Pakiri Sand Extraction Consents

Assessment of Effects on Coastal Processes - New Consent Area

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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

1. Introduction

1.1 Background

McCallum Brothers Ltd (MBL) have been extracting sand from the nearshore of the Mangawhai-Pakiri embayment in the northern Hauraki Gulf 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. MBL have already lodged consent for the renewal of these consents to allow for the continued supply of sand for the Auckland concrete industry.

MBL now wish to apply for a new consent to extract from an area further offshore from the existing consent area as shown in Figure 1.2, being located approximately between the 15m and 25m (CD) water depths between the current inshore coastal consent area held by MBL and the offshore consent held by Kaipara Ltd (KL)[2]. It is understood that this new consent area is to replace the existing MBL inshore consent area, and that MBL will surrender their current coastal permits should the permits to extract from the proposed new area be granted. MBL is seeking consent to extract sand for a 35 year term at an annual average rate of 125,000 m^3/year over any rolling 5 year period and a maximum rate of 150,000 m^3 over any 12-month period, with the temporal and spatial distribution of the extraction volume being managed in the same way as the existing consents, being limited to a maximum of 15,000 m^3 over any consecutive 30 day period and to be balanced across the application area.

In preparation for an application for this new consent, Jacobs have been commissioned to report on the physical coastal processes' operating in the Mangawhai-Pakiri embayment and to assess the potential effect of the proposed sand extraction operation from the new proposed extraction area on these coastal processes. This report draws heavily on the investigations and findings reported by Jacobs (2020) in the assessment of coastal processes for the renewal of the current inshore extraction permits.

The Mangawhai-Pakiri embayment contains 25 km of sandy beaches between the rocky headlands of Bream Tail and Cape Rodney (Figure 1.1), and is exposed to Pacific Ocean swells from north to southeast. 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).

[1] Chart datum (CD), which has a zero depth at Lowest Astronomical Tide (LAT).
[2] It is noted that the KL consent area shown on Figure 1.2 is there proposed consent under a recent application, with their existing extraction area being slightly further offshore at a miminum distance of 2 km from the MHWS contour.

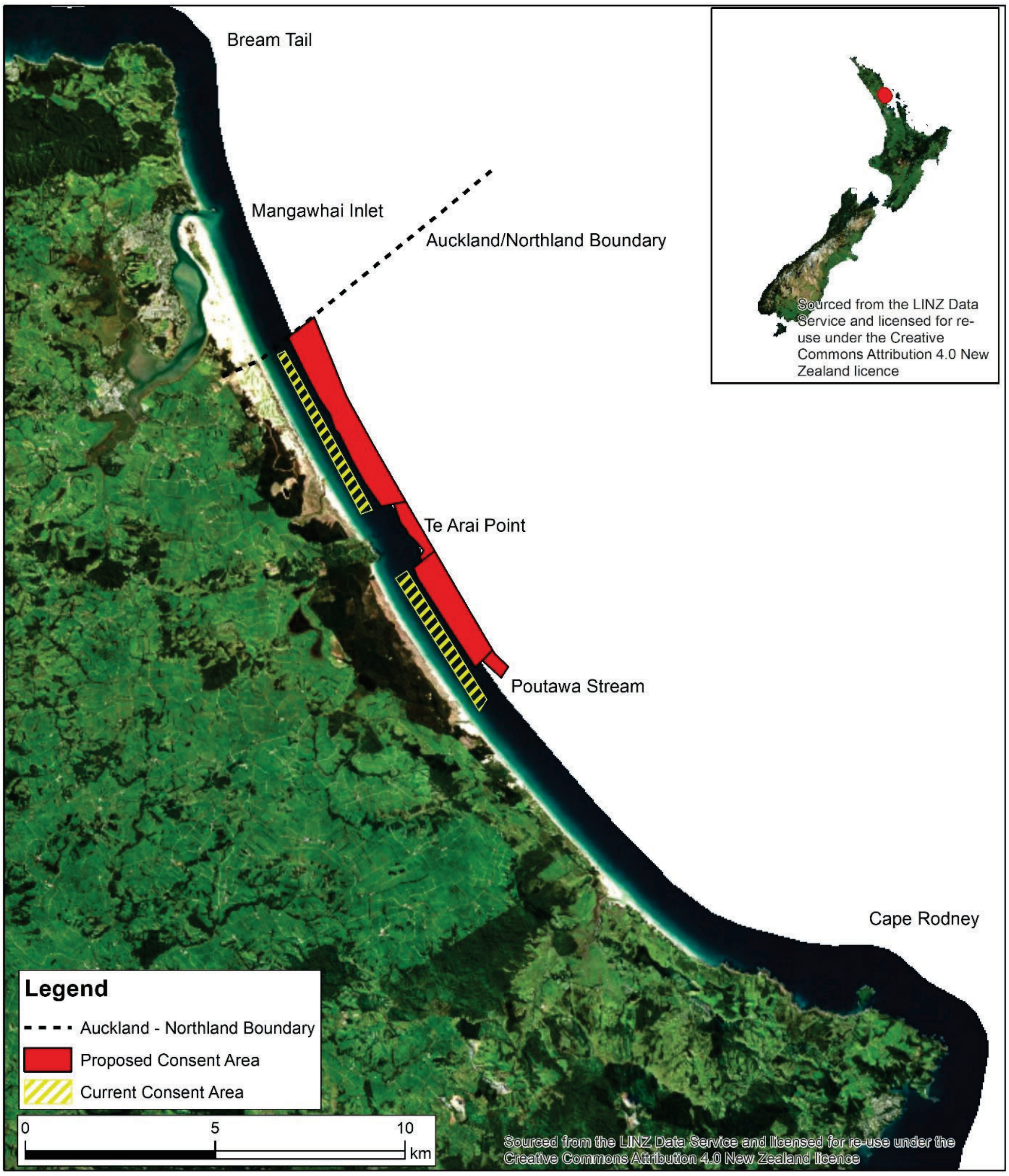


Figure 1.1: Mangawhai-Pakiri Embayment showing the current and the proposed new consent area for McCallum Bros Ltd Inshore Sand Extraction.

1.2 Scope of Report

The scope of this assessment includes the following components:

- Review of previous studies and Environment Court (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 proposed consent area in particular.
- Assessment of the potential effects of the proposed extraction from the proposed new extraction area 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 current inshore consents since 2006, and recent investigations undertaken for the purpose of the assessment for the renewal of the existing consent and for this application for the new consent area.

1.3 Description of the Extraction Activity

1.3.1 Consent Area

MBL is seeking consent to extract sand from the New Consent Area, as shown in Figure 1.2. In terms of water depth contours, this proposed extraction area is between the 15 m and 25 m contours as shown on Hydrographic Chart NZ522. These water depths are in terms of Chart Datum (CD), being the water depth below the Lowest Astronomical Tide (LAT). In terms of Mt. Eden Datum used for land elevations (e.g. in beach surveys), MSL is 1.9 m above the zero base of CD for Auckland, therefore water depths of 15 - 25 m CD are equivalent to -17 to -27 m MSL. Note that the 2019 bathymetry presented in this report is in terms of MSL datum rather than CD.

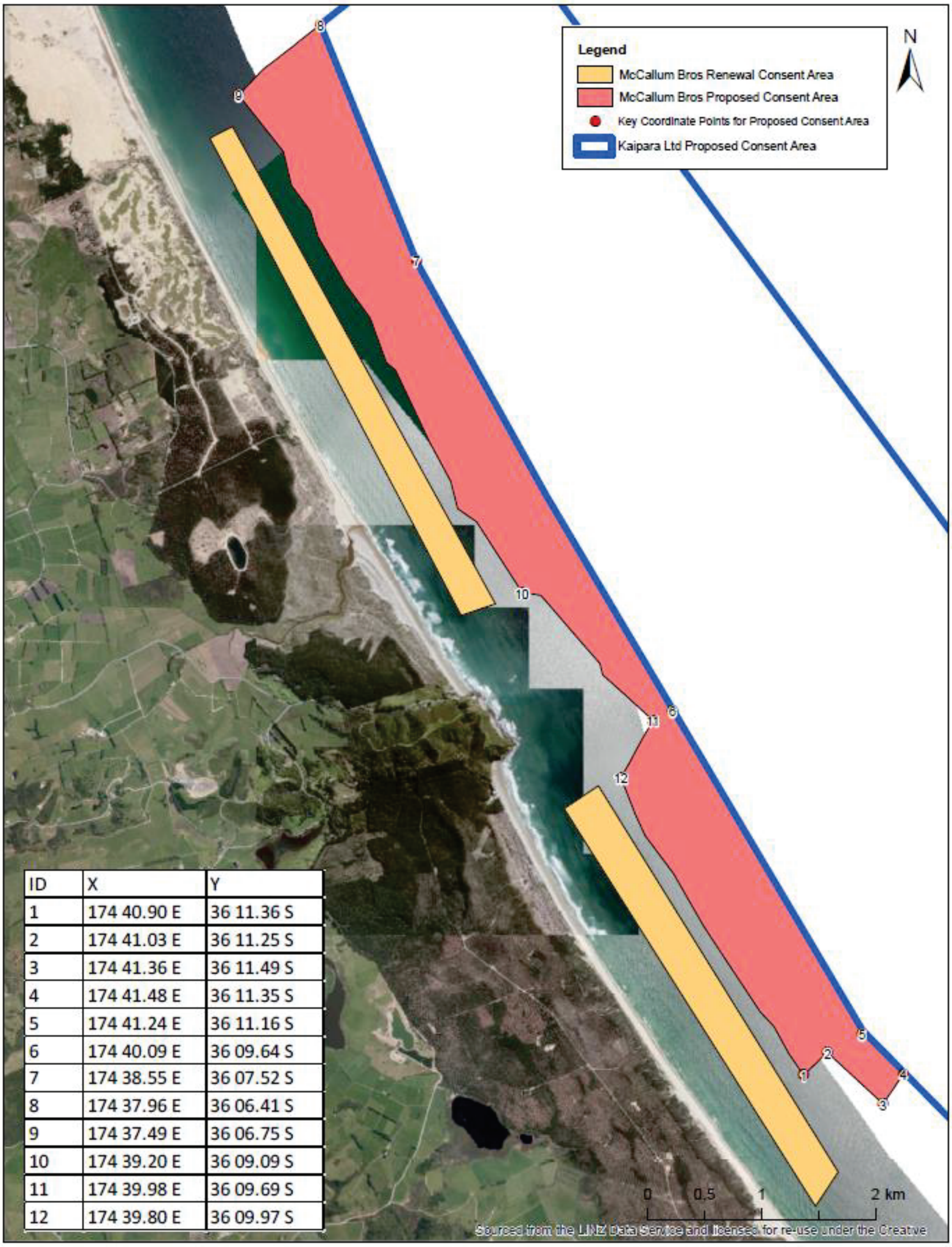
For simplicity and to avoid ambiguity, it is proposed that the new consent area be demarcated solely by the coordinates given in Figure 1.2 without reference to the water depths.

As shown in Figure 1.2, the proposed consent area extends a total of 10.4 km alongshore, with the northern and southern boundaries being defined by the same limits as the existing inshore consents, but with no exclusion area proposed offshore of Te Arai Point, due to the greater offshore distance from the headland reef structures. The width of the proposed extraction area varies between 670-790 m in the wider northern and southern zones, is around 350 m in the smaller southern area, and in the order of 380 m around Te Arai Point. The proposed extraction area does not intersect with any of the planning overlays in the Auckland Unitary Plan (AUP) and the southern limit of the consent area is located in the order of 10 km from the northern limit of the Goat Island Marine Reserve. The proposed extraction area covers a total area in the order of 6.6 km^2, compared to 2.6 km^2 for the existing inshore consent area.

1.3.2 Extraction Volumes and Operation

MBL is seeking consent to extract sand for a 35 year term at a annual average rate of 125,000 m^3/year over any rolling 5 year period and a maximum rate of 150,000 m^3 over any 12-month period, with the temporal and spatial distribution of the extraction volume being managed in the same way as the existing consents, being limited to a maximum of 15,000 m^3 over any consecutive 30 day period and to be balanced across the application area via the usage of extraction cells.

The proposed sand extraction will be undertaken by trailing suction dredgers. MBL's previous trailing suction dredge the 'Coastal Carrier', has been phased out and replaced by the new trailing suction dredge vessel, the 'William Fraser'. The 'William Fraser' has been specifically built for trailing suction dredging of sand and has a number of new technologies that provide improvements in the operation of the vessel whilst minimising other impacts on the surrounding environment. 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 causes less seabed disturbance.



ID	X	Y
1	174 40.90 E	36 11.36 S
2	174 41.03 E	36 11.25 S
3	174 41.36 E	36 11.49 S
4	174 41.48 E	36 11.35 S
5	174 41.24 E	36 11.16 S
6	174 40.09 E	36 09.64 S
7	174 38.55 E	36 07.52 S
8	174 37.96 E	36 06.41 S
9	174 37.49 E	36 06.75 S
10	174 39.20 E	36 09.09 S
11	174 39.98 E	36 09.69 S
12	174 39.80 E	36 09.97 S

Figure 1.2: McCallum Bros Ltd (MBL) existing and proposed new Pakiri Sand Extraction Areas on an overlay of Bathymetric Chart NZ522 water depth contours in terms of chart datum (CD), with the proposed new consent area being shown to be within the 15 m and 25 m (CD) depth contours.

1.4 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 historically been engaged in extraction activities from the Mangawhai-Pakiri embayment, with ARC records indicating that sand extraction from the embayment has been occurring since the 1920's. Although exact records are not available before 1966, it is estimated that the extraction volumes prior to this could have been in the order of 2 million m^3, some of which we understand was extracted from the dune field rather than from the nearshore. A summary of the sand extraction volumes identified from available data is presented in Table 1.1, and is summarised below.

Table 1.1: Mangawhai-Pakiri sand extraction volumes 1966-2019 (volumes rounded to 100 m3)

Period	Mangawhai Inlet Ebb Tide Delta Extraction volume (m^3)	Inshore Extraction volume (m^3) (e.g. in depths < 10 m CD)	Offshore Extraction volume (m^3) (e.g. in depths > 25 m CD)	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 the 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 delta 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 again in 1989.

Under the RMA 1991, coastal permits to extract sand 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 inshore extraction area. The data presented in the Mangawhai Pakiri Sand Study (MPSS) Module 3 (Hume et al, 1988) 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.

Extraction volumes from 1997 to 2003 can be deduced from the information presented in MPSS Module 3 and at 2005/06 Environment Court hearing as being 843,000 m^3, but 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 to extract from the existing inshore extraction areas. Renewal of Consents for extraction from the Mangawhai Inlet entrance were not applied for when they expired.

Extraction volumes since 2003 have been supplied by MBL for both the inshore and offshore areas. MBL have undertaken all the extraction from the offshore area authorized by KL's 2003 consent under contract with KL, and these volumes are presented in **Appendix A**. The data shows a combined total of 2.25 million m^3 has been extracted over the 17 years, of which 677,600 m^3 has been from the MBL inshore consent area and 1.57 million m^3 from the KL offshore consent area, giving an average annual total extraction rate (2003-2019 inclusive) of 132,300 m^3/yr from all water depths within the Managwhai-Pakiri embayment. However, there is considerable variance in the annual extraction volume, with a minimum extraction of 98,800 m^3 in 2011 and a maximum of 218,300 m^3 in 2019. MBL extraction records show that approximately 35% of the extraction from the KL area has been from water depths less than 30 m CD. Therefore, the combined extraction rate from less than the -30 m CD contour since 2003 is in the order of 1.228 million m^3 at an average rate in the order of 72,000 m^3/yr.

In summary, Table 1.1 shows that a total of around 5.4 million m^3 of sand has been extracted from the Mangawhai-Pakiri embayment since 1966, at an average rate in the order of 102,000 m^3/yr. Of this volume, 1.572 million m^3 has been extracted from the Kaipara offshore consent area in depths greater than the 25 m (CD) and 4.407 million m^3 from depths less than 25 m at an average extraction rate in the order of 72,000 m^3/yr since 1966.

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 (6 modules) 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 as part of this assessment.

- 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.
- Jacobs (2020) Pakiri Sand Extraction consents: Assessment of Effects on Coastal Processes.

As indicated in Section 1.1, this report draws heavily on the investigations and findings reported by Jacobs (2020) in the assessment of coastal processes for the renewal of the current inshore extraction permits.

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[3] 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 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 is shown in Figure 2.1.

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. There is also an additional pre-current consent survey in April 2004. All surveys were undertaken as far as possible at high water to maximise overlap with beach surveys. Plots of these surveys along each profile are presented in Appendix N.

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.

[3] Global Navigation Satellite System

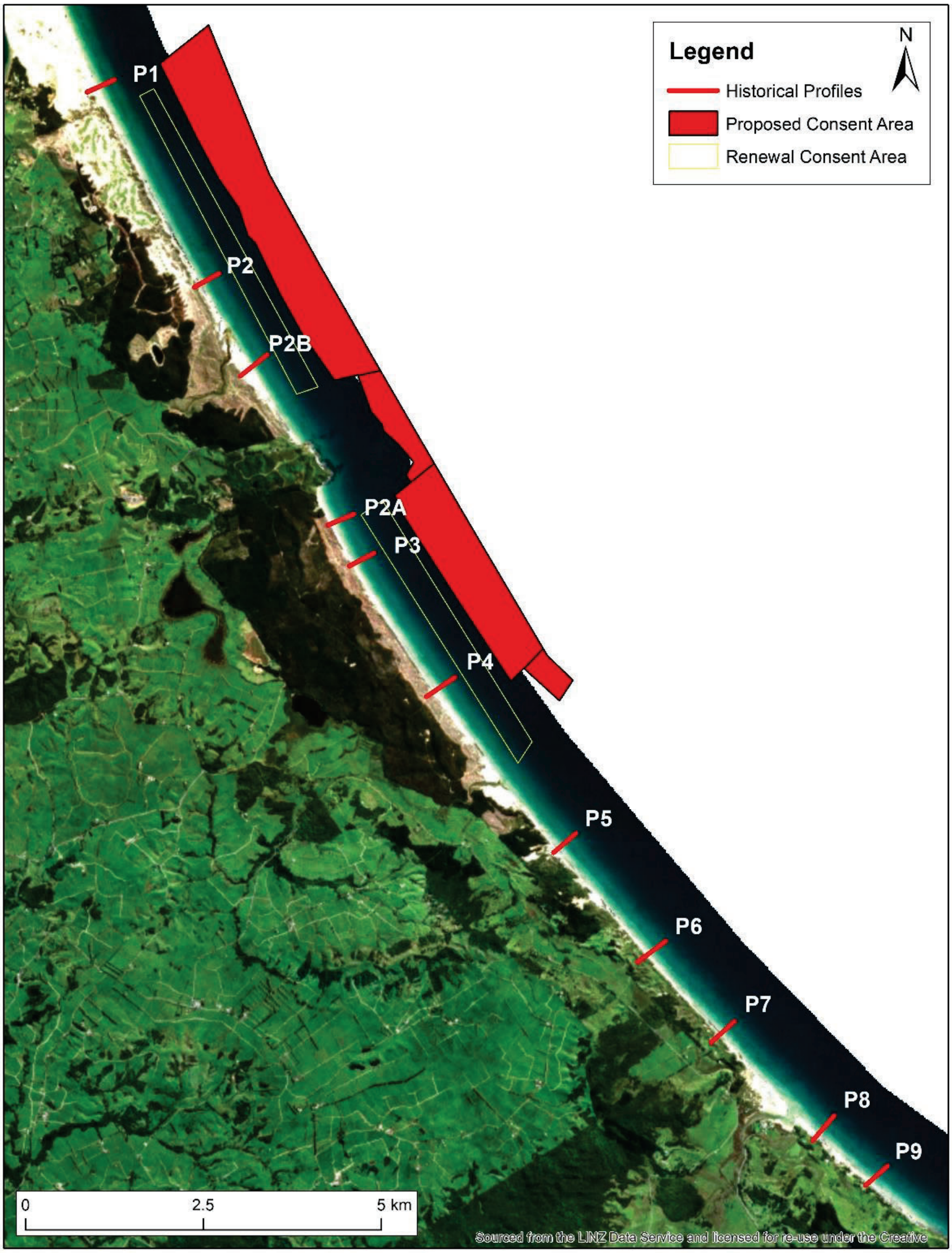


Figure 2.1: Location of historical beach profiles used in shoreline position/volume and bathymetry change monitoring under existing MBL extraction consents.

2.3 Recent MBL Field Investigations

In addition to the work discussed above, a number of recent field investigations have been undertaken to provide further information for both this assessment and the assessment for the renewal of the existing consent. 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 CD water depth contour from the Mangawhai River mouth to the Pakiri River was undertaken in March 2019 and extended seaward to around the 30 m CD depth contour during a subsequent survey in October 2019. The areas covered in these surveys are 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 in Mt. Eden Datum is presented in **Appendix G,** and reporting of the survey results are presented in section 3.2.2. This datum is the same as the land datum used to survey the beach topography, so that a seamless profile across the beach and nearshore can be produced. However, as noted in Section 1.3.1 this is a different datum than the bathymetry presented on the Hydrographic Chart NZ522 which is Chart Datum (CD), where the zero base of the datum is approximately the level of the Lowest Astronomical Tide (LAT). The difference between the two datums is 1.91 m with this being the elevation of MSL on CD for Auckland (LINZ standard port data). Therefore, the seabed contours from the recent bathymetric surveys presented in Appendix G are in the order of 2 m greater than the corresponding water depths at the same location shown on Hydrographic Chart NZ522 (e.g. 25 m (CD) ≈ -27 m (MSL)).

