ATTACHMENT SEVENTEEN

Assessment of Surf Breaks Effects (Metocean Solutions)

McCALLUM BROS LTD

Established 1904

Assessment of Effects on Surf Breaks at Te Ākau Bream Bay

Hindcast wave modelling study to estimate the potential impacts of the proposed Te Ākau Bream Bay sand extraction activity on local surf breaks

Report prepared for McCallum Bros. Ltd.

July 2024

MetOcean SOLUTIONS

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1. Introduction

McCallum Bros. Ltd (MBL) has commissioned MetOcean Solutions (a division of Meteorological Service of New Zealand Ltd) to undertake a desktop study of the potential impact of the proposed Te Ākau Bream Bay sand extraction activity on local surf breaks in terms of surfability and potential wave attenuation/dissipation.

A modelling and analysis exercise of the wave conditions in the area is required to provide an initial characterisation of any potential effects of sand extraction. Seven regionally significant surf breaks (as defined by the New Zealand Surfing Guide Book and Northland Regional Council[1], NRC) are present on the east coast of Te Ākau Bream Bay (Table 1.1, Figure 1.1), These surf breaks are located inshore of the proposed extraction area and could potentially be affected (Figure 2.4).

The purpose of this study is to investigate the potential effects of sand extraction and bathymetric changes on nearshore surfability. However, it is recognised that there are uncertainties associated with any future bathymetry evolution.

This report is to form part of the Application of Effects on the Environment to support a coastal permit application for sand extraction off Te Ākau Bream Bay.

Numerical hindcast data have been used to characterise the wave and wind climate at these surf breaks, with data sources detailed in Section 2 of the report. Analytical methods to calculate the wave parameters are described in Section 3. A gridded wave field for typical surfing days is analysed in Section 4. The wave climate at each representative site is detailed in Section 5. Conclusions are provided in Section 6 and the references cited are listed in the final Section.

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

1 https://data-nrcgis.opendata.arcgis.com/datasets/NRCGIS::regionally-significant-surf-breaks-1/explore?location=-35.978252%2C174.610447%2C11.88

Table 1.1 Name of surf breaks, coordinates and water depths of offshore representative data reporting sites.

Surf breaks	Offshore representative site coordinates in World Geodetic System 1984 (WGS84)		Water depth (m MSL)	Source
	Longitude (°E)	Latitude (°N)		
Te Poupouwhenua Marsden Point Beach	174.4995	-35.8609	6.31	NZ Surfing Guide Book
Ruakākā	174.4808	-35.8879	9.96	NRC
Ruakākā River Mouth	174.4746	-35.9024	13.97	NZ Surfing Guide Book
Waipū River Mouth	174.4941	-35.9884	13.92	NZ Surfing Guide Book & NRC
Waipū Cove	174.5156	-36.0182	13.92	NZ Surfing Guide Book & NRC
Wairahi Langs Beach	174.5412	-36.0367	14.15	NZ Surfing Guide Book & NRC
Langs Bombie	174.5538	-36.0372	14.03	NRC

