurred in 2012 and 2014 (eight events), with 2007 having seven events. The least number of storms occurred in 2015 with one event, and 2010 with two events.

3.4.2 Currents

3.4.2.1 From Literature Review

Module 4 of the MPSS reports the findings from the deployment of six current meters over a two-month period (Oct-Dec 1995) as part of the investigations programme, which were used for the calibration and verification of a numerical hydrodynamic model of current patterns within the embayment. Four of the six current meters were deployed at two different locations along the P1 profile at Mangawhai Beach, with three being at different depths (10 m, 3 m & 1 m above seabed) at the Offshore Reference Station (ORS) located 800 m offshore (water depth 15 m) and the fourth at approximately 1 m from the seabed at the Inshore Reference Station (IRS – 300m offshore in 6.5 m water depth). The remaining two current meters were deployed at the two headlands, Bream Tail and Cape Rodney at either end of the embayment.

The resulting basic statistical parameters of the current speed distributions for the six deployments is re-produced in Table 3.4.

[7] GNS/NIWA, Natural Hazards 2007)

Table 3.4: Current speed statistics from MPSS current meter deployments Oct-Dec 1995 (Bell et al 1997, Table 4.4 p25)

Parameter	Bream Tail	Cape Rodney	IRS	ORS-1m	ORS-3m	ORS-10m
Median (cm/s)	5.3	23	4	6.1	6.5	11.3
90-percentile (cm/s)	12.6	42	10	9.8	14.8	22.6
Maximum (cm/s)	31	69	100	27	33	41

Although the distribution of current speeds was greatly skewed towards low current speeds, it is noted that the recording period did not include the two largest wave events discussed above (January and June 1996). However, during a storm event on 24-25 Nov1995 the 1-minute average current speeds reached 100 cm/s at IRS. It is also noticeable that current velocities at ORS increased with height from the seabed, being double at 10 m height than those at 1 m height.

3.4.2.2 Modelled Mangawhai-Pakiri Currents 2000-2018

Tables of the summaries of the 19 years (2000-2018) modelled three-hourly current data for sites P1 and P2 in 29 & 32 m (MSL) water depth respectively in the Mangawhai-Pakiri embayment (see Figure 2.4 for location) are presented in MetOcean Solutions (2019, Chapter 5 – p100-114), which is reproduced in **Appendix E**. In relation to the sand extraction activity the key currents are those near the seabed which have the potential to influence sediment transport. Direction roses for the near-bottom non-tidal currents are presented in Figure 3.9 and the depth averaged tidal currents in Figure 3.10.

The results indicate that both non-tidal and tidal currents have similar speed distributions at P1 and P2, but with a slight difference in the dominant directions of the non-tidal currents. While only about 5% of these near bed currents at 30 m water depth have sufficient speed to entrain fine sand (from sampling 15% of sediment at this depth) and only 2% have sufficient speed to entrain medium sand (from sampling 70% of sediment at this depth), the current velocities are sufficient to transport this sand for around 50% of the time if it has already been entrained by wave currents. Although the currents at both sites are bi-directional, as shown by the inclusion of the shoreline orientation on the directional roses, the near bed currents around the 30 m contour are net onshore (56% of the time at P1 to the north of Te Arai Point, and 54% of the time on the P2 to the south of the Te Arai headland).

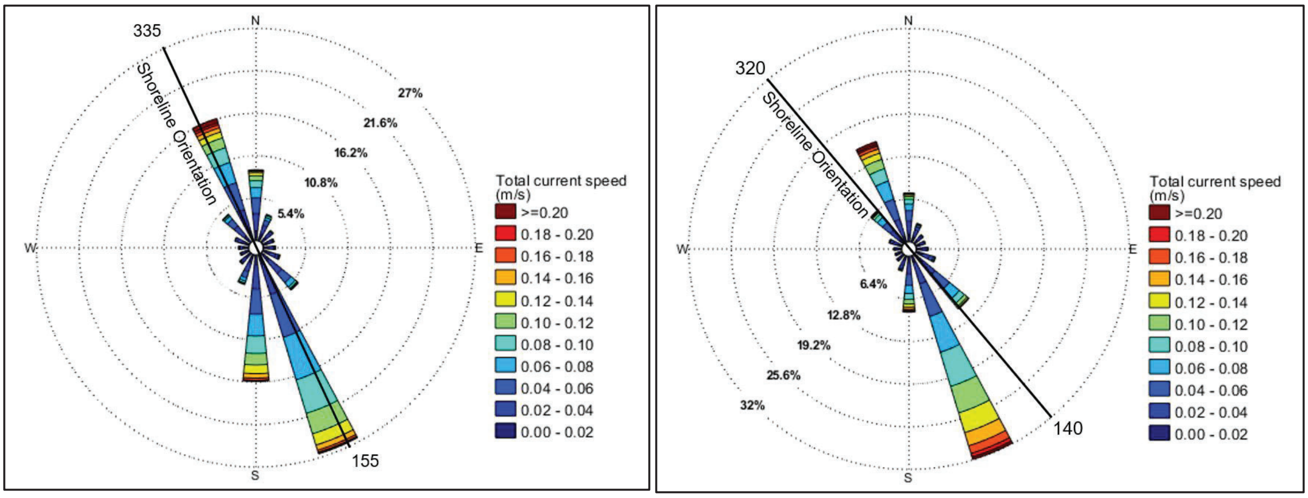

Figure 3.9: Modelled near bed non tidal current directional roses over 19 years (2000-2018) for a) P1 and b) P2. Source MetOcean Solutions (2019)

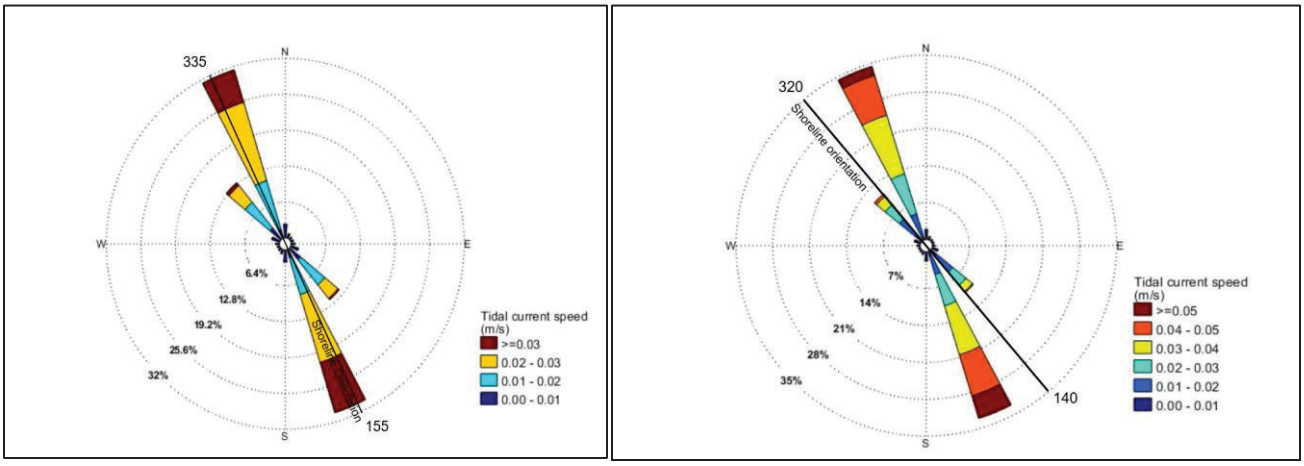

Figure 3.10: Modelled depth averaged tidal current directional roses over 19-years (2000-2018) for a) P1 and b) P2. Source MetOcean Solutions (2019)

For tidal currents, the modelled results were similar to those presented in the MPSS, being pre-dominantly along the coast at low velocities and net current being near zero. These tidal currents are insufficient to initiate sand transport on the sea bed and are likely to provide little additional assistance to the transport of sand already entrained.

The modelled data indicates higher non-tidal current velocities in greater water depths, (e.g. max and 10 percentile near bottom velocities modelled at 30 m depth of 0.5 m/s and 0.11 m/s respectively.

3.4.3 Hydrodynamic Modelling Results

Module 5 of the MPSS (Black et al, 1998) presents the results of using long-term tide, and wind data from Mokohinau Island (1961-84) to numerically model water circulation and sediment transport processes at embayment and regional scales, with the field data on waves and currents being used to calibrate and verify the modelling results. The models used were the wave refraction and sediment suspension model WBEND, and the hydrodynamic model 3DD.

The resulting vector diagram of residual (net) depth averaged currents generated by wind and potential sediment pathways from modelling of wind averaged over 23-years of record is presented as Figure 3.11.

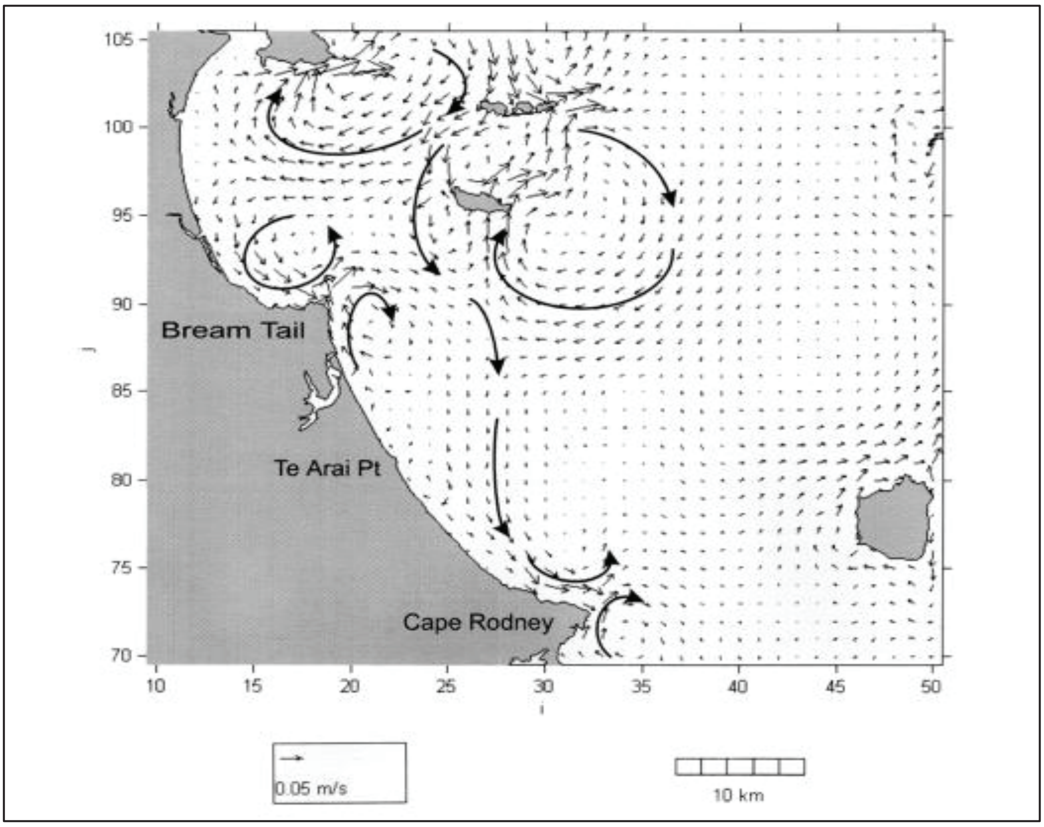

Figure 3.11: Vector diagram of residual (net) depth averaged currents generated by wind and potential sediment pathways from modelling of wind averaged over 23-years of record. Note faster currents have longer arrows. (From Hume et al. 1999)

3.5 Historical Shoreline Movements

3.5.1 From Literature Review

3.5.1.1 MPSS Reports

Module 1 of the MPSS (Nichol et al, 1996) presents the results of shoreline change analysis from cadastral plans dating back to 1856, but notes that the data coverage is patchy, with no single plan covering the entire study area and for some sections plans only date back to 1965.

In summarising the results of the shoreline change analysis, Hume et al. (1999) (MPSS Module 6) reported that since 1921 the shoreline position as referenced by the HWM (High Water Mark) had fluctuated back and forth by up to 40m with no fixed trend or pattern, and that the movements of the dune vegetation/toe line away from river and creek mouths were less than 10 m over the same period, suggesting the shoreline has been essentially stable during the period covered by historical records.

An analysis of beach position changes from the profile network established by the Auckland Regional Water Board following the severe erosion events in 1978 and surveyed regularly through to 1997 is presented in MPSS module 3 (Hume et al 1998), which showed that the shoreline is very dynamic, with the HWM (+2.0 m contour) fluctuating in position 10-60 m over short time periods (e.g. months -years), but with overall net change in position over 20 years in the order of <5 – 10 m and some sites showing progradation and others retreat.

3.5.1.2 Environment Court Decision 2006

In its decision, the Environment Court found that the evidence of shoreline movements within the embayment were not attributable to sand extraction.

3.5.2 Updated Analysis of Historical Shoreline Movements from Aerial Photographs

As outlined in Section 2.4.2, DSAS was used to calculate net shoreline change and linear regression rates of shoreline movements as defined by the vegetation line or dune toe position at 100 m spaced transects from four sets of aerial photograph imagery between the early 1960's and 2018 (e.g. 1961/63, 1982, 2007/08 and 2018) for the area north of the Pakiri River. The mapping of the shoreline positions at each of the imagery dates plus the spatial distribution of the linear regression rates of shoreline retreat are presented in **Appendix J** for each of the north and south extraction areas, and the southern control area.

As well as the total record, to investigate the influence of the 1978 storms and subsequent dune reconstruction activities, the record was divided into two-time frames, 1961/63 to 1982, and 1982 to 2018, except for the southern control area between P5 and P7, where the 1960's images were not available. The key points from the analysis are summarised as follows:

- For all areas the envelope of total shoreline movements were greater than the net movements, with the dune line position fluctuating between retreat and advance within different time periods in response to wind, waves and berm sand storage.
- The majority of the 121 transects (77%) with images covering the total record from 1961/63 to 2018 displayed net dune line advance with the average advance rate over all transects for the 50+ year period being +0.40 m/yr.
- Of the 28 transects with net retreat over the 50+ years, 21 (75%) were around the Poutawa Stream mouth therefore likely to be influenced by mouth channel migration along the shore, and a further 3 were immediately south of Te Arai Point, therefore influenced by headland processes.
- Within the combined extraction areas, 96% of the transects displayed net advance over the 50+ year period, with an average advance rate of +0.60 m/yr.
- Despite the dune reconstruction activities following the 1978 storms, the effect of the storms on dune retreat is shown by 60% of the transects displaying net erosion during the 1961/63-1982 period, including all transects south of transect 87 (between profile P3 & P4 in the southern extraction area). Understandably transects in the southern control area displayed the greatest retreat due to not being included in the dune re-construction activities, with an average retreat distance of -44 m for the available sites north of Pakiri River (transects 1-14) and south of Poutawa Stream (transects 50-57). However, for the most extensive dune re-construction areas north of Te Arai Point, 62% of the transects displayed net dune advance over this period, probably as a result of the re-construction activities, with an average advance rate of 0.33 m/yr over the whole northern extraction area (transects 110-165).
- For transects with images from 1982 to 2018 (total 155), only 15% (23 transects) displayed net erosion over this 36 year period, of which nine are located with 1 km immediately south of Te Arai Point (Transects 97-106 – north of P3 profile), an area which experienced up to 19 m of dune line retreat from 1996 to 2000, but has stabilised since (from profile P2A data), and a further six transects are located on either side of Poutawa stream (transects 55-60) and three on the north side of Te Arai Stream (transects 128-130) where dune retreat is influenced by stream mouth migration.
- Even including the above areas of localised retreat, since 1982, the dune line within the extraction areas have advanced by an average of 0.59 m/yr in the southern area and 1.40 m/yr in the northern area.

These updated results on historical shoreline movements over the last 50+ years show predominantly dune line advance over the majority of the Mangawhai-Pakiri embayment with isolated pockets of retreat that can generally be explained by coastal processes of river mouth migration and lee headland processes.

Further comparison of the historical shoreline movements within the extraction areas and the southern control area are presented in the assessment of effects section 4.3.1.

3.5.3 Updated Analysis of Beach Profiles 1978-2019

Longer-term **Appendix K** shows the beach cross sections at the 11 historical profile sites (Figure 2.1) at the following three times:

1. From the first survey at each profile by Auckland Regional Water Board (varies between 1978 to 2000),
2. Interpolated from the initial GPS survey in April 2007 under the existing resource consent
3. Interpolated from the most recent drone survey in March 2019 (except P9 as not included in drone survey, so most recent survey is March 2017).

For comparative purposes, **Appendix L** presents the recent 6 monthly profiles from September 2017 to March 2019 interpolated from the SurveyWorx drone surveys.

For the analysis of beach movements, the net changes in position of the 3.5 m contour, a proxy for the foredune toe position, and the 5.5 m contour, being representative of movements on the foredune face, over the whole survey record are presented in Table 3.5. Net changes in beach width (taken as distance between the 3.5 m and 1 m contour) and beach volume (volume above the 0 m contour from between the 3.5 m and 1 m contours) are also presented.

Table 3.5: Net beach contour movements and volume changes over the total survey record for historical beach profiles.

Profile	Period	Net Dune Face movements (5.5 m contour)	Net Beach Toe movements (3.5 m contour)	Net Beach Width change (3.5 m - 1 m contour)	Net Beach Volume change (3.5 m - 1 m contour)
P1	1978-2019	+3.3 m @0.08m/yr	+1.6 m @0.04m/yr	+38.8 m	+45.9 m^3/m
P2	1988-2019	+4.9 m @0.16m/yr	+1.1 m @0.04m/yr	+13.4 m	+3.4 m^3/m
P2B	1993-2019	+66.6 m @2.56m/yr	+50.5 m @1.94m/yr	-38.2 m	+15.2 m^3/m
P2A	1990-2019	+5.1 m @0.18m/yr	+7.0 m @0.24m/yr	-3.7 m	+16.3 m^3/m
P3	1981-2019	+27.5 m @0.73m/yr	+18.4 m @0.49m/yr	-6.1 m	+25.2 m^3/m
P4	1978-2019	+0.6 m @0.01m/yr	+5.3 m @0.13m/yr	+30.0 m	+44.4 m^3/m
P5	1978-2019	+8.2 m @0.20m/yr	+21.1 m @0.52m/yr	+38.3 m	+92.5 m^3/m
P6	1978-2019	+1.2 m @0.03m/yr	+4.1 m @0.08m/yr	+29.2 m	+49.8 m^3/m
P7	1978-2019	+12.2 m @0.30m/yr	+12.9 m @0.32m/yr	+24.1 m	+60.4 m^3/m
P8	1978-2019	+6.8 m @0.17m/yr	+10.9 m @0.27m/yr	+21.8 m	+65.2 m^3/m
P9	2000-2017	-10.6 m @ -0.62m/yr	-13.1 m @ -0.77m/yr	+6.1 m	+-21.5 m^3/m

Although the profiles display a range of beach and dune morphologies and are spread throughout the embayment in both the extraction and control areas; all sites except the southernmost site P9 displayed net dune face and beach toe advance and net foreshore volume growth over the last 35-40 years from the severely eroded dune and foreshore morphologies present post the 1978 storm events. The greatest dune advance was recorded at site P2B, located around 1 km north of Te Arai Point with advance in excess of 50 m since 1993 at rates around 2 m/yr. This rapid advance of the dune position has resulted in a near 40 m reduction in foreshore width at this site, but foreshore volumes have still experienced a net increase. The sites further north experienced the least net advance, with both P1 and P2 having dune toe advance rates of less 0.05 m/yr. Dune toe advance at sites south of Te Arai Point to the Pakiri River were variable, having toe advance rates between 0.1 m/yr and 0.5 m/yr. The erosion trend at the P9 site is considered to be influenced by the considerably different time period of analysis at this site (eg. not started till 2000 and not surveyed since April 2017).

Apart from site P2B, the only two sites to experience a net reduction in beach width were P2A and P3 to the south of Te Arai Point, but at distances less than the beach toe advance, hence the net movement of the 1m contour has kept pace or exceeded the beach toe advance. Correspondingly, all sites have experienced a net gain in foreshore volume. However accumulation rates appear to be lower than reported in the MPSS.

Due to the different start dates of the surveys for the profile sites and questions on the representativeness of the historical profiles for the total length of the embayment, no attempt has been made to calculate accumulated increase in beach volume storage from this material, such as presented in the MPSS. However, it is noted that all sites experienced a net volume increase over the total length of their respective survey records. In addition,

Further analysis of the profile sites and the total beach from the 6-monthly surveys since 2007 required under the current consent monitoring are presented under the assessment of effects (section 4.3.2).

3.6 Sediment Budget

A sediment budget approach involves quantifying inputs to and losses from a nearshore - beach system. So, a coastal compartment with fewer inputs than outputs will erode, and vice versa. In general, major gains to a nearshore – beach system is from longshore transport into the compartment, river supply, cliff erosion, and onshore transport across the inner continental shelf. Losses include longshore transport out of the system, wind transport landward of the beach and dunes, and for the Mangawhai-Pakiri embayment – sand extraction.

An important consideration related to a sediment budget is whether the nearshore - beach system is a “closed” or “open” sediment system, with the former being where embayed coastal compartments are disconnected and isolated from the adjoining compartments by headlands or offshore muds such that sediment transfers into and out of the compartments are very limited. Few systems are “closed” in the strict sense as most have inputs and outputs to and from one or more of the potential sources of sediment.

An important consideration for the Mangawhai-Pakiri embayment is the extent of diabathic (cross-shore transport) and related to where the depth of closure (i.e. depth at which sediment exchanges between the beach and nearshore due to wave action no longer occur) is located in relation to the sand extraction activities.

3.6.1 MPSS Sediment Budget

Module 6 of the MPSS (Hume et al 1999) presents a sediment budget for the Mangawhai-Pakiri embayment based on the investigations and information presented in the preceding modules. This sediment budget is re-produced in Figure 3.12 and the key points are explained below.

Total inputs to the sediment budget were estimated to range from 8,000 to 72,000 m^3/yr with a best estimate of 20,000 m^3/yr, while total losses were estimated at an average of 109,000 m^3/yr. Therefore, the sediment budget had a best estimate net deficit of 89,000 m^3/yr, with a possible range of 37,000 to 101,000 m^3/yr. Although it is recognised that the interpretation presented in Module 6 of MPSS supersedes that presented in the previous modules, it is noted that this net deficit is not consistent with the conclusion reached from the numerical modelling in Module 5 (Black et al., 1998) that the *“net inputs of new sand into the embayment are of the same order or less than the amount being mined each year”.*

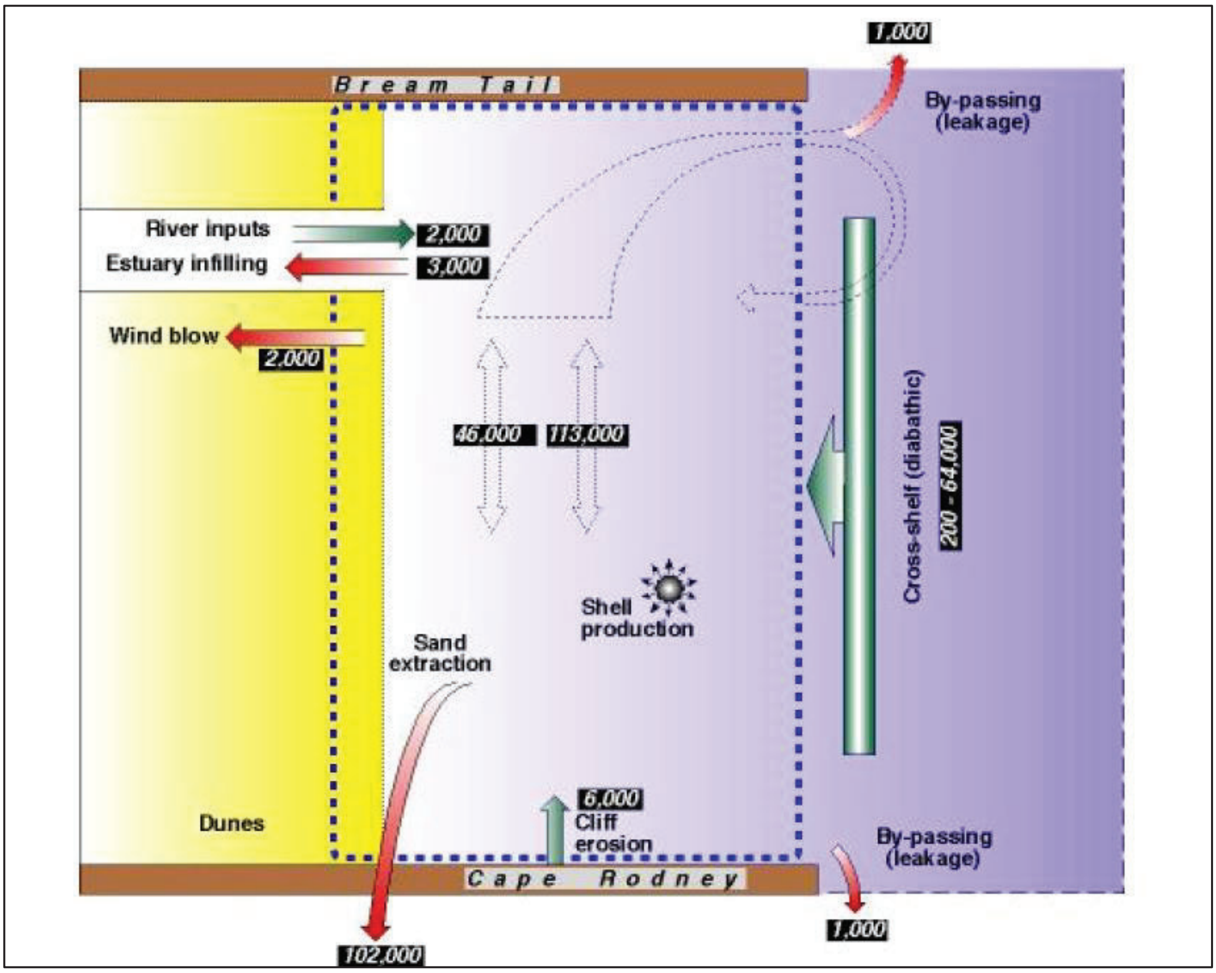

Figure 3.12: Sediment budget for Mangawhai-Pakiri embayment as presented in MPSS Module 6 (Hume et al 1999, Figure 3.3). Volumes are net figures in m³/yr.

3.6.2 Environment Court Decision 2006

In its 2006 Decision, the Environment Court, having heard extensive evidence disagreed with the conclusions in the MPSS and held that the embayment was in net sediment budget surplus, before sand extraction, of 144,000 m³/yr[8].

3.6.3 Updated Estimates of Sand Inputs

As part of the investigations programme for this consent renewal application, the following further assessment of sand inputs into the Mangawhai-Pakiri sediment budget have been undertaken.

3.6.3.1 Biogenic Sand Supply

As stated in section 2.4.3, this assessment was undertaken by Bioresearches Ltd (Bioresearches, 2019b), which is presented in **Appendix F**. This assessment was based on the fauna abundance data collected by Bioresearches in various local projects (listed in section 2.4.3), and fauna growth rate equations obtained from the international literature.

The results of the assessment were that the annual shell production within the embayment within an assumed closure depth of -27 m (MSL) (25 m CD) and assuming shell densities of 1.1 -1.4 t/m³ were in the range of 4,600 – 5,800 m³/yr when calculated using growth rate and 5,800 – 7,400 m³/yr when calculated by mortality size. The annual shell production in the -27 m to -32 m contour band (25-30 m CD) was also calculated, being

[8] Inputs of 150,000m3/yr, and losses excluding extraction of 6,000 m3/yr

in the range of 4,000 - 5,400 m^3/yr depending on the method used. Thus, the inclusion of this area in the biogenic sand budget of the Pakiri – Mangawhai embayment gives figures of approximately 8,800 to 12,400 m^3 of annual biogenic sand production for the area from the shoreline (0 m contour) to the -32 m contour. It is noted that the report states that it was not possible to provide an estimation of the error associated with the results produced.

The results obtained from the Bioresearches updated analysis of biological production indicates that 4,600 – 7,400 m^3/yr of biogenic sand production should be included in the sediment budget inputs for shell production within the -27 m MSL contour (25 CD), with an additional 4,000 - 5,400 m^3/yr being part of the cross-shore transport from the inner continental shelf.

3.6.3.2 Cross shore sediment supply from inner continental shelf

Assessing the potential cross-shore sediment supply involved the following three components to assess the diabathic sediment transport across the 25 m CD water depth (-27 m MSL contour):

a) Using the Metocean Solutions (2019) wave and current modelling to re-calculate the theoretical seabed sediment entrapment at the -30 m MSL contour;

b) Trench infill observations and measurements from the KL consent area in depths > 25 m CD; and

c) Presence of sand ripples

The results of these assessments are summarised below.

Theoretical seabed sediment entrainment at 30 m CD water depth

As reported in section 3.4.1.2, from the 40-year modelled wave climate, the orbital motion for around 80% of the waves (e.g. those with T_p>6 sec) would have penetrated to the seabed at the 30 m water depth. Maximum orbital velocities within these waves were calculated to be up to 0.5 m/s (for H_s >5 m & T_p ≥12 seconds. The orbital velocities were above the threshold velocity to entrain the sand grain sizes found at this depth for around 10% of the time and via the process known as "Bedload Creep" [9], there is potential for a net shoreward movement of entrained sand under wave action.

In addition, and as reported in section 3.4.2.2, for residual (i.e. non-tidal) near-bed currents the 40 year MOSL modelled data indicates current velocities in 30 m have the ability to entrain sediment sizes present at this depth 5% of the time (i.e. without wave currents), and to transport sand already entrained by waves 50% of the time. Figure 3.9 indicates that there is a small dominance of onshore transport in these current directions.

Trench infill observations and measurements in depths greater than 25 m CD

The basis of this assessment was to determine whether or not significant mobilisation of bed sediment occurs at water depths greater than 25 m CD.

The trench infill measurements from extraction trenches in water depths greater than 25 m CD are presented in Table 3.6 along with exceedance of waves and current above thresholds for sediment entrainment and observations from the divers taking the measurements. The wave and current data from a 3 hourly time series of modelled data at Mangawhai-Pakiri P1 site in 30 m of water depth provided by MOSL for the period from November 2018 to June 2019.

[9] "Bedload Creep" is the slow net movement of sediment in the direction of wave propagation caused by stronger orbital currents under the wave crests.

Table 3.6: Trench Infill results in water depths greater than 25 m

Trench	Total Observation period	No of Days	Max Hs (m)	Modelled % time exceed entrainment threshold		% time currents exceed transport threshold(1)	Infill Depth (mm)(2)	Infill volume (m^3/m/day)(3)	Diver Observations
				By waves	By currents				
>25 m A	30/10-13/11/2018	15	1.57	0	0	46.1	100	0.06	30/11: Surge from swell noticeable on the bottom and sediment moving (Hs=0.9 m, Tp=9.4 s)
>25 m B	19/11-7/12/2018	18	2.82	0	0	44.1	250	0.175	20/11: Surge from swell noticeable on the bottom (Hs=0.9-1 m, Tp=9 s) 7/12: Track largely non-existent after high event on 30/11 (max Hs=2.82 m, Tp= 7.2 s)
>25 m C	14/4-2/5/2019	35	1.01	0	1.4	28.9	200	0.14	Lot of shell present in area at time of final observation.
>25 m D(4)	27/11-5/12/2019	8	No data	No data	No data	No data	40(4)	0.06(4)	Track much shallower than Coastal Carrier

Notes: (1) Is theoretical % of time that currents in any direction could transport sand if it had already been entrained.
(2) Average trench depth from Coastal Carrier in this water depth is 300 mm.
(3) Average fill volume to totally infill trench from Coastal Carrier in this water depth is 0.21 m^3/m
(4) Trench extracted by William Fraser. Average Trench depth is 0.105mm and total infill volume is 0.115 m^3/m

The key points that can be made from the measurements and observations are summarised as follows:

- At no time during any of the observation periods were the combination of wave heights and periods above the theoretical critical threshold for entrainment of the seabed sand sediments. This includes a high energy event on 30/11 which essentially completely infilled the trench. This event did not reach storm status on the Marsden Point wave buoy data.
- Despite the lack of events theoretically capable of entraining sediment, infill occurred across all observation periods, indicating that transport from the adjacent seabed was occurring.
- This is supported by diver observations of sediment moving on the bed due to swell.
- The near-bed current modelling indicated that if sediment was already entrained (e.g, by waves or currents), the near-bed currents were of sufficient strength to transport sand for 30-45% of the time.
- While infill volumes were generally low, the results showed even in these water depths trenches could be totally infilled within a 1 – 2 month period without extreme storm events.

Presence of sand ripples

As shown in Figure 3.3, the photographs taken during the trench infill measurements showed the periodic presence of large sand ripples adjacent to the trenches in water depths greater than 25 m, which imply sand transport on the seabed at these depths. An indication of the scale of this transport is shown in the comparison of the seabed in the same location adjacent to Trench B between observations on the 29/11/2018 and 7/12/2018 as shown in Figure 3.13, with the large ripples forming over this 8-day period as a result of seabed sand transport in the high energy wave conditions experienced on the 30/11 (Hs=2.82 m, Tp=7.2 s). Again, this event was below the threshold for wave orbital velocity to entrain sand, yet clearly significant sand transport had occurred.

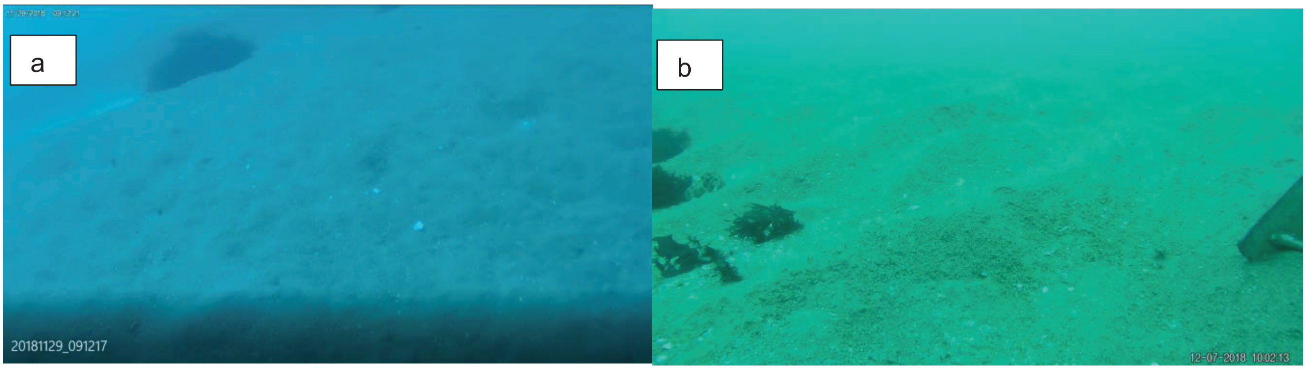

Figure 3.13: Evidence of sand transport in 26-27 m water depths from comparison of sand ripples adjacent to trench infill B: a) on 29/11/2018; b) on 7-12-2018 following high energy wave event on 30/11.

Summary

The results indicate that there is likely to be large volumes of sand being entrained on the seabed at water depths greater than 25 m CD and that the near bed currents are capable of transporting this sediment.

3.6.3.3 Longshore Sediment Supply around Bream Tail

The results of the sediment sampling and photos (Figure 3.14 – sample locations, Table 3.7 sediment size results, **Appendix M – seabed and sample photos**) indicate that sand is found across a wide swath of the seabed off the headland out to 30 m water depths. From the sampling results in Table 3.7, similar sized sand as found in the extraction area at Pakiri (i.e. fine and medium sand) was found in samples from both close to the headland (e.g. SED8) and in water depths deeper than 30 m MSL (SED11, 13). As shown on Figure 3.11, both of these areas were identified in the MPSS as areas of larger residual currents, therefore are potential sediment pathways from sediment in Bream Bay into the Mangawhai-Pakiri embayment.

The supply of sediment to the Mangawhai-Pakiri embayment from this source was found by the Environment Court in its 2006 Decision to be 25,000 m^3/yr. The updated data gathered to date, being the presence of sand sized sediment out to 30 m water depths, that current velocities are capable of transporting, and the presence of large sand ripples indicating that it is in transport, tends to support these transport volumes.

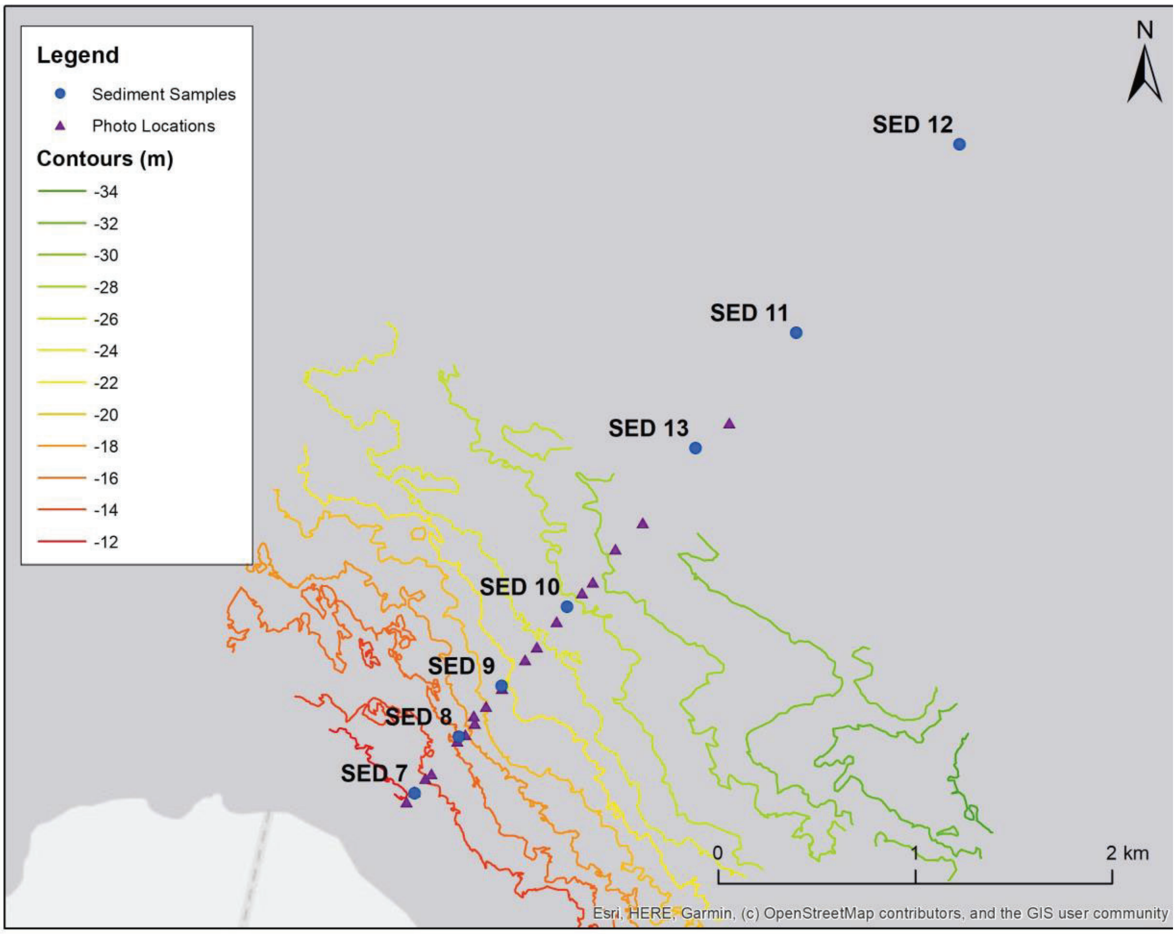

Figure 3.15: Location of Bream Tail seabed sediment samples and photos

Table 3.7: Sediment size results for Bream Tail samples

Sample	Water depth at time of sampling	Mean grain size	% of sample medium sand (0.5-0.25 mm)	% of sample fine sand (0.25-0.125 mm)	Notes
SED7	12.9	N/A	N/A	N/A	Rock so could not get sample
SED8	18.7	0.367 mm medium sand	31%	39%	Predominantly sand
SED9	20.4	2.261 mm very coarse sand	3%	nil	Coarse Shell deposit
SED10	25.4	1.112 mm very coarse sand	33%	4%	Predominantly shell with some sands
SED11	31.7	0.236 mm fine sand	34%	45%	Predominantly sand with some muds
SED12	30.0	N/A	N/A	N/A	Seabed rose again, sample was difficult to obtain due to high mud content
SED13	28.6	0.5334 Coarse sand	39%	13%	Shell and sand deposit

3.6.3.4 Supply from Cliffs and Rivers

The Environment Court in its 2006 Decision, found that inputs from rivers were 17,000 m^3/yr and from cliffs was 6,000 m^3/yr. For the purpose of this assessment, those input volumes have been adopted.

3.6.3.5 Updated Sediment Budget

The results of the above assessments of sediment inputs, leaving aside for now the inputs from diabathic cross-shore transport, result in volumes of supply from biogenic sand, longshore sources, cliffs and rivers in the vicinity of 55,000 m^3/yr. The natural losses from the embayment are to onshore winds, to Mangawhai Inlet and small losses around Cape Rodney. The Environment Court (2006) quantified these are 6,000 m^3/yr in total. In addition, sand extraction since 1966 from the Pakiri inshore and Mangawhai Inlet ebb tide delta have averaged 90,000 m^3/yr (from Table 1.2).

As outlined above in section 3.5.2, recorded net accretion at the dune toe has averaged +0.4 m/yr over the last 50 years. From the examination of the beach profiles, this equates to a beach volume gain above the MSL contour in the order of 1.4 m^3/m/yr, which over the whole embayment (25 km) is an additional 35,500 m^3/yr of sand input required to supply this sand storage. This is considered to be a minimum volume, as it does not include the volume required for the corresponding advance of the upper nearshore. It can be inferred that the source of this stored volume must be from cross-shore diabathic transport.

On this basis, the updated sediment budget for the nearshore-beach environment out to the -25 m CD contour would be as shown in Table 3.7

Table 3.7: Updated sediment budget out to 25 m CD water depth on basis that inputs exceed losses over last 50 years due to storage as shoreline accretion.

Inputs		Losses	
Source	**Volume (m^3/yr)**	**Source of Losses**	**Volume (m^3/yr)**
Cliffs	6,000	Onshore winds	2,000
Rivers	17,000	Mangawhai Inlet	3,000
Biogenic from <25 m depth	7,000	Around Cape Rodney	1,000
Around Bream Tail	25,000	Extraction from < 25 m depth	90,000
Diabathic supply (cross-shore from >25 m depth)	76,500	**Total Losses** **Storage/Surplus**	**96,000**
		Storage in dune/beach as accretion	35,500
Total	**131,500**		**131,500**

The sand budget in Table 3.7 supports ongoing inshore sand extraction of 90,000m3/yr whereas, in this application, MBL is proposing future annual extraction at the rate of only 76,000m3. It follows that if the budget were adjusted to allow for future sand extraction at a rate of 76,000m3, the inferred diabathic supply necessary to achieve a balanced budget would be 62,500m3. This illustrates the fact that in a budget of this kind the inferred volume of diabathic supply is a variable and does not represent a fixed estimate of actual diabathic supply volumes. In fact, in the Mangawhai - Pakiri embayment there are several indications that the annual volume of diabathic supply is greater than 76,500m3/yr. For example, the volume of storage in the dunes/beach (shown as 35,500m3) is very conservative and does not allow for greater volumes of accretion to the north of Te Arai Point measured since 1982 (see Table 4.2 below) and accretion has continued in the face of sea level rise which suggests addition storage in the vicinity of 38,000-50,000m3/yr (see Section 3.7 below).

3.7 Sea Level Rise Effects

It is well documented that rising sea level will theoretically result in a relative erosional response of sand beach systems in relation to their existing behaviour. Hence, assuming future sediment inputs remain the same currently accretionary beaches may continue to accrete but at slower rates, currently stable beaches may become erosional, and eroding beaches are likely to have increased rates of retreat.

Using the common “Bruun rule” approach suggests that for a New Zealand average historical sea level rise of 1.7 mm/yr (from Bell et al., 2000) the associated shoreline retreat at Mangawhai-Pakiri would be in the order of 0.09-0.17 m/yr (equivalent to 4.5-8.5 m net retreat since the 1950’s), which for the 25 km length of the embayment would equate to around 38,000 – 50,000 m^3/yr of volume being lost from the beach-dune environment to the nearshore. However, there is no evidence of wide spread beach erosion in the long-term record of shoreline movements. This is confirmed by the results of the assessment of historical erosion in section 3.5.2, which indicated that the position of the dune toe had advanced by an average of 0.4 m/yr since 1961/1963 over the whole bay.

It is also well documented that sea level rise is predicted to accelerate in the future, with New Zealand rates averaged over the next 100 years projected to be in the range of 5.5 – 13.6 mm/yr (i.e. 0.55 -1.36 m total rise by 2120[10]) (MfE 2017). Applying the “Bruun Rule” approach to the accelerated rates of sea level rise above the contemporary rates gives estimated shoreline retreat in the range of -7 to -20 m by 2070 and -13 to -50 m by 2120. However, these future retreat estimates do not account for shoreline advance that is known to be occurring with contemporary sea level rise at this embayment. The shoreline will continue to advance to some degree until the erosional effects of sea level rise are greater than the advance due to surplus sediment inputs. Applying the more conservative shoreline advance of +0.4 m/yr since 1961/63 (rather than 1.4 m/yr since 1982), the resulting estimates of future shoreline movements are for stability to continue with small advance over the next 50 years (e.g. to 2070) and for maximum shoreline retreat in the order of -10 m over the next 100 years (e.g. up to 2120).

[10] Ministry for the Environment (2017) give sea level rise projections for a number of climate change scenarios from a base sea level averaged over 1986-2005 period. Therefore, the projections need to be reduced by approximately 0.05m to get rise from 2020.

4. Assessment of Effects

4.1 Key Factors

There are three key factors relevant to the assessment of the potential adverse physical effects of the sand extraction activity on coastal processes:

1. Sand extraction has been occurring in the Mangawhai-Pakiri embayment for a very long time, close to 100 years, with estimates of greater than 7 million m^3 since the 1920's, and records of 5.4 million m^3 having been extracted since 1966 (Table 1.2). Given these large volumes over this considerable length of time, it would be expected that any physical effects on nearshore seabed levels and/or shoreline erosion would be evident.

2. Under an embayment wide sediment budget approach to the sustainability of the extraction activity, any significant prolonged net deficit of the sediment budget due to sand extraction would be observed as either adjustments of the nearshore profiles, or dune erosion and beach/dune volume losses to maintain equilibrium nearshore profiles.

3. Over shorter time frames, any changes to shoreline position, beach volume, or nearshore profiles due to extraction would most likely be greatest within the extraction areas. It follows that the use of a control area (e.g. non extraction area to the south of Poutawa Stream) and any relative differences in dune, beach and nearshore responses between these areas will be helpful in identifying the likelihood of potential adverse physical effects as a result of sand extraction.

The following assessment of effects considers each of these factors.

4.2 Effects on Nearshore Bathymetry

As stated in Section 4.1, under a sediment budget approach, any significant prolonged net deficit of the sediment budget due to sand extraction would be observed as either adjustments of nearshore profiles or dune erosion and beach/dune volume losses. The following section examines the data for nearshore profile change to determine whether there is any evidence of change that can be attributed to sand extraction.

4.2.1 Changes in Nearshore Seabed Profiles 2004-2019

The comparison of three-yearly bathymetric profiles collected as part of the current consent monitoring requirements are presented in **Appendix M**. The net 2004-2019 change in seabed elevations at fixed distances across each profile are presented in Table 4.1.

The key points from this comparison are:

- There is no evidence of erosion in the central embayment.
- The profiles show a general increase in the seabed elevation in the most recent surveys.
- The profiles show that the morphology of the shoreface has not changed.
- There is no evidence of seabed erosion within the MBL extraction areas despite extraction of 625,000 m^3 of sand from the MBL consent areas since 2004.
- There is no evidence of material difference in elevation changes between profiles in the MBL extraction areas, and those in the non-extraction control area to the south of Poutawa Stream.
- There is no evidence of any effect on sea bed levels of the extraction of around 1.17 million m^3 of sand from the nearshore in water depths less than 30 m CD since 2004.

Table 4.1: Change in nearshore seabed elevations 2004 to 2019

		Change in Seabed Elevation from 2004 to 2019 survey

Profile	Location	Offshore Profile Distance		
		500 m (-5 to -7 m MSL)	1000 m (-16 to -19 m MSL)	1500 m (-23 to -25 m MSL)
P1	North of Extraction Areas	-0.2	0.4	0.6
P2	North Extraction Area	0.6	0.1	0.5
P2B	North Extraction Area	-0.6	1.1	0.3
P2A	South Extraction Area	-0.1	0.5	0.3
P3	South Extraction Area	-0.6	0.1	0.6
P4	South Extraction Area	0.0	-0.1	0.4
P5	Southern Control Area	0.2	-0.8	0.7
P6	Southern Control Area	0.5	0.7	0.1
P7	Southern Control Area	0.0	0.3	No 2019 data
P8 & P9	Southern Control Area	Not surveyed in 2019		

In consideration of potential future effects, we can make the following statements:

- The lack of evidence of past seabed erosion indicates that the continuation of MBL extraction rate averaged over the last 15 years of 45,200 m^3/yr will not result in sea bed erosion either within the extraction area or across the wider nearshore out to 25 m CD water depth.
- The historical inshore extraction volumes and the updated sediment budget in section 3.6.3.5 for water depths less than 25 m CD indicate that extraction of 76,000 m^3/yr as applied for is very unlikely to result in significant seabed erosion either within the extraction area or across the wider nearshore out to 25 m CD water depths.
- The lack of evidence of past seabed erosion indicates that the continued combined extraction from both MBL and KL extraction areas at similar average rates as since 2004 (i.e. 146,700 m^3/yr) is very unlikely to result in significant seabed erosion within the extraction area or across the wider nearshore out to 25 m CD water depth.

4.2.2 Nearshore Bar Changes

Plots of the nearshore bar from the three-yearly bathymetric monitoring profile surveys in from 2004 to 2016 are presented in **Appendix O**. Note the 2019 bathymetric surveys undertaken with multibeam sonar did not go as far inshore to include the bar formation due to vessel draft constraints.

The plots show the position and magnitude of the bar formation being very variable in time and space, which supports the very large transfers and recycling of sand between the beach/dunes and the nearshore driven by waves and wave driven currents and indicated by the rapid trench infill reported in section 3.2.3. Module 6 (Hume et al. (1999) noted that these bars can be up to 2 m in height and move in position. They occur along the entire length of the embayment, but may not always be present at any particular time or location.

The plots in Appendix O also show that the MBL extraction areas are at least 100 m seaward of the position of the nearshore bars, as required under the current consent conditions, and that the surveyed changes in the bars presence and magnitude appear to be similar between the extraction areas and the non-extraction areas to the north and south.

From these observations it is concluded that there is no evidence that extraction from the MBL inshore consent area is affecting the presence, position or size of the nearshore bars. Considering the processes operating, it is further considered that it is unlikely to change with continued extraction from these areas at the volumes applied for.

4.2.3 Effects on Surf Breaks

The surf breaks along Te Arai and Pakiri Beaches are described in the Auckland Unitary Plan (AUP) as being “beach breaks”, where the surfing opportunity is provided by waves arriving oblique to the shore break on the nearshore bars due to the localised increased seabed elevation and slopes. As indicated above, there is a high degree of variability in bar position and magnitude due to the large transfers and recycling of sand within the dune-beach-nearshore system driven by wave action.

Based on the lack of evidence of effect of the inshore extraction on the presence, position, or size of the nearshore bars, it is considered that the proposed continuation of the MBL extraction will not have a material adverse effect on the surfing breaks at Te Arai and Pakiri Beaches.

4.3 Coastal Erosion

As stated in Section 4.1, under a sediment budget approach, any significant prolonged net deficit of the sediment budget due to sand extraction would be observed as either adjustments of nearshore profiles or dune erosion and beach/dune volume losses. The following section examines the data for shoreline change to determine whether there is any evidence of coastal erosion that can be attributed to sand extraction.

In its 2006 decision the Environment Court, having reviewed the extensive evidence said “*we find that signs of shoreline retreat and erosion cannot be attributed to past sand extraction, and that past extraction has had no detectable effect on the environment”.*

The following assessment focuses on whether there is any additional information since 2006 that changes the Court’s conclusions on the lack of effect of sand extraction on coastal erosion.

4.3.1 Shoreline Movements from Aerial Photographs

The analysis of the DSAS results in Section 3.5.2 was further examined to determine whether there were differences in shoreline movements between the extraction areas and the southern control area that could be attributed to the sand extraction. Unfortunately, the 1961/63 images do not cover the whole of the southern control area, so that analysis of the total DSAS record is limited to post 1982. However, as pointed out in Section 3.5.2, these southern sites were not included in the dune re-construction activities post the 1978 storms, therefore a comparison with the extraction sites is not relevant for this period.

The results of this analysis are presented in Table 4.2.

The key points from the analysis can be summarised as follows:

- There is a large range of shoreline responses across the different time periods for all three areas, erosion and accretion occurring within each area during each of the time periods.

- Over the total period since 1961/63, both extraction areas have experienced average net shoreline advance, with the northern area being at a rate of close to 1 m/yr over the 50+ years, and the southern area at a slower rate of +0.15 m/yr. There is no evidence of long-term shoreline erosion due to sand extraction.

- The difference in shoreline behaviour between the northern and southern extraction areas is present in both the 1961/63 to 1982 and the 1982 to 2018 periods. Although there have historically been higher extraction rates from the southern area, it is considered that other reasons such as more dune reconstruction post 1978 significant storm erosion in the northern area, sediment supply around Bream Tail, and southward sediment transport being trapped by Te Arai Point can also explain the pattern of shoreline advance.

- The shoreline retreat in the 1961/63 in the southern extraction area was less than experienced in the parts of the southern control area with photographs.

- Since 1982, there has been shoreline advance of all areas. Again, while the southern extraction area has the least net average shoreline advance of the three areas, the rate is very similar as the southern control area. For the differences between the northern and southern extraction areas, it is noted that extraction volumes since 2005 are equal across both areas, and that the above natural process will be still be influencing the shoreline responses in each area.

- Based on these results, there is no evidence of long-term shoreline erosion due to sand extraction.

Table 4.2: Summary of shoreline movements from aerial photographs 1961/63 to 2018

Area	DSAS Transects (1)	Total period 1961/1963 - 2018			Rate 1961/63 – 1982 (m/yr)	Rate 1982 - 2018 (m/yr)
		Envelope of movement (m)	Net Movement (m)	Net Movement Rate (m/yr)		
Northern Extraction Area (2)	110-165	Range: 8.4 – 220 Avg: 68.6	Range: -3.1 – +171.1 Avg: +56.9	Range: -0.05 – +2.98 Avg: +0.99	Range: --3.61 – +3.41 Avg: +0.33	Range: -1.8 – +6.08 Avg: +1.39
Southern Extraction Area (3)	64-106	Range: 6.4 – 56.3 Avg: 30.3	Range: -17.9 – +40.9 Avg: +8.9	Range: -0.31 – +0.71 Avg: +0.15	Range: -2.66 – +1.51 Avg: -0.62	Range: -0.23 – +1.56 Avg: +0.59
Southern Control Area (4)	1-14: North of Pakiri R.	Range: 15.1 – 189.4 Avg: 64.3	Range: 1.6 – 10.3 Avg: +5.7	Range: +0.10 – +0.19 Avg: +0.11	Range: -0.37 – -9.39 Avg: -2.91	Range: +0.38 – +5.23 Avg: +1.77
	50-57: South Poutawa	Range: 14.7 – 48.8 Avg: 29.3	Range -3.8 - -48.8 Avg: -21.2	Range: -0.07 - -0.85 Avg: -0.37	Range: -0.29 - -1.58 Avg: -0.97	Range: -1.19 - +0.45 Avg: -0.05
	1-57: whole control area	(5)				Range: -1.19 - +5.23 Avg: +0.71

Note: (1) See Appendix J for location of DSAS transects.
(2) Northern Extraction Area – Te Arai Point to northern boundary
(3) Southern Extraction Area – north of Poutawa Stream to Te Arai Point
(4) Southern Control Area –Pakiri River to south of Poutawa Stream
(5) 1960's images not available for transects 15-49 in the Southern control area

4.3.2 Surveyed Shoreline Movements 2007-2019

As outlined in Section 2.2.1 since 2007 MBL have been required under their current consent conditions to undertake six monthly topographic surveys of the beach and foredunes over a 20 km length of the Mangawhai-Pakiri embayment covering both the northern and southern extraction areas, and the 6.5 km south to the Pakiri River. The beach profiles at the eleven historical positions are interpolated from these surveys. Examples of the magnitude of 6 monthly profile changes at the historical profile sites as captured by the drone surveys between October 2017 and March 2019 are presented in **Appendix L.** The profile changes are interpreted under Consent Condition 21, which states that at 12 monthly intervals the conditions of the consent may be reviewed if:

(a) The volume of sand within the beach profile (0-3.5 m) shows loss at three adjacent profile sites sustained over three consecutive surveys

(b) The excursion distances at +1.0 m or +2.0 m or +3.5 m contours at three adjacent profile sites are all landward over three consecutive surveys.

The results of these interpretations have been provided in annual reports to the former Auckland Regional Council and now Auckland Council. The annual analysis undertaken for these interpretation reports is not repeated in the following assessment, however the key points are:

- The criteria for review under Condition 21 has never been reached.
- All major beach contour retreat and volume losses can be explained by storm events as recorded at the Marsden Point wave buoys.
- Post winter profiles (i.e. from surveys in Sept-Oct) generally display less beach volume and slight retreat of beach contours than post summer profiles (i.e. March-April surveys).
- On an annual basis, the profiles in the extraction areas are not performing any worse that the profiles in the southern control area.

These results confirm the well-established patterns from nearly 40-year record of annual and six-monthly beach profile surveys that the beach foreshore profiles are very dynamic to short-term changes in wave conditions, with retreat of beach contours and volume losses occurring in association with storm events followed by on-shore recovery during calmer conditions.

4.3.2.1 Excursion Distance Analysis 2007-2019

Historical Beach Profiles

Excursion Distance Analysis (EDA) is a technique where the distances to various beach contours from a fixed baseline over successive surveys are plotted and analysed for trends in movement. The EDA plots for the 1 m, 2 m, 3.5 m and 5.5 m contours at each of the historical profile sites since the current consent monitoring started in April 2007 are presented in **Appendix P**. The 1 m and 2 m contours have been included to demonstrate the rapid and variable response of the beach foreshore to wave conditions. However, as with the MHW position from the cadastral surveys, they do not provide a very reliable indicator of medium-term changes in shoreline position. Therefore, as above, the analysis of medium-term shoreline movements is limited to the movements of the 3.5 m contour as a proxy for the foredune toe position, and the 5.5 m contour, being representative of movements on the foredune face. The plots of the movement of these contours across all profile sites are presented in Figures 4.1 (3.5 m contour), and 4.2 (5.5m contour).

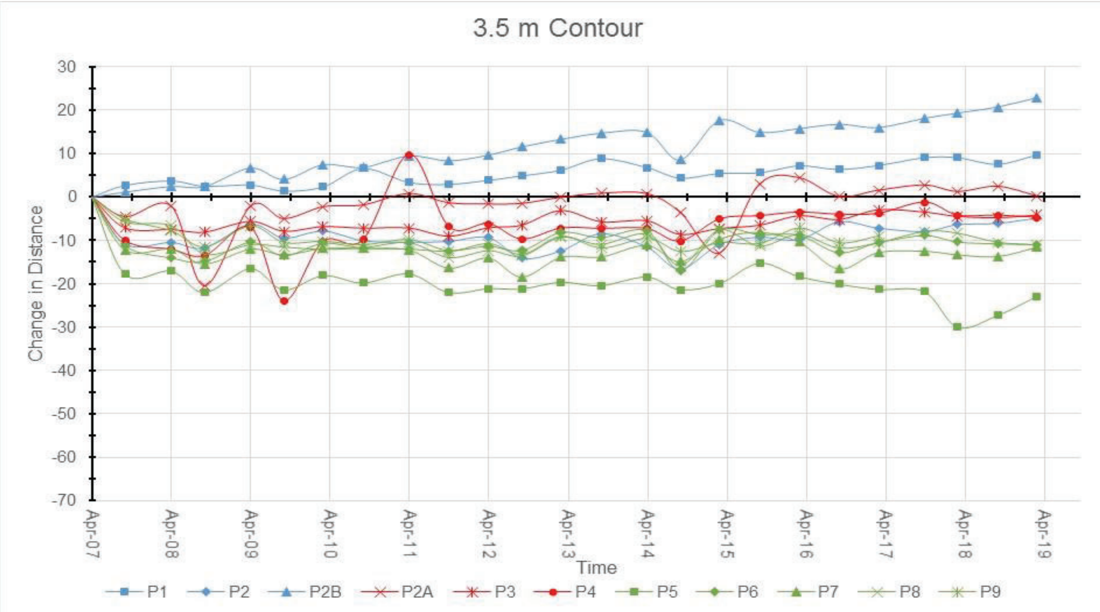

Figure 4.1: Excursion distance plot of the 3.5m contour (proxy for beach toe position) at historic profile sites 2007 – 2019

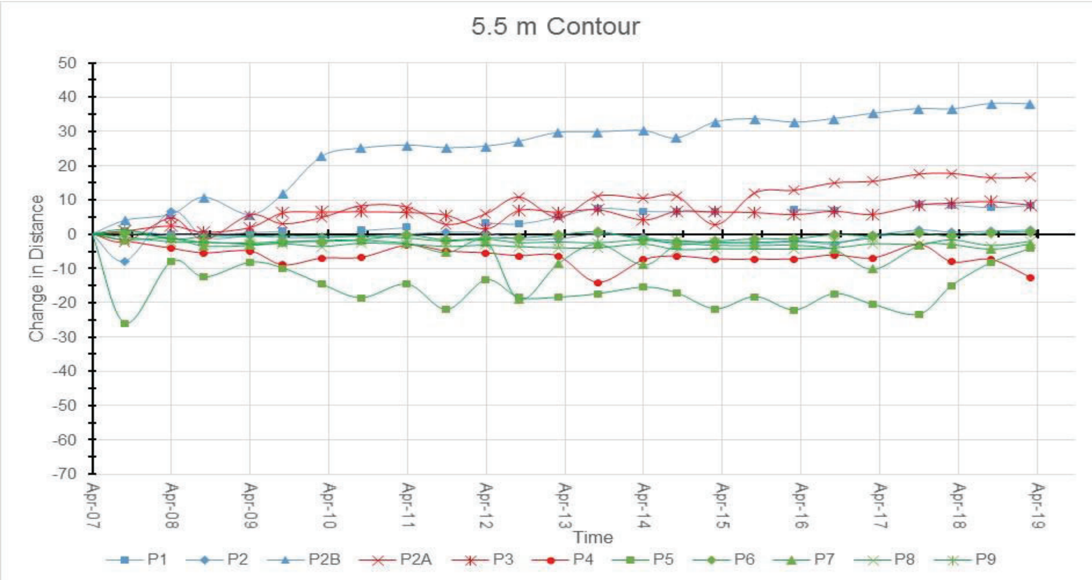

Figure 4.2: Excursion Distance plot of the 5.5m contour (proxy of dune face position) at historic profile sites 2007 – 2019.

The effects of the sand extraction can be examined by comparing the EDA trends across the two extraction zones and the southern control area as shown by the different colour codes in Figures 4.1 and 4.2. Note for this analysis, although they are technically outside of the extraction areas, site P1 is included in the northern extraction area and P2A in the southern extraction area. The following general trends over the 12-year survey period can be identified from the figures:

- A weak pattern of general retreat over winter periods and accretion over summer periods is evident across all contours.
- Apart from profile P2B (accretion), and profile P5 (erosion), the net movements of all sites over the 12-year period are less than ± 10 m for both the dune toe and dune face positions. At P2B, the dune toe accreted 22.8 m and the dune line accreted by 38 m, while at P5 the dune face eroded 22.9 m. These are both considered to be site specific changes driven by profile location.
- Larger retreat is evident over the winter of 2007 in response to the significant storm event in July of that year, particularly for profiles south of Te Arai Point in both southern extraction and southern contour areas. As can be seen in Figure 4.1, while all profiles showed dune toe recovery following this event, for 7 of the 8 profiles south of Te Arai Point the dune toe has not totally recovered back to the April 2007 position.
- The dune face did not respond to the July 2007 storm with the same magnitude of retreat, and only half of the profiles south of Te Arai Point had not recovered back to April 2007 positions by March 2019.
- A smaller short-term erosion response of the dune toe is also evident in the winter of 2014 in response to a significant storm in that year, however recovery has been quicker and more complete than in 2007.
- At other times, both sets of contours at individual sites can be seen to vary in position by up to 20 m between 6-monthly surveys, particularly to the south of Te Arai Point (e.g. P2A, P4, P5 and P7). These are short-duration changes that are generally reversed by the next survey, which suggests that some of the variability may be due to uncertainty in the interpolation of profiles from the topographical surveys.
- Over the total 12-year period, apart from the dune face at P4, the profiles in the extraction areas have performed better than the profiles in the southern control area, with either more advance or less erosion of both the dune toe and dune face positions in the extraction areas.
- For comparison between the extraction areas, the profile sites in the northern extraction area can be seen to generally perform better than those in the southern extraction area. Since extraction volumes were equalised across both areas throughout the survey period, this indicates that natural processes rather than extraction are the reason for these differences. These results re-enforce the results and interpretation of the longer-term aerial photograph analysis in Section 4.3.1.

Further analysis of the EDA of the 3.5 m and 5.5 m contours is presented in Table 4.3 for assessment of the response to the most significant storms in July 2007 and July 2014. This analysis uses the 6 monthly surveys pre and post these storm events to assess whether there are differences in the magnitude of storm erosion and length of time to recover back to the pre-storm survey positions between the extraction areas and the southern control area.

The key points from Table 4.3 results are:

- Dune toe and face erosion was greater in the July 2007 storm than the July 2014 storm, indicating that the earlier event was the larger.
- Dune toe retreat in response to both storm events over the survey period was greater at the profiles in the southern control area than the profiles in either of the extraction areas.
- There was a similar pattern for dune face storm response for the July 2007 storm event, with the storm erosion being in the southern control area, but not for the July 2014 event.
- Storm dune toe erosion was greater in the southern extraction area than in the northern extraction area. in both events.
- Post storm recovery duration was variable across profile sites, with all areas having sites where recovery back to pre- July 2007 positions has not occurred, however this is more frequent in the southern control area than the extraction areas.

Table 4.3: Storm response of 3.5 m and 5.5 m contours to significant storm events in July 2007 and July 2014.

Area	Pre & Post Storm surveys	Dune Toe (3.5 m contour)		Dune Face (5.5 m contour)	
		Average Profile Change	Post Storm Recovery	Average Profile Change	Post Storm Recovery
Northern Extraction Area (Profiles P1, P2, P2B)	Apr-Sept 2007	-2.3 m	P1, P2B: 6 months. P2 not by 12 yrs (Mar 19).	-1.0 m	P1, P2B: 6 months. P2: 1 yr
	Apr-Sept 2014	-4.6 m	P2, P2B: 1 yr P1: 2 yrs	-1.5 m	P1: 6 months P2B: 1 yr P2: 3 yrs
Southern Extraction Area (Profiles P2A, P3, P4)	Apr-Sept 2007	-7.3 m	P2A: 3.5 yrs P3, P4 not by 12 yrs (Mar 19).	-1.1 m	P2A: 1 yr P3: 6 months P4 not by 12 yrs (Mar 19).
	Apr-Sept 2014	-3.5 m	P4: 1 yr P2A: 1.5 yrs P2: 2 yrs	+1.4 m	P2A, P3, P4: 6 months
Southern Control Area (Profiles P5, P6, P7, P8, P9)	Apr-Sept 2007	-10.4 m	All profiles not by 12 yrs (Mar 19)	-4.6 m	P6, P8: 6 months P5, P7, P9: not by 12 yrs (Mar 19)
	Apr-Sept 2014	-5.2 m	P6, P7, P8: 1 yr P5: 1.5 yrs P9: 2 yrs	+0.3 m	P7: 6 months P6: 1.5 yrs P8, P9: 3 yrs P5 not by 12 yrs (Mar 19)

There is no evidence from these results that the profile sites in the extraction areas are performing worse than in the southern control area, and no evidence that sand extraction has resulted in greater storm erosion or less recovery of the dune toe and dune face position.

Topographic Survey, 100 m Profile Analysis

A weakness of the historical profile analysis is the ability of the eleven profiles to adequately represent the 20 km of beach within the extraction and control area. This was recognised in MBL's current consent conditions with Condition 13 requiring the topographic surveys to have data points at least every 100 m along the beach. The required density of survey data points has been considerably exceeded by all the six-monthly monitoring surveys since 2007, allowing profiles at the required 100 m interval to be interpolated from the data, and compiled into the 3-dimensional temporal-spatial heat maps of cumulative change in distance to beach contours from a fixed baseline. Examples of the resulting heat maps for the 3.5 m contour (proxy for dune toe) are shown in Figure 4.3 and for the 5.5 m contour (proxy for dune face) in Figure 4.4.

It is noted that the significant erosion hot spots shown around Te Arai point on both heat maps are an anomaly of the method, as the contour has a null distance from the baseline. For this reason, the area around Te Arai Point, shown as being between the northern and southern extraction areas is excluded from the analysis.

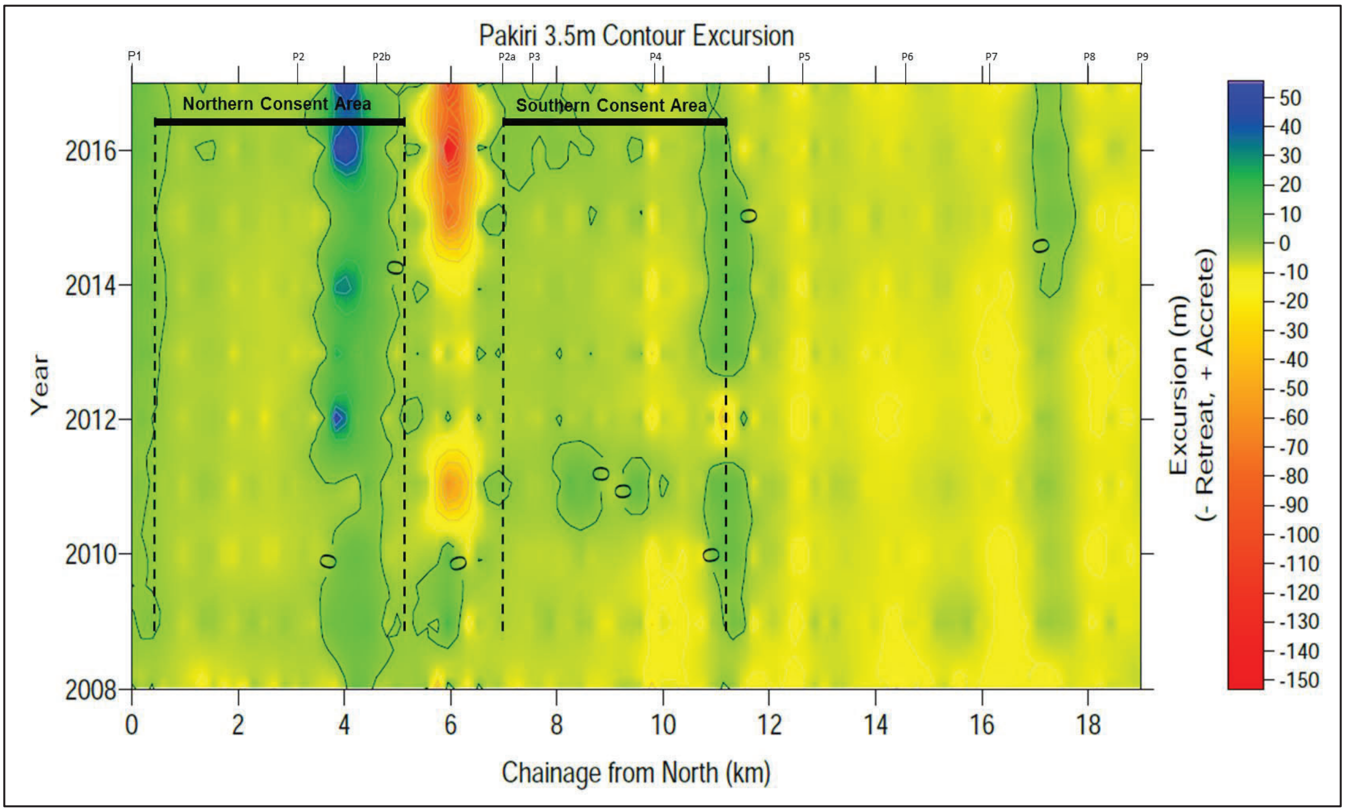

Figure 4.3: Temporal-spatial heat map of distance excursion of the 3.5 m contour from topographic surveys 2007-2017

For the proxy dune toe position (3.5 m contour), the key points from the analysis include:

- The majority of the northern extraction area displays net retreat in the order of 10-20 m over the whole period. This primarily occurred in the initial April-September 2007 period in response to the significant storm in July 2007 with the dune toe being generally stable since this time.
- The exception to this trend is the area on the immediate northern side of Te Arai Point (includes profile 2B) that shows dune toe advance over an increasing length of beach front, which by 2017 had increased to around 500 m wide. Around Te Arai Stream (chainage 4 m) this advance is shown to be in the order of 40-50 m by 2016-2017.
- The majority of the southern extraction area also displays similar trends of net retreat since 2007 but by a smaller magnitude (e.g. <10 m), and general stability since the July 2007 storm. The exception to this

pattern is a band of low dune toe advance at the southern end of the extraction area (e.g. north of Poutawa Stream), which has been present since 2009 except for erosion in the 2012 storm.

- The southern control area also displays similar trends of net retreat since 2007 and general stability since the July 2007 storm, but with the retreat being more pronounced (e.g. up to 20 m) and more widespread.

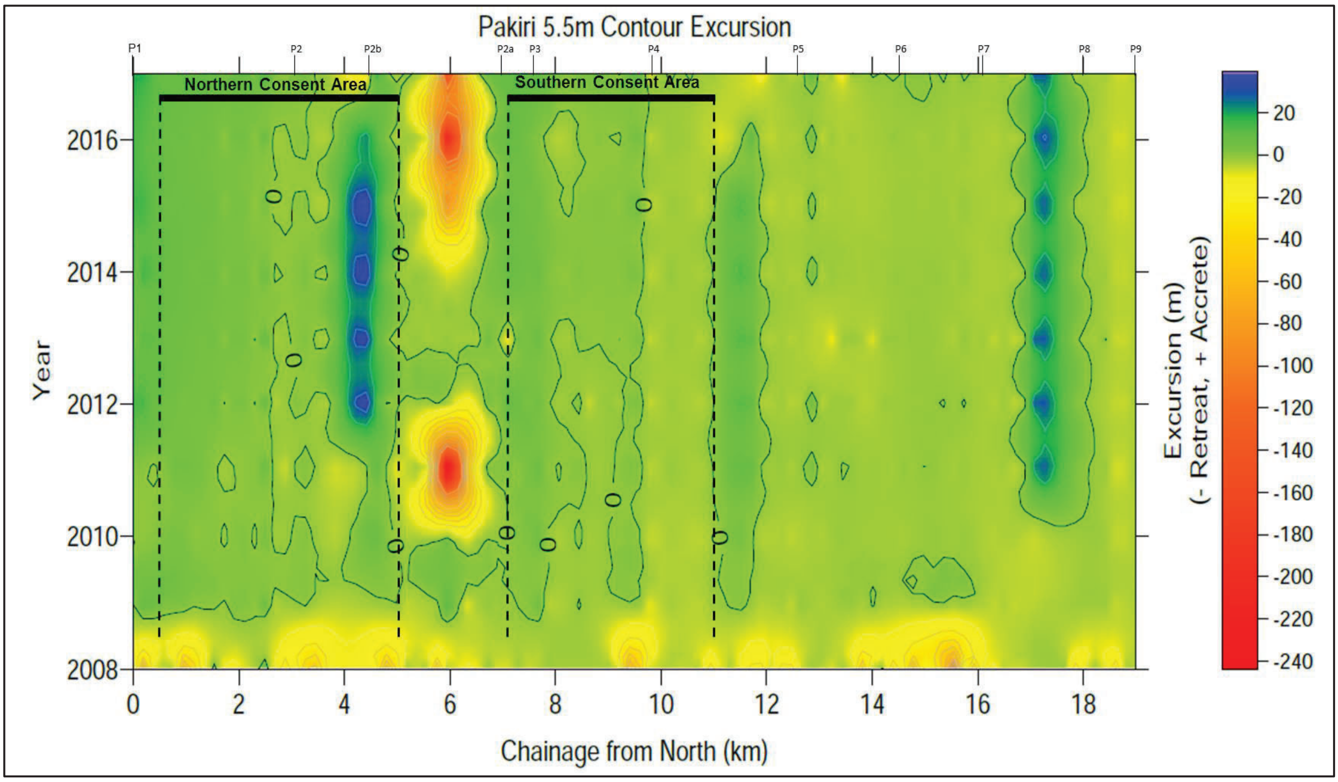

Figure 4.4: Temporal-spatial heat map of distance excursion of the 5.5 m contour from topographic surveys 2007-2017

For the proxy dune face position (5.5 m contour- Figure 4.4), the key points from the analysis include:

- The northern extraction area shows general accretion of 10-20 m, except for a periodic low scale erosion cell (e.g. <10 m) around profile P2, and higher rates of dune advance by greater than 20 m around profile P2B.

- The southern extraction area shows general accretion of 10-20 m from Te Arai Point south to around profile P4, which gives way to persistent small scale erosion (< 10 m) to the southern end of the extraction area.

- Apart from around the Poutawa Stream and Pakiri River mouth areas, the southern control area shows low scale erosion (e.g. < 10 m) over the whole survey period.

These results indicate that when considered over the whole areas, the extraction areas are performing as well, if not better that the southern control area, and that there is no evidence that the continued sand extraction is adversely effecting dune movements.

4.3.3 Beach Volumes

As well as retreat of beach contours, coastal erosion can also be manifested as a loss of beach volume. The following analysis of volume change has been undertaken from the topographical survey dataset. This is considered more appropriate for the calculation of beach volumes than the extrapolation of cross section volumes from the historical profiles due to the limited number of profiles, and the uncertainty about how representative these profiles are over the large distances between them.

For comparative temporal volume analysis over multiple survey dates the calculations need to be made over the same area and to the same base level, with elevation data being available for the whole area in each survey date. Prior to 2017 the base level used from the surveys by beach vehicle was the 0 m contour with volumes in the foredune and beach calculated from a fixed landward boundary to 1 m contour. However, the change to UAV surveys resulted in the seaward extent of the surveys being limited in several areas to above 1 m contour. As a result, the volume data collected pre-2017 is not comparable to the data collected post 2017, so the following analysis is presented for the two time periods.

It is noted that a limitation of the beach volume analysis is that it is dependent on the position of a highly mobile lower beach contour (e.g. 1 m contour), therefore the results can be totally influenced by short-term variations in the position of this contour, which may not represent longer term patterns of change.

Cut and Fill Mapping

Spatial cut and fill maps of change in beach surface elevation for the whole topographical survey area from Mangawhai Spit to the Pakiri River are presented in **Appendix Q** for the period April 2007 – March 2017

The mapping shows a patchy pattern of beach elevation loss (cut) and gain (fill), with areas of cut being more prevalent that areas of fill. However, breaking down the survey period into two five-year intervals revealed that fill areas dominated in the more recent 5-year period, within which higher rates of extraction have occurred.

There appears to be little noticeable difference in the ratio of cut and fill between the extraction areas and control areas. Any further interpretation of the mapping is limited by the magnitude of change in elevation not being shown.

Temporal Volume Changes

Total beach and foredune volume above the 0 m contour within the fixed dune boundary for the two extraction areas and the southern control area for the surveys from April 2007 to March 2017 are presented in Figure 4.5. The volume changes from surveys from October 2017 to March 2019 are presented in Figure 4.6. As above, the values presented in each of the figures are not comparable, having been calculated from different areas.

The key points from this analysis include:

- The influence of the significant storm in July 2007 is clearly shown in Figure 4.5 with large foredune/beach volume losses totalling in the order of 1.6 million m^3 occurred across the whole embayment. However, all three areas suffered similar rates of volume loss of around 90 m^3/m.
- Volumes in all three areas experienced similar patterns of volume change from September 2007 to March 2017, with all experiencing seasonal trends of summer gains and winter losses until March 2015, when the pattern reversed to summer losses and winter gains.
- Within the envelope of seasonal variation, the volumes have remained similar across all areas within the period September 2007 to March 2017 with the net changes being in the same order of magnitude as the seasonal variations.
- Since October 2017, Figure 4.6 shows that beach volumes in the southern control area have been more variable than in the extraction areas, however all areas experienced net gains over the 18-month period.

These results show no evidence of the sand extraction having a material impact on the natural fluctuations in beach volume.