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 new and 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 35 sediment samples were collected from the seabed off Bream Tail and in Bream Bay 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

Mean Gain Size (mgs)		Sorting	
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**. Further photograph transects were taken off Bream Tail in water depth from 14 m to 30 m (photograph locations from main transect shown in Figure 3.15). At each site a single drop camera photograph of a 1 m^2 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 on the seabed were also taken by divers during dredge infill measurements (described in section 2.3.5), with estimates recorded on ripple wavelength and amplitude.

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

Dredge trench infill measurements were undertaken in approximately 10 m water depth in the MBL existing inshore consent area and in 25-30 m water depth in the KL consent area. Due to there not being a consent to allow dredging in the proposed new consent area, no infill measurements were possible in this area.

The methodology involved MBL divers undertaking repeated measurements of the width and depth of the dredge trench at the same location over a period of days and weeks following dredging until the trench was no longer visible on the seabed. The purpose of measurements was to determine the rate of trench infill on both the inner and outer limits of the proposed consent area, establish the duration of sea bed disturbance from the dredge activity between the extraction trenches and to assess the nature and magnitude of sand volumes moving on the seabed in water depths greater than 25 m CD. 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, the locations of the measurements are shown in Figure 2.3, and the measurement dates in Table 2.2. While most of the infill measurements were from trenches dredged by the 'Coastal Carrier', the most recent >25 m CD depth trench (E), was dredged by the 'William Fraser'. 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.

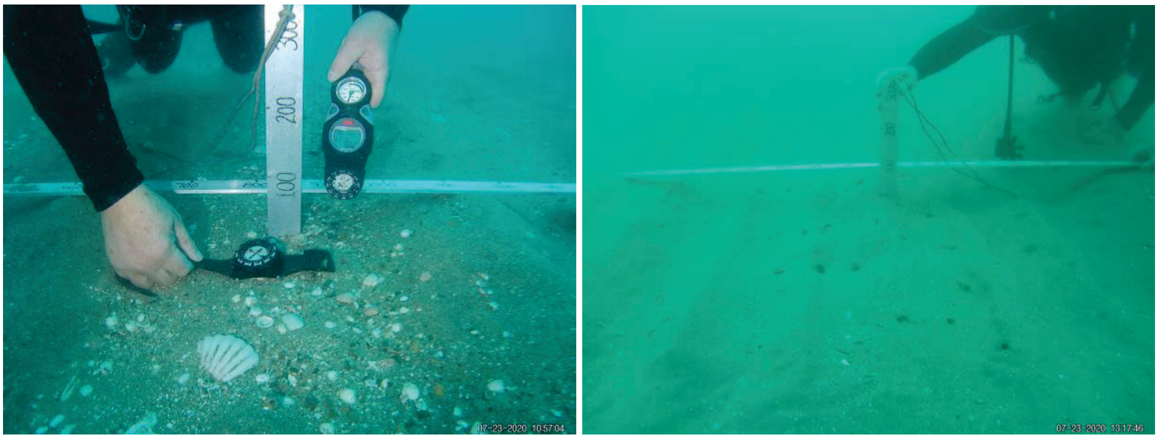


Figure 2.2: Dredge trench infill measurement methodology. Photos from William Fraser trenches.

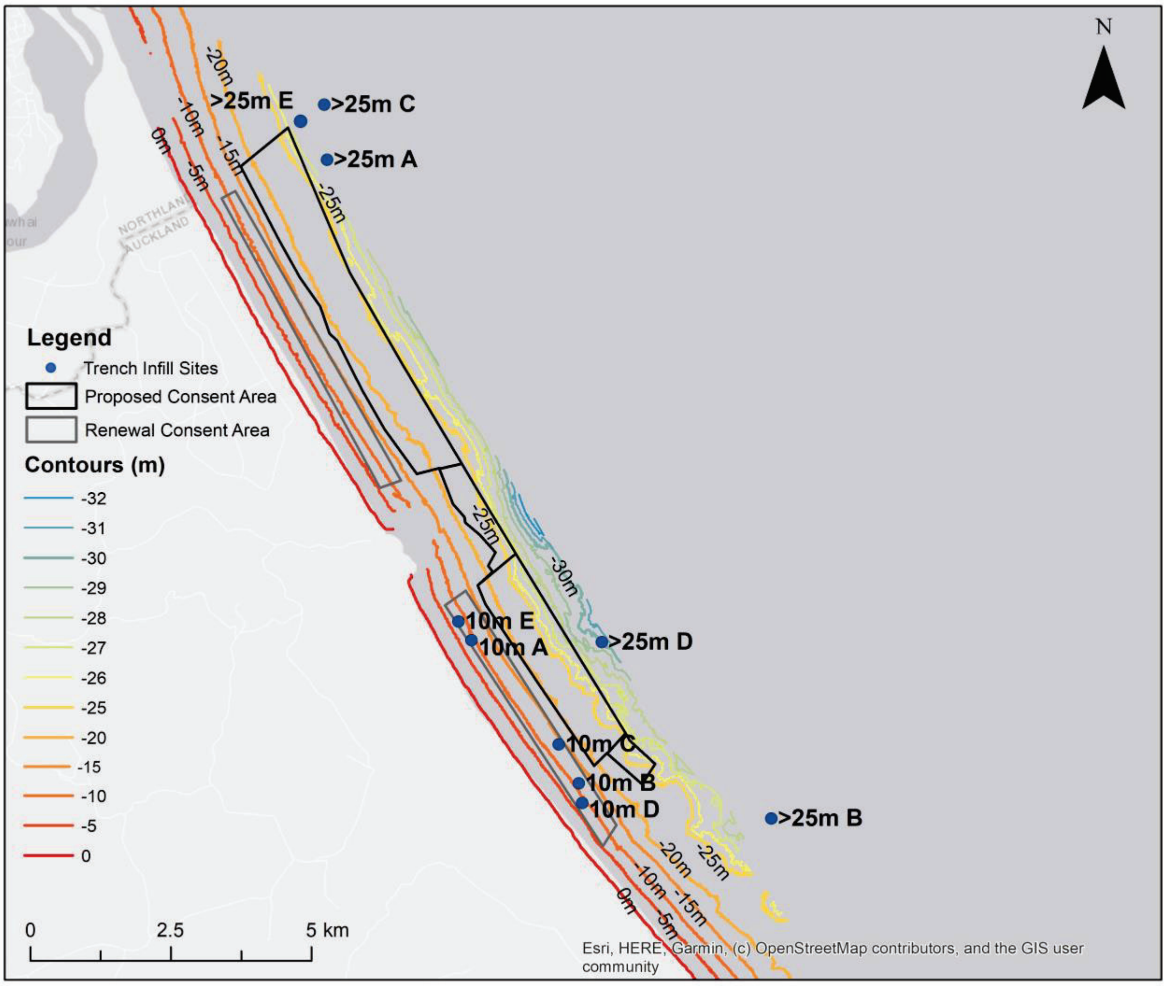


Figure 2.3: Location of dredge trench infill measurements. Depth contours in terms of MSL.

Table 2.2: Dates of dredge trench infill measurements in 25 – 30 m water depths

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	
>25 m Trench E	1/7/2020	3/7/2020	23/7/2020		

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.

Details of methodologies used in the modelling of each metocean parameter are given in the 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 WRF wind data, 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 3.5.1.2 and 3.5.2.2 respectively.

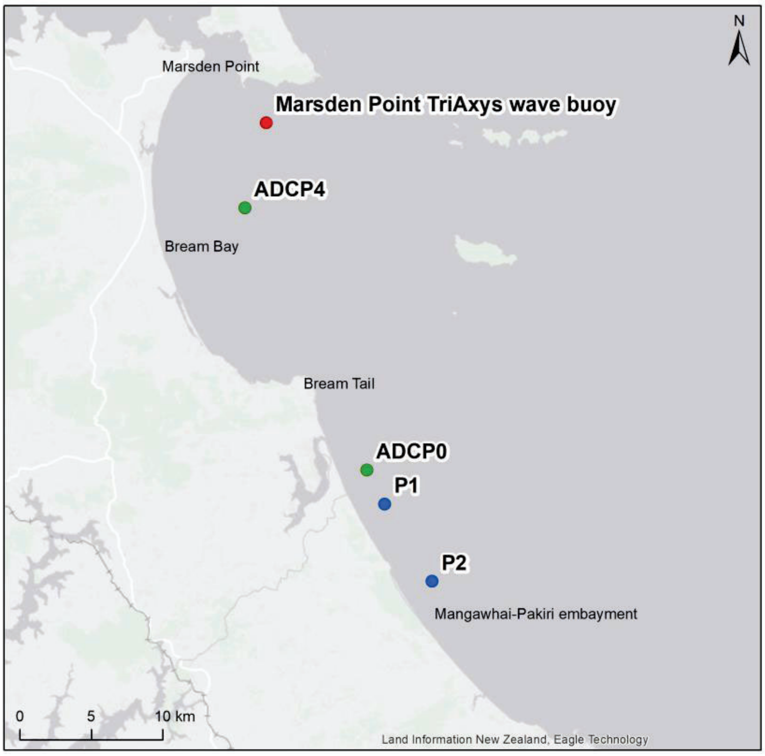


Figure 2.4: Location of ADCP sites (ADCP4 & ADCP0) used in validation of hydrodynamic modelling of ocean currents at sites P1 and P2.

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 a maximum of ± 5 m in the areas of least certainty.

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.

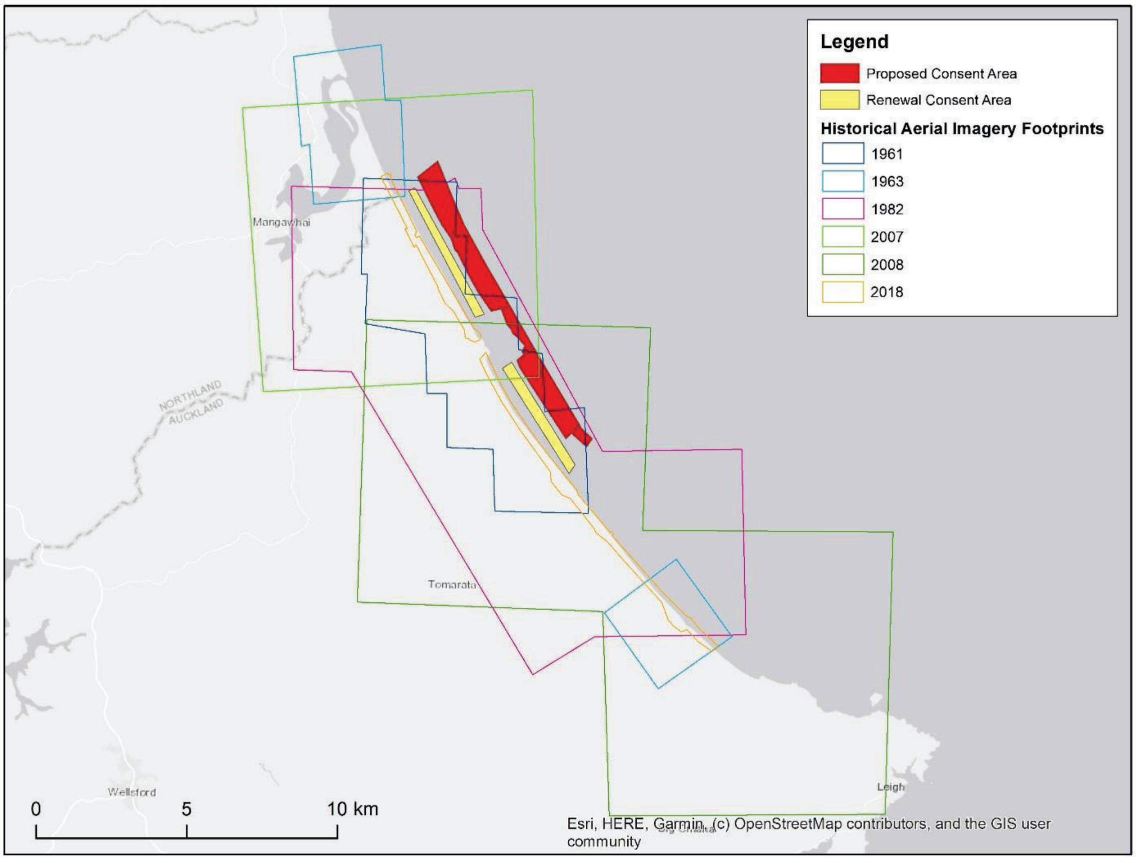


Figure 2.5: Coverage of aerial imagery used in the Digital Shoreline Analysis System

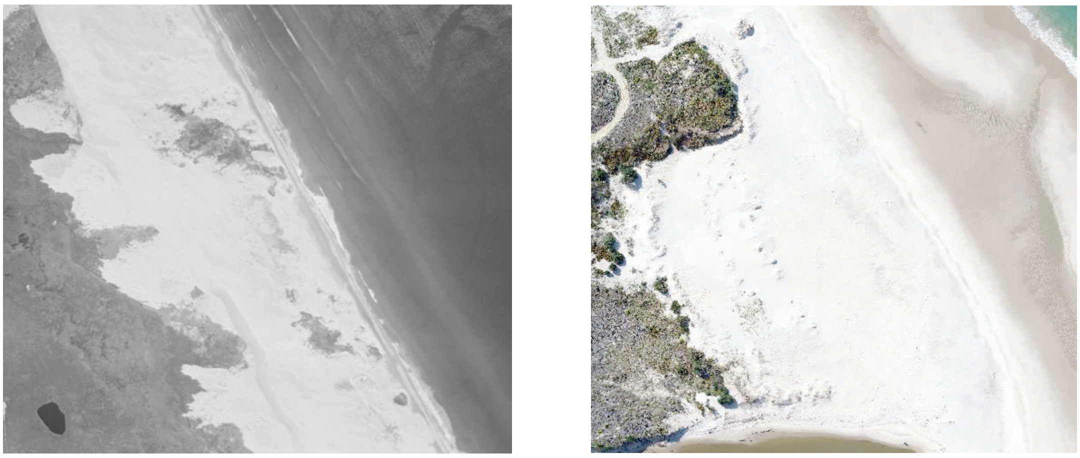


Figure 2.6: Examples of poor aerial imagery quality; a) 1963 black and white image, b) 2018 over-exposed image.

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 and long-shore from deeper water. 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) based on fauna abundance data collected by them in various local projects and fauna growth rate equations obtained from the international literature. This assessment is re-produced in **Appendix F**.

Offshore sediment supply

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 25m CD within the Mangawhai-Pakiri embayment. This transport also includes longshore transport from deeper than 25 m CD.

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.

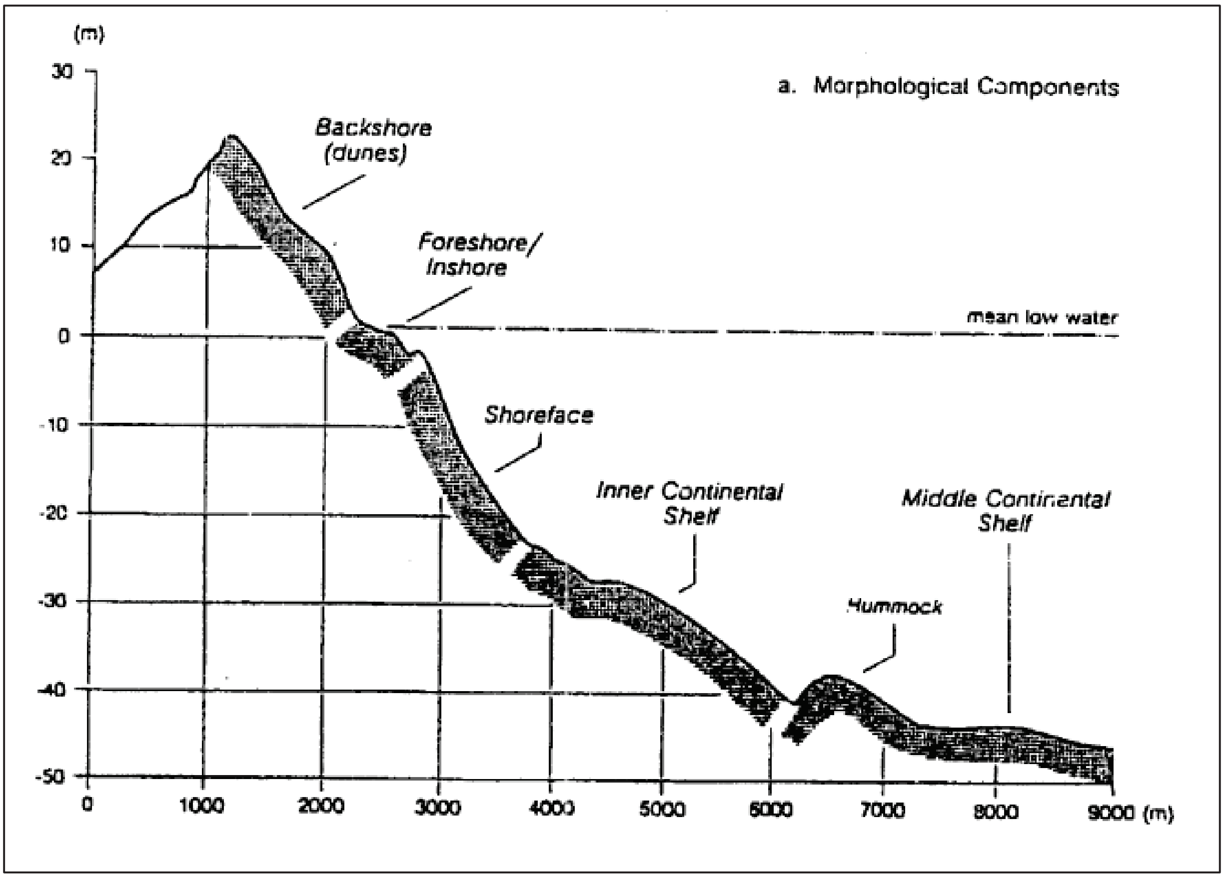


Figure 3.1: Morphological components of the Mangawhai-Pakiri embayment after Hilton (1990, p65)

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 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 (Hume et al., 1999) 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. The size of the Holecene sand resource within and ajoining current and proposed extraction areas is estimated to be in the order of 70-120 million m^3. The underlying Pleistocene sand volume is estimated to be in the order of 2 billion m^3.

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 the findings of the MPSS to be:

- 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,
- That the movements of the dune vegetation/toe line were less than 10 m over the same period and
- 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.

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[4] 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.

The bathymetry of the northern Hauraki Gulf from these hydrographic charts are shown in Figure 3.2 with the major depth contours of 30 m, 50 m and 100 m CD highlighted. As shown on the chart, while the contours up to 30m depth along the Mangawhai-Pakiri embayment are generally parallel with the shoreline, the 50 m depth contour displays a relative convex bulge opposite the embayment, hence a flatter sea bed slope across the middle continential shelf in this area, suggesting a potential larger buildup of sediment on this part of the shelf relative to other parts of the northern Hauraki Gulf.