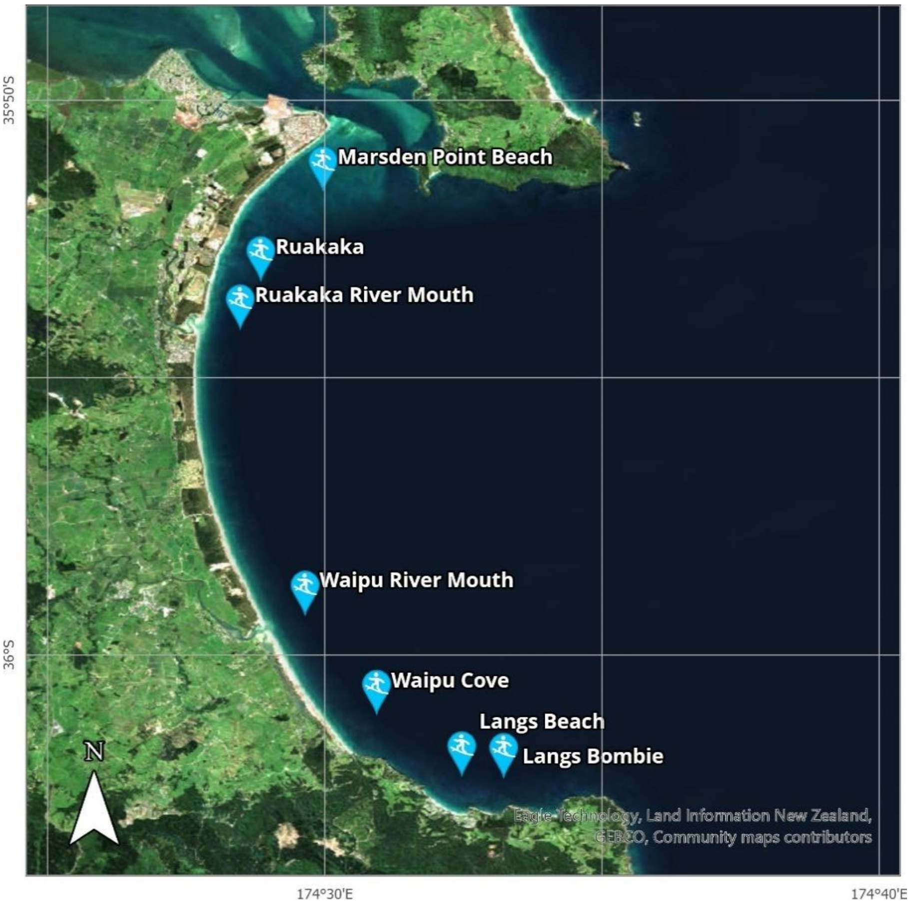

Figure 1.1 Reporting sites representative of surf breaks within Te Ākau Bream Bay