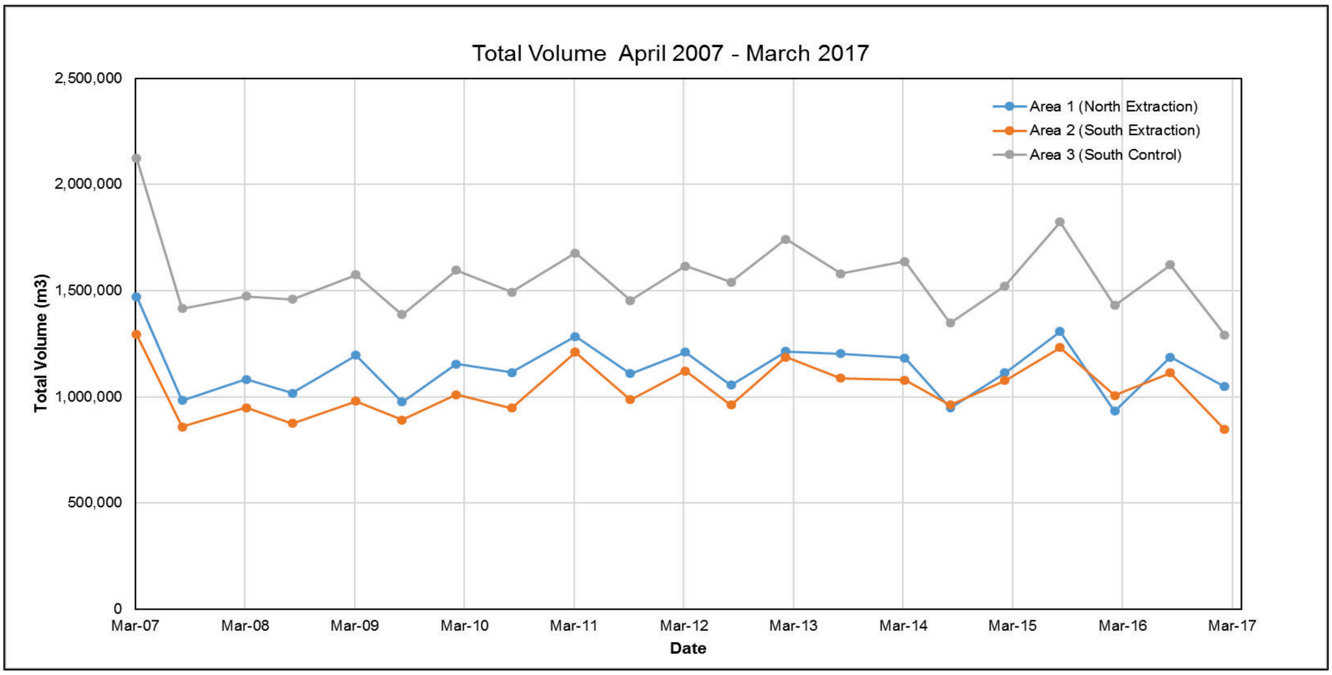

Figure 4.5: Beach volumes by area from topographic surveys April 2007 – March 2017

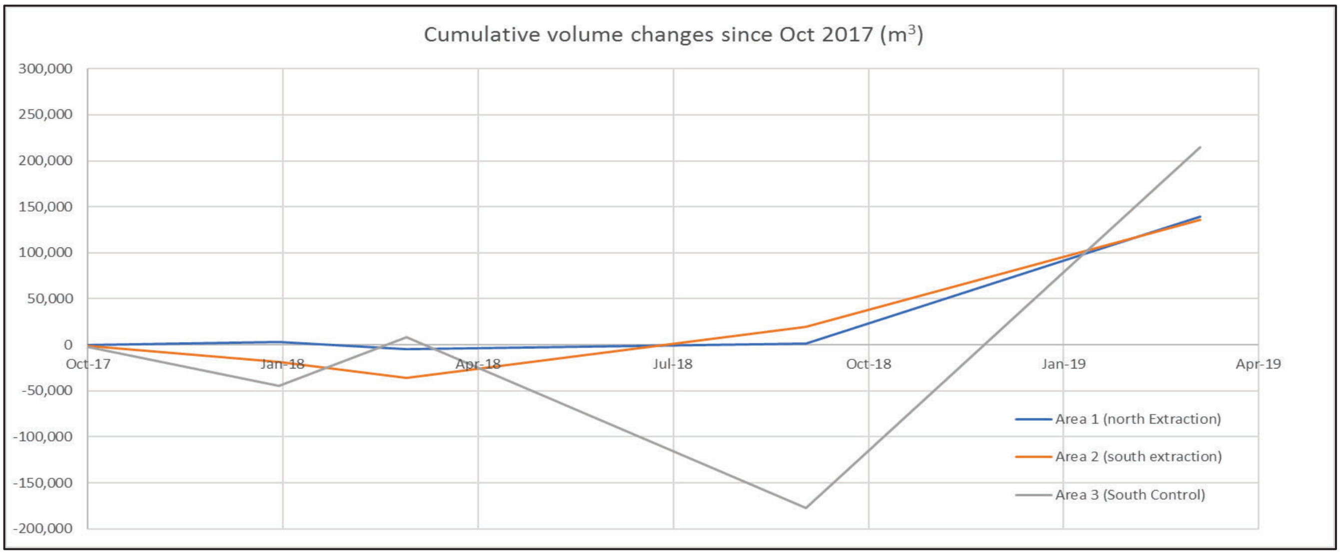

Figure 4.6: Beach volume changes by area from topographic surveys October 2017 – March 2019

4.4 Cumulative Effects

The terms of Kaipara Limited's 2003 coastal permit to extract sand from the offshore area (beyond 25m CD) are set out in Section 1.3.2 above. The volumes excavated by KL and the combined volumes excavated by MBL and KL are summarised in Table 1.3.

Since 2004 extraction has occurred from both an inshore area (5-10 m CD) contour by MBL at total volumes of 624,600 m^3, and from at offshore area at water depths greater than 25 m CD by KL at total volumes of 1.57 million m^3, of which approximately 35% has been from depths less than 30 m CD.

The cumulative effects of both the MBL and KL extraction on coastal processes can be considered in the following manner:

- There is no evidence of any effect on sea bed levels less than the -30 m contour from the combined extraction of 2.2 million m^3 of sand since 2004.
- There is no evidence of beach erosion from the combined extraction since 2004.
- The extraction by KL will have no influence on the ability of wave and current processes to transport sand across the -25 m CD contour boundary to the sediment budget presented in section 3.6.3.5. This extraction will also not reduce the availability of the sand to be transported at this depth by these processes.
- Therefore, the cross-shore diabathic transport rates into the nearshore and the MBL extraction area will be the same as established in section 3.6.3.5, and the sediment budget will continue to be in surplus.

4.5 Sustainability of the Sand Resource

As outlined in Section 3.1, the size of the Holocene sand resource in the nearshore at water depths less than 25 m CD was estimated by the MPSS as being in the range of 70-120 million m^3. From Table 1.2, inshore extraction since 1966 (including from the Mangawhai Inlet) is given as being 3.856 million m^3. The proposed extraction of 76,000 m^3/yr under application to renew the current inshore consents would equate to another 2.66 million m^3 over the 35-year period applied for.

Therefore, if there was no input of new sand, the total cumulative inshore extraction by the end of the period covered by the application would be between 5-9% of the total size of the resource. However, total inputs over the 35-year consent could be in the order of 4.5 million m^3 over the next 35 years.

Given that the application for the renewal of the MBL inshore consent is for extraction at the same volumes as the current consent, being 76,000 m^3/yr, there would be no foreseeable adverse effects on the coastal processes, including shoreline erosion, over the 35 years applied for.

5. Conclusions

The volume of Holocene sand located on the shoreface at water depths less than approximately 25 m CD within the Mangawhai-Pakiri embayment is estimated to be in the range of 70-120 million m^3. Extraction of this sand has been occurring since the 1920's, with total volumes extracted recorded to be 5.4 million m^3 since 1966. Since 2004 extraction has occurred from both an inshore area (5-10 m CD) contour by MBL at total volumes of 624,600 m^3, and from at offshore area at water depths greater than 25 m CD by KL at total volumes of 1.57 million m^3, of which approximately 35% has been from depths less than 30 m CD.

The question addressed by this assessment is what adverse effects on coastal processes will future extraction by MBL at a proposed rate of up to 76,000 m^3/yr have on their own, and in combination with the future extraction by KL at rates of up to 150,000 m^3/yr from less than the 30 m CD contour.

Long-term shoreline movements measured from aerial photography over the last 50+ years, show a general embayment wide shoreline advance of 0.4 m/yr, hence no evidence of long-term erosion due to sand extraction, and no evidence of difference in rates of movements between extraction and control areas.

Nearshore seabed profiles since 2004 do not show any evidence of extraction effect in either the inshore area of MBL extraction or over the general nearshore out to the -30 m CD contour from the combined inshore and offshore extractions.

Recent beach surveys since 2004 show that beach responses to storm events, both in terms of storm cut and post storm recovery, has not been any worse in extraction areas than control areas, hence no evidence of adverse effect from the extraction.

The sediment budget for the Mangawhai-Pakiri embayment out to the -25 m contour averaged over the last 50 years shows natural sediment losses of 6,000 m^3/y, and losses to extraction of 90,000 m^3/yr. Sand storage as beach accretion averages 35,500 m^3/yr. Known sediment inputs from rivers, cliffs, biogenic production, and around Bream Tail total 55,000 m^3/yr, with inferred input from cross-shore diabathic transport of 76,500 m^3/yr.

Based on the sediment budget, there is more than sufficient sand within the inputs to sustain the extraction of 76,000 m^3/yr sought by MBL in their consent application.

In terms of any cumulative effects of both the MBL and KL extraction on coastal processes there is no evidence of any effect on sea bed levels less that the -30 m contour or of increased beach erosion from the combined extraction since 2004. The extraction by KL will have no influence on the ability of wave and current processes to transport sand across the -25 m CD contour boundary and this extraction will also not reduce the availability of the sand to be transported at this depth by these processes. Therefore, the cross-shore diabathic transport rates into the nearshore and the MBL extraction area will be the same stated above and the sediment budget will continue to be in surplus.

These factors, taken together with all the material in this report, support the writer's conclusion that the sand extraction proposed by MBL's application for a renewal of its current coastal permit would not have a discernible adverse effect on coastal processes in the Mangawhai - Pakiri embayment.

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Pakiri Sand Extraction Consents

Assessment of Effects on Coastal Processes Appendix

IZ111900-NM-RPT-0001 | B

20 January 2020

McCallum Bros Ltd

Appendix A. Mangawhai-Pakiri Sand Extraction Volumes 2003-2019

Extraction Volumes supplied by McCallum Bros Ltd

Table 1: Inshore Extraction Area

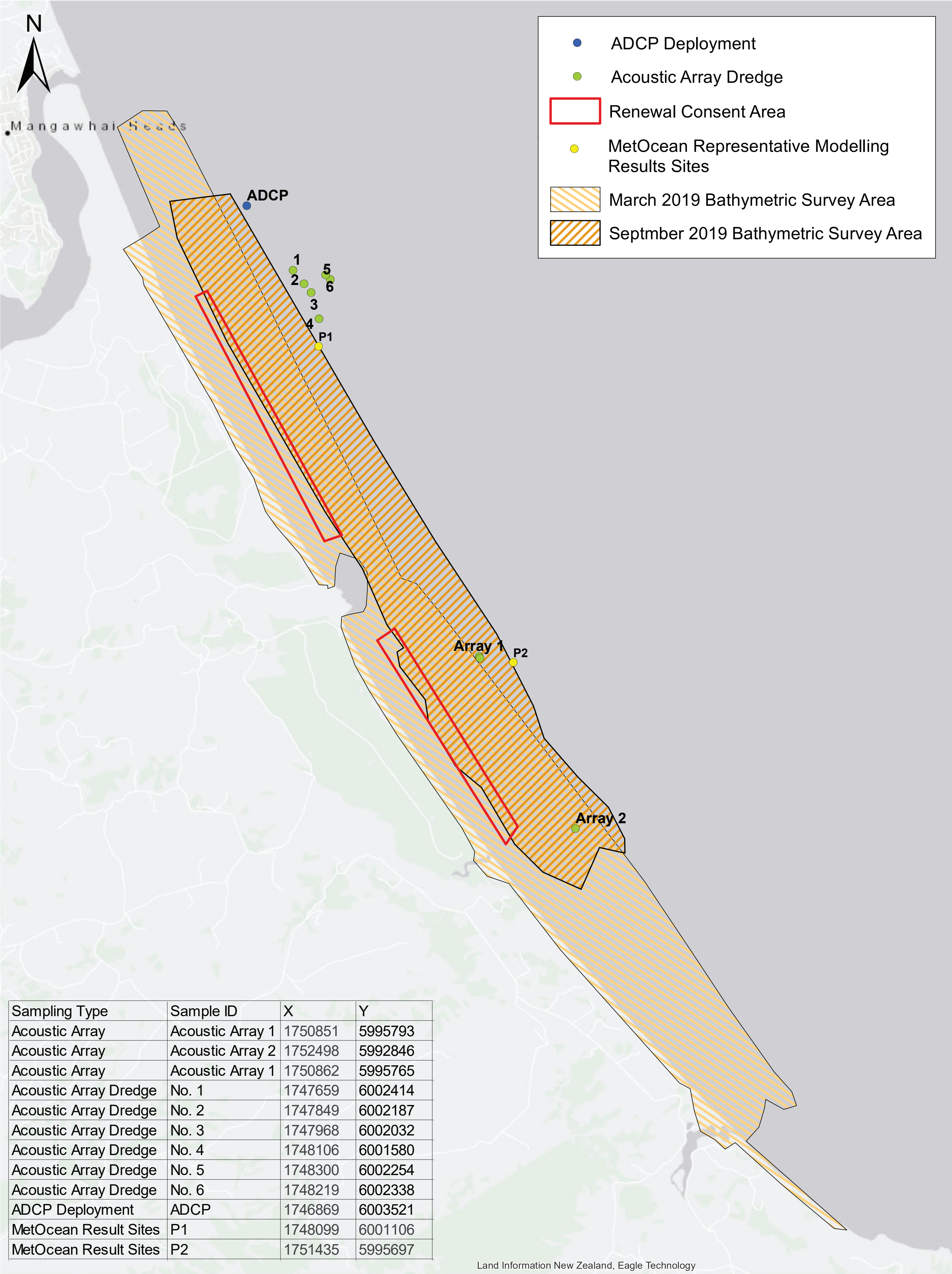
Inshore Extraction Area. Volumes in m^3																	
	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
September		6200	7810	7100	5,680	2,080	2,730	920	2,300	1,380	2,300	920	1,600	1,260	800	3,930	5,400
October		6700	7100	5680	5,680	2,130	2,840	4,140	460	2,300	1,840	1,380	920	1,380	800	6,900	8,120
November		6475	7810	4970	4,970	6,790	1,420	2,300	1,840	920	1,840	1,380	920	1,380	800	7,800	7,060
December		7375	4260	5680	5,680	710	4,260	-	1,840	2,300	1,380	2,300	920	1,840	1,720	4,700	5,400
January	2050	2850	3450		2,780	2,740	460	1,840	460	920	-	-	1,380	920	800	7,240	6,000
February	3650	3675	7110		4,320	3,540	460	460	3,220	2,300	1,380	920	920	920	1,140	1,260	3,200
March	8425	5925	7030	1380	4,730	2,130	-	2,760	2,300	2,760	1,380	920	920	1,380	800	5,920	6,020
April	5275	5775	7920	4600	9,090	4,930	-	920	2,760	1,598	2,300	2,180	920	2,060	460	5,500	7,660
May	4675	3300	8020	1380	6,990	5,680	1,610	1,840	1,840	1,840	920	460	1,380	2,090	1,260	8,020	7,440
June	5950	7090	5960		2,330	3,550	1,320	2,300	2,760	3,220	920	1,226	1,720	1,260	920	6,280	5,120
July	6425	3775	5680		1,400	4,260	1,840	2,300	1,380	1,840	920	920	1,840	2,060	1,720	7,120	7,520
August	7175	3165	7100		9,250	4,970	2,300	2,760	2,300	1,380	1,380	800	1,260	1,720	2,670	6,930	5,780
TOTAL	**53,000**	**62,305**	**79,250**	**65,450**	**62,900**	**43,510**	**19,240**	**22,540**	**23,460**	**22,758**	**16,560**	**13,406**	**14,700**	**18,270**	**13,890**	**71,600**	**74,720**

Note: Entries since 2009 with a dash indicate that there was no extraction during these months. It is assumed that months with blanks prior to 2009 were also nil returns, but this cannot be confirmed.

Table 2: Offshore Extraction Area

Offshore Extraction Area. Volumes in m^3																
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
September				2750	7420	12800	7760	5000	10520	3,748	7,760	10,660	9,320	13,925	14,580	13,660
October				3160	5980	7600	7530	6900	5495	8,096	10,680	15,480	10,120	13,540	6,720	12,060
November				7360	4780	4600	7360	10660	7660	8,990	10,880	12,060	11,020	15,120	9,540	12,750
December				4600	5105	7300	5630	5920	3620	4,430	6,900	7,460	8,740	11,560	7,820	10,460
January				2720	5980	6860	5260	4100	7645	4,557	10,120	8,740	7,820	14,560	6,420	12,360
February				7820	8170	5440	9740	7240	7128	9,660	9,391	9,140	8,960	10,520	8,240	13,140
March				5112	8300	5980	6220	6420	6268	7,082	8,000	9,530	10,400	15,000	9,820	12,850
April				3680	7550	6440	5760	6380	5260	6,350	12,660	11,120	13,540	11,240	9,300	11,800
May				5520	9600	10768	7050	7660	9722	7,240	8,820	11,880	12,980	13,980	12,760	10,940
June				1840	5520	6260	7700	4790	7738	5,920	9,186	10,440	10,620	15,370	8,720	11,040
July				6820	6430	6820	8180	5365	5000	9,220	11,379	10,100	10,900	14,060	14,060	10,530
August				4600	9270	2300	6780	4960	3160	7,360	10,560	10,580	13,980	13,160	10,340	11,960
TOTAL	**97,354**	**72,980**	**60,834**	**55,982**	**84,105**	**83,168**	**84,970**	**75,395**	**79,216**	**82,653**	**116,336**	**127,190**	**128,400**	**162,035**	**118,320**	**143,550**

Appendix B. MBL 2019 Instrument deployment and Bathymetric survey locations.



Sampling Type	Sample ID	X	Y
Acoustic Array	Acoustic Array 1	1750851	5995793
Acoustic Array	Acoustic Array 2	1752498	5992846
Acoustic Array	Acoustic Array 1	1750862	5995765
Acoustic Array Dredge	No. 1	1747659	6002414
Acoustic Array Dredge	No. 2	1747849	6002187
Acoustic Array Dredge	No. 3	1747968	6002032
Acoustic Array Dredge	No. 4	1748106	6001580
Acoustic Array Dredge	No. 5	1748300	6002254
Acoustic Array Dredge	No. 6	1748219	6002338
ADCP Deployment	ADCP	1746869	6003521
MetOcean Result Sites	P1	1748099	6001106
MetOcean Result Sites	P2	1751435	5995697

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ADCP, Acoustic Array Dredge Sampling Locations and Bathymetric Survey Extents

CLIENT	McCallum Bros
PROJECT	Pakiri Sand Extraction Consent Renewal
SCALE	1:60,000 @ A3
PROJECT CODE	IZ111900
PROJECT MANAGER	IW
DRAWN	KM
PROJECT DIRECTOR	DT
DATE	12/18/2019

0 1 2 3 4 5 km

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Appendix C. Bathymetric Survey Methodology

Bathymetric Survey Methodology

All bathymetric surveys were undertaken under the supervision of Survey Worx Ltd, registered professional surveyors.

The surveys were undertaken using a WASSP WMB 3250 Multibeam and SMC IMU108 motion sensor mounted on MBL vessel Acheron III. The WASSP, GPS antenna and motion sensor were positioned on the vessel on mounts manufactured specifically for the installation of the equipment by Electronic Navigation Limited.

The WASSP typically transmits a pure tone pulse of 160 kHz and 150 ms long within a swath of120° (across-track) per 1.5° (along-track), at a ping rate varying with water depth. On receive, the signal is sampled at a rate of 15 kHz, and 224 beams are formed using the Fast Fourier Transform (FFT) algorithm. The receiving beam width in the across-track plane varies with the beam steering angle from 1.5°at normal incidence up to 3.0°at 60°. The data were acquired with Hypack/ Hysweep 2010 survey software and recorded in both the Simrad .all format and the Hypack .hsx format. Tides corrections were provided by tide models supplied by Electronic Navigation Limited.

No squat and settlement trials using total station were carried out for preparation to this survey. An estimation of the dynamic draught of the vessel was measured by computing the mean difference between data acquired (1) at survey speed and (2) while static, over a flat calibration area near compass dolphin (Port of Auckland). The measured difference was 0.06 m.

Vessel attitude and heave during survey were measured by the motion sensor, and input directly into the WASSP Processing Unit for integration by the WASSP firmware.

Vessel position was measured by a Trimble R6 model 3 GPS receiver, computing a Network (RTK GPS) solution from radio corrections. No geodetic controls on land were used.

An estimate of the sounding error budget for the survey is listed below. The estimates provided are for soundings gathered at minimum, intermediate, and maximum depth levels and are developed on system accuracies for 60° angle (outer beams). LINZ accuracy standards are indicated for information, but contract did not specify any standard to meet.

	Source of error	Depth in meters		
		30 m	35 m	40 m
a	Draught Setting	0.05	0.05	0.05
b	Variation of Draught	0.05	0.05	0.05
c	Sound Velocity	0.12	0.13	0.15
d	Spatial Variation in SV	0.1	0.1	0.1
e	Temporal Variation in SV	0.05	0.05	0.05
f	Application of Measured SV	0.05	0.05	0.05
g	Depth Measurement (Instrument)	0.3	0.32	0.35
h	Depth Measurement (Resolution)	0.01	0.01	0.01
I	Heave	0.2	0.2	0.2
j	Settlement and Squat	0.2	0.2	0.2
k	Roll, Pitch and Seabed Slope	NA	NA	NA
l	Tidal Readings	0.5	0.5	0.5
m	Co-Tidal Correction	NA	NA	NA
n	Tide Corrections	0.05	0.05	0.05
o	Trace Reading	NA	NA	NA
	Total Standard Error $\sqrt{}$ $a^2 + b^2 +$…	0.82	0.83	0.84
	LINZ accuracy standards			
	MB Special	0.34	0.36	0.39
	MB-1	0.5	0.54	0.59
	MB-2	0.67	0.72	0.78
	MB-3	0.84	0.9	0.98

Notes:

• a: No bar check was carried out. Worst-case value estimated from total station measurements standard error, and static waterline visual estimation.

• b: Estimation from change in tank contents.

• c: Based on SV-plus accuracy.

• d,e: Worst-case estimation considering size of survey area and frequency of SV casts.

• f: SV applied in WASSP WMB3250 and in post-processing with Hypack.

• g,h: Estimations from WASSP WMB3250 sounding accuracy from WASSP document, using outer beams.

• i: Significant errors in heave measurements due to sea conditions at time of acquisition

• j: Maximum error in dynamic draught estimation procedure.

• k: Not applicable. Single-beam only.

• l: Significant potential error as tide models were used instead of measurements. Maximum error estimated from comparison between lines and cross-lines.

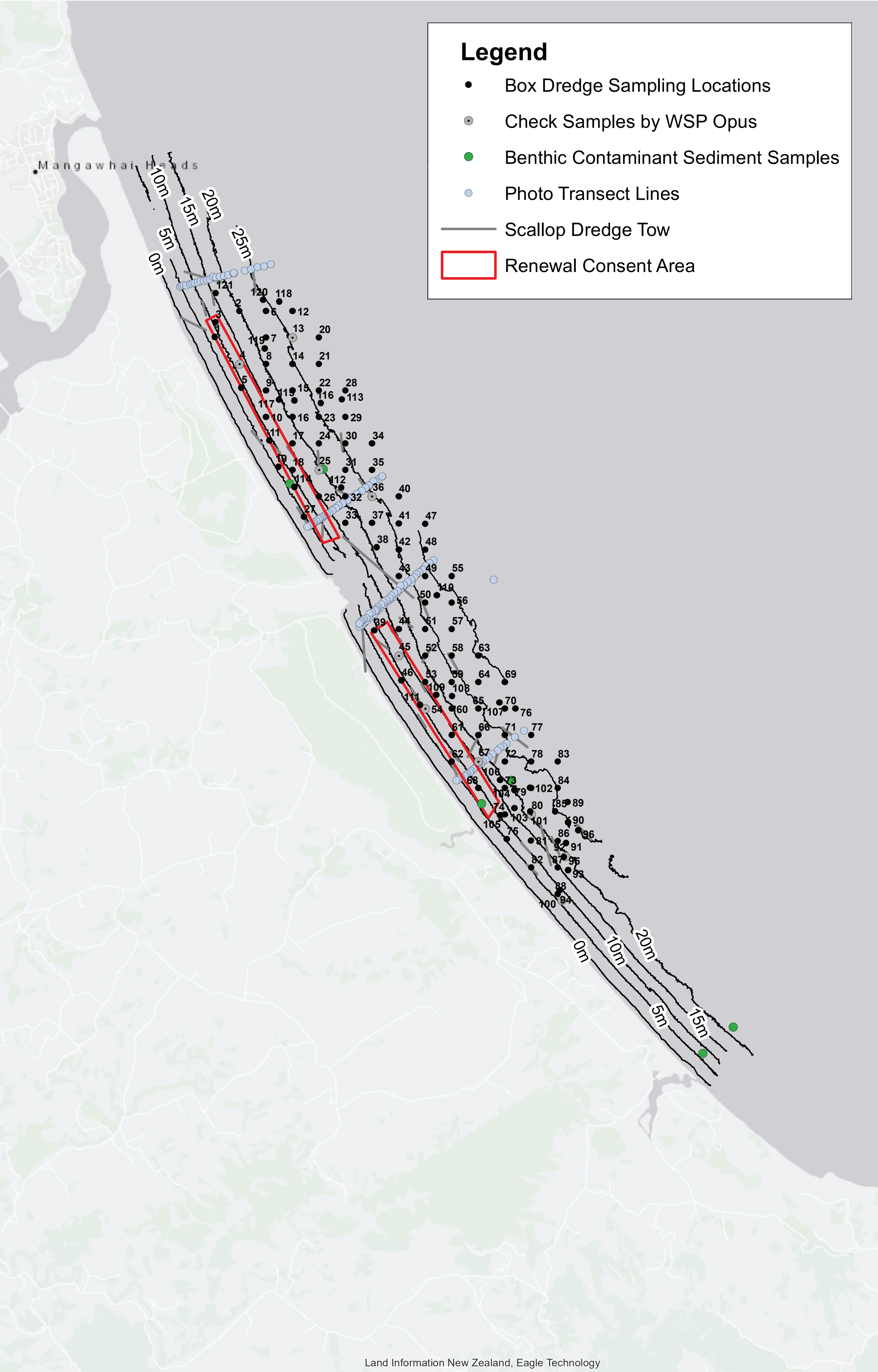
• m: Not applicable. Tide models were used.

• n: tide data sampled at 6 minutes. Interpolation is done by Hypack software.

• o: Not applicable. Soundings were derived digitally.

Appendix D. Seabed Sediment Sampling Locations

	NZTM	
Sample ID	X	Y
1	1746153	6001652
2	1746619	6002139
3	1746164	6001925
4	1746619	6001139
5	1746657	6000694
6	1747119	6002139
7	1747119	6001639
8	1747119	6001139
9	1747119	6000639
10	1747119	6000139
11	1747181	5999700
12	1747619	6002139
13	1747619	6001639
14	1747619	6001139
15	1747619	6000639
16	1747619	6000139
17	1747619	5999639
18	1747619	5999139
19	1747353	5999202
20	1748119	6001639
21	1748119	6001139
22	1748119	6000639
23	1748119	6000139
24	1748119	5999639
25	1748119	5999139
26	1748119	5998639
27	1747835	5998256
28	1748619	6000639
29	1748619	6000139
30	1748619	5999639
31	1748619	5999139
32	1748619	5998639
33	1748619	5998139
34	1749119	5999639
35	1749119	5999139
36	1749119	5998639
37	1749119	5998139
38	1749206	5997683
39	1749160	5996113
40	1749619	5998639
41	1749619	5998133
42	1749619	5997639
43	1749619	5997139
44	1749619	5996139
45	1749619	5995639
46	1749670	5995173
47	1750119	5998124
48	1750119	5997639
49	1750119	5997139
50	1750119	5996639
51	1750119	5996139
52	1750119	5995639
53	1750119	5995139
54	1750119	5994639
55	1750619	5997139
56	1750619	5996639
57	1750619	5996139
58	1750619	5995639
59	1750619	5995139
60	1750619	5994639
61	1750619	5994139
62	1750619	5993639
63	1751119	5995639
64	1751119	5995139
65	1751119	5994639
66	1751119	5994139
67	1751119	5993639
68	1751119	5993139
69	1751619	5995139
70	1751619	5994639
71	1751619	5994139
72	1751619	5993639
73	1751619	5993139
74	1751619	5992639
75	1751656	5992176
76	1751820	5994638
77	1752119	5994139
78	1752119	5993639
79	1752119	5993139
80	1752119	5992639
81	1752114	5992149
82	1752119	5991639
83	1752619	5993639
84	1752619	5993139
85	1752568	5992699
86	1752619	5992139
87	1752619	5991639
88	1752619	5991139
89	1752803	5992873
90	1752810	5992494
91	1752775	5992103
92	1752761	5991851
93	1752809	5991592
94	1752653	5991212
95	1752732	5991837
96	1753002	5992343
100	1752690	5991022
101	1752100	5992701
102	1752097	5993145
103	1751803	5992760
104	1751801	5993106
105	1751538	5992629
106	1751530	5993291
107	1751518	5994753
108	1750629	5994872
109	1750327	5994895
110	1750337	5996778
111	1750022	5994710
112	1748537	5998808
113	1748548	6000474
114	1747656	5998825
115	1747655	6000452
116	1748152	6000403
117	1747367	6000464
118	1747371	6002321
119	1747094	6001433
120	1747064	6002349
121	1746173	6002476
SED 9	1743576	6010593
SED 10	1743851	6010912
SED 11	1744814	6012020
SED 13	1744383	6011506



J:\IE\Projects\02_New Zealand\IZ111900\06 Technical\Spatial\MXD\BioDredge_SedimentSamplingLocations.mxd

CLIENT McCallum Bros	
PROJECT Pakiri Sand Extraction Consent Renewal	
SCALE 1:71,119 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

Benthic Ecology and Sediment Sampling Locations

0 1 2 3 4 5 km

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Appendix E. Pakiri Hindcast MetOcean Study: Wind, wave and current ambient and extreme statistics. Report by MetOcean Solutions, August 2019.

Pakiri Hindcast Metocean Study

Wind, wave and current ambient and extreme statistics

Report prepared for JACOBS and McCallum Bros Ltd

August 2019

MetOcean SOLUTIONS

Document History

Versions

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1.0	07/10/2019	Approved for release

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Contents

List of Tables

List of Figures

1. Introduction

JACOBS and McCallum Bros Ltd has commissioned MetOcean Solutions (MOS, subsidiary of Meteorological Service of New Zealand Ltd) to provide a summary of metocean conditions offshore Pakiri, New Zealand (Figure 1.1, Table 1.1). An overview of the metocean conditions is required to provide an initial characterisation of the environment from a marine operability perspective, plus identify potential hazards and document the important aspects of the environmental conditions that may require further attention.

Numerical hindcasting techniques are the primary source of oceanographic and meteorological data used in preparing this report, and a brief summary of the data sources is provided in Section 2. Results for the site specific wind conditions are provided in Section 3. The wave climate is detailed in Section 4. The current climate is described in Section 5. Workability statistics are given in Section 6. Extreme statistics are reported in Section 7. Metocean statistics for the period Nov 2018 – Jun 2019 are compared to the long term statistics in Section 8. Analytical methods are described in Section 9 and the references cited are listed in the final Section 10.

Note that the standard oceanographic directional conventions are applied in this report, with waves and winds reported in the 'coming from' directional reference.

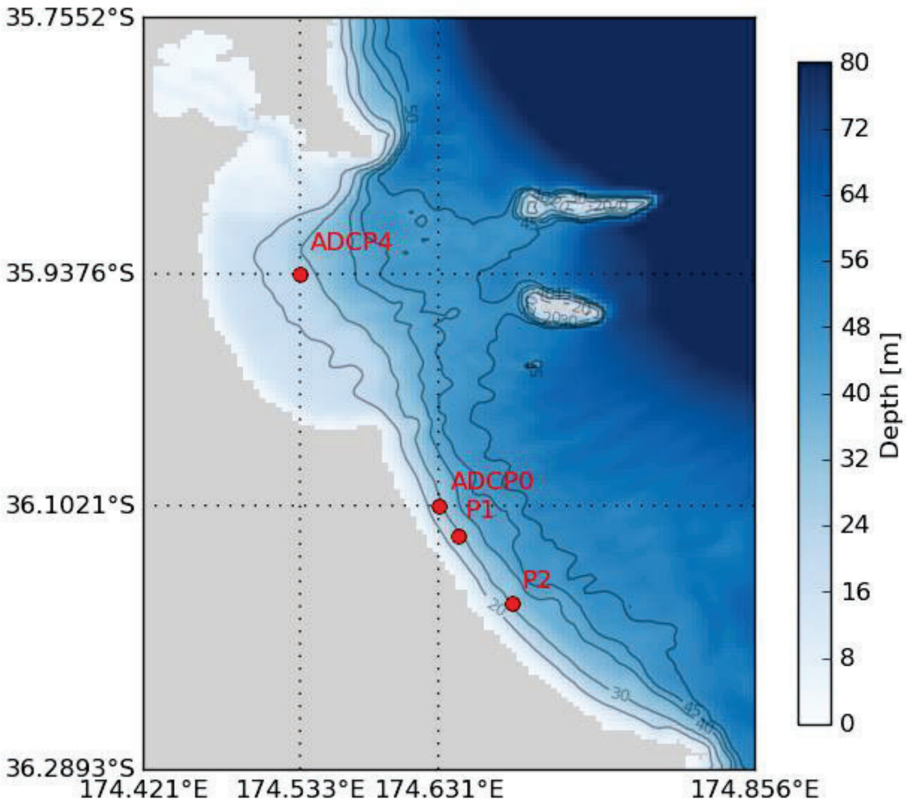

Figure 1.1 *Map showing the area of interest and the representative sites P1 and P2 offshore Pakiri, New Zealand. Also shown are the current validation sites ADCP0 and ADCP4.*

Table 1.1 *Coordinates and approximate water depth at the representative data reporting and validation sites.*

Site	World Geodetic System 1984 (WGS84)		Water depth (m)
	Longitude	Latitude	
P1	174.645715° E	36.123430° S	29
P2	174.683809°E	36.171665° S	32
ADCP0	174.631300° E	36.102070° S	25
ADCP4	174.533060° E	35.937560° S	25

2. Metocean datasources

2.1. Wind data

The near surface wind and visibility fields were prescribed by a 38-year regional atmospheric hindcast carried out by MOS. The WRF (Weather Research and Forecasting) model was established over all New Zealand at hourly intervals and 12 km resolution with a nested domain over central regions at 4 km resolution. The hindcast was specifically tuned to provide highly accurate marine wind fields for metocean studies around New Zealand.

The WRF model boundaries were sourced from the CFSR (Climate Forecast System Reanalysis) dataset distributed by NOAA (Saha et al., 2010).

Validation of the WRF reanalysis has been undertaken at various locations around New Zealand.

2.2. Wave data

Directional wave spectra within the Hauraki Gulf have been defined from a 40-year period (1979–2018) high-resolution SWAN (Simulating WAves Nearshore) wave hindcast. First, a global scale wave hindcast was produced by MetOcean Solutions Ltd using the WW3 (WAVEWATCH III) model with a resolution of 0.5° by 0.5° applying the source terms parameterizations of Ardhuin et al. (2010). The CFSR wind field was used for wind forcing and the Tolman and Chalikov (1996) physics options were applied in the model configuration. No wave height data assimilation was performed on this hindcast. These hindcast data were extracted at 3-hour intervals and were used to prescribe spectral boundaries for a regional New Zealand North Island SWAN wave model domain (at 0.04° by 0.04° resolution, i.e. approximately 4 km). Finally, a high resolution nest of the Hauraki Gulf (at 0.008° by 0.008° resolution, i.e. approximately 800 m) has been implemented and run over 37 years. Both SWAN model domains are illustrated in Figure 2.1.

SWAN is a third generation ocean wave propagation model which solves the spectral action density balance equation (Booij et al., 1999). The model simulates the growth, refraction and decay of each frequency-direction component of the complete sea state, providing a realistic description of the wave field as it changes in time and space. Physical processes that are modelled include the generation of waves by surface wind, dissipation by white-capping, resonant nonlinear interaction between the wave components, bottom friction and depth limited breaking dissipation. A detailed description of the model equations, parameterisations and numerical schemes can be found in Holthuijsen et al. (2007) and in the SWAN documentation[1]. SWAN was configured with 23 frequency bins and 36 directional bins.

SWAN was run with wind fields specified from the WRF model as described in Section 2.1. Model depths were constructed from a combination of several surveys which include multibeam, single beam, LiDAR, Electronic Nautical Charts (ENCs), obtained from different organisations (including councils, NIWA, LINZ and the Department of Conservation).

[1] http://swanmodel.sourceforge.net/online_doc/online_doc.htm

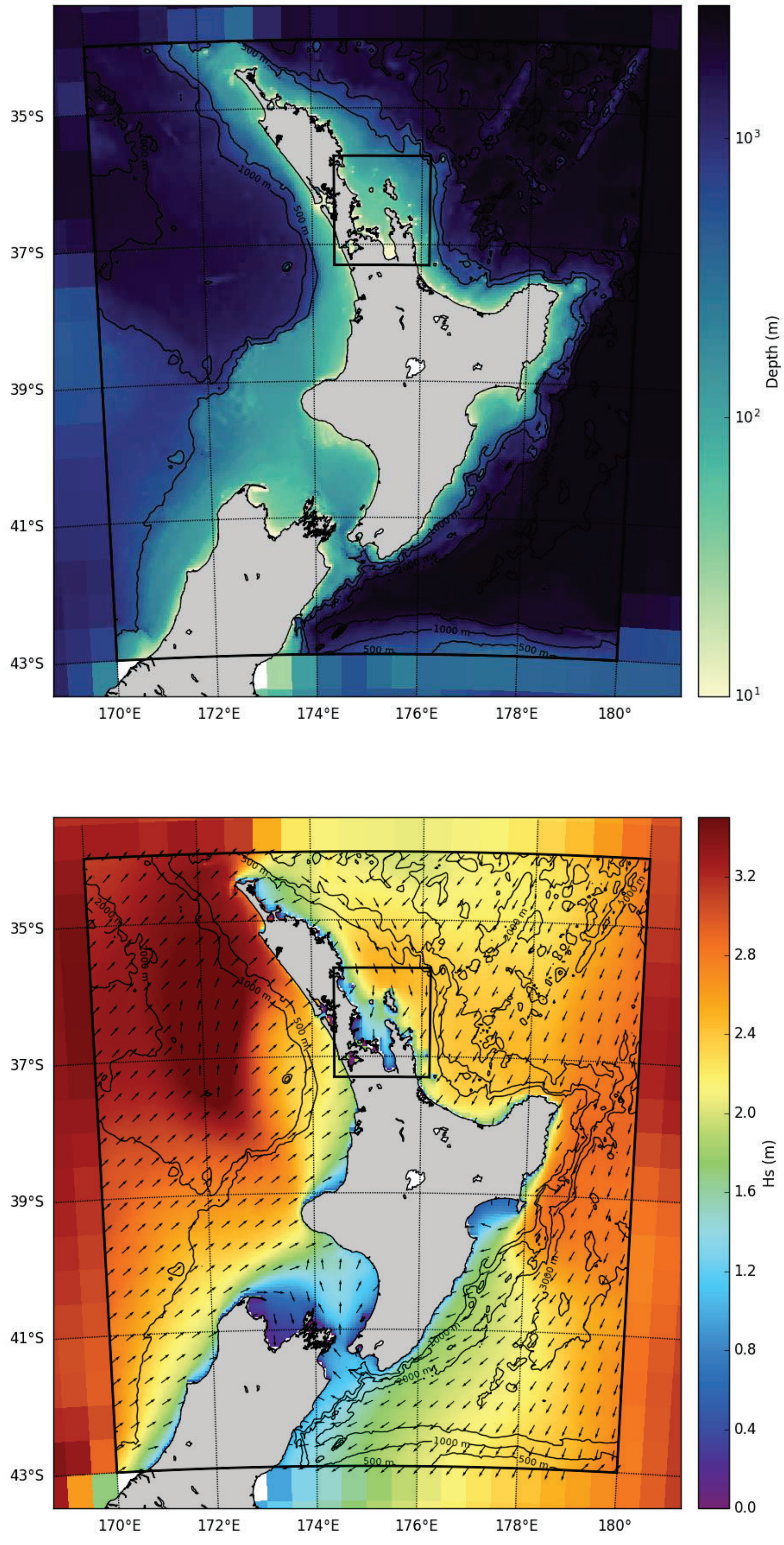

Figure 2.1. Snapshots of (top) model depths and (bottom) significant wave height from the regional NZ North Island 4-km SWAN domain on 01 January 2012, shown within the area delimited by the outer black rectangle. Model data from the 0.5° global wave model are shown outside of this area. Extension of high resolution Hauraki Gulf 800-m SWAN nest is shown by the inner black rectangle.

2.3. Current data

A 19-year (Jan 2000 – Jun 2018) hindcast was performed using the ROMS hydrodynamic model version 3.7 (Haidvogel 2008) to characterise the tidal and residual shelf scale circulation regime of the Hauraki Gulf. The application of the ROMS model at regional scale fully captures the interaction of the wind and tidal circulation with the morphology of the Hauraki Gulf. This modelling tool has been used widely in the scientific and commercial consultancy communities for a wide range of ocean basin at regional and coastal scales.

ROMS has a curvilinear horizontal coordinate system and solves the hydrostatic, primitive equations subject to a free-surface condition. It is a state-of-the-art model widely used for regional and coastal dynamics assessment. Its terrain-following vertical coordinate system results in accurate modelling of shelf seas with variable bathymetry, allowing the vertical resolution to be inversely proportional to the local depth. Besides tidal and wind-driven currents, ROMS resolves frontal structures and baroclinic pressure gradients quite well. Vertical mixing may be resolved by different separate turbulent closure schemes, that are flexible to shallow and deep water dynamics. These features make ROMS particularly well-adapted for the modelling of regional hydrodynamic systems and ROMS is one of the hydrodynamic models most used for regional study applications. It is a modern code which captures sub-, meso- and macro-scale hydrodynamic mechanisms while maintaining robustness, accuracy and numerical stability.

The ROMS model data was used to calculate ambient and extreme residual (non-tidal) current and surge statistics reported in this study.

ROMS model domains

The hindcast setup was configured with a three-level nesting approach to best transfer the energy gradually from larger to smaller coastal scales, and to properly resolve the flow associated with local and remote forcing, both essential for the resultant currents in the area of interest. The open boundary conditions that were imposed to the highest level nest (NZ) consisted of tri-dimensional velocity, temperature, salinity and sea surface height fields derived from the 6-hourly Climate Forecast System Reanalysis (CFSR) product (Saha et al., 2010) from the National Centers for Environmental Prediction (NCEP), which consisted of a 0.5 degree global reanalysis with comprehensive data assimilation.

The larger scale ROMS nest encompassed the entire New Zealand area with 7 km horizontal resolution, the goal of which was to absorb the basin scale circulation estimated by the CFSR global reanalysis, thus avoiding a large parent-to-child resolution step. This domain, called NZ hereinafter, was able to more adequately capture the oceanic circulation and its variability. The second domain (HRKI) covered the entire Hauraki Gulf and continental shelf surrounding the area of interest with a horizontal resolution of 1.7 km. With this grid spacing, the local bathymetry was more accurately captured resulting in fine scale representation of the local coastal currents. The third domain (Pakiri) covers the northern Hauraki Gulf including the area of interest with a much higher resolution (350 m), and resolved the detailed, local wind-driven and tidal circulation, producing accurate currents and thermohaline fields to support the subsequent local scale hydrodynamic models.

The 3D flow and thermohaline fields were transferred from the top level domains to the refined ones by the offline one-way nesting technique commonly used with ROMS.CFSR 3D fields were fed to NZ at 6-hourly intervals and NZ-HRKI and HRKI / Pakiri ROMS at 3-hourly intervals.

All ROMS domains were submitted to spin-up phases prior to the 19-year hindcast period to allow the adjustment of the coarser initial conditions to higher resolution and its better represented bathymetry. The spin-up times were hierarchically established according to the main scales that each one was required to resolve. This information, along with all other relevant information for each of the hydrodynamic model domains considered for this study, is summarised in Table 2.1. The bathymetry for the ROMS grids was derived from electronic navigation charts and field data whenever available.

Table 2.1 ROMS model nests configurations.

Model Settings	NZ	HRKI	Pakiri
Horizontal Resolution	8 km (0.08° x 0.06°)	1.7 km (0.02° x 0.02°)	400-300 m (0.004° x 0.003°)
Dimension	3D	3D	3D
Vertical layers	30	19	N.A.
Tidal forcing	No	No	Yes
Meteo forcing	MSL WRF NZRA	MSL WRF NZRA	MSL WRF NZRA

ROMS model validation

The final hydrodynamic hindcast product was validated against co-temporal current time series obtained from measured data at locations ADCP4 and ADCP0 as illustrated in *Figure 2.2*.

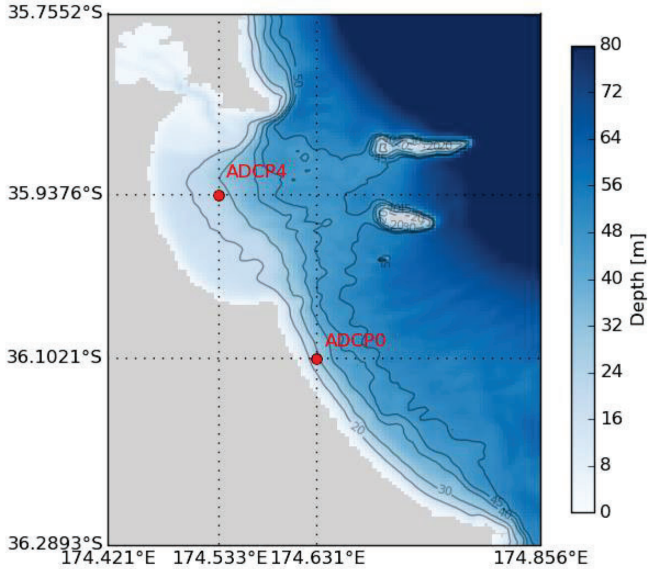

Figure 2.2. *Bathymetry map showing the measurement locations.*

Modelled and measured current time series were vertically-averaged from 5 to 25 m depth and re-sampled to 1-hour intervals for a consistent time-domain comparison of total, non-tidal and tidal currents. The tidal flow was obtained from a harmonic decomposition. A 30-hour low-pass filter was applied to separate the non-tidal flow from the total signal. This approach was used in order to reduce potential noise contamination from the t due to the short time extent of the measured current data used for the analysis.

Although the period covered by the measurements are not long enough to assess the model performance throughout all possible weather scenarios, results from modelled and measured depth-averaged currents comparison indicate the model resolves faithfully the circulation regime at both locations (*Figure 2.3*-*Figure 2.8*). Flow orientation and direction are reasonably well reproduced by the model, as shown on the Rose plots (*Figure 2.5*-*Figure 2.6*). The model generally underestimates the current magnitudes by approximately 30% (*Figure 2.3*-*Figure 2.4*), which in part is due to non-tidal (residual) flow forced by strong wind events not being well replicated and an overall underestimation of the tidal magnitudes.

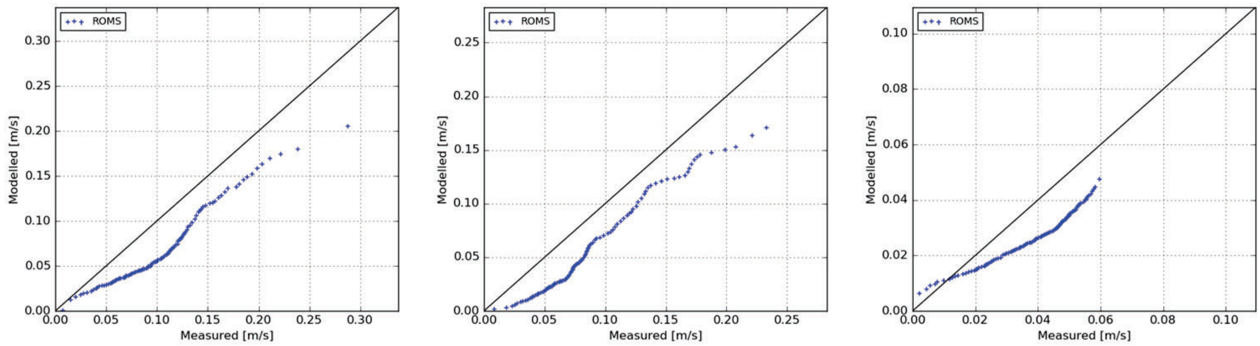

Figure 2.3. Quantile-Quantile plots of the measured and modelled total (left), non-tidal (center) and tidal (right) depth-averaged current speed at location ADCP4 (12 June – 13 July 2016).

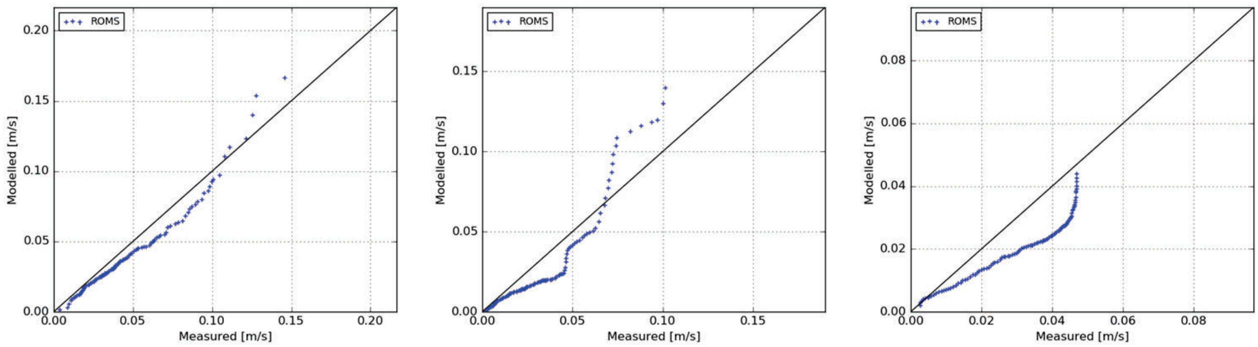

Figure 2.4. Quantile-Quantile plots of the measured and modelled total (left), non-tidal (center) and tidal (right) depth-averaged current speed at location ADCP0 (20 – 31 May 2019).

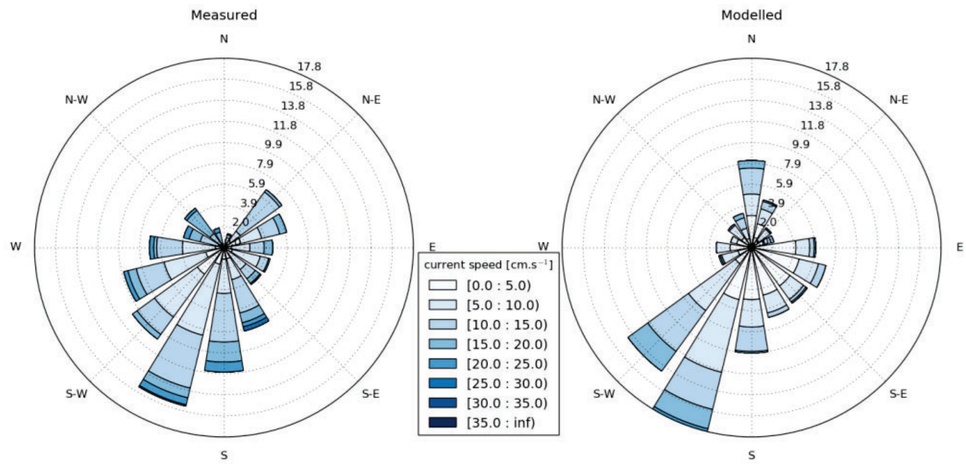

Figure 2.5. Measured (left) and modelled (right) total depth-averaged current rose at location ADCP4 (12 June – 13 July 2016).

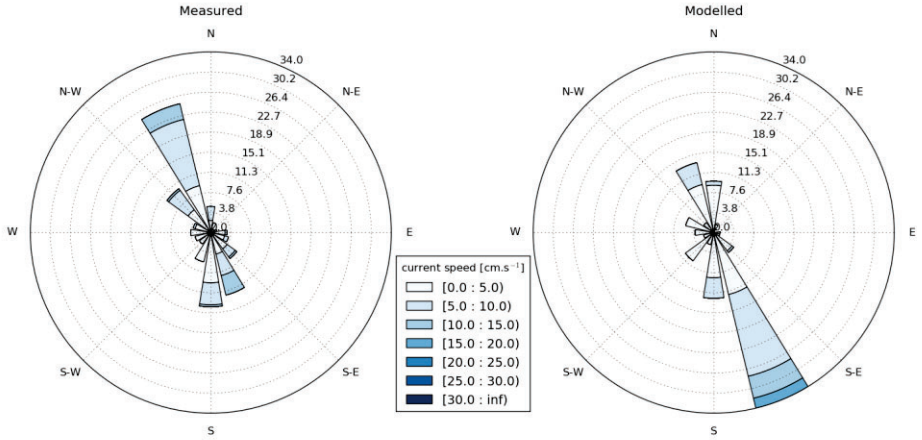

Figure 2.6. Measured (left) and modelled (right) total depth-averaged current rose at location ADCP0 (20 – 31 May 2019).

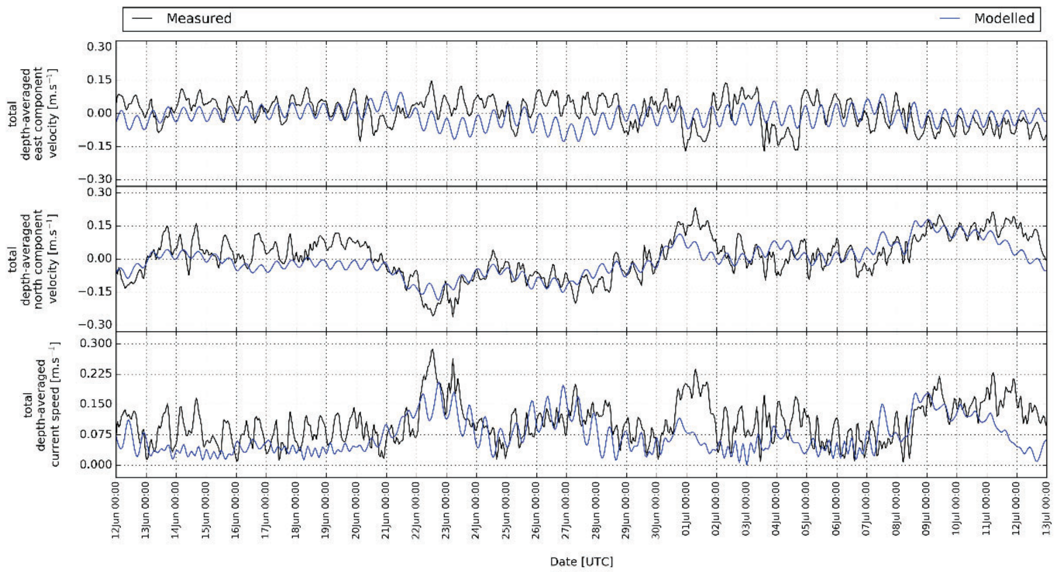

Figure 2.7. Time series of modelled (blue) and measured (black) total depth-averaged current velocity at location ADCP4 (12 June – 13 July 2016).

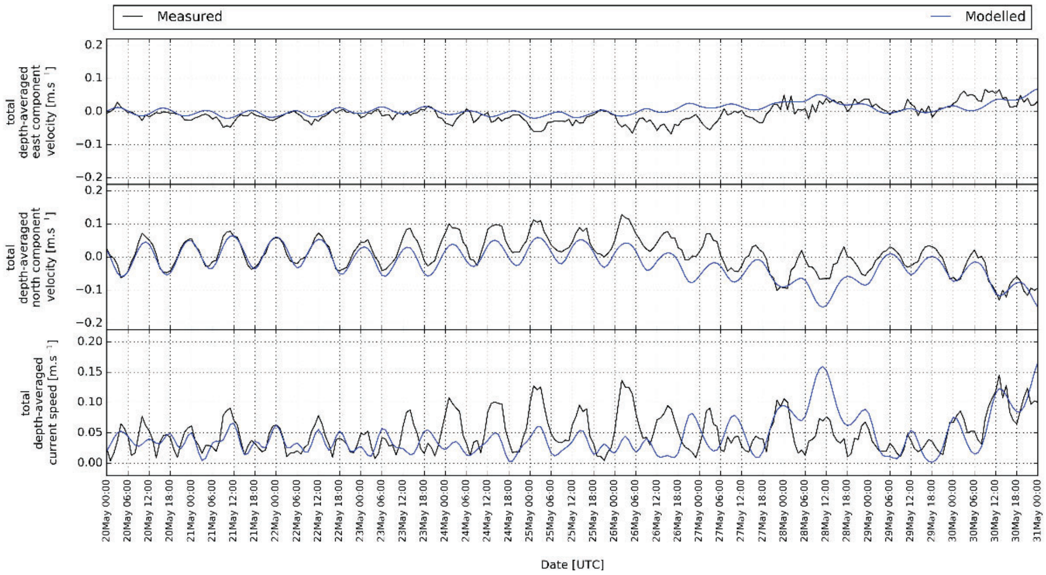

Figure 2.8. Time series of modelled (blue) and measured (black) total depth-averaged current velocity at location ADCP0 (20 – 31 May 2019).

3. Wind climate

3.1. P1

A summary of the wind speed statistics for the 10-minute mean at 10 m elevation at P1 is provided in Table 3.1.

The monthly and annual 10-min wind speed exceedance probabilities are provided in Table 3.2, and indicate the wind speeds exceeding 18 m.s^{-1} can occur throughout the year, with March having the highest occurrence of strong wind events at P1.

The annual joint probability distribution of the wind speed and direction is presented in Table 3.3.

The annual and monthly non-exceedance persistence probabilities for 10-min wind speed at P1 (Table 3.4 to Table 3.15) can be used to estimate the operational uptime for tasks with wind speed limitations of variable duration. For example, at P1 on average in February, wind speeds are less than 4.0 m.s^{-1} for durations of 36 hours and greater for 1.43% of the time (Table 3.5).

The monthly and annual 10-min wind roses are illustrated in Figure 3.1, showing the annual predominance of winds coming mainly from the WSW quadrants.

Table 3.1 Annual and monthly 10-min wind speed statistics at P1.

Period (01 Jan 1979 – 31 Dec 2018)	10-min wind speed statistics (1)												
	10-min wind speed (m/s)			Exceedance percentile for 10-min wind speed (m/s)									Main (4) Direction(s)
	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	20.96	6.03	2.90	0.80	1.78	2.53	5.76	8.31	9.78	11.24	13.03	14.12	NE SW
February	19.19	5.88	2.85	0.70	1.68	2.35	5.64	8.08	9.58	10.86	12.85	14.14	E SW
March	25.43	6.10	2.95	0.78	1.77	2.48	5.86	8.40	9.89	11.28	13.31	14.32	E SW
April	21.49	6.01	2.88	0.87	1.75	2.46	5.73	8.33	9.79	11.21	12.76	13.76	SW
May	21.57	6.44	3.03	0.85	1.83	2.62	6.18	8.93	10.51	11.79	13.28	14.35	SW W
June	24.44	6.84	3.25	0.94	1.96	2.84	6.52	9.42	11.10	12.81	14.57	15.82	SW W
July	24.38	7.01	3.48	0.98	2.06	2.92	6.51	9.67	11.77	13.69	15.59	16.73	SW W
August	20.58	6.77	3.22	1.03	2.03	2.84	6.38	9.29	11.15	12.76	14.47	15.55	SW W
September	22.17	6.79	3.16	0.88	2.01	2.82	6.55	9.29	10.90	12.45	14.27	15.66	SW W
October	20.93	6.74	2.99	0.91	2.06	2.88	6.58	9.20	10.74	11.97	13.43	14.29	SW W
November	19.96	6.52	2.93	0.94	2.09	2.81	6.31	8.86	10.30	11.66	13.23	14.62	SW W
December	20.54	6.04	2.80	0.82	1.88	2.65	5.80	8.25	9.79	11.09	12.60	13.75	N SW W
Winter(3)	24.44	6.87	3.32	0.98	2.02	2.87	6.47	9.46	11.34	13.08	14.91	16.12	SW W
Spring	22.17	6.69	3.03	0.91	2.05	2.84	6.48	9.12	10.66	12.05	13.66	14.86	SW W
Summer(2)	20.96	5.98	2.85	0.78	1.78	2.51	5.73	8.23	9.72	11.07	12.84	13.98	E SW
Autumn	25.43	6.19	2.96	0.83	1.78	2.51	5.92	8.56	10.10	11.48	13.12	14.21	SW
All	25.43	6.43	3.07	0.87	1.90	2.66	6.14	8.84	10.47	11.98	13.77	14.98	SW W

Notes: (1) All statistics derived from hindcast wind data (10-min mean at 10 m AMSL) for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the winds approach.

Table 3.2 Monthly and annual 10-min wind speed exceedance probabilities (%) at P1.

U_{10min} (m/s)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>2	93.58	92.87	93.63	93.31	93.98	94.80	95.25	95.20	95.01	95.28	95.45	94.33	94.40
>4	74.15	72.87	74.65	74.75	77.57	80.67	80.97	80.20	80.77	81.61	79.74	75.43	77.80
>6	46.57	44.71	47.94	46.00	52.59	56.53	56.65	55.10	57.21	57.59	54.37	46.77	51.87
>8	22.70	20.71	23.38	22.96	29.16	32.83	33.38	31.33	32.45	31.76	28.92	21.94	27.66
>10	8.97	8.10	9.50	9.00	12.86	15.94	17.88	15.44	14.81	14.14	11.62	8.95	12.29
>12	3.49	2.83	3.75	3.42	4.45	7.03	9.23	7.04	6.26	4.95	4.08	2.78	4.96
>14	1.10	1.07	1.27	0.88	1.26	2.83	4.28	2.66	2.28	1.23	1.36	0.82	1.76
>16	0.37	0.30	0.41	0.27	0.32	0.85	1.64	0.75	0.82	0.23	0.40	0.21	0.55
>18	0.13	0.06	0.15	0.08	0.06	0.26	0.55	0.21	0.21	0.06	0.14	0.06	0.17
>20	0.03	0.00	0.07	0.03	0.01	0.06	0.27	0.05	0.04	0.02	0.00	0.03	0.05
>22	0.00	0.00	0.05	0.00	0.00	0.01	0.08	0.00	0.01	0.00	0.00	0.00	0.01
>24	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.3 Annual joint probability distribution (in %) of the wind speed and wind direction at P1.

U10min (m/s)	Wind direction (degT)									
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5	Total	Exceed%
>0<=2	0.72	0.75	0.65	0.45	0.62	0.93	0.82	0.65	5.59	100.00
>2<=4	1.97	2.20	1.93	1.55	1.98	3.11	2.16	1.71	16.61	94.40
>4<=6	2.66	2.33	2.36	2.21	2.70	6.07	4.32	3.28	25.93	77.80
>6<=8	2.50	2.03	2.35	1.70	1.51	6.45	4.73	2.94	24.21	51.87
>8<=10	2.02	1.40	1.68	1.13	0.67	3.51	3.35	1.60	15.36	27.66
>10<=12	1.35	0.84	1.05	0.62	0.25	1.22	1.36	0.64	7.33	12.29
>12<=14	0.69	0.57	0.57	0.38	0.08	0.30	0.43	0.18	3.20	4.96
>14<=16	0.24	0.28	0.29	0.17	0.02	0.08	0.09	0.04	1.21	1.76
>16<=18	0.07	0.09	0.11	0.06	0.01	0.01	0.02	0.01	0.38	0.55
>18<=20	0.02	0.03	0.05	0.01	*	*	*	*	0.11	0.17
>20<=22	0.01	0.01	0.01	0.01	-	-	-	*	0.04	0.05
>22<=24	*	*	*	0.01	-	-	-	-	0.01	0.01
>24<=26	-	*	-	*	-	-	-	-		
Total	12.25	10.53	11.05	8.30	7.84	21.68	17.28	11.05	100.00	

Notes: * represents less than 0.005%.

Table 3.4 Annual and monthly non-exceedance persistence (%) for wind speed below 2.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	1.16	0.05	0.00	0.00	0.00	0.00	0.00
Feb	1.71	0.30	0.00	0.00	0.00	0.00	0.00
Mar	1.56	0.16	0.00	0.00	0.00	0.00	0.00
Apr	2.54	0.93	0.16	0.00	0.00	0.00	0.00
May	2.42	1.21	0.18	0.10	0.00	0.00	0.00
Jun	2.02	0.90	0.07	0.00	0.00	0.00	0.00
Jul	1.39	0.36	0.08	0.00	0.00	0.00	0.00
Aug	1.68	0.66	0.00	0.00	0.00	0.00	0.00
Sep	1.67	0.47	0.07	0.00	0.00	0.00	0.00
Oct	1.20	0.25	0.00	0.00	0.00	0.00	0.00
Nov	0.70	0.05	0.00	0.00	0.00	0.00	0.00
Dec	0.52	0.05	0.00	0.00	0.00	0.00	0.00
annual	1.56	0.45	0.05	0.01	0.00	0.00	0.00

Table 3.5 Annual and monthly non-exceedance persistence (%) for wind speed below 4.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	18.55	10.60	5.23	2.77	1.34	0.34	0.00
Feb	20.09	12.71	6.88	3.62	1.43	0.33	0.33
Mar	18.80	13.11	7.49	3.98	2.34	1.65	0.29
Apr	19.56	14.33	9.33	6.73	3.80	1.90	0.30
May	17.35	13.28	9.22	7.39	3.63	1.37	0.00
Jun	14.49	10.35	7.40	5.47	2.67	1.78	0.60
Jul	14.70	10.48	6.94	4.90	2.49	1.12	0.72
Aug	14.17	9.52	5.73	3.22	1.88	0.74	0.00
Sep	13.82	9.74	5.76	3.67	1.82	0.38	0.00
Oct	13.00	8.06	3.64	1.65	0.62	0.00	0.00
Nov	13.98	7.48	3.17	1.58	0.74	0.60	0.00
Dec	16.92	8.97	4.12	1.98	0.33	0.17	0.00
annual	16.42	10.88	6.35	4.01	2.00	0.92	0.19

Table 3.6 Annual and monthly non-exceedance persistence (%) for wind speed below 6.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	48.94	43.69	35.72	30.92	25.01	17.41	9.56
Feb	50.66	46.30	38.94	33.44	26.73	16.28	9.71
Mar	47.44	42.06	36.18	31.62	25.83	18.25	9.12
Apr	49.85	44.65	39.97	35.59	29.28	21.57	12.54
May	42.88	39.18	35.74	31.91	26.60	21.85	13.34
Jun	39.29	35.58	31.32	28.24	22.56	16.84	7.68
Jul	38.72	33.85	29.74	26.38	19.97	14.50	7.79
Aug	40.31	35.47	29.63	26.15	19.34	13.13	5.14
Sep	37.63	32.34	26.76	22.48	18.69	14.08	7.73
Oct	37.58	31.53	24.42	19.38	14.59	9.85	5.46
Nov	40.30	33.79	25.29	21.69	15.62	9.51	4.49
Dec	47.98	41.74	33.05	27.03	21.57	13.85	6.81
annual	43.62	38.64	32.60	28.28	22.73	16.11	8.94

Table 3.7 Annual and monthly non-exceedance persistence (%) for wind speed below 8.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	74.96	72.31	68.22	64.72	60.63	52.99	43.66
Feb	76.91	74.56	71.93	68.86	64.99	58.80	48.85
Mar	74.32	71.74	68.82	66.89	62.76	59.81	48.95
Apr	74.44	71.40	69.42	67.00	63.39	56.64	47.73
May	67.51	64.98	62.16	59.60	54.26	48.03	39.94
Jun	63.94	61.63	58.58	56.06	49.77	43.39	32.56
Jul	63.83	60.72	57.73	54.83	47.94	43.04	31.84
Aug	65.90	63.18	60.45	57.72	51.81	44.66	31.49
Sep	64.48	61.04	56.57	52.93	47.26	42.08	32.25
Oct	65.00	62.02	56.49	53.18	47.91	39.80	28.58
Nov	68.12	63.82	57.66	53.37	47.73	40.06	30.50
Dec	76.01	73.30	68.66	64.01	60.55	51.46	40.41
annual	69.73	66.98	63.53	60.50	55.88	49.84	40.11

Table 3.8 Annual and monthly non-exceedance persistence (%) for wind speed below 10.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	90.18	89.47	88.65	87.60	85.32	82.39	77.31
Feb	91.34	90.43	89.56	88.47	87.52	85.25	80.91
Mar	89.49	88.73	87.51	86.32	84.79	82.15	78.09
Apr	90.01	88.93	88.34	87.65	85.80	82.64	76.39
May	85.57	84.28	82.64	81.36	78.63	74.19	68.22
Jun	82.35	80.31	78.69	77.76	74.27	70.44	60.68
Jul	80.21	78.84	77.04	75.31	71.08	67.44	59.38
Aug	82.97	81.45	79.84	78.31	75.24	70.86	60.98
Sep	83.39	81.68	79.82	77.98	73.05	67.47	59.29
Oct	84.67	82.82	80.57	78.80	74.97	70.58	62.03
Nov	87.53	85.71	83.45	82.23	79.17	74.02	65.88
Dec	90.14	88.98	87.66	86.63	84.35	80.74	76.15
annual	86.52	85.30	84.03	82.94	80.50	77.14	71.42

Table 3.9 Annual and monthly non-exceedance persistence (%) for wind speed below 12.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	96.14	95.93	95.71	95.57	95.25	94.49	92.13
Feb	96.92	96.67	96.55	96.29	95.75	95.41	93.87
Mar	95.90	95.70	95.43	95.04	94.41	93.50	91.45
Apr	96.20	95.64	95.35	94.86	94.30	93.00	90.42
May	94.98	94.46	94.06	93.33	92.24	91.10	87.33
Jun	92.33	91.70	91.25	90.31	88.57	86.63	81.49
Jul	89.78	89.00	88.41	87.54	85.92	83.39	76.59
Aug	92.23	91.74	90.69	89.88	88.11	86.80	81.60
Sep	93.07	92.49	91.63	90.94	89.74	86.61	82.10
Oct	94.53	93.89	93.11	92.25	91.18	88.13	84.44
Nov	95.54	95.24	94.52	94.08	93.43	91.98	89.49
Dec	97.05	96.68	96.11	95.51	94.98	94.27	92.46
annual	94.57	94.19	93.79	93.30	92.66	91.58	89.16

Table 3.10 Annual and monthly non-exceedance persistence (%) for wind speed below 14.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	98.65	98.59	98.41	98.41	98.41	98.26	97.82
Feb	98.83	98.71	98.57	98.48	98.38	98.38	97.96
Mar	98.57	98.46	98.30	98.30	98.19	98.03	97.64
Apr	99.00	98.96	98.79	98.79	98.57	98.41	98.16
May	98.57	98.42	98.31	98.17	98.06	97.77	96.96
Jun	96.91	96.47	96.24	96.07	95.66	94.56	93.07
Jul	95.16	94.97	94.81	94.52	93.89	93.34	90.40
Aug	97.07	96.84	96.78	96.56	95.64	94.88	93.54
Sep	97.44	97.33	96.88	96.72	96.30	94.77	93.54
Oct	98.69	98.63	98.57	98.28	97.83	97.25	95.70
Nov	98.53	98.53	98.42	98.26	98.04	97.76	96.82
Dec	99.08	99.05	99.00	98.92	98.92	98.48	98.10
annual	98.06	97.95	97.85	97.76	97.66	97.51	97.07

Table 3.11 Annual and monthly non-exceedance persistence (%) for wind speed below 16.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	99.58	99.58	99.53	99.53	99.43	99.43	99.43
Feb	99.68	99.63	99.57	99.49	99.26	99.26	98.77
Mar	99.56	99.56	99.56	99.48	99.48	99.48	99.48
Apr	99.71	99.64	99.64	99.64	99.53	99.36	99.36
May	99.65	99.55	99.55	99.47	99.47	99.47	99.47
Jun	99.10	99.02	99.02	98.95	98.75	98.58	98.18
Jul	98.18	98.08	98.02	97.94	97.63	97.21	95.98
Aug	99.14	99.04	98.99	98.99	98.68	98.53	98.17
Sep	99.08	99.08	98.98	98.68	98.68	98.21	97.13
Oct	99.77	99.77	99.77	99.77	99.77	99.77	99.34
Nov	99.60	99.60	99.60	99.60	99.60	99.47	98.76
Dec	99.78	99.78	99.73	99.73	99.73	99.58	99.37
annual	99.41	99.39	99.36	99.32	99.31	99.28	99.21

Table 3.12 Annual and monthly non-exceedance persistence (%) for wind speed below 18.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.83	99.83	99.83	99.83	99.83	99.83	99.83
Feb	99.94	99.94	99.89	99.89	99.89	99.89	99.65
Mar	99.83	99.83	99.83	99.83	99.83	99.83	99.83
Apr	99.92	99.92	99.92	99.92	99.92	99.92	99.74
May	99.93	99.93	99.93	99.93	99.93	99.93	99.93
Jun	99.72	99.69	99.64	99.64	99.54	99.38	99.17
Jul	99.39	99.35	99.29	99.29	99.29	99.29	99.09
Aug	99.79	99.79	99.79	99.79	99.79	99.79	99.61
Sep	99.76	99.76	99.76	99.76	99.76	99.60	99.18
Oct	99.94	99.94	99.94	99.94	99.94	99.94	99.76
Nov	99.83	99.83	99.83	99.83	99.83	99.68	99.68
Dec	99.94	99.94	99.94	99.94	99.94	99.94	99.94
annual	99.82	99.82	99.81	99.81	99.81	99.81	99.81

Table 3.13 Annual and monthly non-exceedance persistence (%) for wind speed below 20.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.93	99.93	99.93	99.93	99.93	99.93	99.93
Apr	99.97	99.97	99.97	99.97	99.97	99.97	99.97
May	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Jun	99.94	99.94	99.89	99.89	99.79	99.79	99.79
Jul	99.70	99.63	99.63	99.63	99.63	99.63	99.63
Aug	99.95	99.95	99.95	99.95	99.95	99.95	99.95
Sep	99.96	99.96	99.96	99.96	99.96	99.96	99.96
Oct	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	99.97	99.97	99.97	99.97	99.97	99.97	99.97
annual	99.95	99.94	99.94	99.94	99.94	99.94	99.94

Table 3.14 Annual and monthly non-exceedance persistence (%) for wind speed below 22.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.95	99.95	99.95	99.95	99.95	99.95	99.95
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Jul	99.91	99.91	99.91	99.91	99.91	99.91	99.91
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	99.99	99.99	99.99	99.99	99.99	99.99	99.99

Table 3.15 Annual and monthly non-exceedance persistence (%) for wind speed below 24.0 m/s at P1.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Jul	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	100.00	100.00	100.00	100.00	100.00	100.00	100.00

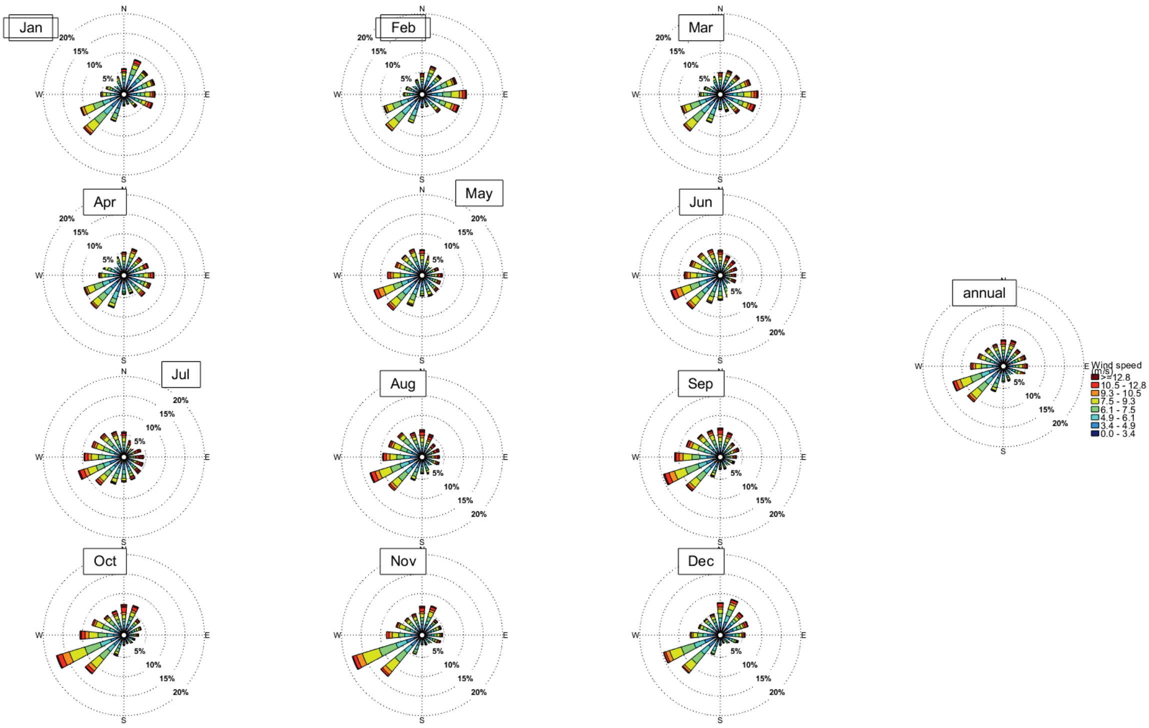

Figure 3.1 Monthly and annual wind rose plot (10-minute mean at 10 m AMSL) at P1. Sectors indicate the direction from which the winds blow.

3.2. P2

A summary of the wind speed statistics for the 10-minute mean at 10 m elevation at P2 is provided in Table 3.16.

The monthly and annual 10-min wind speed exceedance probabilities are provided in Table 3.17, and indicate the wind speeds exceeding 18 $m.s^{-1}$ can occur throughout the year, with March having the highest occurrence of strong wind events at P2.

The annual joint probability distribution of the wind speed and direction is presented in Table 3.18.

The annual and monthly non-exceedance persistence probabilities for 10-min wind speed at P2 (Table 3.19 to Table 3.30) can be used to estimate the operational uptime for tasks with wind speed limitations of variable duration. For example, at P2 on average in February, wind speeds are less than 4.0 $m.s^{-1}$ for durations of 36 hours and greater for 3.18% of the time (Table 3.20).

The monthly and annual 10-min wind roses are illustrated in Figure 3.2, showing the annual predominance of winds coming mainly from the SW quadrants.

Table 3.16 Annual and monthly 10-min wind speed statistics at P2.

Period (01 Jan 1979 – 31 Dec 2018)	10-min wind speed statistics [1]												
	10-min wind speed (m/s)			Exceedance percentile for 10-min wind speed (m/s)									Main [4] Direction(s)
	max	**mean**	**std**	**p1**	**p5**	**p10**	**p50**	**p80**	**p90**	**p95**	**p98**	**p99**	
January	20.24	5.83	2.81	0.89	1.79	2.51	5.51	8.06	9.51	10.99	12.74	13.69	NE SW
February	18.46	5.69	2.76	0.82	1.72	2.35	5.39	7.80	9.33	10.61	12.50	13.76	E SW
March	24.84	5.91	2.86	0.77	1.78	2.47	5.65	8.11	9.61	11.05	12.91	13.94	E SW
April	21.42	5.83	2.80	0.81	1.74	2.44	5.50	8.08	9.54	10.94	12.43	13.51	SW
May	21.05	6.28	2.98	0.87	1.83	2.57	5.97	8.74	10.31	11.51	13.10	14.04	SW W
June	23.61	6.67	3.20	0.94	1.96	2.80	6.34	9.24	10.89	12.60	14.26	15.45	SW W
July	23.37	6.84	3.41	0.92	2.06	2.88	6.31	9.44	11.54	13.39	15.24	16.39	SW W
August	20.54	6.59	3.17	0.96	1.95	2.76	6.19	9.13	10.91	12.50	14.21	15.22	SW W
September	21.74	6.63	3.11	0.82	1.88	2.78	6.38	9.09	10.70	12.24	14.05	15.38	SW W
October	20.24	6.56	2.92	1.03	2.09	2.84	6.37	8.98	10.48	11.77	13.15	13.95	SW W
November	19.93	6.33	2.86	1.00	2.09	2.80	6.10	8.63	10.09	11.42	12.95	14.24	SW W
December	19.89	5.86	2.72	0.93	1.91	2.62	5.56	8.01	9.51	10.81	12.34	13.36	N SW W
Winter[3]	23.61	6.70	3.26	0.94	2.00	2.82	6.29	9.27	11.09	12.80	14.62	15.77	SW W
Spring	21.74	6.51	2.97	0.95	2.01	2.81	6.28	8.89	10.41	11.81	13.36	14.55	SW W
Summer[2]	20.24	5.79	2.76	0.86	1.80	2.49	5.49	7.95	9.45	10.82	12.52	13.62	E SW
Autumn	24.84	6.01	2.89	0.81	1.79	2.49	5.71	8.32	9.85	11.23	12.82	13.87	SW
All	24.84	6.26	3.00	0.88	1.89	2.64	5.93	8.62	10.24	11.73	13.47	14.66	SW W

Notes: (1) All statistics derived from hindcast wind data (10-min mean at 10 m AMSL) for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the winds approach.

Table 3.17 Monthly and annual 10-min wind speed exceedance probabilities (%) at P2.

U_{10min} (m/s)	Exceedance (%)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**annual**
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>2	93.74	93.02	93.60	93.36	93.89	94.91	95.34	94.75	94.46	95.31	95.44	94.46	94.36
>4	72.27	71.21	73.11	73.19	75.82	79.19	80.01	78.68	79.76	80.24	78.49	73.75	76.33
>6	42.96	41.04	44.87	42.60	49.63	54.26	54.17	52.52	55.10	55.16	51.32	43.26	48.95
>8	20.47	18.21	20.88	20.76	27.42	30.92	31.76	29.24	30.46	29.33	26.29	20.07	25.52
>10	7.87	7.17	8.26	8.11	11.74	14.68	16.86	14.51	13.31	12.48	10.47	7.79	11.13
>12	2.90	2.62	3.37	2.85	3.80	6.31	8.45	6.33	5.55	4.31	3.70	2.51	4.40
>14	0.80	0.84	0.96	0.70	1.02	2.36	3.76	2.25	2.02	0.95	1.09	0.70	1.46
>16	0.33	0.20	0.33	0.25	0.20	0.74	1.23	0.60	0.69	0.20	0.29	0.18	0.44
>18	0.11	0.02	0.09	0.05	0.03	0.21	0.47	0.17	0.17	0.07	0.07	0.06	0.13
>20	0.01	0.00	0.05	0.02	0.01	0.06	0.24	0.02	0.02	0.01	0.00	0.00	0.04
>22	0.00	0.00	0.05	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.01
>24	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.18 Annual joint probability distribution (in %) of the wind speed and wind direction at P2.

U10min (m/s)	Wind direction (degT)									
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5	Total	Exceed%
>0<=2	0.70	0.71	0.60	0.46	0.64	0.96	0.89	0.67	5.63	100.00
>2<=4	2.08	2.23	2.06	1.65	2.45	3.39	2.39	1.79	18.04	94.36
>4<=6	2.83	2.31	2.50	2.40	2.87	6.75	4.67	3.06	27.39	76.33
>6<=8	2.49	1.92	2.41	1.68	1.49	5.82	4.93	2.69	23.43	48.95
>8<=10	1.97	1.34	1.64	1.10	0.60	2.74	3.39	1.60	14.38	25.52
>10<=12	1.25	0.83	0.99	0.60	0.22	0.82	1.38	0.64	6.73	11.13
>12<=14	0.64	0.53	0.54	0.36	0.07	0.21	0.41	0.17	2.93	4.40
>14<=16	0.22	0.24	0.24	0.14	0.02	0.04	0.08	0.04	1.02	1.46
>16<=18	0.06	0.08	0.09	0.05	0.01	0.01	0.01	0.01	0.32	0.44
>18<=20	0.01	0.02	0.03	0.02	*	-	*	*	0.08	0.13
>20<=22	0.01	0.01	0.01	0.01	-	-	-	-	0.04	0.04
>22<=24	-	*	*	0.01	-	-	-	-	0.01	0.01
>24<=26	-	-	-	*	-	-	-	-		
Total	12.26	10.22	11.11	8.48	8.37	20.74	18.15	10.67	100.00	

Notes: * represents less than 0.005%.