[4] Royal New Zealand Navy

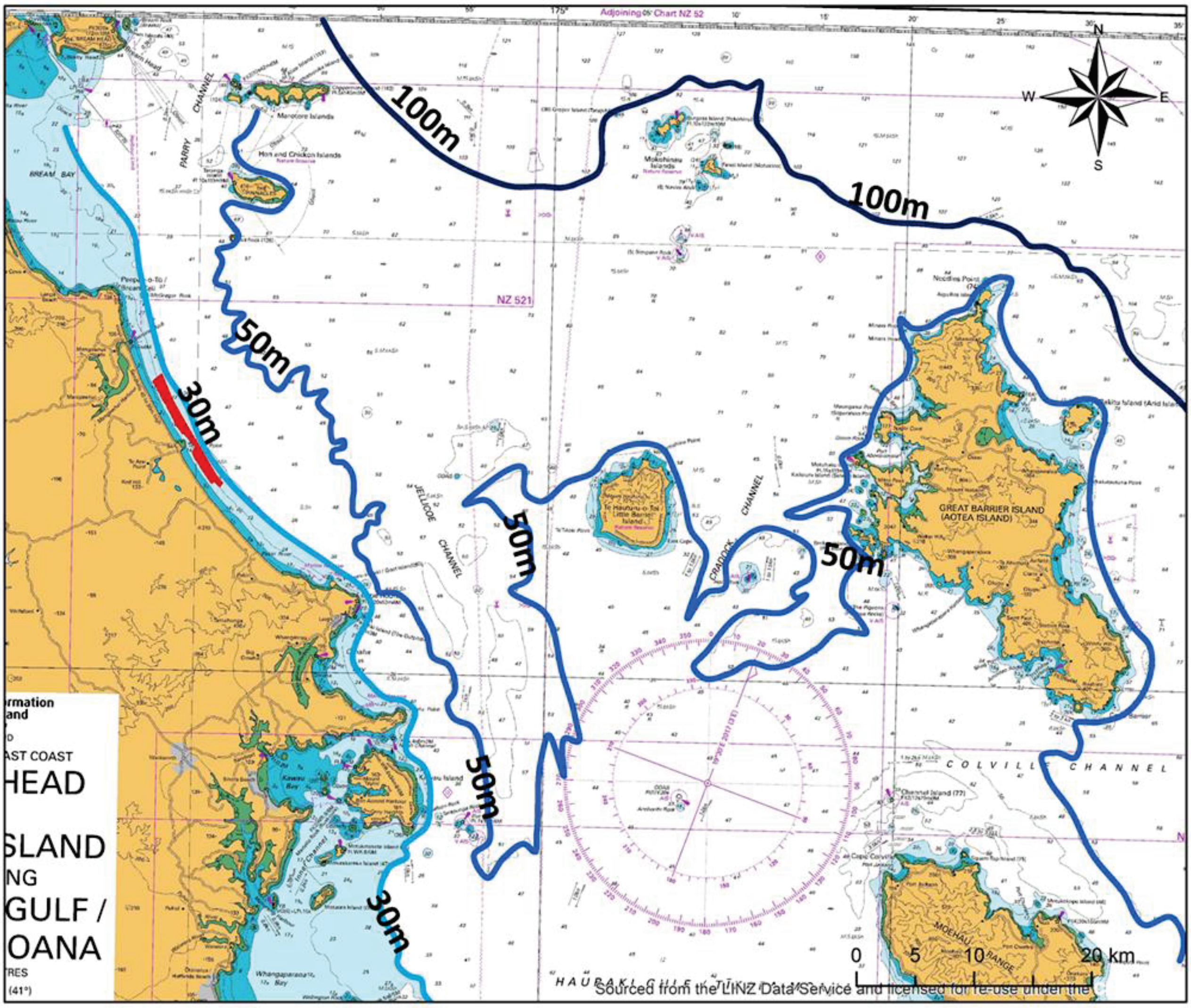


Figure 3.2: LINZ Hydrographic Chart (NZ522) of the Northern Haurakai Gulf showing the MBL proposed extraction area in Red.

3.2.2 2004 to 2019 Bathymetric Profiles

The three yearly bathymetric surveys (2004, 2007, 2010, 2013, 2016, 2019) along an extension of the 11 historical beach profile sites carried out as part of the current consent conditions are presented in **Appendix N,** the net 2004-2019 change in seabed elevations at fixed distances across each profile and nearshore volume change from 500 to 1000 m offshore from the MSL contour are presented in Table 3.1.

In general these profiles show that the seabed levels across all depths and all profiles were similar in the 2004, 2007, and 2010 profiles, before undergoing a rise by 0.3 to 0.5 m in the 2013 survey, and relative stability again through the 2013, 2016 and 2019 profiles. However, although this magnitude of change is greater that the depth accuracy given in section 2.2.2 for individual surveys (± 0.25 m), there is no obvious physical processes reason during the 2010-2013 period for this rapid rise in seabed level followed by relative stability through to 2019. Despite enquiries of Greg Cox, Managing Director of Discovery Marine Ltd (DML), who undertook a number of the bathymetric surveys, the reasons for the this change have not been reliably established.

Table 3.1: Change in nearshore seabed elevations and volumes 2004 to 2019

Profile	Location	Change in Seabed Elevation from 2004 to 2019 survey: Offshore Profile Distance from MSL 500 m(1)	1000 m (2)	1500 m (3)	2004-2019 Change in nearshore volume between 500 – 1000 m offshore: Total Volume change (m3/m)	Vol change per year ($m^3/m/yr$)	Average elevation change over profile length (m/yr) (4)
P1	North of Extraction Areas	-0.2	0.4	0.6	+226	+15.1	+0.015
P2	North Extraction Area	0.6	0.1	0.5	+229	+15.3	+0.015
P2B	North Extraction Area	-0.6	1.1	0.3	+227	+15.1	+0.015
P2A	South Extraction Area	-0.1	0.5	0.3	-1	-0.1	-0.0001
P3	South Extraction Area	-0.6	0.1	0.6	+217	+14.5	+0.014
P4	South Extraction Area	0.0	-0.1	0.4	+191	+12.7	+0.013
P5	Southern Control Area	0.2	-0.8	0.7	+264	+17.6	+0.018
P6	Southern Control Area	0.5	0.7	0.1	+333	+22.2	+0.022
P7	Southern Control Area	0.0	0.3	No 2019 data	+157	+10.5	+0.011
P8 & P9	Southern Control Area	Not surveyed in 2019					

Note (1) Depth range at 500 m offshore distance is in range -5 to -7 m MSL for individual profiles. For some profiles the elevation s influenced by the presence of the nearshore bar

(2) Depth range at 1000 m offshore distance is in range -16 m to -19 m MSL for individual profiles.

(3) Depth range at 1500 m offshore distance is in range -23 m to -25 m MSL for individual profile

(4) Profile length is 1000m from 500 m offshore distance to 1500 m profile distance

3.2.3 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 (Figure 3.2), with the difference between the datums being 1.91 m. Therefore, the seabed contours from the recent bathymetric surveys presented in Appendix G are in the order of 2 m greater than the corresponding water depths at the same location shown on Hydrographic Chart NZ522 (e.g. 25 m (CD) ≈ -27 m (MSL)).

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. Also shown on the relevant profiles is the position of the existing MBL inshore extraction area and the indicative position of the proposed new consent area.

As can be seen from the maps in Appendix G, and highlighted in the following Table (3.2) 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. From the LINZ Hydographic charts, the inner-continental shelf slopes from the 30 m to the 50 m water depth contours are much flatter in the range 1:350 to 1:500, with the mid continenial shelf slopes between the 50 m and 100m water depth contours having similar slopes.

Table 3.2: 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)
P6	1:49	1:96 (To -26m contour)
P7	1:48	1:87 (To -23m contour)

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)) 0.27 – 0.44 mm),
- Nearshore sediments (0-15 m water depth) are very well sorted fine sands (mgs 0.25 mm) which get finer as water depth approaches 15 m,
- Remainder of the inner continental shelf (15 to 40m water depth): Medium to coarse sands (mgs 0.71-1.0mm). The inner continental shelf ends 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 40 m (CD) water depths. The MPSS estimated that the volume of modern Holocene quartz-feldspathic sands and calcareous material from local shell production located offshore to be in the order of 82-142 million m^3, with 85% of this (e.g. 70-120 million m^3) being located at water depths less than approximately 25 m CD.

3.3.2 2019 Sediment Sampling Results

The sediment size distributions along with the mean grain 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 current 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), which includes the proposed new MBL extraction area: 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), which includes the KL extraction consent area: 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 concrete industry quality control requirements, 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 are presented in Bioresearches (2019a) and examples of the images with ripples from the proposed new extraction consent area are presented in Figure 3.3. Bioresearches (2019a) summarised the bedform micro-topography across the existing and proposed new consent areas as follows:

- Inshore of the current MBL sand extraction areas (e.g <5 m water depths)- fine sand with irregular small or no ripples,
- Across the current MBL inshore extraction area (e.g 5-10 m water depths)- increasing sand size with shell debris, and sand ripple amplitude increases with increasing depths,
- Proposed MBL new extraction area (e.g 15 – 25 m water depths) - larger wave length, low amplitude ripples.

Large sand ripples were also found by divers in greater water depths of 26 -31 m when undertaking the trench infill measurements on five different dates between November 2018 and July 2020. The largest of these ripples found on 3/7/2020 had amplitudes in the order 100mm and wave lengths in the order of 400-500 mm as shown in the images in Figure 3.4 (c &d).

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 3.5.

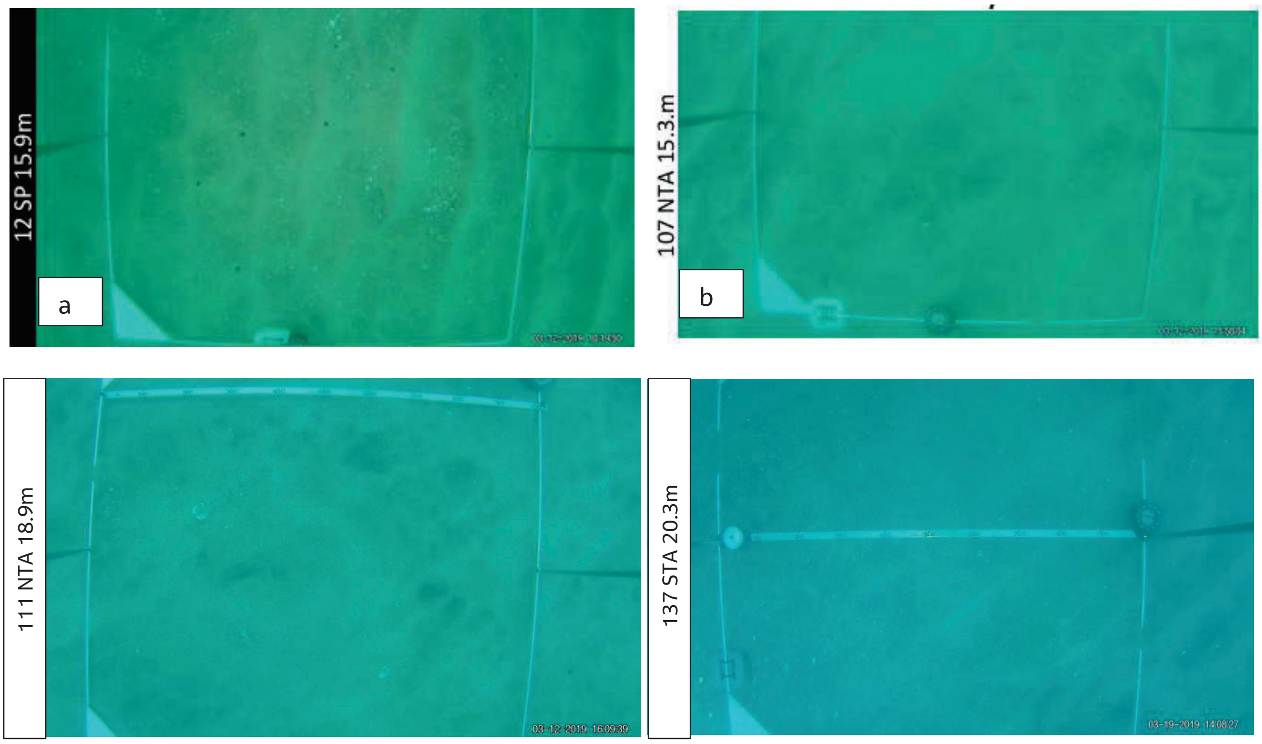


Figure 3.3: Images of sand ripple bedforms: a) South Pakiri Transect at 15.9 m depth; b) North Te Arai Beach Transect at 15.3 m depth, c) North Te Arai Beach Transect at 18.9 m depth, d) South Te Arai Beach Transect at 20.3 m.

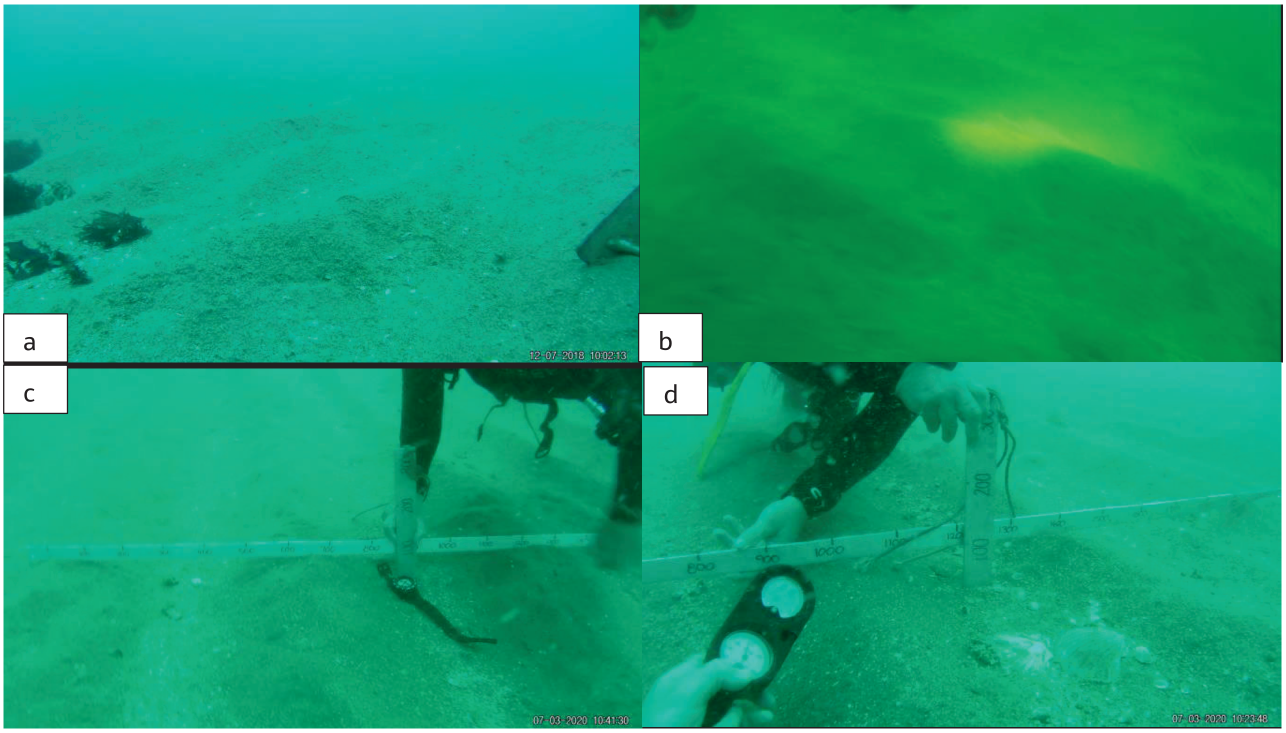


Figure 3.4: Images of sand ripple bedforms in water depths greater than 25 m: a) 26-27 m water depth adjacent to trench infill B on 7/12/2018; b) 31 m water depth adjacent to trench infill C on 16/4/2019; c) amplitude and wave length of ripples in 26m water depth on 3/7/2020; d) amplitude and wave length of ripples in 28 m water depth on 3/7/2020

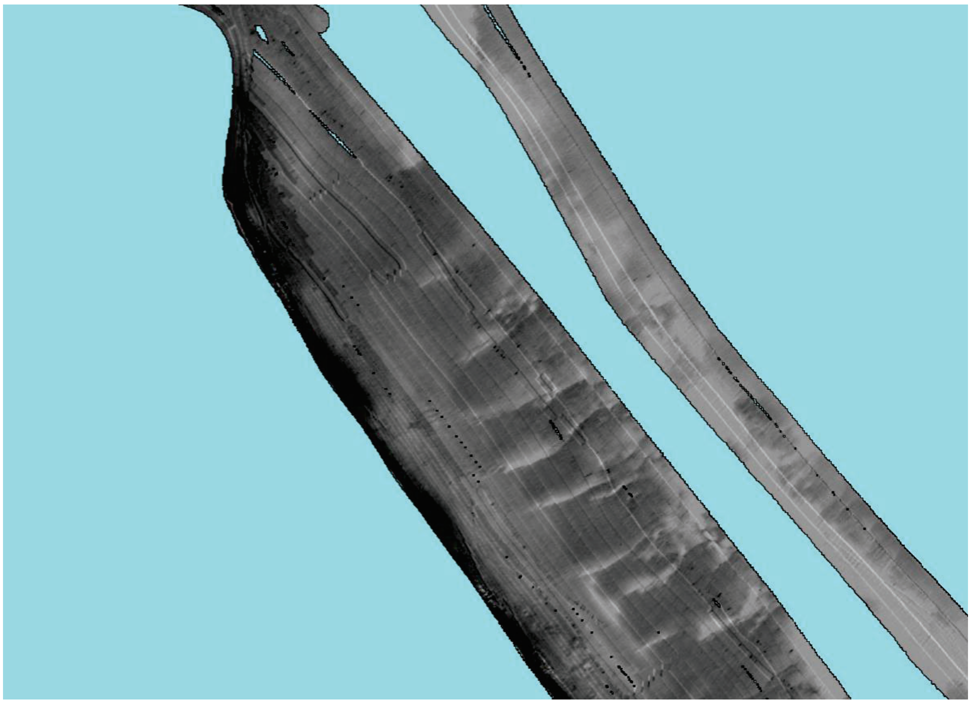


Figure 3.5: Backscatter mosaic from multibeam survey south of Te Arai Point showing fingers of fine sand overlaying shore-normal bands of coarser sand.

3.4 Biogenic Sand Production

3.4.1 From Literature Review

Hilton (1990) quantified the carbonate content of surficial sediments south of Te Arai Point to be in the order of 2-5% of the total sample of well sorted fine sand in water depths less than 25 m CD (i.e. -27 m MSL), increasing to 20-30% in the area with water depth 25 – 30 m CD (i.e -27 to -32 m CD). Hilton determined that the carbonates consisted mostly of fragments of benthic macrofauna of molluscan origin, which based on the benthic biota data collected in the embayment since 1990 has not changed (Bioresearches 2019b) with molluscs still dominating the biota.

By integrating data from trawls, Hilton (1990) was able to estimate the total mass of live shell material in the surficial seabed sediments (i.e. the top 10-15 cm in this case) to be at an average concentration of 97g/m², with the total weight out to the 25 m CD depth being 5,300 tonnes within his study area to the south of Te Arai Point. To calculate biogenic sand production, Hilton assumed that all shellfish species had a similar life span of 10-year, hence 10% of the population would die every year and the shell becomes part of the biogenic sand. Based on these assumptions, he calculated that the existing weight of shell material would increase to 73,000,000 tonnes after 100 years. However, as pointed out by Bioresearches (2019b) this calculation was incorrect, with Hilton mistakenly adding the dead shell material back into the live shell material for the annual recalculation of dead shell production, therefore the over-calculation of dead shell production was compounded each year resulting in a gross overestimate of the production rate over time.

Hume et al (1999) converted Hilton's figures to a total production rate of around 900,000 m^3/yr (at bulk density of 1.6 tonnes/m^3) for the total Mangawhai-Pakiri embayment, but also recognised that it was erroneous and did not use this production rate in the MPSS sediment budget calculations. As a result, the MPSS did not produce a separate biogenic sand production rate, instead suggesting that it was part of the 12,000 m^3/yr of diabathic sand transport across the 25 m CD water depth contour. This approach implied that there was no biogenic sand production from shoreward of the 25 m CD depth contour.

The 2006 Environment Court decision rejected this biogenic sand production approach, instead agreeing with the evidence presented by Barnett (2005), that the biogenic sand production rate could be inferred as approximately 90,000m³/yr for the sediment budget to balance.

3.4.2 2019 Assessment

As a result of the uncertainties in the biogenic sand production rate outlined above, Bioresearches Ltd (2019b) were commissioned to undertake a re-assessment of the production rate based on fauna abundance data collected by them in various local projects and fauna growth rate equations obtained from the international literature. This assessment uses more recent information than available at the time of Hilton's 1990 assessment, although Bioresearches point out that population size, mortality and recruitment are still not well understood. The Bioresearches assessment is reproduced in **Appendix F** of this report.

The results of the assessment were that the annual shell production within the whole Mangawhai-Pakiri embayment within 0 m to -27 m (MSL) (e.g. to 25 m CD) and assuming shell densities of 1.1 -1.4 t/m^3 (from international literature) were in the range of 4,600 – 5,800 m^3/yr when calculated using growth rate and 5,800 – 7,400 m^3/yr when calculated by mortality size. The annual shell production in the -27 m to -32 m (MSL) contour band (e.g 25-30 m CD water depths) was also calculated, being 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 (MSL) 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 (e.g. 25 m CD), with an additional 4,000 - 5,400 m^3/yr being part of the cross-shore transport from the inner continental shelf.

3.5 Wave and Currents

3.5.1 Waves

3.5.1.1 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.

3.5.1.2 Modelled Mangawhai-Pakiri Waves 1979-2018

Tables of the monthly and annual summaries of the 40 years (1979-2018) modelled three-hourly directional wind 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 3.6.

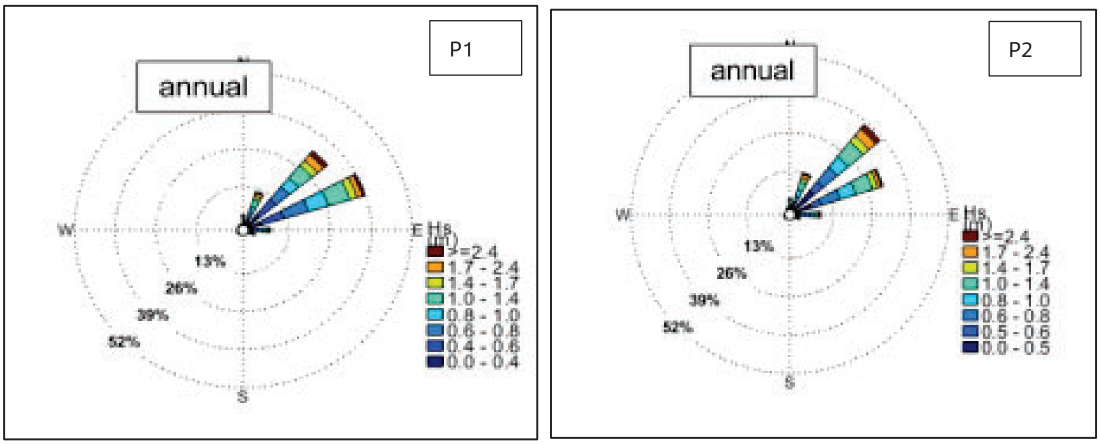


Figure 3.6: Wave direction-height roses for sites P1 and P2 from modelling of wave climate 1979-2018. Source MetOcean Solutions (2019)

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 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 a bigger percentage of larger waves than reported over the 18-month period recorded in the MPSS (e.g 4% with Hs> 2 m).