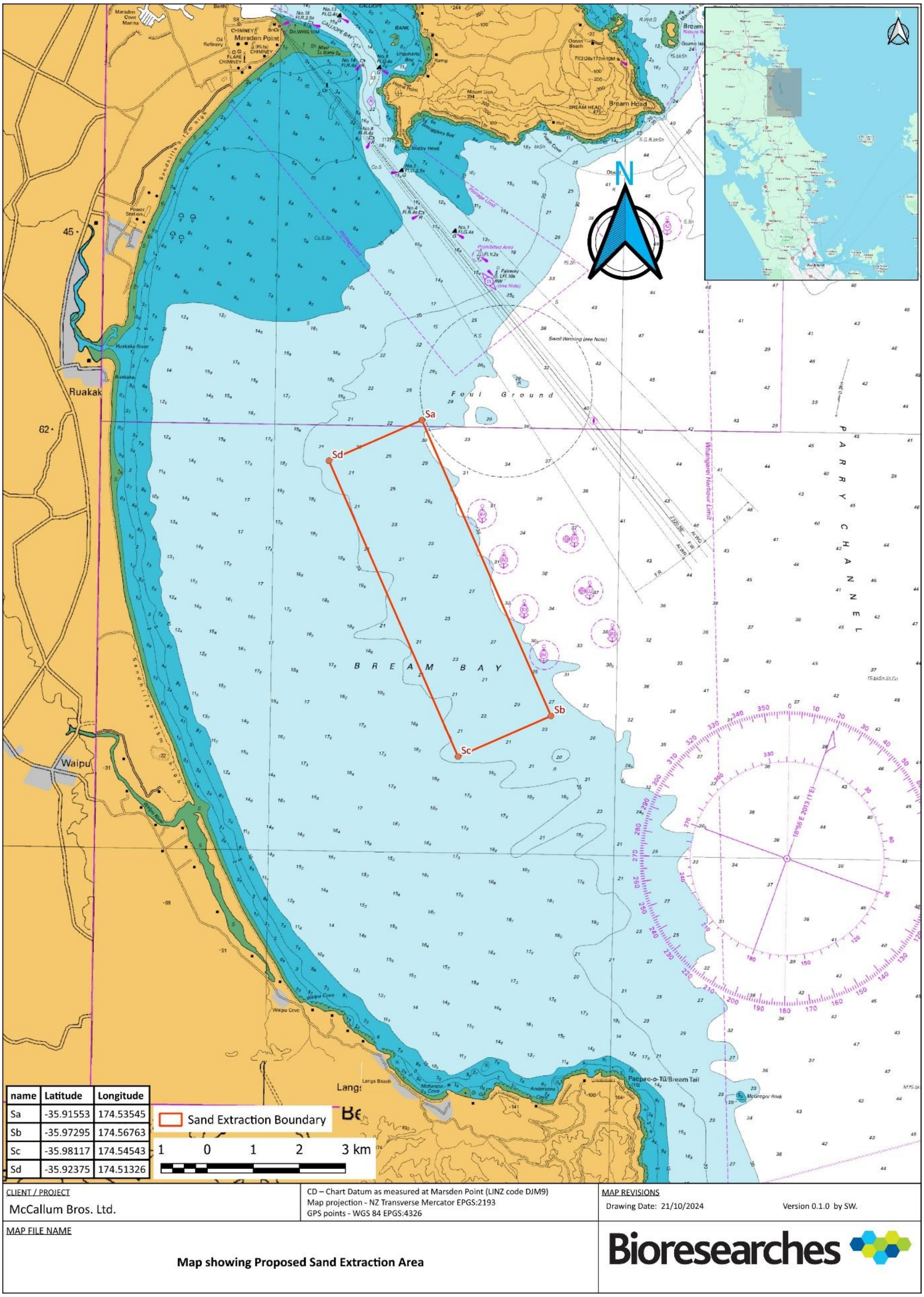

Figure 1.2 Map showing proposed Sand Extraction area.

2.Metocean data sources

2.1 Bathymetry

The morphology of coastal and oceanic regions is a major controlling factor of physical oceanographic dynamics, including the characteristics of waves, tides and currents and underpins modelling of these processes.

Bathymetry data were obtained from the sources listed in Table 2.1.

Table 2.1 Bathymetry data sources used in creation of the SWAN model grid.

Name	Area of coverage	Date(s) of acquisition	Resolution (if gridded)	Vertical Datum	Source
Te Ākau Bream Bay Multibeam Hydrographic Survey	Te Ākau Bream Bay Sand Extraction area, control area, and transects	2-8 April 2024	1 m	CD (Marsden Point)	Discovery Marine Limited for McCallum Bros Ltd
Whangarei Harbour Multibeam Hydrographic Surveys	Harbour entrance and channels	2020, 2022	2 m	CD (Marsden Point)	MetOcean archive
Shipping Lane Multibeam Hydrographic Survey	Outer area of Te Ākau Bream Bay and offshore areas	1999	20 m	LAT	Land Information New Zealand
Electronic Navigation Chart point depths and contours	Nearshore contours and sparse point depths	Various	N/A	LAT	Land Information New Zealand
Global Gridded Bathymetry 2022	Whole Area	Various	450 m	MSL	GEBCO

2.1.1 SWAN Model grid creation

The SWAN model grid was prepared by resampling each of the high resolution (HR) datasets to 30-m resolution, reprojecting to New Zealand Transverse Mercator (EPSG: 2193), and adjusting depths to height below mean sea level (depth positive). High resolution datasets were overlaid and merged with more recently acquired multibeam data prioritized over older datasets and ENC data. The spatial extent covered by the HR data is depicted in Figure 2.1 (A). An interpolation of depths for areas in proximity to the HR data was performed to fill data gaps, as shown in Figure 2.1 (B). Remaining gaps were filled with GEBCO data with smoothing applied to overlapping edges of the HR Data and

GEBCO to minimize artificial rifts and artefacts. Onshore areas of the grid were blanked out using polygon features in the dataset [NZ Coastlines and Islands Polygons (Topo 1:50k)] available on LINZ data service. The final grid was resampled to 0.0005 deg (~150 m) resolution is depicted in Figure 2.1(C).