Table 3.19 Annual and monthly non-exceedance persistence (%) for wind speed below 2.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	1.00	0.10	0.00	0.00	0.00	0.00	0.00
Feb	1.49	0.34	0.00	0.00	0.00	0.00	0.00
Mar	1.52	0.16	0.00	0.00	0.00	0.00	0.00
Apr	2.56	0.77	0.08	0.00	0.00	0.00	0.00
May	2.57	1.13	0.33	0.11	0.00	0.00	0.00
Jun	2.22	0.88	0.07	0.00	0.00	0.00	0.00
Jul	1.47	0.47	0.09	0.09	0.00	0.00	0.00
Aug	2.08	0.76	0.00	0.00	0.00	0.00	0.00
Sep	2.11	0.69	0.07	0.00	0.00	0.00	0.00
Oct	1.25	0.26	0.00	0.00	0.00	0.00	0.00
Nov	0.92	0.05	0.00	0.00	0.00	0.00	0.00
Dec	0.46	0.00	0.00	0.00	0.00	0.00	0.00
annual	1.65	0.47	0.05	0.02	0.00	0.00	0.00

Table 3.20 Annual and monthly non-exceedance persistence (%) for wind speed below 4.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	20.71	12.82	6.26	3.33	1.54	0.34	0.00
Feb	21.94	15.61	9.67	5.85	3.18	0.83	0.39
Mar	20.70	15.03	8.99	5.59	2.79	1.97	0.00
Apr	20.95	15.76	11.11	7.82	4.71	2.35	0.58
May	18.94	14.43	10.65	8.79	5.08	1.72	0.90
Jun	15.60	11.69	8.51	6.58	3.90	2.64	0.89
Jul	15.36	11.70	7.98	5.34	2.92	1.44	0.45
Aug	16.11	11.04	7.25	4.40	2.80	0.53	0.00
Sep	14.82	10.83	6.76	4.40	2.15	0.39	0.00
Oct	14.32	9.80	5.00	3.06	1.35	0.37	0.00
Nov	15.12	8.57	3.69	2.10	0.82	0.54	0.32
Dec	18.78	10.51	5.11	2.70	0.72	0.00	0.00
annual	17.92	12.48	7.68	5.09	2.73	1.16	0.36

Table 3.21 Annual and monthly non-exceedance persistence (%) for wind speed below 6.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	52.78	48.30	39.95	34.99	29.30	22.05	11.84
Feb	54.79	50.79	44.51	39.31	32.83	23.94	14.83
Mar	51.05	46.45	40.55	36.20	30.50	24.25	13.98
Apr	53.77	49.68	44.76	41.28	34.19	26.22	18.61
May	46.36	42.53	39.54	36.18	30.54	26.53	16.99
Jun	41.89	38.15	34.42	31.02	25.14	19.31	10.97
Jul	41.90	37.30	33.06	29.31	22.28	17.88	10.02
Aug	42.85	38.89	33.51	29.97	22.49	16.31	8.00
Sep	39.99	34.70	29.93	25.54	21.75	16.54	10.02
Oct	40.22	34.80	27.86	23.44	17.63	12.68	6.46
Nov	43.90	38.07	30.11	25.17	19.72	12.74	7.45
Dec	52.07	46.96	38.50	33.17	27.53	20.00	10.97
annual	46.92	42.49	36.77	32.58	26.85	20.53	12.63

Table 3.22 Annual and monthly non-exceedance persistence (%) for wind speed below 8.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	77.26	75.02	71.75	68.89	65.24	59.32	49.15
Feb	80.10	78.32	76.05	73.66	70.27	64.87	57.23
Mar	77.00	75.01	72.71	70.95	67.29	64.20	55.26
Apr	76.92	74.27	72.41	70.24	66.59	61.57	51.68
May	69.36	66.82	64.26	62.18	56.68	51.54	42.17
Jun	65.85	63.44	61.05	58.91	53.37	47.02	35.60
Jul	65.41	62.51	60.31	57.63	51.07	45.69	34.09
Aug	67.89	65.27	62.67	59.86	54.70	47.85	34.44
Sep	66.92	63.67	59.40	55.92	50.36	45.09	34.59
Oct	67.73	64.89	59.40	56.86	51.73	44.44	33.42
Nov	71.31	67.61	61.52	58.24	52.02	44.24	34.22
Dec	77.99	75.40	71.45	68.21	65.28	56.96	46.49
annual	72.07	69.55	66.57	64.07	59.68	54.02	44.53

Table 3.23 *Annual and monthly non-exceedance persistence (%) for wind speed below 10.0 m/s at P2.*

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	91.36	90.83	89.92	89.15	87.68	85.32	80.07
Feb	92.42	91.73	90.84	90.12	88.84	87.03	82.93
Mar	91.01	90.33	89.52	88.63	87.23	84.59	81.11
Apr	91.01	90.23	89.47	88.68	86.84	84.14	78.68
May	86.94	85.84	84.32	82.84	80.41	76.70	71.20
Jun	83.50	81.44	79.98	79.15	76.54	72.44	63.98
Jul	81.53	80.25	78.38	76.36	73.31	69.01	60.36
Aug	83.97	82.75	81.01	79.63	76.51	72.55	62.88
Sep	85.15	83.79	82.02	80.11	75.77	70.93	63.24
Oct	86.21	84.79	82.61	80.61	77.07	73.70	66.64
Nov	88.67	87.20	85.21	84.51	81.74	77.13	70.35
Dec	91.52	90.58	89.25	88.37	86.97	82.86	78.29
annual	87.80	86.80	85.57	84.58	82.55	79.55	74.29

Table 3.24 Annual and monthly non-exceedance persistence (%) for wind speed below 12.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	96.78	96.58	96.30	96.30	96.10	95.79	92.84
Feb	97.18	97.02	96.90	96.57	95.99	95.65	94.29
Mar	96.37	96.06	95.90	95.67	94.85	94.41	92.86
Apr	96.75	96.16	95.99	95.57	95.26	94.06	92.39
May	95.74	95.28	94.90	94.32	93.44	92.57	89.11
Jun	93.16	92.43	92.16	91.22	90.00	87.94	84.03
Jul	90.57	89.92	89.61	88.89	86.79	83.93	77.92
Aug	92.97	92.46	92.01	91.15	89.39	88.08	83.20
Sep	93.83	93.34	92.60	91.52	90.51	87.82	84.20
Oct	95.15	94.79	94.05	93.32	92.15	89.50	85.79
Nov	95.99	95.62	94.85	94.49	93.97	92.81	90.02
Dec	97.30	97.14	96.69	96.17	95.64	94.94	93.76
annual	95.17	94.82	94.54	94.10	93.54	92.61	90.48

Table 3.25 Annual and monthly non-exceedance persistence (%) for wind speed below 14.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	99.10	99.07	99.07	99.00	98.90	98.90	98.70
Feb	99.00	98.88	98.82	98.73	98.63	98.63	98.19
Mar	98.95	98.81	98.64	98.64	98.53	98.53	98.34
Apr	99.21	99.10	98.99	98.99	98.77	98.60	98.38
May	98.86	98.79	98.79	98.64	98.52	98.37	97.96
Jun	97.48	97.06	97.01	97.01	96.58	95.64	94.58
Jul	95.80	95.63	95.45	95.16	94.73	93.90	91.57
Aug	97.48	97.29	97.29	97.07	96.34	95.60	94.28
Sep	97.75	97.71	97.26	97.19	96.67	95.45	94.64
Oct	98.99	98.89	98.89	98.74	98.62	98.20	96.72
Nov	98.81	98.81	98.76	98.68	98.36	98.23	97.54
Dec	99.24	99.20	99.20	99.12	99.12	98.98	98.63
annual	98.40	98.31	98.25	98.21	98.10	97.98	97.72

Table 3.26 Annual and monthly non-exceedance persistence (%) for wind speed below 16.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	99.63	99.63	99.58	99.58	99.58	99.58	99.58
Feb	99.76	99.76	99.63	99.63	99.40	99.40	98.92
Mar	99.64	99.64	99.64	99.56	99.56	99.56	99.56
Apr	99.73	99.65	99.65	99.65	99.55	99.39	99.39
May	99.80	99.73	99.73	99.65	99.65	99.65	99.65
Jun	99.22	99.22	99.17	99.09	98.90	98.74	98.33
Jul	98.65	98.56	98.56	98.48	98.05	97.89	97.26
Aug	99.31	99.21	99.16	99.16	99.06	99.06	98.51
Sep	99.23	99.23	99.23	98.93	98.93	98.63	97.51
Oct	99.80	99.80	99.80	99.80	99.80	99.80	99.13
Nov	99.70	99.70	99.70	99.70	99.70	99.56	99.33
Dec	99.81	99.81	99.76	99.76	99.76	99.63	99.63
annual	99.53	99.51	99.50	99.47	99.45	99.44	99.39

Table 3.27 Annual and monthly non-exceedance persistence (%) for wind speed below 18.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.85	99.85	99.85	99.85	99.85	99.85	99.85
Feb	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Mar	99.91	99.91	99.91	99.91	99.91	99.91	99.91
Apr	99.95	99.95	99.95	99.95	99.95	99.95	99.95
May	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Jun	99.79	99.75	99.70	99.70	99.60	99.45	99.24
Jul	99.49	99.46	99.46	99.46	99.46	99.46	99.25
Aug	99.83	99.83	99.83	99.83	99.83	99.83	99.83
Sep	99.82	99.82	99.82	99.82	99.82	99.67	99.24
Oct	99.93	99.93	99.93	99.93	99.93	99.93	99.75
Nov	99.93	99.85	99.85	99.85	99.85	99.70	99.70
Dec	99.94	99.94	99.94	99.94	99.94	99.94	99.94
annual	99.87	99.85	99.85	99.85	99.85	99.85	99.85

Table 3.28 Annual and monthly non-exceedance persistence (%) for wind speed below 20.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.95	99.95	99.95	99.95	99.95	99.95	99.95
Apr	99.98	99.98	99.98	99.98	99.98	99.98	99.98
May	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Jun	99.94	99.94	99.94	99.94	99.84	99.84	99.84
Jul	99.71	99.64	99.64	99.64	99.64	99.64	99.64
Aug	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Sep	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Oct	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	99.96	99.96	99.96	99.96	99.96	99.96	99.96

Table 3.29 Annual and monthly non-exceedance persistence (%) for wind speed below 22.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.95	99.95	99.95	99.95	99.95	99.95	99.95
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Jul	99.96	99.96	99.96	99.96	99.96	99.96	99.96
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	99.99	99.99	99.99	99.99	99.99	99.99	99.99

Table 3.30 Annual and monthly non-exceedance persistence (%) for wind speed below 24.0 m/s at P2.

U10min (m/s)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jul	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	100.00	100.00	100.00	100.00	100.00	100.00	100.00

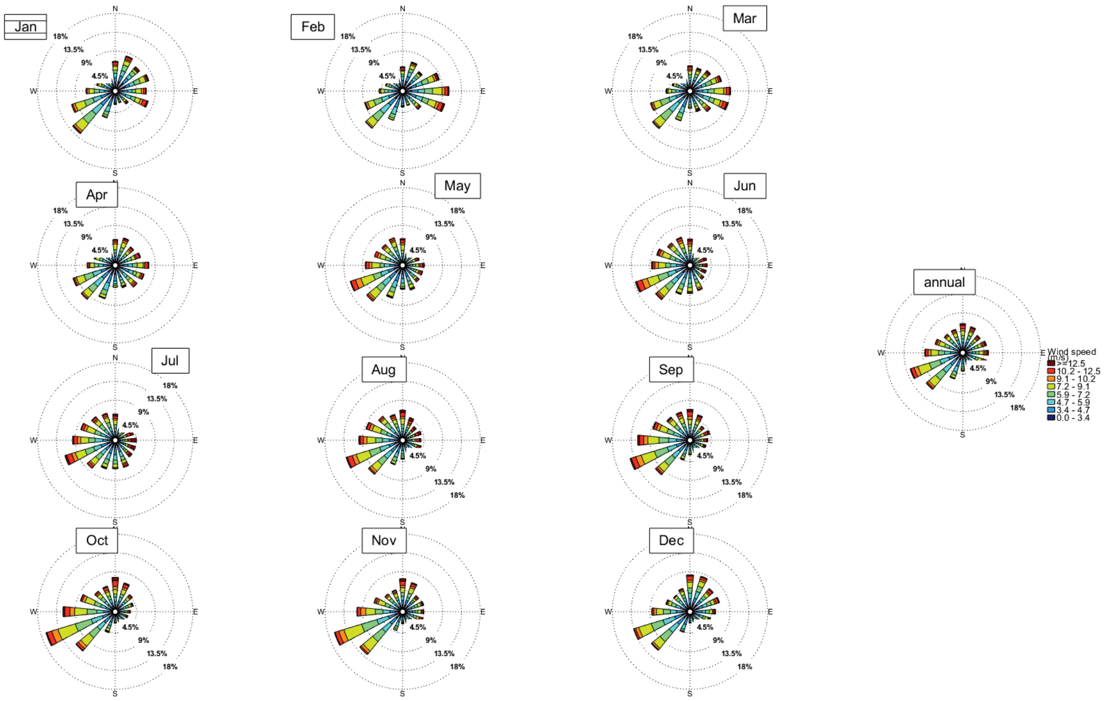

Figure 3.2 Monthly and annual wind rose plot (10-minute mean at 10 m AMSL) at P2. Sectors indicate the direction from which the winds blow.

4. Wave climate

4.1. P1

A summary of the total significant wave height statistics (H_s) at P1 is provided in Table 4.1. Summary of significant wave height statistics for swell and windseas components are provided in Table 4.2 and Table 4.3 respectively. Details on the partitioning method for sea and swell components are presented in Section 8.2.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.4.
The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.5.

The annual and monthly non-exceedance persistence probabilities for total significant wave height at P1 (Table 4.6 to Table 4.18) can be used to estimate the operational uptime for tasks with wind speed limitations of variable duration. For example, at P1 on average in February, total significant wave heights are less than 0.5 m for durations of 36 hours and greater for 5.51% of the time (Table 4.7).

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.1, showing the predominance of waves incoming from the ENE sector.

Table 4.1 Annual and monthly total significant wave height statistics at P1.

Period (01 Jan 1979 – 31 Dec 2018)	Total significant wave height statistics (1)													
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)									Main (4) Direction(s)
	min	**max**	**mean**	**std**	**p1**	**p5**	**p10**	**p50**	**p80**	**p90**	**p95**	**p98**	**p99**	
January	0.25	5.10	0.97	0.52	0.33	0.41	0.48	0.85	1.28	1.62	1.96	2.51	2.84	NE
February	0.25	4.38	1.01	0.51	0.34	0.44	0.52	0.89	1.33	1.64	1.98	2.48	2.91	NE E
March	0.19	5.23	1.01	0.56	0.31	0.42	0.49	0.86	1.36	1.69	2.04	2.66	3.06	NE E
April	0.14	5.20	0.94	0.56	0.25	0.34	0.39	0.81	1.29	1.65	2.07	2.55	2.85	NE E
May	0.10	5.14	0.89	0.59	0.19	0.27	0.33	0.73	1.24	1.66	2.07	2.59	2.98	NE E
June	0.10	5.97	0.96	0.70	0.19	0.26	0.32	0.75	1.40	1.92	2.35	2.97	3.42	NE E
July	0.08	6.37	1.02	0.79	0.19	0.28	0.34	0.77	1.46	2.05	2.75	3.44	3.83	NE E
August	0.13	5.49	0.94	0.67	0.21	0.29	0.34	0.75	1.30	1.80	2.34	3.00	3.41	NE E
September	0.09	5.20	0.90	0.61	0.22	0.30	0.35	0.73	1.26	1.68	2.09	2.68	3.24	NE E
October	0.15	4.70	0.81	0.51	0.23	0.29	0.34	0.66	1.12	1.51	1.88	2.29	2.58	N NE E
November	0.14	5.56	0.83	0.53	0.25	0.33	0.37	0.68	1.13	1.48	1.82	2.35	2.77	NE E
December	0.23	4.97	0.92	0.50	0.30	0.39	0.44	0.79	1.22	1.53	1.86	2.43	2.71	NE
Winter(3)	0.08	6.37	0.97	0.72	0.19	0.27	0.33	0.76	1.38	1.91	2.47	3.18	3.62	NE E
Spring	0.09	5.56	0.85	0.55	0.23	0.30	0.35	0.69	1.17	1.55	1.93	2.43	2.84	N NE E
Summer(2)	0.23	5.10	0.97	0.51	0.32	0.41	0.47	0.84	1.28	1.60	1.93	2.48	2.84	NE
Autumn	0.10	5.23	0.95	0.57	0.23	0.33	0.39	0.81	1.29	1.67	2.07	2.59	2.97	NE E
All	0.08	6.37	0.93	0.60	0.23	0.32	0.38	0.78	1.28	1.68	2.09	2.70	3.14	NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.2 Annual and monthly significant swell wave height statistics at P1.

Period (01 Jan 1979 – 31 Dec 2018)	Significant swell wave height statistics (1)													
	Significant swell wave height (m)				Exceedance percentile for significant swell wave height (m)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.14	3.94	0.59	0.35	0.20	0.25	0.28	0.49	0.77	1.03	1.35	1.68	1.85	NE
February	0.14	3.13	0.63	0.35	0.19	0.25	0.29	0.54	0.83	1.09	1.29	1.60	1.87	NE E
March	0.10	4.01	0.61	0.39	0.17	0.24	0.28	0.50	0.84	1.07	1.34	1.70	2.03	NE E
April	0.07	3.98	0.55	0.39	0.14	0.19	0.22	0.43	0.79	1.05	1.32	1.67	1.96	NE E
May	0.04	4.12	0.49	0.40	0.07	0.11	0.14	0.36	0.70	0.99	1.29	1.67	1.99	NE E
June	0.02	4.97	0.53	0.49	0.06	0.10	0.13	0.36	0.78	1.17	1.54	1.94	2.32	NE E
July	0.03	5.34	0.58	0.58	0.06	0.09	0.12	0.37	0.87	1.33	1.76	2.33	2.69	NE E
August	0.06	4.44	0.52	0.45	0.09	0.13	0.15	0.37	0.75	1.05	1.37	1.91	2.37	NE E
September	0.03	4.15	0.47	0.42	0.07	0.11	0.13	0.34	0.67	0.94	1.29	1.66	2.15	NE E
October	0.06	3.42	0.39	0.31	0.08	0.11	0.13	0.28	0.55	0.79	1.03	1.39	1.57	NE E
November	0.07	4.51	0.43	0.34	0.10	0.14	0.17	0.32	0.59	0.81	1.03	1.39	1.65	NE E
December	0.08	3.79	0.54	0.33	0.16	0.21	0.25	0.44	0.71	0.95	1.17	1.50	1.71	NE
Winter(3)	0.02	5.34	0.54	0.51	0.07	0.11	0.14	0.37	0.79	1.18	1.58	2.07	2.50	NE E
Spring	0.03	4.51	0.43	0.36	0.08	0.12	0.14	0.31	0.60	0.85	1.12	1.47	1.74	NE E
Summer(2)	0.08	3.94	0.58	0.35	0.18	0.24	0.27	0.49	0.78	1.03	1.27	1.60	1.80	NE
Autumn	0.04	4.12	0.55	0.40	0.09	0.15	0.20	0.44	0.78	1.04	1.32	1.68	1.99	NE E
All	0.02	5.34	0.53	0.41	0.08	0.13	0.17	0.41	0.74	1.02	1.33	1.72	2.06	NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.3 Annual and monthly significant sea wave height statistics at P1.

Period (01 Jan 1979 – 31 Dec 2018)	Significant sea wave height statistics (1)													
	Significant sea wave height (m)				Exceedance percentile for significant sea wave height (m)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.13	3.29	0.73	0.44	0.20	0.28	0.32	0.62	0.99	1.28	1.63	2.10	2.34	N NE E
February	0.13	3.18	0.76	0.43	0.23	0.31	0.36	0.65	1.03	1.30	1.66	2.10	2.43	NE E
March	0.08	3.39	0.77	0.47	0.19	0.28	0.33	0.63	1.05	1.38	1.72	2.15	2.42	NE E
April	0.08	3.35	0.73	0.46	0.14	0.22	0.28	0.62	1.00	1.33	1.71	2.12	2.36	NE E
May	0.05	3.33	0.71	0.49	0.12	0.20	0.25	0.57	0.99	1.35	1.75	2.20	2.47	N NE E
June	0.06	3.61	0.76	0.56	0.12	0.19	0.24	0.59	1.09	1.54	2.01	2.49	2.71	N NE
July	0.03	3.48	0.80	0.61	0.12	0.21	0.26	0.60	1.10	1.67	2.27	2.68	2.87	N NE E
August	0.06	3.29	0.75	0.55	0.14	0.21	0.26	0.58	1.05	1.51	2.01	2.46	2.66	N NE
September	0.06	3.27	0.74	0.51	0.15	0.24	0.28	0.59	1.02	1.40	1.83	2.29	2.61	N NE
October	0.05	3.23	0.68	0.45	0.16	0.23	0.27	0.55	0.94	1.28	1.65	2.07	2.30	N NE
November	0.09	3.26	0.68	0.45	0.17	0.25	0.29	0.55	0.94	1.26	1.59	2.09	2.39	N NE
December	0.10	3.29	0.71	0.44	0.18	0.26	0.31	0.59	0.96	1.26	1.62	2.00	2.35	N NE
Winter(3)	0.03	3.61	0.77	0.58	0.13	0.20	0.25	0.59	1.08	1.56	2.10	2.55	2.76	N NE
Spring	0.05	3.27	0.70	0.47	0.16	0.24	0.28	0.56	0.97	1.32	1.69	2.16	2.42	N NE
Summer(2)	0.10	3.29	0.74	0.44	0.20	0.28	0.33	0.62	0.99	1.28	1.64	2.07	2.37	N NE E
Autumn	0.05	3.39	0.73	0.47	0.14	0.23	0.29	0.61	1.01	1.35	1.72	2.16	2.42	N NE E
All	0.03	3.61	0.73	0.49	0.15	0.23	0.29	0.60	1.01	1.37	1.78	2.28	2.55	N NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.4 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P1.

Hs (m)	**Mean wave direction at peak energy (degT)**									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
>0<=0.5	1.04	14.45	4.89	0.35	0.13	0.72	0.56	0.21	22.35	100.00
>0.5<=1	4.78	27.98	9.86	0.75	0.03	0.09	0.29	0.47	44.25	77.66
>1<=1.5	2.25	13.36	3.95	0.25	-	-	*	0.05	19.86	33.42
>1.5<=2	0.85	5.40	1.38	0.09	-	-	-	*	7.72	13.56
>2<=2.5	0.26	2.24	0.61	0.01	-	-	-	-	3.12	5.84
>2.5<=3	0.07	1.10	0.29	*	-	-	-	-	1.46	2.72
>3<=3.5	0.01	0.54	0.14	*	-	-	-	-	0.69	1.25
>3.5<=4	*	0.28	0.04	-	-	-	-	-	0.32	0.56
>4<=4.5	-	0.11	0.01	-	-	-	-	-	0.12	0.24
>4.5<=5	-	0.05	0.01	-	-	-	-	-	0.06	0.12
>5<=5.5	-	0.02	0.01	-	-	-	-	-	0.03	0.05
>5.5<=6	-	0.01	*	-	-	-	-	-	0.01	0.01
>6<=6.5	-	*	*	-	-	-	-	-		
Total	9.26	65.54	21.19	1.45	0.16	0.81	0.85	0.73	100.00	

Notes: * represents less than 0.005%.

Table 4.5 Annual joint probability distribution (in %) of the total significant wave height and peak period at P1.

Hs (m)	Peak period (s)											
	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	Total	Exceed%
>0<=0.5	2.14	0.70	1.77	9.24	5.39	1.73	0.81	0.33	0.10	0.03	22.24	100.00
>0.5<=1	2.31	4.66	7.98	17.84	7.85	2.46	0.79	0.26	0.08	0.01	44.24	77.66
>1<=1.5	*	4.57	3.35	7.24	3.43	0.99	0.25	0.03	0.01	-	19.87	33.42
>1.5<=2	-	1.49	1.84	2.22	1.55	0.52	0.08	0.01	*	-	7.71	13.56
>2<=2.5	-	0.04	1.56	0.71	0.55	0.21	0.03	*	-	-	3.10	5.84
>2.5<=3	-	-	0.77	0.35	0.26	0.08	0.01	*	-	-	1.47	2.72
>3<=3.5	-	-	0.19	0.31	0.13	0.05	*	*	*	-	0.68	1.25
>3.5<=4	-	-	0.02	0.21	0.06	0.02	*	*	-	-	0.31	0.56
>4<=4.5	-	-	*	0.08	0.03	0.01	-	-	-	-	0.12	0.24
>4.5<=5	-	-	-	0.03	0.03	0.01	-	-	-	-	0.07	0.12
>5<=5.5	-	-	-	0.01	0.02	*	-	-	-	-	0.03	0.05
>5.5<=6	-	-	-	*	0.01	*	-	-	-	-	0.01	0.01
>6<=6.5	-	-	-	-	*	-	-	-	-	-		
Total	4.45	11.46	17.48	38.24	19.31	6.08	1.97	0.63	0.19	0.04	100.00	
>Exceed%	99.90	95.45	83.99	66.50	28.25	8.92	2.85	0.88	0.24	0.04		

Notes: * represents less than 0.005%.

Table 4.6 Annual and monthly non-exceedance persistence (%) for significant wave height below 0.0 m at P1.

Hs (m)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00
annual	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.7 Annual and monthly non-exceedance persistence (%) for significant wave height below 0.5 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	11.76	11.03	10.02	9.23	7.21	5.36	2.99
Feb	8.28	7.59	6.91	6.20	5.51	4.14	2.32
Mar	10.44	9.48	8.81	8.16	7.26	5.59	3.08
Apr	20.52	19.55	18.78	17.94	15.70	13.76	8.83
May	27.01	26.14	24.77	23.37	20.27	18.77	14.00
Jun	29.01	27.92	26.86	25.76	23.33	20.50	14.58
Jul	24.54	23.64	22.44	20.56	17.83	14.24	9.93
Aug	26.64	25.64	24.52	22.71	18.89	15.07	9.62
Sep	26.50	25.42	24.11	23.23	20.15	17.70	11.15
Oct	31.28	29.68	27.01	25.11	21.32	17.95	11.26
Nov	28.10	26.34	24.42	22.51	18.31	13.43	7.89
Dec	16.18	14.90	13.76	13.13	10.05	7.31	3.55
annual	21.79	20.77	19.60	18.43	15.83	13.34	8.81

Table 4.8 Annual and monthly non-exceedance persistence (%) for significant wave height below 1.0 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	63.47	62.42	61.08	60.60	58.31	55.48	50.51
Feb	58.75	58.01	56.79	56.19	53.64	51.16	43.89
Mar	60.88	60.14	59.38	58.18	56.27	54.59	50.02
Apr	64.32	63.66	63.00	62.08	60.00	57.34	52.31
May	68.64	68.26	67.39	66.81	65.23	63.04	57.79
Jun	65.54	64.81	63.52	62.71	59.73	57.64	52.42
Jul	63.31	62.73	61.83	61.03	57.69	54.64	48.97
Aug	66.51	66.04	65.20	64.24	62.26	59.50	52.01
Sep	67.50	66.68	65.76	64.75	62.05	59.01	52.09
Oct	74.14	73.56	73.09	71.95	70.06	67.65	61.34
Nov	73.61	72.72	71.85	70.90	68.75	65.73	59.67
Dec	67.16	66.32	64.70	64.21	62.57	60.42	54.76
annual	66.26	65.69	64.85	64.18	62.28	60.17	55.33

Table 4.9 Annual and monthly non-exceedance persistence (%) for significant wave height below 1.5 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	87.12	86.80	86.67	86.34	85.29	84.01	81.21
Feb	86.31	85.96	85.30	84.86	83.93	83.44	80.67
Mar	84.58	84.13	83.80	82.89	81.22	80.41	77.85
Apr	86.52	86.18	86.00	85.75	84.30	83.16	80.59
May	87.19	86.94	86.69	86.22	84.77	84.30	82.17
Jun	82.34	82.03	81.71	81.21	80.54	78.36	74.55
Jul	80.57	80.24	79.71	79.39	78.14	75.83	70.77
Aug	84.58	84.28	83.98	83.39	82.01	81.10	77.64
Sep	86.44	86.25	85.77	84.85	83.60	81.63	76.70
Oct	89.59	89.20	88.90	88.26	87.43	86.10	82.86
Nov	90.45	90.08	89.28	89.02	88.61	87.98	85.42
Dec	88.91	88.64	88.04	87.88	87.44	85.76	83.82
annual	86.26	86.03	85.73	85.40	84.63	83.69	81.52

Table 4.10 Annual and monthly non-exceedance persistence (%) for significant wave height below 2.0 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	95.30	95.19	95.14	95.14	94.68	94.40	92.68
Feb	95.08	94.97	94.90	94.74	94.47	94.31	93.46
Mar	94.48	94.45	94.40	94.32	93.69	93.24	91.04
Apr	94.21	94.04	93.93	93.93	93.21	92.92	91.66
May	94.23	94.14	93.97	93.59	93.17	93.03	91.34
Jun	91.11	90.82	90.66	90.34	89.45	88.79	86.56
Jul	89.36	89.20	89.03	88.87	88.17	87.27	83.68
Aug	92.56	92.41	92.24	92.16	91.29	89.93	88.36
Sep	94.23	94.17	93.87	93.71	92.88	92.12	89.31
Oct	96.03	95.97	95.72	95.65	94.99	94.52	92.36
Nov	96.25	96.10	95.98	95.81	95.49	95.16	94.28
Dec	96.04	95.93	95.56	95.49	95.15	95.15	94.73
annual	94.08	94.01	93.92	93.85	93.61	93.31	92.15

Table 4.11 Annual and monthly non-exceedance persistence (%) for significant wave height below 2.5 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	97.85	97.81	97.75	97.75	97.54	97.40	96.71
Feb	98.04	97.95	97.89	97.73	97.46	97.29	97.07
Mar	97.49	97.49	97.42	97.42	97.30	97.01	96.82
Apr	97.53	97.29	97.18	97.11	96.77	96.27	95.82
May	97.64	97.60	97.60	97.43	97.43	96.67	96.49
Jun	95.89	95.84	95.67	95.50	95.38	94.57	92.96
Jul	93.62	93.59	93.47	93.47	93.04	92.76	90.55
Aug	95.88	95.85	95.79	95.79	95.26	94.95	94.09
Sep	97.34	97.26	97.07	97.07	96.84	96.20	94.64
Oct	98.71	98.67	98.62	98.62	98.39	98.06	97.12
Nov	98.48	98.43	98.38	98.22	97.99	97.99	97.57
Dec	98.22	98.17	98.02	97.87	97.87	97.71	97.52
annual	97.23	97.19	97.13	97.11	97.06	96.98	96.69

Table 4.12 Annual and monthly non-exceedance persistence (%) for significant wave height below 3.0 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.30	99.30	99.30	99.23	99.12	99.12	98.90
Feb	99.12	99.12	99.00	98.81	98.81	98.81	98.13
Mar	98.82	98.82	98.77	98.77	98.77	98.77	98.53
Apr	99.25	99.22	99.17	99.09	98.86	98.68	98.68
May	99.00	99.00	98.95	98.95	98.75	98.75	98.39
Jun	98.02	97.98	97.82	97.73	97.63	97.29	96.66
Jul	96.28	96.17	96.05	96.05	95.81	95.67	94.32
Aug	97.90	97.81	97.81	97.64	97.55	97.41	97.23
Sep	98.65	98.65	98.60	98.52	98.52	98.36	97.68
Oct	99.70	99.70	99.70	99.62	99.62	99.62	98.99
Nov	99.32	99.32	99.32	99.32	99.19	99.19	98.72
Dec	99.35	99.31	99.31	99.31	99.12	98.95	98.95
annual	98.73	98.71	98.68	98.68	98.66	98.65	98.61

Table 4.13 Annual and monthly non-exceedance persistence (%) for significant wave height below 3.5 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.78	99.78	99.78	99.78	99.78	99.78	99.78
Feb	99.66	99.66	99.53	99.53	99.31	99.31	98.80
Mar	99.48	99.48	99.43	99.43	99.43	99.43	99.43
Apr	99.70	99.70	99.70	99.70	99.59	99.42	99.42
May	99.58	99.54	99.54	99.54	99.54	99.54	99.54
Jun	99.08	99.05	98.93	98.84	98.73	98.73	98.31
Jul	98.09	98.02	98.02	98.02	97.92	97.77	96.42
Aug	99.17	99.06	98.95	98.95	98.95	98.80	98.80
Sep	99.29	99.29	99.29	99.21	99.21	99.05	98.86
Oct	99.93	99.93	99.93	99.93	99.93	99.93	99.73
Nov	99.69	99.69	99.69	99.69	99.69	99.55	99.31
Dec	99.70	99.70	99.70	99.70	99.59	99.59	99.59
annual	99.43	99.41	99.40	99.40	99.40	99.40	99.36

Table 4.14 Annual and monthly non-exceedance persistence (%) for significant wave height below 4.0 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.90	99.90	99.90	99.90	99.90	99.90	99.90
Feb	99.98	99.98	99.98	99.98	99.98	99.98	99.72
Mar	99.73	99.73	99.73	99.73	99.73	99.73	99.73
Apr	99.87	99.87	99.87	99.87	99.87	99.87	99.68
May	99.82	99.78	99.78	99.78	99.78	99.78	99.78
Jun	99.54	99.54	99.54	99.46	99.36	99.36	98.94
Jul	99.19	99.19	99.19	99.19	99.09	99.09	98.88
Aug	99.72	99.72	99.72	99.72	99.72	99.72	99.52
Sep	99.63	99.59	99.59	99.51	99.51	99.51	99.30
Oct	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Nov	99.81	99.81	99.81	99.81	99.81	99.67	99.67
Dec	99.88	99.88	99.88	99.88	99.88	99.88	99.88
annual	99.76	99.75	99.75	99.75	99.75	99.75	99.75

Table 4.15 Annual and monthly non-exceedance persistence (%) for significant wave height below 4.5 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.94	99.94	99.94	99.94	99.94	99.94	99.94
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.83	99.83	99.83	99.83	99.83	99.83	99.83
Apr	99.96	99.96	99.96	99.96	99.96	99.96	99.96
May	99.94	99.94	99.94	99.94	99.94	99.94	99.94
Jun	99.79	99.79	99.79	99.79	99.69	99.69	99.50
Jul	99.58	99.53	99.53	99.53	99.53	99.53	99.53
Aug	99.93	99.93	99.93	99.93	99.93	99.93	99.93
Sep	99.85	99.85	99.85	99.85	99.85	99.85	99.63
Oct	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Nov	99.86	99.86	99.86	99.86	99.86	99.70	99.70
Dec	99.96	99.96	99.96	99.96	99.96	99.96	99.96
annual	99.88	99.88	99.88	99.88	99.88	99.88	99.88

Table 4.16 Annual and monthly non-exceedance persistence (%) for significant wave height below 5.0 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.94	99.94	99.94	99.94	99.94	99.94	99.94
Apr	99.98	99.98	99.98	99.98	99.98	99.98	99.98
May	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Jun	99.93	99.93	99.93	99.93	99.93	99.93	99.93
Jul	99.75	99.75	99.75	99.75	99.75	99.75	99.75
Aug	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Sep	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	99.91	99.91	99.91	99.91	99.91	99.91	99.73
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	99.95	99.95	99.95	99.95	99.95	99.95	99.95

Table 4.17 Annual and monthly non-exceedance persistence (%) for significant wave height below 5.5 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Jul	99.90	99.90	99.90	99.90	99.90	99.90	99.90
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	99.93	99.93	99.93	99.93	99.93	99.93	99.74
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	99.98	99.98	99.98	99.98	99.98	99.98	99.98

Table 4.18 Annual and monthly non-exceedance persistence (%) for significant wave height below 6.0 m at P1.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jul	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	100.00	100.00	100.00	100.00	100.00	100.00	100.00

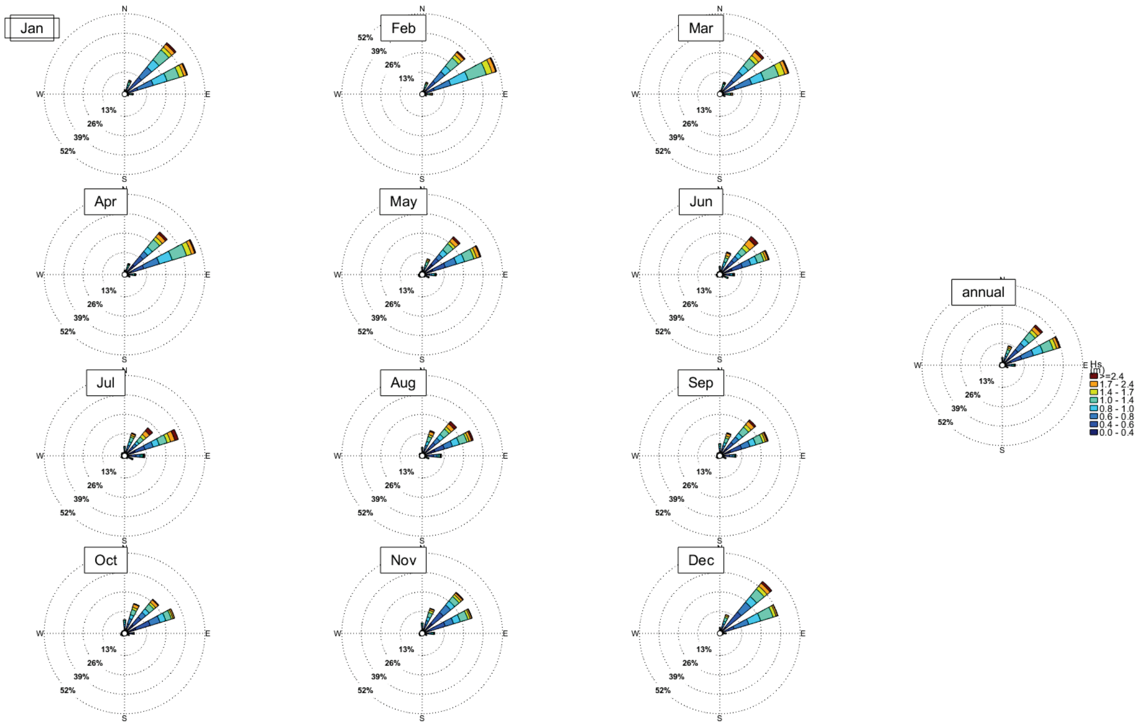

Figure 4.1 Monthly and annual wave rose plot for the total significant wave height at P1. Sectors indicate the direction from which waves approach.

4.2. P2

A summary of the total significant wave height statistics (H_s) at P2 is provided in Table 4.19. Summary of significant wave height statistics for swell and windseas components are provided in Table 4.20 and Table 4.21 respectively. Details on the partitioning method for sea and swell components are presented in Section 8.2.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.22.
The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.23.

The annual and monthly non-exceedance persistence probabilities for total significant wave height at P2 (Table 4.24 to Table 4.36) can be used to estimate the operational uptime for tasks with wind speed limitations of variable duration. For example, at P2 on average in February, total significant wave heights are less than 0.5 m for durations of 36 hours and greater for 5.56% of the time (Table 4.25).

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.2, showing the predominance of waves incoming from the NE sector.

Table 4.19 Annual and monthly total significant wave height statistics at P2.

Period (01 Jan 1979 – 31 Dec 2018)	Total significant wave height statistics (1)													
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.25	5.24	0.98	0.52	0.33	0.42	0.48	0.85	1.29	1.62	1.97	2.51	2.86	NE
February	0.24	4.47	1.02	0.51	0.35	0.44	0.52	0.90	1.33	1.65	1.97	2.49	2.95	NE E
March	0.19	5.18	1.01	0.57	0.32	0.42	0.49	0.87	1.36	1.70	2.06	2.65	3.05	NE E
April	0.14	5.30	0.95	0.56	0.26	0.34	0.39	0.82	1.30	1.65	2.10	2.58	2.89	NE E
May	0.10	5.18	0.90	0.60	0.19	0.28	0.34	0.75	1.25	1.68	2.09	2.59	3.05	NE E
June	0.09	6.02	0.97	0.72	0.18	0.26	0.32	0.77	1.42	1.96	2.39	3.04	3.48	NE E
July	0.08	6.31	1.04	0.80	0.19	0.28	0.34	0.79	1.48	2.07	2.75	3.46	3.87	NE E
August	0.14	5.55	0.95	0.67	0.21	0.29	0.35	0.76	1.33	1.83	2.36	3.02	3.45	NE E
September	0.09	5.22	0.92	0.62	0.22	0.30	0.36	0.75	1.28	1.70	2.12	2.71	3.29	N NE E
October	0.14	4.71	0.82	0.52	0.23	0.30	0.34	0.67	1.14	1.53	1.92	2.34	2.62	N NE E
November	0.16	5.49	0.84	0.53	0.25	0.33	0.39	0.69	1.14	1.50	1.84	2.35	2.82	NE E
December	0.21	5.08	0.93	0.51	0.31	0.39	0.45	0.80	1.23	1.55	1.87	2.46	2.74	NE
Winter(3)	0.08	6.31	0.99	0.73	0.19	0.28	0.33	0.77	1.41	1.94	2.50	3.21	3.65	NE E
Spring	0.09	5.49	0.86	0.56	0.23	0.31	0.36	0.70	1.19	1.57	1.97	2.47	2.89	N NE E
Summer(2)	0.21	5.24	0.97	0.51	0.32	0.42	0.48	0.85	1.29	1.61	1.95	2.49	2.86	NE
Autumn	0.10	5.30	0.96	0.58	0.24	0.33	0.40	0.82	1.31	1.68	2.08	2.60	3.01	NE E
All	0.08	6.31	0.94	0.60	0.23	0.32	0.38	0.79	1.29	1.69	2.12	2.72	3.18	NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.20 Annual and monthly significant swell wave height statistics at P2.

Period (01 Jan 1979 – 31 Dec 2018)	Significant swell wave height statistics [1]													
	Significant swell wave height (m)				Exceedance percentile for significant swell wave height (m)									Main [4] Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.14	4.23	0.60	0.36	0.21	0.25	0.29	0.50	0.77	1.04	1.36	1.71	1.91	NE
February	0.14	3.25	0.63	0.35	0.20	0.26	0.30	0.54	0.84	1.09	1.31	1.62	1.91	NE E
March	0.10	4.11	0.62	0.40	0.17	0.25	0.29	0.51	0.84	1.08	1.36	1.77	2.11	NE E
April	0.08	4.14	0.56	0.40	0.15	0.20	0.23	0.44	0.78	1.05	1.33	1.70	2.06	NE E
May	0.04	4.19	0.50	0.41	0.07	0.11	0.14	0.37	0.71	0.99	1.30	1.70	2.05	NE E
June	0.02	5.06	0.54	0.51	0.07	0.11	0.14	0.36	0.79	1.20	1.60	2.05	2.42	NE E
July	0.03	5.27	0.58	0.58	0.06	0.10	0.12	0.38	0.88	1.36	1.77	2.38	2.77	NE E
August	0.06	4.54	0.53	0.46	0.09	0.13	0.15	0.38	0.76	1.07	1.40	1.99	2.42	NE E
September	0.03	4.31	0.48	0.43	0.06	0.11	0.14	0.35	0.67	0.95	1.29	1.75	2.22	NE E
October	0.05	3.46	0.39	0.32	0.08	0.11	0.14	0.29	0.55	0.79	1.06	1.42	1.60	NE E
November	0.07	4.45	0.43	0.34	0.10	0.15	0.17	0.33	0.59	0.82	1.05	1.42	1.64	NE E
December	0.09	3.95	0.54	0.34	0.17	0.22	0.26	0.45	0.71	0.95	1.21	1.53	1.81	NE
Winter[3]	0.02	5.27	0.55	0.52	0.07	0.11	0.14	0.38	0.80	1.20	1.62	2.13	2.56	NE E
Spring	0.03	4.45	0.43	0.37	0.08	0.12	0.15	0.32	0.60	0.85	1.13	1.52	1.80	NE E
Summer[2]	0.09	4.23	0.59	0.35	0.19	0.24	0.28	0.49	0.77	1.03	1.29	1.64	1.87	NE
Autumn	0.04	4.19	0.56	0.41	0.10	0.16	0.20	0.44	0.78	1.05	1.33	1.73	2.07	NE E
All	0.02	5.27	0.53	0.42	0.09	0.14	0.17	0.41	0.74	1.03	1.35	1.78	2.12	NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.21 Annual and monthly significant sea wave height statistics at P2.

Period (01 Jan 1979 – 31 Dec 2018)	Significant sea wave height statistics (1)													
	Significant sea wave height (m)				Exceedance percentile for significant sea wave height (m)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.13	3.28	0.74	0.44	0.20	0.28	0.32	0.63	0.99	1.29	1.64	2.08	2.30	N NE E
February	0.12	3.15	0.77	0.43	0.23	0.32	0.36	0.65	1.03	1.30	1.65	2.08	2.43	NE E
March	0.08	3.35	0.77	0.46	0.20	0.28	0.33	0.64	1.05	1.37	1.71	2.13	2.44	NE E
April	0.08	3.34	0.73	0.46	0.15	0.22	0.28	0.63	1.01	1.34	1.70	2.10	2.34	N NE E
May	0.05	3.33	0.72	0.49	0.13	0.20	0.25	0.58	1.01	1.37	1.76	2.21	2.46	N NE E
June	0.06	3.59	0.77	0.57	0.12	0.18	0.24	0.60	1.11	1.56	2.02	2.49	2.72	N NE E
July	0.03	3.47	0.81	0.61	0.12	0.21	0.26	0.62	1.12	1.67	2.25	2.65	2.84	N NE E
August	0.06	3.27	0.76	0.55	0.14	0.21	0.26	0.59	1.07	1.52	2.02	2.46	2.66	N NE E
September	0.06	3.27	0.75	0.51	0.14	0.24	0.28	0.61	1.05	1.42	1.85	2.30	2.62	N NE
October	0.07	3.19	0.69	0.46	0.17	0.24	0.28	0.56	0.96	1.30	1.67	2.10	2.31	N NE
November	0.09	3.22	0.69	0.45	0.17	0.25	0.29	0.57	0.95	1.28	1.63	2.07	2.42	N NE
December	0.10	3.27	0.72	0.44	0.18	0.26	0.31	0.60	0.97	1.28	1.64	2.03	2.37	N NE
Winter(3)	0.03	3.59	0.78	0.58	0.13	0.20	0.26	0.61	1.10	1.58	2.10	2.55	2.75	N NE E
Spring	0.06	3.27	0.71	0.47	0.17	0.24	0.28	0.58	0.99	1.34	1.71	2.17	2.45	N NE
Summer(2)	0.10	3.28	0.74	0.44	0.20	0.28	0.33	0.63	1.00	1.29	1.64	2.06	2.36	N NE E
Autumn	0.05	3.35	0.74	0.47	0.15	0.23	0.29	0.62	1.02	1.36	1.72	2.14	2.41	N NE E
All	0.03	3.59	0.74	0.49	0.15	0.24	0.29	0.61	1.03	1.38	1.79	2.27	2.55	N NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 1979 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.22 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P2.

Hs (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5	Total	Exceed%
>0<=0.5	0.98	14.18	4.43	0.26	0.28	0.51	0.63	0.14	21.41	100.00
>0.5<=1	5.04	28.90	9.22	0.44	0.05	0.24	0.28	0.31	44.48	78.59
>1<=1.5	2.47	14.24	3.37	0.12	-	0.04	*	*	20.24	34.12
>1.5<=2	0.93	5.75	1.11	0.03	-	*	-	-	7.82	13.88
>2<=2.5	0.32	2.42	0.50	*	-	-	-	-	3.24	6.06
>2.5<=3	0.09	1.18	0.25	-	-	-	-	-	1.52	2.81
>3<=3.5	0.02	0.56	0.12	-	-	-	-	-	0.70	1.29
>3.5<=4	*	0.28	0.03	-	-	-	-	-	0.31	0.59
>4<=4.5	*	0.13	0.01	-	-	-	-	-	0.14	0.27
>4.5<=5	-	0.06	0.01	-	-	-	-	-	0.07	0.13
>5<=5.5	-	0.03	0.01	-	-	-	-	-	0.04	0.05
>5.5<=6	-	0.01	*	-	-	-	-	-	0.01	0.01
>6<=6.5	-	*	*	-	-	-	-	-		
Total	9.85	67.74	19.06	0.85	0.33	0.79	0.91	0.45	100.00	

Notes: * represents less than 0.005%.

Table 4.23 Annual joint probability distribution (in %) of the total significant wave height and peak period at P2.

Hs (m)	Peak period (s)										
	2-4	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
>0<=0.5	1.79	0.81	1.86	8.70	5.25	1.58	0.77	0.37	0.14	0.04	21.31	100.00
>0.5<=1	2.26	4.64	8.32	17.49	8.17	2.32	0.76	0.35	0.13	0.03	44.47	78.59
>1<=1.5	*	4.66	3.82	7.18	3.31	0.97	0.26	0.03	0.01	*	20.24	34.12
>1.5<=2	-	1.40	2.04	2.31	1.43	0.54	0.09	0.01	*	-	7.82	13.88
>2<=2.5	-	0.03	1.60	0.75	0.59	0.21	0.04	0.01	-	-	3.23	6.06
>2.5<=3	-	-	0.75	0.38	0.28	0.09	0.01	*	-	-	1.51	2.81
>3<=3.5	-	-	0.20	0.32	0.13	0.05	*	*	*	*	0.70	1.29
>3.5<=4	-	-	0.02	0.21	0.06	0.03	*	*	*	-	0.32	0.59
>4<=4.5	-	-	*	0.10	0.04	0.01	*	*	-	-	0.15	0.27
>4.5<=5	-	-	-	0.03	0.03	0.01	-	-	-	-	0.07	0.13
>5<=5.5	-	-	-	0.01	0.02	0.01	-	-	-	-	0.04	0.05
>5.5<=6	-	-	-	*	0.01	*	-	-	-	-	0.01	0.01
>6<=6.5	-	-	-	-	*	*	-	-	-	-		
Total	4.05	11.54	18.61	37.48	19.32	5.82	1.93	0.77	0.28	0.07	100.00	
>Exceed%	99.90	95.85	84.32	65.71	28.22	8.90	3.08	1.13	0.36	0.07		

Notes: * represents less than 0.005%.

Table 4.24 Annual and monthly non-exceedance persistence (%) for significant wave height below 0.0 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00
annual	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.25 *Annual and monthly non-exceedance persistence (%) for significant wave height below 0.5 m at P2.*

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	10.98	10.18	8.91	8.12	6.84	5.00	1.55
Feb	8.00	7.46	6.91	6.16	5.56	4.40	2.58
Mar	10.10	9.54	8.65	7.94	7.12	5.46	3.15
Apr	19.71	18.80	18.09	17.29	15.14	13.40	8.94
May	26.44	25.46	24.15	23.15	20.43	18.64	14.62
Jun	28.00	27.04	25.89	24.99	22.80	20.27	12.41
Jul	24.01	22.94	21.39	19.82	17.29	13.87	9.83
Aug	25.87	25.04	23.49	21.94	18.59	15.69	9.83
Sep	24.91	23.90	22.41	21.57	18.48	16.58	9.74
Oct	29.85	27.94	26.05	24.10	21.01	17.65	10.12
Nov	26.30	24.32	22.79	20.48	16.24	12.59	7.21
Dec	14.82	13.66	12.40	11.92	8.88	6.67	3.28
annual	20.85	19.84	18.65	17.59	15.22	13.02	8.34

Table 4.26 Annual and monthly non-exceedance persistence (%) for significant wave height below 1.0 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	63.33	62.58	61.03	60.40	57.74	54.53	50.85
Feb	58.26	57.39	56.47	55.57	53.29	50.15	44.26
Mar	60.12	59.71	58.89	58.10	55.84	54.62	49.30
Apr	64.23	63.38	62.62	61.81	59.85	56.89	51.50
May	67.63	67.20	66.74	65.86	64.05	61.26	55.75
Jun	64.71	64.01	63.05	61.77	59.34	57.50	52.71
Jul	62.48	61.92	61.08	60.19	56.25	52.75	47.93
Aug	65.30	64.76	64.00	63.10	61.16	58.57	49.94
Sep	66.40	65.59	64.61	63.78	61.11	57.92	50.89
Oct	73.42	72.74	72.15	71.12	69.02	65.84	59.62
Nov	72.79	72.09	70.91	70.26	68.55	65.31	58.61
Dec	66.63	65.84	64.28	63.97	62.20	60.24	54.24
annual	65.55	64.99	64.18	63.53	61.65	59.24	54.31

Table 4.27 Annual and monthly non-exceedance persistence (%) for significant wave height below 1.5 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	87.02	86.83	86.71	86.30	85.25	84.02	81.09
Feb	86.02	85.61	84.95	84.76	83.82	83.47	81.17
Mar	84.62	84.32	83.76	83.12	81.54	80.42	77.77
Apr	86.56	86.39	85.95	85.52	84.29	83.17	79.66
May	86.73	86.42	86.24	85.61	85.06	83.24	81.08
Jun	81.81	81.48	81.37	80.78	79.75	77.54	73.93
Jul	80.26	79.92	79.46	79.13	77.77	76.09	70.51
Aug	84.27	83.98	83.69	83.14	81.66	80.43	77.33
Sep	85.96	85.77	85.30	84.46	83.08	81.12	76.57
Oct	89.29	89.05	88.53	88.14	87.22	85.90	82.42
Nov	89.89	89.57	88.78	88.46	87.70	86.88	83.79
Dec	88.29	88.01	87.52	87.45	86.46	84.92	82.60
annual	85.94	85.74	85.42	85.12	84.33	83.36	81.14

Table 4.28 Annual and monthly non-exceedance persistence (%) for significant wave height below 2.0 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	95.17	95.13	95.13	95.06	94.73	94.13	92.54
Feb	95.02	94.95	94.89	94.73	94.46	94.09	93.44
Mar	94.39	94.35	94.35	94.28	93.53	93.09	91.15
Apr	94.19	94.08	93.97	93.88	93.14	92.84	91.34
May	93.96	93.86	93.64	93.26	92.86	92.71	90.53
Jun	90.45	90.24	89.92	89.85	88.61	88.10	85.61
Jul	89.10	88.90	88.72	88.48	87.86	87.11	83.05
Aug	92.24	92.05	91.78	91.63	90.61	89.54	88.19
Sep	93.84	93.70	93.39	93.06	92.47	91.57	88.53
Oct	95.67	95.61	95.27	95.19	94.64	93.88	91.21
Nov	96.27	96.09	95.96	95.89	95.57	95.25	94.35
Dec	95.89	95.78	95.42	95.33	94.99	94.99	94.12
annual	93.86	93.79	93.68	93.60	93.37	93.04	91.82

Table 4.29 Annual and monthly non-exceedance persistence (%) for significant wave height below 2.5 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	97.91	97.87	97.74	97.74	97.64	97.50	96.81
Feb	98.02	97.89	97.82	97.74	97.47	97.30	97.07
Mar	97.41	97.41	97.28	97.28	97.17	96.88	96.69
Apr	97.51	97.31	97.20	97.12	96.78	96.47	96.28
May	97.57	97.54	97.49	97.40	97.27	96.50	96.50
Jun	95.63	95.50	95.39	95.23	95.11	94.12	92.73
Jul	93.59	93.56	93.44	93.44	93.02	92.88	90.68
Aug	95.68	95.68	95.62	95.62	94.86	94.22	93.57
Sep	97.18	97.15	96.91	96.91	96.68	96.03	94.24
Oct	98.58	98.51	98.46	98.46	98.23	97.73	97.01
Nov	98.42	98.38	98.31	98.16	97.93	97.93	97.50
Dec	98.08	98.01	97.90	97.67	97.67	97.51	97.09
annual	97.14	97.10	97.02	97.00	96.95	96.85	96.62

Table 4.30 Annual and monthly non-exceedance persistence (%) for significant wave height below 3.0 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.28	99.25	99.25	99.17	99.07	99.07	98.84
Feb	99.09	99.09	98.98	98.80	98.70	98.70	98.21
Mar	98.84	98.84	98.79	98.79	98.79	98.79	98.36
Apr	99.21	99.18	99.12	99.05	98.82	98.64	98.64
May	98.90	98.90	98.84	98.84	98.64	98.64	98.28
Jun	97.91	97.83	97.72	97.54	97.54	97.20	96.57
Jul	96.23	96.13	96.13	96.13	95.88	95.60	94.03
Aug	97.84	97.75	97.75	97.67	97.43	97.43	97.06
Sep	98.55	98.55	98.50	98.42	98.18	98.02	97.11
Oct	99.70	99.70	99.70	99.62	99.62	99.62	98.99
Nov	99.29	99.29	99.22	99.22	99.09	99.09	98.62
Dec	99.31	99.27	99.27	99.27	99.08	98.91	98.91
annual	98.69	98.67	98.64	98.64	98.60	98.59	98.50

Table 4.31 Annual and monthly non-exceedance persistence (%) for significant wave height below 3.5 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.73	99.73	99.73	99.73	99.73	99.73	99.73
Feb	99.67	99.67	99.55	99.45	99.34	99.34	98.80
Mar	99.44	99.41	99.41	99.41	99.31	99.31	99.31
Apr	99.69	99.69	99.69	99.69	99.58	99.58	99.40
May	99.50	99.46	99.46	99.46	99.46	99.46	99.46
Jun	99.05	99.05	98.93	98.84	98.73	98.73	98.31
Jul	98.08	97.99	97.99	97.99	97.90	97.58	96.22
Aug	99.07	98.99	98.89	98.89	98.89	98.74	98.74
Sep	99.23	99.23	99.23	99.16	99.16	98.99	98.80
Oct	99.92	99.92	99.92	99.92	99.92	99.92	99.72
Nov	99.67	99.67	99.67	99.67	99.54	99.54	99.31
Dec	99.70	99.70	99.70	99.70	99.60	99.60	99.60
annual	99.40	99.38	99.37	99.37	99.37	99.37	99.33

Table 4.32 Annual and monthly non-exceedance persistence (%) for significant wave height below 4.0 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.89	99.89	99.89	99.89	99.89	99.89	99.89
Feb	99.95	99.95	99.95	99.95	99.85	99.85	99.59
Mar	99.70	99.70	99.70	99.70	99.61	99.61	99.61
Apr	99.87	99.87	99.87	99.87	99.87	99.87	99.68
May	99.78	99.70	99.70	99.70	99.70	99.70	99.70
Jun	99.47	99.47	99.41	99.41	99.31	99.31	98.88
Jul	99.14	99.14	99.14	99.14	99.03	99.03	98.57
Aug	99.68	99.68	99.62	99.62	99.62	99.62	99.42
Sep	99.53	99.53	99.53	99.45	99.45	99.45	99.25
Oct	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Nov	99.80	99.80	99.80	99.80	99.80	99.66	99.66
Dec	99.86	99.86	99.86	99.86	99.86	99.86	99.86
annual	99.72	99.72	99.72	99.72	99.70	99.70	99.70

Table 4.33 Annual and monthly non-exceedance persistence (%) for significant wave height below 4.5 m at P2.

Hs (m)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	99.93	99.93	99.93	99.93	99.93	99.93	99.93
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.83	99.83	99.83	99.83	99.83	99.83	99.83
Apr	99.92	99.92	99.92	99.92	99.92	99.92	99.74
May	99.94	99.94	99.94	99.94	99.94	99.94	99.94
Jun	99.78	99.78	99.78	99.78	99.68	99.68	99.48
Jul	99.55	99.51	99.51	99.51	99.51	99.51	99.51
Aug	99.90	99.90	99.90	99.90	99.90	99.90	99.90
Sep	99.84	99.84	99.84	99.84	99.84	99.84	99.63
Oct	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Nov	99.86	99.86	99.86	99.86	99.86	99.70	99.70
Dec	99.92	99.92	99.92	99.92	99.92	99.92	99.92
annual	99.87	99.87	99.87	99.87	99.87	99.87	99.87

Table 4.34 Annual and monthly non-exceedance persistence (%) for significant wave height below 5.0 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	99.98	99.98	99.98	99.98	99.98	99.98	99.98
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	99.92	99.92	99.92	99.92	99.92	99.92	99.92
Apr	99.98	99.98	99.98	99.98	99.98	99.98	99.98
May	99.96	99.96	99.96	99.96	99.96	99.96	99.96
Jun	99.91	99.91	99.91	99.91	99.91	99.91	99.91
Jul	99.77	99.77	99.77	99.77	99.77	99.77	99.77
Aug	99.96	99.96	99.96	99.96	99.96	99.96	99.96
Sep	99.96	99.91	99.91	99.91	99.91	99.91	99.91
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	99.91	99.91	99.91	99.91	99.91	99.91	99.73
Dec	99.98	99.98	99.98	99.98	99.98	99.98	99.98
annual	99.94	99.94	99.94	99.94	99.94	99.94	99.94

Table 4.35 Annual and monthly non-exceedance persistence (%) for significant wave height below 5.5 m at P2.

Hs (m)	Duration (hours)						
	6	**12**	**18**	**24**	**36**	**48**	**72**
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	99.97	99.97	99.97	99.97	99.97	99.97	99.97
Jul	99.88	99.88	99.88	99.88	99.88	99.88	99.88
Aug	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	99.99	99.99	99.99	99.99	99.99	99.99	99.99

Table 4.36 Annual and monthly non-exceedance persistence (%) for significant wave height below 6.0 m at P2.

Hs (m)	Duration (hours)						
	6	12	18	24	36	48	72
Jan	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mar	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Apr	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Jul	99.96	99.96	99.96	99.96	99.96	99.96	99.96
Aug	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dec	100.00	100.00	100.00	100.00	100.00	100.00	100.00
annual	100.00	100.00	100.00	100.00	100.00	100.00	100.00

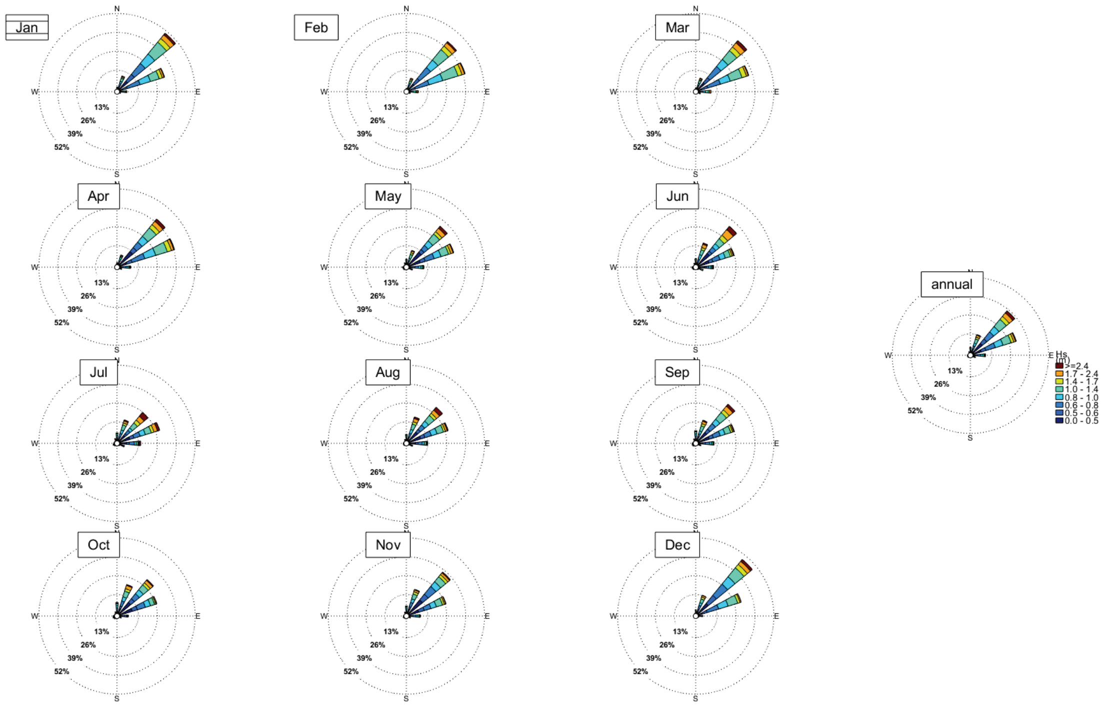

Figure 4.2 Monthly and annual wave rose plot for the total significant wave height at P2. Sectors indicate the direction from which waves approach.

5. Current climate

5.1. P1

A summary of the surface, mid-depth and near-bottom non-tidal current speed statistics at P1 are provided in Table 5.1, Table 5.2 and Table 5.3 respectively.

The annual joint probability distribution of the non-tidal surface, mid-depth and near-bottom current speed and direction is presented from Table 5.4 to Table 5.6.

The annual joint probability distribution of tidal depth-averaged current speed and direction is presented in Table 5.7, with the corresponding rose provided in Figure 5.1.

Table 5.1 Annual and monthly surface non-tidal current speed statistics at P1.

Period (01 Jan 2000 – 31 Dec 2018)	Surface current speed statistics (1)													
	Surface current speed (m/s)				Exceedance percentile for surface current speed (m/s)									Main (4) Direction(s)
	min	**max**	**mean**	**std**	**p1**	**p5**	**p10**	**p50**	**p80**	**p90**	**p95**	**p98**	**p99**	
January	0.00	0.50	0.13	0.07	0.01	0.03	0.04	0.12	0.19	0.23	0.27	0.32	0.36	SE NW
February	0.00	0.59	0.12	0.07	0.01	0.02	0.04	0.10	0.17	0.21	0.25	0.31	0.36	SE NW
March	0.00	0.52	0.10	0.07	0.01	0.02	0.03	0.09	0.15	0.20	0.24	0.30	0.33	SE NW
April	0.00	0.52	0.09	0.07	0.01	0.01	0.02	0.08	0.14	0.18	0.22	0.27	0.32	SE S NW
May	0.00	0.45	0.10	0.07	0.01	0.02	0.02	0.08	0.15	0.19	0.24	0.28	0.30	SE S NW
June	0.00	0.57	0.10	0.07	0.01	0.02	0.03	0.09	0.16	0.20	0.25	0.29	0.32	SE S
July	0.00	0.82	0.12	0.10	0.01	0.02	0.03	0.10	0.18	0.24	0.30	0.38	0.47	SE S
August	0.00	0.60	0.11	0.07	0.01	0.02	0.03	0.10	0.17	0.21	0.26	0.30	0.34	SE S
September	0.00	0.57	0.12	0.08	0.01	0.03	0.04	0.11	0.18	0.22	0.27	0.32	0.37	SE
October	0.00	0.49	0.13	0.07	0.01	0.03	0.04	0.12	0.18	0.23	0.26	0.31	0.35	E SE
November	0.00	0.51	0.13	0.07	0.01	0.03	0.04	0.12	0.18	0.23	0.27	0.32	0.35	E SE
December	0.00	0.57	0.13	0.08	0.01	0.03	0.05	0.12	0.19	0.23	0.27	0.33	0.36	E SE
Winter(3)	0.00	0.82	0.11	0.08	0.01	0.02	0.03	0.09	0.17	0.22	0.27	0.33	0.38	SE S
Spring	0.00	0.57	0.13	0.07	0.01	0.03	0.04	0.11	0.18	0.23	0.27	0.32	0.35	E SE
Summer(2)	0.00	0.59	0.13	0.08	0.01	0.03	0.04	0.12	0.18	0.22	0.27	0.32	0.36	SE NW
Autumn	0.00	0.52	0.10	0.07	0.01	0.02	0.02	0.08	0.15	0.19	0.23	0.28	0.32	SE S NW
All	0.00	0.82	0.12	0.08	0.01	0.02	0.03	0.10	0.17	0.22	0.26	0.31	0.35	SE NW

Notes: (1) All statistics derived from hindcast current data for the period 01 January 2000 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the currents is going to.

Table 5.2 Annual and monthly mid-depth non-tidal current speed statistics at P1.

Period (01 Jan 2000 – 31 Dec 2018)	Mid-depth current speed statistics (1)													
	Mid-depth current speed (m/s)				Exceedance percentile for mid-depth current speed (m/s)									Main (4) Direction(s)
	min	**max**	**mean**	**std**	**p1**	**p5**	**p10**	**p50**	**p80**	**p90**	**p95**	**p98**	**p99**	
January	0.00	0.31	0.06	0.04	0.01	0.01	0.02	0.05	0.10	0.12	0.15	0.18	0.20	N SE S NW
February	0.00	0.37	0.06	0.04	0.00	0.01	0.01	0.05	0.09	0.12	0.14	0.18	0.20	N SE S NW
March	0.00	0.32	0.06	0.05	0.00	0.01	0.01	0.04	0.09	0.12	0.15	0.19	0.22	N SE S NW
April	0.00	0.30	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.11	0.13	0.17	0.19	N SE S NW
May	0.00	0.28	0.06	0.04	0.00	0.01	0.01	0.05	0.09	0.12	0.14	0.17	0.19	SE S NW
June	0.00	0.32	0.06	0.04	0.00	0.01	0.01	0.05	0.10	0.12	0.15	0.17	0.19	SE S NW
July	0.00	0.59	0.07	0.06	0.00	0.01	0.01	0.06	0.11	0.14	0.18	0.24	0.31	SE S NW
August	0.00	0.39	0.07	0.05	0.00	0.01	0.02	0.06	0.10	0.13	0.15	0.18	0.21	SE S
September	0.00	0.39	0.07	0.05	0.00	0.01	0.02	0.06	0.10	0.13	0.15	0.19	0.22	SE S
October	0.00	0.31	0.07	0.04	0.01	0.01	0.02	0.06	0.11	0.13	0.15	0.18	0.19	SE S
November	0.00	0.34	0.07	0.05	0.01	0.01	0.02	0.06	0.10	0.13	0.16	0.18	0.20	SE S NW
December	0.00	0.42	0.06	0.04	0.01	0.01	0.02	0.05	0.09	0.12	0.15	0.19	0.21	N SE S NW
Winter(3)	0.00	0.59	0.07	0.05	0.00	0.01	0.01	0.05	0.10	0.13	0.16	0.20	0.23	SE S
Spring	0.00	0.39	0.07	0.05	0.01	0.01	0.02	0.06	0.10	0.13	0.15	0.18	0.21	SE S NW
Summer(2)	0.00	0.42	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.12	0.15	0.18	0.21	N SE S NW
Autumn	0.00	0.32	0.06	0.04	0.00	0.01	0.01	0.04	0.09	0.12	0.14	0.17	0.20	N SE S NW
All	0.00	0.59	0.06	0.05	0.00	0.01	0.01	0.05	0.10	0.12	0.15	0.18	0.21	SE S NW

Notes: (1) All statistics derived from hindcast current data for the period 01 January 2000 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the currents is going to.

Table 5.3 Annual and monthly near-bottom non-tidal current speed statistics at P1.

Period (01 Jan 2000 – 31 Dec 2018)	Near-bottom current speed statistics (1)													
	Near-bottom current speed (m/s)				Exceedance percentile for near-bottom current speed (m/s)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.00	0.27	0.04	0.03	0.00	0.01	0.01	0.04	0.06	0.09	0.10	0.14	0.16	N S NW
February	0.00	0.32	0.04	0.03	0.00	0.01	0.01	0.03	0.06	0.08	0.11	0.14	0.17	N S
March	0.00	0.27	0.05	0.04	0.00	0.01	0.01	0.04	0.07	0.10	0.12	0.15	0.17	N SE S
April	0.00	0.26	0.05	0.03	0.00	0.01	0.01	0.04	0.07	0.10	0.11	0.14	0.17	N SE S
May	0.00	0.25	0.06	0.04	0.00	0.01	0.01	0.05	0.09	0.11	0.13	0.15	0.17	N SE S
June	0.00	0.30	0.06	0.04	0.00	0.01	0.01	0.05	0.09	0.11	0.13	0.15	0.17	N SE S
July	0.00	0.51	0.07	0.05	0.01	0.01	0.02	0.05	0.10	0.13	0.16	0.21	0.26	N SE S
August	0.00	0.33	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.11	0.13	0.16	0.18	SE S
September	0.00	0.34	0.06	0.04	0.01	0.01	0.02	0.06	0.09	0.12	0.14	0.16	0.18	SE S
October	0.00	0.26	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.11	0.13	0.16	0.17	S
November	0.00	0.30	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.10	0.12	0.15	0.18	N S
December	0.00	0.36	0.04	0.03	0.00	0.01	0.01	0.04	0.06	0.08	0.10	0.13	0.17	N S
Winter(3)	0.00	0.51	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.12	0.14	0.17	0.20	N SE S
Spring	0.00	0.34	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.11	0.13	0.16	0.18	S
Summer(2)	0.00	0.36	0.04	0.03	0.00	0.01	0.01	0.04	0.06	0.08	0.10	0.14	0.17	N S
Autumn	0.00	0.27	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.10	0.12	0.15	0.17	N SE S
All	0.00	0.51	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.11	0.13	0.16	0.18	N SE S

Notes: (1) All statistics derived from hindcast current data for the period 01 January 2000 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the currents is going to.

Table 5.4 Annual joint probability distribution (in %) of the surface non-tidal current speed and direction at P1.

Ures (m/s)	Direction (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
>0<=0.05	2.61	2.02	2.48	3.80	2.79	1.60	1.58	2.77	19.65	100.00
>0.05<=0.1	3.02	2.52	4.07	7.21	3.73	2.08	2.47	4.15	29.25	80.41
>0.1<=0.15	1.98	1.52	3.21	7.22	2.97	1.74	2.06	3.15	23.85	51.17
>0.15<=0.2	0.97	0.48	1.46	5.44	2.05	0.59	1.05	2.30	14.34	27.25
>0.2<=0.25	0.34	0.07	0.45	3.35	1.19	0.13	0.30	1.39	7.22	12.94
>0.25<=0.3	0.12	0.01	0.10	1.59	0.55	0.01	0.09	0.72	3.19	5.71
>0.3<=0.35	0.03	-	0.02	0.68	0.25	-	0.02	0.45	1.45	2.52
>0.35<=0.4	0.01	-	*	0.20	0.08	-	*	0.27	0.56	1.06
>0.4<=0.45	*	-	-	0.07	0.03	-	-	0.16	0.26	0.51
>0.45<=0.5	*	-	-	0.02	0.01	-	-	0.08	0.11	0.24
>0.5<=0.55	-	-	-	0.01	0.01	-	-	0.05	0.07	0.13
>0.55<=0.6	-	-	-	-	*	-	-	0.02	0.02	0.06
>0.6<=0.65	-	-	-	-	-	-	-	0.01	0.01	0.04
>0.65<=0.7	-	-	-	-	-	-	-	0.01	0.01	0.02
>0.7<=0.75	-	-	-	-	-	-	-	*		0.01
>0.75<=0.8	-	-	-	-	-	-	-	0.01	0.01	0.01
>0.8<=0.85	-	-	-	-	-	-	-	0.01	0.01	0.01
Total	9.08	6.62	11.79	29.59	13.66	6.15	7.57	15.55	100.00	

Notes: * represents less than 0.005%.

Table 5.5 Annual joint probability distribution (in %) of the mid-depth non-tidal current speed and direction at P1.

Ures (m/s)	**Direction (degT)**									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
>0<=0.05	7.04	2.75	2.94	10.70	11.10	3.17	3.03	7.82	48.55	100.00
>0.05<=0.1	4.42	0.12	0.13	10.00	11.80	0.23	0.21	6.32	33.23	51.54
>0.1<=0.15	1.18	*	-	4.13	5.22	0.01	0.01	2.67	13.22	18.29
>0.15<=0.2	0.27	-	-	1.15	1.21	*	-	1.08	3.71	5.02
>0.2<=0.25	0.04	-	-	0.16	0.17	-	-	0.54	0.91	1.32
>0.25<=0.3	0.01	-	-	0.02	0.01	-	-	0.20	0.24	0.41
>0.3<=0.35	*	-	-	*	*	-	-	0.10	0.10	0.17
>0.35<=0.4	-	-	-	-	-	-	-	0.03	0.03	0.07
>0.4<=0.45	-	-	-	-	-	-	-	0.02	0.02	0.04
>0.45<=0.5	-	-	-	-	-	-	-	0.01	0.01	0.02
>0.5<=0.55	-	-	-	-	-	-	-	0.01	0.01	0.01
>0.55<=0.6	-	-	-	-	-	-	-	*		
Total	12.96	2.87	3.07	26.16	29.51	3.41	3.25	18.80	100.00	

Notes: * represents less than 0.005%.

Table 5.6 Annual joint probability distribution (in %) of the near-bottom non-tidal current speed and direction at P1.

Ures (m/s)	Direction (degT)									
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5	Total	Exceed%
>0<=0.05	9.31	4.13	3.55	10.71	14.38	3.79	2.87	6.71	55.45	100.00
>0.05<=0.1	6.43	0.72	0.30	5.13	16.41	0.51	0.14	3.06	32.70	44.64
>0.1<=0.15	2.06	0.06	*	0.81	5.50	0.04	0.01	0.97	9.45	11.88
>0.15<=0.2	0.62	*	-	0.10	0.72	-	*	0.40	1.84	2.40
>0.2<=0.25	0.16	-	-	0.01	0.03	-	-	0.17	0.37	0.57
>0.25<=0.3	0.04	-	-	-	*	-	-	0.09	0.13	0.20
>0.3<=0.35	0.01	-	-	-	-	-	-	0.03	0.04	0.07
>0.35<=0.4	0.01	-	-	-	-	-	-	0.01	0.02	0.04
>0.4<=0.45	*	-	-	-	-	-	-	0.01	0.01	0.02
>0.45<=0.5	-	-	-	-	-	-	-	*		
>0.5<=0.55	-	-	-	-	-	-	-	*		
Total	18.64	4.91	3.85	16.76	37.04	4.34	3.02	11.45	100.00	

Notes: * represents less than 0.005%.

Table 5.7 Annual joint probability distribution (in %) of the depth-averaged tidal current speed and direction at P1.

Ures (m/s)	Direction (degT)									
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5	Total	Exceed%
0-0.02	8.40	1.24	1.59	13.27	7.22	1.20	1.58	14.88	49.38	100.00
0.02-0.04	0.16	-	-	24.87	0.14	-	-	24.94	50.11	50.62
0.04-0.06	-	-	-	0.43	-	-	-	0.08	0.51	0.51
Total	8.56	1.24	1.59	38.57	7.36	1.20	1.58	39.90	100.00	

Notes: * represents less than 0.005%.

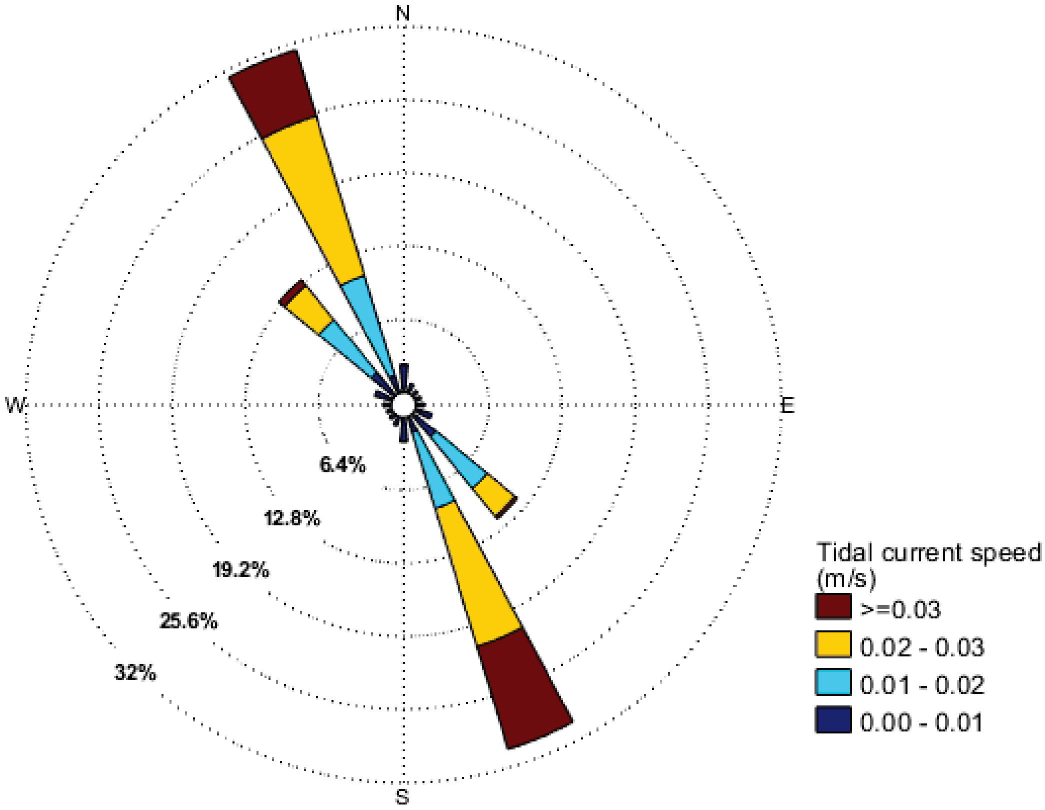

Figure 5.1 Tidal current rose at P1. Sectors indicate the direction to which the current is flowing.

5.2. P2

A summary of the surface, mid-depth and near-bottom non-tidal current speed statistics at P2 are provided in Table 5.8, Table 5.9 and Table 5.10 respectively.

The annual joint probability distribution of the non-tidal surface, mid-depth and near-bottom current speed and direction is presented from Table 5.11 to Table 5.13.

The annual joint probability distribution of tidal depth-averaged current speed and direction is presented in Table 5.14, with the corresponding rose provided in Figure 5.2.

Table 5.8 Annual and monthly surface non-tidal current speed statistics at P2.

Period (01 Jan 2000 – 31 Dec 2018)	Surface current speed statistics (1)													
	Surface current speed (m/s)				Exceedance percentile for surface current speed (m/s)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.00	0.51	0.13	0.07	0.01	0.03	0.04	0.12	0.19	0.23	0.27	0.32	0.36	SE NW
February	0.00	0.53	0.12	0.07	0.01	0.02	0.03	0.11	0.17	0.21	0.26	0.32	0.36	SE NW
March	0.00	0.55	0.10	0.07	0.01	0.02	0.03	0.09	0.15	0.20	0.23	0.29	0.32	SE NW
April	0.00	0.50	0.09	0.07	0.01	0.01	0.02	0.08	0.14	0.18	0.22	0.27	0.30	SE NW
May	0.00	0.44	0.11	0.07	0.01	0.02	0.02	0.09	0.17	0.21	0.25	0.29	0.32	SE
June	0.00	0.57	0.11	0.08	0.01	0.02	0.03	0.10	0.17	0.22	0.26	0.30	0.34	SE
July	0.00	0.79	0.13	0.09	0.01	0.02	0.03	0.11	0.19	0.25	0.30	0.36	0.44	SE
August	0.00	0.58	0.12	0.08	0.01	0.02	0.03	0.11	0.18	0.23	0.26	0.30	0.33	SE
September	0.00	0.56	0.13	0.08	0.01	0.03	0.04	0.12	0.19	0.24	0.28	0.33	0.38	E SE
October	0.00	0.48	0.13	0.08	0.01	0.03	0.04	0.12	0.19	0.24	0.28	0.32	0.35	E SE
November	0.00	0.46	0.13	0.07	0.01	0.03	0.04	0.12	0.19	0.23	0.27	0.32	0.35	E SE
December	0.00	0.55	0.13	0.08	0.01	0.03	0.05	0.12	0.19	0.23	0.27	0.33	0.36	E SE
Winter(3)	0.00	0.79	0.12	0.08	0.01	0.02	0.03	0.11	0.18	0.23	0.27	0.33	0.36	SE
Spring	0.00	0.56	0.13	0.08	0.01	0.03	0.04	0.12	0.19	0.24	0.28	0.32	0.36	E SE
Summer(2)	0.00	0.55	0.13	0.07	0.01	0.03	0.04	0.12	0.18	0.23	0.27	0.32	0.36	SE NW
Autumn	0.00	0.55	0.10	0.07	0.01	0.02	0.02	0.09	0.15	0.20	0.24	0.28	0.32	SE NW
All	0.00	0.79	0.12	0.08	0.01	0.02	0.03	0.11	0.18	0.22	0.27	0.32	0.35	SE NW

Notes: (1) All statistics derived from hindcast current data for the period 01 January 2000 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the currents is going to.

Table 5.9 Annual and monthly mid-depth non-tidal current speed statistics at P2.