- 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).

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[5] to be up to 0.5 m/s (for H_s >5 m & $T_p \geq 12$ 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.

However, it is noted that presence of infragravity waves, being long period waves (e.g periods of 20-250 seconds) generated by the phasing of different short period wind wave groups (e.g. periods of 2-20 seconds) can also induce cross-shore transport in the wave shoaling zone, which can include beyond the 30 m water depth in storm conditions. Therefore sediment entrainment frequencies at these depths are likely to be greater than indicated above.

3.5.1.3 Recorded Marsden Point Waves 2007-2020

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 a precise representation 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.

The summary wave statistics from the 13 years of time series data are presented in Table 3.3 and Figure 3.7 to 3.9, 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 13-year record was 0.72 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 81% of the 13-year period, exceeded 2 m 3% of the time, and 3 m 0.4% of the time. This indicates less frequency of large waves than the modelled record, reflected in the Marsden recorded 1 percentile H_s being 2.52 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.

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

- The average mean wave period (T_m) was 5.86 seconds, with the highest frequencies being in the 4-7 second range, 91% being less than 9.1 seconds, and only 1% being greater than 11.3 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 (63%) 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 3.9). 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 similar mean H_s (0.72 m and 0.73 m), but with winter having slightly more higher waves (3.1% > 2 m compared to 2.3% in summer), more slightly longer wave periods (1 percentile Tm = 11.60 seconds in winter compared to 10.8 seconds in summer), and slightly less waves from ENE-East directions (69% in winter compared to 72% in summer). This was a similar result to the modelled wave data for Mangawhai -Pakiri.

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.

Table 3.3: Summary wave statistics from Northport wave buoys at Marsden Point January 2007 to March 2020.

Parameter	Total Record 2007-2020	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)	0.72 m	0.72 m	0.73 m
Median Significant Wave Height (median Hs)	0.57 m	0.55 m	0.61 m
1 percentile Hs	2.52 m	2.60 m	2.44 m
0.1percentile Hs	4.08 m	4.61 m	3.71 m
% Hs ≤ 1m	80.9%	79.1%	80.5%
% Hs > 2 m	2.8%	3.1%	2.3%
% Hs > 3 m	0.3%	0.4%	0.3%
Average Mean Wave Period (mean Tm)	5.86 sec	5.83 sec	5.89 sec
Median Mean Wave Period (median Tm)	5.5 sec	5.5 sec	5.7 sec
10 percentile Tm	8.8 sec	9.1 sec	8.6 sec
1 percentile Tm	11.3 sec	11.6 sec	10.8 sec

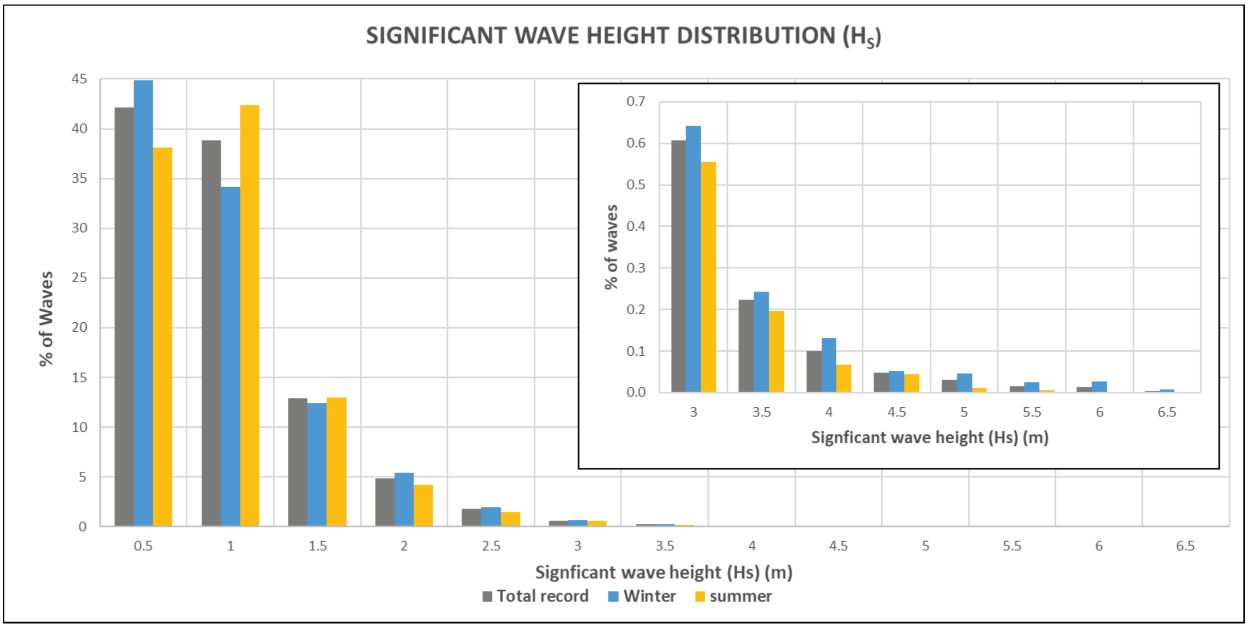


Figure 3.7: Significant wave height (Hs) distribution from Marsden Point wave buoys 2007-2020.

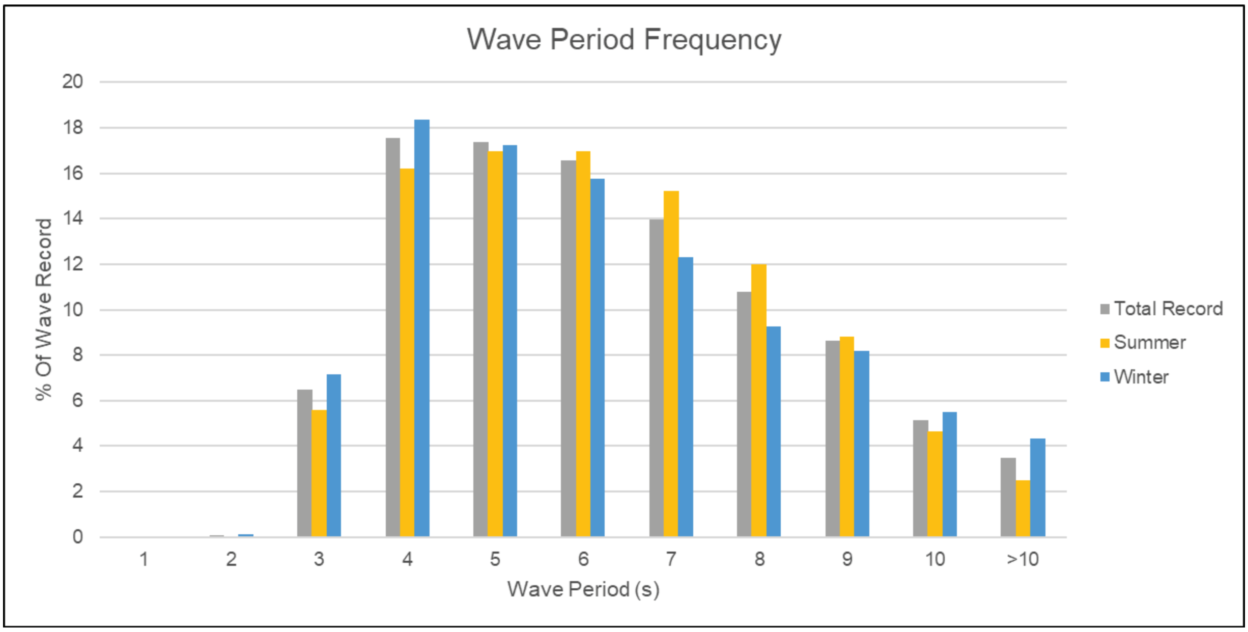


Figure 3.8: Mean wave period (Tm) distribution from Marsden Point wave buoys 2007-2020

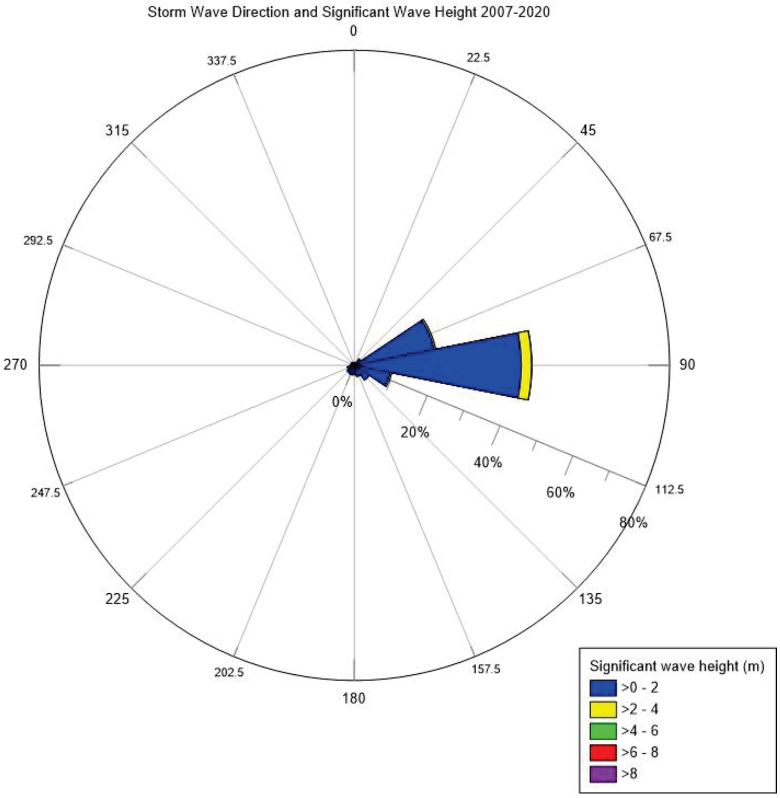


Figure 3.9: Wave direction distribution from Marsden Point wave buoys 2007-2020.

3.5.1.4 Marsden Point Storm Events 2007-2020

For the purpose of this analysis, storm events have been defined as periods when H_s exceeded the 1 percentile H_s of 2.52 m (total record) for longer than 3 consecutive hours. Applying this criteria, 70 storm events occurred over the 13-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 (65) 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 3.5.1.2, 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 16 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 10^{th} July, and is unlikely to have recorded the total storm duration or largest wave height. Other records[6] note that this 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.

[6] GNS/NIWA, Natural Hazards 2007)

In terms of monthly distribution, the highest frequency of storms occurred in March and July (10-11 storms over the 13-year record), with the least being in November (one storm).

In terms of seasonality, more storms (44) occurred in the winter six months from April to September, than in the summer (26) from October to March, with winter storms generally having larger wave heights and longer durations. This seasonal storm distribution is reflected in the 6 monthly record of shoreline change. 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, 2010 with two events, and 2019 with two events.

3.5.2 Currents

3.5.2.1 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.

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.

3.5.2.2 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 3.10 and the depth averaged tidal currents in Figure 3.11.

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. Although only about 5% of these near bed currents at 30 m water depth have sufficient speed to entrain fine sand and only 2% have sufficient speed to entrain medium sand, 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).

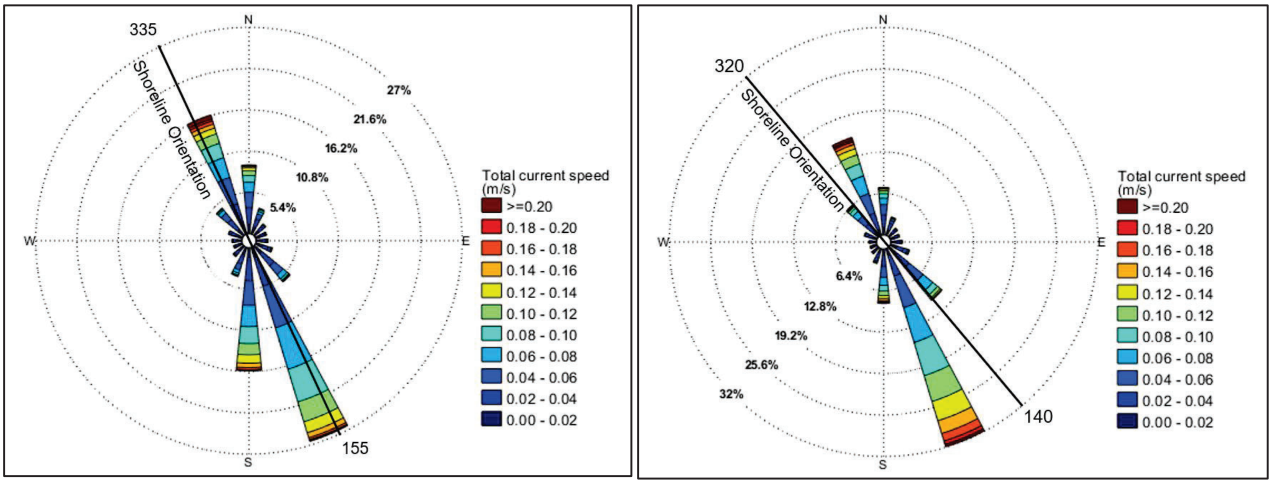


Figure 3.10: Modelled near bed non tidal current directional roses over 19 years (2000-2018) for a) P1 and b) P2. Source MetOcean Solutions (2019)

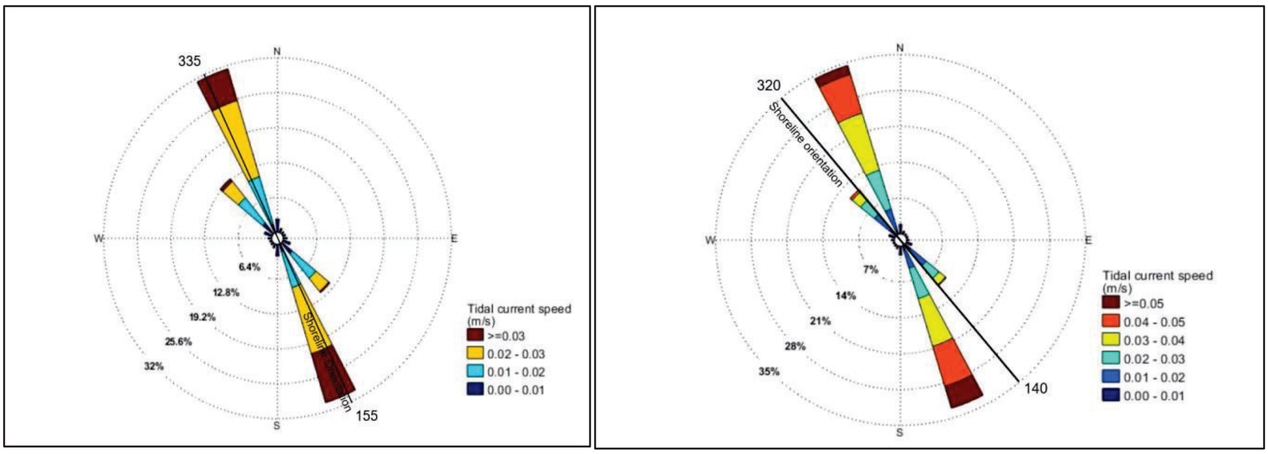


Figure 3.11: Modelled depth averaged tidal current directional roses over 19-years (2000-2018) for a) P1 and b) P2. Source MetOcean Solutions (2019)

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. However, 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 that the MPSS.

3.6 Sediment Transport

3.6.1 From Literature Review

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 3.12. The figure shows a major sediment transport pathway into the Mangawhai-Pakiri embayment from between Bream Tail and the Hen & Chicken Islands that combines transport from Bream Bay around Bream Tail, and from deeper waters around the Hen & Chicken islands. However, the sediment budget produced in the MPSS summary report (Module 6, Hume et al, 1999) and reproduced as Figure 3.17 of this report, does not include this major pathway as a sediment input into the Mangawhai-Pakiri embayment, instead showing diabathic transport across the whole bay length in the range of 200-64,000 m^3/yr with a best estimate of 12,000 m^3/yr and a net leakage out of the embayment past Bream Tail at an average annual rate of 1,000 m3/yr. This would appear to be a contradiction, as pointed out by Dr. Alastair Barnett in his evidence to the 2005/2006 Environment Court hearing.

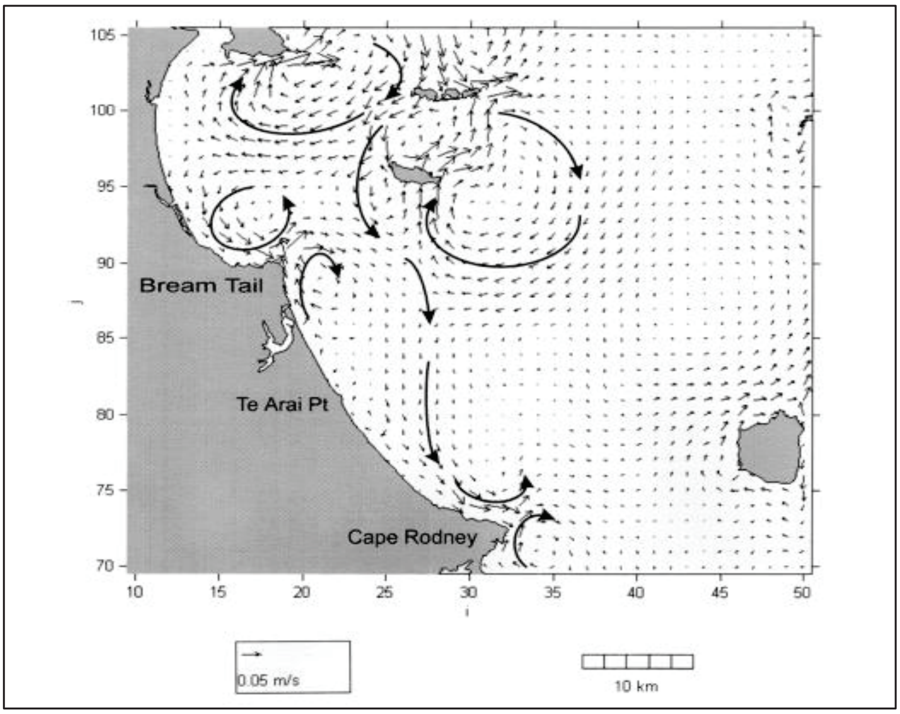


Figure 3.12: Vector diagram of residual (net) depth averaged currents generated by wind and potential sediment pathways from modelling of wind averaged over 23-years of record. Note faster currents have longer arrows. (From Hume et al. 1999)

The Environment Court in its 2006 Decision found that the supply of sediment to the Mangawhai-Pakiri embayment from around Bream Tail was most likely in the order of 25,000 m^3/yr as indicated in the evidence presented by Dr. Barnett.

3.6.2 Qualitative assessment of Longshore Sediment Supply around Bream Tail

As indicated in Section 2.4.3, sediment samples, photographic surveys and diver observations were undertaken in 2019 and 2020 as part of a qualitative assessment of sediment transport around Bream Tail into the Mangawhai-Pakiri embayment.

The results of the sediment sampling and photos (Figure 3.13 – sample locations, Figure 3.14 sediment size results, **Appendix M – Bream Tail seabed and sample photos**) indicate that sand is found across a wide swath of the seabed off the Bream Tail headland out to 30 m water depths. From the sampling results in Figure 3.14, 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. SED19-8) and in water depths deeper than 30 m MSL (SED19-11, 20-1, 20-2). These deeper samples are in locations that correspond with those identified in Figure 3.12 above, as being areas of larger residual currents, therefore are potential sediment pathways from sediment in Bream Bay into the Mangawhai-Pakiri embayment. This is supported by the photographs taken by MBL divers presented in Figure 3.15 of sand ripples present on the seabed around Bream Tail in depths from 8 m to 16 m.

This qualitative data; 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 the transport rates around the Bream Tail from the 2006 Environment Court decision.