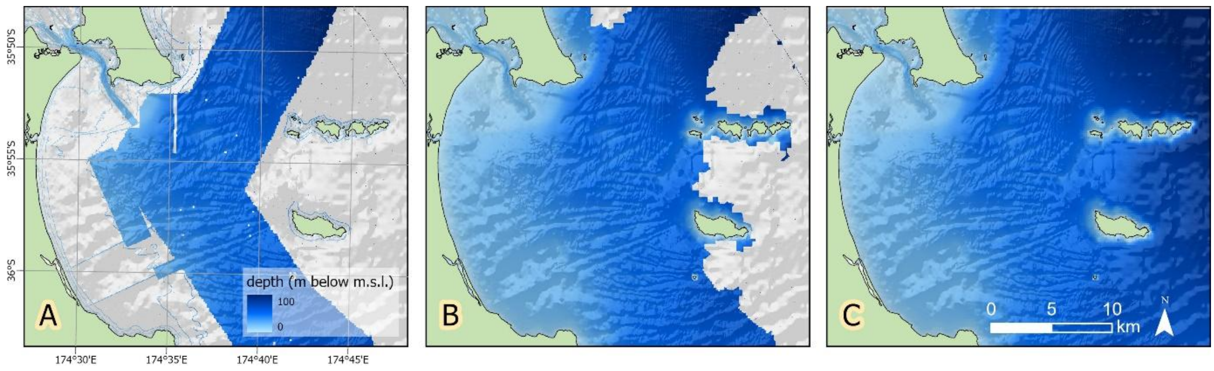

Figure 2.1 Steps used to create the SWAN model grid from various bathymetry sources. (A) High resolution (HR) datasets including multibeam survey and ENC point depths and contours are overlaid. (B) Depths of areas in proximity to HR sources are interpolated. (C) Remaining gaps (mostly offshore) are filled with GEBCO depths.

2.2 Wind data

Near-surface wind conditions (at 10-m elevation) were extracted from the hourly Climate Forecast System Reanalysis CFSR and CFSv2 products (Saha et al., 2010) from the National Centres for Environmental Prediction (NCEP). The data spans 43 years (Jan 1979 – Dec 2023) at hourly intervals and has a spatial resolution of 0.31° (approximately 30 km) until March 2011 and 0.20° (approximately 20 km) beyond April 2011. The wind speeds are 10-minute means. The CSFR is available from Jan 1979 to December 2010 and the CSFRv2 data is available from January 2011.

2.3 Wave data

The long-term hindcast wave modelling was performed using a modified version of Simulating WAve Nearshore (SWAN)[2]. This section describes the details of the wave model and the technique employed in the simulations.

2.3.1 Model description

SWAN is a third generation ocean wave propagation model which solves the spectral action density balance equation (Booij et al., 1999). The model simulates the growth, refraction and decay of each frequency-direction component of the complete sea state,

[2] Modified from SWAN version of the 40.91 release

providing a realistic description of the wave field as it changes in time and space. Physical processes that can be modelled include the generation of waves by surface wind, dissipation by white-capping, resonant nonlinear interaction between the wave components, bottom friction and depth-induced wave breaking dissipation. A detailed description of the model equations, parametrisations and numerical schemes can be found in Holthuijsen et al. (2007) and in the SWAN documentation[3].

2.3.2 Model setup

The model was configured in non-stationary mode including all third-generation physics. The ST6 configuration (Rogers et al., 2012) and the bottom friction scheme of Collins (1972) with a coefficient of 0.015 were applied. Depth-induced wave breaking dissipation was modelled according to Battjes and Janssen (1978). The wave spectra were discretised with 36 directional bins (10 degrees directional resolution) and up to 41 frequencies logarithmically spaced between 0.060 and 3.002 Hz at 10% increments.

A dynamical downscaling nesting approach was applied to resolve the nearshore region around the sites of interest. To fully capture the details of the coastal line and bathymetry in the area, 4 regular SWAN nests were defined with resolutions of ~4 km, 750 m, 100 m and 30 m to resolve the small-scale bathymetric features of the Te Ākau Bream Bay region and the potential effects of extraction (see Figure 2.2).

Full spectral boundaries for the parent SWAN hindcast domain were prescribed from a global implementation of the WAVEWATCHIII (WW3) spectral wave model (Tolman, 1991), run at 0.5 degree resolution with the source terms of Ardhuin et al. (2010). The model was forced with surface winds from a configuration of the Weather Research and Forecasting (WRF) as described in the previous subsection.