Period (01 Jan 2000 – 31 Dec 2018)	Mid-depth current speed statistics (1)													
	Mid-depth current speed (m/s)				Exceedance percentile for mid-depth current speed (m/s)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.00	0.29	0.06	0.04	0.01	0.01	0.02	0.05	0.09	0.12	0.14	0.18	0.20	SE S NW
February	0.00	0.33	0.06	0.04	0.00	0.01	0.01	0.05	0.09	0.12	0.15	0.18	0.21	SE S NW
March	0.00	0.35	0.06	0.04	0.00	0.01	0.01	0.04	0.08	0.11	0.14	0.18	0.21	SE NW
April	0.00	0.27	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.11	0.14	0.17	0.18	SE NW
May	0.00	0.27	0.06	0.05	0.00	0.01	0.01	0.05	0.10	0.14	0.16	0.19	0.20	SE NW
June	0.00	0.31	0.07	0.05	0.00	0.01	0.02	0.06	0.11	0.14	0.16	0.19	0.21	SE NW
July	0.00	0.53	0.08	0.06	0.00	0.01	0.02	0.07	0.12	0.16	0.19	0.23	0.28	SE NW
August	0.00	0.37	0.08	0.05	0.01	0.01	0.02	0.07	0.12	0.14	0.16	0.18	0.20	SE
September	0.00	0.36	0.07	0.05	0.00	0.01	0.02	0.06	0.12	0.14	0.17	0.20	0.23	SE
October	0.00	0.29	0.07	0.05	0.01	0.01	0.02	0.06	0.11	0.14	0.16	0.19	0.21	SE S NW
November	0.00	0.31	0.07	0.05	0.01	0.01	0.02	0.05	0.10	0.13	0.16	0.18	0.20	SE S NW
December	0.00	0.40	0.06	0.04	0.01	0.01	0.02	0.05	0.09	0.12	0.15	0.18	0.21	SE S NW
Winter(3)	0.00	0.53	0.08	0.05	0.00	0.01	0.02	0.07	0.12	0.14	0.17	0.20	0.23	SE NW
Spring	0.00	0.36	0.07	0.05	0.01	0.01	0.02	0.06	0.11	0.14	0.16	0.19	0.21	SE S NW
Summer(2)	0.00	0.40	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.12	0.15	0.18	0.20	SE S NW
Autumn	0.00	0.35	0.06	0.05	0.00	0.01	0.01	0.04	0.09	0.12	0.15	0.18	0.20	SE NW
All	0.00	0.53	0.07	0.05	0.00	0.01	0.02	0.05	0.10	0.13	0.16	0.19	0.21	SE NW

Notes: (1) All statistics derived from hindcast current data for the period 01 January 2000 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the currents is going to.

Table 5.10 Annual and monthly near-bottom non-tidal current speed statistics at P2.

Period (01 Jan 2000 – 31 Dec 2018)	Near-bottom current speed statistics (1)													
	Near-bottom current speed (m/s)				Exceedance percentile for near-bottom current speed (m/s)									Main (4) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.00	0.26	0.05	0.03	0.00	0.01	0.01	0.04	0.07	0.09	0.11	0.14	0.17	N SE S NW
February	0.00	0.29	0.04	0.03	0.00	0.01	0.01	0.03	0.07	0.09	0.11	0.14	0.17	N SE S NW
March	0.00	0.26	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.10	0.12	0.15	0.17	N SE S NW
April	0.00	0.30	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.10	0.12	0.15	0.17	N SE S
May	0.00	0.24	0.06	0.04	0.00	0.01	0.01	0.05	0.10	0.13	0.15	0.17	0.19	N SE S
June	0.00	0.29	0.07	0.04	0.01	0.01	0.02	0.06	0.10	0.13	0.14	0.17	0.19	SE S
July	0.00	0.47	0.07	0.05	0.01	0.01	0.02	0.07	0.11	0.14	0.17	0.20	0.25	SE S
August	0.00	0.32	0.07	0.04	0.01	0.01	0.02	0.07	0.11	0.13	0.14	0.17	0.18	SE S
September	0.00	0.33	0.07	0.04	0.00	0.01	0.02	0.06	0.11	0.13	0.15	0.18	0.20	SE S
October	0.00	0.24	0.07	0.04	0.00	0.01	0.02	0.06	0.11	0.13	0.15	0.17	0.18	SE S
November	0.00	0.28	0.06	0.04	0.00	0.01	0.02	0.05	0.09	0.12	0.14	0.17	0.18	SE S NW
December	0.00	0.35	0.05	0.04	0.00	0.01	0.01	0.04	0.07	0.09	0.11	0.15	0.17	N SE S NW
Winter(3)	0.00	0.47	0.07	0.05	0.01	0.01	0.02	0.06	0.11	0.13	0.15	0.18	0.20	SE S
Spring	0.00	0.33	0.07	0.04	0.00	0.01	0.02	0.06	0.10	0.13	0.15	0.17	0.19	SE S
Summer(2)	0.00	0.35	0.05	0.03	0.00	0.01	0.01	0.04	0.07	0.09	0.11	0.14	0.17	N SE S NW
Autumn	0.00	0.30	0.05	0.04	0.00	0.01	0.01	0.04	0.08	0.11	0.13	0.16	0.18	N SE S NW
All	0.00	0.47	0.06	0.04	0.00	0.01	0.01	0.05	0.09	0.12	0.14	0.17	0.19	SE S NW

Notes: (1) All statistics derived from hindcast current data for the period 01 January 2000 to 31 December 2018.
(2) Summer: April to September.
(3) Winter: October to March.
(4) Main directions are those with greater than 15% occurrence and represent directions from which the currents is going to.

Table 5.11 Annual joint probability distribution (in %) of the surface non-tidal current speed and direction at P2.

Ures (m/s)	Direction (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
>0<=0.05	2.15	1.73	2.44	4.01	2.26	1.39	1.69	2.93	18.60	100.00
>0.05<=0.1	2.41	2.29	3.73	7.75	2.72	2.09	2.52	3.99	27.50	81.46
>0.1<=0.15	1.57	1.50	3.47	7.69	2.56	1.70	2.25	3.09	23.83	53.96
>0.15<=0.2	0.77	0.50	2.00	6.58	1.70	0.58	1.25	2.18	15.56	30.08
>0.2<=0.25	0.21	0.07	0.75	4.30	0.90	0.11	0.46	1.30	8.10	14.54
>0.25<=0.3	0.06	*	0.21	2.21	0.42	0.02	0.15	0.69	3.76	6.44
>0.3<=0.35	0.01	*	0.04	1.00	0.12	-	0.03	0.42	1.62	2.66
>0.35<=0.4	*	-	0.01	0.31	0.05	-	0.01	0.23	0.61	1.04
>0.4<=0.45	*	-	*	0.09	0.01	-	*	0.13	0.23	0.43
>0.45<=0.5	-	-	-	0.03	*	-	-	0.06	0.09	0.19
>0.5<=0.55	-	-	-	0.01	*	-	-	0.03	0.04	0.09
>0.55<=0.6	-	-	-	*	-	-	-	0.02	0.02	0.05
>0.6<=0.65	-	-	-	-	-	-	-	0.01	0.01	0.03
>0.65<=0.7	-	-	-	-	-	-	-	*		0.01
>0.7<=0.75	-	-	-	-	-	-	-	0.01	0.01	0.01
>0.75<=0.8	-	-	-	-	-	-	-	*		
Total	7.18	6.09	12.65	33.98	10.74	5.89	8.36	15.09	100.00	

Notes: * represents less than 0.005%.

Table 5.12 Annual joint probability distribution (in %) of the mid-depth non-tidal current speed and direction at P2.

Ures (m/s)	Direction (degT)									
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5	Total	Exceed%
>0<=0.05	5.38	2.40	3.19	12.90	7.79	2.64	3.29	8.81	46.40	100.00
>0.05<=0.1	2.23	0.08	0.25	17.11	4.22	0.17	0.35	7.81	32.22	53.68
>0.1<=0.15	0.31	*	*	10.60	1.05	*	*	3.09	15.05	21.42
>0.15<=0.2	0.03	-	-	3.53	0.18	-	-	1.19	4.93	6.33
>0.2<=0.25	-	-	-	0.61	0.02	-	-	0.43	1.06	1.41
>0.25<=0.3	-	-	-	0.07	-	-	-	0.16	0.23	0.34
>0.3<=0.35	-	-	-	0.01	-	-	-	0.05	0.06	0.11
>0.35<=0.4	-	-	-	*	-	-	-	0.03	0.03	0.05
>0.4<=0.45	-	-	-	-	-	-	-	0.01	0.01	0.02
>0.45<=0.5	-	-	-	-	-	-	-	0.01	0.01	0.01
>0.5<=0.55	-	-	-	-	-	-	-	*		
Total	7.95	2.48	3.44	44.83	13.26	2.81	3.64	21.59	100.00	

Notes: * represents less than 0.005%.

Table 5.13 Annual joint probability distribution (in %) of the near-bottom non-tidal current speed and direction at P2.

Ures (m/s)	Direction (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
>0<=0.05	7.51	3.53	4.12	12.81	9.15	3.13	3.07	7.77	51.09	100.00
>0.05<=0.1	4.79	0.54	0.54	13.03	8.06	0.41	0.25	4.80	32.42	49.02
>0.1<=0.15	1.54	0.03	0.01	4.85	4.74	0.04	0.01	1.62	12.84	16.54
>0.15<=0.2	0.35	*	-	0.88	1.20	-	-	0.62	3.05	3.66
>0.2<=0.25	0.07	-	-	0.08	0.10	-	-	0.23	0.48	0.62
>0.25<=0.3	0.01	-	-	0.01	*	-	-	0.06	0.08	0.14
>0.3<=0.35	*	-	-	-	-	-	-	0.03	0.03	0.06
>0.35<=0.4	-	-	-	-	-	-	-	0.01	0.01	0.02
>0.4<=0.45	-	-	-	-	-	-	-	0.01	0.01	0.01
>0.45<=0.5	-	-	-	-	-	-	-	*		
Total	14.27	4.10	4.67	31.66	23.25	3.58	3.33	15.15	100.00	

Notes: * represents less than 0.005%.

Table 5.14 Annual joint probability distribution (in %) of the depth-averaged tidal current speed and direction at P2.

Utide (m/s)	Direction (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.02	6.16	0.95	1.24	7.29	5.58	0.94	1.25	7.62	31.03	100.00
0.02-0.04	0.76	-	-	20.12	0.63	-	-	24.32	45.83	68.96
0.04-0.06	-	-	-	12.70	-	-	-	10.27	22.97	23.13
0.06-0.08	-	-	-	0.16	-	-	-	-	0.16	0.16
Total	6.92	0.95	1.24	40.27	6.21	0.94	1.25	42.21	100.00	

Notes: * represents less than 0.005%.

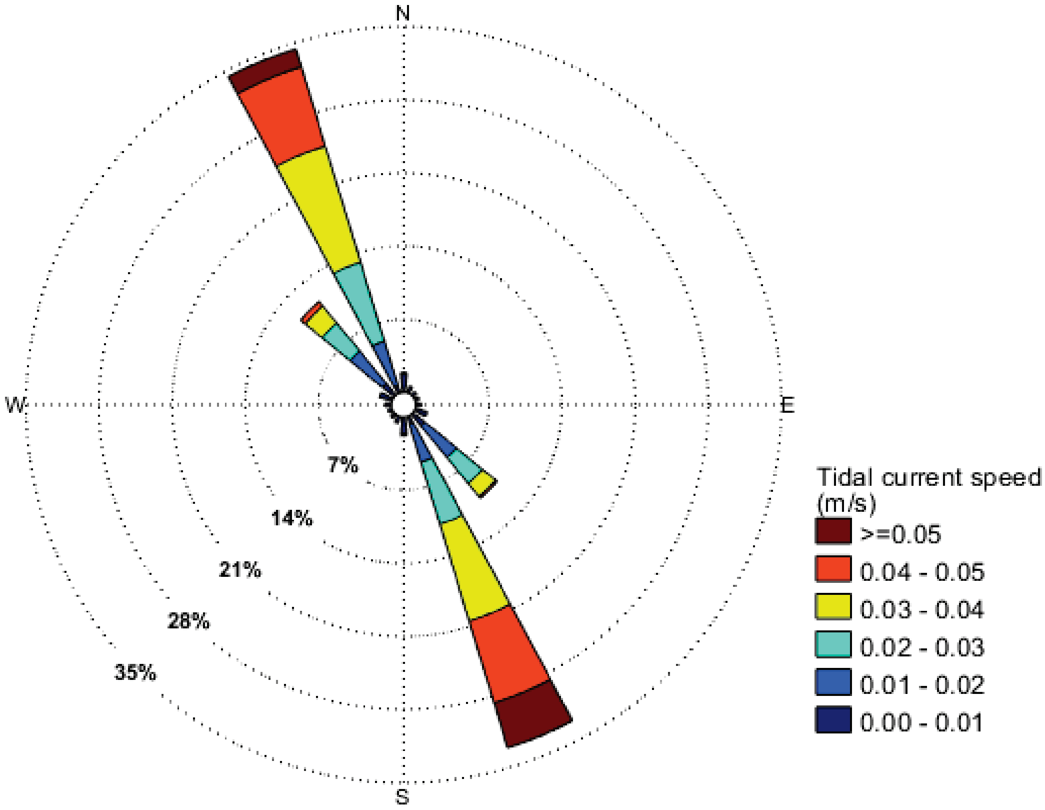

Figure 5.2 Tidal current rose at P2. Sectors indicate the direction to which the current is flowing.

6. Workability statistics

Annual and monthly workability statistics for the operational area are presented in Table 6.1 to Table 6.4 to as persistence probabilities for the following co-temporal criteria:

- Hs swell < 1.5 m and Wind speed < 25 knots (from NW to SE, clockwise) or Wind speed < 40 knots (from SE to NW, clockwise).

- Hs swell < 2.5 m and Wind speed < 25 knots (from NW to SE, clockwise) or Wind speed < 40 knots (from SE to NW, clockwise).

An example interpretation is as follows. Based on the limiting criteria indicated above, the month of February has the highest workability (Table 6.1); for durations of at least 12 consecutive hours the average workability is 97.91%.

Table 6.1 Annual and monthly workability probabilities (% of workable time) for marine operations at P1 for several durations. Workability is based on Hs swell < 1.5 m and Wspd < 25 knots (from NW to SE, clockwise) or Wspd < 40 knots (from SE to NW, clockwise).

%	Duration (hours)											
	> 6	**> 12**	**> 18**	**> 24**	**> 30**	**> 36**	**> 42**	**> 48**	**> 54**	**> 60**	**> 66**	**> 72**
Jan	97.17	97.02	96.91	96.76	96.76	96.64	96.64	96.48	96.30	95.88	95.40	95.40
Feb	98.07	97.91	97.84	97.58	97.46	97.18	97.01	96.46	96.03	95.79	95.79	95.79
Mar	97.48	97.39	97.27	97.11	97.01	96.50	96.36	96.20	96.02	95.81	95.11	95.11
Apr	97.45	97.13	97.07	96.99	96.89	96.76	96.62	96.29	96.08	95.86	94.91	94.91
May	97.50	97.25	97.18	96.68	96.48	96.36	96.22	96.06	95.66	95.66	95.44	95.44
Jun	95.93	95.39	95.26	95.01	94.90	94.63	94.18	93.47	93.08	92.19	91.95	91.95
Jul	95.09	94.88	94.52	94.18	94.07	93.16	92.84	91.63	91.23	90.35	90.10	88.51
Aug	97.17	96.95	96.82	96.59	96.07	95.81	95.38	94.86	94.67	94.46	93.99	92.95
Sep	97.98	97.81	97.48	97.17	96.73	96.33	96.04	95.36	94.77	93.22	92.26	91.74
Oct	98.91	98.73	98.37	98.29	97.98	97.85	97.55	96.88	96.51	96.10	95.15	94.64
Nov	98.95	98.88	98.69	98.19	97.66	97.66	97.23	97.23	97.23	97.23	96.26	95.99
Dec	98.42	98.30	97.99	97.76	97.76	97.63	97.48	97.48	97.10	96.90	96.90	96.65
Annual	97.53	97.36	97.26	97.08	97.01	96.95	96.79	96.59	96.41	96.16	96.00	95.78

Table 6.2 Annual and monthly workability probabilities (% of workable time) for marine operations at P2 for several durations. Workability is based on Hs swell < 1.5 m and Wspd < 25 knots (from NW to SE, clockwise) or Wspd < 40 knots (from SE to NW, clockwise).

%	Duration (hours)											
	> 6	**> 12**	**> 18**	**> 24**	**> 30**	**> 36**	**> 42**	**> 48**	**> 54**	**> 60**	**> 66**	**> 72**
Jan	97.01	96.73	96.51	96.51	96.51	96.38	96.38	96.38	96.38	96.18	95.70	95.44
Feb	97.95	97.80	97.60	97.52	97.52	97.12	96.95	96.76	96.56	96.10	96.10	96.10
Mar	97.25	97.14	97.03	96.87	96.87	96.25	95.80	95.80	95.62	95.20	94.73	94.22
Apr	97.14	96.75	96.75	96.67	96.46	96.21	96.21	95.86	95.28	95.06	94.83	94.83
May	97.42	97.25	97.25	96.79	96.39	96.26	96.11	95.95	95.57	95.57	95.10	95.10
Jun	95.38	95.10	94.93	94.53	94.42	94.16	93.69	92.99	92.20	91.75	91.51	91.51
Jul	95.00	94.78	94.50	94.16	93.83	93.05	92.59	92.42	91.65	90.57	90.07	89.01
Aug	97.07	96.97	96.91	96.60	96.19	96.07	95.36	94.83	94.64	94.64	93.94	92.93
Sep	97.67	97.54	97.22	96.97	96.76	96.64	96.33	95.65	95.25	94.59	93.63	93.12
Oct	98.61	98.37	98.00	97.85	97.54	97.41	97.12	96.61	96.22	96.22	95.28	94.52
Nov	99.06	99.00	98.87	98.45	98.04	97.92	97.46	97.46	97.46	97.23	96.51	96.51
Dec	98.25	98.01	97.75	97.60	97.49	97.49	97.49	97.32	96.75	96.75	96.53	96.53
Annual	97.34	97.18	97.09	96.94	96.85	96.78	96.62	96.53	96.29	96.17	96.03	95.85

Table 6.3 Annual and monthly workability probabilities (% of workable time) for marine operations at P1 for several durations. Workability is based on Hs swell < 2.5 m and Wspd < 25 knots (from NW to SE, clockwise) or Wspd < 40 knots (from SE to NW, clockwise).

%	Duration (hours)											
	> 6	**> 12**	**> 18**	**> 24**	**> 30**	**> 36**	**> 42**	**> 48**	**> 54**	**> 60**	**> 66**	**> 72**
Jan	99.72	99.64	99.48	99.48	99.48	99.48	99.48	99.32	99.14	98.92	98.68	98.43
Feb	99.79	99.54	99.47	99.19	99.09	98.66	98.66	98.47	98.04	98.04	98.04	97.76
Mar	99.53	99.46	99.34	99.25	99.05	98.67	98.67	98.51	98.13	97.92	97.92	97.92
Apr	99.68	99.20	99.14	99.14	99.04	98.92	98.78	98.44	98.24	98.02	97.79	97.79
May	99.73	99.54	99.48	99.15	99.05	98.93	98.63	98.31	97.72	97.72	97.72	97.72
Jun	99.50	99.15	99.09	99.00	98.89	98.48	97.87	96.98	96.59	96.14	95.90	95.64
Jul	99.15	98.88	98.53	98.19	98.08	97.55	97.39	96.71	96.51	95.85	95.12	93.52
Aug	99.33	99.05	98.92	98.77	98.46	98.08	97.65	97.30	96.92	96.71	96.23	95.20
Sep	99.66	99.48	99.15	98.83	98.49	98.09	97.80	97.29	96.69	95.59	94.63	93.84
Oct	99.88	99.77	99.35	99.27	99.07	98.82	98.53	97.86	97.67	97.67	96.50	95.99
Nov	99.82	99.75	99.62	99.30	98.98	98.98	98.25	98.25	98.25	98.25	97.77	97.50
Dec	99.77	99.69	99.33	99.01	98.90	98.90	98.75	98.75	98.37	98.17	98.17	98.17
Annual	99.65	99.48	99.37	99.26	99.20	99.13	98.95	98.83	98.65	98.59	98.40	98.18

Table 6.4 Annual and monthly workability probabilities (% of workable time) for marine operations at P2 for several durations. Workability is based on Hs swell < 2.5 m and Wspd < 25 knots (from NW to SE, clockwise) or Wspd < 40 knots (from SE to NW, clockwise).

%	Duration (hours)											
	> 6	**> 12**	**> 18**	**> 24**	**> 30**	**> 36**	**> 42**	**> 48**	**> 54**	**> 60**	**> 66**	**> 72**
Jan	99.77	99.66	99.55	99.55	99.55	99.55	99.55	99.55	99.55	99.33	99.10	98.85
Feb	99.80	99.60	99.48	99.21	99.21	99.07	99.07	98.88	98.68	98.45	98.45	98.45
Mar	99.59	99.46	99.34	99.26	99.26	99.01	98.72	98.55	98.37	98.17	98.17	97.92
Apr	99.58	99.20	99.08	99.00	98.90	98.90	98.90	98.56	98.56	98.34	98.34	98.34
May	99.74	99.55	99.55	99.23	99.12	99.01	98.70	98.38	98.00	98.00	98.00	98.00
Jun	99.36	99.17	99.06	98.97	98.87	98.59	97.98	97.09	96.71	96.04	95.80	95.27
Jul	99.09	98.76	98.48	98.14	97.92	97.38	97.23	97.06	96.28	95.63	95.14	93.81
Aug	99.43	99.25	99.07	98.91	98.71	98.33	97.76	97.41	97.03	97.03	96.55	95.53
Sep	99.65	99.47	99.28	99.03	98.92	98.66	98.36	97.84	97.45	97.01	96.29	95.50
Oct	99.95	99.81	99.43	99.12	98.91	98.66	98.52	98.02	98.02	98.02	97.09	96.33
Nov	99.89	99.82	99.77	99.43	99.22	99.22	98.63	98.63	98.63	98.63	97.92	97.92
Dec	99.81	99.59	99.33	99.10	98.90	98.90	98.90	98.73	98.16	98.16	98.16	98.16
Annual	99.66	99.50	99.42	99.29	99.26	99.19	99.06	98.96	98.85	98.81	98.69	98.52

7. Extreme metocean statistics

Note an arbitrary minimum number of 10 storm peaks has been was chosen for reliable distribution fitting. This results in specific directional return period values being omitted (see Section 9.3).

7.1. P1

The directional return period values for wind, wave and current extremes are given in Table 7.1 to Table 7.9 for 1, 10, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 7.1.

Table 7.1 Annual independent omni-directional extreme criteria for wind, wave and current at P1.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	18.31	22.13	24.69	25.78
10min wind speed	U_{10min}	$m.s^{-1}$	19.74	23.95	26.79	27.98
1 min wind speed	U_{1min}	$m.s^{-1}$	21.57	26.29	29.47	30.82
3s wind gust	U_{3s}	$m.s^{-1}$	23.95	29.34	32.97	34.51
Significant wave height	H_s	m	4.46	5.67	6.29	6.52
Peak wave period	T_p	s	9.61	10.73	11.25	11.43
Maximum individual wave height	H_{max}	m	8.57	10.59	11.54	11.91
Maximum individual wave crest	C_{max}	m	5.53	6.78	7.38	7.59
Surface current speed	U_{surf}	$m.s^{-1}$	0.51	0.67	0.78	0.82
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.30	0.41	0.48	0.51
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.26	0.36	0.43	0.46

Table 7.2 Annual independent North extreme criteria for wind, wave and current at P1.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	14.03	16.99	19.01	19.87
10min wind speed	U_{10min}	$m.s^{-1}$	15.03	18.28	20.51	21.46
1 min wind speed	U_{1min}	$m.s^{-1}$	16.31	19.93	22.43	23.50
3s wind gust	U_{3s}	$m.s^{-1}$	17.97	22.09	24.93	26.15
Significant wave height	H_s	m	2.41	3.10	3.43	3.54
Peak wave period	T_p	s	6.80	7.44	7.70	7.79
Maximum individual wave height	H_{max}	m	4.67	5.88	6.50	6.71
Maximum individual wave crest	C_{max}	m	2.96	3.75	4.14	4.29
Surface current speed	U_{surf}	$m.s^{-1}$	0.24	0.34	0.41	0.44
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.14	0.19	0.23	0.24
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.21	0.33	0.43	0.47

Table 7.3 *Annual independent North-East extreme criteria for wind, wave and current at P1.*

Parameter	Symbol	Units	Return period (year)			
			1	**10**	**50**	**100**
Hourly wind speed	U_{1h}	$m.s^{-1}$	14.28	17.96	20.42	21.46
10min wind speed	U_{10min}	$m.s^{-1}$	15.30	19.36	22.07	23.22
1 min wind speed	U_{1min}	$m.s^{-1}$	16.60	21.15	24.19	25.49
3s wind gust	U_{3s}	$m.s^{-1}$	18.30	23.48	26.96	28.43
Significant wave height	H_s	m	4.34	5.44	5.91	6.06
Peak wave period	T_p	s	9.70	10.72	11.11	11.24
Maximum individual wave height	H_{max}	m	8.34	10.30	11.23	11.57
Maximum individual wave crest	C_{max}	m	5.33	6.58	7.17	7.38
Surface current speed	U_{surf}	$m.s^{-1}$	0.17	0.21	0.25	0.27
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.08	0.13	0.18	0.20

Table 7.4 *Annual independent East extreme criteria for wind, wave and current at P1.*

Parameter	Symbol	Units	Return period (year)			
			1	**10**	**50**	**100**
Hourly wind speed	U_{1h}	$m.s^{-1}$	14.72	19.33	22.51	23.88
10min wind speed	U_{10min}	$m.s^{-1}$	15.78	20.87	24.40	25.91
1 min wind speed	U_{1min}	$m.s^{-1}$	17.15	22.86	26.82	28.53
3s wind gust	U_{3s}	$m.s^{-1}$	18.92	25.44	29.98	31.93
Significant wave height	H_s	m	2.99	4.66	5.75	6.20
Peak wave period	T_p	s	16.71	19.21	20.27	20.63
Maximum individual wave height	H_{max}	m	6.13	8.98	10.52	11.02
Maximum individual wave crest	C_{max}	m	3.91	5.75	6.75	7.06
Surface current speed	U_{surf}	$m.s^{-1}$	0.20	0.29	0.36	0.40
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.5 *Annual independent South-East extreme criteria for wind, wave and current at P1.*

Parameter	Symbol	Units	Return period (year)			
			1	**10**	**50**	**100**
Hourly wind speed	U_{1h}	$m.s^{-1}$	14.05	18.54	21.63	22.95
10min wind speed	U_{10min}	$m.s^{-1}$	15.04	20.01	23.43	24.89
1 min wind speed	U_{1min}	$m.s^{-1}$	16.32	21.89	25.74	27.39
3s wind gust	U_{3s}	$m.s^{-1}$	17.99	24.35	28.76	30.65
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.40	0.50	0.56	0.59
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.22	0.29	0.34	0.36
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.14	0.19	0.23	0.24

Table 7.6 *Annual independent South extreme criteria for wind, wave and current at P1.*

Parameter	Symbol	Units	Return period (year)			
			1	**10**	**50**	**100**
Hourly wind speed	U_{1h}	$m.s^{-1}$	10.57	14.03	16.25	17.19
10min wind speed	U_{10min}	$m.s^{-1}$	11.25	15.01	17.45	18.47
1 min wind speed	U_{1min}	$m.s^{-1}$	12.12	16.29	18.98	20.11
3s wind gust	U_{3s}	$m.s^{-1}$	13.25	17.94	20.98	22.26
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.31	0.38	0.42	0.44
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.20	0.27	0.31	0.33
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.19	0.23	0.26	0.28

Table 7.7 *Annual independent South-West extreme criteria for wind, wave and current at P1.*

Parameter	Symbol	Units	Return period (year)			
			1	**10**	**50**	**100**
Hourly wind speed	U_{1h}	$m.s^{-1}$	12.86	16.39	18.90	19.99
10min wind speed	U_{10min}	$m.s^{-1}$	13.74	17.60	20.34	21.54
1 min wind speed	U_{1min}	$m.s^{-1}$	14.87	19.15	22.20	23.52
3s wind gust	U_{3s}	$m.s^{-1}$	16.35	21.17	24.61	26.11
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.18	0.23	0.29	0.31
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.8 *Annual independent West extreme criteria for wind, wave and current at P1.*

Parameter	Symbol	Units	Return period (year)			
			1	**10**	**50**	**100**
Hourly wind speed	U_{1h}	$m.s^{-1}$	13.10	15.84	17.66	18.43
10min wind speed	U_{10min}	$m.s^{-1}$	14.00	17.00	18.99	19.83
1 min wind speed	U_{1min}	$m.s^{-1}$	15.16	18.49	20.71	21.64
3s wind gust	U_{3s}	$m.s^{-1}$	16.67	20.44	22.94	24.00
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.21	0.31	0.41	0.46
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.9 Annual independent North-West extreme criteria for wind, wave and current at P1.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	11.58	14.91	17.16	18.12
10min wind speed	U_{10min}	$m.s^{-1}$	12.35	15.98	18.45	19.49
1 min wind speed	U_{1min}	$m.s^{-1}$	13.33	17.36	20.09	21.25
3s wind gust	U_{3s}	$m.s^{-1}$	14.61	19.15	22.23	23.55
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.47	0.71	0.87	0.95
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.30	0.48	0.60	0.66
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.23	0.43	0.57	0.63

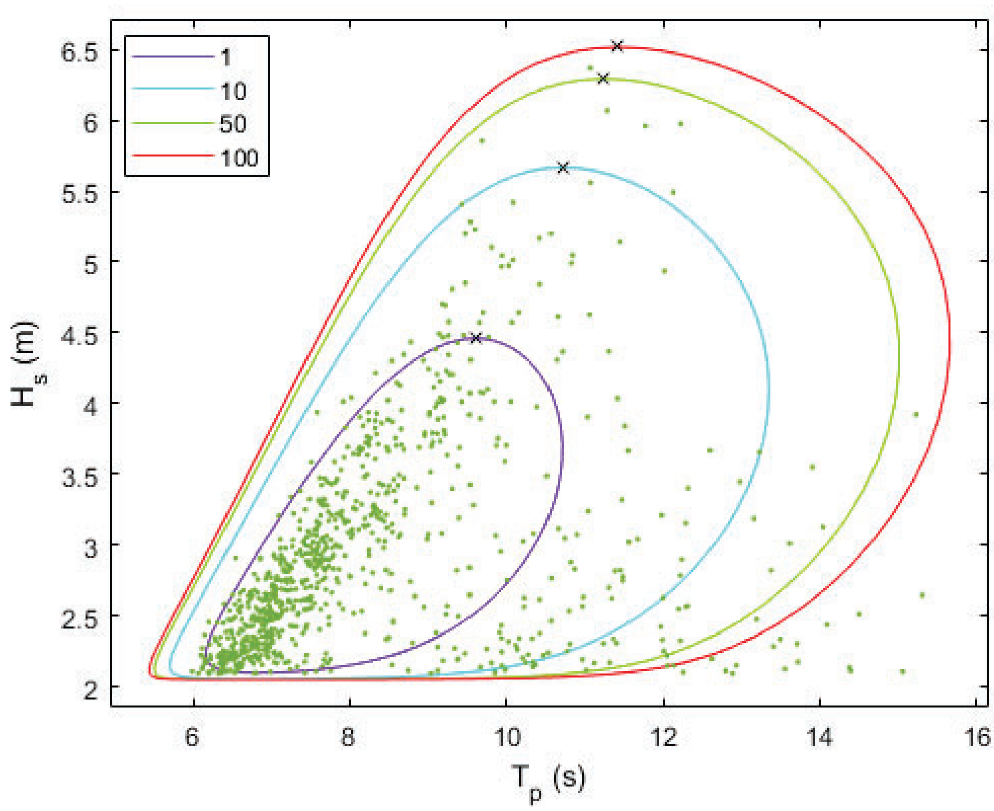

Figure 7.1 Contour plot of omni-directional bi-variate (Hs-Tp) return period values for 1, 10, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic Hs and associated Tp return period values for each ARI indicated in the legend at P1.

7.2. P2

The directional return period values for wind, wave and current extremes are given in Table 7.10 to Table 7.18 for 1, 10, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 7.2.

Table 7.10 Annual independent omni-directional extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	17.89	21.51	23.93	24.95
10min wind speed	U_{10min}	$m.s^{-1}$	19.27	23.26	25.93	27.06
1 min wind speed	U_{1min}	$m.s^{-1}$	21.04	25.51	28.50	29.77
3s wind gust	U_{3s}	$m.s^{-1}$	23.35	28.44	31.85	33.29
Significant wave height	H_s	m	4.51	5.74	6.39	6.62
Peak wave period	T_p	s	9.72	10.91	11.48	11.67
Maximum individual wave height	H_{max}	m	8.64	10.66	11.61	11.96
Maximum individual wave crest	C_{max}	m	5.59	6.83	7.42	7.63
Surface current speed	U_{surf}	$m.s^{-1}$	0.49	0.63	0.72	0.76
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.30	0.39	0.46	0.48
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.27	0.36	0.42	0.45

Table 7.11 Annual independent North extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	13.87	16.85	18.87	19.73
10min wind speed	U_{10min}	$m.s^{-1}$	14.84	18.12	20.35	21.29
1 min wind speed	U_{1min}	$m.s^{-1}$	16.10	19.76	22.25	23.31
3s wind gust	U_{3s}	$m.s^{-1}$	17.74	21.89	24.72	25.93
Significant wave height	H_s	m	2.54	3.42	3.90	4.08
Peak wave period	T_p	s	6.95	7.79	8.18	8.32
Maximum individual wave height	H_{max}	m	4.89	6.41	7.21	7.47
Maximum individual wave crest	C_{max}	m	3.12	4.08	4.62	4.79
Surface current speed	U_{surf}	$m.s^{-1}$	0.21	0.33	0.41	0.45
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.10	0.14	0.18	0.20
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.17	0.25	0.31	0.33

Table 7.12 Annual independent North-East extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	13.89	17.47	19.83	20.82
10min wind speed	U_{10min}	$m.s^{-1}$	14.87	18.81	21.42	22.52
1 min wind speed	U_{1min}	$m.s^{-1}$	16.13	20.54	23.46	24.69
3s wind gust	U_{3s}	$m.s^{-1}$	17.77	22.79	26.11	27.52
Significant wave height	H_s	m	4.42	5.55	6.04	6.20
Peak wave period	T_p	s	9.75	10.65	11.00	11.11
Maximum individual wave height	H_{max}	m	8.48	10.50	11.43	11.77
Maximum individual wave crest	C_{max}	m	5.38	6.66	7.24	7.45
Surface current speed	U_{surf}	$m.s^{-1}$	0.17	0.20	0.24	0.26
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.13 Annual independent East extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	14.39	18.98	22.09	23.42
10min wind speed	U_{10min}	$m.s^{-1}$	15.42	20.48	23.93	25.40
1 min wind speed	U_{1min}	$m.s^{-1}$	16.74	22.42	26.29	27.94
3s wind gust	U_{3s}	$m.s^{-1}$	18.46	24.93	29.36	31.25
Significant wave height	H_s	m	2.85	4.45	5.47	5.90
Peak wave period	T_p	s	16.96	19.22	20.14	20.45
Maximum individual wave height	H_{max}	m	5.75	8.48	10.16	10.71
Maximum individual wave crest	C_{max}	m	3.67	5.46	6.50	6.84
Surface current speed	U_{surf}	$m.s^{-1}$	0.23	0.30	0.37	0.40
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.14 Annual independent South-East extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	13.56	18.02	21.05	22.35
10min wind speed	U_{10min}	$m.s^{-1}$	14.51	19.43	22.78	24.22
1 min wind speed	U_{1min}	$m.s^{-1}$	15.72	21.24	25.01	26.62
3s wind gust	U_{3s}	$m.s^{-1}$	17.31	23.59	27.91	29.75
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.41	0.51	0.58	0.60
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.25	0.30	0.34	0.36
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.19	0.25	0.29	0.31

Table 7.15 Annual independent South extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	10.30	13.88	16.29	17.31
10min wind speed	U_{10min}	$m.s^{-1}$	10.96	14.85	17.48	18.60
1 min wind speed	U_{1min}	$m.s^{-1}$	11.80	16.10	19.01	20.26
3s wind gust	U_{3s}	$m.s^{-1}$	12.90	17.73	21.01	22.41
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.27	0.34	0.38	0.39
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.12	0.18	0.24	0.28
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.20	0.24	0.28	0.29

Table 7.16 Annual independent South-West extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	12.16	15.50	17.87	18.90
10min wind speed	U_{10min}	$m.s^{-1}$	12.98	16.62	19.21	20.33
1 min wind speed	U_{1min}	$m.s^{-1}$	14.03	18.06	20.92	22.16
3s wind gust	U_{3s}	$m.s^{-1}$	15.40	19.93	23.16	24.56
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.18	0.24	0.31	0.34
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.17 Annual independent West extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	13.07	15.71	17.45	18.19
10min wind speed	U_{10min}	$m.s^{-1}$	13.97	16.85	18.76	19.57
1 min wind speed	U_{1min}	$m.s^{-1}$	15.12	18.33	20.45	21.35
3s wind gust	U_{3s}	$m.s^{-1}$	16.63	20.25	22.65	23.66
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.24	0.34	0.40	0.42
Mid-depth current speed	U_{mid}	$m.s^{-1}$	-	-	-	-
Near-bottom current speed	U_{bot}	$m.s^{-1}$	-	-	-	-

Table 7.18 Annual independent North-West extreme criteria for wind, wave and current at P2.

Parameter	Symbol	Units	Return period (year)			
			1	10	50	100
Hourly wind speed	U_{1h}	$m.s^{-1}$	11.61	14.97	17.26	18.24
10min wind speed	U_{10min}	$m.s^{-1}$	12.38	16.04	18.55	19.62
1 min wind speed	U_{1min}	$m.s^{-1}$	13.37	17.43	20.21	21.40
3s wind gust	U_{3s}	$m.s^{-1}$	14.65	19.23	22.37	23.72
Significant wave height	H_s	m	-	-	-	-
Peak wave period	T_p	s	-	-	-	-
Maximum individual wave height	H_{max}	m	-	-	-	-
Maximum individual wave crest	C_{max}	m	-	-	-	-
Surface current speed	U_{surf}	$m.s^{-1}$	0.45	0.69	0.87	0.95
Mid-depth current speed	U_{mid}	$m.s^{-1}$	0.28	0.43	0.55	0.60
Near-bottom current speed	U_{bot}	$m.s^{-1}$	0.23	0.40	0.53	0.58

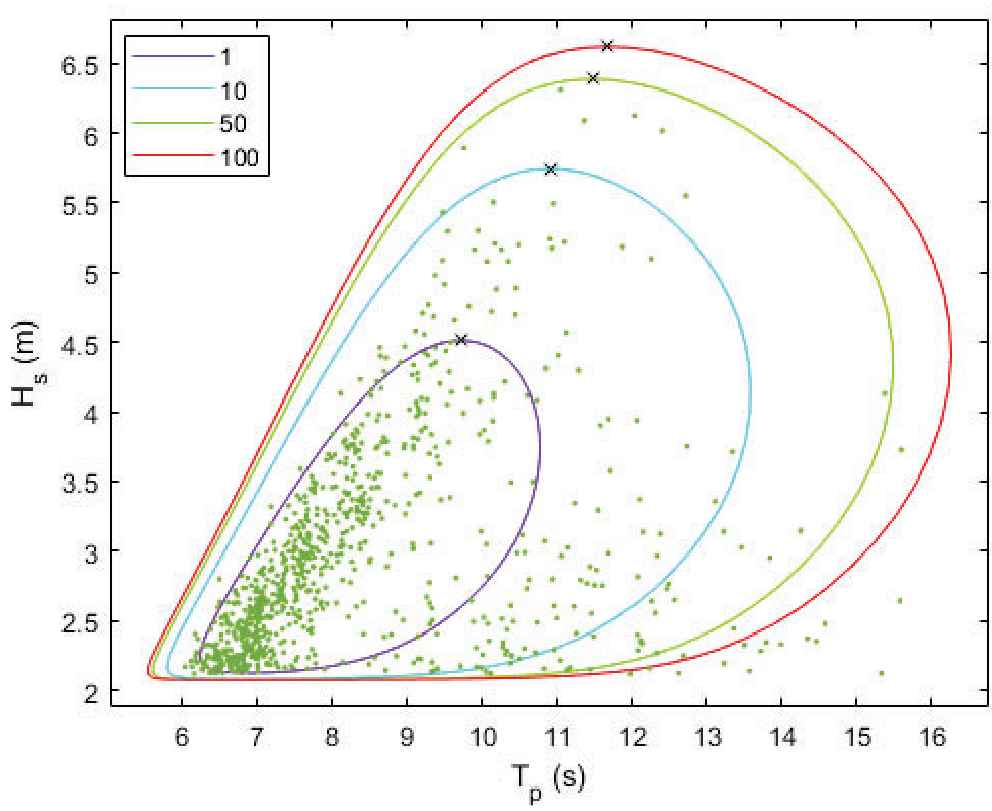

Figure 7.2 Contour plot of omni-directional bi-variate (Hs-Tp) return period values for 1, 10, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic Hs and associated Tp return period values for each ARI indicated in the legend at P2.

8. Nov 2018 – Jun 2019

In this section, metocean statistics for the period Nov 2018 – Jun 2019 for one representative site P1 are compared to the long term statistics in Table 8.1 - Table 8.5, Figure 8.1 - Figure 8.5.

From Nov 2018 – Jun 2019, wind conditions were slightly below the averaged long term conditions from 1979-2019, while wave height conditions were significantly lower than the averaged values (Table 8.1 and Table 8.2). The maximum values for wind speed and significant wave height within the period Nov 2018 - Jun 2019 (15.50 $m.s^{-1}$ and 2.83 m, respectively) were also significantly lower than the 1-year omnidirectional ARI values (i.e. 19.74 $m.s^{-1}$ and 4.46 m, respectively, see Table 7.1).

From Nov 2018 – Jun 2019, current conditions were slightly below the averaged long term conditions from 2000-2019 at all levels through the water column (Table 8.3-Table 8.5). The maximum values for current speeds for the period Nov 2018 - Jun 2019 (0.38, 0.20 and 0.17 $m.s^{-1}$ for surface, mid-depth and near-bottom, respectively) were also significantly lower than the 1-year omnidirectional ARI values (i.e. 0.51, 0.30 and 0.26 $m.s^{-1}$, respectively, see Table 7.1).

At the studied location on the east side of NZ, storm conditions are dominated by the passage of post-tropical cyclones, typically from November to April. The weather effects from the last cyclone season (2018-2019) were less severe than the typical storm conditions at the studied location.

Table 8.1 Comparison between the long term wind speed statistics and the recent Nov 2018 – Jun 2019 period at P1. Only the Nov-Jun period is considered for each year.

Parameter	Units	Period	Mean	P25	P75	P99	Max
Wind speed, U_{10min}	**$m.s^{-1}$**	**1979-2019 average**	6.22	4.10	8.02	14.39	18.92
		Nov 2018-Jun 2019	5.45	3.43	7.20	12.45	15.50

Table 8.2 Comparison between the long term significant wave height statistics and the recent Nov 2018 – Jun 2019 period at P1. Only the Nov-Jun period is considered for each year.

Parameter	Units	Period	Mean	P25	P75	P99	Max
Significant wave Height, Hs	**m**	**1979-2019 average**	0.94	0.56	1.15	2.94	4.30
		Nov 2018-Jun 2019	0.74	0.51	0.90	2.04	2.83

Table 8.3 Comparison between the long term residual surface current speed statistics and the recent Nov 2018 – Jun 2019 period at P1. Only the Nov-Jun period is considered for each year.

Parameter	Units	Period	Mean	P25	P75	P99	Max
Surface current speed, U_{surf}	**$m.s^{-1}$**	**2000-2019 average**	0.11	0.06	0.15	0.34	0.48
		Nov 2018-Jun 2019	0.10	0.04	0.14	0.29	0.38

Table 8.4 Comparison between the long term residual mid-depth current speed statistics and the recent Nov 2018 – Jun 2019 period at P1. Only the Nov-Jun period is considered for each year.

Parameter	Units	Period	Mean	P25	P75	P99	Max
Mid-depth current speed, U_{mid}	**$m.s^{-1}$**	**2000-2019 average**	0.06	0.03	0.08	0.20	0.29
		Nov 2018-Jun 2019	0.05	0.02	0.08	0.16	0.20

Table 8.5 Comparison between the long term residual near-bottom current speed statistics and the recent Nov 2018 – Jun 2019 period at P1. Only the Nov-Jun period is considered for each year.

Parameter	Units	Period	Mean	P25	P75	P99	Max
Near-bottom current speed, U_{bot}	**$m.s^{-1}$**	**2000-2019 average**	0.05	0.02	0.07	0.17	0.25
		Nov 2018-Jun 2019	0.04	0.02	0.05	0.13	0.17

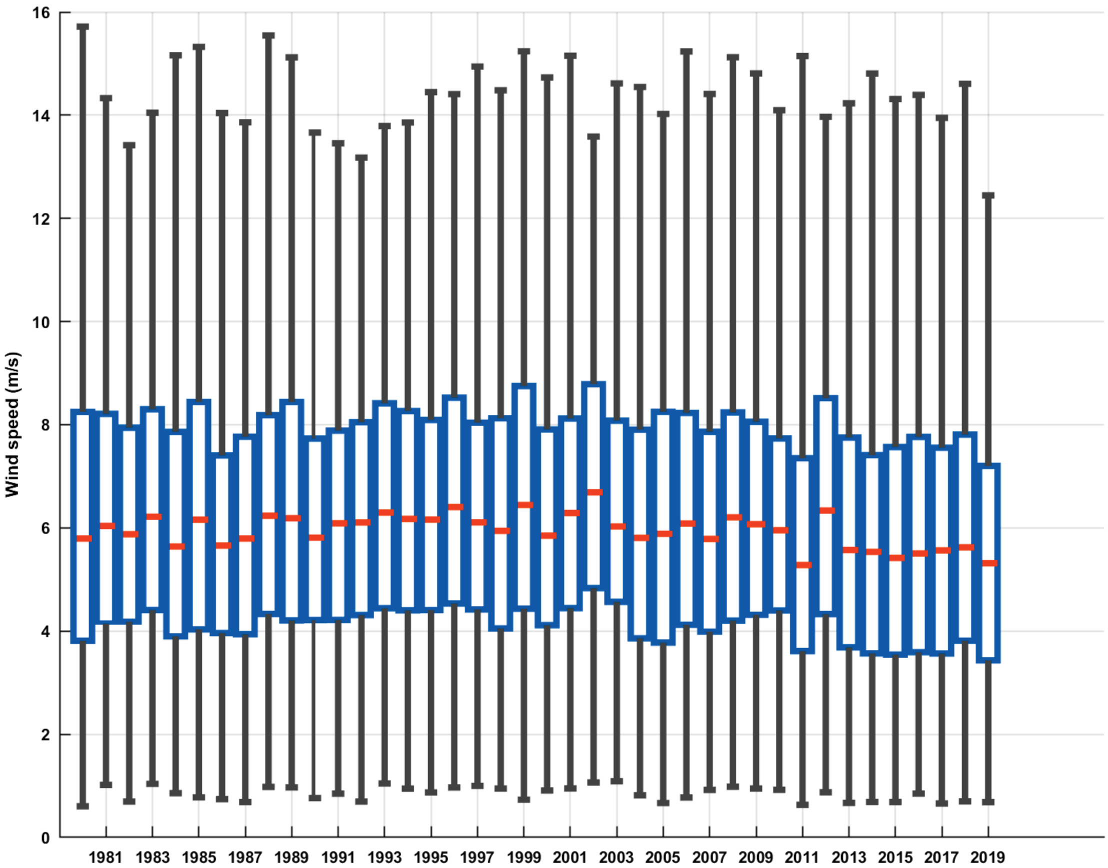

Figure 8.1 *Box plot of wind speed considering only the period Nov-Jun for each year since 1979 at P1. Each period is labelled by the year corresponding the end of the period (e.g. Nov 2018 - Jun 2019 is labelled "2019" on the x-axis). The blue boxes are delimited by the 25th and 75th percentiles of each period bin, while the red line indicates the median and the limits of the dark lines are the 1st and 99th percentiles.*

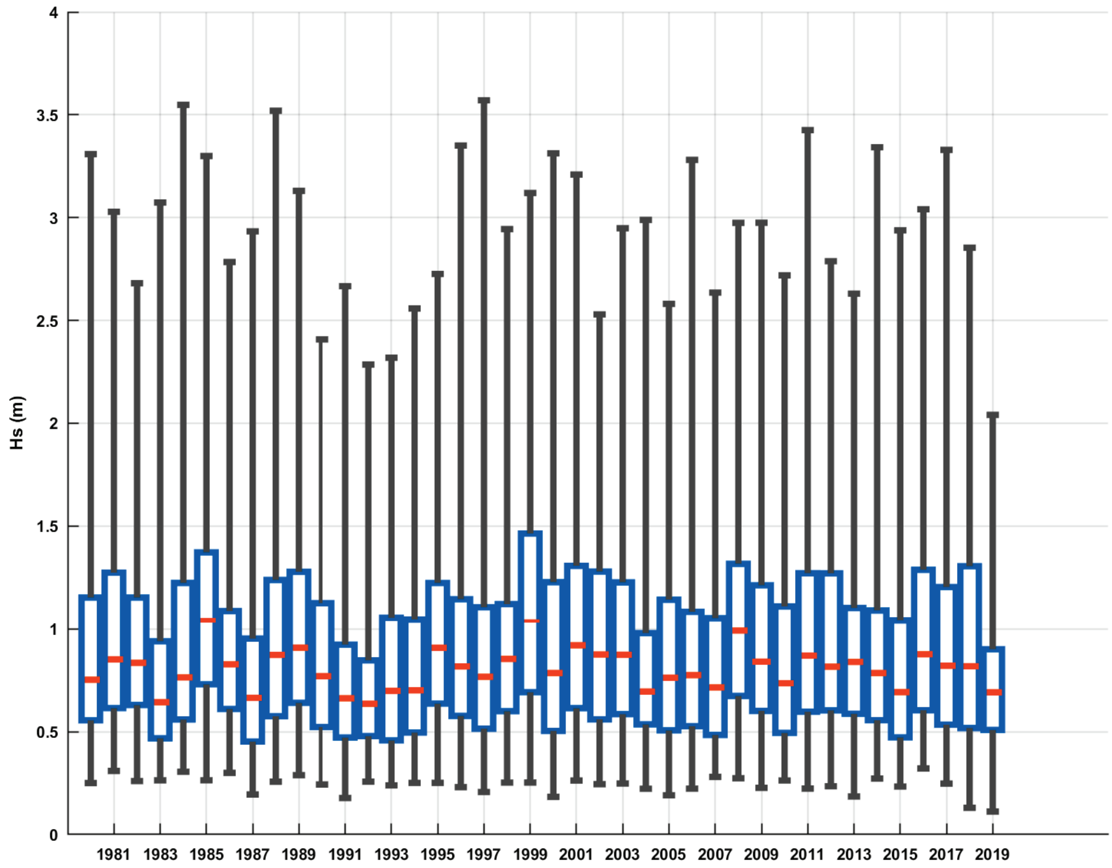

Figure 8.2 As Figure 8.1 but for significant wave height.

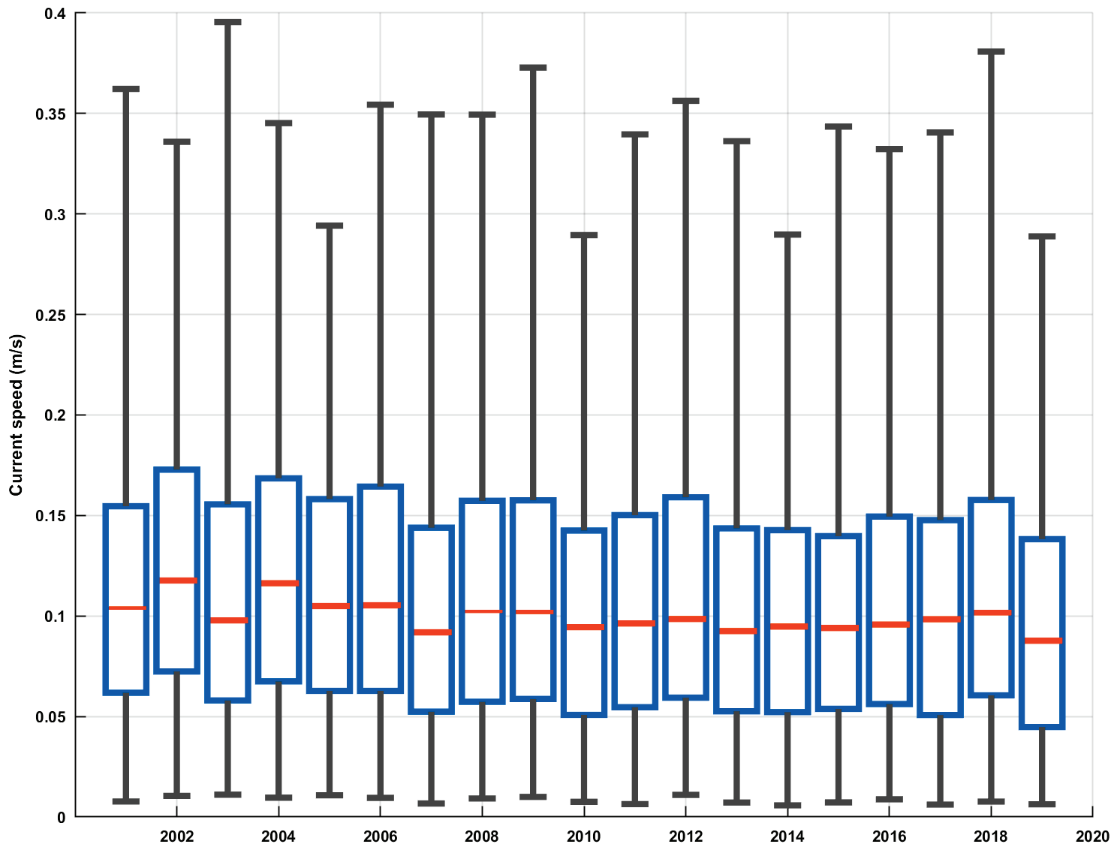

Figure 8.3 As Figure 8.1 but for residual surface current speed.

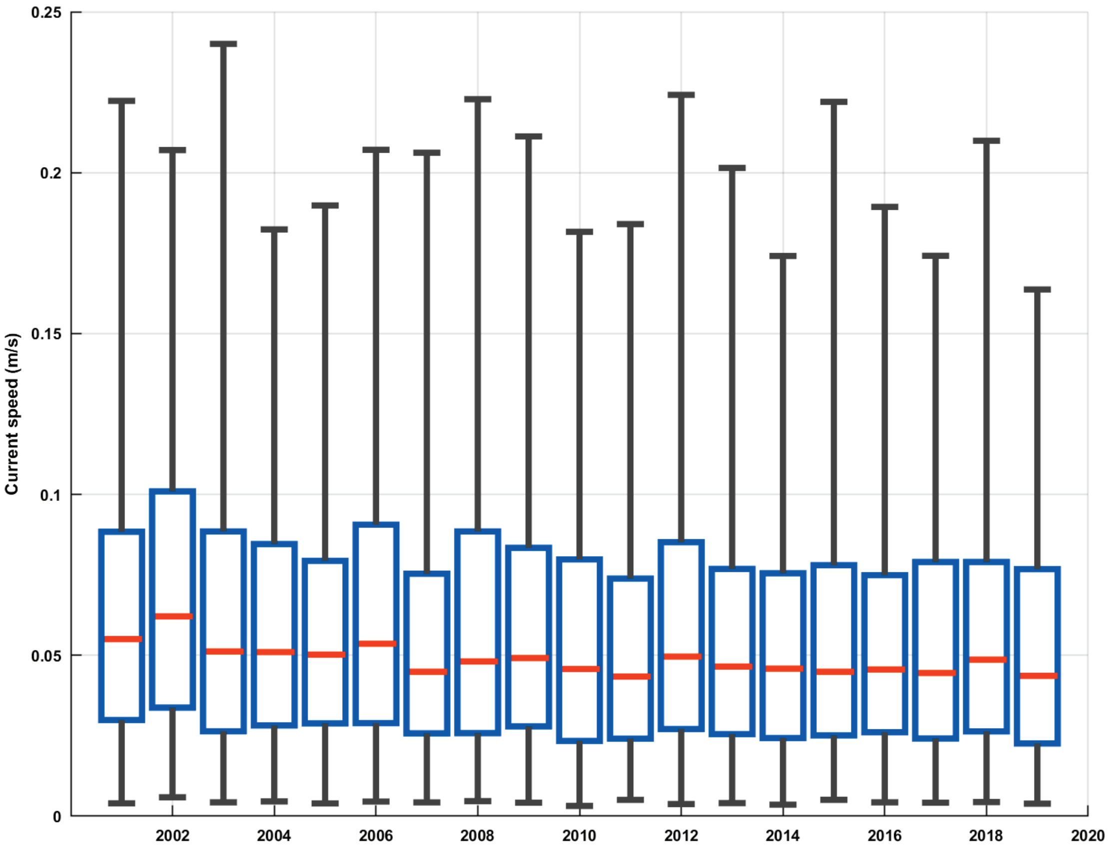

Figure 8.4 As Figure 8.1 but for residual mid-depth current speed.

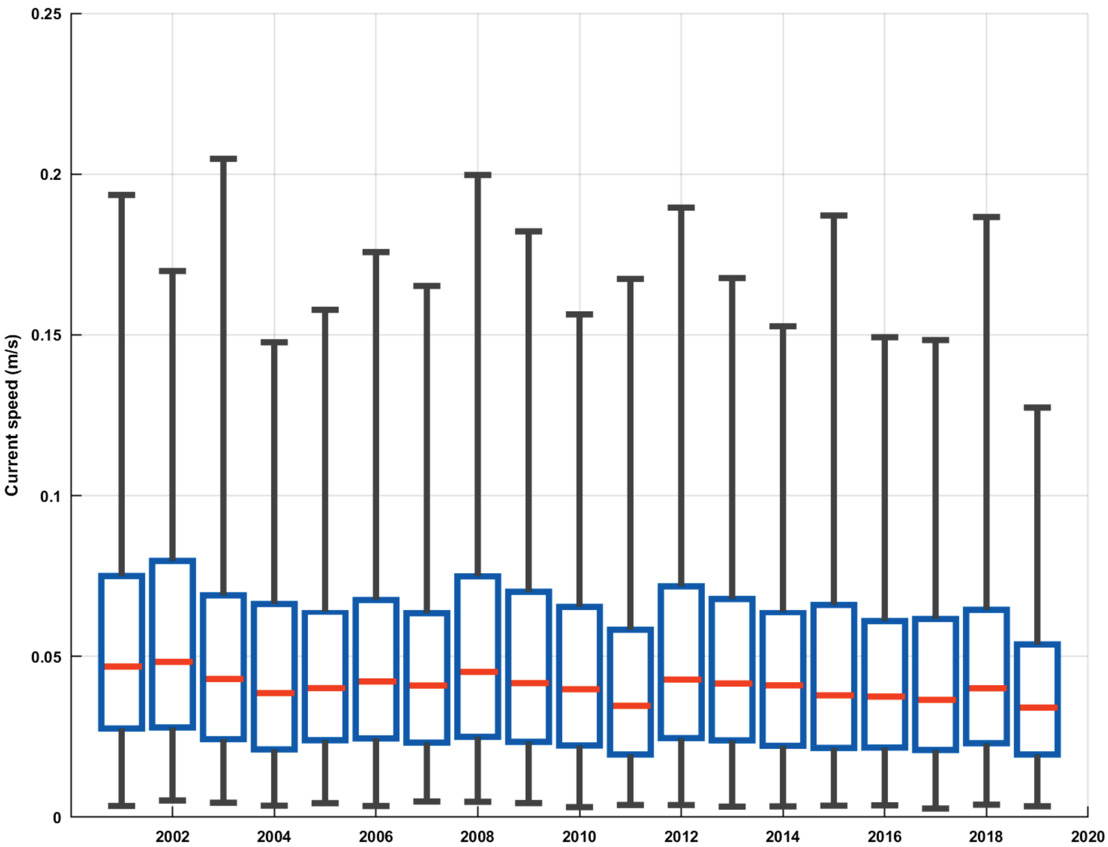

Figure 8.5 As Figure 8.1 but for residual near-bottom current speed.

9. Analytical methods

9.1. Wind

In order to define the design wind speeds, the 10-minute velocity means were extrapolated to shorter (i.e. 3 and 60 seconds) and longer periods (i.e. 1 hour) using the guidelines provided by ISO (2015).

9.2. Wave

The wave spectra were post-processed to calculate wave statistics for the total wave field, as well as for sea and swell components. The spectral partitioning method consists of a split at the frequency corresponding to 8 s period, with sea and swell assigned to the high- and low-frequency parts, respectively. For the total spectra and each partition, one-dimensional frequency spectra were defined by integrating over all directions:

$$E(f) = \int_{-\pi}^{\pi} E(f,\theta)d\theta. \tag{9.1}$$

Spectral moments were calculated as

$$m_x = \iint f^x E(f,\theta)df\, d\theta, \tag{9.2}$$

The significant wave height, Hs, mean direction at peak energy, θp, and peak wave period, Tp , are defined as:

$$H_s = 4\sqrt{m_0}, \tag{9.3}$$

$$Dpm = \tan^{-1}\frac{\int_{-\pi}^{\pi} E(f_p,\theta)\sin\theta\, d\theta}{\int_{-\pi}^{\pi} E(f_p,\theta)\cos\theta\, d\theta}, \tag{8.4}$$

$$T_p = 1/f_p, \tag{9.5}$$

where fp is the peak wave frequency of the one-dimensional spectra and En(fp,θ) is the energy contained in the peak wave frequency band. Note that Tp and θp require spectral peaks within a given partition and are not defined when peaks are not identified for that partition.

9.3. Extreme

Directional return period values have been calculated from the hindcast time series of wind, wave and current.

A *Peaks over Threshold* (POT) sampling method is used for event selection, applying the 95th percentile exceedance level as the threshold with a 24 hour window. For wind extreme value analysis (EVA), the 3-parameter Weibull distribution were applied, with Maximum Likelihood Method (MLM) used to find the best-fit of the sampled events to the model distribution. For wave EVA, the selected events were fitted to a Pareto distribution, with the location parameter fixed by the threshold and the MLM used to obtain the scale and shape parameters.

Bivariate return period values were calculated for significant wave height and peak period. The method of Repko et al. (2005) was employed, which considers the distribution of H_s and wave steepness, s. A joint probability distribution function (PDF) is calculated by multiplying marginal distributions of H_s and s (thus assuming they are independent), after which the PDF is transformed back into H_s/T_p space. In addition, a minimum wave steepness threshold of 0.005 is applied to exclude events with very long wave periods, which are not believed to be representative of extreme conditions.

The marginal distributions for H_s and s are estimated by fitting the POT values to a Weibull distribution using the maximum likelihood method (as implemented in the WAFO toolbox). Contours of the return period values were constructed from the joint PDF using the Inverse FORM method (Winterstein et al., 1993) at the return year levels.

The methods used to estimate extreme maximum individual wave height (H_{max}) and maximum wave crest (C_{max}) account for the long-term uncertainty in the severity of the environment and the short-term uncertainty in the severity of the maximum wave of a given sea state, as suggested by Tromans and Vanderschuren (1995) and recommended by ISO (2015). The most probable value of the extreme individual wave height (H_{mp}) of each storm is obtained from the product of the Foristall distributions of individual wave height in each hindcast interval within the storm duration (Forristall, 1978; ISO, 2015). The same technique is used for the most probable value of the extreme individual wave crest (C_{mp}) but using the Weibull distribution with scale and shape parameters dependent on the wave steepness and the Ursell number (ISO, 2015; Forristall, 2000). Note that the resulting short-term distributions for each storm are dependent on the number of intervals with H_s values near the region of maximum peak H_s. The uncertainty in the height and crest of the maximum wave of any storm is represented as a short-term probability distribution conditional on H_{mp} and C_{mp}, respectively (Tromans and Vanderschuren, 1995). The long-term distributions of H_{mp} and C_{mp} are then fitted to Pareto distributions. Finally, the convolutions of the short- and long-term distributions give the complete long-term distributions of H_{max} and C_{max} (Tromans and Vanderschuren, 1995; ISO 2015).

Note an arbitrary minimum number of 10 storm peaks has been was chosen for reliable distribution fitting. This results in specific directional return period values being omitted.

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Appendix F. Assessment of Biogenic Sand Production. Report by Bioresearches, October 2019

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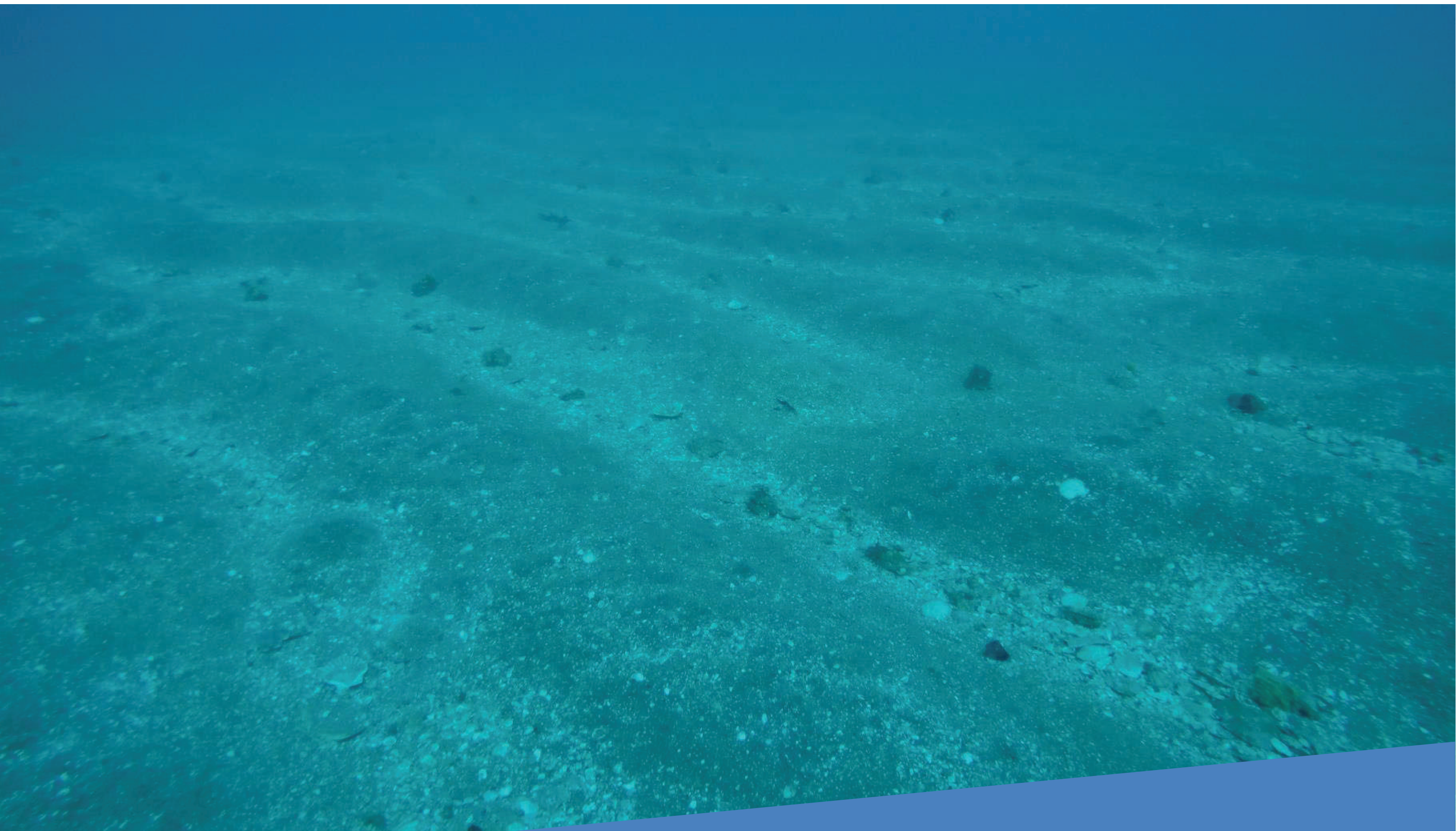
Assessment of Biogenic Sand Production, Pakiri Embayment

October 2019



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Assessment of Biogenic Sand Production, Pakiri Embayment October 2019

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Reference: Bioresearches (2019). Assessment of Biogenic Sand Production, Pakiri Embayment. Report for McCallum Brothers Limited. pp 36

Cover Illustration: Seabed sandscape showing Biogenic shell lag (May 2014)

CONTENTS

1. INTRODUCTION

1.1 Biogenic Sand

Sands in the Pakiri – Mangawhai embayment are primarily quartzo-feldspathic (Schofield, 1970). The sands also contain varying amounts of carbonate, which is generally of biological origin. Biogenic sand is defined as the fraction of sand formed by dead marine biota, and is mostly composed of molluscs, echinoids, foraminifera and bryozoans (De Falco *et al*., 2017).

In order to provide input into a sand budget model, an assessment of the annual biogenic sand production in the Pakiri – Mangawhai embayment, has been calculated from population estimates of living shellfish in the benthic biota of the bay. The Pakiri – Mangawhai embayment has been defined for the purpose of this study, as from Bream Tail to Goat Island, based on these locations providing barriers, limiting but not excluding sand transport alongshore (Hume, 2005). The barriers are rocky reefs that extend from low tide, to at least 27m below mean sea level. The 25m below chart datum contour, which equates to 27m below mean sea level, was defined as the depth of closure during the previous consenting process in 2005 (Hilton, 1990; Healy, 1996; Hilton and Hesp, 1996) (Figure 1). All depths used henceforth in this report will be in reference to mean sea level.

The depth of closure (DOC) is an important concept used in coastal engineering as it defines the offshore extent of cross-shore sediment transport. The DOC is a theoretical depth along a beach profile where sediment transport is very small or non-existent. Its location is dependent on wave height and period, and occasionally, sediment grain size. More specifically, Kraus (1998) states that the "depth of closure for a given or characteristic time interval is the most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore." Since the wave height and period change seasonally and over shorter time periods such as storm events, the DOC will theoretically change, this is supported by Nicholls *et al*. (1998), Dolbeth *et al.* (2007) and Carvalho *et al*. (2012). Therefore, rather than a specific or average depth, the DOC should be expressed as a depth range or transitional zone. The transport of material across this average DOC "boundary" is not precluded as the actual DOC would vary depending on wave conditions. Therefore, the additional area offshore of the 27m average DOC, covering 27 – 32m has been included as a separate area in the calculations of biogenic sand production.

1.2 Previous Studies

Hilton (1990) quantified the carbonate content of surficial sediments south of Te Arai Point. In the fine, very well sorted sands of the upper shoreface, Hilton reported the carbonate was only 2-5% of the total sample in depths less than 27m, however this increased to 20-30% in the area between the 27 – 32m depth contours. Hilton determined that the carbonates consisted mostly of fragments of benthic macrofauna of molluscan origin. Based on the benthic biota data collected in the embayment since 1990 (ASR, 2003, 2006, Bioresearches, 1993, 2011, 2016, 2017, 2019a,b, Grace 1991, 2005) this has not changed with molluscs still dominating the biota.

Hilton (1990), by integrating data from trawls, was able to estimate the total mass of live shell material in the surficial seabed sediments (the top 10-15 cm in this case). He reported an average concentration of shell of 97g/m^2.

Hilton (1990) assumed that for a shellfish species of a 10-year life expectancy, 10% of the population would die every year and the shell becomes part of the biogenic sand. This assumes a constant population size, and that recruitment and mortality were constant, which they are generally not. It also appears that he assumed all shellfish had a similar life span, which is also not a valid assumption. His assumptions were based on the information available in 1990, greater information on life span is now available but the population size, mortality and recruitment are still not well understood. Based on these assumptions, he calculated that the existing weight of shell material, 5,300 tonnes, would increase to 73,000,000 tonnes after 100 years. This calculation was incorrect. Hilton mistakenly added the dead shell material back to the live shell material each year for a compounding recalculation of dead shell production over the 100-year time frame. This process grossly overestimated the production of dead shell material over time. Based on his assumptions the live shellfish population was not expected to change year to year therefore the production should be the same each year. Even if the shellfish population varied in size between years the expected dead shell production would not approach the tonnage Hilton calculated. Correcting Hiltons dead shell production calculation overtime, results in an annual shell material production of 530 tonnes, translating to 482m^3/year assuming shell material has a density of 1.1Mg/m^3. Hume *et al.* (1999) suggests these values cover half the bay and should be doubled to a corrected value of 964m^3/year, which is considerably less than that Hilton reported in 1990 of 900,000m^3/year.

The NIWA sand study (Hume *et al.*, 1999) considered Hilton's original shell production value of 900,000m^3/year erroneous and suggested biogenic sand production was less than 12,000m^3/year based on a sediment budget. Barnett in his 2005 environment court evidence suggested it should be near 90,000m^3/year. Neither of the latter estimates of Barnett or NIWA were based on biological science. Hilton's (1990) corrected estimate of 964m^3/year is based on actual biological production but was subject to invalid assumptions which could have resulted in greater production. None of the studies have measured annual variation in production or the effects of long-term ecological changes such as species loss on production.

1.3 Current Study

This assessment is based on the fauna abundance data collected as part of the assessment of effects of sand extraction from the McCallum Bros Ltd (MBL) consented areas in, and from areas further offshore in 2019 (Bioresearches, 2019a,b); from the assessment of effects of the Auckland Offshore sand extraction by Kaipara Limited in 2017 (Bioresearches, 2017); and from an intertidal seafood resources survey for Auckland Regional Council in 1993 (Bioresearches, 1994). In addition, growth rate equations were obtained from New Zealand and international literature. This estimation can be added to that of the non-biogenic sand (i.e. from river, shore and cliff) to make the total sediment input to the budget of the bay.

The study is initially based on the previously accepted enclosed embayment model with a DOC at 27m below mean sea level. It excludes the Mangawhai estuary as a biogenic sand source as estuaries are considered to be sediment "sinks" rather than sources. In addition to the predefined DOC embayment area, an area offshore has been added to the assessment for biogenic sand production, as have rocky shore habitats not previous assessed, and the results provided for each individual area.

MBL has a current consent to extract a maximum allowance of 76,000m^3/year of sand in consent defined extraction areas as shown in pink in Figure 1 and Figure 2 within a nominal water depth range of 7 to 12m. If the consent is to be renewed, the assessment of biogenic sand production will likely form part of the assessment determining a suitable volume of sand for extraction.

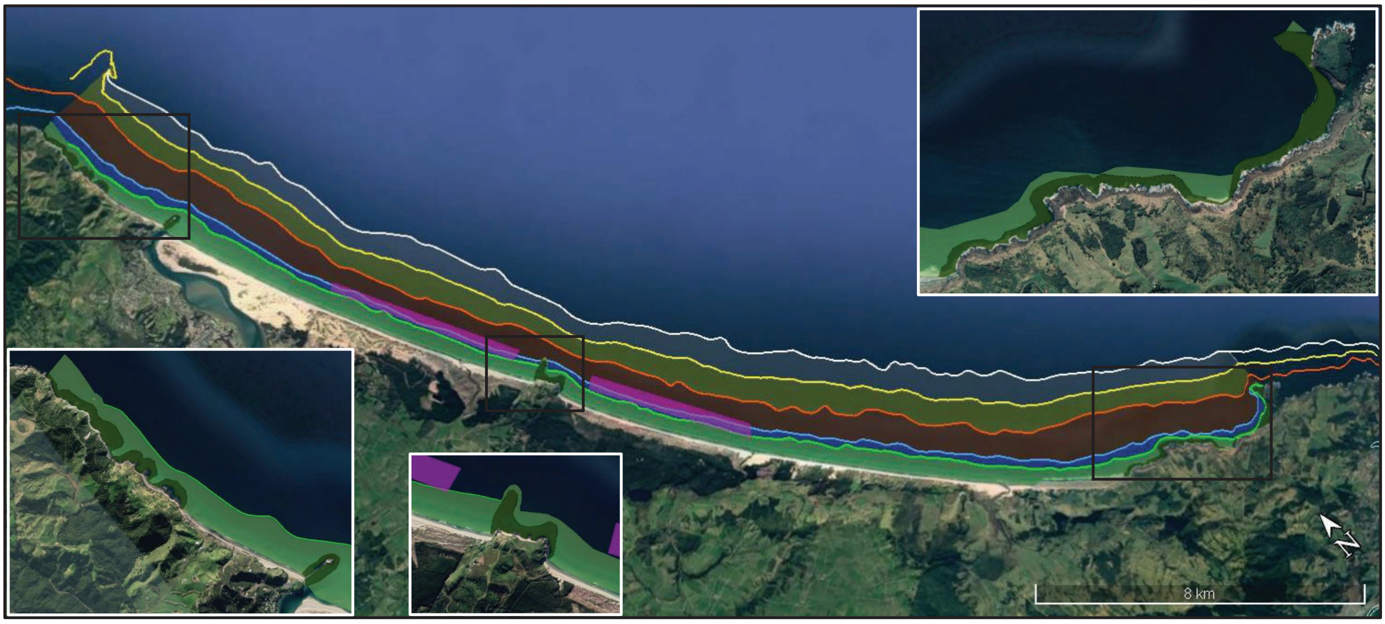

Figure 1 ***Pakiri – Mangawhai embayment with bathymetry mean sea level contours (light green: 7m; blue: 12m; orange: 22m; yellow: 27m; white 32m), the extent of the areas within these contours, and the extraction areas (in pink). The surface considered for the rocky shore is presented in dark green in the three inserts. Map produced with Google Earth 2019 ©.***

2. METHODS

The annual biogenic sand production has been estimated following four major steps:

a) The estimation of densities of benthic biota taxa in number per $100m^2$
b) The estimation of the shell weight in $g/100m^2$
c) The estimation of the annual shell production (growth) in $g/100m^2$ /year
d) The extrapolation of the 3 parameters above for each area and for the whole bay

2.1 Density of benthic biota taxa

The most recent assessment of benthic biota in the Pakiri – Mangawhai embayment, was conducted in early 2019 and used two sampling methods to determine its relative abundance and diversity:

1. **Benthic Infauna:** this involved the collection of 117 samples of benthic biota with a box dredge (18cm wide to a depth of approximately 5-10cm, for a length of approximately 90cm) in a pattern uniformly distributed from the shore to the 27m bathymetric contour on each side of Te Arai point, following a sampling design by Dr Grace. Sample locations are shown in Figure 2 as white squares. Subsamples were screened through a 1mm mesh sieve, and the total sample through a 3.15mm mesh sieve. The 1mm screened samples consisted mostly of polychaetes, amphipods and isopods (Bioresearches 2019a), which are considered a minor source for sand formation. Polychaetes have no calcareous part and small arthropods have a fragile chitin exoskeleton, which would degrade quickly, thus not contributing significantly to biogenic sand production. Therefore, only the 3.15mm screened samples, which contained molluscs and echinoderms, were considered for the biogenic sand production calculation.
2. **Benthic Epifauna:** this involved 33 (65cm wide) variable length dredge tows targeting different depths (white thick lines in Figure 2). The dredge was fitted with a 15mm square mesh bag, thus retained larger biota, the majority of which were molluscs and benthic arthropods, for which the individual lengths were measured.

Analyses of benthic biota showed little difference in community composition and densities between the area north of Te Arai point and the area south of Te Arai point (Bioresearches 2019a, b), but revealed significant differences between inshore (< 12m depth) areas and deeper ones, highlighting the importance of depth in shaping the benthic community composition. Based on these results, biota samples were separated into three depth defined areas, 7 to 12m, 12 to 22m and 22 to 27m, then used to estimate the production of biogenic sand in each area, and the calculations subsequently combined to assess sand production at the level of the whole Pakiri – Mangawhai embayment.

The current 2019 study did not sample from much less than 7m depth. It is known from historical studies (Bioresearches, 1994, 2016) that this 0 – 7m zone has potentially high numbers of some taxa which are not present in deeper waters, such as the tuatua *Paphies subtriangulata*. In addition, rocky shores are present north and south of the embayment, and at Te Arai Point, with gastropod communities different from the rest of the Bay which is dominated by soft sediment. Therefore, the 0 – 7m depth zone has been included and the historical data used to define densities of taxa present. The first historical study relevant to the surf zone of Pakiri Beach and the rocky shore is the assessment of intertidal seafood resources in 1993 where quantitative sampling of edible seafood was carried out at every kilometre along the beach (Bioresearches, 1994). Sample sites are marked as yellow diamonds in Figure 2. The second historical study is the assessment of the benthic ecology along the Hawaiki submarine cable route project landing on the northern part of the Pakiri – Mangawhai embayment (Bioresearches, 2016). Subtidal benthic biota was assessed by grab sampling and tow sampling at regular depths along the cable route. The grab samples only provided qualitative information on biota (presence, not densities) at regular depths, as there were only up to three samples per bathymetry area, and this was considered insufficient to represent the quantity of clumped-distributed species such as molluscs.

While the DOC of the Pakiri – Mangawhai embayment was defined as the 27m depth contour in the 2005 environment court hearing, this does not totally, preclude transport of material across this depth contour as this theoretical boundary is likely the midpoint of a transitional depth range across which limited on-offshore transport intermittently occurs. Therefore, the biogenic sand production from the 27m – 32m depth contours has also been calculated. The samples collected in this area were from three different methods (Table 1): 20 box dredge samples were collected during the 2019 inshore-midshore survey detailed previously (Bioresearches, 2019b). In addition, 31 grab samples were collected with a Ponar grab sampler (229 x 229 mm), and 8 dredge tow samples were also available from a previous study in 2017 (Bioresearches, 2017) orange squares and lines in Figure 2). Data sets from the three samples methods were combined, and the highest average density from either method was retained for each taxon in each depth-defined area.

The four studies use differing sampling methods and also sampled different faunal populations as represented by the differing composition of biota. Therefore the biogenic sand production calculation was based on a combination of the methods, providing representation of all major contributors of sand production. When the data sets were combined, the highest average density from either method was retained for each taxon in each depth-defined area.

The surface area for each of the five areas (0 to 7m, 7 to 12m, 12 to 22m, 22 to 27m, and 27 to 32m) was calculated by defining a polygon constrained by the bathymetry contours relative to mean sea level defined from the Land information New Zealand chart NZ3000522 in Google Earth. The extent of the bay was constrained in the north, to a line between Bream Tail and McGregor Rock, and in the south to a line north from the northern point of Goat Island. A 27m bathymetry contour was interpolated from the 22 and 32m contours using QGIS software. Table 1 presents the surface of each area and identifies the samples collected in each area. The embayment as described has a total surface area of 55,246,242m² to the 27m contour, or 71,064,438m² to the 32m contour.