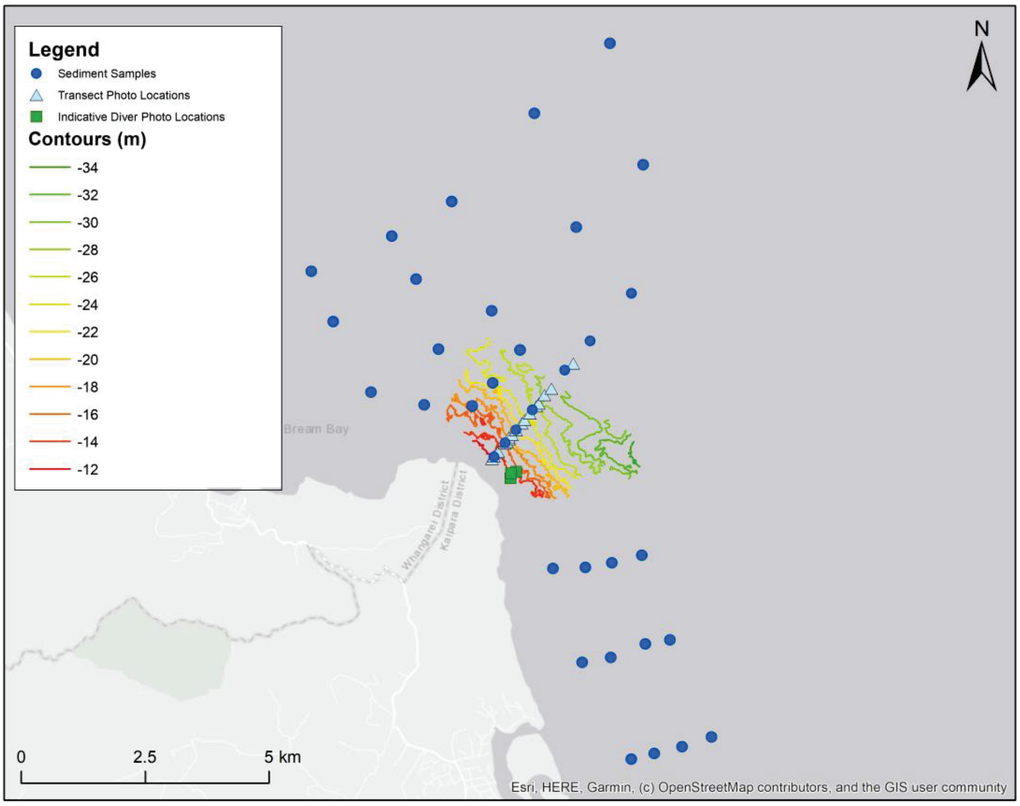


Figure 3.13: Location of Bream Tail seabed sediment samples and photos

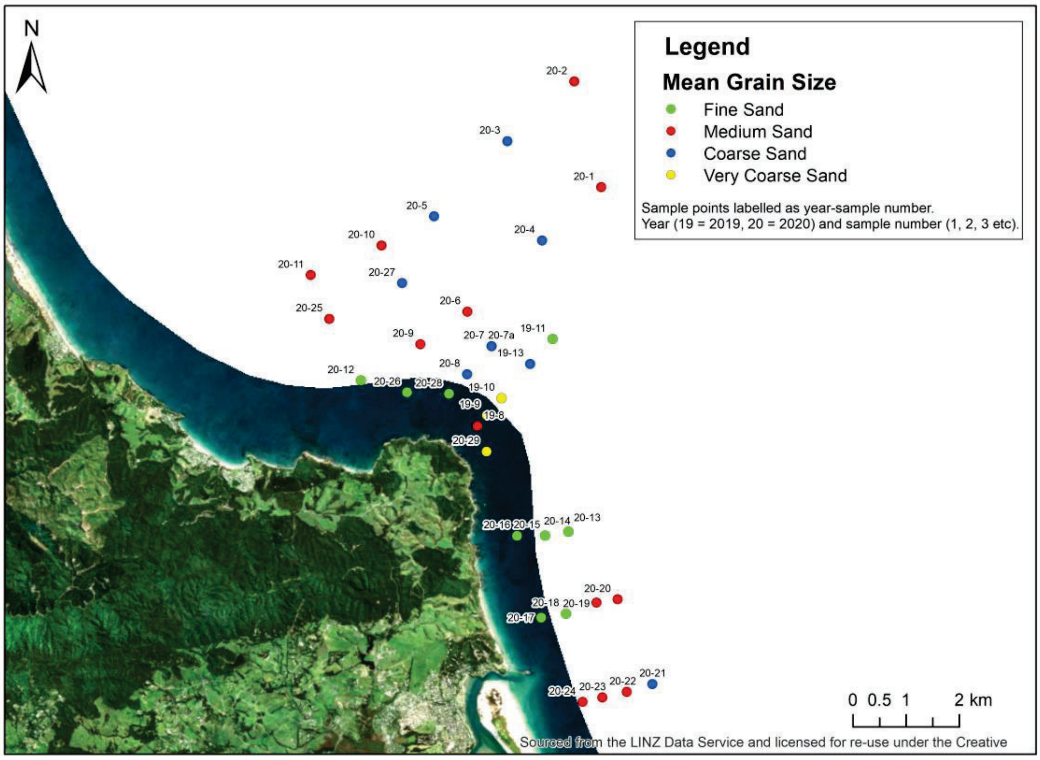


Figure 3.14: Mean sediment size results for Bream Tail and Bream Bay sediment samples.

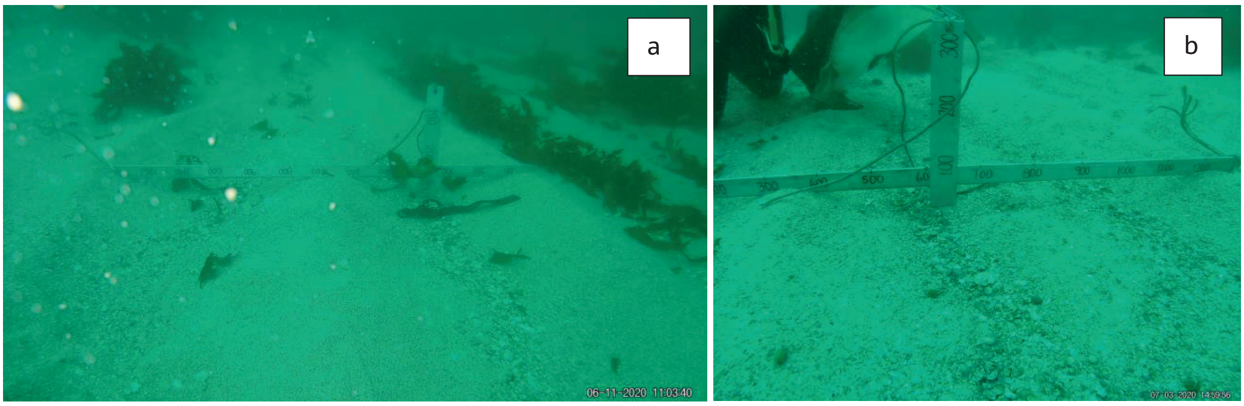


Figure 3.15: Sand ripples around Bream Tail; a) in 8 m water depth taken by MBL divers 11/6/2020, b) in 17 m water depth taken by MBL divers 03/07/2020

3.6.3 Presence of Sand Ripples in Water Depths Greater Than 25 m CD

As shown in Figure 3.16, the photographs taken during the trench infill measurements in the KL consent area 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 below in Figure 3.16, 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 theoretical threshold for wave orbital velocity to entrain sand, yet clearly significant sand transport had occurred as a result of wave action.

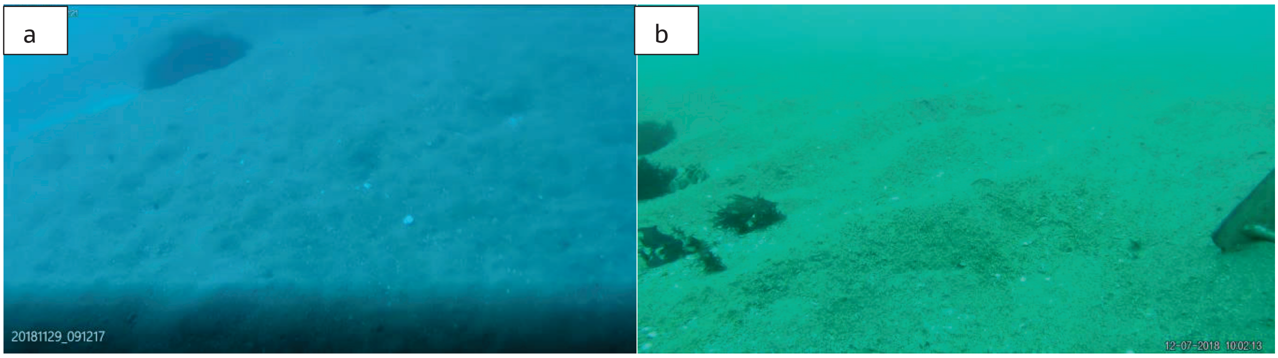


Figure 3.16: Evidence of sand transport in 26-27 m water depths from comparison of sand ripples adjacent to trench infill B: a) on 29/11/2018; b) on 7-12-2018 following high energy wave event on 30/11.

3.6.4 Dredge Trench Infill Measurements

As described in Section 2.3.5, a series of infill measurements were undertaken for a number of trenches located in both the the MBL inshore consent area and the KL 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. The purpose of this work was to determine the speed at which trenches are infilled by sediment transport on the nearshore seabed and whether dredging might have localised long term effects on the bathymetry of the seabed from not infilling completely.

3.6.4.1 Inshore Consent Area Trenches

The results of this assessment are presented in Table 3.5. 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.

The results show that extraction trenches within the MBL inshore extraction area in water depths between -6 m and -10 m MSL infill rapidly, sometimes in a matter of days, and mostly in less than two weeks. This emphasises the substantial rates of sand transport at these depths under most conditions, driven by waves and wave driven currents, and the connectivity between the inshore extraction area and the beach/dunes.

Table 3.5: Extraction Trench Infill Rates and Durations in the existing MBL Inshore Extraction Area

Trench	Start Date	Final Obs date	Days to infill	Infill Rate ($m^3/m/day$)	Notes
(1)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.
(1)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.
(1)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.
(2)Trench E 10 m	28/11/2019	15/12/2019	17	0.0068	Depressions present along the old track on the 15/12, 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: (1) Dredged by 'Coastal Carrier'. Volume to infill trench is 0.18 m^3/m. (2) Dredged by 'William Fraser'. Volume to infil trench is 0.115 m^3/m Trench D not included as only one observation was taken the day after it was dredged.					

These results indicate that the shallow extraction trenches are short lived before being totally infilled. Hence, by spacing out the interval between re-dredging the same track the formation of permanent trenches that could alter wave patterns approaching the nearshore bar and beaches will not occur.

3.6.4.2 Offshore Consent Area Trenches

The basis of this assessment was to use trench infill measurements from the inner part of the KL offshore area to determine whether or not significant entrainment and transportation of bed sediment occurs at water depths greater than 25 m CD. The trench infill measurements from these experiments 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 as presented in section 3.5.1.2.

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 presence of fresh sand ripples in water depths greater than 25 m CD.
- 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 the occurrence of extreme storm events. Note that infill durations will be shorter with the 'William Fraser' than the 'Coastal Carrier' due to the smaller trench depth and volume required to infill.

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)	Infill volume (m^3/m/day)	Diver Observations
				By waves	By currents				
>25 m A(2)	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(2)	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(2)	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(3)	27/11-15/12/2019	19	No data	No data	No data	No data	40(4)	0.01(4)	Track much shallower than Coastal Carrier
>25 m E(3)	03/07–23/07/2020	23	No data	No data	No data	No data	120(4)	0.01(4)	23/07/20 - Dive was undertaken post a short lived 4m storm event the week prior (duration 12 hrs). Track not present in any form and completely overshadowed by large sand ripples 0.6 to 0.8m wide and 100-150mm high

Notes: (1) Is theoretical % of time that currents in any direction could transport sand if it had already been entrained.
(2) Trench extracted by 'Coastal Carrier'. In this water depth average trench depth is 0.3 m and average volume to totally infill is 0.21 m^3/m.
(3) Trench extracted by William Fraser. Average Trench depth is 0.105mm and total infill volume is 0.115 m^3/m

3.7 Historical Shoreline Movements

3.7.1 From Literature Review

3.7.1.1 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 (taken as being the +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.

3.7.1.2 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.

3.7.2 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. The results from this analysis is presented in Table 3.7.

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 spatial distribution of the rates of shoreline change over the total period are also summarised in Figure 3.17.

Table 3.7: 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

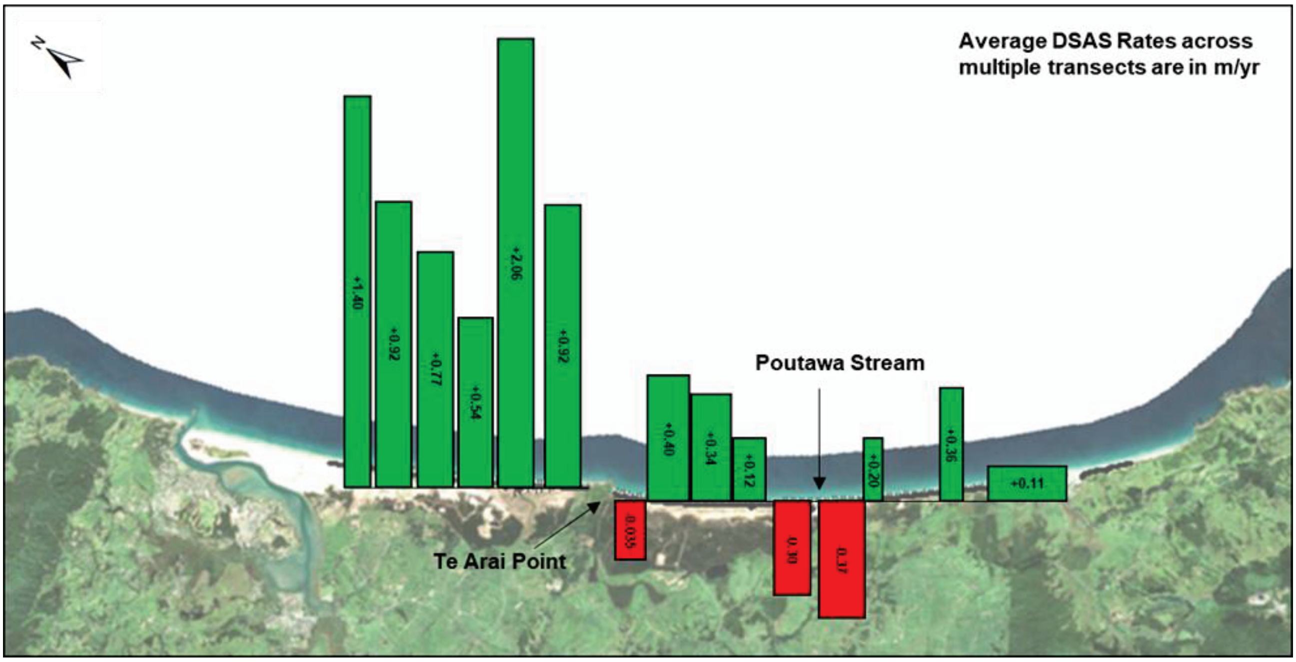


Figure 3.17: Spatial distribution of total shoreline change 1961/63 to 2018 from aerial photographs or from long-term beach profiles P5 & P6 since 1978 south of Poutawa Stream where 1960's aerial photographs were not available.

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

- Although there are a large range of shoreline responses across the different time periods for all three areas, 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.
- The greatest advance was for the transects within two kms north of Te Arai Point, with average advance of +1.5 m/yr. This is consistent with sand accumulating against the headland in net southerly longshore transport as presented in evidence of Derek Todd to the 2005 Environment Court hearing.
- 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 in a net southern transport regime.
- 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.
- 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.
- 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).
- Since 1982, there has been shoreline advance of all areas. Of the 155 transects with images from 1982 to 2018, 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.

Further comparison of the historical shoreline movements within the extraction areas and the southern control area are presented in the assessment of effects section 4.2.3.1.

3.7.3 Updated Analysis of Beach Profiles 1978-2019

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, which varies between 1978 to 2000 for different profiles,
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 2020 (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 2020 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 3.8. 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 3.8: Net beach and dune 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)	Beach and foredune Volume change (>1m contour)
P1	1978-2020	+4.3 m @0.10m/yr	+4.7 m @0.11m/yr	+39.9 m	+59.8 m^3/m	49.2 m^3/m
P2	1988-2020	+8.9 m @0.28m/yr	+2.2 m @0.07m/yr	+25.4 m	+16.8 m^3/m	20.7 m^3/m
P2B	1993-2020	+68.9 m @2.55m/yr	+53.2 m @1.99m/yr	-34.2 m	+30.8 m3/m	238.5 m^3/m
P2A	1990-2020	+6.9 m @0.23m/yr	+11.4 m @0.38m/yr	+7.5 m	+33.2 m3/m	2.2 m^3/m
P3	1981-2020	+28.6 m @0.73m/yr	+19.8 m @0.51m/yr	-18.3 m	+18.3 m^3/m	137.6 m^3/m
P4	1978-2020	+3.8 m @0.09m/yr	+7.7 m @0.18m/yr	+15.8 m	+40.4 m^3/m	74.4 m^3/m
P5	1978-2020	-9.6 m @-0.23m/yr	+25.8 m @0.61m/yr	+34.6 m	+105.6 m^3/m	143.1 m^3/m
P6	1978-2020	0 m @0.00m/yr	+8.5 m @0.20m/yr	+30.5 m	+22.2 m^3/m	43.0 m^3/m
P7	1978-2020	+12.6 m @0.30m/yr	+15.2 m @0.36m/yr	+15.0 m	+48.3 m^3/m	78.9 m^3/m
P8	1978-2020	+5.1 m @0.12m/yr	+42.5 m @1.01m/yr	+30.0 m	+53.0 m^3/m	96.5 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	N/A

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 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. It is the same pattern for the dune face, except for P5 to the south of Poutawa Stream, where the -20 m retreat that has occurred in the last year is due to local site conditions within the dune blow out where this profile is located.

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 large increase in the dune volume (>200 m^3/m), but around 35 m reduction in foreshore width at this site. However, foreshore volumes still experienced a net increase, indicating a general increase in foreshore elevation.

The sites further north experienced the least net beach toe advance, with both P1 and P2 having advance rates in the order of 0.1 m/yr. Dune toe advance at sites south of Te Arai Point to the Pakiri River were variable, having toe advance rates between 0.18 m/yr and 1 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). Excluding the P9 site for this reason, the average dune toe advance over the remaining 10 profiles was 0.54 m/yr, which supports the accretion results from the aerial photograph anaylsis presented in Sectiuon 3.7.2. This includes the sites (P6 & P7) in the southern control area between the Poutawa Stream and the Pakiri River excluded from the aerial photograph analysis due to not being covered by the 1960's images.

Apart from site P2B, the only site to experience a net reduction in beach width was P3 to the south of Te Arai Point, where the net movement of the 1m contour has not kept pace or exceeded the beach toe advance. However, all sites including P2B and P3, have experienced a net gain in foreshore volume. However, accumulation rates appear to be lower than reported in the MPSS. Similarly all sites experienced net gains in volume across the foreshore - foredune profiles, indicating that volume accumulation in association with shoreline advance has occurred right across the active beach-dune profile.

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, with the average foreshore volume increases across all profiles of 1.1 m^3/m/yr, and across the dune-beach areas of 2.5 m^3/m/yr. These sediment accumulation volumes are an important storage element in the sediment budget considerations presented in the following sections.

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 4.2.3).

3.7.4 Excursion Distance Analysis 2007-2020

3.7.4.1 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 3.18 (3.5 m contour), and 3.19 (5.5m contour). Within these figures the extractions zones and the southern control are presented by different colours. 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.