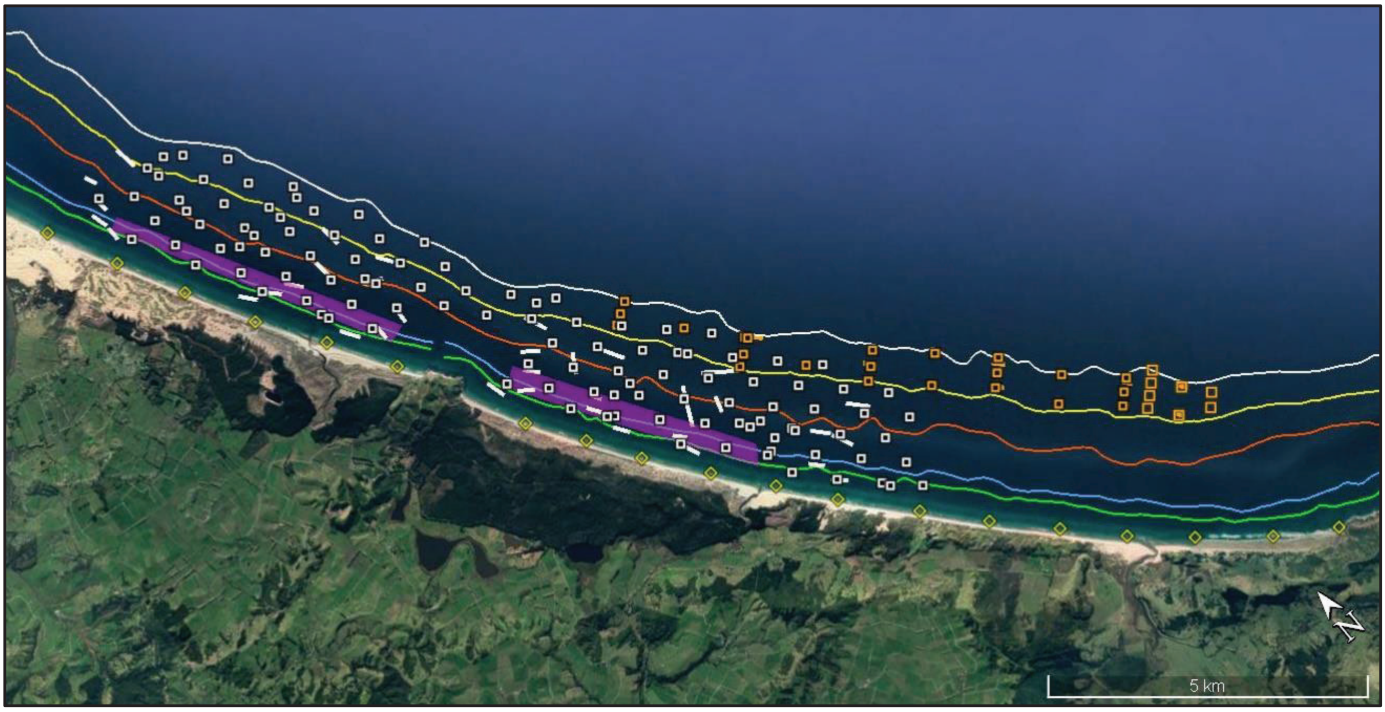

Figure 2 Pakiri – Mangawhai embayment with bathymetry contours, benthic infauna samples and epifauna tows. Map produced with Google Earth 2019 ©.

Key

bathymetry contours (green: 5m; blue: 10m; orange: 20m; yellow: 25m; white: 30m)

benthic infauna samples (white squares: 2019 box dredge samples; Orange squares: 2017 grab samples; yellow diamonds: 1993 quadrats)

epifauna dredge tows (white lines: 2019 samples; orange lines: 2017 samples)

The sand extraction areas are shaded in pink.

Table 1 Benthic samples used to determine the number, weight and growth of biota for biogenic sand calculation.

Area		Rocky shore	0 – 7m depth	7m - 12m depth	12m - 22m depth	22m - 27m depth	27m – 32m depth
Surface (m^2)		1,011,139 m^2	11,549,658 m^2	5,754,054 m^2	20,968,451 m^2	16,558,156 m^2	15,818,196 m^2
Infauna (Box dredge)	**Sample codes (PIB)**	-	-	1, 4, 5, 11, 18, 19, 27, 39, 44, 45, 46, 62, 68, 75, 82, 88, 94, 100, 114	2, 3, 8, 9, 10, 16, 17, 25, 26, 32, 33, 52, 53, 54, 60, 61, 66, 67, 73, 74, 80, 81, 86, 87, 92, 93, 101, 103, 104, 105, 106, 108, 111, 117, 121	6, 7, 13 to 15, 22 to 24, 30, 31, 36 to 38, 42, 43, 50, 51, 57 to 59, 64, 65, 70 to 72, 78, 79, 84, 85, 90, 91, 95, 96, 102, 107, 112, 115, 116, 119, 120	12, 20, 21, 28, 29, 34, 35, 40, 41, 49, 56, 63, 69, 76, 77, 83, 89, 110, 113, 118
	Total (year sampled)	-	-	**19** (2019)	**35** (2019)	**40** (2019)	**20** (2019)
Infauna (grab sample)	**Sample codes**	-	Extrapolated from historical studies (see text)	-	-	-	TN(W), T0(W, 0, 1), T1(W), T2(W, 0, 1), T3(W), T4(0, 1, 2), T5(W,M), T6(1, 2, 3), T7(W, M), T8(1, 2, 3), T9(1, 2, 3, 4), TC(M, W), T10(1, 2)
	Total (year sampled)	-		-	-	-	**31** (2017)
Epifauna (Tow dredge)	**Tow codes**	-	-	22 to 35	8, 9, 11 to 21	1 to 7, 10	T2A, T4A, T6A, T6B, T8A, T8B, TCA, TCB
	Total (year sampled)	-	-	**14** (2019)	**13** (2019)	**8** (2019)	**8** (2017)
Intertidal seafood	**Sample codes**	7, 21 to 24	1 to 6, 8 to 20				
	Total (year sampled)	**5** (1993)	**19** (1993)				

The surface area sampled by the infauna box dredge was assumed to be relatively constant between samples and estimated to be 0.162m² based on a width of 0.18m and a tow length of approximately 0.9m. The length of each epifauna dredge tow was more variable and calculated surfaces are displayed in Table A 1. The surface area sampled by the infauna grab sampler was calculated as 0.05m² based on a length of 0.229m either side. The biota data from all sampling methods were tabulated, and abundance standardised to numbers per 100m².

Previous analyses of the 94 infauna box dredge samples (3.15mm size mesh) within the 27m depth contour found a total of 104 taxa (Table A 2). To simplify the calculation of shell growth, the original number of taxa was reduced following two steps:

- The taxa with little or no “shell” component (grey text in Table A 2) were discarded for the shell weight and gross calculation.
- The species with a significant “shell” part but with no information on weight and growth, were combined to a higher taxonomic level for which equations from the international literature existed.

Previous analyses of the 35 epifauna dredge tow samples within the 27m depth contour found a total of 29 taxa (Table A 3). Like the infauna samples, the number of taxa were reduced by eliminating those with little or no “shell” component, and in addition, those taxa for which only one individual over the 35 tows were recorded.

Historical intertidal data at Pakiri found tuatua *P. subtriangulata* to be common all along the beach (Table A 4) (Bioresearches 1994). The average density and size of *P. subtriangulata* were used for the estimation of biogenic sand production in the 0 to 7m area. During the study along the Hawaiki cable route (Bioresearches, 2016), two samples of benthic biota were collected within the 7m depth zone: a benthic grab sample at 4m depth, and a 100m long dredge tow centred on the grab sampling location. The sand dollar *Fellaster zelandiae* was found in both samples, while the paddle crab *Ovalipes catharus* was only present in the tow sample. Densities of these two species for the 0 to 7m zone were extrapolated from the densities calculated from the 7 to 12m area. The wheel shell *Zethalia zelandica* was added to the densities of tuatua, paddle crabs and sand dollars, as its distribution is common in shallow depths of soft-bottomed systems and can have dense beds (Hayward & Morley, 2004). Its distribution is clumped thus the high probability of being missed by the 4m grab sample along the cable route.

For the area 27m to 32m with three different types of samples, reduction of taxa followed the same steps as above (removal of taxa with little or “no shell” component and grouping of taxa with one individual only for the whole dataset). The original taxa are presented in Table A 5 (grab samples), Table A 6 (tow samples) and Table A 7 (box samples).

2.2 Shell weight

Of those taxa identified as present in sufficient density, estimates of shell weight /100m² were calculated from individual green weights[1] for each retained taxon. Individual green weights were estimated from the average length measured from tow samples using length-weight equations from the literature (Table A 8). The paddle crab *O. catharus*, the bivalves *Dosinia subrosea*, *Perna canaliculus* and *P. subtriangulata*, and the urchin *Evechinus chloroticus* were the only species with specific information from New Zealand. The green weights of other species found in the Pakiri – Mangawhai embayment samples were estimated from

[1] The weight of fish, aquatic life, or seaweed before any processing commences and before any part is removed.

equations of related species from same genera or families (Table A 8). When taxa had no measured length associated (*i.e.* only collected in box dredge samples), the maximum length found in the literature was used.

2.3 Annual Growth rate shell production

The production of green weight per year was estimated by using taxa specific growth curves from the literature. In most cases, the growth curves correlate age (year) with length (mm), not weight. Therefore, individual lengths at different ages were first calculated with growth equations, then converted to green weight using length-weight equations. Individual growth rates (weight gained per year) were calculated by subtracting the green weights between two consecutive ages. They were averaged to make an average individual green weight growth.

The estimated individual green weight growth was then converted to an individual shell weight growth by applying an estimated percentage of shell weight to green weight (see note 3 in Table A 8). The term “shell” here is not limited to the shell calcium carbonate of molluscs but is also used as a general term for the chitin of arthropods, the test of echinoderms, and the notochord of cephalochordates.

Finally, the individual shell weight growth was multiplied by the number of individuals per 100m^2 to calculate annual shell weight growth in g /100m^2 per year for each taxon.

The methodology presented above uses the average length of each taxon to calculate weight, and the average growth rate over the life span of the animal. However, growth rate can change significantly through life with a rapid growth in the first years and a slow growth when animals reach maturity. Here, the average length of each taxon was used as one age cohort only. Ideally, age-specific growth rates would be used on an age distribution, but for most taxa, growth-specific information was not available. Therefore, the estimation of biogenic production from non-specific averaged growth rates has uncertainties which could not be quantified. In order to check the magnitude of the calculated biogenic production, another method was used by using maximum biomass and maximum age for each taxon and is described below.

2.4 Population mortality shell production

An alternative methodology employed in part by Hilton in 1990, relies on a percentage of the population, based on the maximum age of each taxon, dying each year. This method assumes that recruitment will be the same each year, and that mortality will only occur at maximum age. Both of these assumptions are not likely to be met as such population data is not generally available for the taxon included in this study. However, if these assumptions were true then the production can be given by the equation below, where p= annual shell production; w_i = the weight of the maximum length for the i^{th} taxon (calculated using the length-weight equations from the literature); d_i = the population density (No./100m^2) for the i^{th} taxon; a_i = the maximum age for the i^{th} taxon; and N = the total number of taxa in the sample.

$$p = \sum_{i=1}^{i=N} \frac{(w_i \times d_i)}{a_i}$$

If the assumption of zero juvenile mortality is not met, then this method would overestimate the shell production as fewer individuals will reach maximum size. If the assumption of equal recruitment is not met, then the production will vary between years leading to both over and underestimations. If more detailed information were available on size specific mortality, then the calculation could be modified to reflect this. Similarly, if the variation in recruitment were known then production could be expressed as a range. The method also assumes no variation in growth rates between individuals. Growth rates do vary between individuals as commonly shown by population size frequency plots, in which older age cohorts tend to have a wider size range spread, than younger age cohorts.

The maximum age of a taxon is required for this calculation method, and this basic information is not currently known for many species. Hilton assumed that all biota lived to 10 years of age, which is now known not to be valid. Thus, if taxon were shorter lived than 10 years his method underestimated mortality biomass production. Hilton also used the average population size rather than maximum size in his calculation of the mortality biomass. Again, this will have underestimated the mortality biomass production. This study has used more taxa specific maximum age and size estimates than employed in Hilton (1990) and is therefore a better reflection of actual production.

2.5 Shell production for the Pakiri – Mangawhai embayment

To determine the annual shell production for depth defined areas the equation below was used. Here, P = total production of shell per year (Mg) for the embayment as defined to the 27m depth contour; G_i = the annual shell weight growth (g/100m^2/yr) for the i^{th} taxon; SA = the surface area of the depth-defined area; and N = the total number of taxa in the area. The production from the adjacent deeper 27 - 32m area has also been calculated separately to allow its inclusion if it is determined as relevant based on the wave climate.

$$P = \sum_{i=1}^{i=N} \frac{(G_i \times SA)}{100}$$

To convert shell production from weight to volume (m^3) the density of the shell material is required. The literature suggests compacted shell density ranges between about 1.1Mg/m^3 and 1.4Mg/m^3 depending on the species (Eziefula *et al*., 2018, Mo *et al.*, 2018). A previous study by NIWA on sand budget in the bay assumed a shell density of 1.6Mg/m^3 (Hume *et al*., 1999), however this was not substantiated. A range of values between 1.1 to 1.4Mg/m^3 has been used to provide estimates of the likely range in the volume of biogenic sand produced.

3. RESULTS

3.1 Density of benthic biota taxa

Table A 2 to Table A 7 in the appendices, summarise the original number of taxa and individuals found in the soft sediment, and on the rocky shore. After the reduction of taxa to those likely to produce carbonate shell content, numbers were converted to densities per $100m^2$. The data from the infauna and epifauna surveys were then pooled and separated into habitat type and depth-defined areas. Table 2 to Table 7 provide summaries of data divided by habitat and depth range.

For taxa appearing in both the infauna and epifauna surveys, the data from the survey with the highest density was retained. This was always the box dredge infauna method. However, the epifauna method recorded some taxa not found in the infauna survey, and similarly the reverse also occurred.

Each of these tables consists of two parts: the first, defined by white heading text, is based on the annual growth rate calculations. The second, defined by yellow heading text, is based on the population mortality calculation method.

3.2 Weight and shell production

For the annual growth rate part (blue heading white text) of Table 2 to Table 7, each table is divided by thicker lines into three sections across the table;

a) Left: This covers population density and average length.
b) Middle: This uses formula to estimate green weight based on length, then applies an estimate of percentage shell and density to calculate shell weight per area.
c) Right: This summarises the results of calculations for annual shell growth

The length-weight equations and growth rate equations used for each taxon are listed in Table A 8.

For the mortality part (blue heading yellow text) of Table 2 to Table 7, each table is divided by thicker lines into three sections across the table;

a) Left: This covers population density and maximum size.
b) Middle: This uses formula to estimate green weight based on maximum length, then applies an estimate of percentage shell and density to calculate shell weight of maximum-sized individual per area.
c) Right: This presents a maximum age per taxa and calculates annual weight of shell released by mortality.

Table 8 presents the area of each habitat and depth area and summarises the shell production data from both methods. A total weight of shell production from each method for the entire Pakiri – Mangawhai embayment to the predefined 27m below mean sea level DOC, is presented as bold red numbers. The bold italic red numbers show the range of total volume produced per year by each method. The row of blue numbers at the bottom represent the area 27m – 32m depth, located just offshore of the DOC to the embayment.

Table 2 Weight and growth estimated for the rocky shore area 0m – 7m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(g/y)	(g/y)	(g/100m^2/y)
Gastropods	*Nerita melanotragus*	10680	quadrat	16	0.4	85	0.34	3631	0.94	0.80	8533
	Cellana ornate	5567	quadrat	18	0.4	70	0.28	1559	0.94	0.66	3663
	Cellana radians	3240	quadrat	26	0.7	70	0.49	1588	0.94	0.66	2132
	Lepsiella scobina	42625	quadrat	15	0.4	85	0.34	14493	3.69	3.14	133693
	Melagraphia aethiops	4767	quadrat	15	3.0	85	2.55	12155	0.94	0.80	3809
	Turbo smaragdus	4400	quadrat	26	4.0	85	3.40	14960	0.94	0.80	3516
	Cookia sulcata	1450	quadrat	58	14.0	85	11.90	17255	0.94	0.80	1159
	Haustrum haustorium	550	quadrat	41	5.3	85	4.51	2478	10.00	8.50	4675
	Thais orbita	3750	quadrat	41	5.3	85	4.51	16894	20.00	17.00	63750
Bivalves	*Perna canaliculus*	3100	quadrat	69	32.0	65	20.80	64480	10.00	6.50	20150
Echinoderms	*Evechinus chloroticus*	3125	quadrat	60	65.0	20	13.00	40625	9.00	1.80	5625
Arthropods	*Leptograpsus variegatus*	1800	quadrat	-	5.0	20	1.00	1800	0.50	0.10	180
Total		**85054**						**191919**			**250885**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(y)	(g/100m^2/y)
Gastropods	*Nerita melanotragus*	10680	quadrat	30	1.1	85	0.94	9986	6	1664
	Cellana ornate	5567	quadrat	50	2.0	70	1.40	7793	6	1299
	Cellana radians	3240	quadrat	50	2.0	70	1.40	4536	6	756
	Lepsiella scobina	42625	quadrat	34	7.8	85	6.63	282604	9	31400
	Melagraphia aethiops	4767	quadrat	30	7.1	85	6.04	28767	6	4794
	Turbo smaragdus	4400	quadrat	91	100.0	85	85.00	374000	8	46750
	Cookia sulcata	1450	quadrat	119	117.0	85	99.45	144203	8	18025
	Haustrum haustorium	550	quadrat	65	30.4	85	25.84	14212	8	1777
	Thais orbita	3750	quadrat	110	200.0	85	170.00	637500	8	79688
Bivalves	*Perna canaliculus*	3100	quadrat	160	110.0	65	71.50	221650	4	55413
Echinoderms	*Evechinus chloroticus*	3125	quadrat	160	230.0	20	46.00	143750	15	9583
Arthropods	*Leptograpsus variegatus*	1800	quadrat	50	10.0	20	2.00	3600	4	900
Total		**85054**						**1872604**	**7 (mean max. age)**	**252050**

Table 3 Weight and growth estimated for the Sandy area 0m – 7m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Arthropods	*Ovalipes catharus*	130	Box	37	11.4	20	2.28	296	69.00	13.80	1794
Gastropods	*Zethalia zelandica*	9617	Box	10	2.0	80	1.60	15387	0.94	0.75	7232
Bivalves	*Paphies subtriangulata*	1244	quadrat	28	15.0	65	9.75	12129	0.20	0.13	162
Echinoderms	*Fellaster zelandiae*	422	Box	47	10.0	90	9.00	3798	3.10	2.79	1177
Total		**11413**						**31610**			**10365**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Arthropods	*Ovalipes catharus*	130	Box	130	378.0	20	75.60	9825	4	2456
Gastropods	*Zethalia zelandica*	9617	Box	26	6.0	80	4.80	46162	6	7694
Bivalves	*Paphies subtriangulata*	1244	quadrat	80	74.0	65	48.10	59836	5	11967
Echinoderms	*Fellaster zelandiae*	422	Box	100	18.0	90	16.20	6836	10	684
Total		**11413**						**122659**	**6 (mean max. age)**	**22801**

Table 4 Weight and growth estimated for the Sandy area 7m – 12m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	65	box	9	0.2	20	0.04	3	0.30	0.06	4
	Ovalipes catharus	130	box	24	3.4	20	0.68	88	69.0	13.80	1793
	other arthropods	487	box	10	0.3	20	0.06	29	0.30	0.06	29
Gastropods	*Cominella adspersa*	3	tow	35	5.3	80	4.24	11	3.69	2.95	8
	Zethalia zelandica	9617	box	10	2.0	80	1.60	15387	0.94	0.75	7232
	Amalda australis	227	box	30	3.3	80	2.64	600	3.69	2.95	671
	other gastropod	97	box	25	2.0	80	1.60	156	2.77	2.22	216
Bivalves	*Myadora* spp.	162	box	28	9.0	50	4.50	731	3.50	1.75	284
	Dosinia subrosea	227	box	40	30.0	65	19.50	4435	7.00	4.55	1035
Echinoderms	*Fellaster zelandiae*	422	box	47	8.0	90	7.20	3041	3.10	2.79	1178
	Amphiura sp.	2	tow	80	5.0	90	4.50	7	1.50	1.35	2
	Astropecten polyacanthus	6	tow	130	16.0	90	14.40	82	3.10	2.79	16
Chordates	*Epigonichthys hectori*	422	box	40	0.3	20	0.06	25	0.20	0.04	17
Total		**11867**						**24595**			**12485**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	65	box	15	10.0	20	2.00	130	4	32
	Ovalipes catharus	130	box	130	378.0	20	75.60	9825	4	2456
	other arthropods	487	box	15	10.0	20	2.00	975	4	244
Gastropods	*Cominella adspersa*	3	tow	65	32.0	80	25.60	67	9	8
	Zethalia zelandica	9617	box	26	6.0	80	4.80	46160	6	7693
	Amalda australis	227	box	40	7.8	80	6.24	1419	9	142
	other gastropod	97	box	44	15.0	80	12.21	1190	8	149
Bivalves	*Myadora* spp.	162	box	42	30.0	50	15.00	2437	11	244
	Dosinia subrosea	227	box	57	68.0	65	44.20	10052	11	1005
Echinoderms	*Fellaster zelandiae*	422	box	100	18.0	90	16.20	6842	10	684
	Amphiura sp.	2	tow	80	5.0	90	4.50	7	15	0
	Astropecten polyacanthus	6	tow	200	20.0	90	18.00	103	15	7
Chordates	*Epigonichthys hectori*	422	box	80	1.0	20	0.20	84	8	11
Total		**11867**						**79291**	**9 (mean max. age)**	**12578**

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Table 5 Weight and growth estimated for the Sandy area 12m – 22m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(g/y)	(g/y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	194	box	16	0.8	20	0.15	29	0.30	0.06	12
	Crabs other than *Ovalipes*	282	box	15	0.9	20	0.18	51	1.00	0.20	56
	other arthropods	317	box	10	0.3	20	0.06	19	0.30	0.06	19
Gastropods	*Zethalia zelandica*	53	box	10	2.0	80	1.60	85	0.94	0.75	40
	Sigapatella tenuis	247	box	5	0.01	50	0.005	1	0.10	0.05	12
	Austrofusus glans	1	tow	33	4.4	80	3.54	4	3.69	2.95	3
	Cominella adspersa	176	box	29	3.0	80	2.42	426	3.69	2.95	521
	Amalda spp.	141	box	25	2.0	80	1.56	220	3.69	2.95	417
	Struthiolaria papulosa	2	tow	60	25.9	80	20.70	34	3.69	2.95	5
	other gastropods	229	box	37	6.2	80	4.96	1137	3.69	2.95	677
Bivalves	*Myadora* spp.	1728	box	23	5.0	50	2.50	4321	3.50	1.75	3025
	Dosinia subrosea	88	box	25	10.0	65	6.50	573	7.00	4.55	401
	Nucula nitidula	494	box	13	0.2	50	0.10	49	0.10	0.05	25
	Glycymeris modesta	35	box	26	6.3	65	4.11	145	1.44	0.94	33
	Atrina zelandica	1	tow	45	8.7	65	5.68	4	12.60	8.19	6
	Gari convexa	459	box	25	0.5	65	0.33	152	1.43	0.93	426
Echinoderms	*Fellaster zelandiae*	212	box	47	8.0	90	7.20	1524	3.10	2.79	590
	Astropecten polyacanthus	9	tow	125	16.0	90	14.40	136	3.10	2.79	26
Total		**4668**						**8910**			**6294**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	194	box	15	10.0	20	2.00	388	4	97
	Crabs other than *Ovalipes*	282	box	100	200.0	20	40.00	11287	4	2822
	other arthropods	317	box	15	10.0	20	2.00	635	4	159
Gastropods	*Zethalia zelandica*	53	box	26	6.0	80	4.80	254	6	42
	Sigapatella tenuis	247	box	5	0.0	50	0.01	1	6	0
	Austrofusus glans	1	tow	65	32.0	80	25.60	26	9	3
	Cominella adspersa	176	box	65	32.0	80	25.60	4515	9	502
	Amalda spp.	141	box	40	7.8	80	6.24	880	9	98
	Struthiolaria papulosa	2	tow	65	32.0	80	25.60	42	9	5
	other gastropods	229	box	52	22.0	80	17.57	4028	9	448
Bivalves	*Myadora* spp.	1728	box	42	30.0	50	15.00	25926	11	2357
	Dosinia subrosea	88	box	57	68.0	65	44.20	3898	11	354
	Nucula nitidula	494	box	13	0.2	50	0.10	49	8	6
	Glycymeris modesta	35	box	26	5.0	65	3.25	115	10	11
	Atrina zelandica	1	tow	300	88.0	65	57.20	40	15	3
	Gari convexa	459	box	58	4.0	65	2.60	1192	8	149
Echinoderms	*Fellaster zelandiae*	212	box	100	18.0	90	16.20	3429	10	343
	Astropecten polyacanthus	9	tow	200	20.0	90	18.00	170	15	11
Total		**4668**						**56875**	**9 (mean max. age)**	**7411**

Table 6 Weight and growth estimated for the area Sandy 22m – 27m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	633	box	13	0.6	20	0.12	76	0.30	0.06	38
	Crabs other than *Ovalipes*	201	box	15	0.9	20	0.18	37	1.00	0.20	40
	other arthropods	340	box	10	0.3	20	0.06	20	0.30	0.06	20
Polyplacophora	*Leptochiton* sp.	93	box	10	0.1	50	0.05	5	0.30	0.15	14
Gastropods	*Stiracolpus pagoda*	170	box	24	0.5	80	0.40	68	1.00	0.80	136
	Sigapatella tenuis	293	box	5	0.01	50	0.003	1	0.10	0.05	15
	Cominella quoyana	355	box	21	1.16	80	0.93	329	3.69	2.95	1048
	Amalda spp.	154	box	25	2.0	80	1.56	241	3.69	2.95	456
	other gastropods	556	box	28	2.7	80	2.18	1209	0.20	0.16	89
Bivalves	*Myadora* spp.	401	box	23	5.0	50	2.50	1003	3.50	1.75	702
	Dosinia subrosea	247	box	25	10.0	65	6.50	1605	7.00	4.55	1123
	Nucula nitidula	509	box	13	0.2	50	0.10	204	0.10	0.05	25
	Glycymeris modesta	31	box	26	6.3	65	4.11	127	1.44	0.94	29
	Gari convexa	340	box	25	0.5	65	0.33	113	1.43	0.93	316
Echinoderms	*Amphiura* sp.	123	box	80	5.0	90	4.50	556	1.50	1.35	167
Chordates	*Epigonichthys hectori*	201	box	40	0.3	20	0.06	12	0.20	0.04	8
Total		**4647**						**6322**			**4226**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	633	box	15	10.0	20	2.00	1265	4	316
	Crabs other than *Ovalipes*	201	box	100	200.0	20	40.00	8025	4	2006
	other arthropods	340	box	15	10.0	20	2.00	679	4	170
Polyplacophora	*Leptochiton* sp.	93	box	30	4.0	50	2.00	185	15	12
Gastropods	*Stiracolpus pagoda*	170	box	24	0.5	80	0.40	68	3	23
	Sigapatella tenuis	293	box	5	0.01	50	0.01	1	6	0
	Cominella quoyana	355	box	21	1.2	80	0.96	341	9	38
	Amalda spp.	154	box	40	7.8	80	6.24	963	9	107
	other gastropods	556	box	43	13.4	80	10.75	5970	7	853
Bivalves	*Myadora* spp.	401	box	42	30.0	50	15.00	6019	11	547
	Dosinia maoriana	247	box	57	68.0	65	44.20	10914	11	992
	Nucula nitidula	509	box	13	0.2	50	0.10	51	8	6
	Glycymeris modesta	31	box	26	5.0	65	3.25	100	10	10
	Gari convexa	340	box	58	4.0	65	2.60	883	8	110
Echinoderms	*Amphiura* sp.	123	box	80	5.0	90	4.50	556	15	37
Chordates	*Epigonichthys hectori*	201	box	80	1.0	20	0.20	40	8	5
Total		**4647**						**31497**	**8 (mean max. age)**	**4580**

Table 7 Weight and growth estimated for the Sandy area 27m – 32m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	22467	grab	13	0.6	20	0.12	2696	0.30	0.06	1348
	Crabs other than *Ovalipes*	1400	grab	15	0.9	20	0.18	252	1.00	0.20	280
Polyplacophora	*Leptochiton* sp.	1200	grab	10	0.1	50	0.05	60	0.30	0.15	180
Gastropods	*Epitonium* sp.	200	grab	14	0.2	80	0.16	32	1.00	0.80	160
	Turritellidae	2067	grab	24	0.5	80	0.40	827	1.00	0.80	1653
	Rissoina fictor	154	box	5	0.1	80	0.04	6	1.00	0.80	123
	Sigapatella sp.	2667	grab	5	0.0	50	0.01	13	0.10	0.05	133
	Amalda sp.	1067	grab	25	2.0	80	1.60	1707	3.69	2.95	3149
	Austrofusus glans	133	grab	33	4.4	80	3.54	471	3.69	2.95	394
	Cominella quoyana	988	box	20	1.0	80	0.80	790	3.69	2.95	2916
	Antimelatoma buchanani	62	box	20	1.0	80	0.80	49	3.69	2.95	182
	Zeatrophon ambiguus	200	grab	30	3.3	80	2.67	534	3.69	2.95	590
	Xymenella pusilla	62	box	25	2.0	80	1.56	96	3.69	2.95	182
	Cantharidus sp.	133	grab	10	2.0	80	1.60	213	0.94	0.75	100
	Antisolarium egenum	401	box	5	0.7	80	0.59	238	0.94	0.75	302
	Roseaplagis rufozona	93	box	10	2.0	80	1.60	148	0.94	0.75	70
	Solariella tryphenensis	93	box	5	0.7	80	0.59	55	0.94	0.75	70
	Other gastropods	1600	grab	10	2.0	80	1.60	2560	2.22	1.78	2846
Bivalves	*Hunkydora* & *Myadora*	400	grab	23	5.0	50	2.50	1000	3.50	1.75	700
	Corbula zelandica	401	box	12	5.0	50	2.50	1003	3.50	1.75	702
	Glycymeris modesta	216	box	26	6.3	65	4.10	885	1.44	0.94	202
	Pratulum pulchellum	400	grab	25	5.6	65	3.61	1446	1.44	0.94	374
	Gari & *Hiatula*	2933	grab	25	0.5	65	0.33	953	1.43	0.93	2727
	Pleuromeris sp.	467	grab	8	5.6	65	3.61	1687	1.44	0.94	437
	Purpurocardia purpurata	123	box	26	6.3	65	4.10	506	1.44	0.94	116
	Limatula maoria	333	grab	8	0.0	50	0.01	2	0.10	0.05	17
	Nucula nitidula	3533	grab	8	0.0	50	0.01	18	0.10	0.05	177
	Atrina zelandica	333	grab	45	8.7	65	5.68	1894	12.60	8.19	2730
	Dosinia sp.	267	grab	25	10.0	65	6.50	1733	7.00	4.55	1213
	Tawera sp.	1267	grab	24	10.0	65	6.50	8233	7.00	4.55	5763
	Zemysina globus	62	box	25	10.0	65	6.50	401	7.00	4.55	281
	Lasaeidae	1333	grab	1	0.0	50	0.01	7	0.10	0.05	67
	Pecten novaezelandiae	15	tow	84	55.7	65	36.19	550	50.00	32.50	494
	Other bivalves	667	grab	23	10.0	65	6.50	4333	5.00	3.25	2167
Echinoderms	*Echinocardium* sp.	1733	grab	30	10.0	20	2.00	3467	10.00	2.00	3467
	Astropecten polycanthus	4	tow	114	14.0	90	12.60	53	3.10	2.79	12
	Amphiura sp.	533	grab	80	5.0	90	4.50	2400	1.50	1.35	720
Chordates	*Epigonichthys hectori*	5467	grab	40	0.3	20	0.06	328	0.20	0.04	219
Total		**55474**						**41646**			**37263**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual Mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	22467	grab	15	10.0	20	2.00	44933	4	11233
	Crabs other than *Ovalipes*	1400	grab	100	200.0	20	40.00	56000	4	14000
Polyplacophora	*Leptochiton* sp.	1200	grab	30	4.0	50	2.00	2400	15	160
Gastropods	*Epitonium* sp.	200	grab	14	0.2	80	0.16	32	3	11
	Turritellidae	2067	grab	24	0.5	80	0.40	827	3	276
	Rissoina fictor	154	box	5	0.1	80	0.04	6	3	2
	Sigapatella sp.	2667	grab	8	0.2	50	0.10	267	2	134
	Amalda sp.	1067	grab	40	7.8	80	6.24	6656	10	666
	Austrofusus glans	133	grab	65	32.0	80	25.60	3413	8	427
	Cominella quoyana	988	box	20	1.0	80	0.80	790	8	99
	Antimelatoma buchanani	62	box	20	1.0	80	0.80	49	8	6
	Zeatrophon ambiguus	200	grab	30	3.3	80	2.67	534	8	67
	Xymenella pusilla	62	box	25	2.0	80	1.56	96	8	12
	Cantharidus sp.	133	grab	26	6.0	80	4.80	640	6	107
	Antisolarium egenum	401	box	7	0.8	80	0.64	257	6	43
	Roseaplagis rufozona	93	box	26	6.0	80	4.80	444	6	74
	Solariella tryphenensis	93	box	5	0.7	80	0.59	55	6	9
	Other gastropods	1600	grab	10	2.0	80	1.60	2560	6	401
Bivalves	*Hunkydora* & *Myadora*	400	grab	42	10.0	50	5.00	2000	10	200
	Corbula zelandica	401	box	12	5.0	50	2.50	1003	10	100
	Glycymeris modesta	216	box	26	5.0	65	3.25	702	5	140
	Pratulum pulchellum	400	grab	26	5.0	65	3.25	1300	5	260
	Gari & *Hiatula*	2933	grab	58	11.0	65	7.15	20973	10	2097
	Pleuromeris sp.	467	grab	8	5.6	65	3.64	1699	5	340
	Purpurocardia purpurata	123	box	35	5.0	65	3.25	401	5	80
	Limatula maoria	333	grab	8	0.2	50	0.10	33	2	17
	Nucula nitidula	3533	grab	8	0.2	50	0.10	353	2	177
	Atrina zelandica	333	grab	300	88.0	65	57.20	19067	15	1271
	Dosinia sp.	267	grab	52	40.0	65	26.00	6933	10	693
	Tawera sp.	1267	grab	24	10.0	65	6.50	8233	10	823
	Zemysina globus	62	box	24	10.0	65	6.50	401	10	40
	Lasaeidae	1333	grab	2	0.2	50	0.10	133	2	67
	Pecten novaezelandiae	15	tow	116	128.0	65	83.20	1265	10	127
	Other bivalves	667	grab	30	10.0	65	6.50	4333	9	495
Echinoderms	*Echinocardium* sp.	1733	grab	30	10.0	20	2.00	3467	10	347
	Astropecten polycanthus	4	tow	200	20.0	90	18.00	76	15	5
	Amphiura sp.	533	grab	80	5.0	90	4.50	2400	15	160
Chordates	*Epigonichthys hectori*	5467	grab	80	1.0	20	0.20	1093	8	137
Total		**55474**						**195824**	**7 (mean max. age)**	**35303**

Table 8 Summary of shell production by area in the Pakiri – Mangawhai embayment.

Area	Surface Area	Dominant sampling method	Average density	Actual Shell weight		Annual Shell Growth				Annual Shell Morality			
						Weight		Volume		Weight		Volume	
				Average	Total	Average	Total	Lower	Upper	Average	Total	Lower	Upper
	(m^2)		No./100m^2	g/100m^2	Mg	g/100m^2/y	Mg/y	m^3/y	m^3/y	g/100m^2/y	Mg/y	m^3/y	m^3/y
Rocky shore 0m – 7m	1,011,139	quadrat	85,054	191,919	1,941	250,885	2,537	1,812	2,306	252,050	2,549	1,821	2,317
Shoreline 0m – 7m	11,119,839	box	11,413	31,610	3,515	10,365	1,153	823	1,048	22,802	2,536	1,811	2,305
Shallow 7m - 12m	5,701,399	box	11,867	24,595	1,402	12,485	712	508	647	12,578	717	512	652
Mid 12m - 22m	20,855,709	box	4,668	8,910	1,858	6,294	1,313	938	1,193	7,411	1,600	1,143	1,455
Deep 22m - 27m	16,558,156	box	4,647	5,606	928	4,226	700	500	636	4,580	1,059	757	963
Pakiri – Mangawhai embayment within depth of Closure	55,246,242	box	8,234*	17,457*	9,645	11,609*	**6,414**	***4,581***	***5,831***	14,671*	**8,106**	***5,790***	***7,369***
Offshore 27m – 32m	15,818,196	grab	41,646	56,231	8,895	37,263	**5,894**	***4,210***	***5,358***	35,303	**5,584**	***3,989***	***5,076***

Note:

A range of densities was used for the shell volume with upper defined as 1.1 Mg/m³ and lower as 1.4 Mg/m³ (see text).

It was not possible to estimate errors with the methodologies used.

* area weighted average

4. DISCUSSION

4.1 Shell weight annual production

The majority of the calculations of growth rates of taxa present were not based on taxa specific equations as no such equations have been developed for most New Zealand species. Therefore, similar local or international taxa growth rate equations were substituted. The use of non-specific equations and extrapolations provides an estimate of the production albeit with an increased measure of uncertainty. The present estimation assumed a single cohort per taxa (no size distribution of biota available for box dredge) with no migration in or out the system. Until more data on the biology of the biota become available (population dynamics), building more complex growth models of current biota is pointless.

The annual shell production in the Pakiri – Mangawhai embayment (0m – 27m) was estimated to be around 7,200 tonnes depending on the methodology used (by growth rate 6,414 tonnes or by mortality 8,106 tonnes). This was equivalent to a range in volume of 4,600 – 5,800m³ by growth rate or between 5,800 – 7,400m³ by mortality, depending on different crushed shell densities of 1.1 - 1.4 Mg/m³ used (Eziefula *et al.*, 2018). Given the number of estimations, assumptions and substitutions it was not possible to provide an estimation of the error associated with the results produced by either method.

In general, subtidal marine invertebrate communities can support a high diversity of species with different ecological and life history traits. Species with different adaptations, occupy different niches along a depth gradient, which among other factors, varies with sediment texture and with their ability to cope with the physical environment (Dolbeth *et al.,* 2007). The environmental severity conditioning the fauna is determined by the bottom disturbance, which in turn potentially affects sediment texture, food availability and biotic interactions. Both wave climate and morphological parameters showed that the higher the energy to which the community is subjected, the lower the species number and density in the inhabited area (Dolbeth *et al.,* 2007). The DOC reflects differences in hydrodynamics, with lower energy conditions on the seabed, seawards of this boundary. Therefore, both increased food availability and reduced disturbance may allow for the existence of richer and denser assemblages beyond the DOC (Carvalho *et al*., 2012).

The benthic biota data collected in the Pakiri embayment for both the McCallum Brothers Limited and Kaipara Limited consents and in the past (Hilton, 1990, Bioresearches, 2016) show variations in the species composition and abundance with increased depth. The current data shows the inshore areas (0-12m) are dominated by biota adapted to high wave energy such as wheel shells and sand dollar, both of which can occur in high densities. Further offshore between 12 and 27m depth the biota was diverse, but low in abundance. Here, communities were dominated by a few species of polychaete worms and contained moderate numbers of amphipods, hermit crabs, the bivalves *Nucula* and *Myadora* and the Lancelet, *Epigonichthys hectori*. Beyond the predefined 27m DOC, the biota was still diverse with similar species to those present in the mid shore (12 – 27m) but numbers of individuals, particularly bivalves, were greater beyond the 27m depth.

Table 8 shows the average biomass of biota per 100m² decreased with increasing depth to the 27m depth contour. The highest numbers were recorded in the rocky shore areas. The higher numbers recorded in the shallow sandy environments were mostly due to the high abundances of the wheel shells and sand dollars. The decreasing numbers were the result of fewer biota present and their smaller sizes. Beyond the 27m depth contour, the biomass increased again due to increased numbers of bivalves and echinoderms (Table 7).

As there are uncertainties on the amount of sediment and shell material moving to and from the Pakiri – Mangawhai embayment (0m – 27m) across the predefined 27m DOC, the calculation of annual shell production in the 27m – 32m area is also presented. The production in the 27m – 32m area alone (4,000 - 5,400m³ depending on the methodology) is marginally lower but comparable to that of the whole Pakiri – Mangawhai embayment (0m – 27m) (4,600 – 7,400m³ depending on the methodology). Thus, the inclusion of the 27m – 32m area in the biogenic sand budget of the Pakiri – Mangawhai embayment (0m – 32m) gives figures of approximately 8,800 to 12,400m³ of annual biogenic sand production.

Based on the data included in this study the different sampling methods; grab sampler, box dredge, quadrat and dredge tow, appear to produce different densities of biota. The grab sampler samples the smallest area, but the area sampled is standardised. The box dredge samples a similar volume, but a larger area and the area sample varies depending on how well the dredge operates in the sediment. The quadrat again samples a standardised area. The dredge tow samples are very different to the other two samplers in that the area sampled is much greater and is selective for the larger biota only.

Of the six defined areas sampled, only the 27m -32m area was sampled with the grab sampling method and this method systematically produced greater densities in comparison with box dredge or tow dredge samples in the same area. Nonetheless, the higher densities recorded beyond the 27m depth contour are not solely a bias of sampling methodology. Seabed images recorded in four transects in 2019 reported in Bioresearches (2019b) showed increased proportions of shell fragments on the seabed in areas beyond 25m depth (as recorded at the time of sampling), and corroborates the increased biota recorded in the samples. In the absence of data to directly compare the different sampling methods it has been assumed neither sampling method has any greater bias.

4.2 Comparison with previous estimated numbers

Sands in the Pakiri-Mangawhai embayment are primarily quartzo-feldspathic (Schofield, 1970). They also contain varying amounts of carbonate, as sand material.

Based on the 2019 soft shore calciferous biota densities the estimated average concentration of shell is 142g/m², ranging between 56 and 316g/m², which is comparable with Hilton’s estimate or 97g/m², albeit for slightly different areas. Hilton’s transect areas extended beyond the 27m depth contour and did not include the rocky shore biota, making direct comparison with the current study problematic. When rocky shore biota was included the average concentration of shell increased to 175g/m², due the estimated rocky shore shell biomass of 1920g/m².

Hilton (1990) assumed that for a shellfish species of a 10-year life expectancy, 10% of the population would die every year and the shell becomes part of the biogenic sand. This assumes a constant population size, and that recruitment and mortality were constant, which they are generally not. It also appears that he assumed all shellfish had a similar life span, which is also not a valid assumption. We now know biota range in lifespan from 3 to 15 years. Longer lived species would contribute a lesser percentage of the population per year than a short-lived species. His assumptions were based on the information available in 1990, greater information on life span is now available but the population size, mortality and recruitment are still not well understood. We do know from monitoring data (Grace, 1991, 2005, Bioresearches 2019) that the populations of wheel shell and several other species have varied between years which suggested either mortality or more likely recruitment are not constant.

Based on Hilton's assumptions, he calculated that the existing weight of shell material 5,300 tonnes would increase to 73,000,000 tonnes after 100 years. This calculation was incorrect. Hilton mistakenly added the dead shell material back to the live shell material each year for a compounding recalculation of dead shell production over the 100-year time frame. This process grossly overestimated the production of dead shell material over time. One of the major assumptions is that the live shellfish population does not change year to year therefore the production should be the same each year. To quantify any changes year to year or between seasons would require repeated surveys of taxa abundance and sizes, which is beyond the scope needed for this project. Given that mortality and recruitment vary between years and between species the live shellfish population will vary over time. However even if the shellfish population varied in size between years the expected dead shell production would not approach the tonnage Hilton calculated. Correcting Hiltons dead shell production calculation overtime, results in an annual shell material production of 530 tonnes, translating to 482m³/year assuming shell material has a density of 1.1Mg/m³. Hume *et al.* (1999) suggests these values cover half the bay and should be doubled to a corrected value of 964m³/year, which is considerably less than that Hilton reported in 1990 of 900,000m³/year.

The NIWA sand study (Hume *et al*., 1999) considered Hilton's original shell production value of 900,000 m³/year erroneous and suggested the biogenic sand product was less than 12,000 m³/year based on a sediment budget. Barnett in his 2005 environment court evidence suggested it should be near 90,000 m³/year, neither of the latter estimates were based on biological science.

Of these estimates only the Hilton (1990) corrected estimate of 964m³/year is based on actual biological production, but it was based on invalid assumptions and missing significant sources.

In an ideal world with data on distribution and abundance, growth curves, population structure, recruitment and mortality variability available on each of the specific taxa the total shell production could be refined as the sum of each component taxa per area. The estimate produced in this report has attempted to further refine Hilton's assessment by segregating the seabed into five zones based on species composition and abundance and defined by depth. In addition, rather than assuming that all shellfish grow in the same way, taxa specific growth has been applied to each taxon within each zone. Species-specific growth data, age, population structure, recruitment etc, do not generally exist for the species recorded. Therefore, data from similar taxa have been used as estimates for growth and age. Detailed population structure data was generally not available for any of the taxa recorded, therefore the annual growth of the average known size for each taxon was used to provide one estimate of growth. A second estimate of growth was based on the similar method to Hilton of the annual population mortality as estimated by the reciprocal of maximum age. Variability in recruitment and mortality were not available for in the production estimate. Nonetheless, the similarity of the two estimates produced for the rocky and soft shore environments of the Pakiri-Mangawhai embayment to the 27m depth contour (annual growth 4,581 – 5,831 m³/year, and population mortality 5,790 – 7,369 m³/year), provides some confidence in the calculations, and fits within the 12,000m³ net shoreward transport of material proposed by Hume *et al* (1999).

Addition of the results of biogenic sand production from the 27-32 m contour (Table 8), would increase the production by a further 4,200 – 5,400 m³/year under the annual growth methodology, and 4,000 – 5,000 m³/year under the population mortality methodology.

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6. APPENDICES

Table A 1 Surface area calculated for each tow. The width of the dredge was 650mm for the tows up to a depth of 25m, and 600mm for the tows in the 25 – 30m depth area.

Tow Code	Depth area	Distance (m)	Surface (m^2)
1	20 – 25m	383	248.95
2	20 – 25m	595	386.75
3	20 – 25m	514	334.1
4	20 – 25m	387	251.55
5	20 – 25m	284	184.6
6	20 – 25m	334	217.1
7	20 – 25m	392	254.8
8	10 – 20m	205	133.25
9	10 – 20m	289	187.85
10	20 – 25m	322	209.3
11	10 – 20m	301	195.65
12	10 – 20m	347	225.55
13	10 – 20m	255	165.75
14	10 – 20m	357	232.05
15	10 – 20m	317	206.05
16	10 – 20m	655	425.75
17	10 – 20m	275	178.75
18	10 – 20m	157	102.05
19	10 – 20m	233	151.45
20	10 – 20m	315	204.75
21	10 – 20m	258	167.7
22	5 – 10m	281	182.65

Tow Code	Depth area	Distance (m)	Surface (m^2)
23	5 – 10m	277	180.05
24	5 – 10m	233	151.45
25	5 – 10m	272	176.8
26	5 – 10m	279	181.35
27	5 – 10m	228	148.2
28	5 – 10m	254	165.1
29	5 – 10m	274	178.1
30	5 – 10m	296	192.4
31	5 – 10m	270	175.5
32	5 – 10m	319	207.35
33	5 – 10m	336	218.4
34	5 – 10m	315	204.75
35	5 – 10m	234	152.1
T2 A	25 – 30m	100	60
T4 A	25 – 30m	125	75
T6 A	25 – 30m	100	60
T6 B	25 – 30m	100	60
T8 A	25 – 30m	100	60
T8 B	25 – 30m	99	59.4
TC A	25 – 30m	100	60
TC B	25 – 30m	100	60

Table A 2 Infauna taxa found in the 94 box dredge samples (3.15mm mesh size) collected within 0 to 27m depth (Bioresearches, 2019a,b).

Taxa	Total No.
Polychaeta: *Hydroides* sp.	7
Polychaeta: Spionidae	2
Polychaeta: *Paraprionospio pinnata*	7
Polychaeta: Terebellida	11
Polychaeta: Ampharetidae	19
Polychaeta: ?*Lanice* sp.	2
Polychaeta: Cirratulidae	14
Polychaeta: Eunicidae	3
Polychaeta: Lumbrineries sp.	8
Polychaeta: Onuphidae	4
Polychaeta: Goniadidae	1
Polychaeta: Nephtyidae	6
Polychaeta: ?*Aglaophamus/Nephtys*	6
Polychaeta: Nereididae	1
Polychaeta: Phyllodocidae	10
Polychaeta: Polynoidae	4
Polychaeta: Sigalionidae	21
Polychaeta: *Magelona* cf. *dakini*	3
Polychaeta: Capitellidae	26
Polychaeta: *Armandia maculata*	2
Polychaeta: Maldanidae	525
Polychaeta: *Travisia olens*	1
other polychaeta	59
Nemertea	9
Calanoida	2
Cyclopoida	3
Amphipoda: Gammaridea undet.	9
Amphipoda: Gammaridea sp. 2	3
Amphipoda: Gammaridea sp. 3	22
Amphipoda: Gammaridea sp. 5	1
Amphipoda: Lysianassidae	2
Amphipoda: Phoxocephalidae sp. 1	23
Amphipoda: Phoxocephalidae sp. 2	2
Amphipoda: Phoxocephalidae sp. 3	2
Amphipoda: Haustoriidae	1

Taxa	Total No.
Amphipoda: Liljeborgiidae	2
Amphipoda: *Ampelisca chiltoni*	3
Cumacea: *Cyclaspis*	7
Cumacea: *Diastylopsis thileniusi*	2
Decapoda: *Periclimenes yaldwyni*	2
Decapoda: *Ogyrides delli*	2
Decapoda: *Liocarcinus corrugatus*	4
Decapoda: *Ovalipes catharus*	**2**
Decapoda: *Ebalia laevis*	5
Decapoda: Anomura	11
Decapoda: *Pagurus setosus*	**58**
other decapods	3
Arthropoda: Isopods	20
Arthropoda: Mysidae	10
Arthropoda: Pariliacantha	7
Arthropoda: Tanaidacea	1
Arthropoda: Pycnogonida	1
Arthropoda: Coleoptera undet.	2
Polyplacophora: *Leptochiton inquinatus*	**7**
Gastropoda: *Zethalia zelandica*	**300**
Gastropoda: *Antisolarium egenum*	10
Gastropoda: *Maoricolpus roseus*	2
Gastropoda: *Stiracolpus pagoda*	**11**
Gastropoda: *Sigapatella tenuis*	**33**
Gastropoda: *Trichosirius inornatus*	2
Gastropoda: *Cominella adspersa*	**6**
Gastropoda: *Cominella quoyana*	**28**
Gastropoda: Austrofusus glans	1
Gastropoda: *Amalda australis*	**10**
Gastropoda: *Amalda depressa*	**2**
Gastropoda: *Amalda novaezelandiae*	**13**
Gastropoda: Borsoniidae	3
Gastropoda: *Euterebra tristis*	5
Gastropoda: *Pupa affinis*	20
Gastropoda: *Cylichna thetidis*	3

Taxa	Total No.
other gastropods	4
Bivalvia: *Nucula nitidula*	**61**
Bivalvia: *Glycymeris modesta*	**3**
Bivalvia: *Purpurocardia purpurata*	1
Bivalvia: Galeommatidae	3
Bivalvia: *Scalpomactra scalpellum*	2
Bivalvia: *Gari convexa*	**5**
Bivalvia: *Gari lineolata*	**3**
Bivalvia: *Gari stangeri*	**4**
Bivalvia: *Hiatula nitida*	4
Bivalvia: *Zemysina globus*	6
Bivalvia: *Tawera spissa*	8
Bivalvia: *Dosinia lambata*	**2**
Bivalvia: *Dosinia maoriana*	**5**
Bivalvia: *Dosinia subrosea*	**18**
Bivalvia: *Corbula zelandica*	10
Bivalvia: *Myadora boltoni*	**71**
Bivalvia: *Myadora striata*	**45**
Bivalvia: Myadora subrostrata	**13**
Bivalvia: *Hunkydora novozelandica*	2
other Bivalvia	4
Echinodermata: *Amphiura aster*	**15**
Echinodermata: *Fellaster zelandiae*	**16**
other echinoderms	2
Nematoda	8
Foraminifera	7
Bryozoa: *Selenaria concinna*	68
Porifera	11
Leptothecata	2
Actiniaria	1
Epigonichthys hectori	**67**
Limnichthys polyactis	6
TOTAL	**1896**

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature. The other highlighted taxa were combined into a higher taxonomic level.

Table A 3 Epifauna taxa found in the 35 dredge tow samples collected within 0 to 27m depth (Bioresearches, 2019a,b).

Taxa	Total No.
Polychaete	21
Amphipods	7
Nemertea	3
Isopod	2
Bryozoa	4
Porifera	6
Decapoda: Paguridae	122
Decapoda: *Ovalipes catharus*	**7**
Decapoda: *other than Ovalipes*	9
Gastropoda: Zethalia zelandica	**7**

Taxa	Total No.
Gastropoda: Dicathais orbita	1
Gastropoda: Cominella adspersa	**32**
Gastropoda: Sigapatella tenuis	1
Gastropoda: Ranella australasia	1
Gastropoda: Austrofusus glans	2
Gastropoda: Amalda australis	**5**
Gastropoda: *Zeatrophon mortenseni*	1
Gastropoda: *Struthiolaria papulosa*	4
Bivalvia: *Atrina zelandica*	**3**
Bivalvia: *Pecten novaezealandiae*	**12**

Taxa	Total No.
Bivalvia: *Tawera spissa*	1
Bivalvia: *Dosinia subrosea*	**9**
Bivalvia: *Myadora striata*	**5**
Bivalvia: *Purpurocardia purpurata*	1
Bivalvia: *Ostrea chilensis*	1
Bivalvia: *Gari convexa*	1
Echinodermata: *Fellaster zelandiae*	**38**
Echinodermata: *Amphiura sp.*	**3**
Echinodermata: *Astropecten polyacanthus*	30
Total	**339**

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The taxa with only 1 individual were also excluded before combination of the results with infauna as they would have minimal contribution to sand formation. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 4 Shellfish collected in the intertidal zone along the Pakiri Beach in 1993 (Bioresearches, 1994)

Transect	Station	Species	Number/m²	Average length (mm)
1	70	*Paphies subtriangulata*	4	41.3
2	80	*Paphies subtriangulata*	22	48.1
3	90	*Paphies subtriangulata*	25	51.3
4	100	*Paphies subtriangulata*	25	49.0
5	160	*Paphies subtriangulata*	11	49.8
6	120	*Paphies subtriangulata*	5.3	41.3
7	10	*Nerita melanotragus*	21	22.9
7	20	*Cellana ornata*	43	19.9
7	20	*Leptograpsus variegatus*	18	
7	30	*Cellana radians*	35	32.6
7	30	*Lepsiella scobina*	587	15.3
7	30	*Melagraphia aethiops*	45	16.2
7	30	*Turbo smaragdus*	17	39.4
7	50	*Haustrum haustorium*	4	44.3
7	50	*Thais orbita*	16	43.0
8	120	*Paphies subtriangulata*	11	43.8
9	100	*Paphies subtriangulata*	10	42.4
10	100	*Paphies subtriangulata*	6	46.4
11	100	*Paphies subtriangulata*	16	44.9
13	60	*Paphies subtriangulata*	15	50.5
14	65	*Paphies subtriangulata*	19	44.2
15	50	*Paphies subtriangulata*	13	44.5
16	60	*Paphies subtriangulata*	13	46.7
17	60	*Paphies subtriangulata*	12	45.5
18	150	*Paphies subtriangulata*	5	48.5
19	60	*Paphies subtriangulata*	6	46.1
19	70	*Paphies subtriangulata*	13	51.8
20	90	*Paphies subtriangulata*	5	51.7
		Average *Paphies*	**12**	**46.7**

Note: Transect 7 (grey shaded) was at a rock area at Te Arai Point and was not considered for the 0-5m biota of the biogenic study as the species sampled in 7 are representative of a rock substrate, not of a sand system.

Table A 5 *Infauna taxa found in the 31 grab samples collected within 27 to 32m depth (Bioresearches, 2017).*

Taxa	Total No.
Polychaeta: *Euchone pallida*	46
Polychaeta: Sabellidae	12
Polychaeta: *Hydroides sp.*	1
Polychaeta: *Serpula sp.*	5
Polychaeta: *Phyllochaetopterus*	5
Polychaeta: *Boccardia sp.*	1
Polychaeta: *Paraprionospio*	14
Polychaeta: *Prionospio sp.*	661
Polychaeta: *Spio sp.*	13
Polychaeta: *Spiophanes kroyeri*	34
Polychaeta: *Spiophanes modestus*	1634
Polychaeta: Ampharetidae	109
Polychaeta: Cirratulidae	49
Polychaeta: *Lagis australis*	3
Polychaeta: Terebellidae	91
Polychaeta: Dorvilleidae	6
Polychaeta: Lumbrineridae	15
Polychaeta: *Nothria sp.*	122
Polychaeta: *Onuphis*	4
Polychaeta: Onuphidae	3
Polychaeta: Glyceridae	9
Polychaeta: Goniadidae	61
Polychaeta: Hesionidae	17
Polychaeta: Aglaophamus sp.	11
Polychaeta: Phyllodocidae	87
Polychaeta: Polynoidae	1
Polychaeta: Sigalionidae	64
Polychaeta: *Sphaerosyllis sp.*	39
Polychaeta: Syllidae	63
Polychaeta: *Magelona dakini*	11
Polychaeta: *Barantolla lepte*	9
Polychaeta: *Capitella capitata*	1
Polychaeta: *Notomastus*	8
Polychaeta: *Armandia maculata*	116
Polychaeta: *Leodamas cylindrifer*	2
Polychaeta: *Orbinia papillosa*	6
Polychaeta: Maldanidae	194
Polychaeta: *Aricidea sp.*	8

Taxa	Total No.
Polychaeta: Paraonidae	9
Polychaeta: *Travisia sp.*	21
Hemichordata	7
Phoronida (*Phoronis* sp.)	23
Nemertea	20
Copepoda	12
Amphipoda: Caprellidae	20
Amphipoda: Haustoriidae	96
Amphipoda: Lysianassidae	248
Amphipoda: Oedicerotidae	2
Amphipoda: Phoxocephalidae	506
Amphipoda: Talitridae	2
other amphipods	4526
Cumacea	502
Decapoda: *Pagurus sp.*	337
Decapoda: shrimps	4
Decapoda: crabs other than Ovalipes	21
Isopoda	98
Mysida	19
Podocopida	465
Tanaidacea	43
Ostracoda	660
Polyplacophora: *Ischnochiton maorianus*	18
Gastropoda: *Epitonium sp.*	3
Gastropoda: *Maoricolpus roseus*	30
Gastropoda: *Zeacolpus sp.*	1
Gastropoda: *Philine sp.*	1
Gastropoda: *Relichna aupouria*	2
Gastropoda: *Caecum digitulum*	1
Gastropoda: *Sigapatella tenuis*	**38**
Gastropoda: *Sigapatella sp.*	**2**
Gastropoda: *Tanea sp.*	1
Gastropoda: Rissoidae	4
Gastropoda: *Struthiolaria pap.*	1
Gastropoda: *Tonna sp.*	1
Gastropoda: *Amalda northlandica*	**13**
Gastropoda: *Amalda sp.*	**3**
Gastropoda: *Austrofusus glans*	2

Taxa	Total No.
Gastropoda: *Cominella quoyana*	**2**
Gastropoda: *Cominella virgata*	**9**
Gastropoda: Marginellidae	1
Gastropoda: *Zeatrophon ambiguus*	3
Gastropoda: *Cantharidus sp.*	2
Gastropoda: *Adelphotectonica reevei*	3
Gastropoda Unid. Juv.	9
Bivalvia: *Hunkydora novozelandica*	1
Bivalvia: *Myadora antipodum*	**3**
Bivalvia: *Myadora striata*	**2**
Bivalvia: *Glycymeris modesta*	**1**
Bivalvia: *Glycymeris sp.*	**2**
Bivalvia: *Pratulum pulchellum*	6
Bivalvia: *Gari lineolata*	**4**
Bivalvia: *Hiatula sp.*	40
Bivalvia: *Pleuromeris zelandica*	5
Bivalvia: *Pleuromeris sp.*	2
Bivalvia: *Limatula maoria*	5
Bivalvia: *Corbula zelandica*	3
Bivalvia: *Nucula nitidula*	**53**
Bivalvia: *Atrina zelandica*	**5**
Bivalvia: *Dosinia subrosea*	**2**
Bivalvia: *Dosinia sp.*	**2**
Bivalvia: *Notocallista multistriata*	1
Bivalvia: *Tawera spissa*	1
Bivalvia: *Tawera sp.*	17
Bivalvia: *Myllita vivens*	1
Bivalvia: *Mysella sp.*	19
Bivalvia: *Scalpomactra scalpellum*	2
Bivalvia: *Diplodonta zelandica*	2
Bivalvia Unid. (juv)	3
Echinodermata: *Echinocardium sp.*	26
Echinodermata: *Amphiura sp.*	8
Epigonichthys hectori	82
TOTAL	11634

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 6 *Epifauna taxa found in the 8 dredge tow samples collected within 27 to 32m depth (Bioresearches, 2017).*

Taxa	Total No.
Ascidian	38
Octopus	1
Decapoda: Paguridae	8
Decapoda: *Ovalipes catharus*	**1**
Polyplacophora	2
Gastropod: Cominella adspersa	**1**

Taxa	Total No.
Gastropoda: Struthiolaria sp.	2
Gastropoda: Monoplex parthenopeus	1
Gastropoda: Maoricolpus roseus	1
Gastropoda: Murexsul espinosus	2
Bivalvia: Pecten novaezelandiae	**73**
Bivalvia: Irus reflexus	1

Taxa	Total No.
Bivalvia: Zemysina striatula	2
Bivalvia: Mesopeplum convexum	1
Echinodermata: Astropecten polycanthus	20
TOTAL	154

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 7 Infauna taxa found in the 20 box dredge samples (3.15mm mesh size) collected within 27 to 32m depth (Bioresearches, 2019).

Taxa	Total No.
Polychaeta: *Euchone* sp.	3
Polychaeta: *Hydroides* sp.	17
Polychaeta: *Paraprionospio pin.*	2
Polychaeta: *Malacoceros*	3
Polychaeta: Terebellida	19
Polychaeta: Ampharetidae	24
Polychaeta: Cirratulidae	8
Polychaeta: *Lagis australis*	2
Polychaeta: Eunicidae	3
Polychaeta: Onuphidae	1
Polychaeta: Goniadidae	1
Polychaeta: Nephtyidae	1
Polychaeta: *Aglaophamus*	1
Polychaeta: Nereididae	1
Polychaeta: Phyllodocidae	3
Polychaeta: Polynoidae	3
Polychaeta: Sigalionidae	14
Polychaeta: Syllidae	5
Polychaeta: *Magelona dakini*	5
Polychaeta: Capitellidae	18
Polychaeta: Cossuridae	4
Polychaeta: Maldanidae	93
Polychaeta: *Travisia olens*	4
other polychaeta	52
Nemertea	7
Cyclopoida	1
Amphipoda: Gammaridea	64
Amphipoda: Phoxocephalidae	13
Amphipoda: Haustoriidae	2
Amphipoda: Liljeborgiidae	9
Cumacea: *Cyclaspis*	2
Decapoda: *Liocarcinus corrugatus*	9
Decapoda: *Ebalia laevis*	7
Decapoda: *Notomithrax minor*	2
Decapoda: Anomura	4
Decapoda: Paguridae	55
Isopods	17
Mysidae	1
Tanaidacea	1
Myodocopida	12
Pycnogonida	1
Echinodermata: *Leptochiton inquinatus*	35
Gastropod: *Antisolarium egenum*	13
Gastropod: *Roseaplagis rufozona*	3
Gastropod: *Solariella tryphenensis*	3
Gastropod: *Maoricolpus roseus*	3
Gastropod: *Striacolpus pagoda*	**28**
Gastropod: *Rissoina fictor*	8
Gastropod: *Pisinna semisulcata*	3
Gastropod: *Sigapatella tenuis*	24
Gastropod: *Seila cincta*	2
Gastropod: *Cominella quoyana*	**37**
Gastropod: *Austrofusus glans*	1
Gastropod: *Xymenella pusilla*	2
Gastropod: *Amalda novaezelandiae*	**3**
Gastropod: *Antimelatoma buchanani*	3
Gastropod: *Cylichna thetidis*	3
other gastropods	3
Bivalvia: *Nucula nitidula*	**55**
Bivalvia: *Glycymeris modesta*	**7**
Bivalvia: *Pleuromeris* sp.	11
Bivalvia: *Purpurocardia purpurata*	8
Bivalvia: Galeommatidae	1
Bivalvia: *Scalpomactra scalpellum*	1
Bivalvia: *Gari stangeri*	**14**
Bivalvia: *Hiatula nitida*	3
Bivalvia: *Zemysina globus*	2
Bivalvia: *Tawera spissa*	2
Bivalvia: *Dosinia maoriana*	**5**
Bivalvia: *Dosinia subrosea*	**1**
Bivalvia: *Corbula zelandica*	17
Bivalvia: *Myadora subrostrata*	**6**
Bivalvia: *Hunkydora novozelandica*	1
other bivalvia	6
Echinodermata: *Amphiura aster*	6
Echinodermata: Ophiuroidea	2
other echinoderms	2
Nematoda	18
Foraminifera	41
Bryozoa	45
Porifera	35
Ascidiacea	4
Epigonichthys hectori	41
TOTAL	**1005**

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 8 List of equations used for weight and growth.

Taxa			Allometric equations			Growth equations		
Taxonomic group	**Family**	**Species**	**Species used for weight estimation**	**Equation length –weight (mm - g)**	**Source**	**Species used for growth estimation**	**Equation age –length (y - mm)**	**Source**
Arthropods	Paguridae	*Pagurus setosus*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Pagurus* sp.	curve in Fig. 5	Mc Lay, 1985
Arthropods	Portunidae	*Ovalipes catharus*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Ovalipes catharus*	from info in text	Fisheries NZ 2018, vol 2, p467
Arthropods	Grapsidae	*Leptograpsus variegatus*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Ovalipes catharus*	from info in text	Fisheries NZ 2018, vol 2, p467
Arthropods		Crabs other than *Ovalipes*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Ovalipes catharus*	from info in text	Fisheries NZ 2018, vol 2, p467
Polyplacophora	Leptochitonidae	*Leptochiton* spp.	*Chiton albolineatus*	$W = 0.0002L^{2.7097}$	Flores-Campana *et al.*, 2012	Estimated from other molluscs		
Gastropods	Trochidae	*Zethalia, Antisolarium, Roseaplagis, Melagraphia*	*Monodonta turbinata*	W = 0.5099(L/2)-0.5392	Boucetta *et al.,* 2010	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Solariellidae	*Solariella tryphenensis*	*Monodonta turbinata*	W = 0.5099(L/2)-0.5392	Boucetta *et al.,* 2010	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Neritidae	*Nerita melanotragus*	*Nerita crepidularia*	curve	Jaiswar & Kulkarni 2002	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Nacellidae	*Cellana* spp.	*Patella nigra*	from info in text	Echem 2017	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Turbinidae	*Turbo, Cookia*	*Turbo bruneus*	$W = 0.00017L^{3.091}$	Saleky *et al.*, 2016	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Buccinidae	*Cominella, Austrofusus*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Muricidae (large)	*Haustrum, Thais*	*Hexaplex nigritus*	$W = 0.000004L^{3.7956}$	Escamilla-Montes *et al.*, 2018	*Concholepas concholepas*	$W = 461.37 (1-e^{-0.55(age)})^3$	Rabi & Maravi, 1997
Gastropods	Muricidae (small)	*Lepsiella, Xymenella, Zeatrophon*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Pseudomelatonidae	*Antimelatoma*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Olividae	*Amalda* spp.	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Struthiolaridae	*Struthiolaria papulosa*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Turritellidae	*Stiracolpus pagoda*	*Turritella communis*	Curve p179	Allmon, 2011	assumption of 1g/y from gastropod data of same size		
Gastropods	Epitoniidae	*Epitonium* spp.	*Turritella communis*	Curve p179	Allmon, 2011	assumption of 1g/y from gastropod data of same size		
Gastropods	Rissoniidae	*Rissoina fictor*	*Turritella communis*	Curve p179	Allmon, 2011	assumption of 1g/y from gastropod data of same size		
Gastropods	Calyptraeidae	*Sigapatella tenuis*	assumption of 0.005g			assumption of 0.10g / y		
Bivalves	Myochamidae	*Myadora* spp.	1/2 of *Dosinia subrosea*	curve p80 /2	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Veneridae	*Dosinia, Tawera*	*Dosinia subrosea*	curve p80	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Ungulinidae	*Zemysina globus*	*Dosinia subrosea*	curve p80	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Corbulidae	*Corbula zelandica*	½ of *Dosinia subrosea*	curve p80 /2	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Nuculidae	*Nucula nitidula*	*Nucula* spp.	from info in text	Allen 1954	*Nucula* spp.	from info in text	Allen 1954

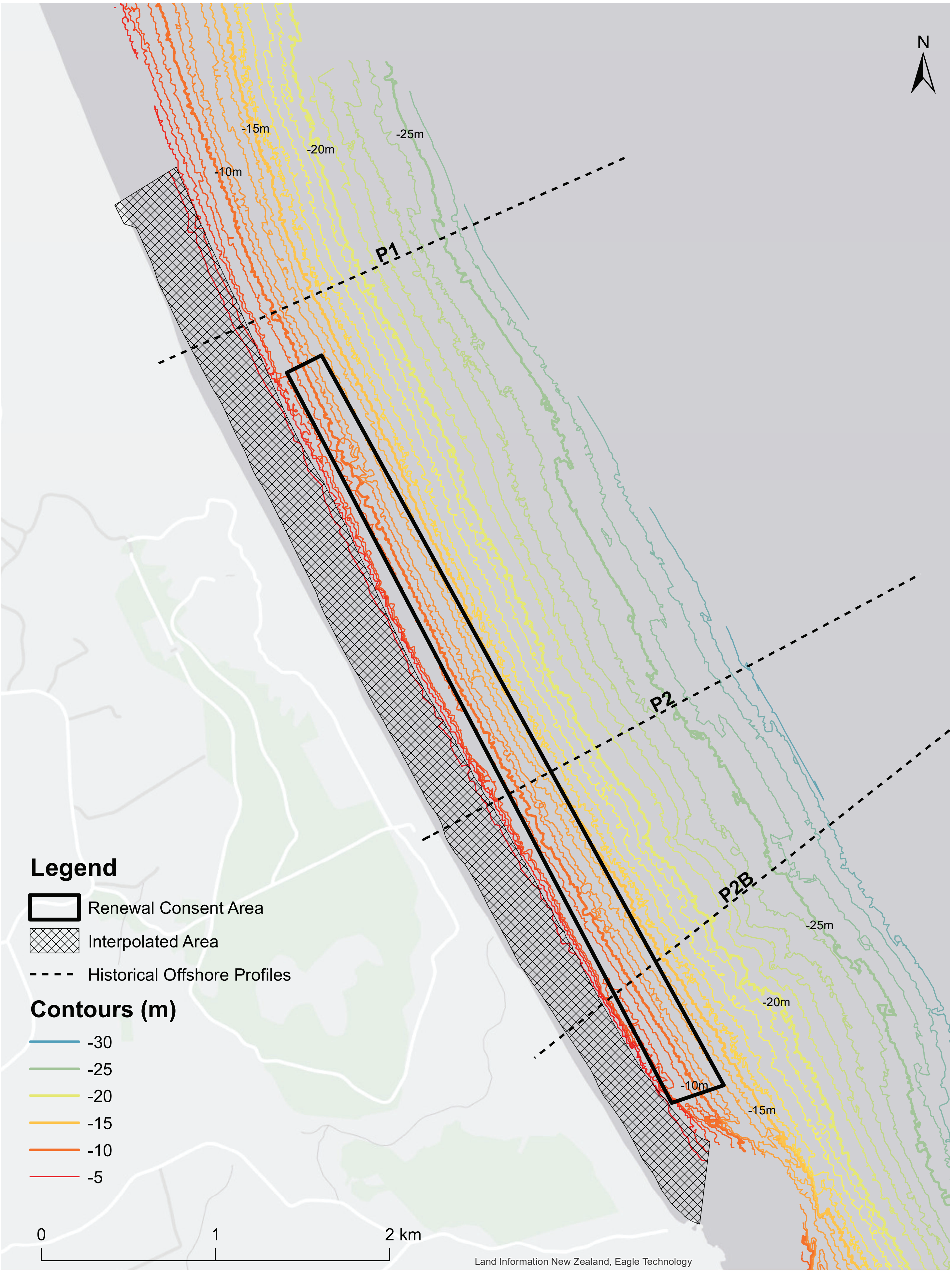
Taxa			Allometric equations			Growth equations		
Taxonomic group	**Family**	**Species**	**Species used for weight estimation**	**Equation length –weight (mm - g)**	**Source**	**Species used for growth estimation**	**Equation age –length (y - mm)**	**Source**
Bivalves	Limidae	*Limatula maoria*	*Nucula* spp.	from info in text	Allen 1954	*Nucula* spp.	from info in text	Allen 1954
Bivalves	Lasaeidae	Lasaeidae	*Nucula* spp.	from info in text	Allen 1954	*Nucula* spp.	from info in text	Allen 1954
Bivalves	Glycymeridae	*Glycymeris modesta*	*Austrovenus stutchburyi*	$W = 0.00014L^{3.29}$	Fisheries NZ 2018, vol 1, p235	*Austrovenus stutchburyi*	$L = 35 (1-e^{-0.26(age)})$	Fisheries NZ 2018, vol 1, p235
Bivalves	Carditidae	*Purpurocardia, Pleuromeris*	*Austrovenus stutchburyi*	$W = 0.00014L^{3.29}$	Fisheries NZ 2018, vol 1, p235	*Austrovenus stutchburyi*	$L = 35 (1-e^{-0.26(age)})$	Fisheries NZ 2018, vol 1, p235
Bivalves	Cardiidae	*Pratulum pulchellum*	*Austrovenus stutchburyi*	$W = 0.00014L^{3.29}$	Fisheries NZ 2018, vol 1, p235	*Austrovenus stutchburyi*	$L = 35 (1-e^{-0.26(age)})$	Fisheries NZ 2018, vol 1, p235
Bivalves	Pinnidae	*Atrina zelandica*	*Pinna bicolor*	W = 3.111Lcm-5.397	Idris *et al.*, 2012	*Pinna bicolor*	$Lcm = 34.66 (1-e^{-0.8(age)})$	Idris *et al.*, 2012
Bivalves	Psammobiidae	*Gari convexa*	*Gari solida* (Jan 1992)	logW=-4.32+2.792log(L)	Urban & Campos, 1994	*Gari solida* (Jan 1992)	$L = 89.6 (1-e^{-0.307(age-0.354)})$	Urban & Campos, 1994
Bivalves	Pectenidae	*Pecten novaezelandiae*	*Pecten novaezelandiae*	$W = 0.00042L^{2.662}$	Fisheries NZ 2014	*Pecten novaezelandiae*	$L = 115.9 (1-e^{-1.2(age)})$	Fisheries NZ 2014
Bivalves	Mytilidae	*Perna canaliculus*	*Perna canaliculus*	From info in text	Fisheries NZ 2018, vol 1, p479	*Perna canaliculus*	From info in text	Fisheries NZ 2018, vol 1, p479
Bivalves	Psammobiidae	*Paphies subtriangulata*	*Paphies subtriangulata*	$W = 0.0002L^{2.927}$	Fisheries NZ 2018, vol 3, p581	*Paphies subtriangulata*	from info in text	Fisheries NZ 2018, vol 3, p581
Echinoderms	Arachnoididae	*Fellaster zelandiae*	*Echinarachnius*	from info in text p56	Lohavanijaya, 1964	*Echinarachnius*	from info in text p56	Lohavanijaya, 1964
Echinoderms	Loveniidae	*Echinocardium* sp.	*Echinocardium cordatum*	log(W)= -3.449 +3.011log(L)	Robinson *et al.*, 2010	*Evechinus chloroticus*	from info in text p657	Fisheries NZ 2018, vol 2, p651
Echinoderms	Echinometridae	*Evechinus chloroticus*	*Evechinus chloroticus*	$W = 0.000627L^{2.88}$	Fisheries NZ 2018, vol 2, p651	*Evechinus chloroticus*	from info in text p657	Fisheries NZ 2018, vol 2, p651
Echinoderms	Amphiuridae	Amphiura sp.	Assumption of ½ Astropecten			Assumption of ½ Astropecten		
Echinoderms	Astropectinidae	*Astropecten polyacanthus*	Echinodermata species	from info in text	Ventura *et al.*, 1995	*Astropecten aranciacus*	$L = 136.75 (1-e^{-0.44(age-0.017)})$	Baeta *et al.*, 2016
Cephalochordates	Brachiostomidae	*Epigonichthys hectori*	*Branchiostoma belcheri*	range 0.2 to 0.3g at 30 to 40mm	Henmi & Yamaguchi, 2003	Assumption of 0.2g / y		

Note1: Many species have no specific information, and equations from species of the same taxonomic group were used. Calculated growth and weight have numerous biases from these approximations. All results were checked for unreasonable weight ranges and readjusted with other equations if not appropriate.

Note 2: *Amalda* spp includes three species (A. *australis*, A. *depressa* and A. *novaezelandiae*). *Cominella* spp includes two species (C. *adspersa* and C. *quoyana*). *Myadora* spp includes two species (M. *boltoni* and M. *striata*). *Dosinia* spp includes 2 species (D. *subrosea* and D. *maoriana*).

Note 3: The percentage shell weight to green weight was estimated for the thick bivalves (*Glycymeris*, *Gari*, and *Dosinia*) from *Dosinia* values (65%) in Aljadani (2013). The percentage shell weight for other taxonomic groups are estimates based on the "shell" volume, thickness and form. 20% was used for the arthropods and Cephalochordates, considering their thin chitin and volume of notochord. 80% was used for the gastropods considering their general thick shell, except for *Sigapatella*. 50% was used for the thin bivalves such as *Myadora*, *Nucula*, and for *Sigapatella*. 90% was used for echinoderms considering the volume of their test relative to their whole body.

Appendix G. 2019 Bathymetry and Offshore Profiles



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PROJECT Pakiri Sand Extraction Consent		
SCALE 1:20,000 @ A3	PROJECT CODE IZ111900	
PROJECT MANAGER IW	DRAWN KM	
PROJECT DIRECTOR DT	DATE 12/18/2019	

2019 Bathymetry and Offshore Profiles
Northern Extraction Area

JACOBS
SPATIAL
Level 2, Wynn Williams building,
47 Hereford Street,
Christchurch Central 8013,
New Zealand
T +64 3 940 4900
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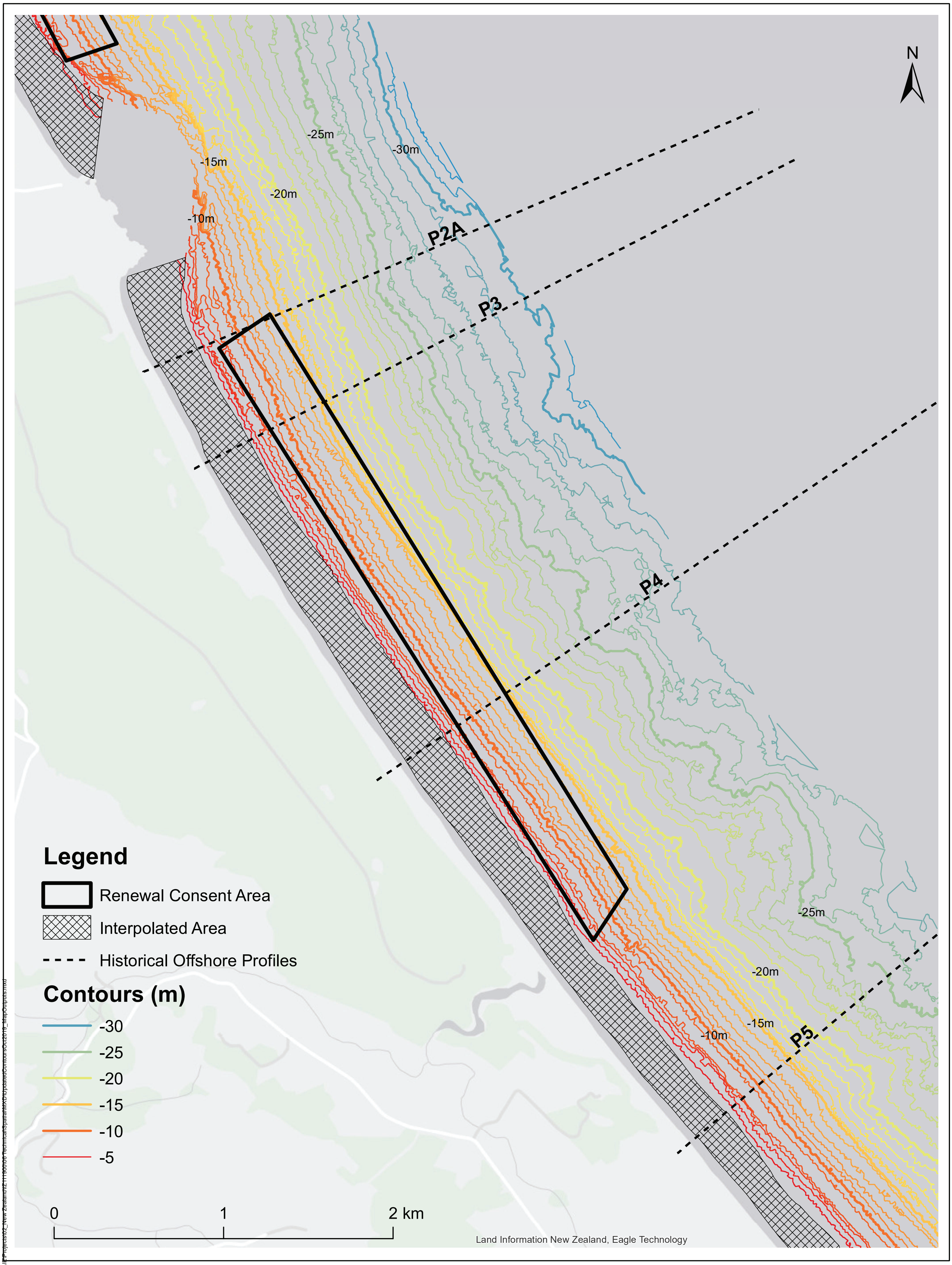

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PROJECT Pakiri Sand Extraction Consent	
SCALE 1:20,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

2019 Bathymetry and Offshore Profiles Southern Extraction Area

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Level 2, Wynn Williams building,
47 Hereford Street,
Christchurch Central 8013,
New Zealand
T +64 3 940 4900
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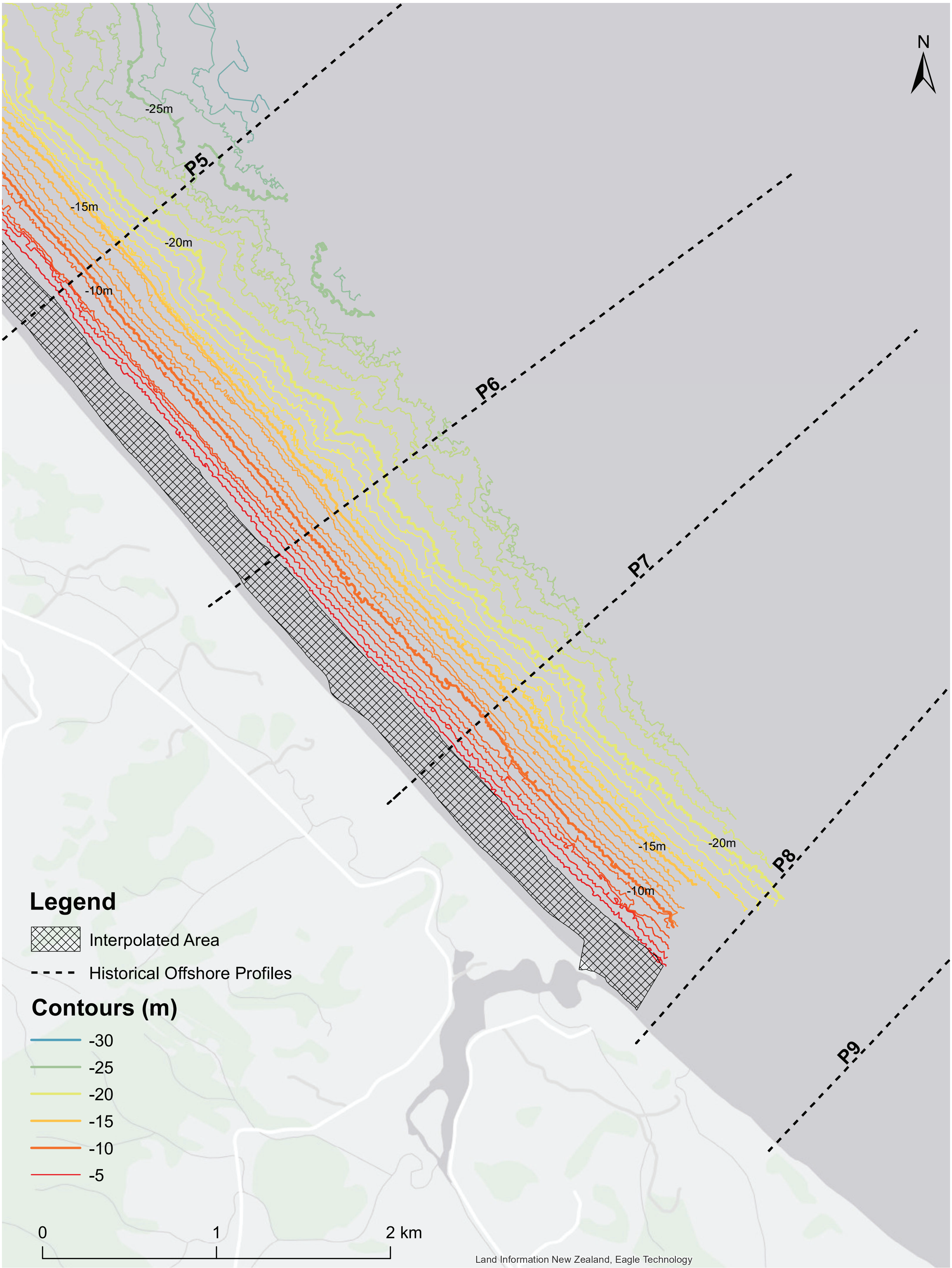

CLIENT McCallum Brothers Limited	
PROJECT Pakiri Sand Extraction Consent	
SCALE 1:20,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

2019 Bathymetry and Offshore Profiles Control Area

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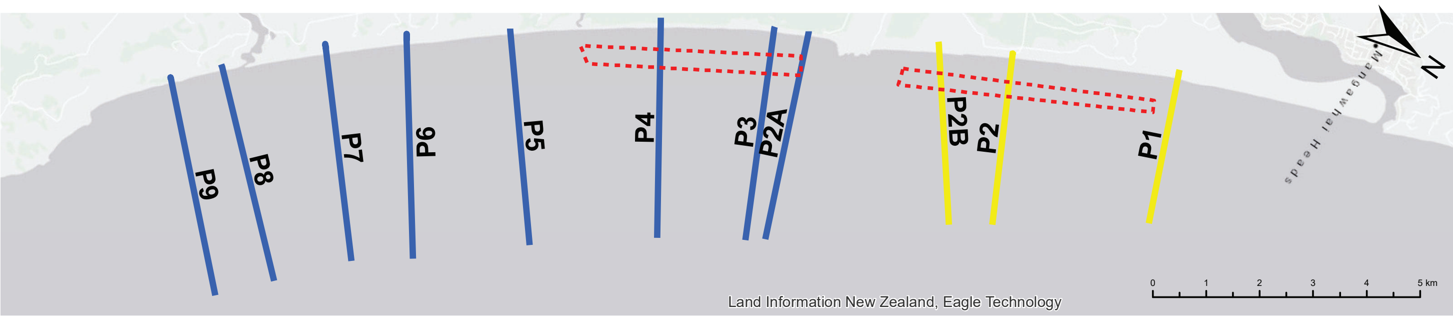

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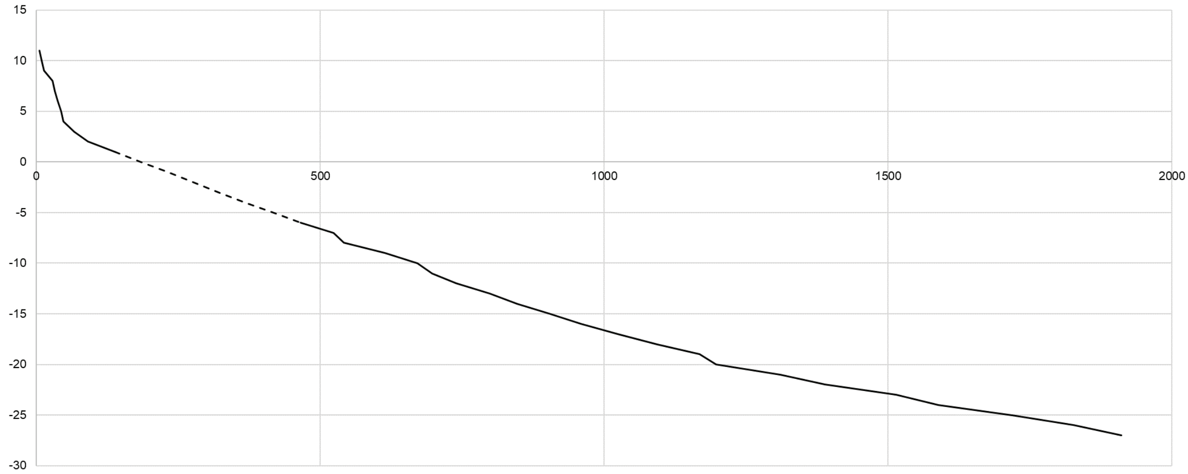

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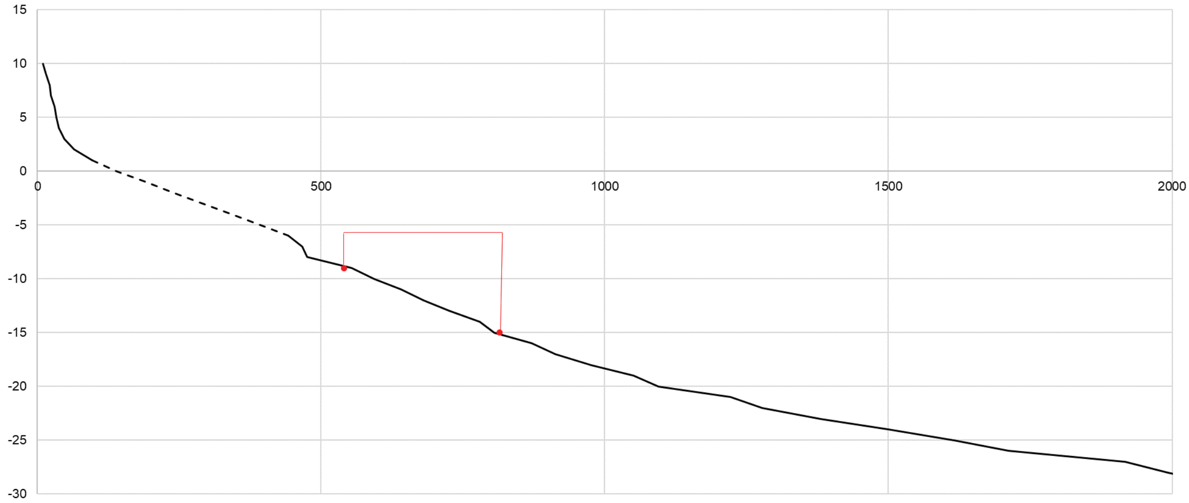

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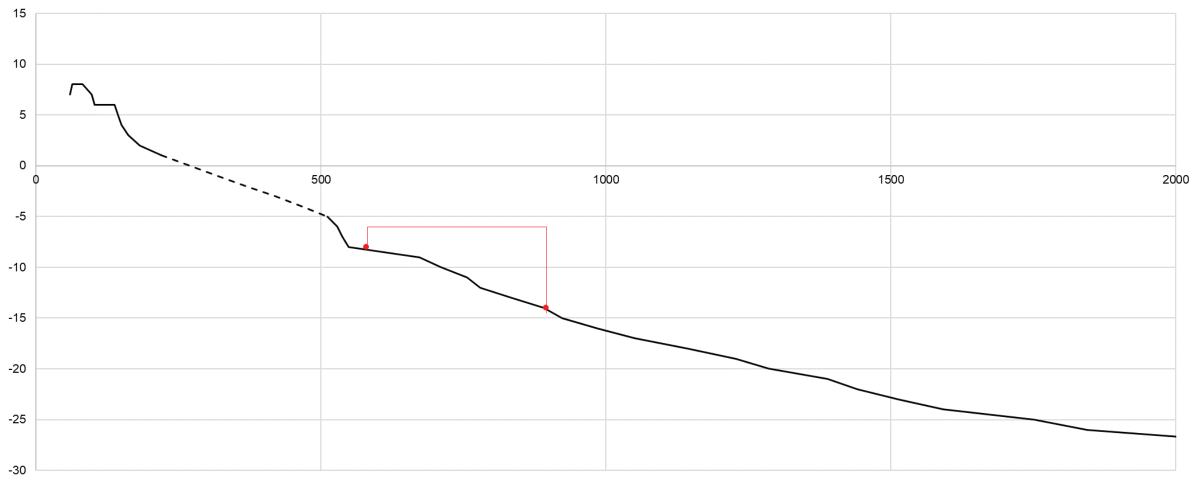

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SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 1/7/2020

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles
- Interpolated Survey Data

2019 Bathymetry and Offshore Profiles

Profiles 1-2b

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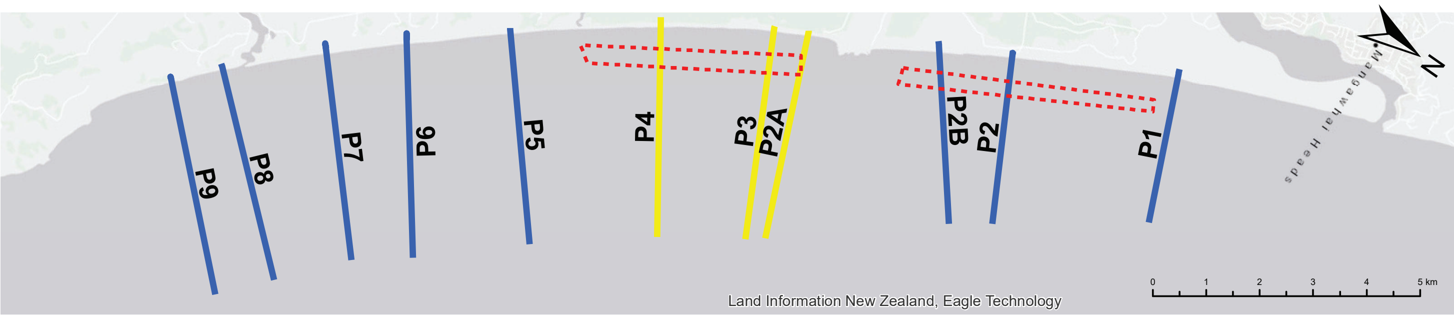

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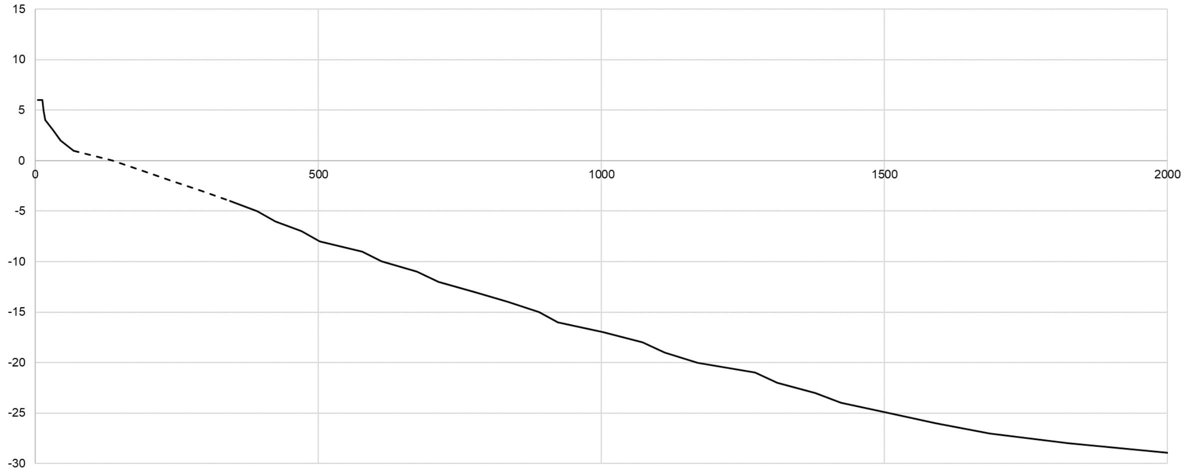

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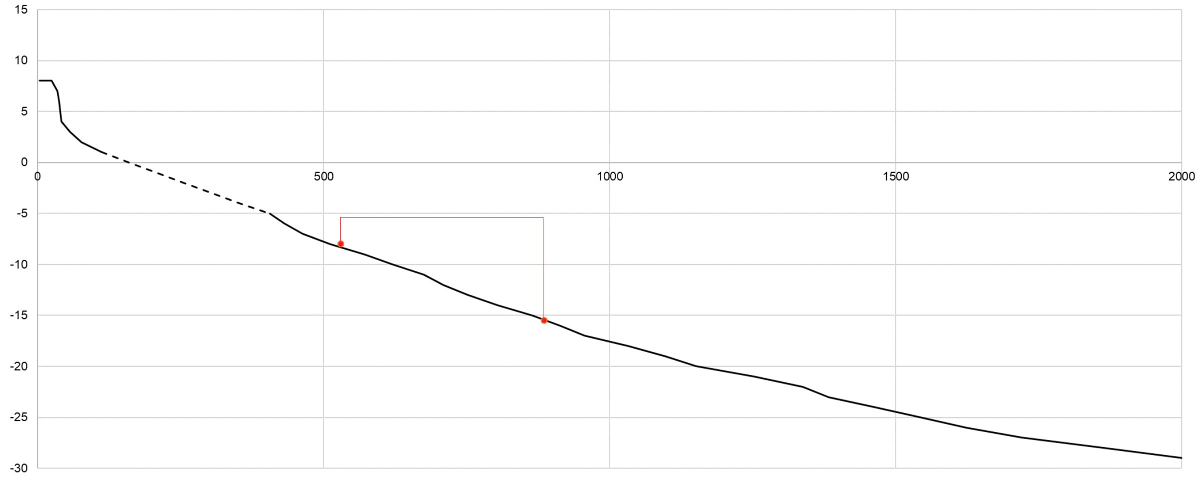

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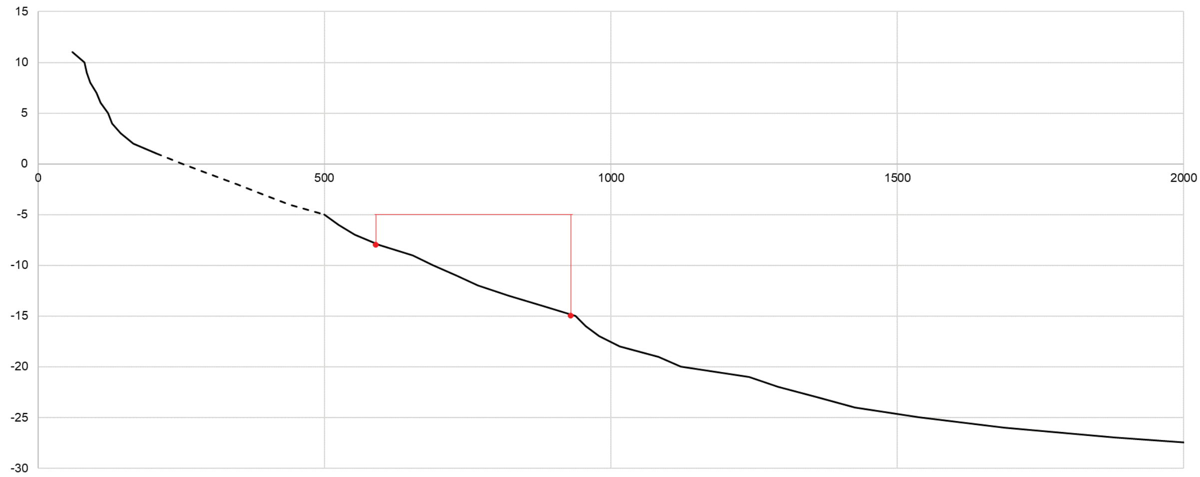

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CLIENT Client	
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SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles
- Interpolated Survey Data

2019 Bathymetry and Offshore Profiles

Profiles 2a-4

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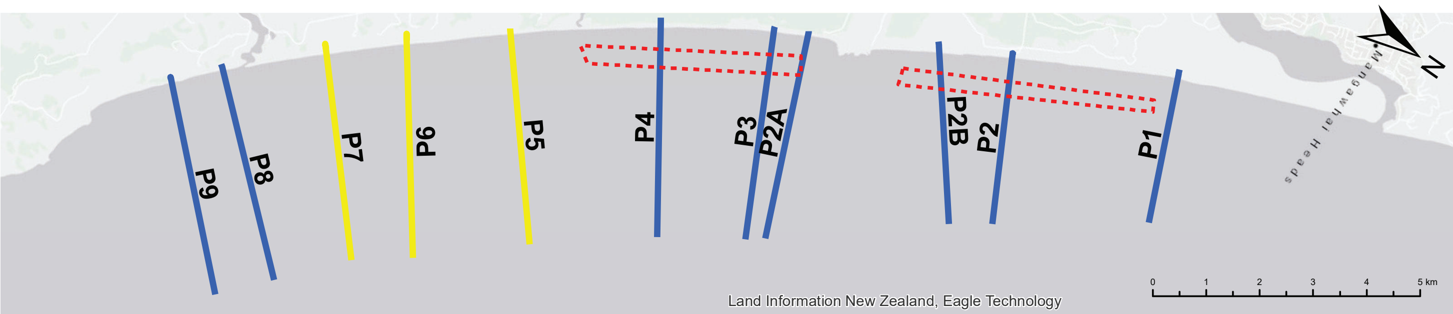

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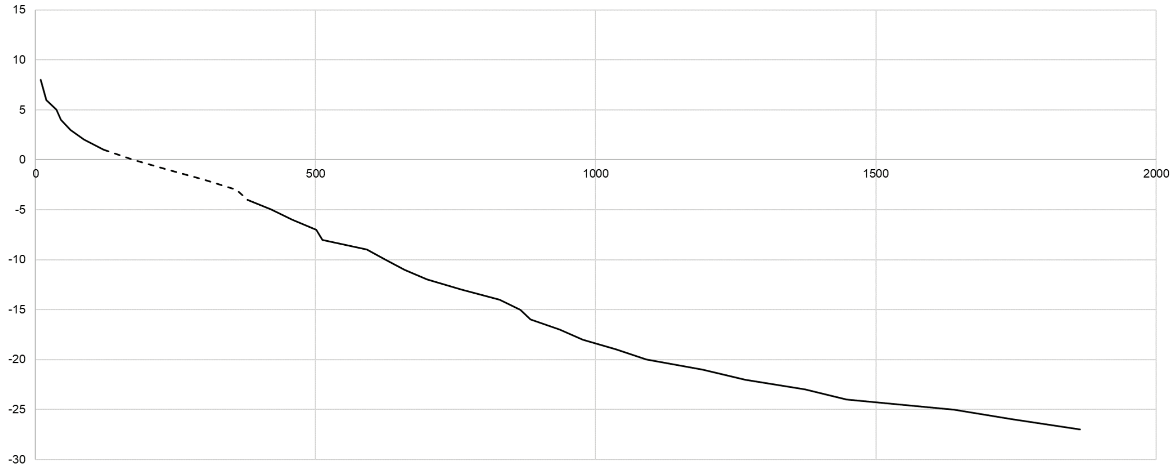
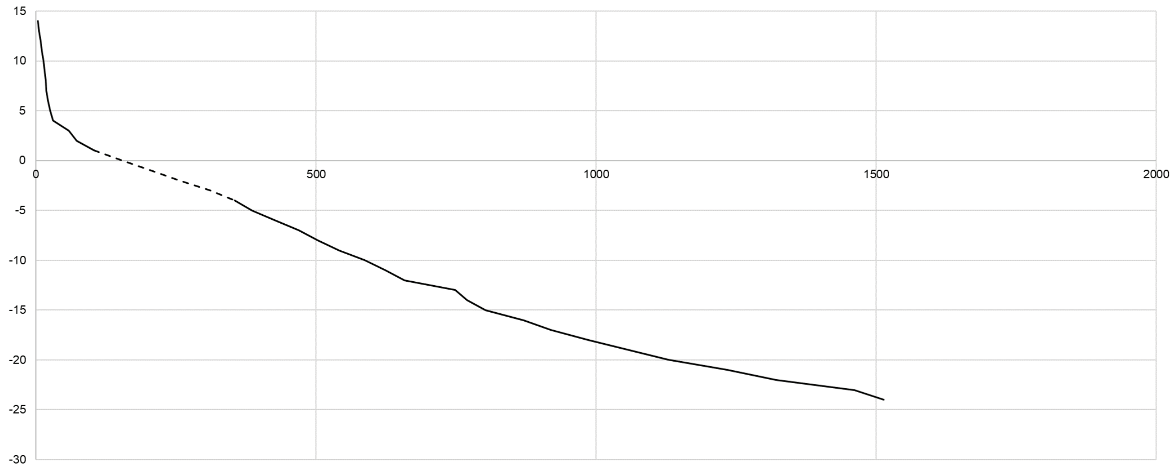
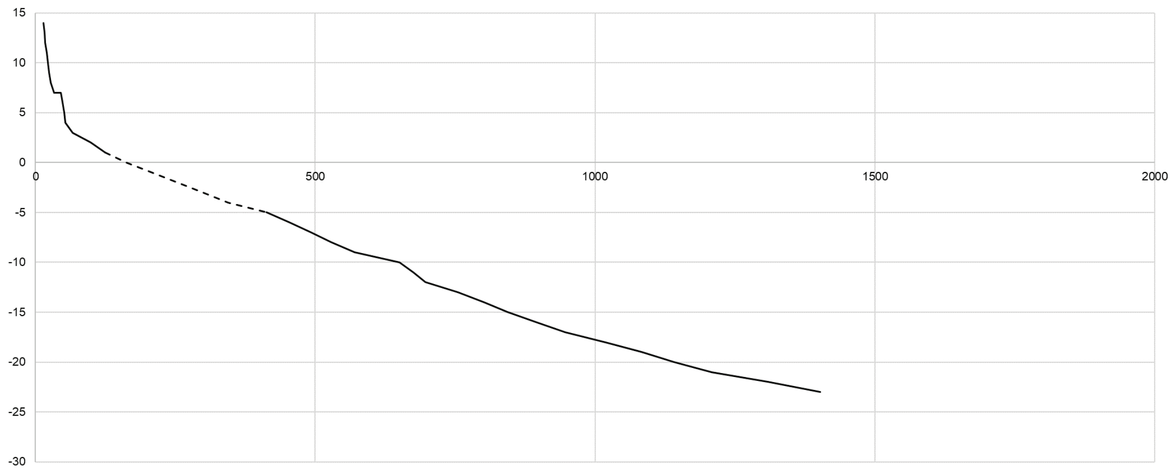


P6



P7



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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

Legend
- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles
- Interpolated Survey Data

2019 Bathymetry and Offshore Profiles

Profiles 5-7

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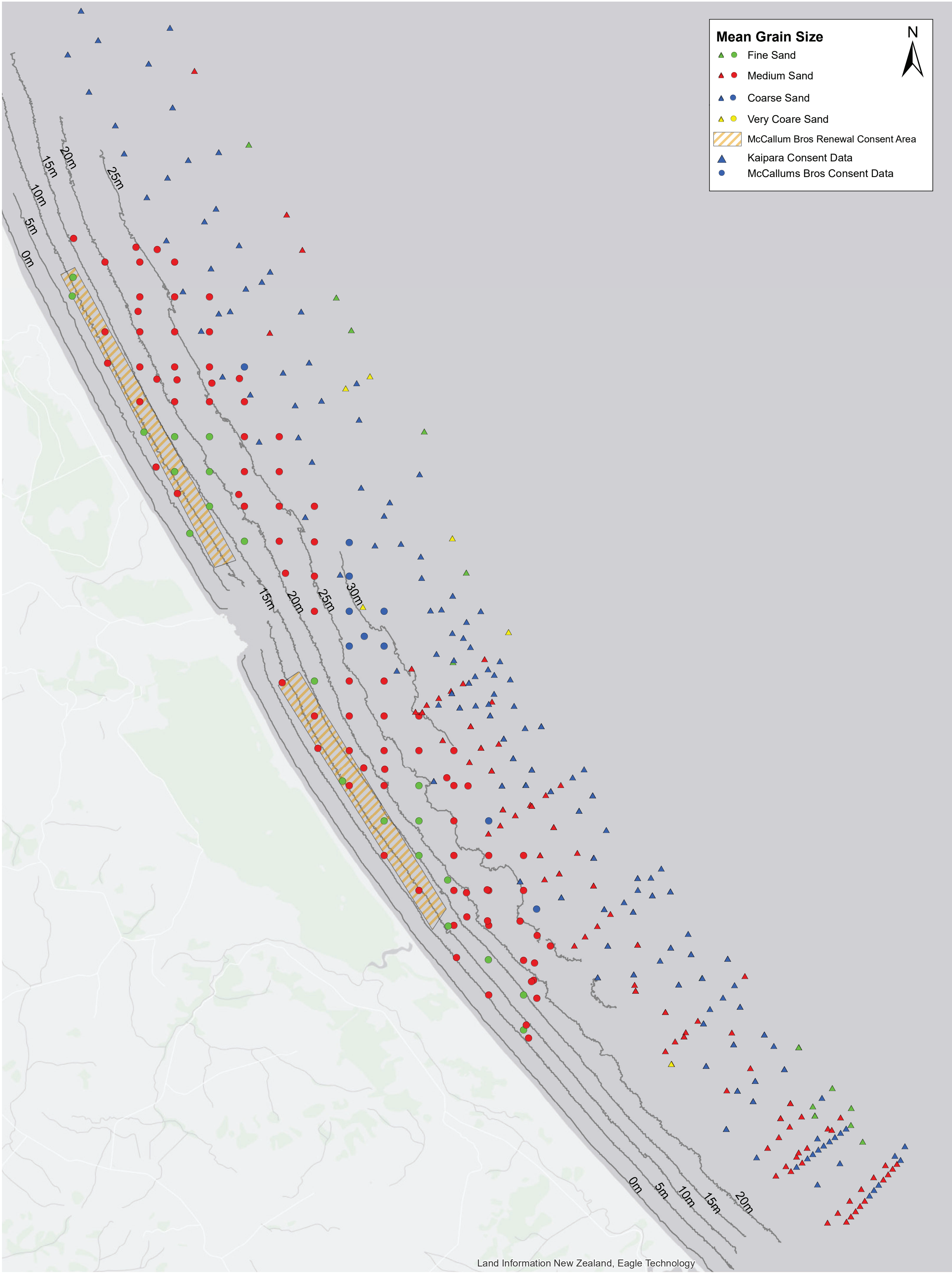
Appendix H. Sediment Sampling Size Distribution Results



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PROJECT Pakiri Sand Extraction Consent Renewal			
SCALE 1:50,000 @ A3	PROJECT CODE IZ111900		
PROJECT MANAGER IW	DRAWN KM		
PROJECT DIRECTOR DT	DATE 1/23/2020		

Mean Grain Size
McCallum Bros and Kaipara Ltd Consent Data

0 1 2 3 4 5 km

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Box-Dredge Samples 0-15m Depth

Sample ID/Trip Number	Sample_ID	Tested By	Depth Below MSL	4.75	Sieve Grading (% Passing) 2.36	1.18	0.6	0.425	0.3	0.15	0.075	5th percentile (mm)	16th percentile (mm)	50th Percentile (mm)	84th Percentile (mm)	95th Percentile (mm)	Graphic mean (mm)	Mean Grain Size Classification	Sorting	Sorting classification	Fineness Modulus
BD27	27	MBL	-4.5	100	100	99	98	95	88	15	0	0.08	0.15	0.22	0.29	0.30	0.22	FineSand	0.07	Very Well Sorted	1.00
BD82	82	MBL	-5	100	100	97	88	80	60	6	0	0.08	0.18	0.27	0.51	0.56	0.32	MediumSand	0.16	Very Well Sorted	1.51
BD75	75	MBL	-6	100	100	98	93	86	72	13	0	0.08	0.16	0.24	0.41	0.50	0.27	MediumSand	0.13	Very Well Sorted	1.26
BD100	100	MBL	-6	100	100	98	93	86	70	10	0	0.08	0.17	0.25	0.41	0.50	0.27	MediumSand	0.12	Very Well Sorted	1.27
BD19	19	MBL	-7	100	100	95	85	69	49	7	0	0.08	0.18	0.31	0.59	0.60	0.36	MediumSand	0.18	Very Well Sorted	1.64
BD62	62	MBL	-7	100	100	100	99	95	76	8	0	0.08	0.17	0.24	0.35	0.30	0.25	MediumSand	0.08	Very Well Sorted	1.15
BD1	1	MBL	-8	100	100	100	99	97	90	13	0	0.08	0.09	-0.71	0.02	0.26	-0.20	VeryFineSand	0.01	Very Well Sorted	0.98
BD39	39	MBL	-8	100	100	100	99	96	71	4	0	0.08	0.18	0.25	0.37	0.29	0.26	MediumSand	0.08	Very Well Sorted	1.23
BD88	88	MBL	-8	100	100	98	97	95	85	14	0	0.08	0.15	0.23	0.30	0.30	0.23	FineSand	0.07	Very Well Sorted	1.07
BD46	46	MBL	-8.5	100	100	98	93	86	63	8	0	0.08	0.17	0.26	0.41	0.50	0.28	MediumSand	0.12	Very Well Sorted	1.37
BD114	114	MBL	-8.5	100	100	98	95	90	73	14	0	0.08	0.16	0.24	0.38	0.43	0.26	MediumSand	0.11	Very Well Sorted	1.20
BD5	5	MBL	-9	100	100	92	71	61	51	8	0	0.08	0.18	0.30	0.96	0.82	0.48	MediumSand	0.31	Very Well Sorted	1.99
BD11	11	MBL	-9	100	100	98	97	93	83	20	0	0.08	0.14	0.22	0.31	0.36	0.22	FineSand	0.09	Very Well Sorted	1.01
BD94	94	MBL	-9	100	100	99	98	94	72	13	0	0.08	0.16	0.24	0.37	0.33	0.26	MediumSand	0.09	Very Well Sorted	1.15
BD68	68	MBL	-9.5	100	100	99	97	90	68	10	0	0.08	0.17	0.25	0.39	0.39	0.27	MediumSand	0.10	Very Well Sorted	1.21
BD111	111	MBL	-10	100	100	98	96	93	81	17	0	0.08	0.15	0.23	0.33	0.38	0.23	FineSand	0.09	Very Well Sorted	1.09
BD54	54	MBL	-10.5	100	100	100	99	97	74	10	0	0.08	0.16	0.24	0.35	0.29	0.25	MediumSand	0.08	Very Well Sorted	1.16
BD3	3	MBL	-11	100	100	100	99	97	87	18	0	0.08	0.14	0.22	0.29	0.27	0.22	FineSand	0.07	Very Well Sorted	0.95
BD18	18	MBL	-11	100	100	99	98	96	86	17	0	0.08	0.15	0.22	0.30	0.29	0.22	FineSand	0.07	Very Well Sorted	0.98
BD105	105	MBL	-11	100	100	99	98	94	84	18	0	0.08	0.14	0.22	0.30	0.33	0.22	FineSand	0.08	Very Well Sorted	1.01
BD4	4	MBL	-12	100	100	96	90	84	66	11	0	0.08	0.16	0.26	0.43	0.57	0.28	MediumSand	0.14	Very Well Sorted	1.40
BD10	10	MBL	-12.5	100	100	100	99	90	43	5	0	0.08	0.19	0.32	0.41	0.37	0.31	MediumSand	0.10	Very Well Sorted	1.44
BD45	45	MBL	-12.5	100	100	97	85	70	49	6	0	0.08	0.18	0.31	0.59	0.57	0.36	MediumSand	0.17	Very Well Sorted	1.65
BD74	74	MBL	-13	100	100	98	92	69	36	4	0	0.09	0.21	0.35	0.54	0.51	0.37	MediumSand	0.15	Very Well Sorted	1.54
BD81	81	MBL	-13.5	100	100	98	96	94	81	19	0	0.08	0.14	0.23	0.33	0.36	0.23	FineSand	0.09	Very Well Sorted	1.07
BD61	61	MBL	-14	100	100	99	98	96	87	18	0	0.08	0.14	0.22	0.29	0.28	0.22	FineSand	0.07	Very Well Sorted	0.98
BD87	87	MBL	-14	100	100	100	99	98	91	11	0	0.08	0.16	0.22	0.29	0.24	0.22	FineSand	0.06	Very Well Sorted	0.98
AVERAGE				100	100	98	94	89	72	12	0	0.08	0.16	0.22	0.39	0.40	0.26	MediumSand	0.11	Very Well Sorted	1.23
STDEV				0	0	2	6	10	15	5	0	0.00	0.02	0.19	0.16	0.14	0.11		0.06		0.26
Max				100	100	100	99	98	91	20	0	0.09	0.21	0.35	0.96	0.82	0.48	MediumSand	0.31	Very Well Sorted	1.99
Min				100	100	92	71	61	36	4	0	0.08	0.09	-0.71	0.02	0.24	-0.20	VeryFineSand	0.01	Very Well Sorted	0.95

	Grain Size	Total	Sorting	Total
Totals	Very Fine Sand	**1**	Very Well Sorted	**27**
	Fine Sand	**10**	Well Sorted	**0**
	Medium Sand	**16**	Moderately Well Sorted	**0**
	Coarse Sand	**0**	Moderately Sorted	**0**
			Poorly Sorted	**0**

Box-Dredge Samples 15-25m Depth

				Sieve Grading (% Passing)																	
Sample ID/Trip Number	**Sample_ID**	**Tested By**	**Depth Below MSL (m)**	**4.75**	**2.36**	**1.18**	**0.6**	**0.425**	**0.3**	**0.15**	**0.075**	**5th Percentile (mm)**	**16th Percentile (mm)**	**50th Percentile (mm)**	**84th Percentile (mm)**	**95th Percentile (mm)**	**Graphic mean (mm)**	**Mean Grain Size classification**	**Sorting**	**Sorting classification**	**Fineness Modulus**
BD26	26	MBL	-15	100	100	99	99	96	88	18	0	0.08	0.14	0.22	0.29	0.28	0.22	FineSand	0.07	Very Well Sorted	0.95
BD67	67	MBL	-15.5	100	100	99	98	97	86	16	0	0.08	0.15	0.22	0.30	0.27	0.22	FineSand	0.07	Very Well Sorted	1.00
BD17	17	MBL	-16	100	100	100	99	97	85	15	0	0.08	0.15	0.23	0.30	0.28	0.23	FineSand	0.07	Very Well Sorted	1.01
BD44	44	MBL	-16	100	100	100	99	98	89	15	0	0.08	0.15	0.22	0.29	0.25	0.22	FineSand	0.06	Very Well Sorted	0.97
BD121	121	MBL	-16	100	100	100	100	92	62	10	0	0.08	0.17	0.27	0.39	0.35	0.27	MediumSand	0.10	Very Well Sorted	1.21
BD9	9	MBL	-17	100	100	100	99	70	16	1	0	0.10	0.30	0.38	0.51	0.41	0.40	MediumSand	0.10	Very Well Sorted	1.56
BD33	33	MBL	-17	100	100	100	99	97	81	10	0	0.08	0.16	0.23	0.32	0.28	0.24	FineSand	0.07	Very Well Sorted	1.08
BD53	53	MBL	-17	100	100	100	97	78	31	2	0	0.09	0.22	0.35	0.48	0.41	0.35	MediumSand	0.11	Very Well Sorted	1.55
BD103	103	MBL	-17	100	100	100	95	74	40	4	0	0.08	0.20	0.34	0.51	0.43	0.35	MediumSand	0.13	Very Well Sorted	1.45
BD93	93	MBL	-17.5	100	100	100	98	87	52	4	0	0.08	0.19	0.29	0.41	0.39	0.30	MediumSand	0.10	Very Well Sorted	1.36
BD109	109	MBL	-17.5	100	100	99	99	93	68	9	0	0.08	0.17	0.25	0.38	0.34	0.27	MediumSand	0.09	Very Well Sorted	1.21
BD73	73	MBL	-18	100	100	100	99	95	75	11	0	0.08	0.16	0.24	0.36	0.30	0.25	MediumSand	0.08	Very Well Sorted	1.12
BD95	95	MBL	-18.5	100	100	99	98	89	49	4	0	0.08	0.19	0.30	0.41	0.38	0.30	MediumSand	0.10	Very Well Sorted	1.42
BD25	25	MBL	-19	100	100	100	99	97	86	20	0	0.08	0.14	0.22	0.30	0.27	0.22	FineSand	0.07	Very Well Sorted	0.94
BD60	60	MBL	-19	100	100	100	98	87	39	3	0	0.08	0.20	0.33	0.42	0.39	0.32	MediumSand	0.10	Very Well Sorted	1.50
BD92	92	MBL	-19	100	100	99	99	93	61	6	0	0.08	0.18	0.27	0.39	0.34	0.28	MediumSand	0.09	Very Well Sorted	1.30
BD106	106	MBL	-19	100	100	99	98	95	81	12	0	0.08	0.16	0.23	0.33	0.30	0.24	FineSand	0.08	Very Well Sorted	1.08
BD117	117	MBL	-19	100	100	100	99	96	71	10	0	0.08	0.16	0.25	0.37	0.29	0.26	MediumSand	0.08	Very Well Sorted	1.17
BD2	2	MBL	-20	100	100	100	99	76	28	3	0	0.09	0.23	0.36	0.49	0.40	0.36	MediumSand	0.11	Very Well Sorted	1.48
BD8	8	MBL	-20	100	100	99	94	45	13	1	0	0.10	0.31	0.44	0.56	0.46	0.44	MediumSand	0.12	Very Well Sorted	1.49
BD104	104	MBL	-20	100	100	100	96	73	30	2	0	0.09	0.23	0.36	0.51	0.42	0.36	MediumSand	0.12	Very Well Sorted	1.55
BD16	16	MBL	-20.5	100	100	100	98	62	17	1	0	0.10	0.29	0.39	0.53	0.41	0.40	MediumSand	0.11	Very Well Sorted	1.51
BD80	80	MBL	-20.5	100	100	100	99	95	70	9	0	0.08	0.17	0.25	0.37	0.30	0.26	MediumSand	0.08	Very Well Sorted	1.19
BD86	86	MBL	-20.5	100	100	100	98	94	76	12	0	0.08	0.16	0.24	0.36	0.33	0.25	MediumSand	0.09	Very Well Sorted	1.13
BD38	38	MBL	-21	100	100	100	100	93	55	5	0	0.08	0.18	0.29	0.40	0.34	0.29	MediumSand	0.09	Very Well Sorted	1.34
BD52	52	MBL	-21	100	100	100	99	95	72	9	0	0.08	0.17	0.25	0.37	0.30	0.26	MediumSand	0.08	Very Well Sorted	1.17
BD66	66	MBL	-21	100	100	100	99	97	85	14	0	0.08	0.15	0.23	0.30	0.28	0.23	FineSand	0.07	Very Well Sorted	1.01
BD101	101	MBL	-21	100	100	98	88	66	42	6	0	0.08	0.19	0.34	0.57	0.55	0.37	MediumSand	0.16	Very Well Sorted	1.58
BD112	112	MBL	-21	100	100	100	91	55	17	1	0	0.10	0.29	0.41	0.57	0.50	0.42	MediumSand	0.13	Very Well Sorted	1.65
BD119	119	MBL	-21	100	100	100	98	58	16	1	0	0.10	0.30	0.40	0.54	0.42	0.41	MediumSand	0.11	Very Well Sorted	1.46
BD32	32	MBL	-21.5	100	100	99	92	60	16	1	0	0.10	0.30	0.40	0.56	0.50	0.42	MediumSand	0.12	Very Well Sorted	1.68
BD108	108	MBL	-21.5	100	100	98	92	58	20	1	0	0.09	0.27	0.40	0.56	0.51	0.41	MediumSand	0.14	Very Well Sorted	1.63
BD7	7	MBL	-22	100	100	99	85	32	10	1	0	0.11	0.33	0.48	0.60	0.55	0.47	MediumSand	0.13	Very Well Sorted	1.66
BD24	24	MBL	-22	100	100	100	100	97	78	11	0	0.08	0.16	0.24	0.34	0.28	0.25	FineSand	0.08	Very Well Sorted	1.10
BD37	37	MBL	-22	100	100	99	96	71	25	1	0	0.09	0.24	0.37	0.52	0.42	0.38	MediumSand	0.12	Very Well Sorted	1.58
BD79	79	MBL	-22	100	100	100	99	92	55	6	0	0.08	0.18	0.28	0.40	0.35	0.29	MediumSand	0.10	Very Well Sorted	1.34
BD91	91	MBL	-22	100	100	100	99	91	46	4	0	0.08	0.19	0.31	0.41	0.36	0.30	MediumSand	0.10	Very Well Sorted	1.45
BD102	102	MBL	-22	100	100	99	88	56	19	1	0	0.09	0.28	0.40	0.58	0.54	0.42	MediumSand	0.14	Very Well Sorted	1.75
BD59	59	MBL	-22.5	100	100	100	99	86	35	2	0	0.09	0.21	0.34	0.42	0.39	0.32	MediumSand	0.10	Very Well Sorted	1.53
BD115	115	MBL	-22.5	100	100	100	95	56	14	1	0	0.10	0.31	0.41	0.55	0.43	0.42	MediumSand	0.11	Very Well Sorted	1.57
BD15	15	MBL	-23	100	100	100	96	54	15	1	0	0.10	0.30	0.41	0.55	0.42	0.42	MediumSand	0.11	Very Well Sorted	1.49
BD43	43	MBL	-23	100	100	100	99	88	39	3	0	0.08	0.20	0.33	0.41	0.38	0.32	MediumSand	0.10	Very Well Sorted	1.48
BD51	51	MBL	-23	100	100	100	99	97	75	11	0	0.08	0.16	0.24	0.35	0.29	0.25	MediumSand	0.08	Very Well Sorted	1.13
BD72	72	MBL	-23	100	100	100	98	80	38	3	0	0.08	0.21	0.34	0.46	0.40	0.34	MediumSand	0.11	Very Well Sorted	1.46
BD6	6	MBL	-24	100	100	99	92	44	12	1	0	0.11	0.32	0.45	0.57	0.50	0.44	MediumSand	0.12	Very Well Sorted	1.56
BD31	31	MBL	-24	100	100	99	95	64	22	1	0	0.09	0.26	0.38	0.54	0.43	0.39	MediumSand	0.12	Very Well Sorted	1.56
BD36	36	MBL	-24	100	100	99	95	68	22	2	0	0.09	0.26	0.38	0.53	0.43	0.39	MediumSand	0.12	Very Well Sorted	1.59
BD14	14	MBL	-24.5	100	100	100	96	50	14	1	0	0.10	0.31	0.43	0.55	0.42	0.43	MediumSand	0.11	Very Well Sorted	1.46
BD65	65	MBL	-24.5	100	100	100	99	97	82	15	0	0.08	0.15	0.23	0.32	0.28	0.23	FineSand	0.07	Very Well Sorted	1.03
BD96	96	MBL	-24.5	100	100	99	95	68	25	1	0	0.09	0.24	0.37	0.53	0.43	0.38	MediumSand	0.12	Very Well Sorted	1.57
BD120	120	MBL	-24.5	100	100	99	95	49	15	1	0	0.10	0.30	0.43	0.56	0.43	0.43	MediumSand	0.11	Very Well Sorted	1.47

AVERAGE				100.00	100.00	99.61	96.76	78.39	46.24	5.94	0.00	0.09	0.22	0.32	0.44	0.38	0.33	Medium Sand	0.10	Very Well Sorted	1.36
STDEV				0.00	0.00	0.57	3.37	18.53	27.10	5.50	0.00	0.01	0.06	0.08	0.10	0.08	0.08		0.02		0.23
Max				100.00	100.00	100.00	100.00	98.00	89.00	20.00	0.00	0.11	0.33	0.48	0.60	0.55	0.47	Medium Sand	0.16	Very Well Sorted	1.75
Min				100.00	100.00	98.00	85.00	32.00	10.00	1.00	0.00	0.08	0.14	0.22	0.29	0.25	0.22	Fine Sand	0.06	Very Well Sorted	0.94

	Grain Size	**Total**	**Sorting**	**Total**
Totals	Very Fine Sand	**0**	Very Well Sorted	**49**
	Fine Sand	**11**	Well Sorted	**0**
	Medium Sand	**38**	Moderately Well Sorted	**0**
	Coarse Sand	**0**	Moderately Sorted	**0**
			Poorly Sorted	**0**

Box-Dredge Samples deeper than -25m

Sample ID/Trip Number	Sample_ID	Tested By	Depth Below MSL	Sieve Grading (% Passing) 4.75	2.36	1.18	0.6	0.425	0.3	0.15	0.075	5th percentile (mm)	16th percentile (mm)	50th Percentile (mm)	84th Percentile (mm)	95th Percentile (mm)	Graphic mean (mm)	Mean Grain Size classification	Sorting	Sorting classification	Fineness Modulus
BD23	23	MBL	-25	100	100	100	94	51	14	1	0	0.10	0.31	0.42	0.56	0.45	0.43	MediumSand	0.12	Very Well Sorted	1.54
BD42	42	MBL	-25	100	100	100	97	61	16	1	0	0.10	0.30	0.39	0.54	0.42	0.41	MediumSand	0.11	Very Well Sorted	1.55
BD71	71	MBL	-25	100	100	100	97	78	37	2	0	0.09	0.21	0.34	0.48	0.41	0.34	MediumSand	0.12	Very Well Sorted	1.49
BD85	85	MBL	-25	100	100	99	98	91	61	7	0	0.08	0.18	0.27	0.40	0.37	0.28	MediumSand	0.10	Very Well Sorted	1.32
BD13	13	MBL	-25.5	100	100	99	92	43	12	1	0	0.11	0.32	0.45	0.57	0.50	0.45	MediumSand	0.12	Very Well Sorted	1.54
BD30	30	MBL	-25.5	100	100	98	85	42	10	1	0	0.11	0.32	0.46	0.60	0.56	0.46	MediumSand	0.14	Very Well Sorted	1.78
BD78	78	MBL	-25.5	100	100	100	99	90	52	6	0	0.08	0.18	0.29	0.41	0.37	0.29	MediumSand	0.10	Very Well Sorted	1.35
BD84	84	MBL	-25.5	100	100	99	90	66	21	1	0	0.09	0.26	0.38	0.56	0.52	0.40	MediumSand	0.14	Very Well Sorted	1.73
BD90	90	MBL	-25.5	100	100	99	94	73	29	2	0	0.09	0.23	0.36	0.52	0.46	0.37	MediumSand	0.13	Very Well Sorted	1.62
BD22	22	MBL	-26	100	100	99	89	42	11	1	0	0.11	0.32	0.45	0.58	0.53	0.45	MediumSand	0.13	Very Well Sorted	1.64
BD41	41	MBL	-26	100	100	100	96	55	17	1	0	0.10	0.29	0.41	0.55	0.42	0.42	MediumSand	0.11	Very Well Sorted	1.51
BD50	50	MBL	-26	100	99	78	45	23	6	1	0	0.14	0.37	0.64	1.52	1.07	0.84	CoarseSand	0.43	Well Sorted	3.05
BD116	116	MBL	-26	100	100	100	99	68	18	1	0	0.10	0.28	0.38	0.52	0.41	0.39	MediumSand	0.11	Very Well Sorted	1.53
BD89	89	MBL	-26.5	100	99	81	55	32	11	1	0	0.11	0.33	0.56	1.38	1.05	0.76	CoarseSand	0.40	Well Sorted	2.74
BD35	35	MBL	-27	100	100	99	92	47	12	1	0	0.11	0.31	0.44	0.57	0.50	0.44	MediumSand	0.12	Very Well Sorted	1.58
BD64	64	MBL	-27	100	100	100	97	74	26	2	0	0.09	0.24	0.36	0.50	0.41	0.37	MediumSand	0.12	Very Well Sorted	1.55
BD70	70	MBL	-27	100	100	95	84	55	22	2	0	0.09	0.26	0.41	0.60	0.60	0.42	MediumSand	0.16	Very Well Sorted	1.85
BD107	107	MBL	-27	100	100	99	87	58	21	1	0	0.09	0.26	0.40	0.58	0.54	0.41	MediumSand	0.15	Very Well Sorted	1.74
BD58	58	MBL	-27.5	100	100	99	92	65	21	1	0	0.09	0.26	0.38	0.55	0.50	0.40	MediumSand	0.13	Very Well Sorted	1.66
BD21	21	MBL	-28	100	100	98	86	42	12	1	0	0.11	0.32	0.46	0.59	0.56	0.46	MediumSand	0.14	Very Well Sorted	1.72
BD29	29	MBL	-28	100	100	97	82	34	12	2	0	0.11	0.32	0.48	0.68	0.58	0.49	MediumSand	0.16	Very Well Sorted	1.77
BD57	57	MBL	-28	100	100	99	96	69	21	2	0	0.09	0.26	0.38	0.52	0.42	0.39	MediumSand	0.12	Very Well Sorted	1.60
BD76	76	MBL	-28	100	100	94	83	51	19	1	0	0.09	0.28	0.42	0.65	0.70	0.45	MediumSand	0.19	Very Well Sorted	1.89
BD77	77	MBL	-28	100	100	95	77	51	19	2	0	0.09	0.27	0.42	0.83	0.60	0.51	CoarseSand	0.21	Very Well Sorted	2.03
BD49	49	MBL	-28.5	100	100	87	65	38	11	1	0	0.11	0.32	0.50	1.10	0.96	0.64	CoarseSand	0.32	Very Well Sorted	2.43
BD110	110	MBL	-28.5	100	100	87	59	25	7	1	0	0.13	0.36	0.55	1.12	0.96	0.68	CoarseSand	0.31	Very Well Sorted	2.53
BD113	113	MBL	-29	100	100	98	85	39	13	2	0	0.10	0.31	0.47	0.60	0.56	0.46	MediumSand	0.14	Very Well Sorted	1.72
BD56	56	MBL	-29.5	100	99	80	62	32	10	1	0	0.11	0.33	0.53	1.43	1.06	0.76	CoarseSand	0.42	Well Sorted	2.57
BD63	63	MBL	-30	100	100	99	95	64	19	2	0	0.09	0.27	0.39	0.54	0.43	0.40	MediumSand	0.12	Very Well Sorted	1.59
BD48	48	MBL	-31	100	99	85	60	31	8	0	0	0.12	0.34	0.54	1.16	1.01	0.68	CoarseSand	0.34	Very Well Sorted	2.58
BD69	69	MBL	>-29	100	100	96	87	54	21	2	0	0.09	0.26	0.41	0.58	0.58	0.42	MediumSand	0.15	Very Well Sorted	1.75
BD47	47	MBL	> -32	100	100	91	71	37	14	1	0	0.10	0.31	0.49	0.98	0.86	0.59	CoarseSand	0.28	Very Well Sorted	2.19
BD55	55	MBL	> -32	100	99	86	69	36	12	1	0	0.11	0.32	0.50	1.11	1.00	0.64	CoarseSand	0.33	Very Well Sorted	2.31
BD40	40	MBL	> -30	100	100	98	86	45	15	2	0	0.10	0.30	0.45	0.59	0.56	0.45	MediumSand	0.14	Very Well Sorted	1.71
BD28	28	MBL	> -29	100	100	94	73	24	7	1	0	0.13	0.37	0.52	0.90	0.70	0.60	CoarseSand	0.22	Very Well Sorted	2.04
BD34	34	MBL	> -29	100	100	98	84	39	12	1	0	0.11	0.32	0.47	0.60	0.56	0.46	MediumSand	0.14	Very Well Sorted	1.75
BD20	20	MBL	> -28	100	100	99	88	46	13	1	0	0.10	0.31	0.44	0.58	0.54	0.45	MediumSand	0.13	Very Well Sorted	1.69
BD83	83	MBL	> -28	100	100	99	94	78	39	3	0	0.08	0.20	0.34	0.49	0.46	0.34	MediumSand	0.13	Very Well Sorted	1.54
BD12	12	MBL	> -27	100	100	99	90	44	14	1	0	0.10	0.31	0.45	0.58	0.52	0.44	MediumSand	0.13	Very Well Sorted	1.60
BD118	118	MBL	> -27	100	100	99	87	40	10	1	0	0.11	0.33	0.46	0.59	0.54	0.46	MediumSand	0.13	Very Well Sorted	1.69

Summary Statistics for depths -25 to -30m

AVERAGE				100.00	99.92	96.17	85.42	52.33	18.78	1.64	0.00	0.10	0.29	0.43	0.68	0.58	0.46	MediumSand	0.17	Very Well Sorted	1.80
STDEV				0.00	0.28	5.93	13.24	17.81	11.98	1.31	0.00	0.01	0.05	0.07	0.28	0.20	0.13		0.09		0.39
Max				100.00	100.00	100.00	99.00	91.00	61.00	7.00	0.00	0.14	0.37	0.64	1.52	1.07	0.84	CoarseSand	0.43	Well Sorted	3.05
Min				100.00	99.00	78.00	45.00	23.00	6.00	1.00	0.00	0.08	0.18	0.27	0.40	0.37	0.28	MediumSand	0.10	Very Well Sorted	1.32

Total	Grain Size	Total	Sorting	Total
	Very Fine	**0**	Very Well Sorted	**37**
	Fine	**0**	Well Sorted	**3**
	Medium Sand	**30**	Moderately Well Sorted	**0**
	Coarse Sand	**10**	Moderately Sorted	**0**
			Poorly Sorted	**0**

Appendix I. Storm Events from Northport Wave Buoys at Marsden Point Jan 2007 to March 2019

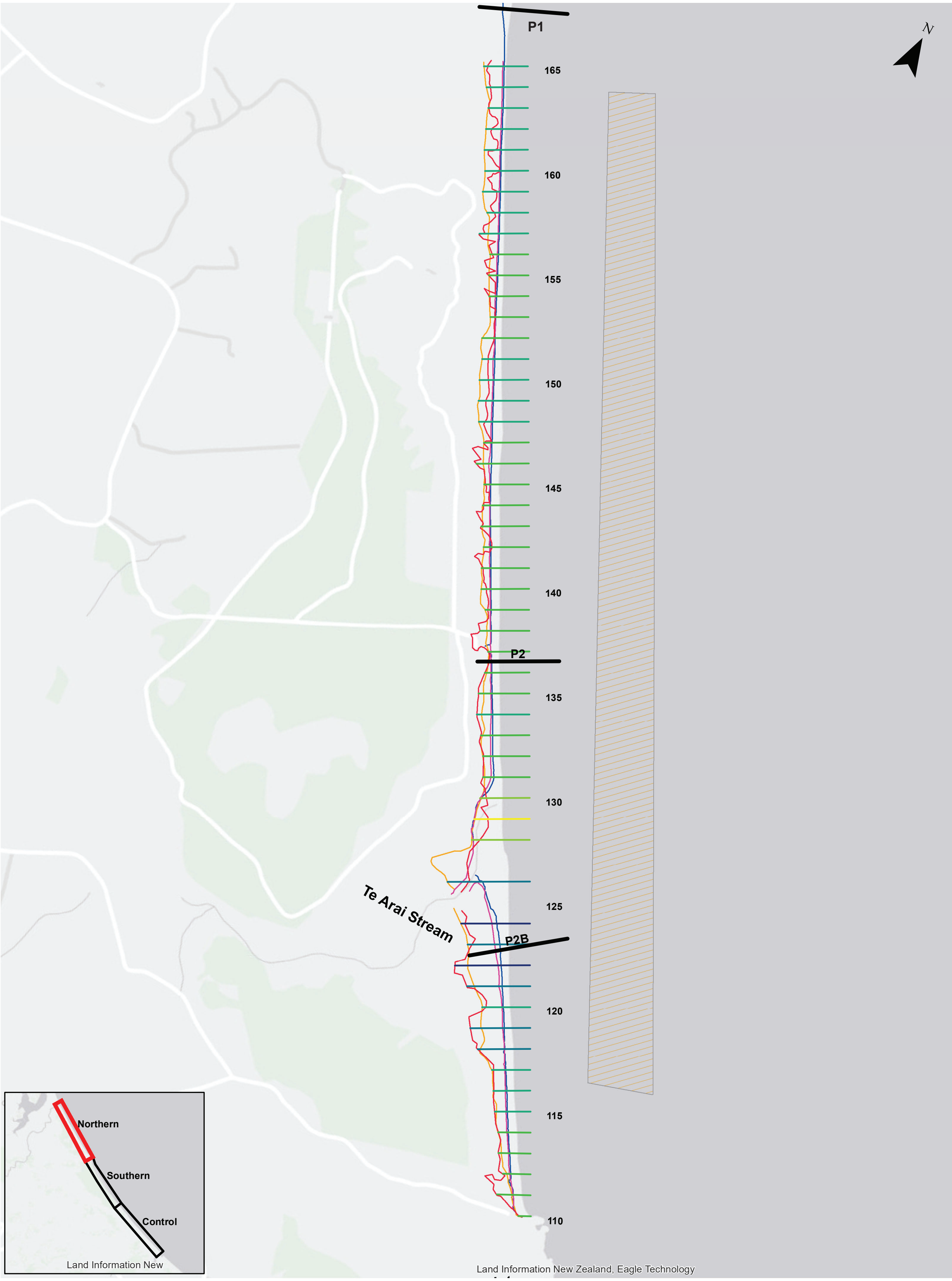
Storm Events from Northport Wave Buoys at Marsden Point Jan 2007 to March 2019

Storm Event Defined as when Hs exceeded the 1 percentile wave height (e.g. Hs>2.29 m) for longer than 3 consecutive hours.

Date	Duration (Hrs)	Max Hs (m)	Tm (sec)	Dir Magnetic	Dir true (deg)	
6/2/2007-9/2/2007	14	2.93	7.4	81.5	100.5	E
10/07/2007	15	5.59	11	65.6	84.6	E
16/07/2007	7	2.92	7.8	72.1	91.1	E
16/8/2007 - 17/8/2007	31	4.26	9.6	61.2	80.2	E
9/09/2007	8	3.52	7.9	72.1	91.1	E
20/09/2007	15	3.21	7.5	69.4	88.4	E
7/12/2007	13	3.59	7.5	71.5	90.5	E
19/1/2008-20/1/2008	23	3.21	8.1	71.9	90.9	E
22/2/2008-24/2/2008	19	3.71	9.5	63.5	82.5	E
4/03/2008	7	3.01	7.1	80.9	99.9	E
18/06/2008	7	3.1	8.3	72.8	91.8	E
26/07/2008	9	5.41	9.5	69.7	88.7	E
28/02/2009	6	3.24	8	64.5	83.5	E
5/3/2009-6/3/2009	19	3.41	8.6	56.7	75.7	ENE
11/7/2009-12/7/2009	35	6.17	10.3	68.8	87.8	E
11/5/2010-12/5/2010	11	3.42	8.8	58.5	77.5	ENE
21/05/2010	4	3.08	7.4	77.5	96.5	E
29/4/2011-2/5/2011	53	3.93	9	66.6	85.6	E
3/6/2011-4/6/2011	17	3.08	8.1	61.2	80.2	E
17/6/2011-18/6/2011	5	2.88	8.1	58.2	77.2	ENE
4/7/2011-5/7/2011	21	4.48	12.1	66.5	85.5	E
4/08/2011	8	3.23	11	75.3	94.3	E
7/01/2012	4	2.89	7.6	95.6	114.6	ESE
19/03/2012	16	3.89	7.9	89.5	108.5	ESE
2/4/2012-5/4/2012	48	5.65	11.6	72.5	91.5	E
3/07/2012	5	3.04	8	66.5	85.5	E
29/7/2012-30/7/2012	10	3.31	8.6	51.5	70.5	ENE
30/8/2012-31/8/2012	19	3.46	8.6	83.1	102.1	ESE
28/09/2012	14	3.62	8.8	78.3	97.3	E
23/12/2012	13	2.96	10.3	69.5	88.5	E
6/01/2013	9	4.15	12.4	75.6	94.6	E
4/05/2013	8	3.47	12.3	65.8	84.8	E
27/6/2013-28/6/2013	10	3.16	9.5	78.9	97.9	E
1/8/2013-3/8/2013	37	3.41	9.1	60.9	79.9	E
24/9/2013-25/9/2013	9	3.73	10.3	87.5	106.5	ESE

Date	Duration (Hrs)	Max Hs (m)	Tm (sec)	Dir Magnetic	Dir true (deg)	
6/2/2014-7/2/2014	13	3.09	7.6	71.1	90.1	E
14/3/2014-16/3/2014	30	5.45	11.1	63.5	82.5	E
17/04/2014	5	3.14	8.9	59	78	E
10/6/2014-11/6/2014	17	3.79	9.5	77.6	96.6	E
8/7/2014-12/7/2014	89	6.37	10.8	57.4	76.4	ENE
30/8/2014-1/9/2014	39	3.54	8.8	68	87	E
29/09/2014	7	2.99	6.9	86	105	ESE
14/12/2014-17/12/2014	48	3.32	7.1	101.3	120.3	ESE
15/3/2015-16/3/2015	26	4.9	13.1	72.6	91.6	E
1/01/2016	5	3.04	7.9	69.8	88.8	E
23/3/2016-24/3/2016	21	3.14	8.6	62.7	81.7	E
9/7/2016-11/7/2016	14	3.16	7.5	85	104	ESE
8/3/2017-9/3/2017	10	3.51	7.9	91.1	110.1	ESE
24/04/2017	4	2.69	10.4	64.9	83.9	E
21/6/2017-22/6/2017	13	3	7.9	59.9	78.9	E
18/11/2017-19/11/2017	24	4.01	7.9	78.6	97.6	E
8/2/2018-9/2/2018	27	3.29	6.7	74.4	93.4	E
12/03/2018	9	3.16	6.5	79.1	98.1	E
2/6/2018-3/6/2018	13	3.08	6.6	64.2	83.2	E
20/6/2018-21/6/2018	32	4.1	7.1	81.5	100.5	E
19/09/2018	4	2.705	6.2	73.4	92.4	E
10/2/2019-11/2/2019	15	3.06	9.7	70	89	E
Total : 57 events					E=44, ESE=8, ENE=5	
max	89	6.37	13.10		120.30	
min			6.20		70.50	

Appendix J. Shoreline Change from DSAS 1961-2018



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CLIENT McCallum Brothers Ltd	
PROJECT Pakiri Sand Extraction Consent Renewal	
SCALE 1:16,710 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/17/2019

Linear Regression Rate (m/yr)

-1.04 - -1	0 - 1
-1 - -0.75	1 - 2
-0.75 - -0.5	2 - 3
-0.5 - -0.25	3 - 4
-0.25 - 0	

Shoreline

1961	2007
1963	2008
1982	2018

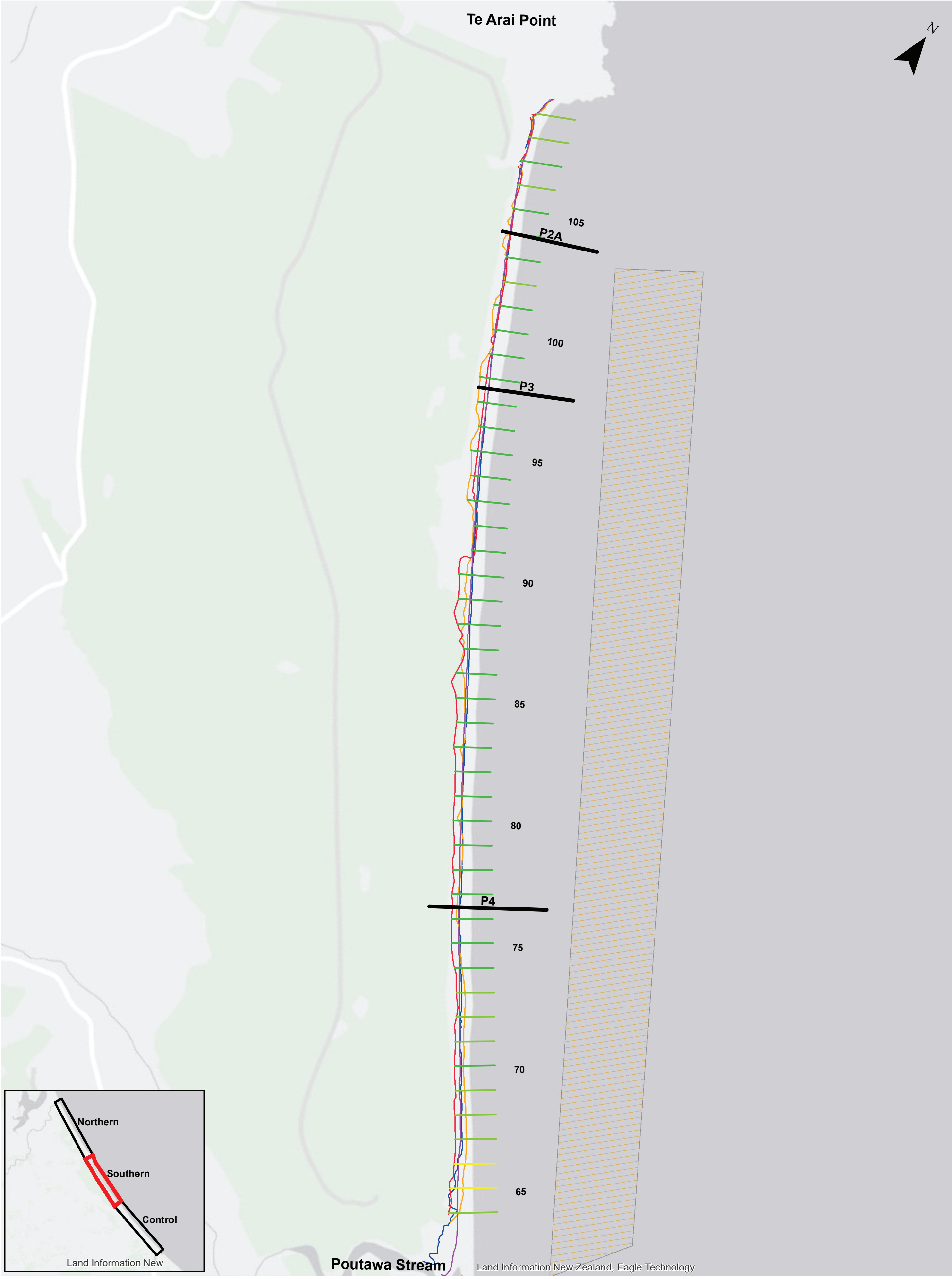
Historical Profile

Consent Area

Shoreline change from DSAS
Northern Extraction Consent Area

0 500 1,000 Meters

JACOBS
SPATIAL
Level 2, Wynn Williams building,
47 Hereford Street,
Christchurch Central 8013,
New Zealand
T +64 3 940 4900
F +64 3 940 4901



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CLIENT McCallum Brothers Ltd	
PROJECT Pakiri Sand Extraction Consent Renewal	
SCALE 1:14,300 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/17/2019

Linear Regression Rate (m/yr)

- -1.04 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4

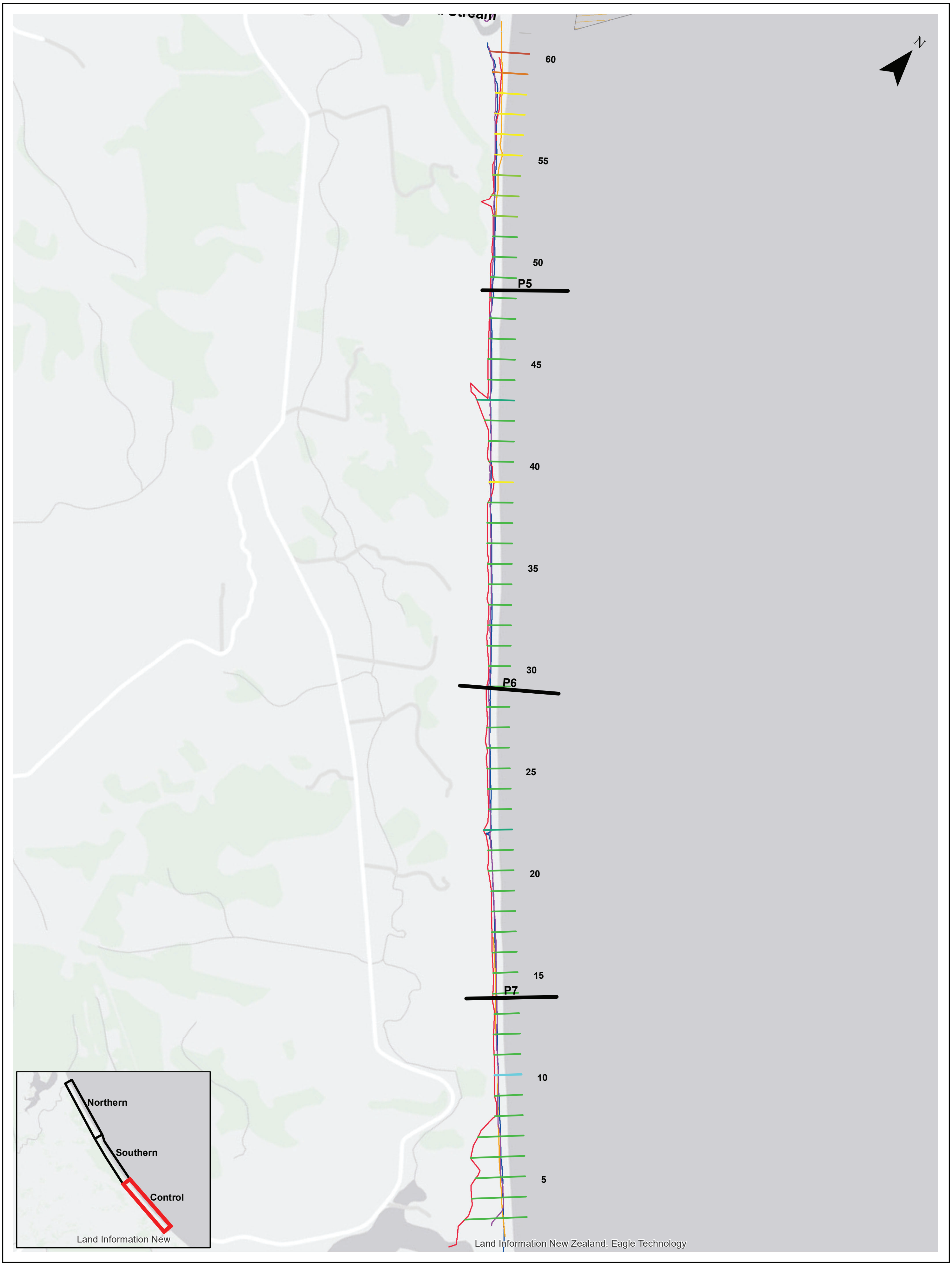
Shoreline

- 1961
- 1963
- 1982
- 2007
- 2008
- 2018
- Historical Profile
- Consent Area

Shoreline change from DSAS Southern Extraction Consent Area

0 500 1,000 Meters

JACOBS
SPATIAL
Level 2, Wynn Williams building,
47 Hereford Street,
Christchurch Central 8013,
New Zealand
T +64 3 940 4900
F +64 3 940 4901



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CLIENT McCallum Brothers Ltd			
PROJECT Pakiri Sand Extraction Consent Renewal			
SCALE 1:16,610 @ A3	PROJECT CODE IZ111900		
PROJECT MANAGER IW	DRAWN KM		
PROJECT DIRECTOR DT	DATE 12/17/2019		

Linear Regression Rate (m/yr)
- -1.04 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4

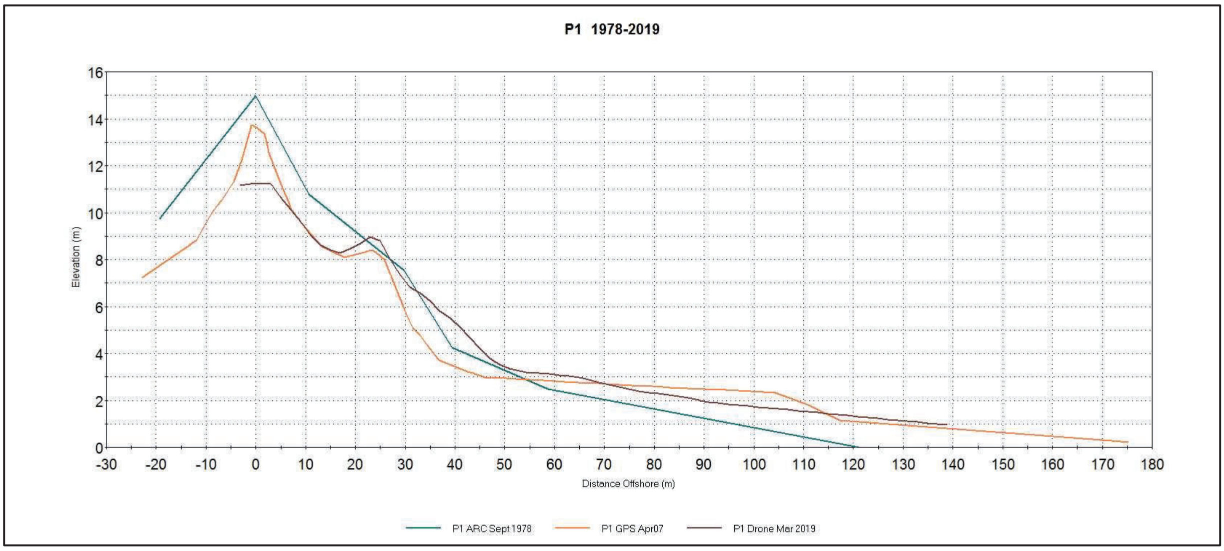
Shoreline
- 1961
- 1963
- 1982
- 2007
- 2008
- 2018
- Historical Profile
- Consent Area

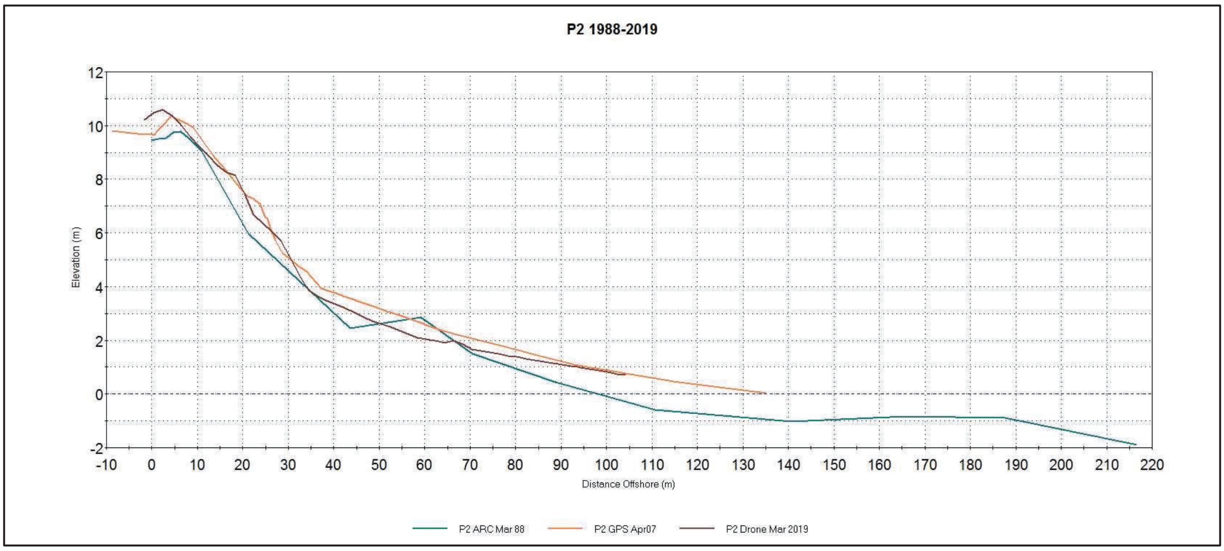
Shoreline change from DSAS Control Area

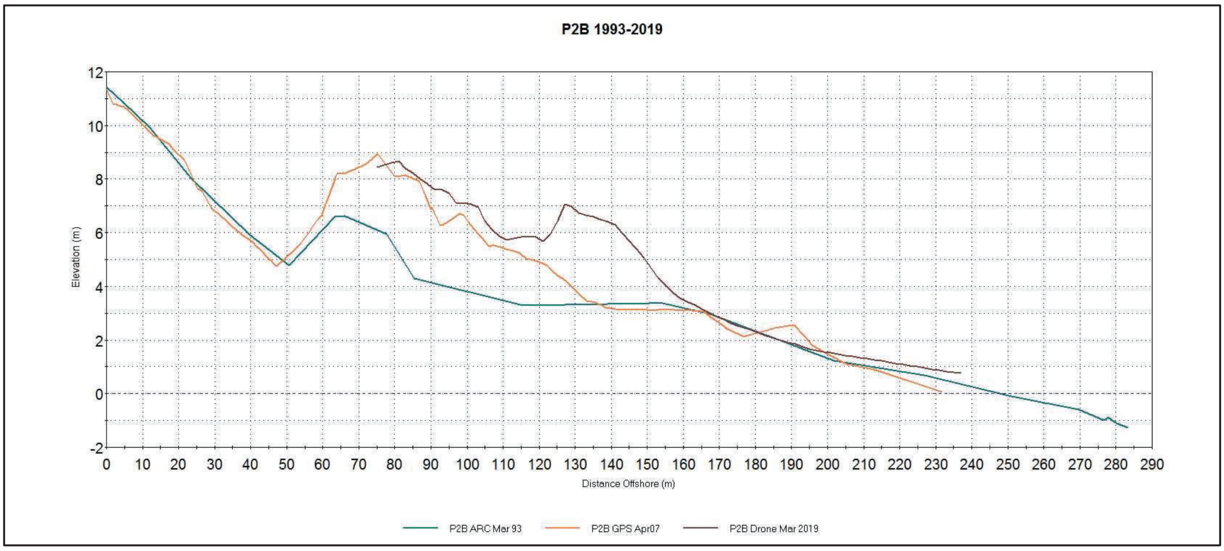
0 500 1,000 Meters

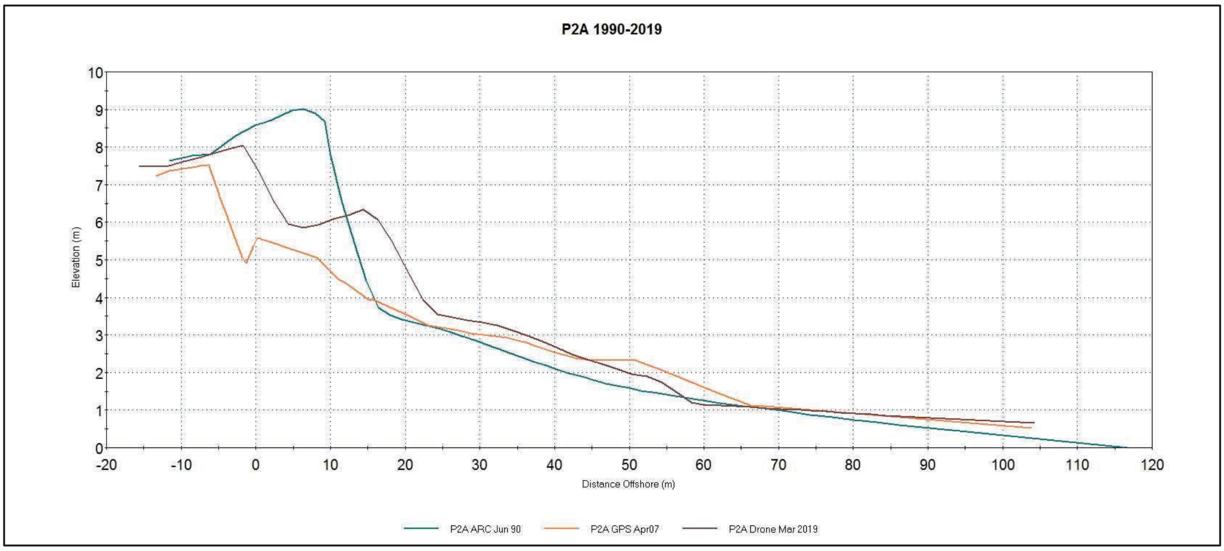
JACOBS SPATIAL
Level 2, Wynn Williams building,
47 Hereford Street,
Christchurch Central 8013,
New Zealand
T +64 3 940 4900
F +64 3 940 4901

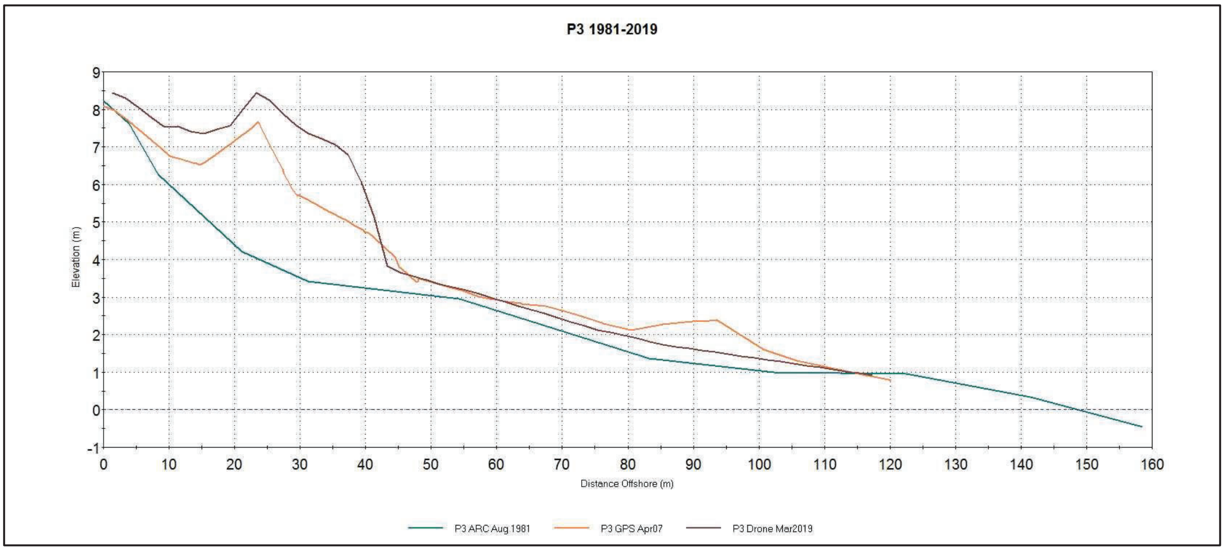
Appendix K. Historical Profile Cross-Sections 1978-2000, 2007, 2017-19