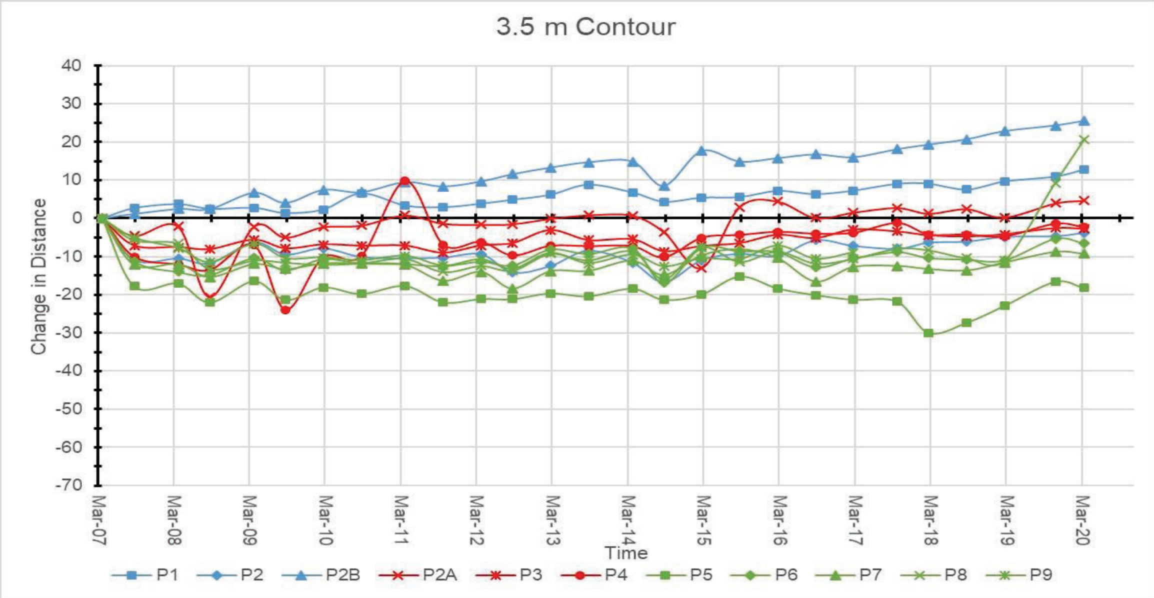


Figure 3.18: Excursion distance plot of the 3.5m contour (proxy for beach toe position) at historic profile sites 2007 – 2020

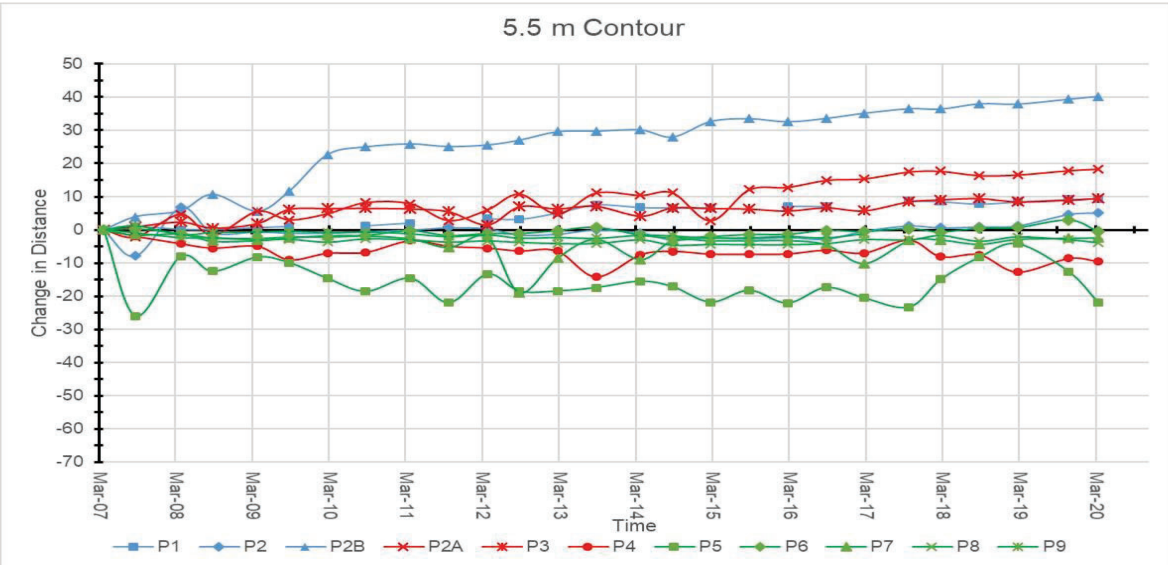


Figure 3.19: Excursion Distance plot of the 5.5m contour (proxy of dune face position) at historic profile sites 2007 – 2020.

The following general trends over the 13-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.
- For the dune toe, large 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 control areas. As can be seen in Figure 4.2, while all profiles showed dune toe recovery following this event, for 6 of the 8 profiles south of Te Arai Point the dune toe has never totally recovered back to the April 2007 position at any time since the event.
- 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 have never recovered back to April 2007 position at any time since the event.
- 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, P7, & P8). These are short-duration changes that are generally reversed by the next survey. However, some of this variability is due to the interpolation of profiles from the topographical surveys.
- Over the total period, half of the sites display net erosion for at least one of the contours, with four sites south of Te Arai Point displaying net erosion at both contours, and three (2 north and 1 south) displaying net accretion at both contours.
- Net movements at both contours are generally below less than ± 10 m over the 13-year period, with only accretion of the dune toe at profiles P2B and P8 being greater than +20 m, and only erosion of the dune face at Profile P5 being by more than -20 m.
- Over the total 13-year period, apart from the dune face at P4, and the large recent dune toe advance at profile P8, 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.
- 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 4.2.3.1.
- Over the total 13-year period, apart from the dune face at P4, and the large recent dune toe advance at profile P8, 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.
- 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 4.2.3.1.

Further analysis of the EDA of the 3.5 m and 5.5 m contours is presented in Section 4.2.3.2 for assessment of the response to the most significant storms in July 2007 and July 2014 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.

3.7.4.2 Topographic Survey, 100 m Profile Analysis

A weakness of the historical profile analysis is the ability of the eleven profiles to adequately represent the 21 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 maps of cumulative change in distance to beach contours from a fixed baseline. Examples of the resulting temporal-spatial change maps for the 3.5 m contour (proxy for dune toe) are shown in Figure 3.20 and for the 5.5 m contour (proxy for dune face) in Figure 3.21.

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

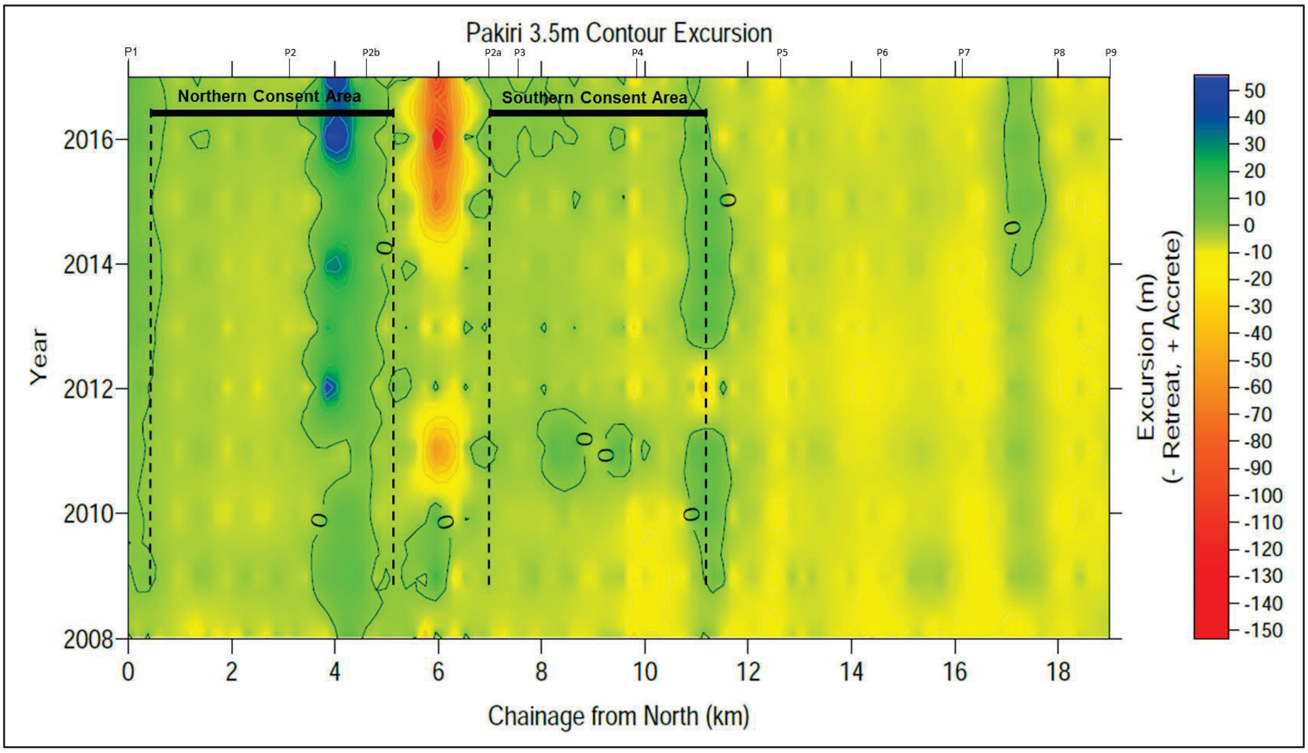


Figure 3.20: Three dimensional temporal-spatial map of distance excursion of the 3.5 m contour from topographic surveys 2007-2017

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 km) 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.

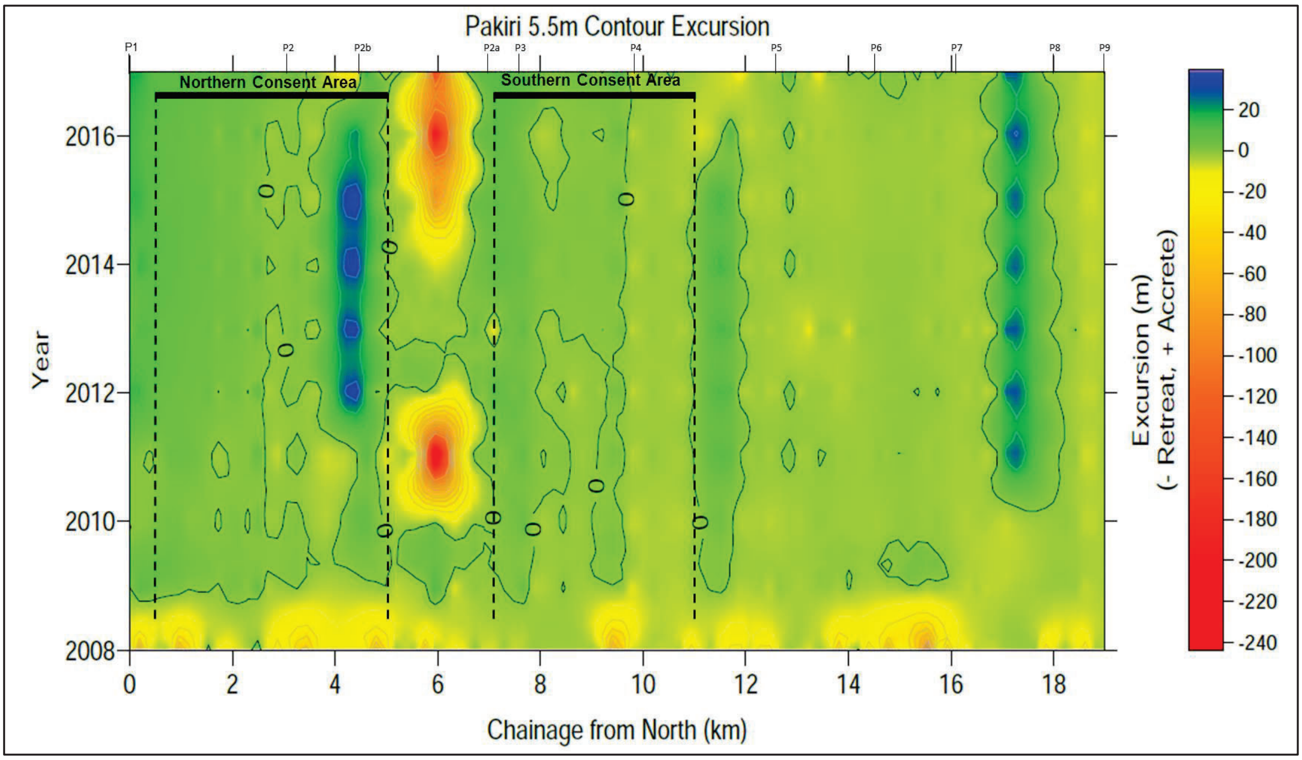


Figure 3.21: Three dimensional temporal-spatial map of distance excursion of the 5.5 m contour from topographic surveys 2007-2017

For the proxy dune face position (5.5 m contour- Figure 4.5), 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.

3.7.5 Beach Volumes Changes

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 influenced by short-term variations in the position of this contour, which may not represent longer term patterns of change.

3.7.5.1 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 than 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.

3.7.5.2 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 3.22. The volume changes from surveys from October 2017 to March 2020 are presented in Figure 3.23. It is also noted that this figure shows an additional survey in January 2018, which was undertaken following a storm event to determine post storm recovery.

As above, the values presented in each of the figures are not comparable, having been calculated from different areas.

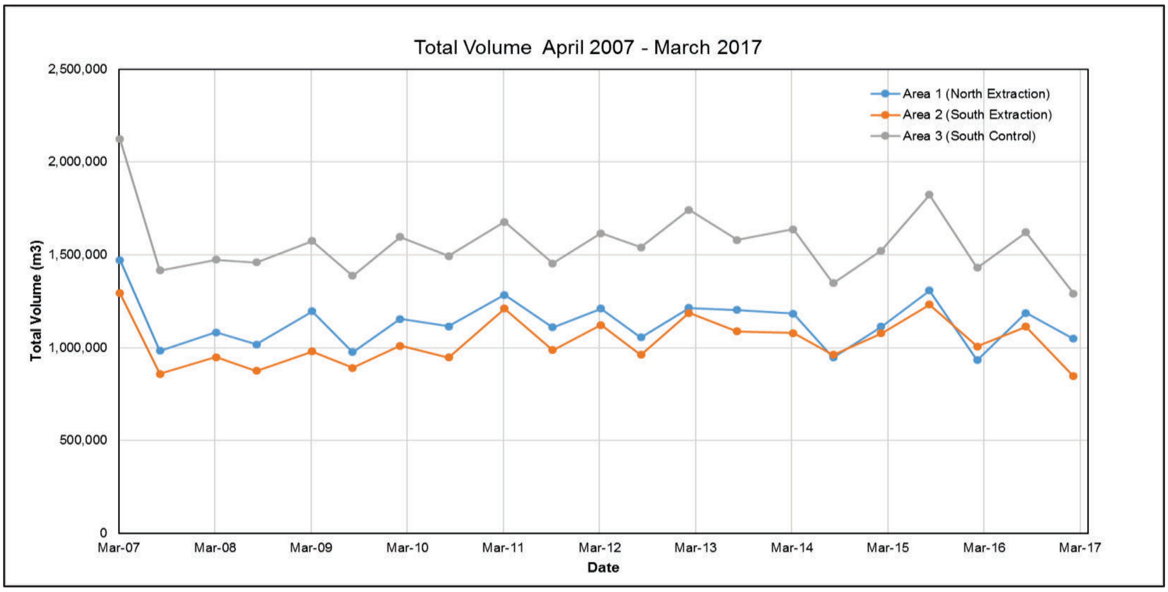


Figure 3.22: Beach volumes by area from topographic surveys April 2007 – March 2017

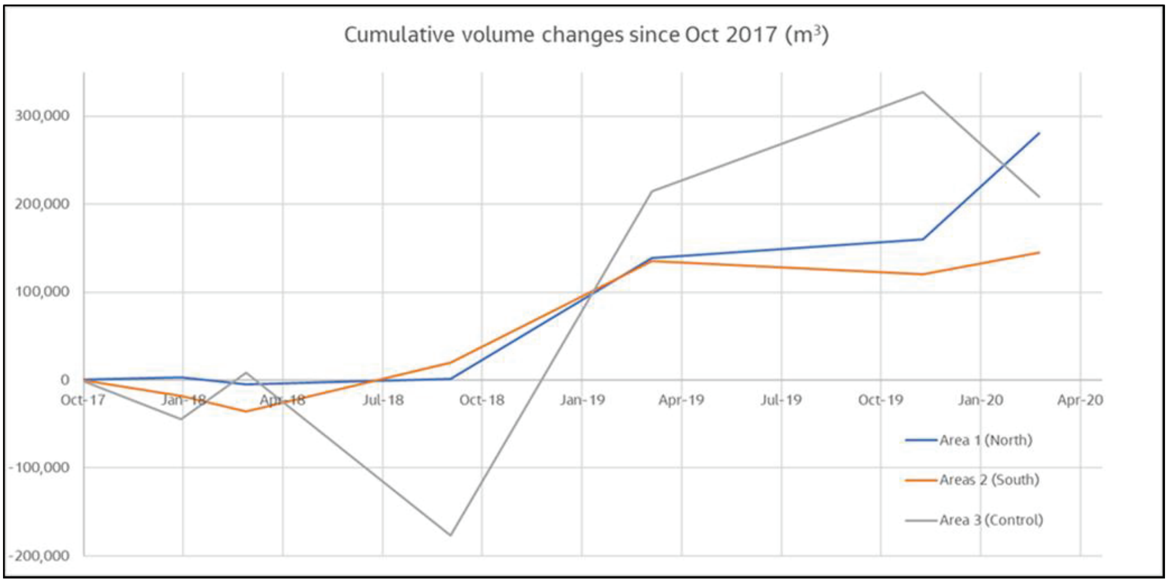


Figure 3.23: Beach volume changes by area from topographic surveys October 2017 – March 2020

The key points from this analysis include:

- The influence of the significant storm in July 2007 is clearly shown in Figure 3.22 with large foredune/beach volume losses totalling in the order of 1.6 million m^3 occurring 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 3.23 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 30-month period.

3.8 Sediment Budget

3.8.1 Principles

A sediment budget is a conceptual coastal management tool used to the balance between sediment added and removed from a coastal system, so can be considered to be like a bank balance; when more material is added than removed there is a sediment *surplus*, and when more is removed than added there is a sediment *deficit*. A surplus in a sediment budget is normally expressed as shoreline advance and sediment accretion, whereas any deficit is expressed as shoreline retreat and sediment erosion. As a conceptual tool, a sediment budget does not include consideration of the internal transfers within the coastal cell, or the processes involved in these transfers (e.g. longshore and cross-shore transport), therefore net long-term shoreline movement within a coastal cell is assumed to be the consequence of an imbalance between the sediment supply (known as *sources)* to the coastal cell, and the sediment losses (known as *sinks)* from the coastal cell.

In general, major sediment sources to a nearshore – beach/dune system is from longshore transport into the compartment, river supply, cliff erosion, and onshore transport across the inner continental shelf. Sediment sinks include longshore transport out of the system, wind transport landward of the beach and dunes, and for the Mangawhai-Pakiri embayment – sand extraction. Within the sediment budget context, net long-term beach accretion such as has been shown in section 3.7 to be occurring at Managawhai-Pakiri, can be considered as *storage* within the sediment budget, therefore sediment sources should be greater than sediment sinks - including sand extraction.

The calculation of a sediment budget requires being able to identify and estimate all the sediment sources and sinks within the coastal compartment, however, this is an extremely difficult task and as a result few sediment budgets have been accurately determined (Morton, 2003). This is the case for the Mangawhai-Pakiri embayment, where there is a large degree of uncertainty in quantifying the volumes associated with most items in the sediment budget, with the volumes presented being an indicative best estimate. For this coastal compartment, the greatest certainty is the extraction volume, and the second most certain is the shoreline accretion, both of which have been recorded over the last 50 – 60 years .

Another important consideration related to a sediment budget is the physical limits of the coastal compartments both along and across-shore, and whether the compartment is a “closed” or “open” sediment transport system across these boundaries. Many embayed coastal compartments are notionally considered to be closed systems, being 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. However, few systems are ‘closed’ in the strict sense as most have inputs and outputs to and from one or more potential sources of sediment from outside the ‘closed’ boundaries.

An important factor in the consideration of ‘closed coastal compartments’ is the concept of ‘depth of closure’, being the maximum depth at which wave conditions can move sand to be exchanged between the beach and the nearshore, therefore being the seaward limit of potential onshore sediment transport supply from the inner continental shelf, with the active beach being defined as extending from the top of the frontal dunes to the depth of closure.

Historically the Mangawhai-Pakiri embayment has been considered to be closed both alongshore around Bream tail and Cape Rodney, and cross-shore landward of the 25 m water depth. However, the evidence presented in this assessment and the findings of the Environment Court indicate that some of these pathways exist in the Mangawhai Pakiri embayment, and under a sediment budget approach provide inputs which account for the sediment stored as long-term beach accretion. Therefore, the embayment should more correctly be considered as being 'partially closed' rather than a totally closed sediment compartment.

3.8.2 MPSS Sediment Budget

Module 6 of the MPSS (Hume et al 1999) presented a sediment budget for the Mangawhai-Pakiri embayment dune-beach-nearshore system landward of the 25 m water depth contour based on the investigations and information presented in the preceding modules. This sediment budget is re-produced in Figure 3.24 and the key points are explained below.

Total sediment sources were estimated to range from 8,000 to 72,000 m^3/yr with a large uncertainty in the diabathic transport supply from deeper than the stated closure depth of -25 m CD (e.g. range 200-64,000 m^3/yr based on sediment transport modelling results). Although not shown in Figure 3.16, the best estimate for diabathic transport was given as 12,000 m^3/yr, which as highlighted in section 3.4.1 of this report includes an unspecified volume of biogeneic sand production.

The sediment budget did not include any consideration of sediment storage as dune-beach accretion on the basis that the shoreline was in dynamic equilibrium, showing neither long-term erosion or accretion trends. As a result, the best estimate of total sources (given as credits) is 20,000 m^3/yr, while the total sinks (given as debits) were estimated at an average of 109,000 m^3/yr, including 102,000 m^3/yr due to sand extraction. Therefore, the embayment was assumed to be essentially closed with a small surplus of 13,000 m^3/yr, which converted to a best estimate net deficit of 89,000 m^3/yr and a possible range of 37,000 to 101,000 m^3/yr due to sand extraction.

However, as recognised by the MPSS, there is no evidence of erosion from this sediment 'deficit'. This is contradictory to the principles of sediment budgets. For the budget to balance there needs to be a greater sand supply coming into the Mangawhai-Pakiri embayment.

It was noted that although the interpretation presented in Module 6 of MPSS supersedes that presented in the previous modules, the final budget does not appear to include the major sediment transport pathway from between Bream Tail and the Hen & Chicken islands as shown in Figure 3.12, and that a 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"*.