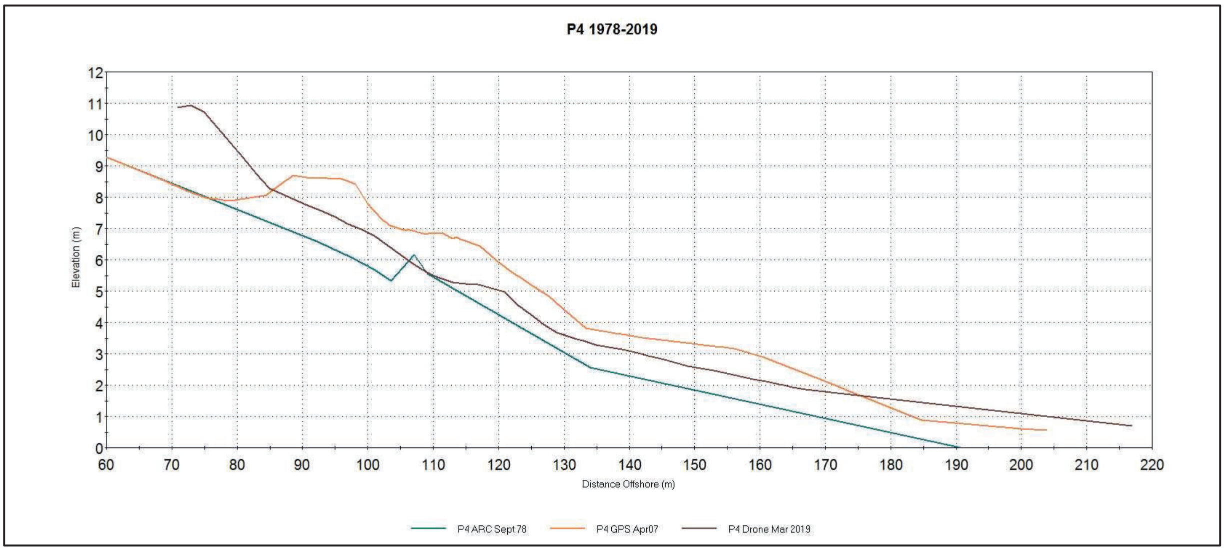

P1 1978-2019
Elevation (m)
Distance Offshore (m)
P1 ARC Sept 1978
P1 GPS Apr07
P1 Drone Mar 2019

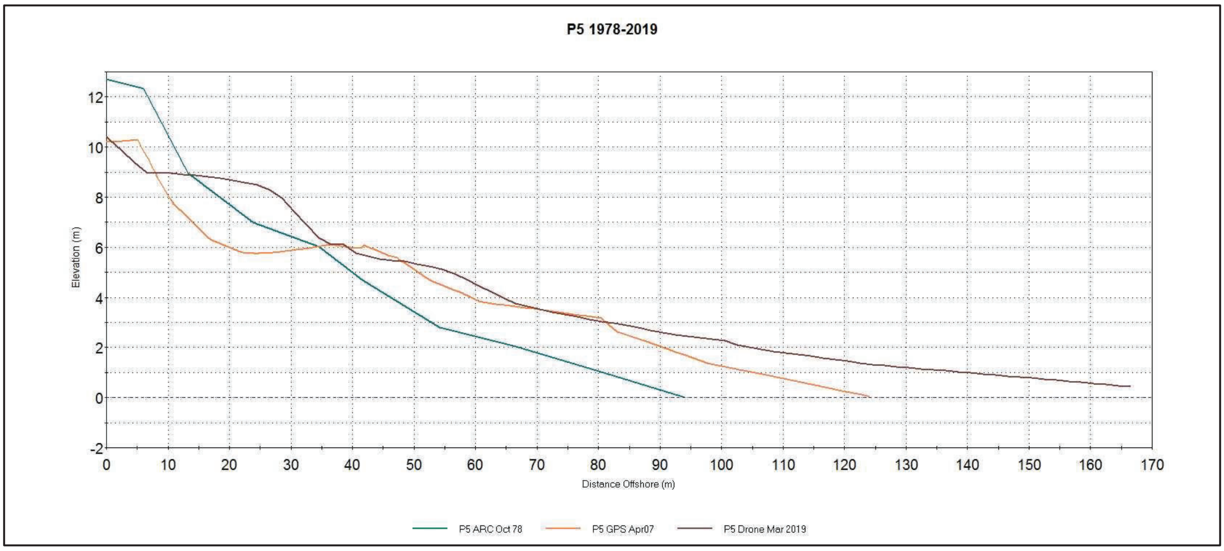

P2 1988-2019
Elevation (m)
Distance Offshore (m)
P2 ARC Mar 88
P2 GPS Apr07
P2 Drone Mar 2019

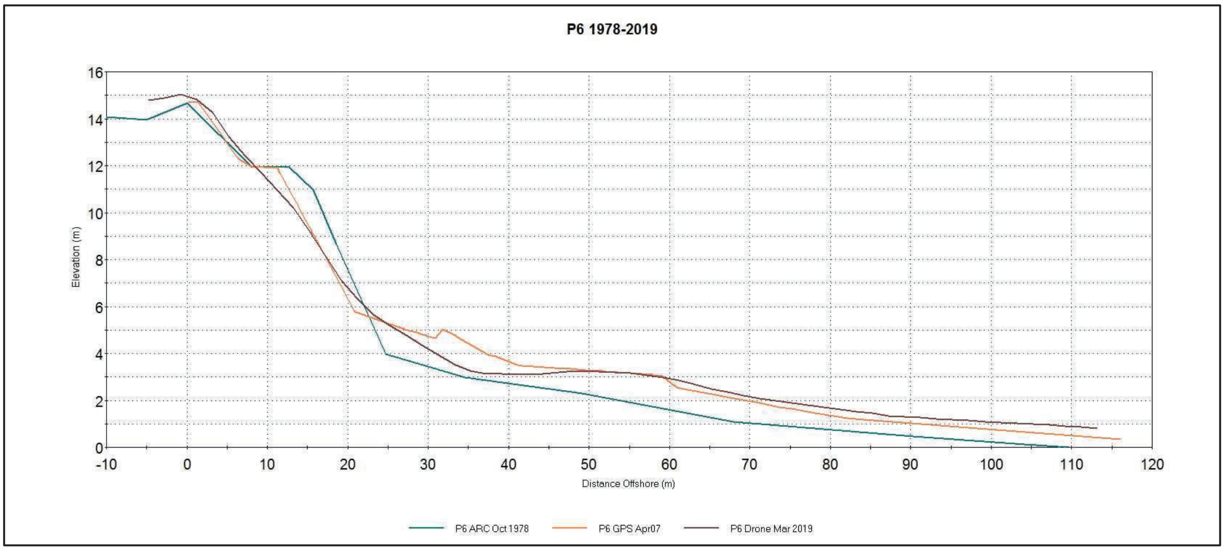

P2B 1993-2019
Elevation (m)
Distance Offshore (m)
P2B ARC Mar 93
P2B GPS Apr07
P2B Drone Mar 2019

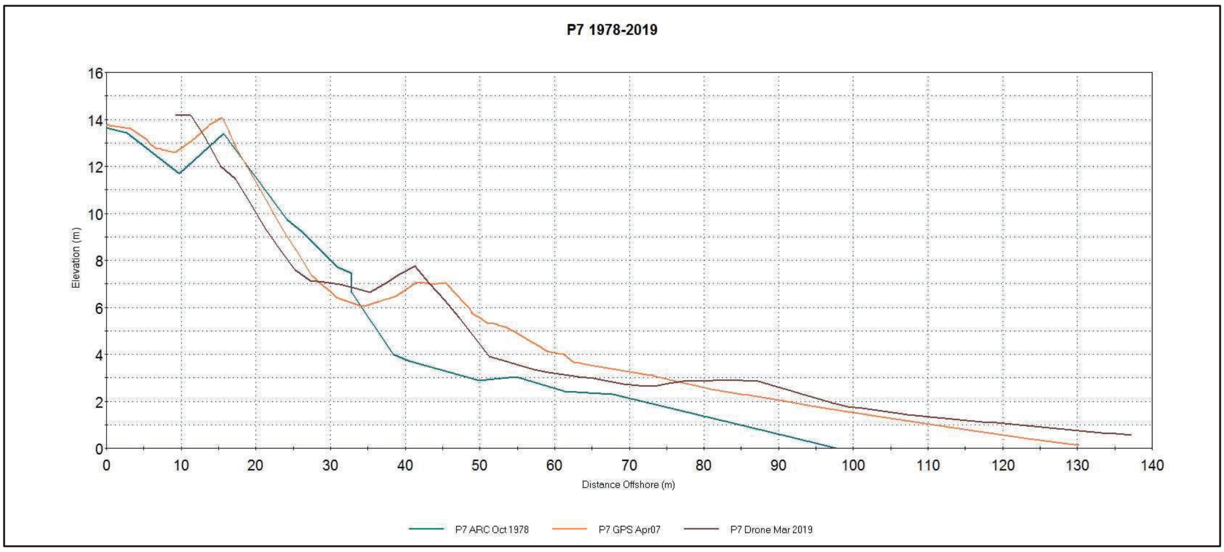

P2A 1990-2019
Elevation (m)
Distance Offshore (m)
P2A ARC Jun 90
P2A GPS Apr07
P2A Drone Mar 2019

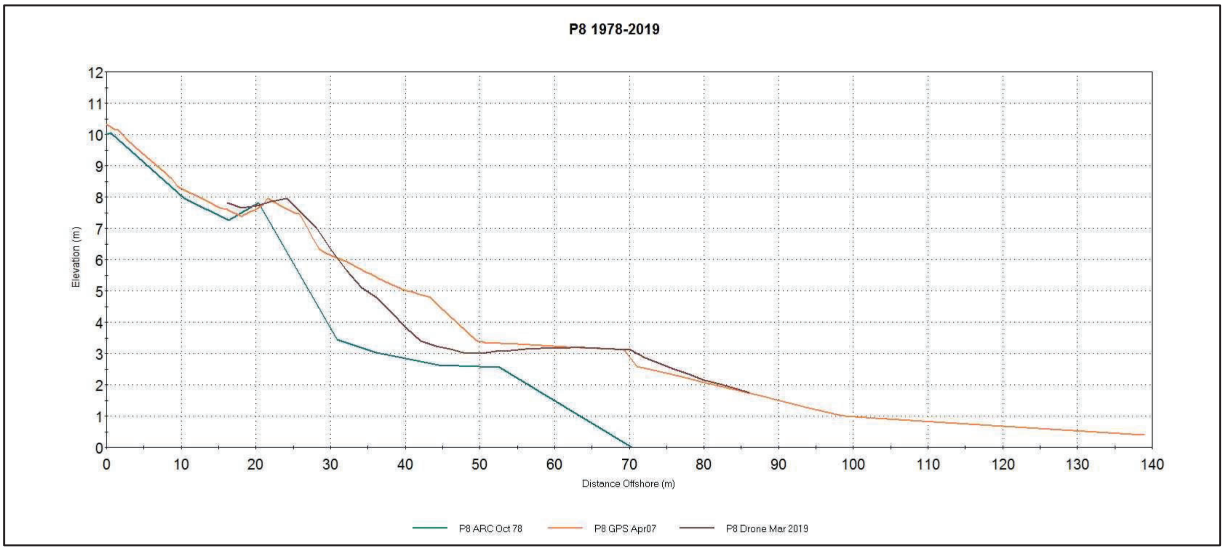

P3 1981-2019
Elevation (m)
Distance Offshore (m)
P3 ARC Aug 1981
P3 GPS Apr07
P3 Drone Mar2019

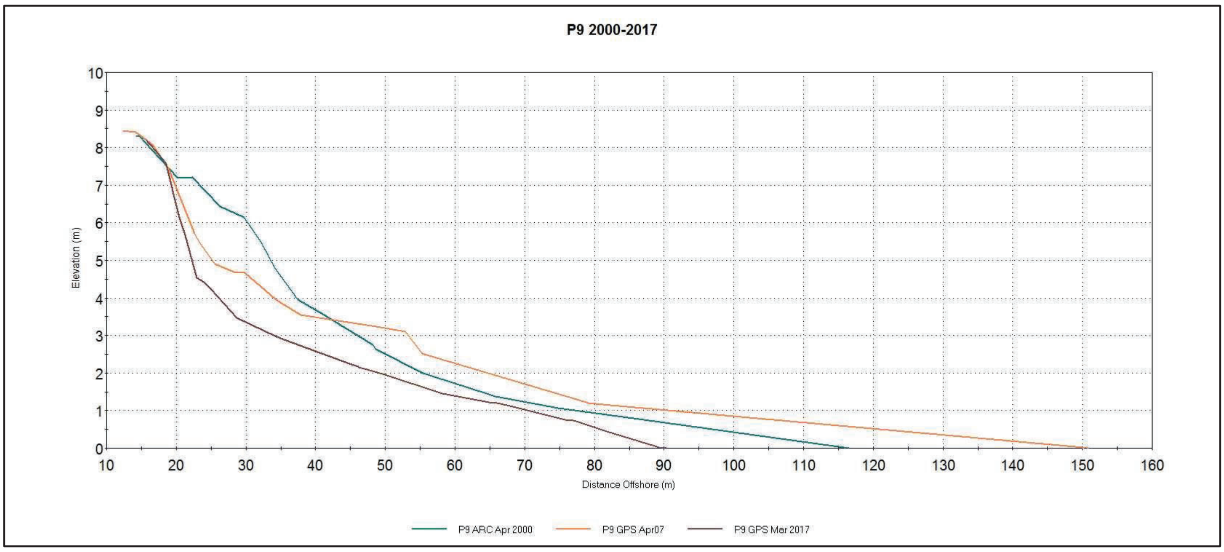

P4 1978-2019
Elevation (m)
Distance Offshore (m)
P4 ARC Sept 78
P4 GPS Apr07
P4 Drone Mar 2019


P5 1978-2019
Elevation (m)
Distance Offshore (m)
P5 ARC Oct 78
P5 GPS Apr07
P5 Drone Mar 2019

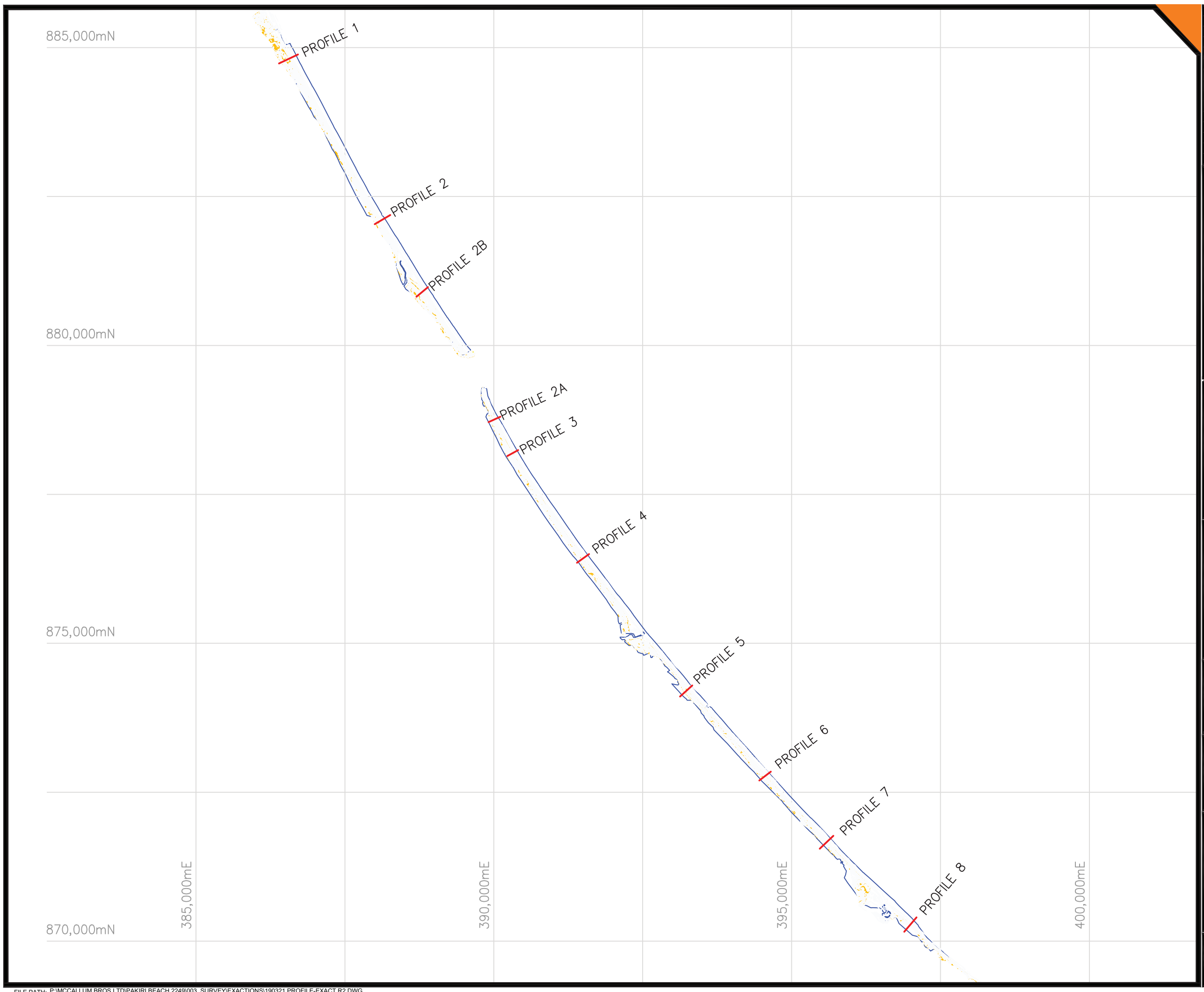

P6 1978-2019
Elevation (m)
Distance Offshore (m)
P6 ARC Oct 1978
P6 GPS Apr07
P6 Drone Mar 2019


P7 1978-2019
Elevation (m)
Distance Offshore (m)
P7 ARC Oct 1978
P7 GPS Apr07
P7 Drone Mar 2019


P8 1978-2019
Elevation (m)
Distance Offshore (m)
P8 ARC Oct 78
P8 GPS Apr07
P8 Drone Mar 2019


P9 2000-2017
Elevation (m)
Distance Offshore (m)
P9 ARC Apr 2000
P9 GPS Apr07
P9 GPS Mar 2017

Appendix L. Historical Profile Surveys 2017-2019 from Surveyworx Drone Surveys



PLOT DATE: 8/1/2019 3:53 PM

FILE PATH: P:\MCCALLUM BROS LTD\PAKIRI BEACH 2249\003_SURVEY\EXACTIONS\190321 PROFILE-EXACT R2.DWG

SURVEYED	SWX	21.03.19
DESIGNED		
DRAWN	SL	05.06.19
CHECKED		
APPROVED		

APPROVED DATE

REVISION	CHANGES	CHECKED	DATE
0	ORIGINAL ISSUE	CH	05.06.19
2	RE ISSUE	CH	01.08.19

NOTES:

BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

SURVEY EQUIPMENT USED:
INSTRUMENT: TRIMBLE ROBOTIC S8 1"
GPS: TRIMBLE R6/R8 SYSTEMS
PRECISE LEVELLING: TRIMBLE DiNi Series 0.3mm DIGITAL
VERTICAL PLUMMING: FOIF DZJ2 LASER PLUMMIT

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www.surveyworx.co.nz
517 Mt Wellington Hway, Auckland, NZ

NZIS REGISTERED PROFESSIONAL SURVEYOR

MEMBERS OF: NZIS New Zealand Institute of Surveyors Te Rōpū Kairūri o Aotearoa

CLIENT

McCULLUM BROS

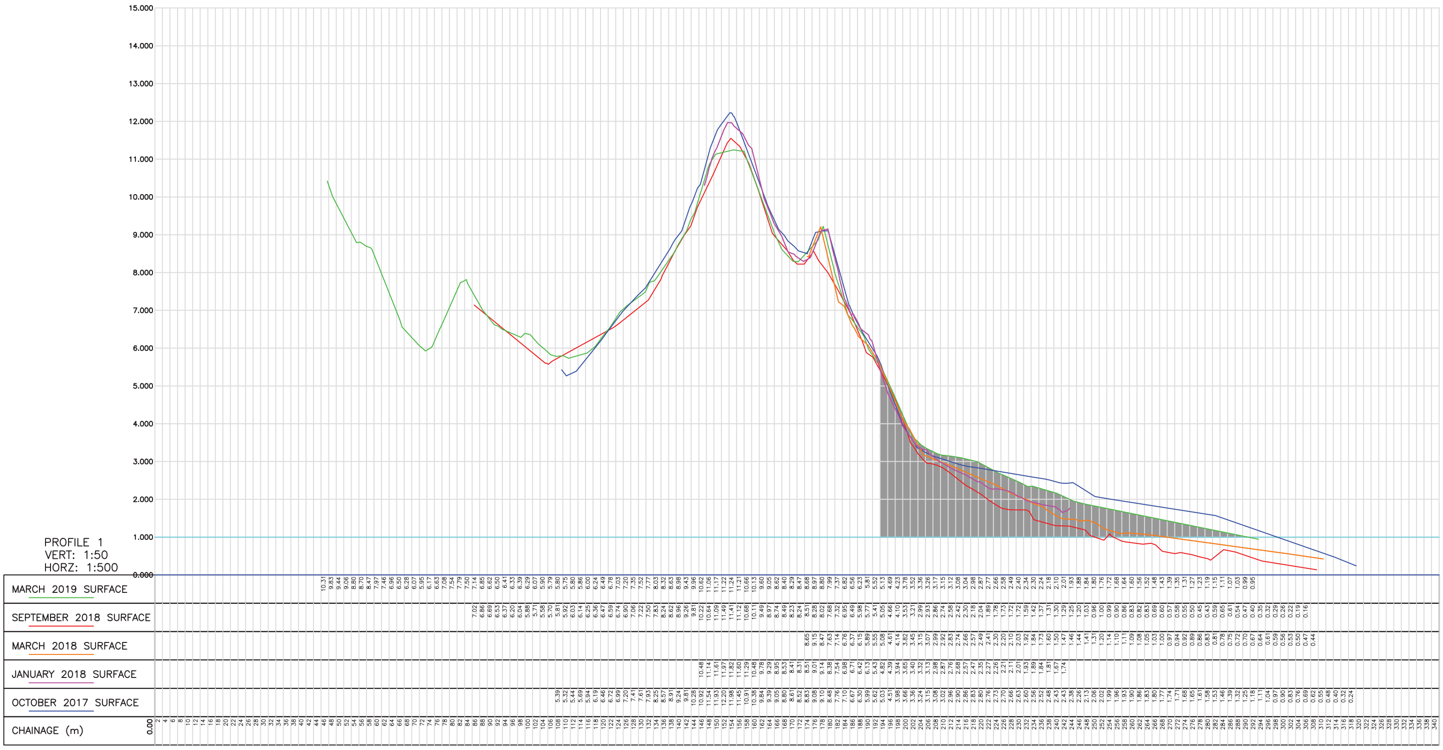
PROJECT

PAKIRI BEACH

TITLE

AERIAL SURVEY
OCTOBER 2017-
MARCH 2019
PROFILE LOCATIONS

SCALE	NTS (A1)	NTS (A3)
DRAWING No 2249-705-11	SHEET 0 of 10	REVISION 2



PROFILE 1

SURVEYED	SWX	21.03.2019	APPROVED	DATE
DESIGNED				
DRAWN	SL/LK	18.07.2019		
TRACED				
REVISION		CHANGES	CHECKED	DATE
2	RE ISSUE		MC	01.08.19
0	ORIGINAL ISSUE		MC	18.07.19

PLOT DATE: 8/1/2019 3:53 PM

NOTES:

BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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1016A Great South Road, Penrose Auckland, NZ

NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT	McCULLUM BROS
PROJECT	PAKIRI BEACH
TITLE	AERIAL SURVEY OCTOBER 2017-MARCH 2019 PROFILE
SCALE	1:500 (A1) 1:1000 (A3)
SHEET	1 of 10
REVISION	2
DRAWING No	2249-705-11

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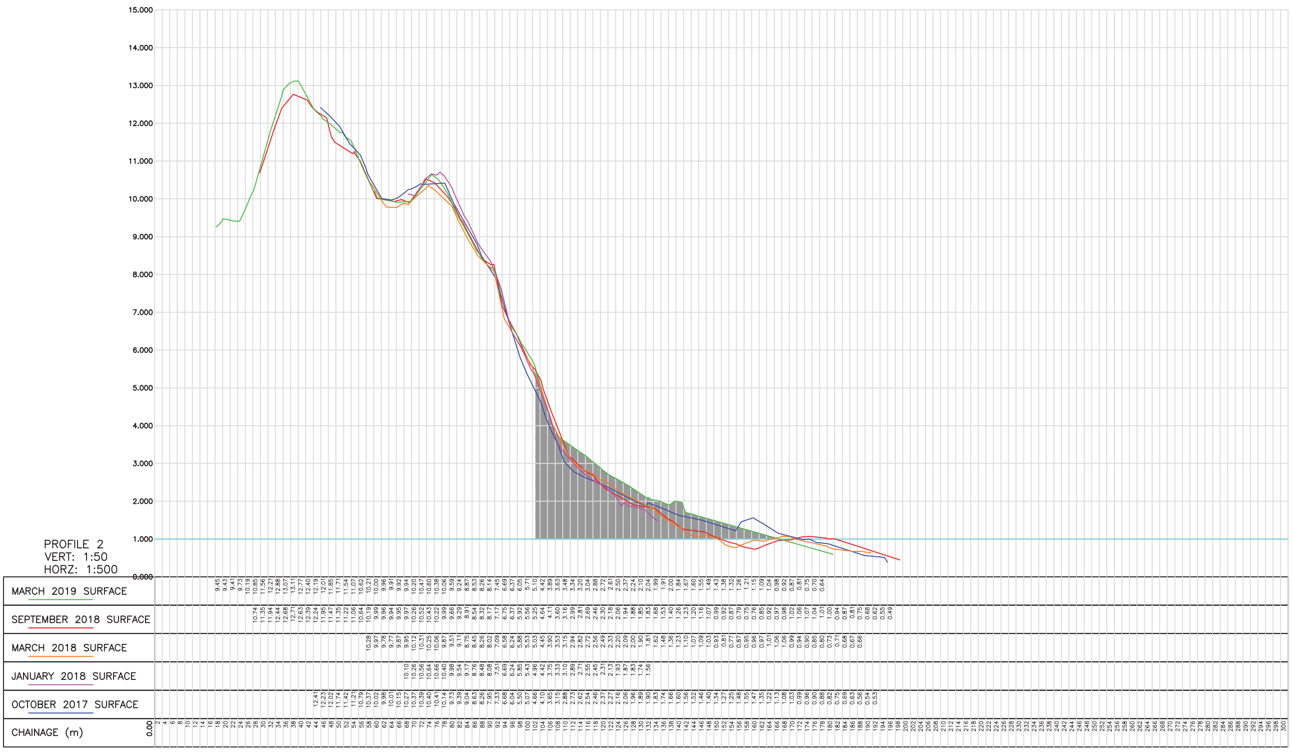

PROFILE 2

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DESIGNED				
DRAWN	SL/LK	18.07.2019		
TRACED				
REVISION		CHANGES	CHECKED	DATE
2	RE ISSUE		MC	01.08.19
0	ORIGINAL ISSUE		MC	18.07.19

PLOT DATE: 8/1/2019 3:53 PM

NOTES:

BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN: 800 000 mN: 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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1016A Great South Road, Penrose Auckland, NZ

NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT: McCULLUM BROS

PROJECT: PAKIRI BEACH

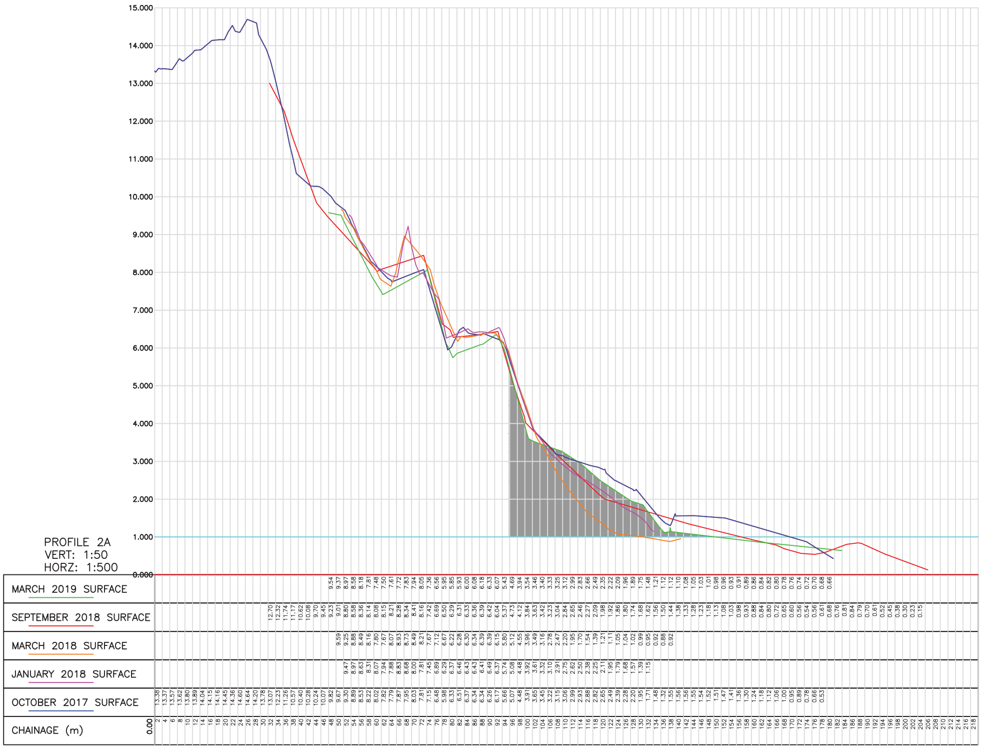
TITLE: AERIAL SURVEY OCTOBER 2017- MARCH 2019 PROFILE

SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 2 of 10 **REVISION:** 2

DRAWING No: 2249-705-11

FILE PATH: P:\MCCALLUM BROS LTD\PAKIRI BEACH 2249\003_SURVEY\EXACTIONS\190321 PROFILE-EXACT R2.DWG



PROFILE 2A

SURVEYED	SWX	21.03.2019	APPROVED	DATE
DESIGNED				
DRAWN	SL/LK	18.07.2019		
TRACED				
REVISION		CHANGES	CHECKED	DATE
2		RE ISSUE	MC	01.08.19
0		ORIGINAL ISSUE	MC	18.07.19

PLOT DATE: 8/1/2019 3:53 PM

NOTES:

BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT	PROJECT	TITLE	SCALE
McCULLUM BROS	PAKIRI BEACH	AERIAL SURVEY OCTOBER 2017-MARCH 2019 PROFILE	1:500 (A1) 1:1000 (A3)

SHEET 3 of 10 — REVISION 2

DRAWING No 2249-705-11

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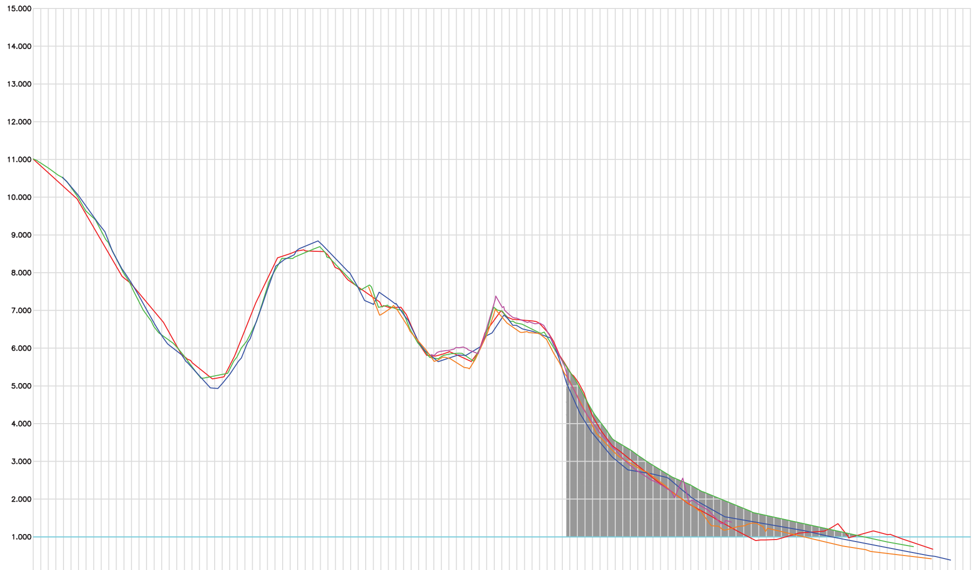

PROFILE 2B
VERT: 1:50
HORZ: 1:500

CHAINAGE (m)	MARCH 2019 SURFACE	SEPTEMBER 2018 SURFACE	MARCH 2018 SURFACE	JANUARY 2018 SURFACE	OCTOBER 2017 SURFACE
0.00	11.01	11.01			
2	10.91	10.83			
4	10.77	10.65			
6	10.63	10.46			
8	10.49	10.28			10.50
10	10.26	10.10			10.28
12	9.97	9.89			10.04
14	9.63	9.55			9.76
16	9.44	9.20			9.48
18	9.10	8.86			9.21
20	8.77	8.51			8.82
22	8.37	8.17			8.38
24	7.97	7.86			8.02
26	7.63	7.70			7.72
28	7.23	7.46			7.38
30	6.89	7.22			7.02
32	6.56	6.98			6.67
34	6.35	6.74			6.35
36	6.20	6.41			6.08
38	6.02	6.05			5.92
40	5.78	5.77			5.71
42	5.52	5.63			5.49
44	5.25	5.46			5.27
46	5.22	5.30			5.04
48	5.26	5.20			4.94
50	5.30	5.23			5.06
52	5.44	5.54			5.31
54	5.78	5.97			5.61
56	6.12	6.47			5.97
58	6.49	6.97			6.42
60	6.99	7.42			6.98
62	7.63	7.84			7.55
64	8.06	8.26			8.11
66	8.38	8.44			8.31
68	8.38	8.50			8.42
70	8.45	8.58			8.61
72	8.53	8.58			8.70
74	8.62	8.57			8.78
76	8.67	8.56			8.78
78	8.40	8.46			8.58
80	8.22	8.14			8.37
82	8.01	7.97			8.17
84	7.81	7.76			7.96
86	7.61	7.62			7.60
88	7.61	7.48			7.25
90	7.48	7.34	7.30		7.16
92	7.09	7.16	6.89		7.45
94	7.12	7.08	7.02		7.31
96	7.05	7.08	7.05		7.18
98	6.94	6.99	6.75		6.89
100	6.45	6.60	6.41		6.57
102	6.11	6.14	6.18		6.17
104	5.87	5.83	5.94		5.90
106	5.74	5.79	5.67	5.80	5.74
108	5.78	5.83	5.74	5.92	5.67
110	5.84	5.90	5.73	5.94	5.74
112	5.86	5.83	5.62	6.02	5.80
114	5.83	5.73	5.49	6.02	5.81
116	5.69	5.66	5.54	5.92	5.90
118	5.96	5.95	5.91	5.94	6.02
120	6.44	6.47	6.35	6.53	6.33
122	7.07	6.75	6.93	7.20	6.49
124	6.98	6.99	6.83	7.10	6.80
126	6.74	6.80	6.62	6.89	6.73
128	6.66	6.76	6.48	6.79	6.60
130	6.60	6.74	6.42	6.71	6.50
132	6.50	6.72	6.40	6.67	6.45
134	6.40	6.66	6.38	6.66	6.38
136	6.30	6.43	6.20	6.45	6.30
138	5.97	6.10	5.82	6.05	6.03
140	5.67	5.70	5.45	5.66	5.44
142	5.38	5.38	5.12	5.09	4.88
144	5.06	5.13	4.73	4.70	4.43
146	4.69	4.74	4.33	4.33	4.06
148	4.33	4.21	3.94	4.03	3.75
150	4.05	3.86	3.64	3.76	3.51
152	3.78	3.58	3.43	3.53	3.26
154	3.55	3.36	3.22	3.32	3.05
156	3.43	3.21	3.06	3.08	2.89
158	3.31	3.05	2.95	2.90	2.76
160	3.16	2.88	2.83	2.74	2.73
162	3.02	2.72	2.73	2.61	2.70
164	2.89	2.57	2.60	2.49	2.66
166	2.77	2.41	2.45	2.39	2.61
168	2.65	2.26	2.28	2.26	2.56
170	2.54	2.12	2.12	2.10	2.39
172	2.46	1.98	1.98	2.51	2.22
174	2.37	1.84	1.85	1.95	2.05
176	2.26	1.73	1.71	1.86	1.93
178	2.16	1.62	1.49	1.74	1.81
180	2.08	1.51	1.29	1.56	1.70
182	2.00	1.40	1.23	1.35	1.59
184	1.92	1.28	1.20	1.41	1.51
186	1.84	1.17	1.26		1.48
188	1.75	1.07	1.29		1.44
190	1.67	0.96	1.36		1.41
192	1.61	0.91	1.33		1.37
194	1.56	0.92	1.18		1.34
196	1.52	0.93	1.19		1.30
198	1.48	0.97	1.14		1.27
200	1.43	1.02	1.09		1.23
202	1.39	1.08	1.05		1.20
204	1.35	1.11	1.00		1.16
206	1.30	1.13	0.95		1.12
208	1.26	1.14	0.90		1.07
210	1.22	1.19	0.86		1.03
212	1.17	1.29	0.81		0.98
214	1.13	1.22	0.76		0.95
216	1.08	0.98	0.73		0.91
218	1.04	1.03	0.70		0.87
220	1.00	1.09	0.66		0.83
222	0.95	1.15	0.61		0.79
224	0.91	1.11	0.58		0.75
226	0.87	1.06	0.56		0.71
228	0.83	1.02	0.54		0.68
230	0.79	0.95	0.51		0.64
232	0.76	0.88	0.49		0.60
234		0.81	0.46		0.56
236		0.74	0.44		0.52
238		0.67			0.49
240					0.45
242					0.40
244					
246					
248					

PROFILE 2B

SURVEYED	SWX	21.03.2019	APPROVED	DATE
DESIGNED				
DRAWN	SL/LK	18.07.2019		
TRACED				
REVISION	CHANGES		CHECKED	DATE
2	RE ISSUE		MC	01.08.19
0	ORIGINAL ISSUE		MC	18.07.19

PLOT DATE: 8/1/2019 3:54 PM

NOTES:
BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN: 800 000 mN: 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT: McCULLUM BROS

PROJECT: PAKIRI BEACH

TITLE: AERIAL SURVEY OCTOBER 2017- MARCH 2019 PROFILE

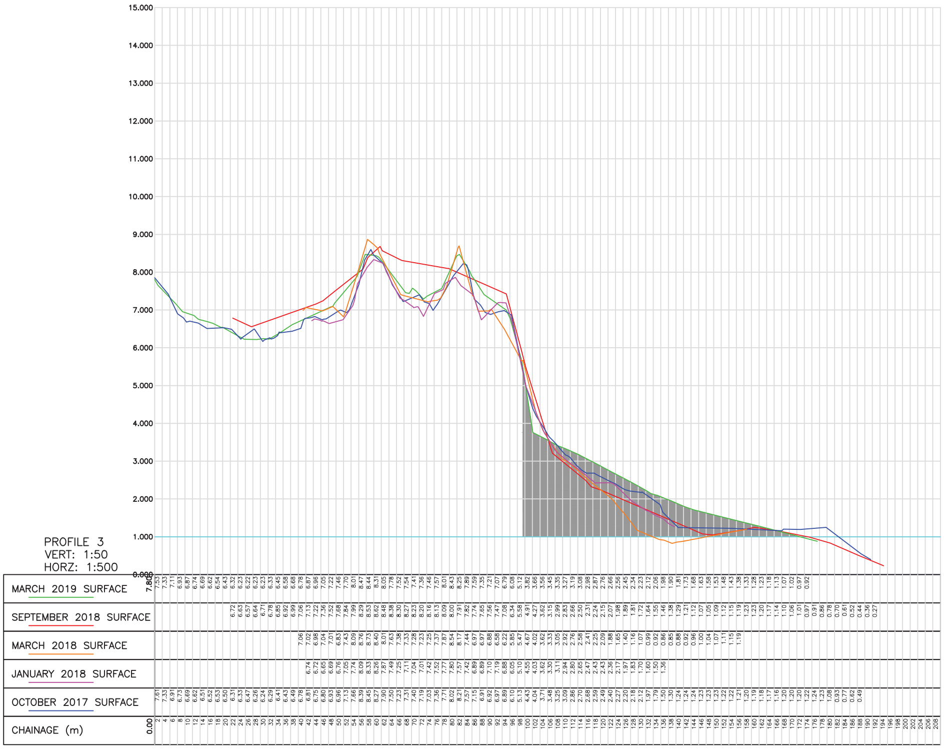
SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 4 of 10

REVISION: 2

DRAWING No: 2249-705-11

FILE PATH: P:\MCCALLUM BROS LTD\PAKIRI BEACH 2249\003_SURVEY\EXACTIONS\190321 PROFILE-EXACT R2.DWG



PROFILE 3

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TRACED				
REVISION		CHANGES	CHECKED	DATE
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0	ORIGINAL ISSUE		MC	18.07.19

PLOT DATE: 8/1/2019 3:54 PM

NOTES:

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ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
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CLIENT: McCULLUM BROS

PROJECT: PAKIRI BEACH

TITLE: AERIAL SURVEY OCTOBER 2017-MARCH 2019 PROFILE

SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 5 of 10

REVISION: 2

DRAWING No: 2249-705-11

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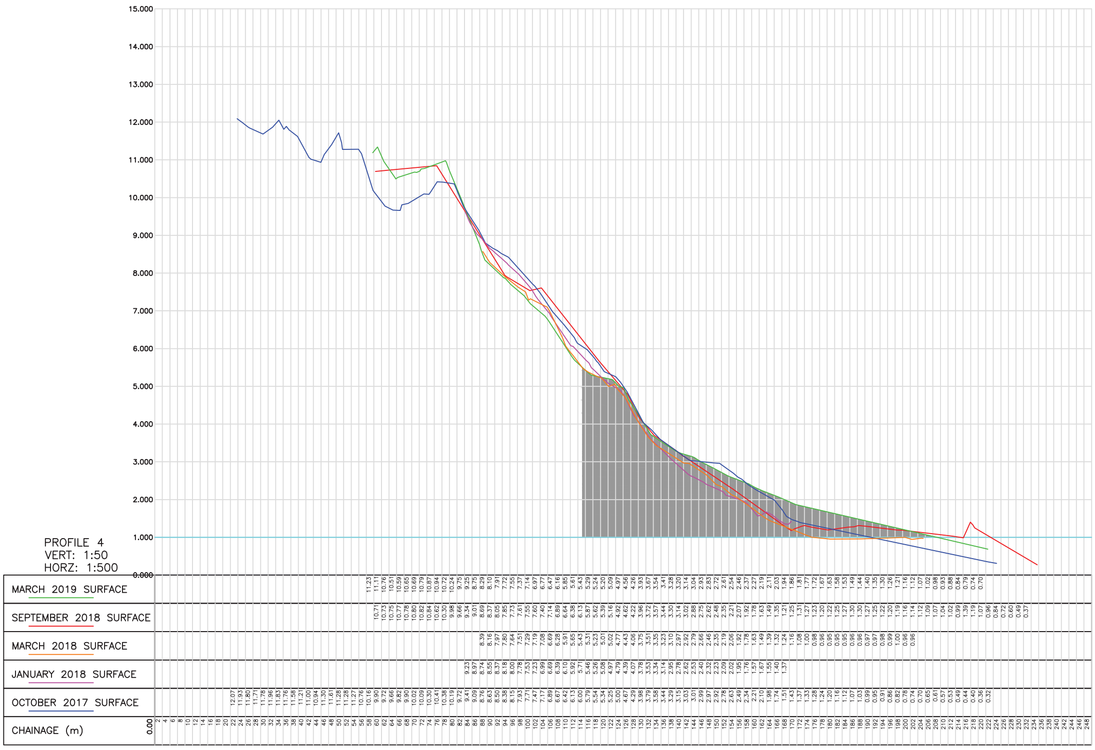

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TRACED				
REVISION		CHANGES	CHECKED	DATE
2	RE ISSUE		MC	01.08.19
0	ORIGINAL ISSUE		MC	18.07.19

PLOT DATE: 8/1/2019 3:54 PM

NOTES:
BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN: 800 000 mN: 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT: McCULLUM BROS

PROJECT: PAKIRI BEACH

TITLE: AERIAL SURVEY OCTOBER 2017- MARCH 2019 PROFILE

SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 6 of 10

REVISION: 2

DRAWING No: 2249-705-11

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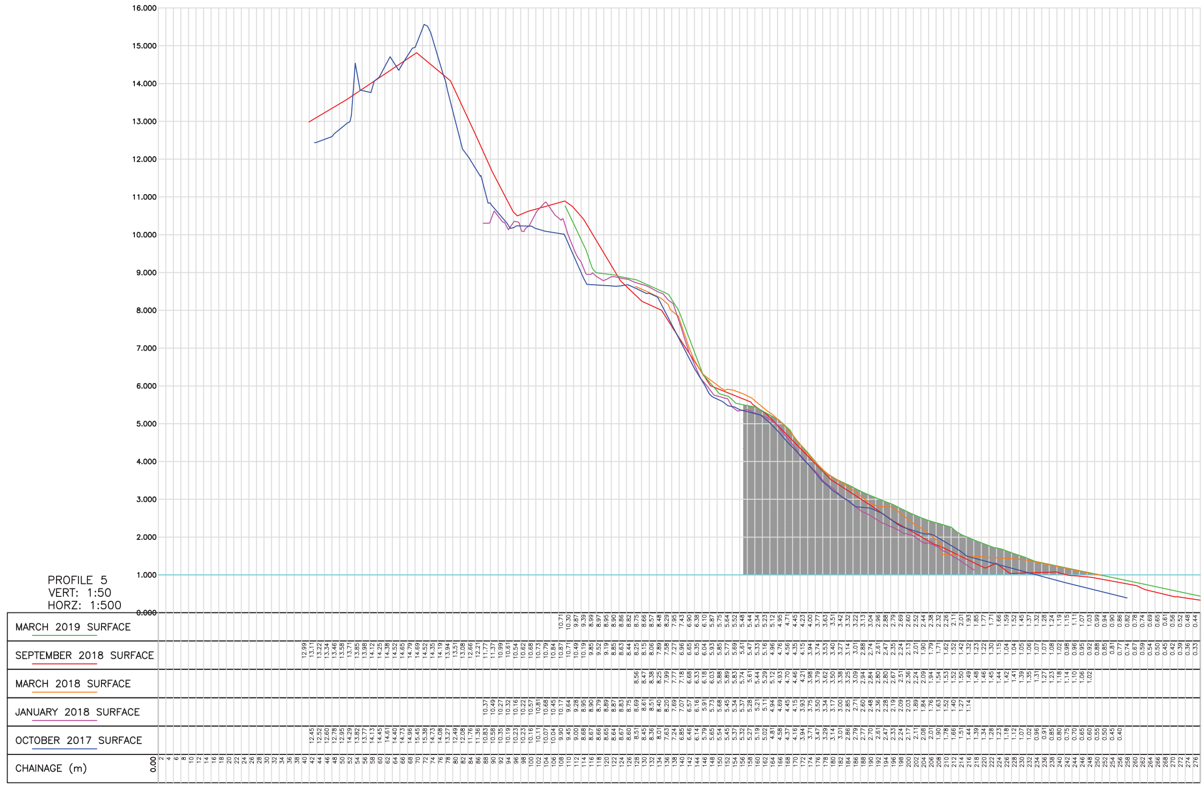

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TRACED				
REVISION	CHANGES		CHECKED	DATE
2	RE ISSUE		MC	01.08.19
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PLOT DATE: 8/1/2019 3:54 PM

NOTES:

BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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PROJECT: PAKIRI BEACH

TITLE: AERIAL SURVEY OCTOBER 2017-MARCH 2019 PROFILE

SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 7 of 10

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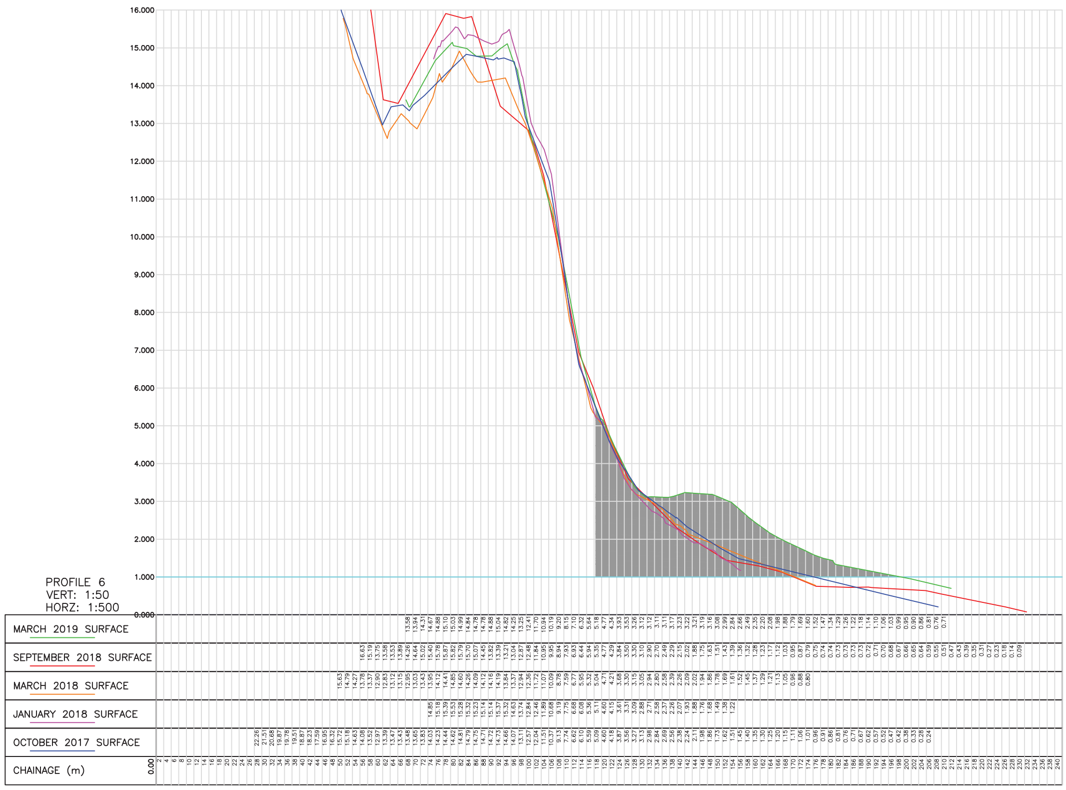

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REVISION	CHANGES	CHECKED	DATE
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PLOT DATE: 8/1/2019 3:54 PM

NOTES:

BEARING AND COORDINATE DATUM IS GEODETIC 2000
ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT: McCULLUM BROS

PROJECT: PAKIRI BEACH

TITLE: AERIAL SURVEY OCTOBER 2017- MARCH 2019 PROFILE

SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 8 of 10

REVISION: 2

DRAWING No: 2249-705-11

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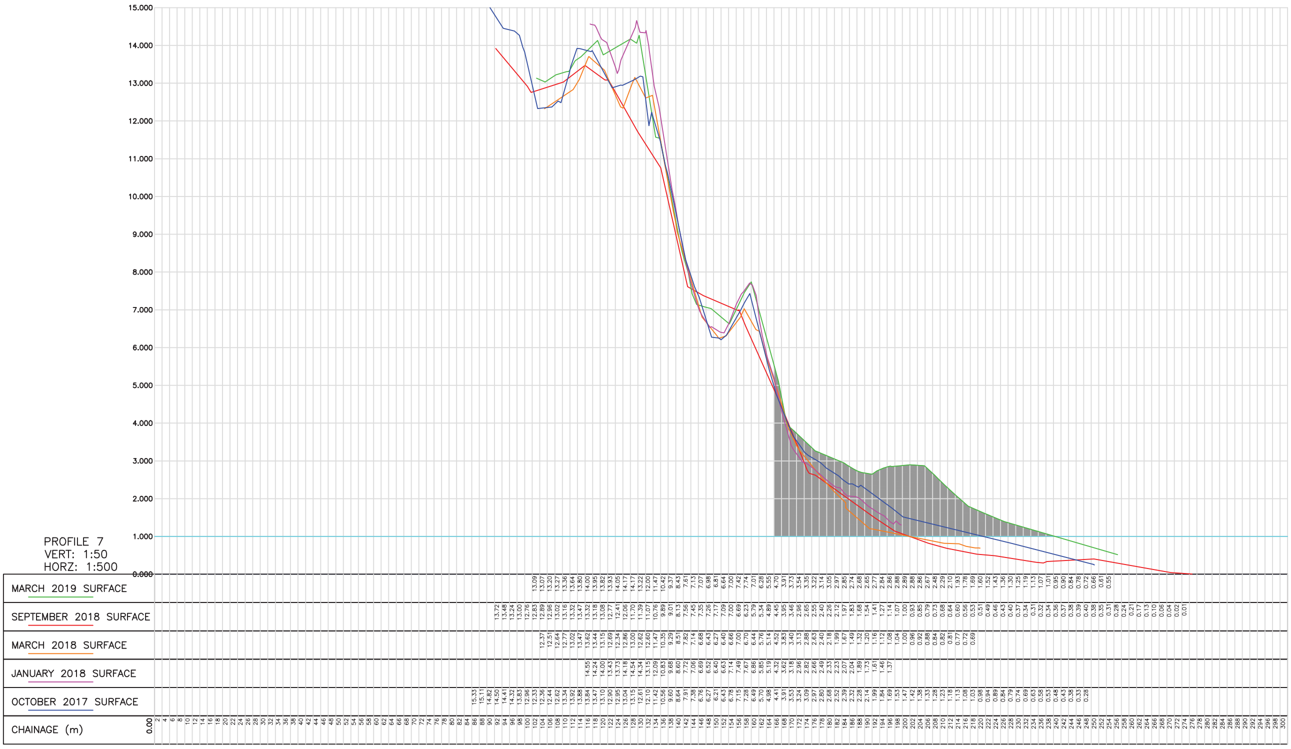

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TRACED				
REVISION		CHANGES	CHECKED	DATE
2	RE ISSUE		MC	01.08.19
0	ORIGINAL ISSUE		MC	18.07.19

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NOTES:

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ORIGIN IS 16 MT. EDEN 800 000 mN, 400 000 mE
PROJECTION IS TRANSVERSE MERCATOR TO OBTAIN
PROJECTION DISTANCES MULTIPLY BY 0.9999

LEVELS ARE IN TERMS OF MEAN SEA LEVEL
ORIGIN DATUM BEING A9J7 (RL84.55m)

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CLIENT	PROJECT	TITLE	SCALE	
McCULLUM BROS	PAKIRI BEACH	AERIAL SURVEY OCTOBER 2017- MARCH 2019 PROFILE	1:500 (A1) 1:1000 (A3)	
			SHEET 9 of 10	REVISION 2
			DRAWING No 2249-705-11	

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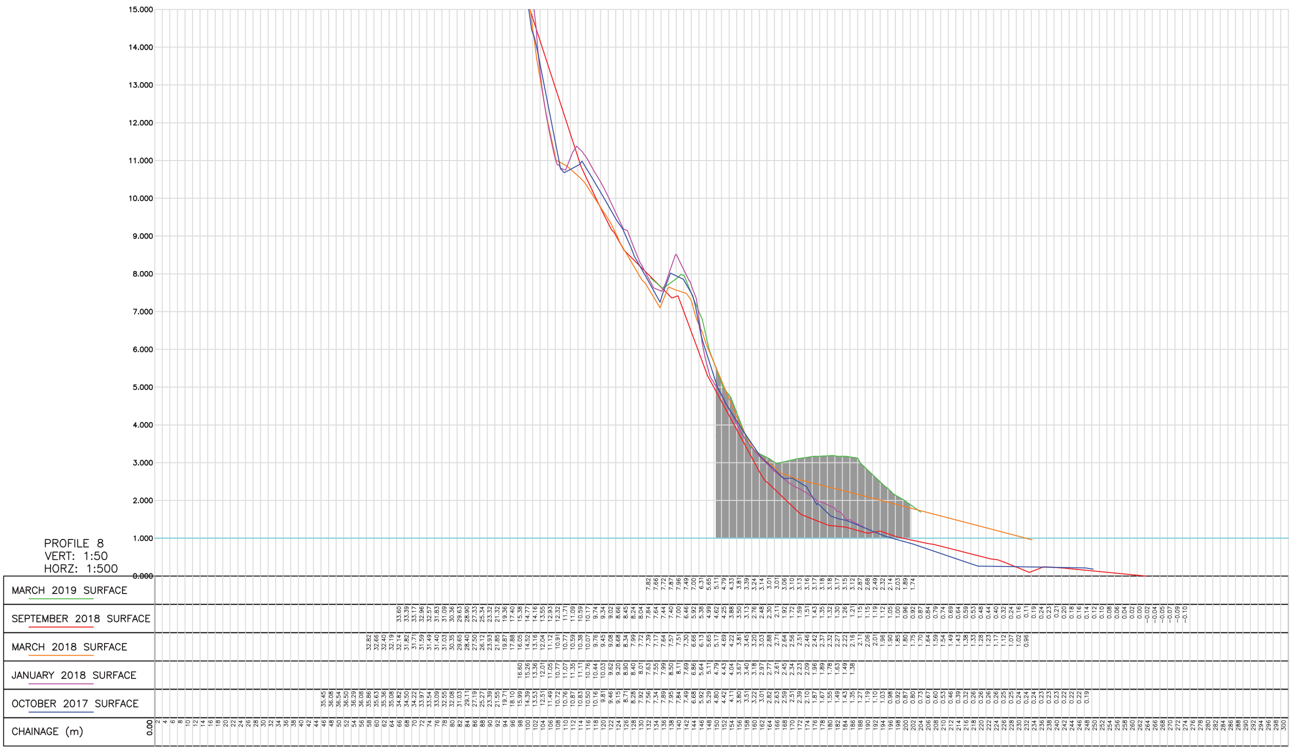

PROFILE 8

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TRACED			
REVISION		CHANGES	CHECKED / DATE

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PLOT DATE: 8/1/2019 3:55 PM

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NZIS REGISTERED PROFESSIONAL SURVEYOR

CLIENT: McCULLUM BROS

PROJECT: PAKIRI BEACH

TITLE: AERIAL SURVEY OCTOBER 2017- MARCH 2019 PROFILE

SCALE: 1:500 (A1) 1:1000 (A3)

SHEET: 10 of 10

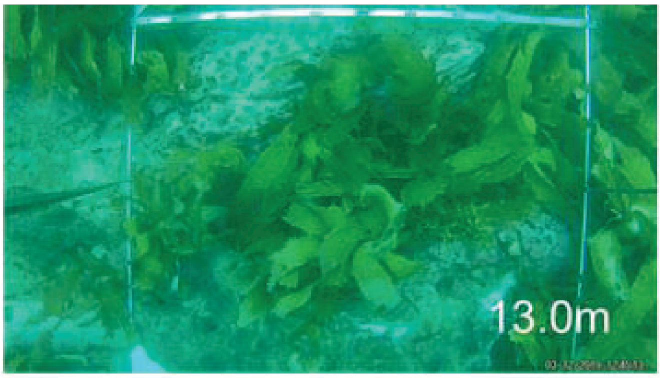
REVISION: 2

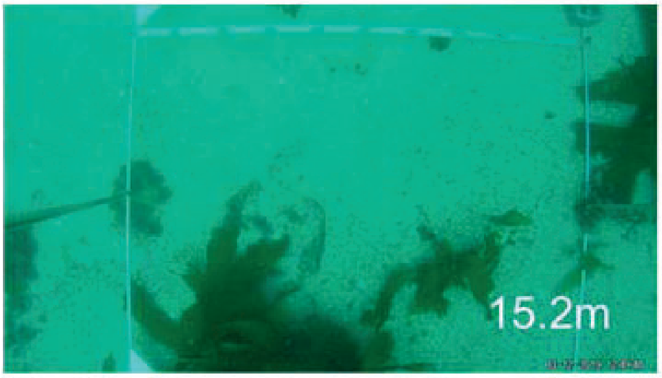
DRAWING No: 2249-705-11

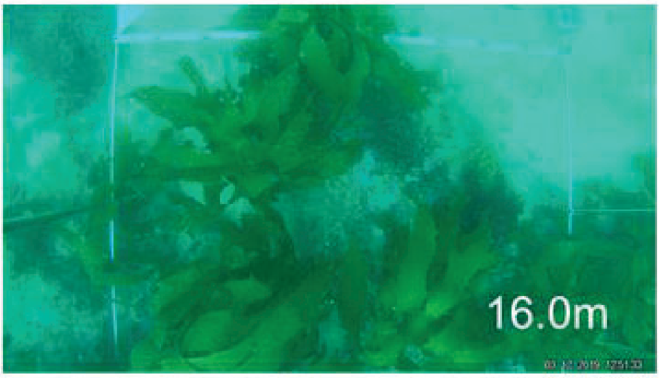
Appendix M. Bream Tail Sediment Photos

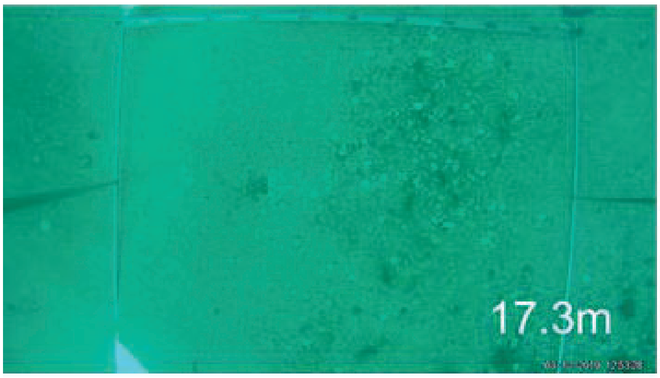
Bream Tail Sediment Photos

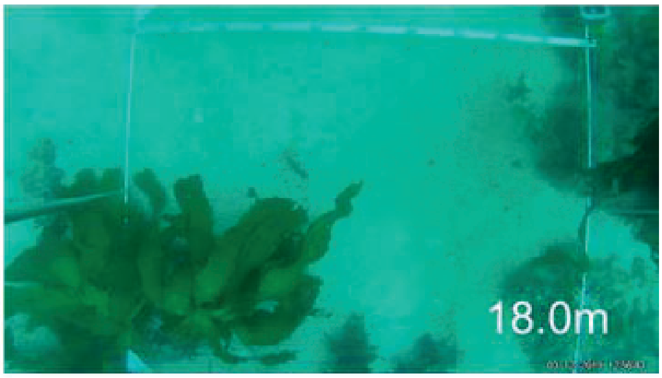
From Seabed micro-topography drop camera transect

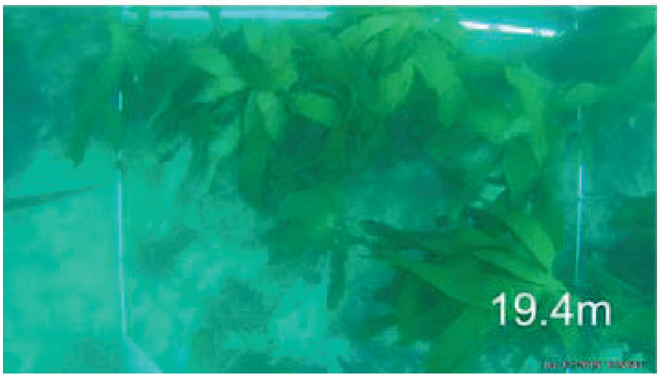


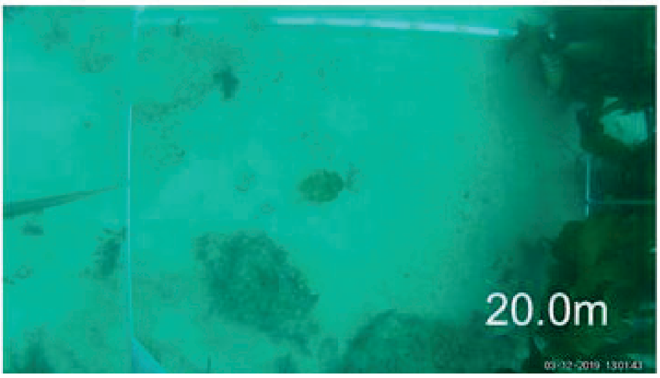


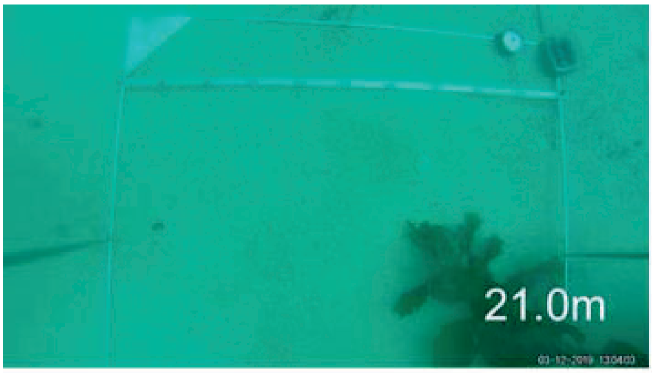








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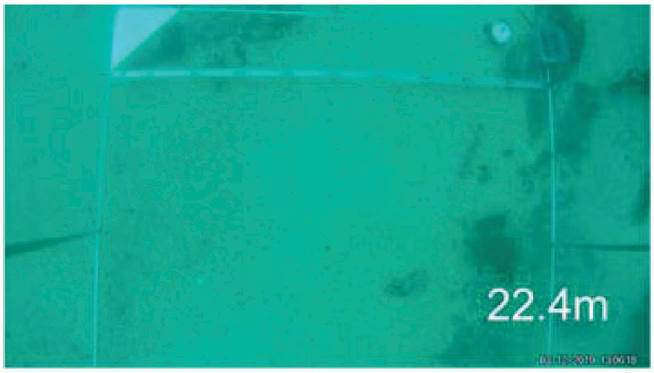
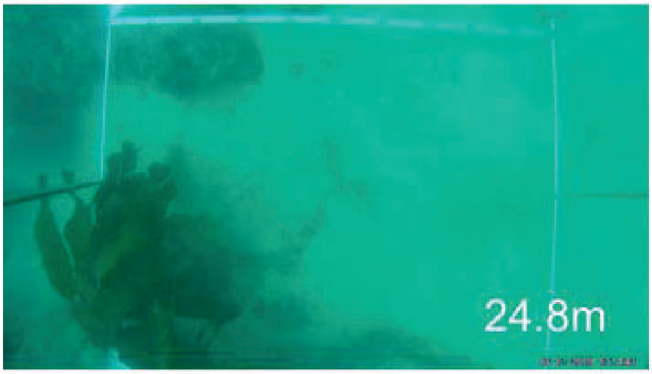

22.4m


23.2m


23.6m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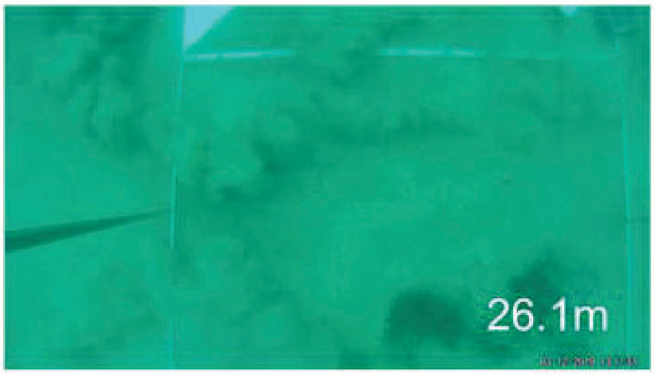
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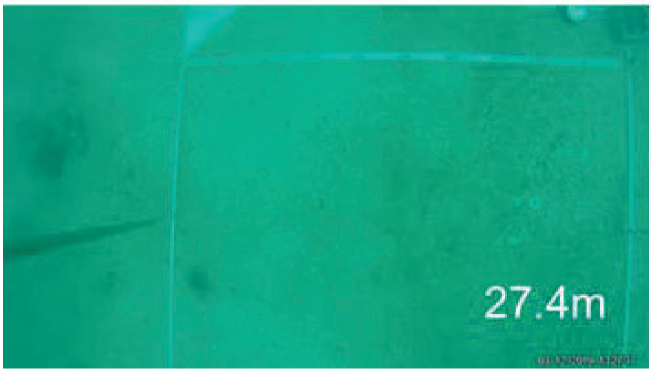
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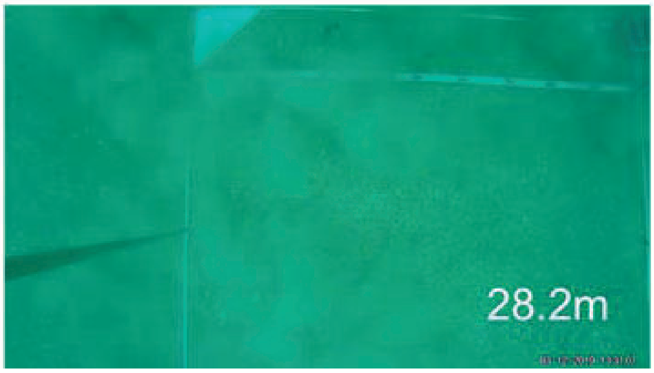
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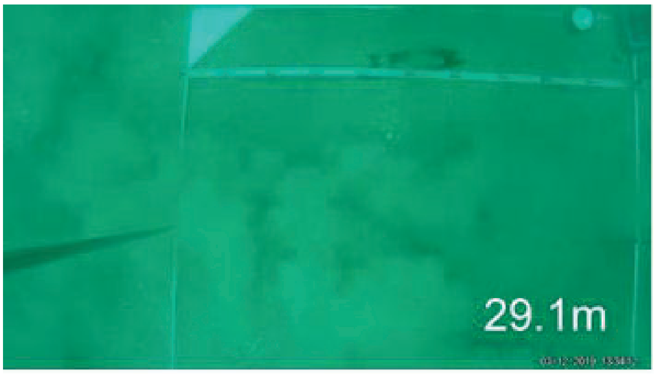
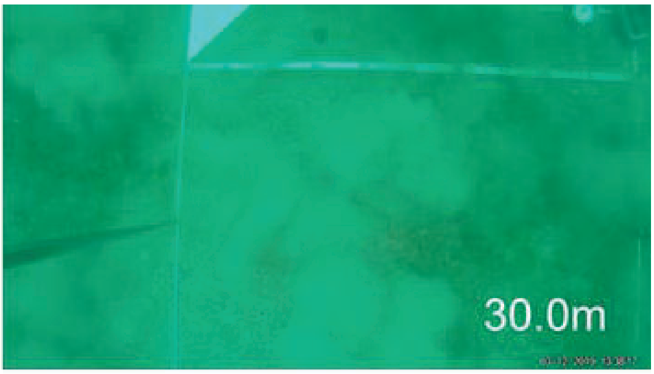
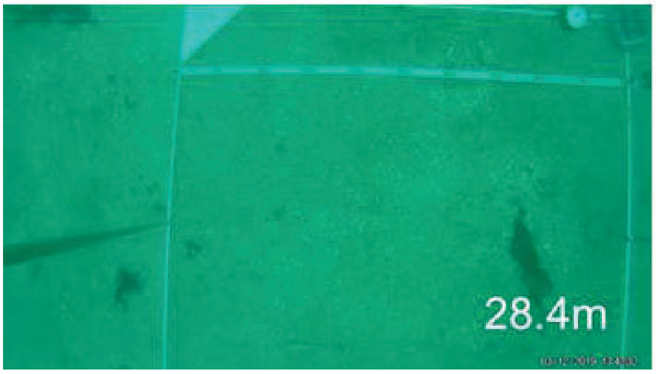
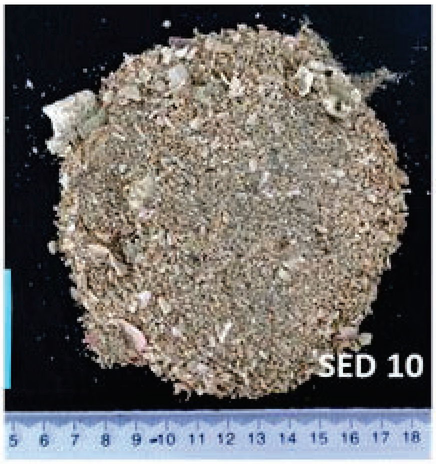
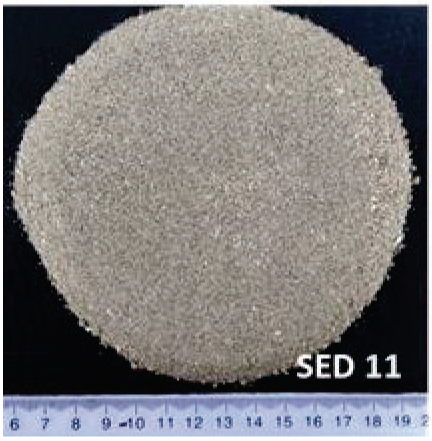




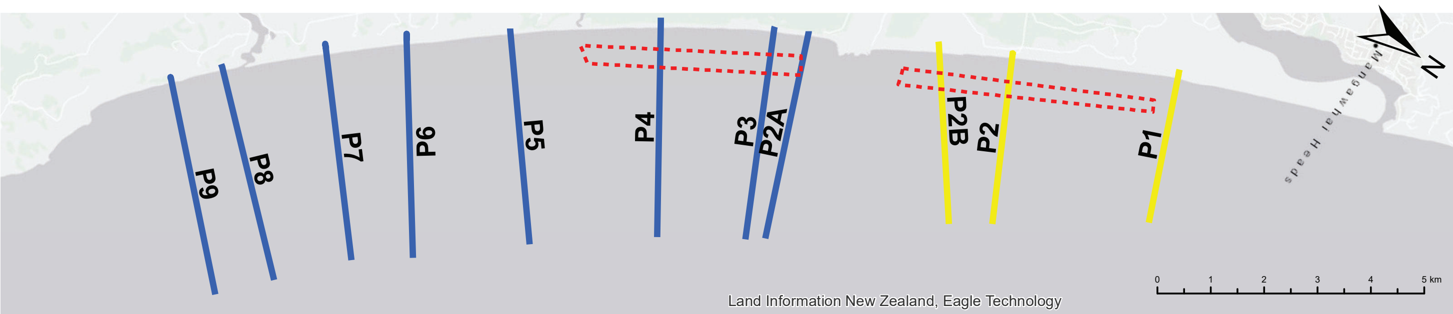


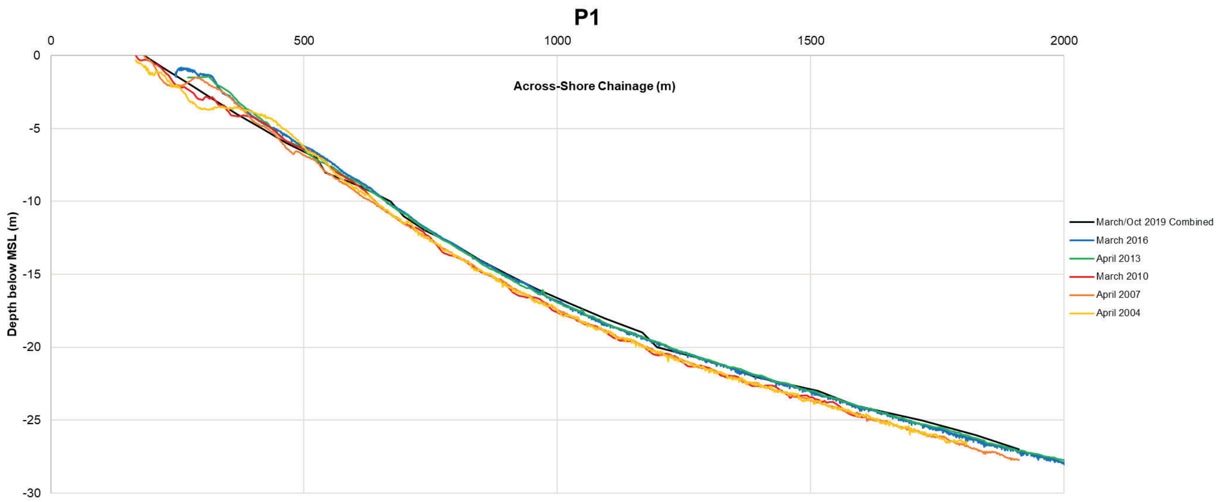
Photographs of sediment samples

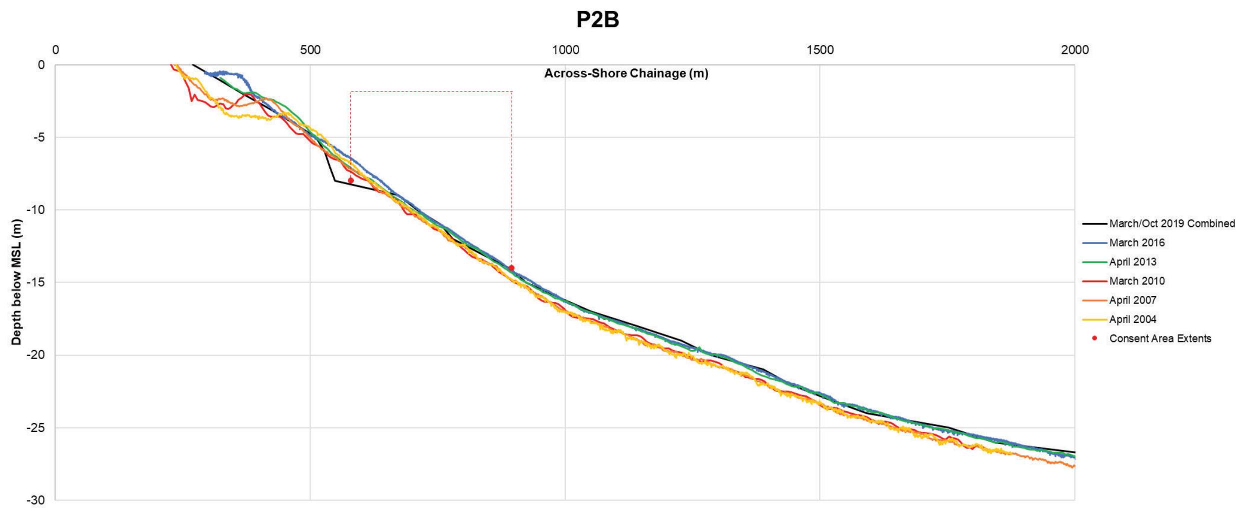




Appendix N. Three Yearly Nearshore Profile Comparisons 2004-2019







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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

Bathymetric Surveys (2004-2019) at Historical Survey Sites

Profiles 1-2b

Note: March/Oct 2019 survey is a combination of a March 2019 (0 to approx -20m contour) survey inshore and the October 2019 survey (seaward of approx -20m contour).

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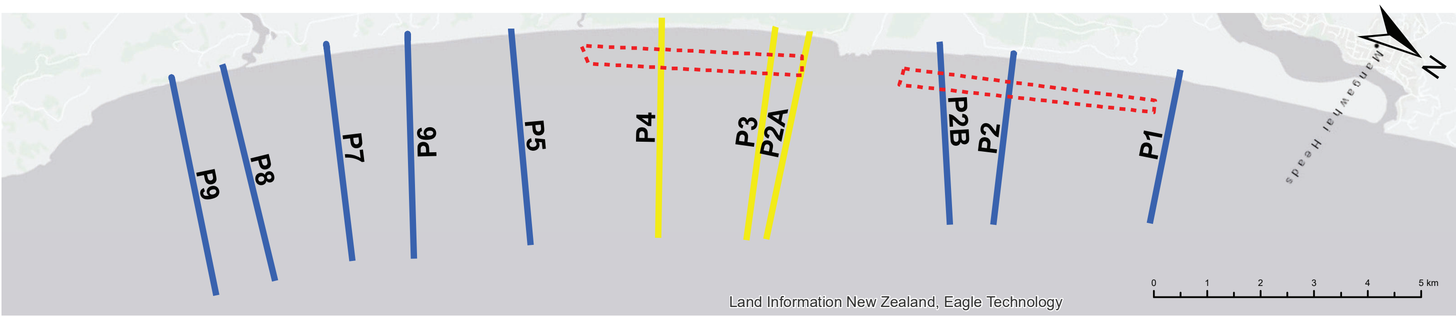
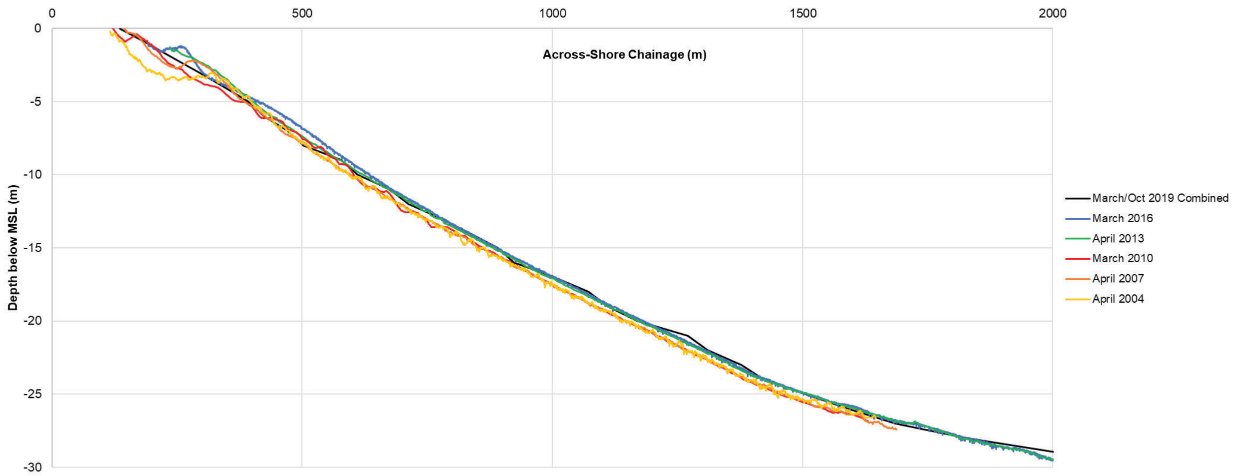
F +64 3 940 4901



P2A



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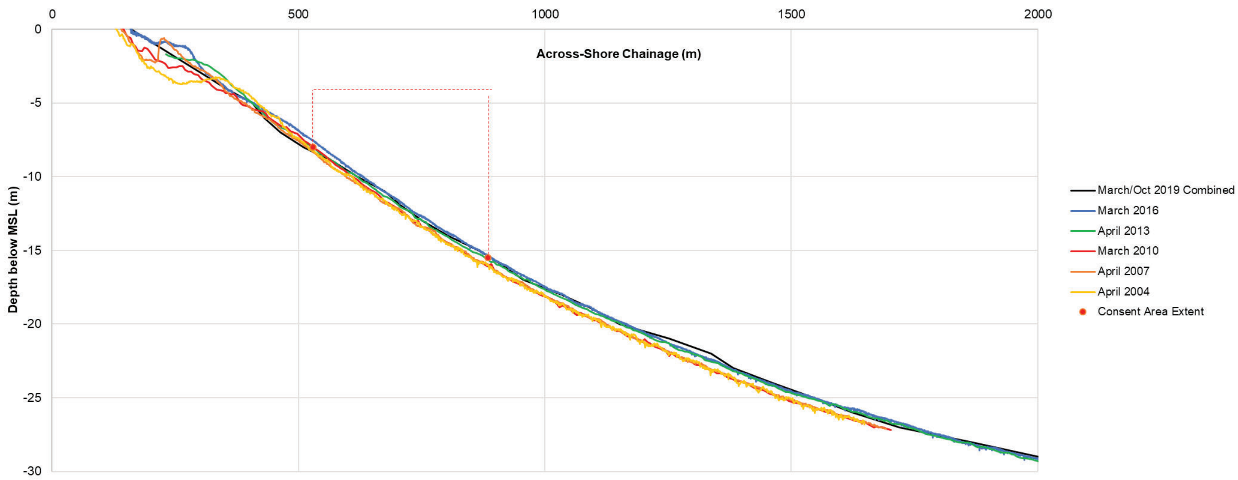

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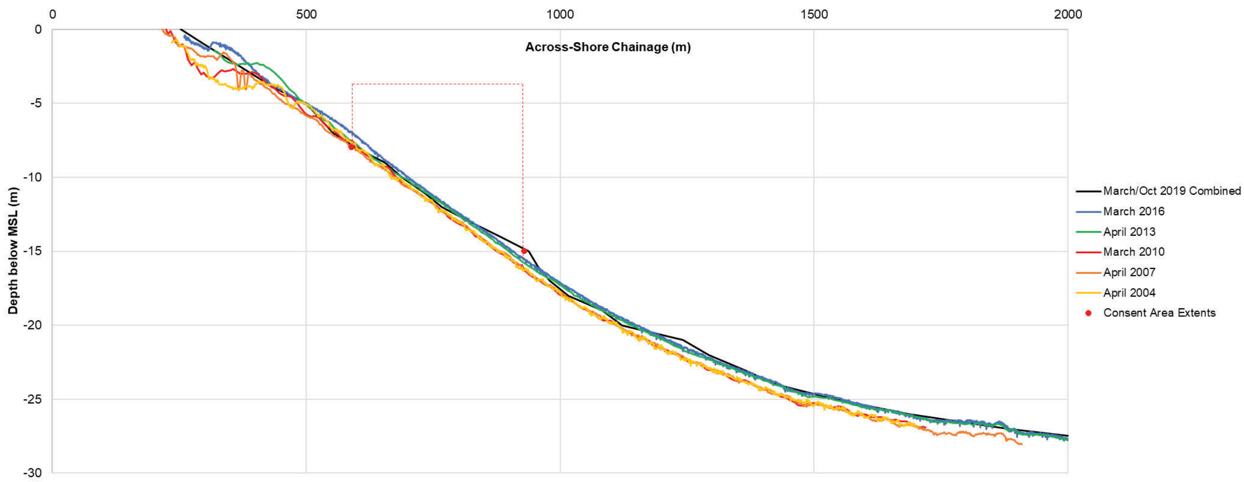

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

Bathymetric Surveys (2004-2019) at Historical Survey Sites

Profiles 2a-4

Note: March/Oct 2019 survey is a combination of a March 2019 (0 to approx -20m contour) survey inshore and the October 2019 survey (seaward of approx -20m contour).