3.8.3 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 sediment budget surplus, before sand extraction, of 144,000 m^3/yr[7].

[7] sources of 150,000m3/yr, and sinks excluding extraction of 6,000 m3/yr

Therefore, given that average sand extraction rates were less than this surplus, there was still a net sediment surplus after extraction, which was consistent with beach accretion evidence presented to the Court.

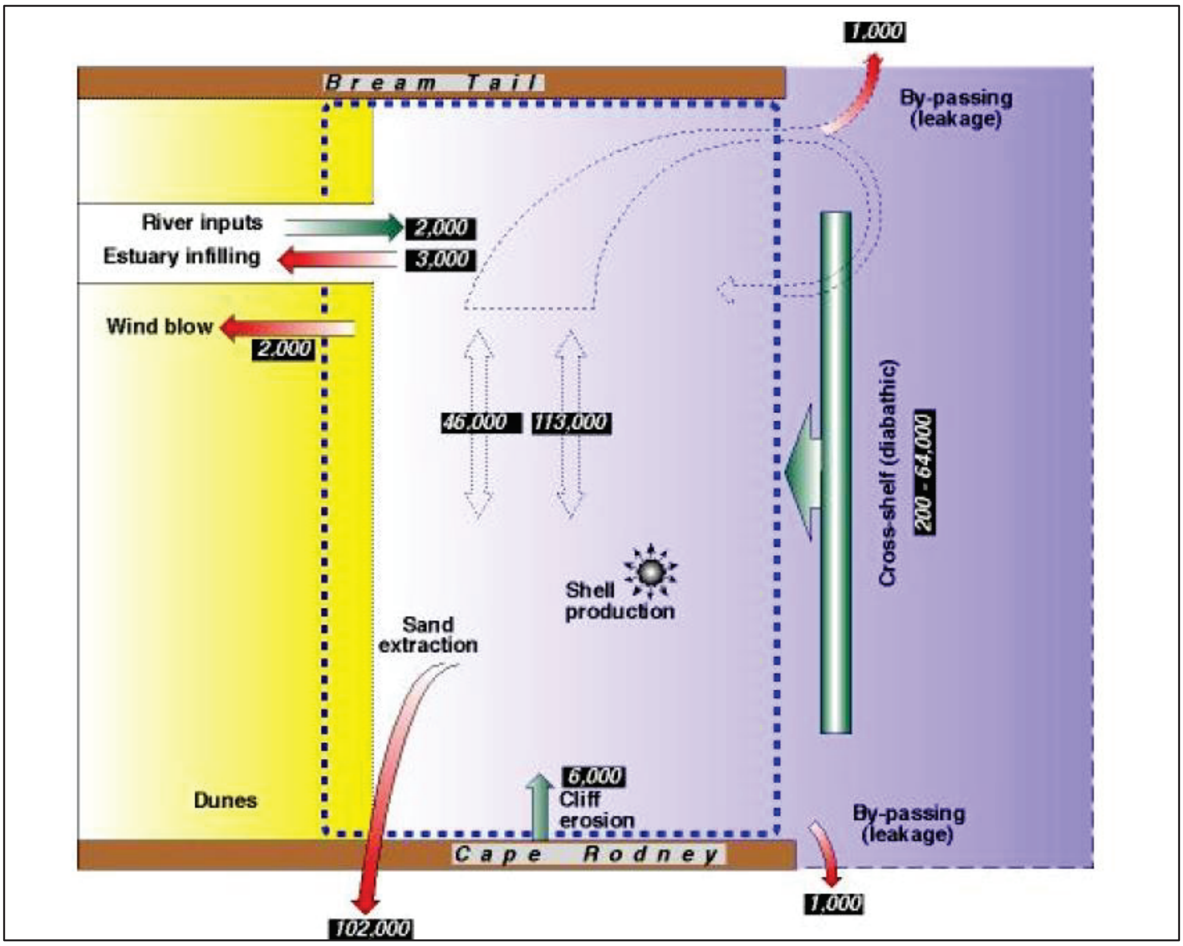


Figure 3.24: Sediment budget for Mangawhai-Pakiri embayment as presented in MPSS Module 6 (Hume et al 1999, Figure 3.3). Volumes are net figures in m^3/yr.

3.8.4 Updated Sediment Budget

3.8.4.1. Updated Estimates of Sand Supply Source

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

Biogenic Sand Supply

As presented in section 3.4.2, an assessment of the biogenic sand production based on local fauna abundance data and international literature on fauna growth rate equations was undertaken by Bioresearches Ltd (Bioresearches, 2019b), which is presented in **Appendix F**.

The results obtained from this assessment 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.

Cross shore sediment supply from the inner continental shelf

The information presented in earlier sections that indicates 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 includes:

a) Theoretical seabed sediment entrainment at the -30 m MSL contour: As reported in section 3.5.1.2, from the MOSL 40-year modelled wind 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" [8], there is potential for a net shoreward movement of entrained sand under wave action.

In addition, the presence of infragravity waves is likely to increase the frequency of sediment suspension and entrainment at water depths up to and beyond 30m water depths to more than that calculated for wind-waves alone.

b) Transport by non-tidal currents: As reported in section 3.5.2.2, for residual (i.e. non-tidal) near-bed currents the 40 year MOSL modelled data indicates current velocities in 30 m water depths 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 3.10 indicates that there is a small dominance of onshore transport in these current directions.

c) Trench infill observations and measurements from the KL consent area in depths > 25 m CD: As stated in section 3.6.4.2, despite the lack of modelled wave 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.

d) Presence of sand ripples in water depth > 25 m CD: As reported in section 3.6.3, the presence of large sand ripples adjacent to the trenches in water depths greater than 25 m CD, implies sand transport is occurring on the seabed at these depths. From the diver observations these ripples have formed without the presence of waves theoretically capable of entraining sediment at these water depths.

Although we can not definitively quantify the volumes of cross-shore transport across the -25 m CD contour from this information, all of these lines of evidence demonstrate that the supply from this source is considerably larger than the estimates in previous sediment budgets. However, by applying the principles of sediment budgets and using the sand storage volume from accretion, we can obtain an estimated sediment supply rate from deeper waters to balance the budget.

Longshore Sediment Supply around Bream Tail

In the vicinity of Bream Tail, the presence of sand sized sediment to beyond 30 m water depths, the presence of large sand ripples, and the occurrence of current velocities capable of transporting sand, indicates that sand is transported around this headland into the Mangawhai-Pakiri embayment and tends to support the transport rates from the 2006 Environment Court decision of 25,000 m^3/yr.

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

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.

3.8.4.2. Updated Estimates of Sand Sinks

From Table 1.1, the average annual extraction volume from the nearshore environment within the -25 m CD contour of the sediment budget has been in the order of 72,000 m^3/yr since 1966.

Other sinks have been retained as per the findings of the 2006 Environment Court, being:
Onshore winds: - 2,000 m^3/yr,
Into Mangawhai Inlet – 3,000 m^3/yr,
Alongshore around Cape Rodney – 1,000 m^3/yr

3.8.4.3. Updated Sand Storage as Accretion

As presented in section 3.7.2, the average rate of dune toe advance over the last 50+ years along the sand beaches from the Pakiri River to the Auckland boundary is +0.4 m/yr. Given that this has been measured by DSAS at 165 transects spaced at 100 m intervals, there is a good degree of confidence in this as a representative average figure for the whole embayment.

For sediment budget calculations of storage volume, this rate of linear advance needs to be coverted to a volume accretion rate. The following two methods were applied to achieve this:

1. First method; following the principle that the advance rate will be consistent across the total active dune-beach- nearshore profile, the accretion volume can be calculated as an average advance rate of +0.4 m/yr multipled by the height of the active profile. This height is taken to be 16 m from the top of the foredune (8 m above MSL from Appendix K & L) to the seaward limit of the extreme surf related sediment transport, i.e the outer limit of nearshore bar at around -8m MSL (from Appendix O). The seaward of extreme surf related sediment transport is verified by calculation of the inner Hallermeiers closure depth from the MOL modelled 40 year hindcast. The resulting average annual storage rate is calculated to be 6.4 m^3/m/yr. For the 21 km of sand beaches from the Mangawhai Inlet to the Pakiri River where the 0.4 m/yr advance rate is known to be relevant, this equates to an annual accretion volume in the order of 135,000 m^3/yr.

2. Second method; from applying the average dune-beach volume accretion rate measured from the 10 historical beach profile sites north of the Pakiri River since 1978 and an assumed corresponding volume increase in the nearshore from the first method as above. As recorded in Table 3.7, over the 27-42 years of profile survey records (from start dates between 1978 and 1993 to end date of 2019) the change in profiles shows an average increase in the dune and beach volume above the 1 m contour of 2.5 m^3/m/yr. It is noted that this is close to the 2.8 m^3/m/yr calculated by linear profile transition given in the first method above, and is within the range of estimates of dune accumulation rates over the last 6,000 years of the Holocene. The linear transition of the nearshore part of the profile to the -8 m contour by +0.4 m/yr would theoretically add another 3.6 m^3/m/yr, however this is considered to be an upper limit, as the advance rate would most likely reduce as the profile approaches the limit of the active zone. Assuming that the advance rate reduces to zero at the limit of the active beach, gives a lower limit of nearshore volume accretion of 1.8 m^3/m/yr. Therefore, the range of average storage volumes across the total profile could be in the order of 4.3 -6.1 m^3/m/yr, which when multiplied out over the same 21 km of sand beach gives a range of 90,000 to 128,000 m^3/yr going into beach storage over the whole embayment. The mid point of this range is 109,000 m^3/yr.

For the calculation of our budget we have adopted a mid-point of the two estimates of 122,000 m^3/yr.

It is noted that this storage volume is higher than the storage volume estimated in Jacobs (2019), due to that volume being calculated from a 1.4 m^3/m/yr beach accretion rate across the beach only, which did not include dune or nearshore accretion. The Jacobs (2019) report noted that the given volume was considered to be a minimum for those reasons. It is noted that the total embayment net storage volume of 122,000 m^3/yr used in the sediment budget could also be considered to be conservatively small, as doesn't include 4 km of beaches located north of the Mangawhai Inlet or south of the Pakiri River.

3.8.4.4. Resulting Updated Sediment Budget

From the above updated sediment sources, sinks and storage volumes presented above, an updated sediment budget out to the 25 m CD water depth (e.g – 27 m MSL) as shown in Table 3.9 and Figure 3.25 can be constructed. As noted above, in constructing this budget, we have estimated cross-shore supply rate from all the measured or estimated volumes for the other components and applied the principles of balancing the budget by the equation:

$$\textit{Cross-shore supply} = (\textit{sinks} + \textit{storage}) - \textit{other sources}$$

Bearing in mind the statement from Morton (2003) that few sediment budgets have been accurately determined due to the difficulty in identifying and quantifying all the components, the resulting best estimate of the cross-shore supply rate is in the order of 145,000 m^3/yr. While the volume from this source is considerably higher than the best estimate of the MPSS, it is noted that that there were inconsistencies with that estimate as pointed in section 3.8.2. Unlike the MPSS, this estimate does account for the supply of sand from between Bream Trail and the Hen and Chicken Islands as shown in Figure 3.12. While we have included this as cross-shore transport, it could also be considered to be an enhancement of the longshore transport entering the north eastern corner of the sediment budget cell. This higher transport rate is consistent with the evidence of higher cross-shore sediment transport rates summarised in section 3.8.4.1. The resulting average daily net transport rates of around 0.015 m^3/m/day are also around the lower end of the measured trench infill rates at 25 m water depth as presented in Table 3.6, indicating that they are in the right order of magnitude.

The resulting updated sediment budget approach suggests that sand sources into the Mangawhai-Pakiri embayment total 200,000 m^3/yr, with sinks excluding extraction of only around 6,000 m^3/yr, hence a natural surplus of around 194,000 m^3/yr, of which 72,000 m^3/yr has been lost to extraction and the remaining 122,000 m^3/yr is being stored as net long-term accretion.

The cross-shore transport rate across the 25 m CD contour in the sediment budget also clearly indicates that the closure depth for cross-shore transport and potential sediment supply to the nearshore-beach -dune system is located at a greater depth.

Table 3.9: Updated sediment budget out to 25 m CD water depth over last 50 years including storage as shoreline accretion.

Sediment Sources (Inputs or credits)		**Sediment sinks (losses or debts)**	
Source	**Volume (m^3/yr)**	**Sink**	**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 < 15 m depth (average from 50 yrs of records)	72,000

Cross-shore supply (including longshore elements) from >25 m depth Calculated to balance budget	145,000	**Total Sinks (Losses or debts)**	**78,000**
		Storage/Surplus Storage in dune/beach/nearshore from +0.4 m beach accretion over 50+ years	122,000
Total Sources	**200,000**	**Total Sinks + Storage**	**200,000**

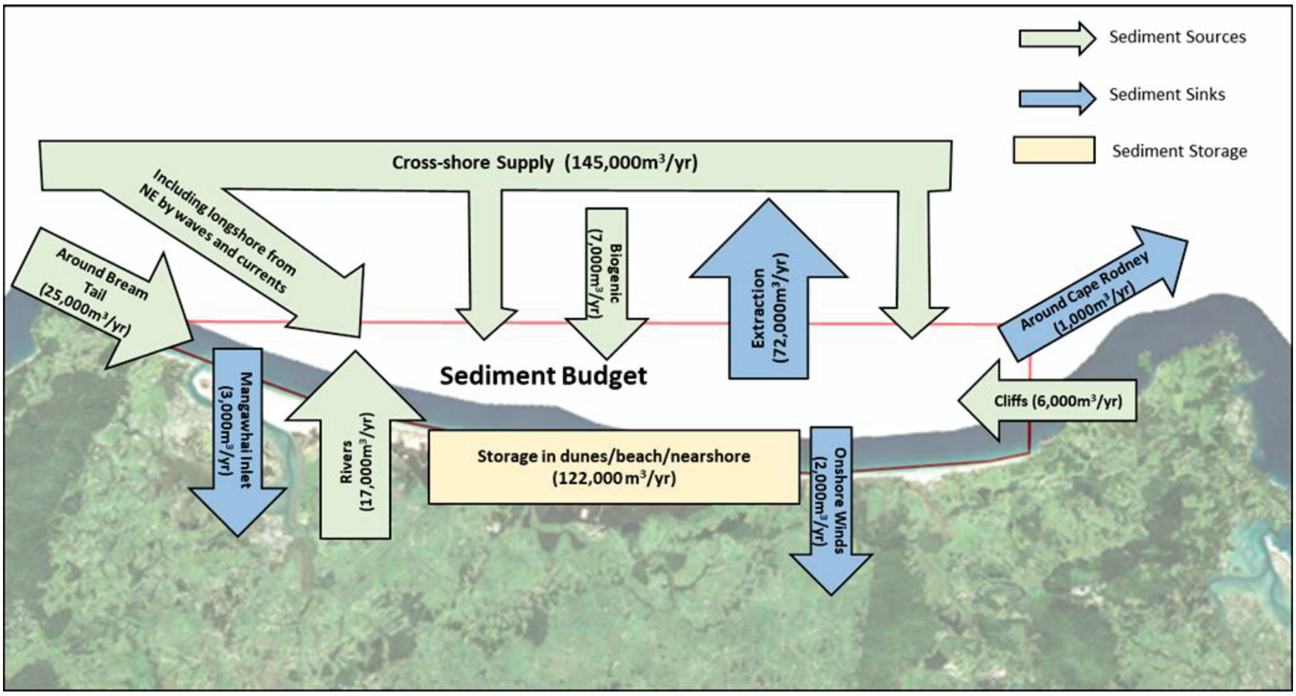


Figure 3.25: Schematic of updated sediment budget for the Mangawhai-Pakiri Embayment

3.9 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, in the long-term, 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 theoretically 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 equates to around 26,500 – 50,000 m^3/yr of volume being lost from the beach-dune environment to the nearshore to maintain an equilibrium beach profile. 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 3.7.2, 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. Although harder to detect, due to a possible datum shift in the data, there is also no evidence of change in nearshore seabed elevations.

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[9]) (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, with the shoreline continuing 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 average shoreline advance rate of +0.4 m/yr since 1961/63, the resulting estimates of future shoreline movements for the range of sea level rise projections indicated by MfE (2017) over the next 30 years from 2020 (0.18 -0.32 m by 2050), being close to the proposed term of consent sought by MBL, range from continued accretion at 0.2 m/yr (under RCP2.6 projections[10]) to stability with no net accretion (under RCP8.5+ projections). Note that the projection for RCP 8.5+ is the most extreme estimate of sea level rise predicted, so accretion is expected to continue to occur in some form based on all other RCP estimates, which are all given the same likelihood of occurring (MfE (2017).

[9] 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.

[10] RCP: Representative Pathway Concentrations – refers to the pathway of change in concentrations of CO^2 in the atmosphere that drive temperature change under the each climate change scenario. The CO^2 pathways are in turn drived by global population and control of CO^2 emissions.

4. Assessment of Effects

4.1 Key Factors

There are five key factors relevant to the assessment of the potential adverse physical effects of the proposed new sand extraction area and volumes on coastal processes:

1. Sand extraction has been occurring in the Mangawhai-Pakiri embayment for a very long time, certainty more than 75 years, with estimates of greater than 7 million m^3 extracted since the 1920's and records show 5.4 million m^3 has been extracted from the total system since 1966 (includes 1.57 million m^3 from deeper than the 25 m CD contour) (Table 1.2). Given these large volumes over this considerable length of time, it would be expected that any physical effects of past historical extraction on nearshore seabed levels and/or shoreline erosion would be evident.

2. Extraction from the proposed new area located between the 15 m CD and 25 m CD depth contours would replace extraction from the existing MBL inshore area between the 5 m CD and 10 m CD depth contours. Therefore, the effect on coastal processes is limited to:
   - An offshore relocation of the landward or inner limit of the extraction zone by approximately 500 m from the existing inshore consent,
   - An increase in area of proposed extraction from 2.7 to 6.6km^2,
   - An increase in the amount of time before the vessel returns to extract from the same area, and
   - A proposed increase in permitted extraction volume by an average of 49,000 m^3/yr (76,000 m^3/yr currently permitted c.f 125,000 m^3/yr now sought).

3. Within a process-response framework, the extraction activity does not affect the drivers of sediment transport (e.g waves and currents) on the nearshore and large volumes of Holocene sand are still available on the seabed to be transported both across and alongshore. Therefore, the natural processes will still transport the same volumes of sand to the beach/dune system, and any effects of extraction will be expressed as a slow lowering of the seabed within the extraction area.

4. Alternatively, under a sediment budget approach, any significant prolonged net deficit of the sediment budget due to sand extraction would be observed as beach/dune volume losses and erosion.

5. Any changes to shoreline position, beach volume, or nearshore profiles due to extraction would most likely be greatest within the extraction areas and any relative differences in past dune, beach and nearshore responses between these areas and non-extracted control areas within the embayment will be helpful in identifying the likelihood of potential adverse physical effects as a result of the proposed new sand extraction area and volumes.

The following assessment of effects considers each of these factors.

4.2 Effect of Past and Existing Extraction

This section considers the effect of the past and existing extraction from depths less that the 25 m CD contour (e.g. -27 m MSL). From Table 1.1 (Section 1.4), inshore extraction since 1966 (including from the Mangawhai Inlet) is given as being 3.856 million m^3 at an average rate in the order of 72,000 m^3/yr.

As stated in Section 4.1, any significant effect of this level of extraction would be observed as either adjustments of nearshore profiles, or dune erosion and beach/dune volume losses.

4.2.1 Effects on Nearshore Bathymetry

4.2.1.1 Changes in Nearshore Seabed Profiles 2004-2019

Changes in seabed profiles are presented in Table 3.1 (Section 3.2.2). Although the profile results show a general rise in seabed level and therefore increase in volume over the 2004-2019 profiles, as indicated in Section 3.2.2, the majority of this appears to have been due to differences in how the data was reduced for tide rather than actual change in seabed level. On this basis, the following points in relation to effects of nearshore extraction can be made from the repeated nearshore surveys:

- There is no evidence of nearshore erosion in the central embayment, with all changes except during the 2010-2013 period being less than the level of survey accuracy.
- The profiles show that the morphology of the shoreface has not changed.
- 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 seabed erosion within the MBL inshore extraction areas despite extraction of 677,600 m^3 of sand from this consent area since 2003 as shown in Table 1.1.
- There is no evidence of any effect on sea bed levels of the extraction of around 1.23 million m^3 of sand from the nearshore in water depths less than 30 m CD since 2003 (e.g. combined extraction from MBL and inner part of KL consent areas).

4.2.1.2 Dredge Trench Infilling

McCallum's current dredging operations are reporting the 900 m^3 hopper of the "William Fraser' is filled with sand in 3-4 hours of dredging, with an average dredging track length of approximately 12 km, which based on the dredge profile 1.6 m wide and 0.1 m deep equates to a sand extraction efficiency by volume of 47%. Based on this, the annual volume limits would restrict the number of dredging trips per year to an average of less than 139 trips, affecting approximately 2.67 km^2 of the 6.6 km^2 extract area. MBL have stated they plan to distribute the dredging spatially evenly within and between management cells. Therefore, theoretically up to 40% of the seabed included in the application area would be dredged in any one year, and any particular area of seabed would not be dredged more than once in any 30 month period.