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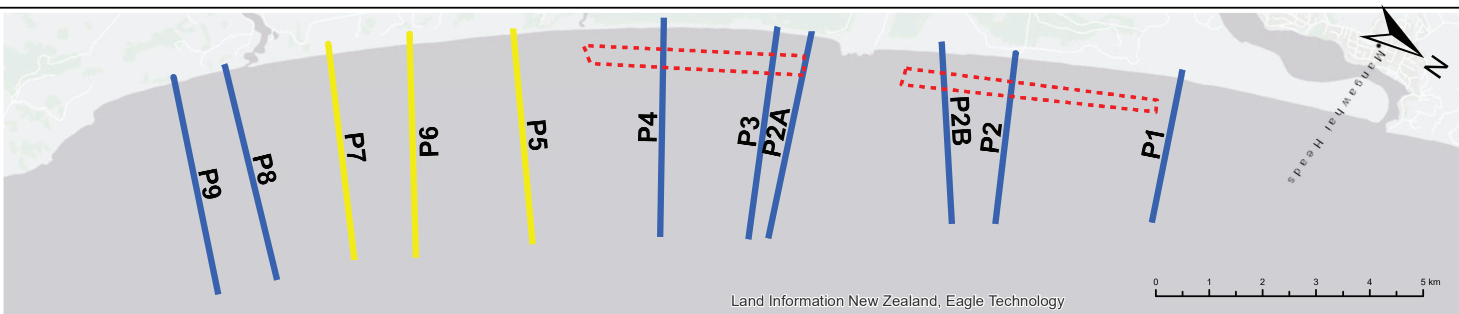

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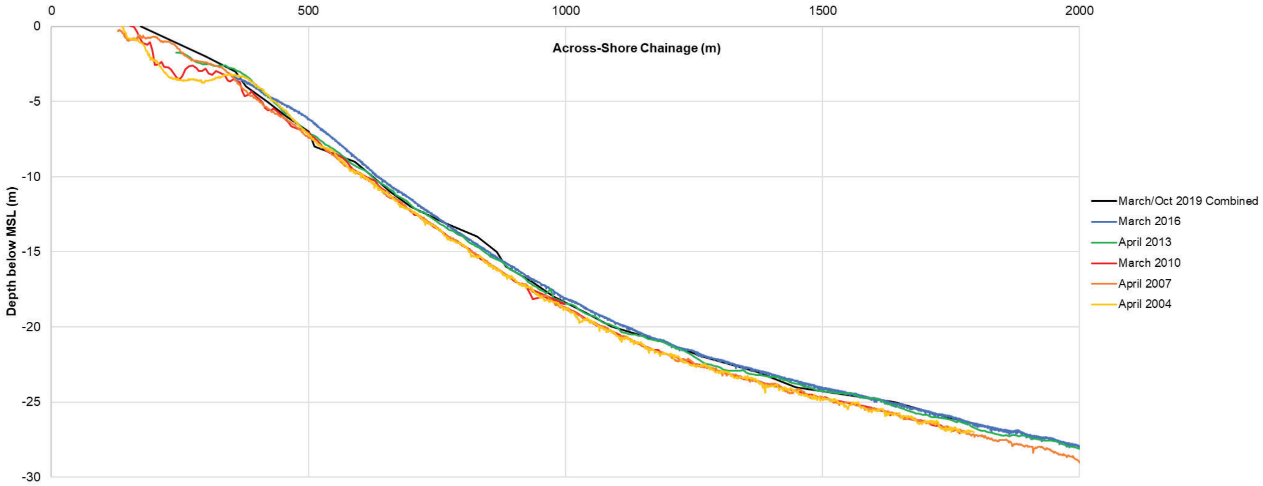

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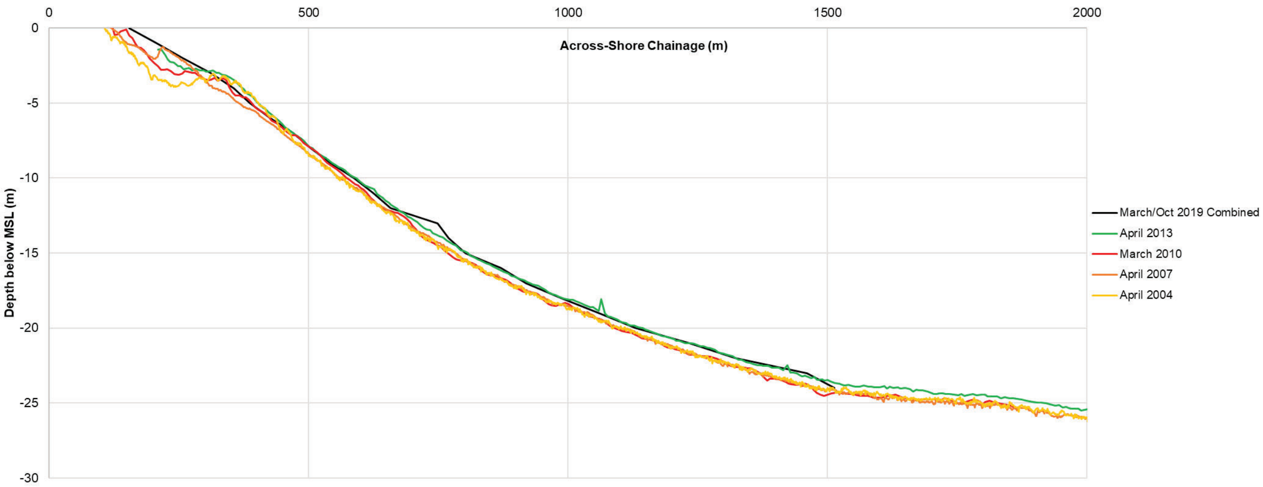

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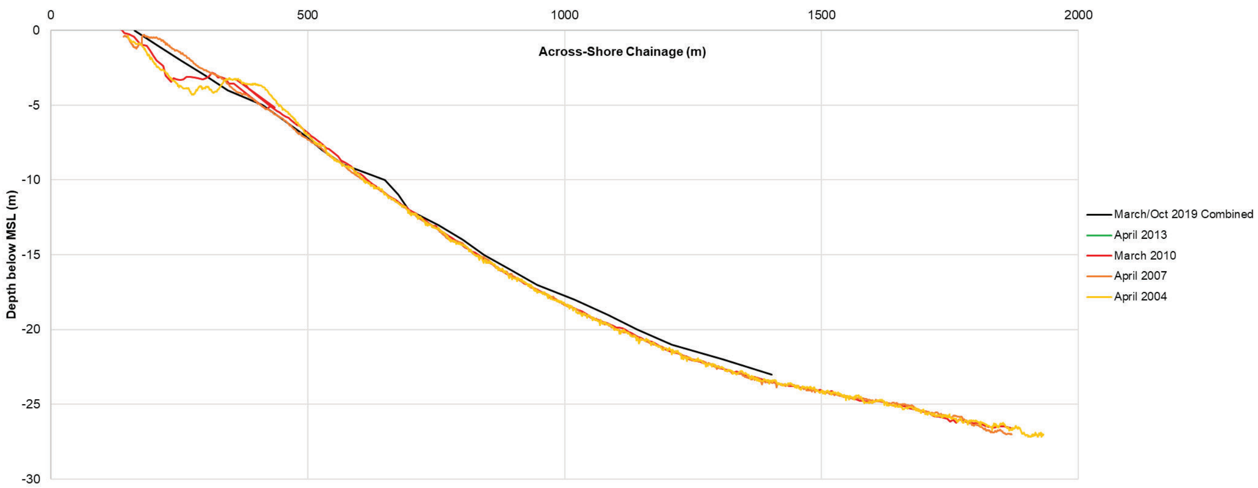

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 1/23/2020

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

Bathymetric Surveys (2004-2019) at Historical Survey Sites

Profiles 5-7

Note: March/Oct 2019 survey is a combination of a March 2019 (0 to approx -20m contour) survey inshore and the October 2019 survey (seaward of approx -20m contour).

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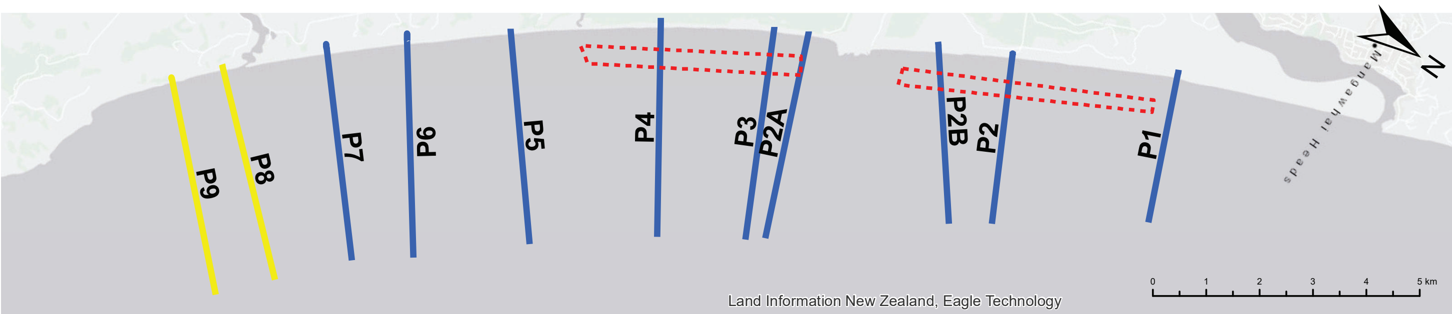

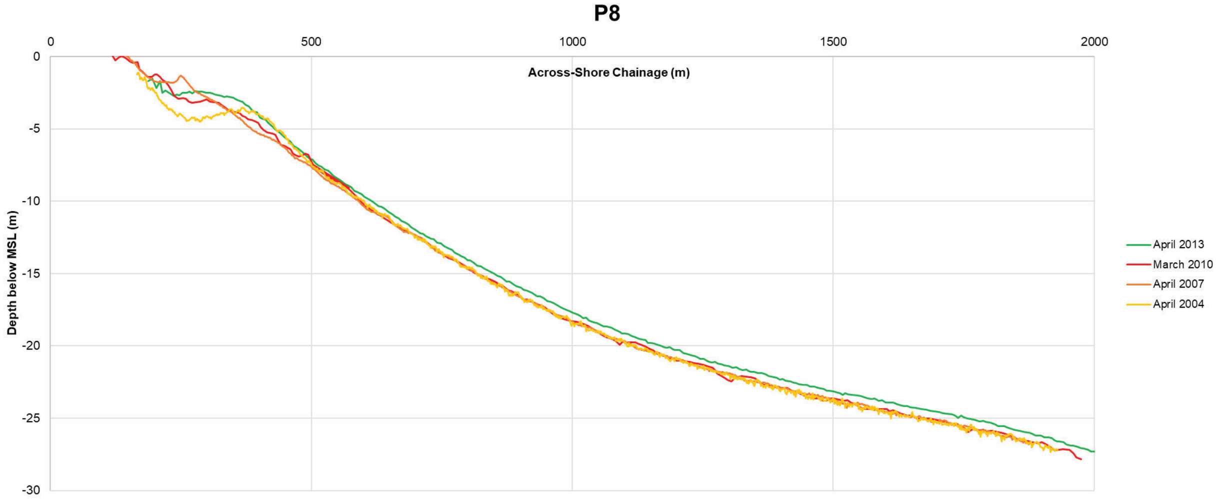

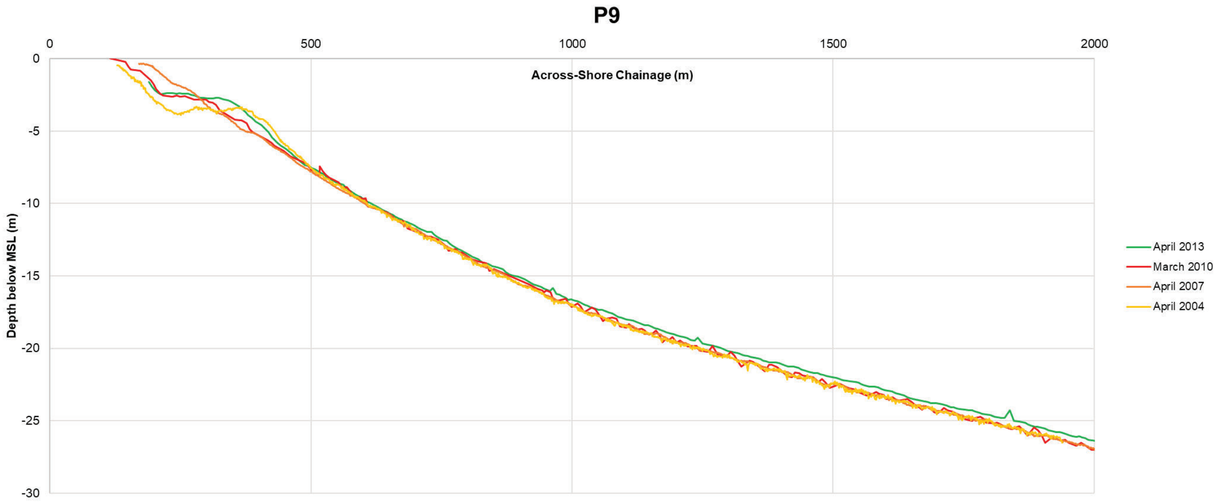

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/18/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

Bathymetric Surveys (2004-2019) at Historical Survey Sites

Profiles 8-9

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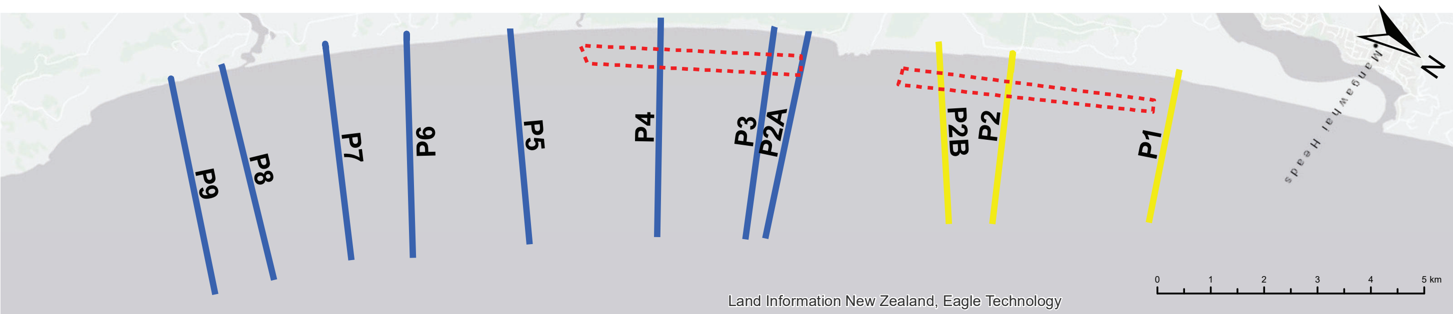
Appendix O. Nearshore Bar Changes 2004-2016



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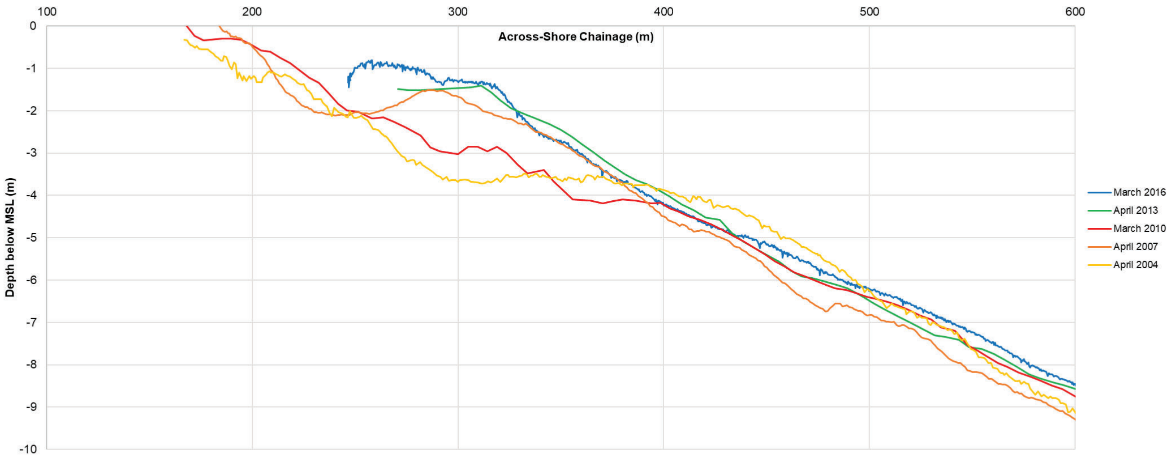

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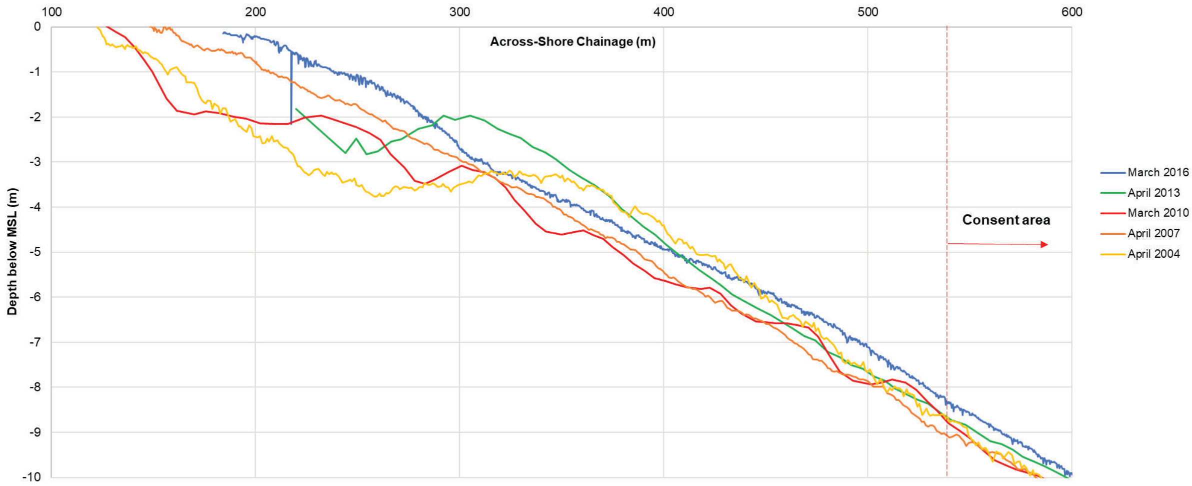

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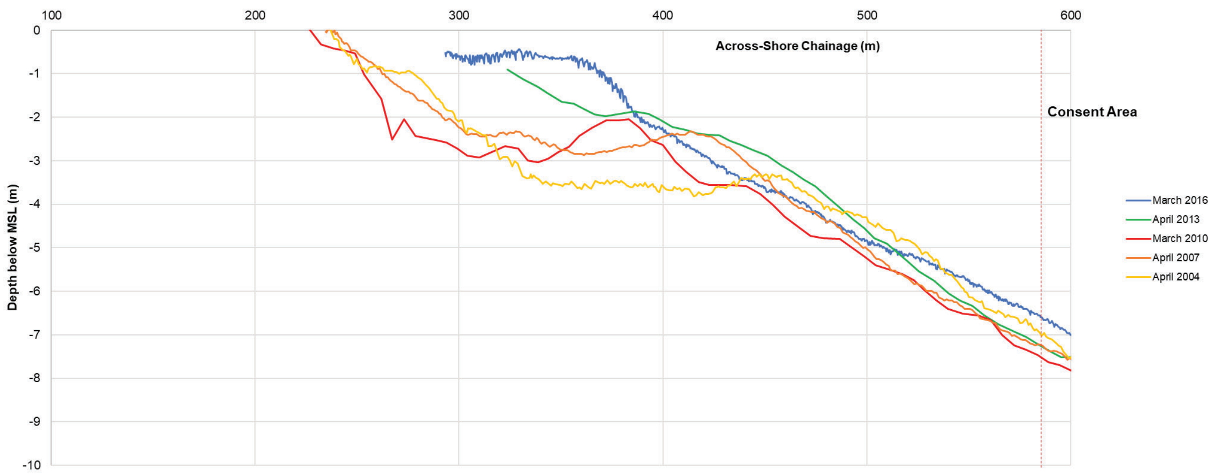

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/6/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

2004-2016 Nearshore Bathymetry at Historical Profiles

Profiles 1-2b

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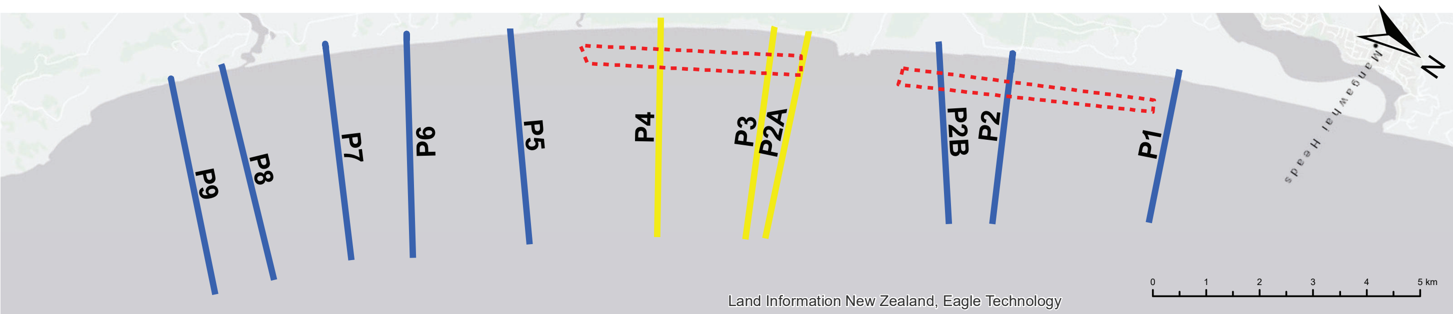

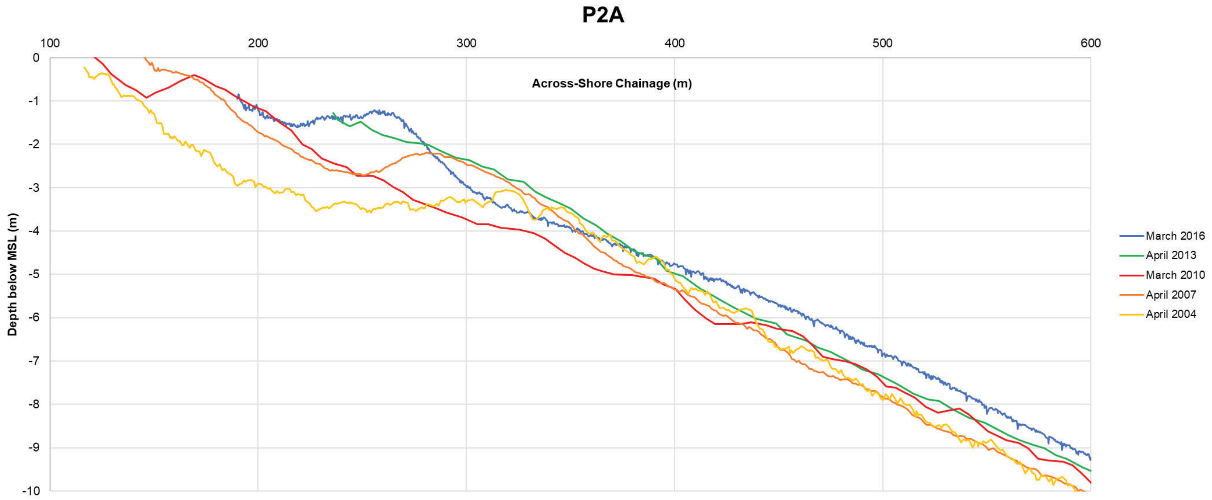

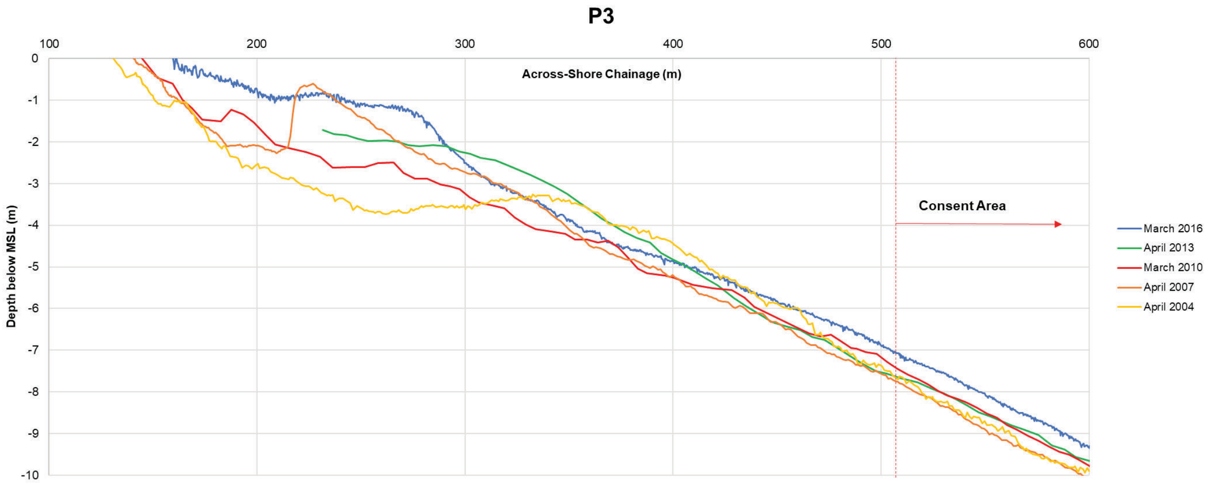

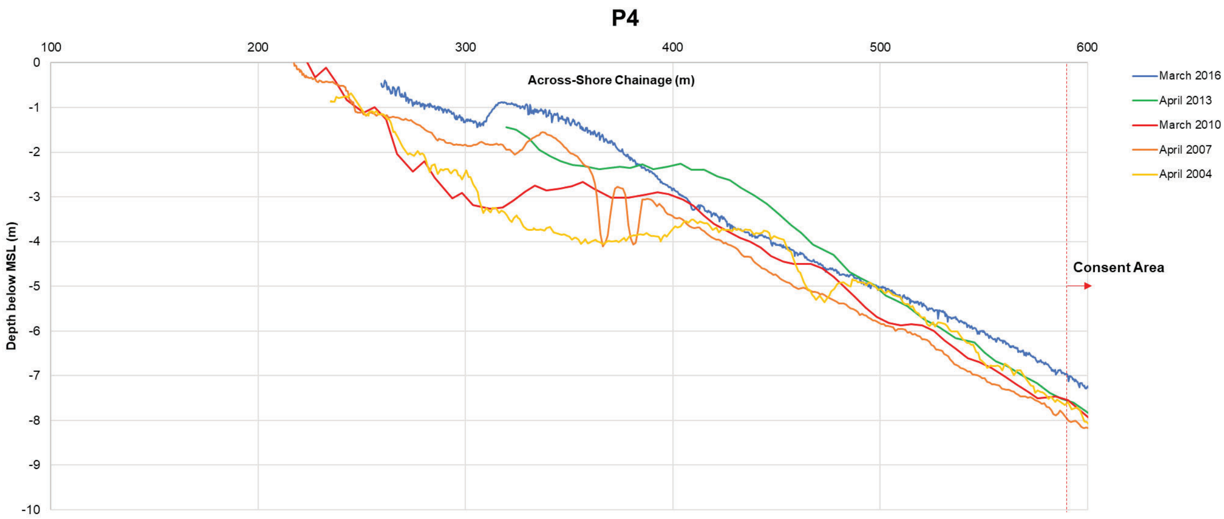

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/6/2019

Legend

Renewal Consent Area
Historical Profiles Analysed
Other Historical Profiles

2004-2016 Nearshore Bathymetry at Historical Profiles

Profiles 2a-4

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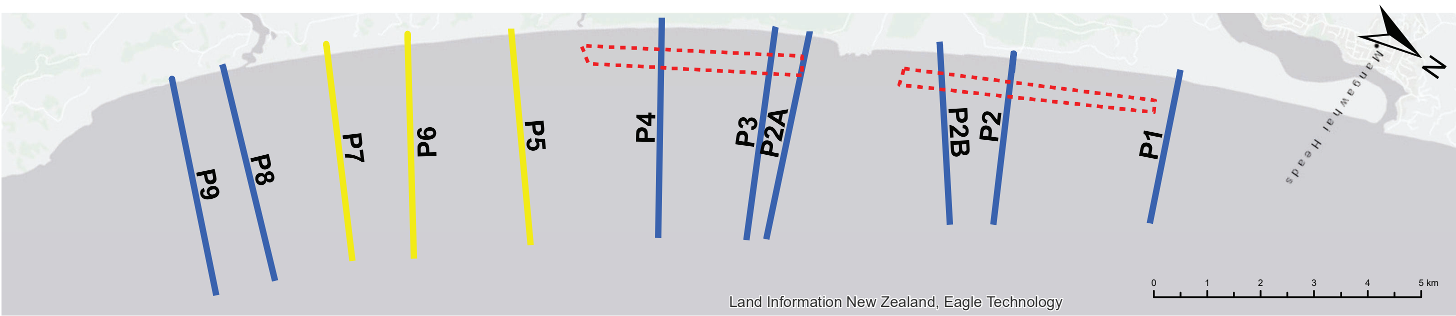

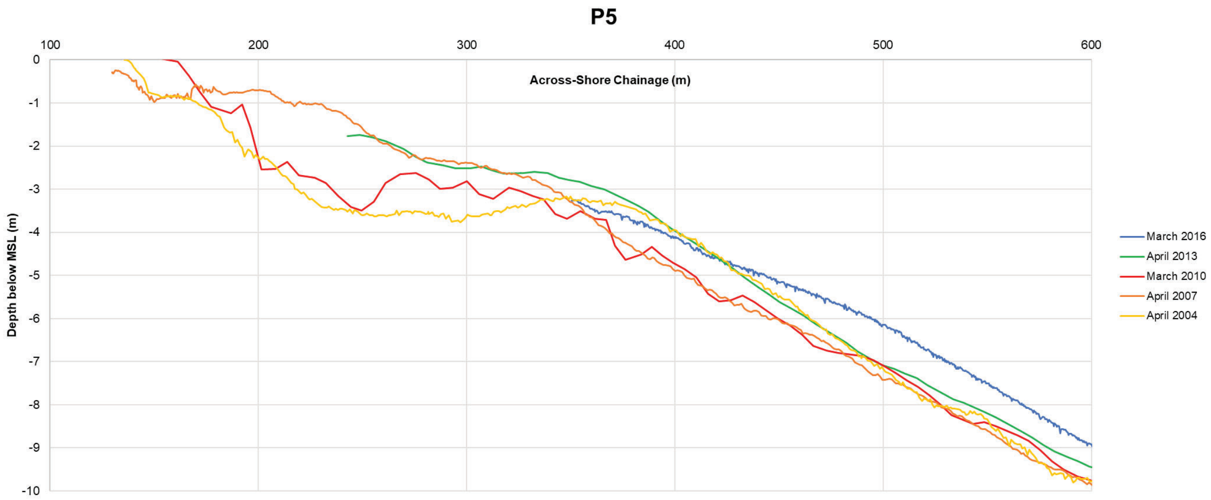

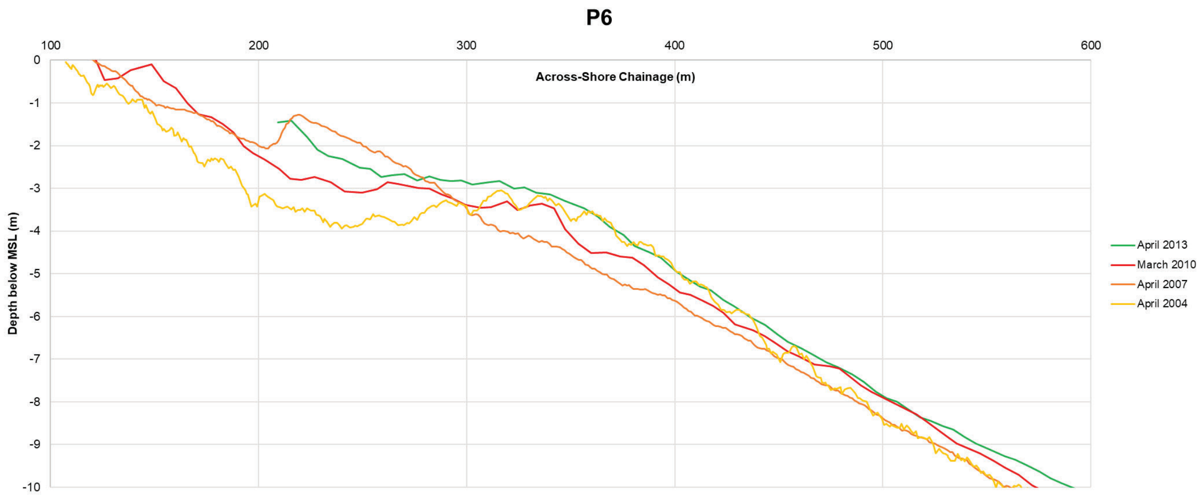

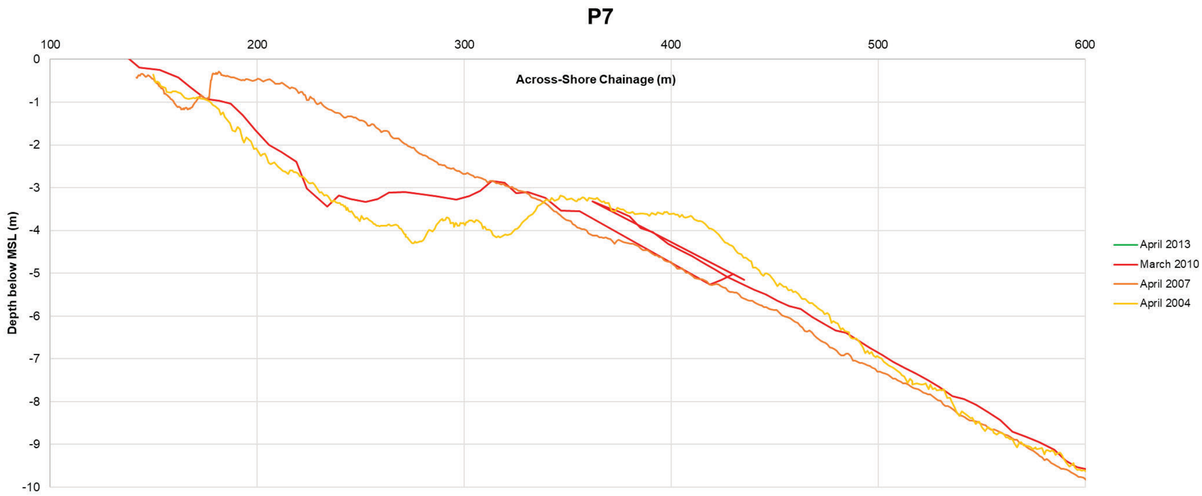

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/6/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

2004-2016 Nearshore Bathymetry at Historical Profiles

Profiles 5-7

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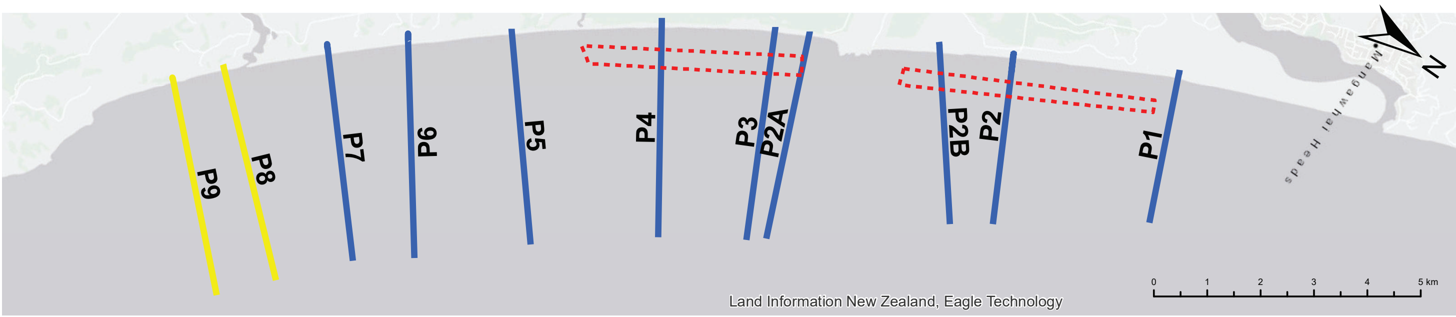

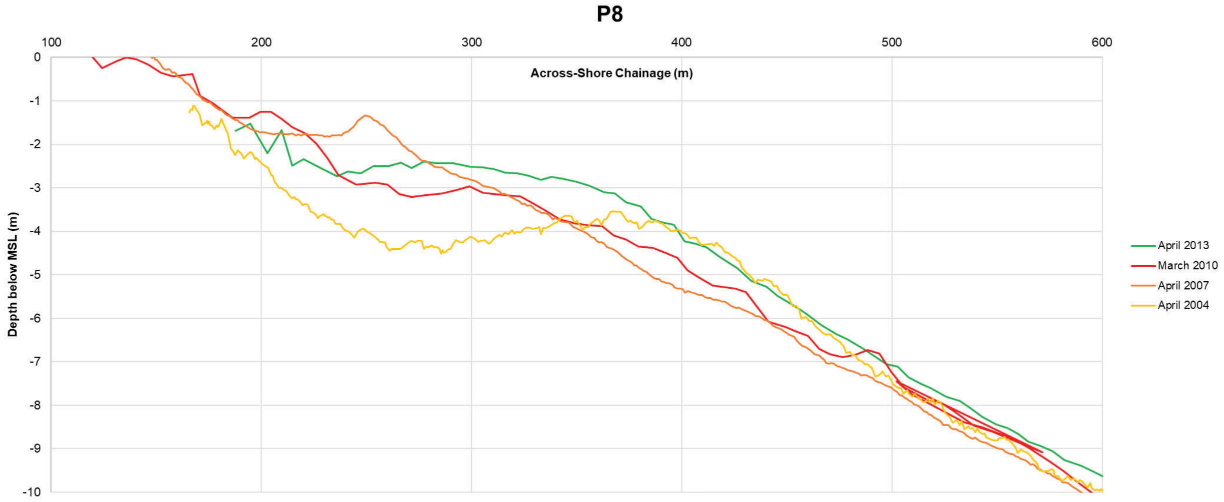

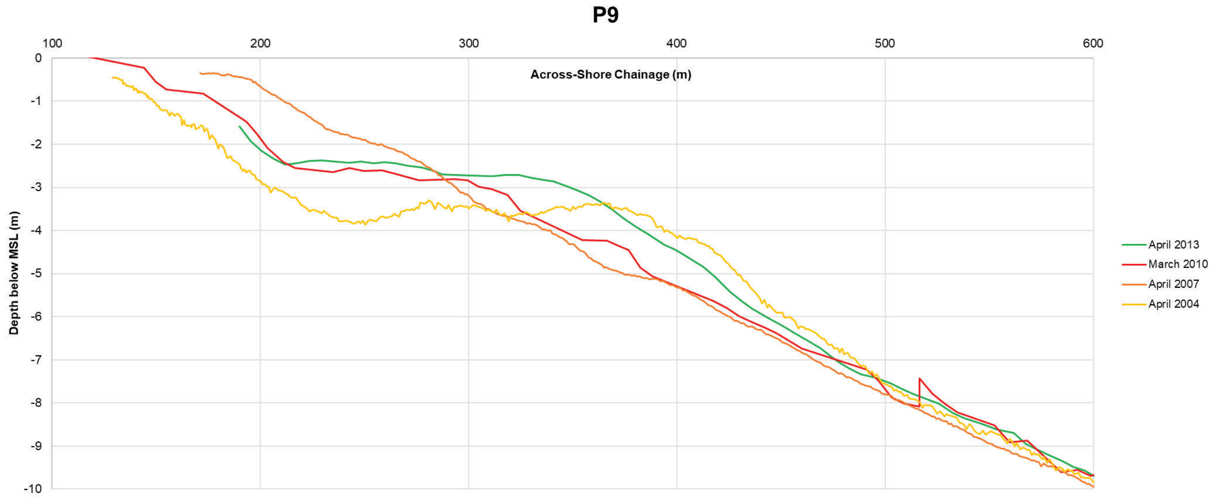

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CLIENT Client	
PROJECT McCallum Brothers Ltd Pakiri Sand Extraction Consent	
SCALE 1:100,000 @ A3	PROJECT CODE IZ111900
PROJECT MANAGER IW	DRAWN KM
PROJECT DIRECTOR DT	DATE 12/6/2019

Legend

- Renewal Consent Area
- Historical Profiles Analysed
- Other Historical Profiles

2004-2016 Nearshore Bathymetry at Historical Profiles

Profiles 8-9

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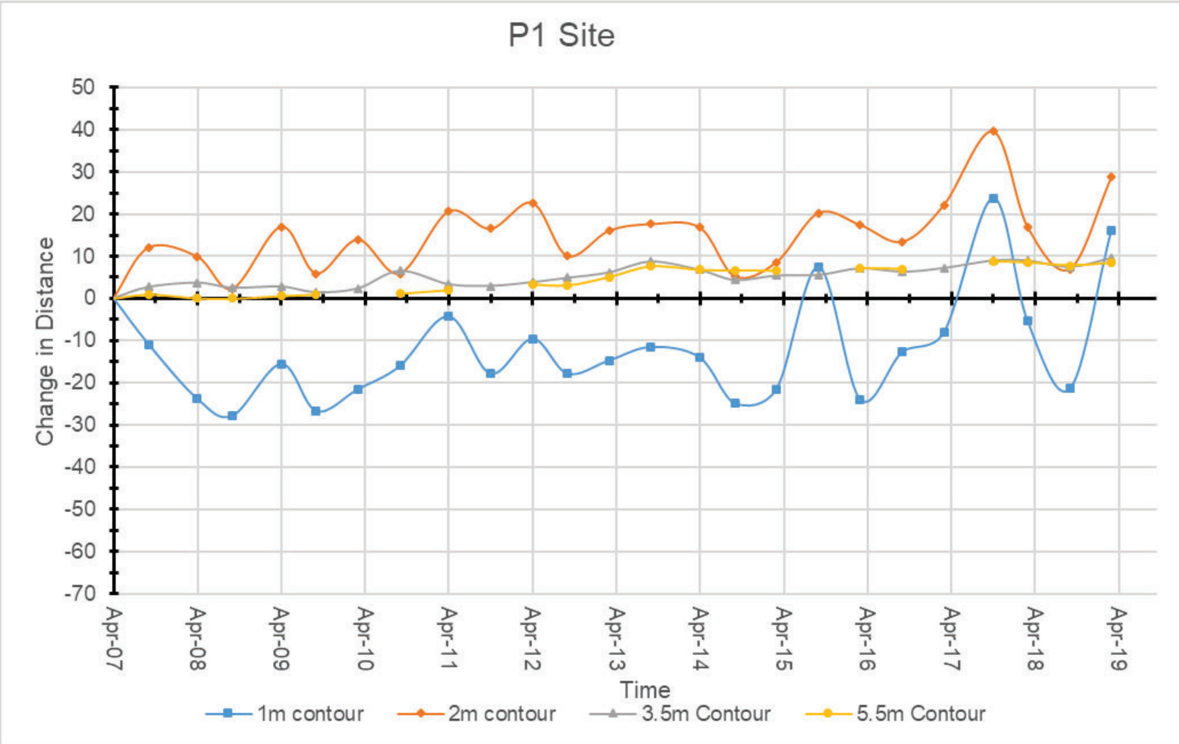
Appendix P. Excursion Distance Analysis - Historical Profile Sites 2007-2019

Net Change over time											
3.5m Contour	**P1**	**P2**	**P2B**	**P2A**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Apr-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep-07	2.7	-10.9	1.2	-4.6	-7.2	-10.1	-17.8	-11.2	-12.2	-5.7	-5.1
Apr-08	3.7	-10.5	2.5	-2.1	-7.6	-12.1	-17.1	-14.0	-12.0	-6.6	-7.8
Sep-08	2.5	-11.7	2.4	-20.6	-8.1	-13.5	-22.0	-14.8	-15.4	-13.2	-11.5
Apr-09	2.8	-6.3	6.7	-2.2	-5.6	-7.1	-16.5	-10.4	-12.0	-11.0	-6.7
Sep-09	1.4	-9.4	4.1	-5.0	-7.9	-24.0	-21.4	-13.5	-13.3	-11.6	-10.5
Mar-10	2.3	-7.8	7.5	-2.3	-6.9	-10.3	-18.1	-10.6	-11.8	-12.1	-10.2
Sep-10	6.6	-10.1	6.8	-1.9	-7.2	-9.9	-19.8	-11.7	-11.8	-11.7	-11.0
Apr-11	3.4	-10.4	9.5	0.8	-7.2	9.8	-17.7	-11.9	-12.2	-10.6	-9.8
Oct-11	2.9	-10.2	8.3	-1.4	-9.1	-6.9	-22.0	-12.5	-16.4	-14.0	-12.4
Apr-12	3.9	-9.4	9.7	-1.6	-7.1	-6.2	-21.1	-11.3	-14.0	-12.4	-10.8
Sep-12	4.9	-14.1	11.6	-1.5	-6.5	-9.7	-21.2	-12.3	-18.4	-13.6	-13.3
Mar-13	6.2	-12.4	13.3	-0.1	-3.1	-7.2	-19.7	-8.1	-13.9	-9.3	-9.1
Sep-13	8.8	-8.5	14.7	0.9	-5.7	-7.3	-20.4	-9.3	-13.8	-10.9	-11.8
Apr-14	6.8	-11.6	14.9	0.8	-5.5	-7.3	-18.4	-7.8	-11.1	-8.6	-9.5
Sep-14	4.4	-16.7	8.5	-3.6	-8.7	-10.2	-21.4	-16.9	-14.9	-15.9	-12.6
Mar-15	5.4	-10.9	17.6	-13.0	-7.3	-5.1	-20.0	-7.6	-9.7	-7.6	-10.5
Sep-15	5.6	-9.3	14.9	3.0	-6.5	-4.4	-15.2	-8.6	-8.1	-11.3	-10.7
Mar-16	7.2	-9.8	15.7	4.5	-4.3	-3.6	-18.3	-8.8	-10.4	-8.7	-7.1
Sep-16	6.3	-5.7	16.7	0.1	-5.2	-4.0	-20.1	-12.8	-16.6	-11.8	-10.6
Mar-17	7.3	-7.2	16.0	1.5	-2.9	-3.8	-21.3	-10.5	-12.8	-10.6	-8.9
Oct-17	9.0	-7.9	18.1	2.8	-3.5	-1.2	-21.8	-8.8	-12.5	-7.9	No data
Mar-18	9.0	-6.3	19.3	1.3	-4.5	-4.2	-30.0	-10.3	-13.3	-8.3	No data
Sep-18	7.5	-6.0	20.7	2.5	-4.8	-4.2	-27.3	-10.7	-13.7	-10.4	No data
Mar-19	9.6	-4.8	22.8	0.3	-4.2	-4.7	-22.9	-10.9	-11.6	-11.0	No data

Net Change over time											
5.5m Contour	**P1**	**P2**	**P2B**	**P2A**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Apr-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep-07	0.9	-7.9	4.0	-2.2	0.9	-1.9	-26.0	0.3	-1.6	-0.9	1.2
Apr-08	0.1	6.8	5.8	4.6	2.4	-4.1	-8.1	-1.1	-1.2	-2.3	-1.4
Sep-08	0.0	-0.9	10.8	-1.7	0.5	-5.5	-12.5	-2.4	-3.4	-2.4	-0.8
Apr-09	0.6	-0.5	5.7	5.6	1.9	-5.0	-8.2	-2.6	-3.3	-3.0	-0.6
Sep-09	1.0	-1.0	11.7	3.0	6.2	-9.0	-9.9	-2.2	-2.4	-2.8	-0.4
Mar-10		-0.9	22.7	4.8	6.5	-7.1	-14.6	-2.2	-1.7	-3.7	-0.7
Sep-10	1.2	-0.5	25.1	8.2	6.5	-6.8	-18.6	-1.7	-1.8	-2.7	-0.6
Apr-11	2.0	0.0	25.9	7.9	6.3	-3.3	-14.6	-0.3	-2.7	-3.0	-1.1
Oct-11		0.7	25.2	2.8	5.5	-4.9	-22.0	-1.7	-5.3	-3.6	-2.0
Apr-12	3.4	0.4	25.6	6.0	1.5	-5.5	-13.4	-1.1	-2.2	-3.3	-1.4
Sep-12	3.1	-1.5	27.1	10.8	7.0	-6.3	-18.5	-1.1	-19.0	-3.7	-2.4
Mar-13	5.1	-1.3	29.6	4.8	6.4	-6.4	-18.5	-0.3	-8.6	-4.1	-2.2
Sep-13	7.6	0.0	29.8	11.1	7.2	-14.1	-17.4	0.7	-2.8	-4.1	-2.5
Apr-14	6.8	-0.9	30.2	10.4	4.2	-7.5	-15.5	-1.6	-9.0	-3.0	-1.6
Sep-14	6.6	-3.0	28.0	11.1	6.7	-6.5	-17.1	-2.4	-3.2	-4.6	-1.8
Mar-15	6.6	-2.3	32.7	2.7	6.5	-7.3	-21.8	-2.0	-3.2	-4.4	-2.4
Sep-15		-2.7	33.6	12.1	6.3	-7.3	-18.2	-1.4	-3.3	-4.4	-2.3
Mar-16	7.2	-2.2	32.6	12.8	5.7	-7.2	-22.1	-1.3	-3.2	-4.4	-1.9
Sep-16	7.0	-2.8	33.7	14.9	6.7	-6.1	-17.4	-0.2	-4.5	-4.1	-2.3
Mar-17		-0.4	35.2	15.4	5.8	-6.9	-20.6	-0.5	-10.2	-2.9	-1.1
Oct-17	8.7	1.2	36.6	17.5	8.5	-3.1	-23.4	0.4	-3.2	-3.0	No data
Mar-18	8.5	0.6	36.5	17.7	9.1	-8.1	-15.0	-0.6	-3.0	-1.7	No data
Sep-18	7.8	0.9	38.1	16.4	9.5	-7.5	-8.3	0.5	-4.3	-3.4	No data
Mar-19	8.4	1.2	38.0	16.6	8.5	-12.7	-4.2	0.7	-2.8	-2.1	No data


P1 Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
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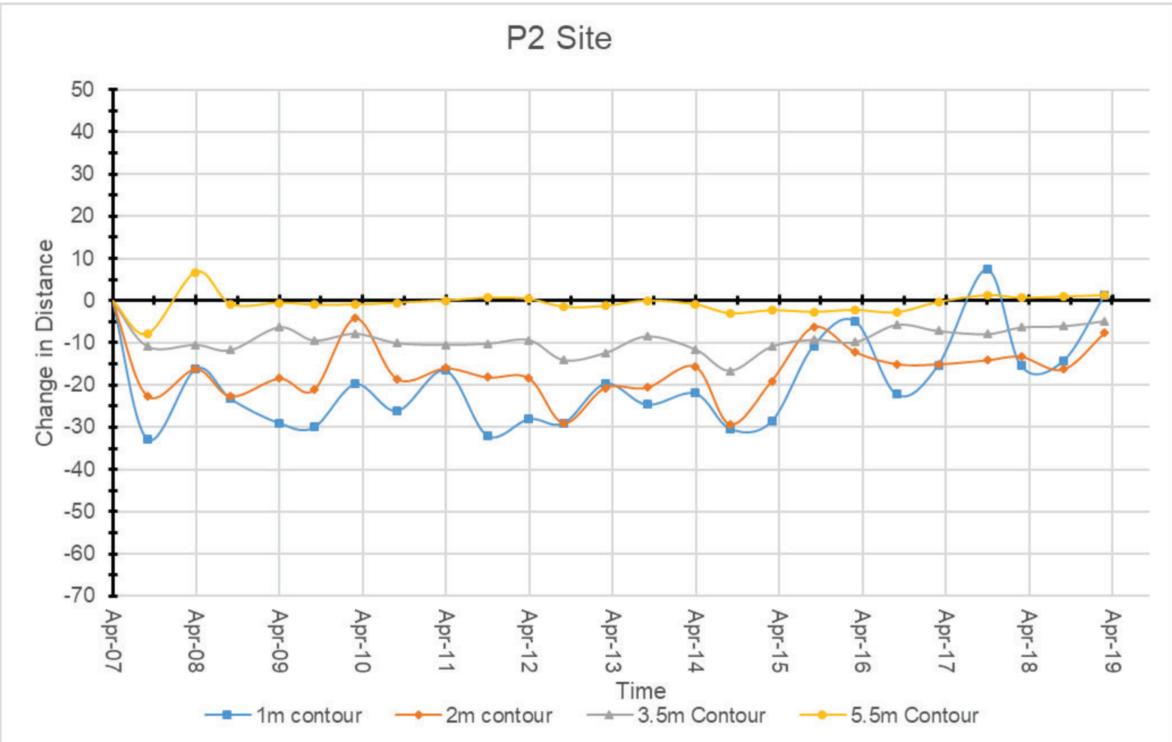
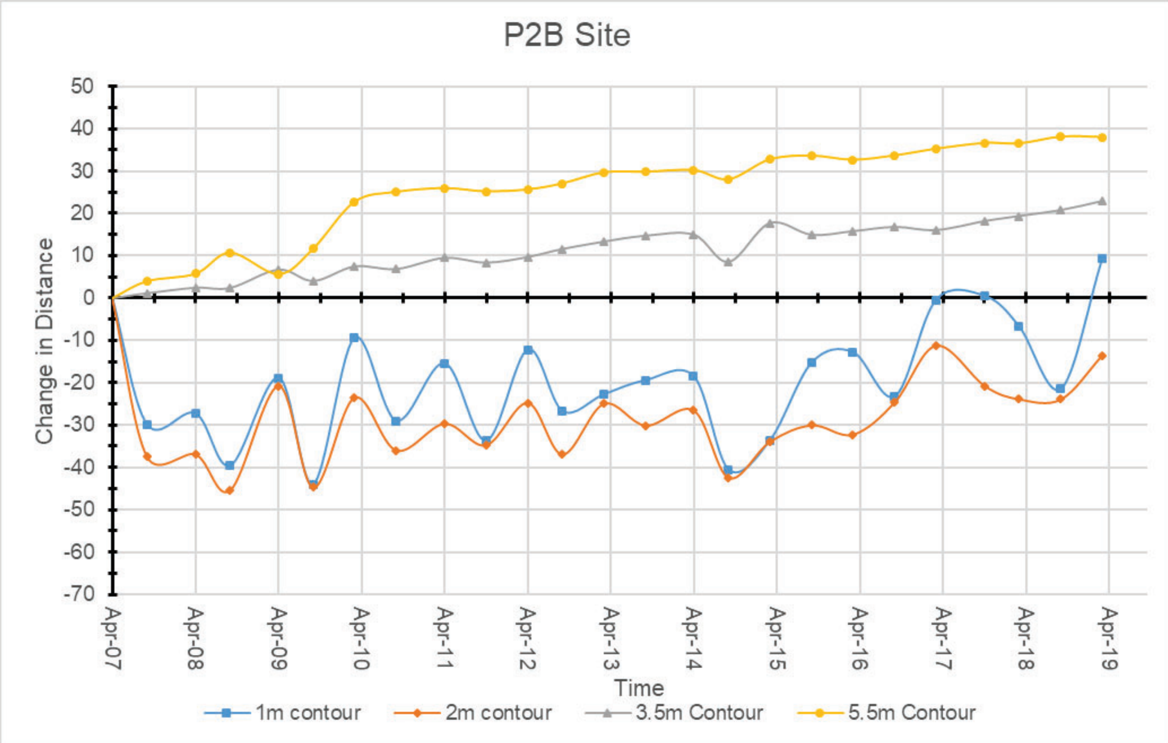
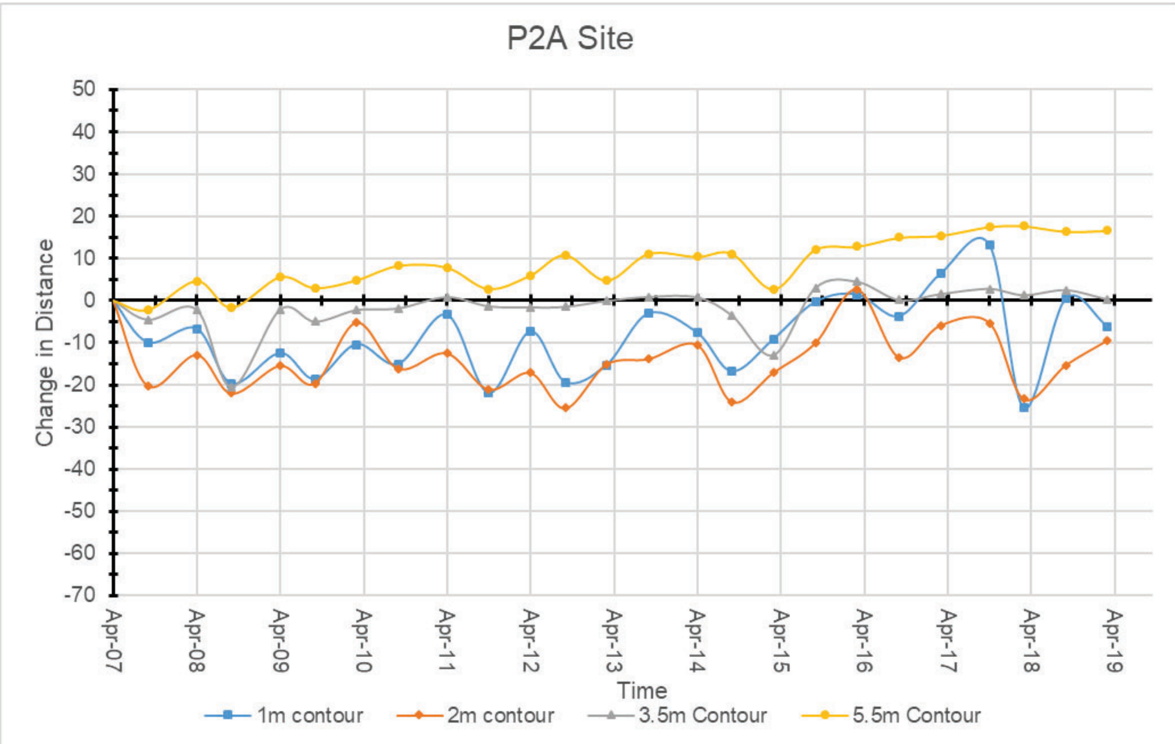
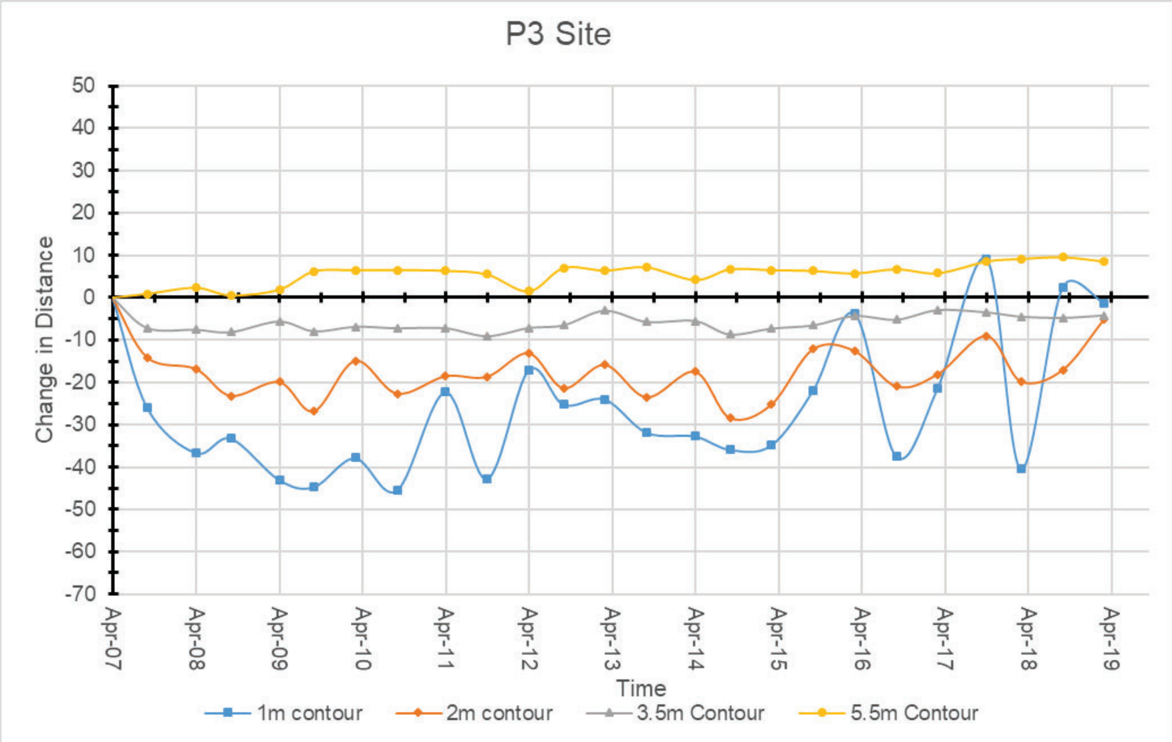
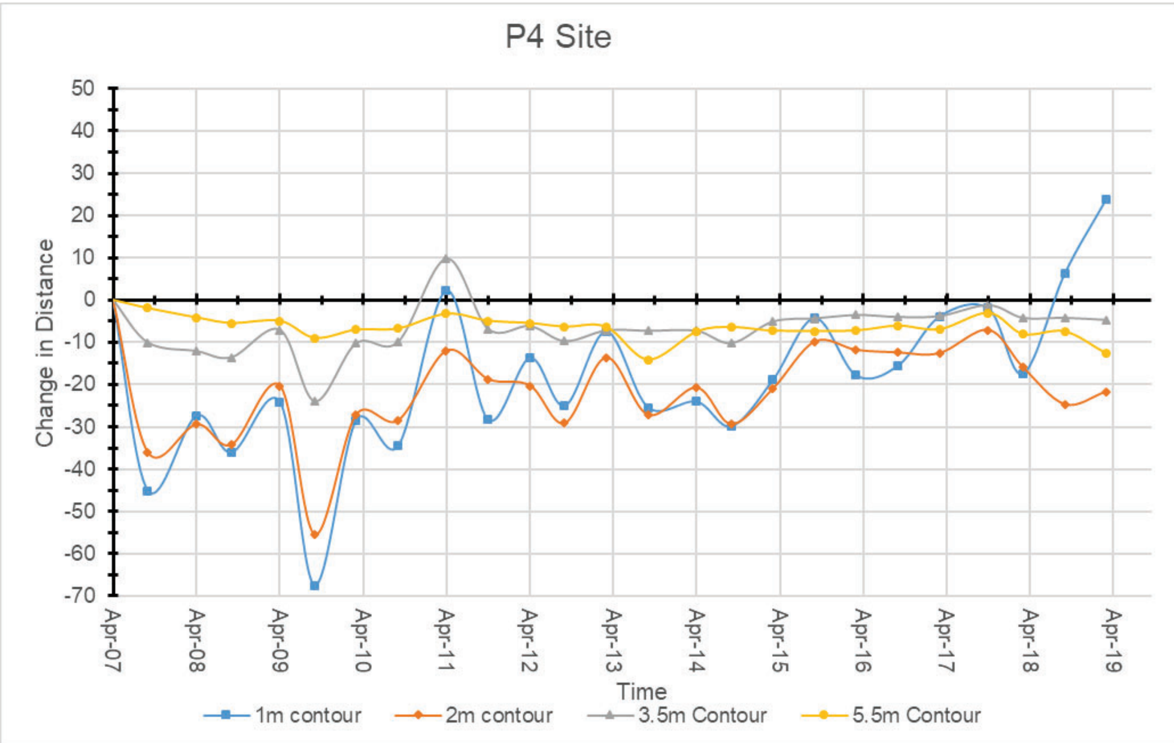
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour

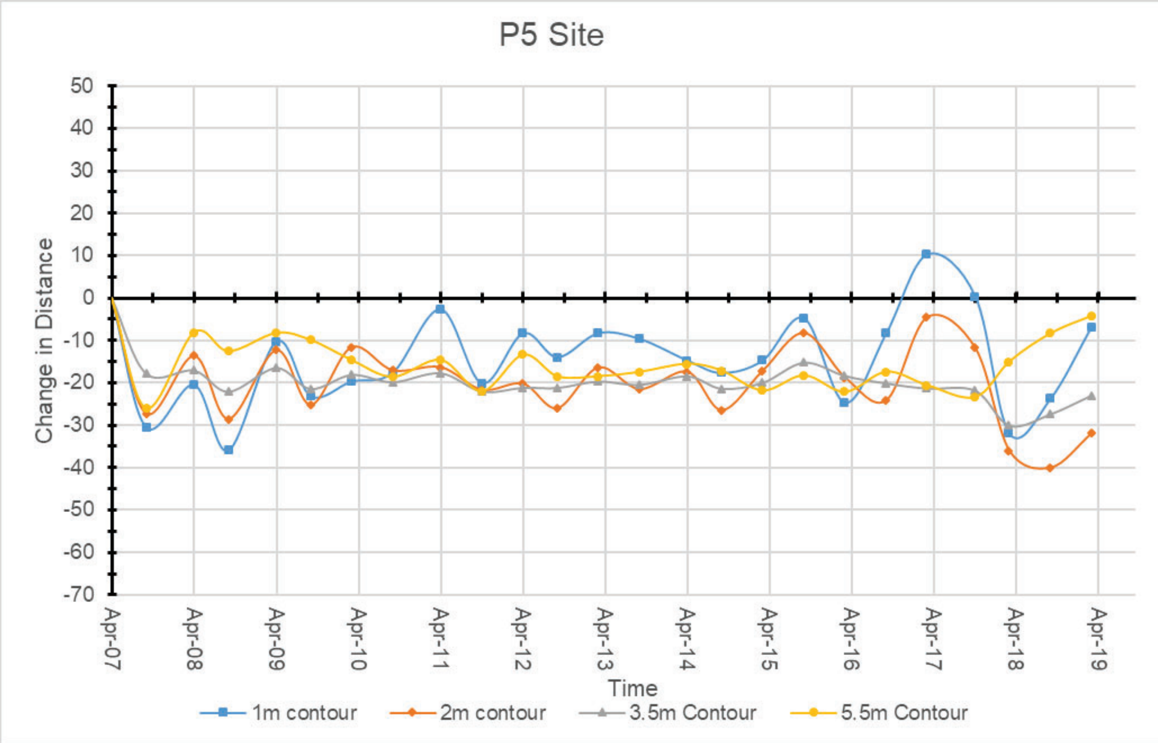

P2 Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour


P2B Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour

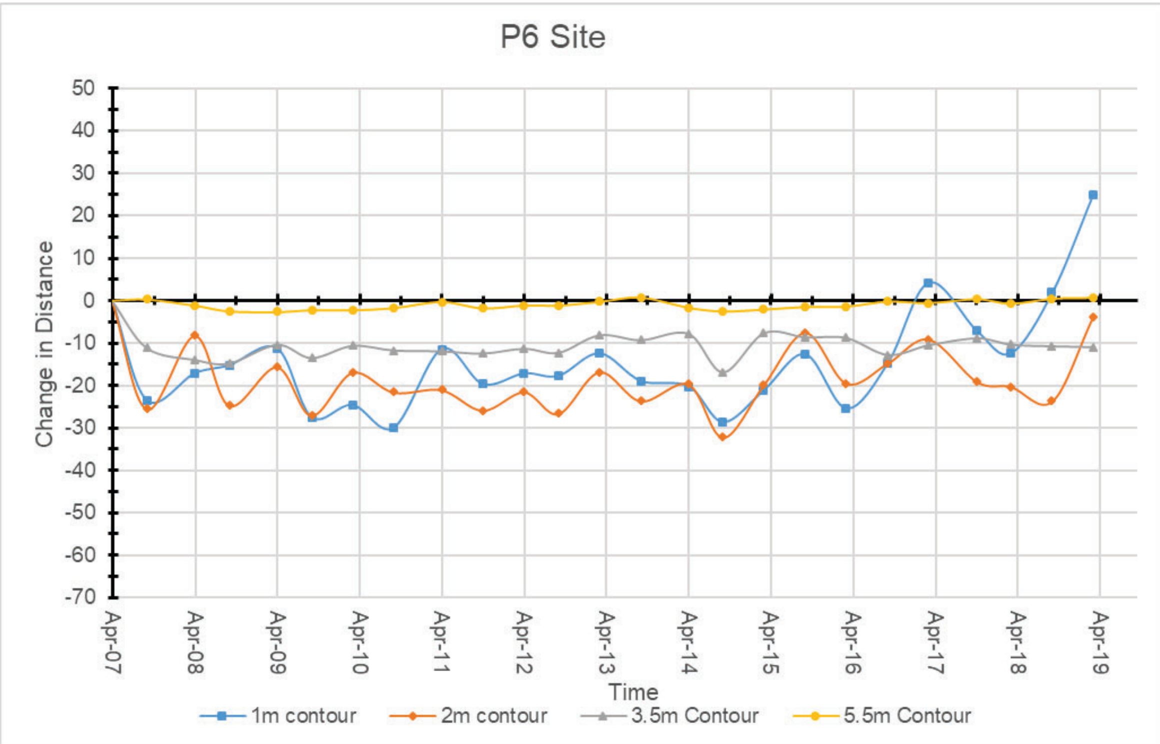

P2A Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour


P3 Site
Change in Distance
Time
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
1m contour
2m contour
3.5m Contour
5.5m Contour

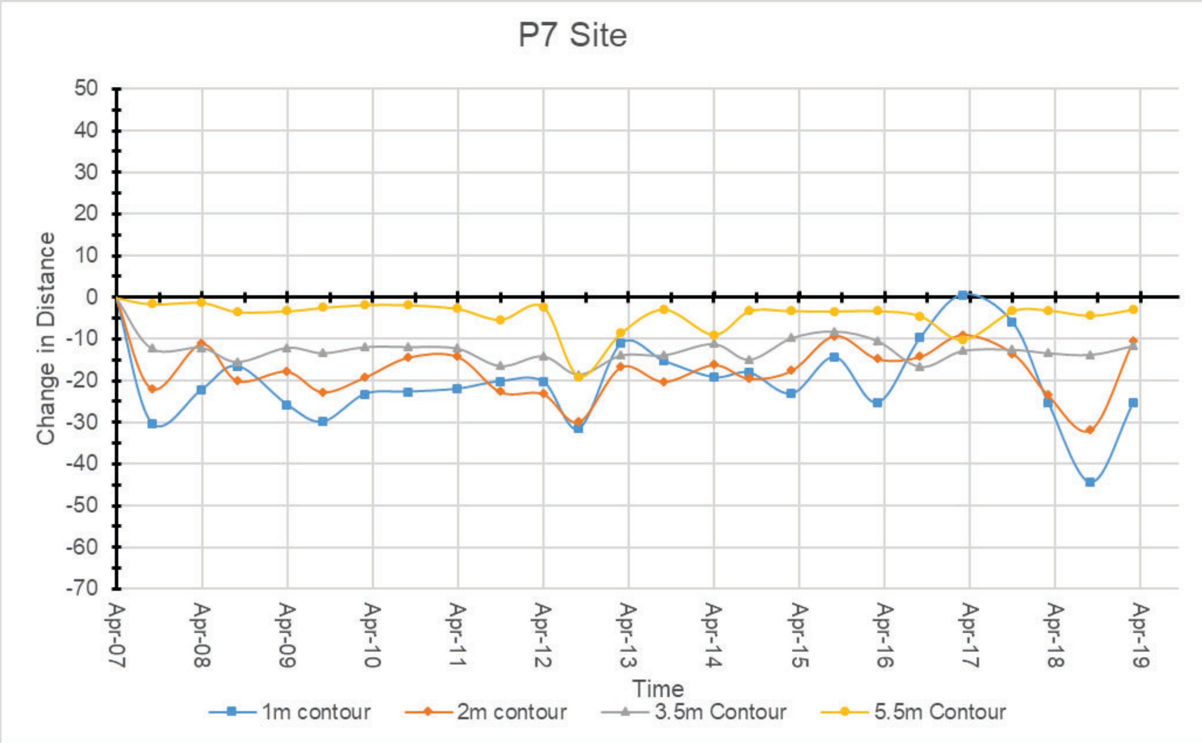

P4 Site
Change in Distance
Time
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
1m contour
2m contour
3.5m Contour
5.5m Contour



P5 Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour



P6 Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour



P7 Site
Change in Distance
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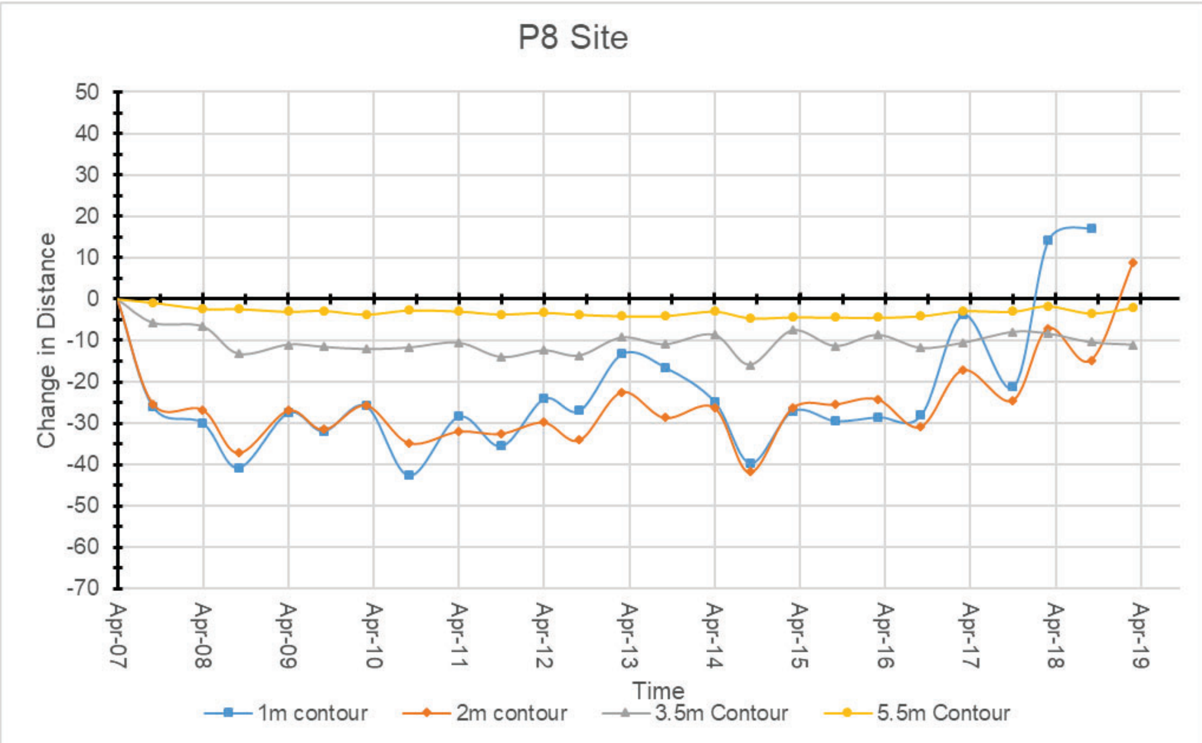
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour



P8 Site
Change in Distance
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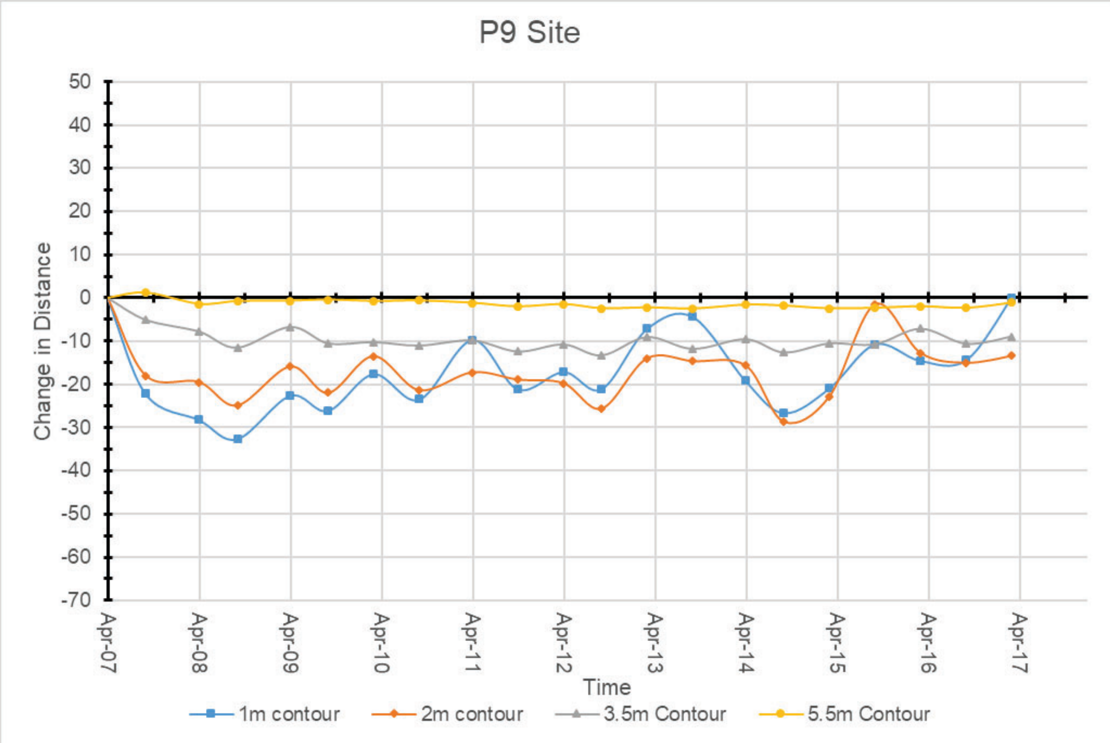
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Apr-18
Apr-19
Time
1m contour
2m contour
3.5m Contour
5.5m Contour


P9 Site
Change in Distance
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
Apr-15
Apr-16
Apr-17
Time
1m contour
2m contour
3.5m Contour
5.5m Contour

Appendix Q. Cut and Fill Volumes 2007-2016

Legend

- Historical Profiles
- Beach Volume Boxes
- Net Gain
- Unchanged
- Net Loss

N

0 100 200 400 600 800 Meters

Pakiri Beach - Elevation Analysis
April 2007 to March 2017

Section 1

CLIENT
McCallum Bros

PROJECT
Pakiri Sand Mining

SCALE 1:25,000 @ A3	*PROJECT CODE* IZ098900
PROJECT MANAGER EM	*DRAWN* TN
PROJECT DIRECTOR DT	*DATE* 29/03/2018
FIGURE NO X	*REVISION* DRAFT

JACOBS

Level 3
86 Customhouse Quay
Wellington
Tel +64 4 914 8412

Legend

- Historical Profiles
- Beach Volume Boxes
- Net Gain
- Unchanged
- Net Loss

N

0 100200 400 600 800 Meters

Pakiri Beach - Elevation Analysis
April 2007 to March 2017

Section 2

CLIENT McCallum Bros	
PROJECT Pakiri Sand Mining	
SCALE 1:25,000 @ A3	PROJECT CODE IZ098900
PROJECT MANAGER EM	DRAWN TN
PROJECT DIRECTOR DT	DATE 29/03/2018
FIGURE NO X	REVISION DRAFT

JACOBS

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86 Customhouse Quay
Wellington
Tel +64 4 914 8412

Legend

- Historical Profiles
- Beach Volume Boxes
- Net Gain
- Unchanged
- Net Loss

N

0 100 200 400 600 800 Meters

Pakiri Beach - Elevation Analysis
April 2007 to March 2017

Section 3

CLIENT McCallum Bros	
PROJECT Pakiri Sand Mining	
SCALE 1:25,000 @ A3	*PROJECT CODE* IZ098900
PROJECT MANAGER EM	*DRAWN* TN
PROJECT DIRECTOR DT	*DATE* 29/03/2018
FIGURE NO X	*REVISION* DRAFT

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