As outlined in Section 3.6.4.2 and shown in Table 3.6, although dredge trenches in 25 m -30 m CD water depth have low infill rates (range of 0.01 to 0.18 m^3/m/day), they generally infilled within 1-2 months of dredging even without storm events. It is most likely that the infill duration will be reduced from those presented in Table 3.6 as the majority of the trenches sampled were dredged by the 'Coastal Carrier", which has an average trench depth of 0.3 m, and fill volume of 0.21 m^3/m compared to the 'William Fraser' that is now being used, which has a shallower average trench depth of 0.105 m and less infill volume of 0.115 m^3/m. An example of the small imprint on the seabed of 'William Fraser' trenches in 30 m CD water depth 8 hours after dredging is shown in Figure 4.1.

Taking these two points together, all dredge trenches within the poroposed extraction depths would naturally infill before the need to re-dredge the same area, therefore there would not be an adverse effect on the seabed elevations.

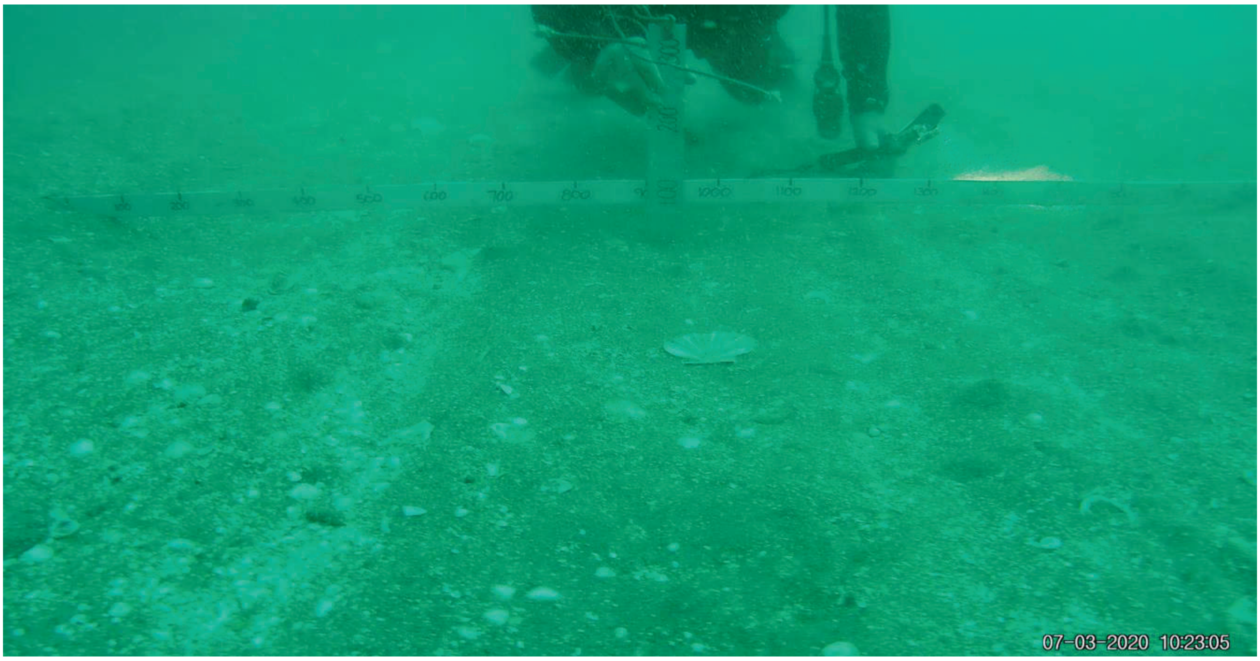


Figure 4.1: Imprint of ‘William Fraser dredge trench in 27.8 m CD water depth 36 hours post dredging.

4.2.2 Effect 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.

Plots of the nearshore bar from the three-yearly bathymetric monitoring profile surveys 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 inshore dredge trench infill reported in section 3.6.4.1. Module 6 (Hume et al. (1999) noted that these bars can be up to 2 m in height, move in position and 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 current MBL inshore consent 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 moving the inner limit of extraction area offshore by a further 500 m and using the trailing suction extraction technique will not have any adverse effect on the bar formation, therefore will not have an adverse effect on the surfing breaks at Te Arai and Pakiri Beaches.

4.2.3 Coastal Erosion

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 could change the Court's conclusions on the lack of effect of sand extraction on coastal erosion.

4.2.3.1 Shoreline Movements from Aerial Photographs

The analysis of the DSAS presented in Table 3.7 in Section 3.7.2 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 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 3.7.2, 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 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.
- Such shoreline retreat as occurred between 1961/63 and 1982 in the southern extraction area was less than experienced in the parts of the southern control area with photographic images back to the 1960s.
- 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 still be influencing the shoreline responses in each area.

Based on these results, there is no evidence of long-term shoreline erosion since the early 1960's due to sand extraction over this nearly 60-year period.

4.2.3.2 Beach Profile Excursion Distance Analysis 2007-2020

From the Excusion Distance Analysis (EDA) plots of the 11 historical profiles presented in Figures 3.18 and 3.19 in Section 3.7.4, the following comparison between the excursion distance patterns for profile sites in extraction sites and the control sites can be made:

- Over the total 13-year period, apart from the dune face at P4, and the large recent dune toe advance at profile P8, 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.
- 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 3.7.2.

Further analysis of the EDA of the 3.5 m and 5.5 m contours is presented in Table 4.1 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.

Table 4.1: 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)

The key points from this analysis 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 greatest 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.

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.

4.2.3.3 Consent Condition 21 Beach Profile Analysis

Under Condition 21 of MBL existing consent, the beach volume and excursion distances from the 11 historical profiles are required to be interpretated each 12 months and 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:

- 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 than the profiles in the southern control area.
- The criteria for review under Condition 21 has only been reached once over the 14 year period, being the excursion distances for the 1m and 2 m contours at profiles P5, P6, and P7 over the three surveys of March 2017, October 2017 and March 2018. However, as noted in the Condition 21 report covering this period (Jacobs, 2019a):
    - There were a number of storms over the 12 month period.
    - For the 1m and 3.5m contour, all three sites experienced advance across both subsequent periods.
    - The same applies for the 2m contour, except for site P6, which experienced -2 m retreat in the winter 2018 period, that has been offset by a 23m advance in the following period.
    - All sites across all contours show net advance across the total two-year period, therefore the erosion in the first year has been offset by accretion across the whole foreshore in the second year.
    - Over the total 12-year period from April 2007, the 1m contour at all three sites, and the 2m contour at P6 and P7 are in net advance, while the 2m contour at P5 has retreated -3.7m over the 12-year period.

  Based on these findings, it was considered that the 12-month erosion of sites P5, P6, and P7 from March 2017 to March 2018 had not manifested into long-term permanent retreat and cannot be attributed to sand extraction. In the circumstances, Council did not consider it necessary to conduct a review under Condition 21.

The results of the analysis under Condition 21 confirm the well-established patterns from a 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.

4.2.3.4 Topographic Survey, 100 m Profile Analysis

As reported in Section 3.7.4.1 (Figures 3.20 & 3.21), from the analysis of interpreted profiles at 100 m intervals from the topographical beach surveys since 2007, there are similar trends in movement of the dune toe position (e.g 3.5 m contour) across the northern and southern extraction areas and the southern control area of retreat in the order of 10-20 m following the July 2007 storm and stability since. However, for the dune face (e.g. 5.5 m contour), both the northern and southern extraction areas show general accretion of 10.20 m, whereas the southern control area showed low scale erosion of less than 10 m.

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

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

4.2.3.5 Beach Volumes

As reported in Section 3.7.5.2., the key points from the temporal volume change analysis included:

- Volumes in the northern extraction, southern extraction, and southern control area all displayed 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 4.7 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 30-month period.

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

4.2.4 Summary

From the above analysis of nearshore profiles, beach surveys, and long-term shoreline movements, the effects of past and existing inshore sand extraction can be summarised as follows:

- 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 -25 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.

- 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 a difference in rates of movements between extraction and control areas.

4.3 Effect of Moving to New Extraction Area

Having established that there is no evidence of adverse effects on physical coastal processes of the past and existing inshore extraction, consideration can now turn to whether there are adverse effects resulting from the proposed extraction in an area further offshore to depths between 15 m CD and 25 m CD, a shift of the inner boundary of around 500 m from the existing consent inner boundary an increase in the extraction area from 2.7 to 6.6km^2, and an increase in the extraction volume by up to an average of 125,000 m^3/yr.

Since the proposed new extraction area is within the same active sediment zone as the existing inshore extraction area, there is no coastal process reason as to why the relocation should result in any additional risk of long-term adverse effects on shoreline erosion. Furthermore, the new area has less connectivity with the dry beach/dune system, therefore any potential short-term storm erosion effects would be less.

It is also recognised that should there be any long-term effects on shoreline position, it would take longer for these to become apparent with extraction from deeper water depths. A monitoring programme over the term of the consent (as in the existing consent) will be required to ensure that any longer-term erosion trends are not occurring. This monitoring could be managed via an Environmental Management Monitoring Plan (EMMP).

A positive effect from increasing the extraction area is that the frequency of needing to extract from the same trench location decreases, allowing more time for seabed recovery and increasing the likelihood that the trench will totally infill before being re-dredged. This in turn reduces the risk of premature change in bed levels with extraction. As stated, the investigations carried out for this assessment indicate that the infill time for trenches in water depths of 25-30 m CD is about 1-2 months for deeper trenches dredged by the 'Coastal Carrier'. The duration between dredging in the same location or over the same track is anticipated to be 30 months based on a planned dredge operating plan which uses a balanced extraction approach. Furthermore, based on the results of the trench infill investigations from the existing inshore extraction area, it is anticipated that infill times will decrease for "William Fraser' trenches, and incrementally so as depth reduces across the proposed extraction area from 25m to the 15 m CD contour.

Even with the proposed increase in volume of the new consent from 76,000 m^3 to 125,000 m^3, the increase in area from 2.7 km^2 to 6.6 km^2 reduces the potential maximum reduction in bedlevel from 28 mm/yr to 19 mm/yr if all the effects were contained in the extraction area and before allowing for any supply of sand into the extraction area, which from the previously discussed transport pathways are known to be occurring. It is also noted that even if these maximum bedload changes occurred, they would not be detectable by survey.

4.4 Effect of Increased Extraction Volume

4.4.1 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 1.1, inshore extraction since 1966 (including from the Mangawhai Inlet) is given as being 3.856 million m^3. The proposed extraction at an average volume of 125,000 m^3/yr would equate to another 4.375 million m^3 over the proposed term of 35-years.

Therefore,in a worst case situation of a totally closed sediment system with no input of new sand, the total cumulative extraction at water depths less than 25 m CD by the end of the period covered by the application would be between 4-6% of the total size of the resource. However, as we see from the sediment budget, the total sediment inputs over the 35-year consent would be in the order of 6.8 million m^3 over this period of time.

On this basis, there is sufficient sand resource available to sustain the proposed new extraction rate over the 35-year term sought. This calculation does not include the significant nearshore Pleistocene sand deposits underlying the Holocene deposits estimated to be more than 2 billion m^3.

4.4.2 Nearshore seabed levels

Under a process-response approach, the effects of increased extraction can be expressed as a lowering of the seabed within the extraction area as the extraction of sand will cause no change in the ability of waves and currents to transport sand into the extraction area and from there onto the beach. This is a different approach to the sediment budget approach in which the potential effects of extraction are assumed to be manifested as loss of sand from beach-dune system.

The increase in extraction rate by up to 49,000 m^3/yr from the current permitted rate to the proposed average of 125,000 m^3/yr under a balanced extraction plan over the whole 6.6 km^2 extraction area would result in a worst case additional lowering of 7 mm/yr if all the effect was contained within the extraction area. Over the proposed 35 year term of the consent this would equate to a total lowering of around 0.24 m. However, cross and alongshore sediment transport processes would spread this potential lowering effect over the nearshore seabed throughout the embayment, reducing this lowering to an average of 1 mm/yr from the additional extraction, and a total of 3 mm/yr for the total 125,000 m^3/yr extraction volume. A change of this magnitude is not detectable, and would have no discernible effect on coastal processes.

4.4.3 Sediment budget

As established in Section 3.8, a sediment budget is a conceptual coastal management tool that can be used to test whether there is likely to be any adverse costal erosion effects of a given extraction volume.

The updated sediment budget presented in Table 3.8 indicates that ongoing sand extraction at the current consents volume of 76,000m^3/yr from inshore of the 25 m CD contour can be supported with continued accretion of the dune-beach environment at close to comtemporary rates.

Under the sediment budget approach, the additional volume involved in the increase to an average of 125,000 m^3/yr would be exclusively at the expense of the sand surplus currently going to storage as accretion on the beach and in the foredunes. This represents the worst case eroision scenario from increase in the actual historical annual extraction volume, with the storage volume decrease being calculated from the equation:

Existing surplus (storage) volume – Increase in Extraction rate = New surplus/storage volume, So can be expressed as: 122,000 – 53,000 = 69,000 m^3/yr

Based on this assessment, increasing the extraction rate to an average of 125,000 m^3/yr would be sustainable. Although shoreline accretion rates would be reduced to approximately half of the comtemporary rates, it would not result in long-term shoreline erosion. There will still be variability in sediment supply and short-term erosion associated with storm events that will occur. However, any increased erosion risk during periods of naturally limited longshore and/or cross shore supply would be countered by the reduced connectivity of the new extraction area with the beach so reducing potential short-term erosion effects. Therefore, variability in supply is less likely to manifest itself in short-term beach erosion with extraction from the proposed new deeper water extraction area.

Accelerated sea level rise will also most likely reduce the past accretion rate and hence beach storage rate over the term of the proposed consent. For the range of accepted sea level rise over the next 30 years (0.18 -0.32 m by 2050 from MfE (2017)), the range of estimated beach responses with increased extraction to an average of 125,000 m^3/yr will be conversion to a dynamically stable beach position (e.g neither net long-term erosion or accretion) under the lowest sea level rise scenario (RCP2.6) to net beach erosion in the order of 5 m (e.g. -0.18 m/yr) under the highest sea level rise scenario (RCP8.5+). It is expected a beach monitoring programme will be undertaken over the length of the consent to check whether any longer-term erosional trends are occurring.

4.5 Cumulative Effects

The updated sand budget assessment has demonstrated the presence of cross-shore sediment supply in the order of 145,000 m^3/yr from water depths beyond the -25 m CD contour position (note below). As noted in section 3.8.4.1, the presence and volume of this transport pathway clearly indicates that the closure depth for cross-shore transport and potential sediment supply to the nearshore-beach -dune system is located at a greater depth than the -25 m CD contour. Given that this transport pathway is in part from the KL offshore extraction area, it is relevant to address whether their activities could affect the supply rate into the MBL proposed extraction area, and the potential for cumulative effects of the combined extraction.

As indicated in Table 1.1, since 2003 extraction has occurred from both an inshore area (-5 to -10 m CD) contour by MBL at total volumes of 677,600 m^3, and from an offshore area at water depths greater than -25 m CD by KL at total volumes of 1.572 million m^3, of which extraction records show 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 significant effects on sea bed levels at less than the -30 m CD contour from the combined extraction of 2.3 million m^3 of sand since 2003.
- There is no evidence of beach erosion from the combined extraction since 2003.
- Extraction by KL will have no significant 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 3.8.4. The KL extraction will also not reduce the availability of the sand to be transported at this depth by these processes.
- Therefore, the cross-shore transport rates into the proposed new MBL extraction area and the beach/nearshore environment as shown in the sand budget in section 3.8.4 and the beach nearshore environment will not change. Hence, it is considered that there is unlikely to be cumulative effects on beach erosion.

5. Conclusions

McCallum Brothers Ltd (MBL) have been extracting sand from the nearshore of the Mangawhai-Pakiri embayment for more than 75 years, and have current consents to extract up to 76,000 m^3/yr from the inshore area between the 5 m and 10 m CD contours. MBL now wish to apply for a new consent to extract sand from an area approximately 500 m further offshore from their existing consent area, being located approximately between the 15 m and 25 m (CD) water depths, which is bounded offshore by the extraction consent held by Kaipara Ltd (KL). It is understood that this new consent area will replace the existing MBL inshore consent area, and that MBL will surrender their current coastal permits should the permits to extract from the proposed new area be granted.

The question addressed by this report is whether there would be any adverse effects on coastal processes arising from the extraction by MBL over its proposed new extraction area. It is noted that the new extraction area lies 500 m further offshore, increases from 2.7 km^2 to 6.6 km^2, and that the proposed extraction volume is 49,000 m^3/yr greater than presently permitted. In addressing this question, a number of assessments of the coastal processes operating within the Mangawhai-Pakiri embayment have been undertaken. The results of previous assessments presented in an earlier report (Jacobs 2020) for a renewal consent for the MBL inshore extraction area have been reproduced or updated in this report as appropriate. From these assessments the following conclusions can be drawn:

- The volume of Holocene sand located on the shoreface at water depths less than 25 m CD was estimated by the MPSS as being in the range of 70-120 million m^3. Inshore extraction since 1966 (including from the Mangawhai Inlet) is given as being 3.856 million m^3, and the proposed extraction at an average volume of 125,000 m^3/yr would equate to another 4.375 million m^3 over a proposed term of 35-years. Therefore, if there was no input of new sand, the total cumulative extraction at water depths less than 25 m CD by the end of the 35 year period covered by the application would be between 4-6% of the total size of the resource. However, total sediment inputs over the 35-year consent would also be in the order of 6.8 million m^3 over this period of time. There is sufficient sand resource available to sustain the proposed new extraction rate over the 35-year term sought.

- 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. There is no evidence of long-term erosion due to sand extraction, and no evidence of a difference in rates of movements between extraction and control areas over this long-term period.

- Beach surveys since 2004 show that beach responses to storm events adjoining extraction areas, both in terms of storm cut and post storm recovery, have not been any worse than in control areas, hence there is no evidence of adverse effects from the extraction.

- Nearshore seabed profiles since 2004 do not show any evidence of extraction effect in either the MBL inshore extraction area or over the general nearshore out to the -30 m CD contour from combined inshore and offshore extractions. A positive effect from increasing the extraction area is that the time period between having to extract from the same trench location increases, therefore allowing more time and increasing the likelihood for the trench to totally infill before being re-dredged. This in turn reduces the risk of premature change in seabed levels with extraction.

- The sediment budget for the Mangawhai-Pakiri embayment out to the -25 m CD contour averaged over the last 50 years shows natural sediment losses of 6,000 m^3/y, and average annual losses to extraction in the order of 72,000 m^3/yr. Sand storage (surplus) as dune/beach/nearshore accretion is estimated to be an average of 122,000 m^3/yr over the last 50+ years. Hence for the sediment budget to balance, the total sediment inputs to the embayment must be in the order of 200,000 m^3/yr. Estimates from rivers, cliffs, biogenic production, and around Bream Tail sources total 55,000 m^3/yr, hence the inferred best estimate input from cross-shore transport to the current extraction area and beach are estimated to be in the region of 145,000 m^3/yr. This cross-shore transport rate is supported by evidence collected in this investigation including measurements of trench infilling and observations of sand ripples at water depths greater than 25 m, theoretical entrainment and transport by wind waves, transport by non-tidal seabed currents and increased frequency of sediment stirring and suspension due-to the presence of infragravity waves.

- Based on this assessment, the extraction at an average rate of 125,000 m^3/yr is sustainable.

- Any increased erosion risk during periods of naturally limited longshore and/or cross shore supply will be countered by the reduced connectivity of the new extraction area with the beach reducing potential short-term erosional effects. Therefore, variability in supply is less likely to manifest itself in short-term beach erosion with extraction from the proposed new deeper water extraction area.

- It is recognised that the likelihood of potential sea level rise effects will increase with time. Under the worst case sea level rise scenario from MfE (2017) (e.g. RCP8.5+), increasing the average annual extraction rate to 125,000 m^3/yr could result in potential beach erosion in the order of 5 m over a 30 year period. Under all other sea level rise scenarios, long term shoreline stability to accretion would still occur.

- There is no evidence of any cumulative effects of both the MBL and KL extraction on:
  - sea bed levels less that the -30 m CD contour
  - the ability of wave and current processes to transport sand across the -25 m CD contour boundary
  - the availability of the sand to be transported at this depth by these processes.
  - beach erosion from the combined extraction since 2004.

- It follows that the sand transport rates into the proposed new MBL extraction area and the beach/nearshore environment will be the same as estimated by the updated sand budget, and hence it is considered that there is unlikely to be cumulative effects on beach erosion.

Based on these factors, taken together with all the material in this report, there is support for the following answer to our fundamental question on effect:

- Based on the accretion that has occurred over the last 50+ years and the estimates of on-going sand inputs into the Mangawhai-Pakiri embayment, an average sand extraction rate of 125,000 m^3/yr from the proposed extraction area would be sustainable and would not result in beach erosion or any other adverse effects on coastal processes.

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

Appendix B. MBL 2019 Instrument Deployment and Bathymetric Survey Locations

Appendix C. Bathymetric Survey Methodology

Appendix D. Seabed Sediment Sampling Locations

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

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

Appendix G. 2019 Bathymetry and Offshore Profiles

Appendix H. Sediment Sampling Size Distribution Results

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

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