[3] http://swanmodel.sourceforge.net/

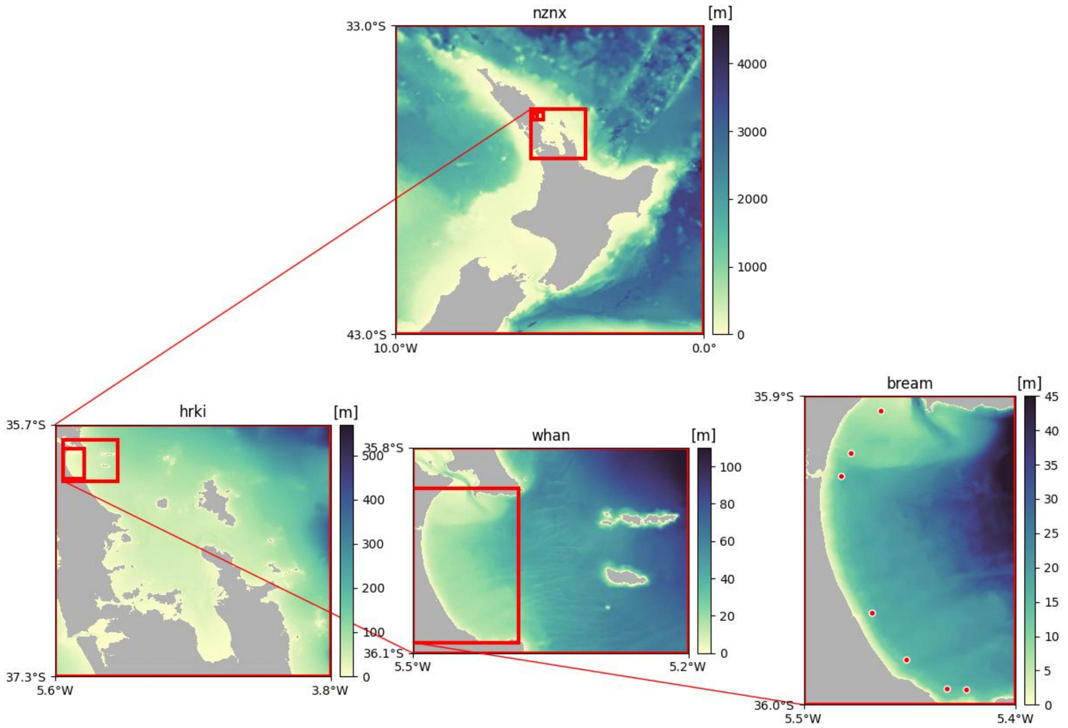

Figure 2.2 Bathymetry maps showing the successive wave model domains (from coarsest to finest anticlockwise from top right). Reporting sites representative of surf breaks are indicated by red dots.

2.3.3 Extraction process

The schematic diagram of trailing suction hopper dredge is provided in Figure 2.3.

Extraction tracks are on average 100 mm deep with a range of 80-120 mm but measurement campaigns undertaken by MBL for the existing offshore swale extraction areas demonstrated that infilling of the tracks typically occurs in a few weeks after extraction.

In this assessment, the effects of extraction are investigated only after the areas considered are fully extracted. Changes in wave parameters typically tend to be more pronounced near the edges of the extraction areas. Therefore, the wave fields are likely to be locally and temporarily affected during the extraction activities in locations where the extraction stops until the following permitting weather window for extraction, which is not investigated in the present study.

In this study, the effects of extraction on the described surf breaks have been investigated based on full extraction volume over the whole 35-year term of the consent with no replenishment of sand in the extraction area. This is considered a worst-case scenario in terms of total bathymetry change, which is highly unlikely to occur in reality based on established and agreed sand transport pathways as described in Jacobs (2020).

We have prepared the bathymetry for the surf assessment assuming a total 8,450,000 m^3 volume extraction (3 years at 150,000 m^3 per annum and 32 years at 250,000 m^3 per annum). Based on the proposed sand extraction areas of 15.4 km^2, a volume of 8,450,000 m^3 results in a thickness height of 54.9 cm of sand removed from the area (see Figure 2.4).

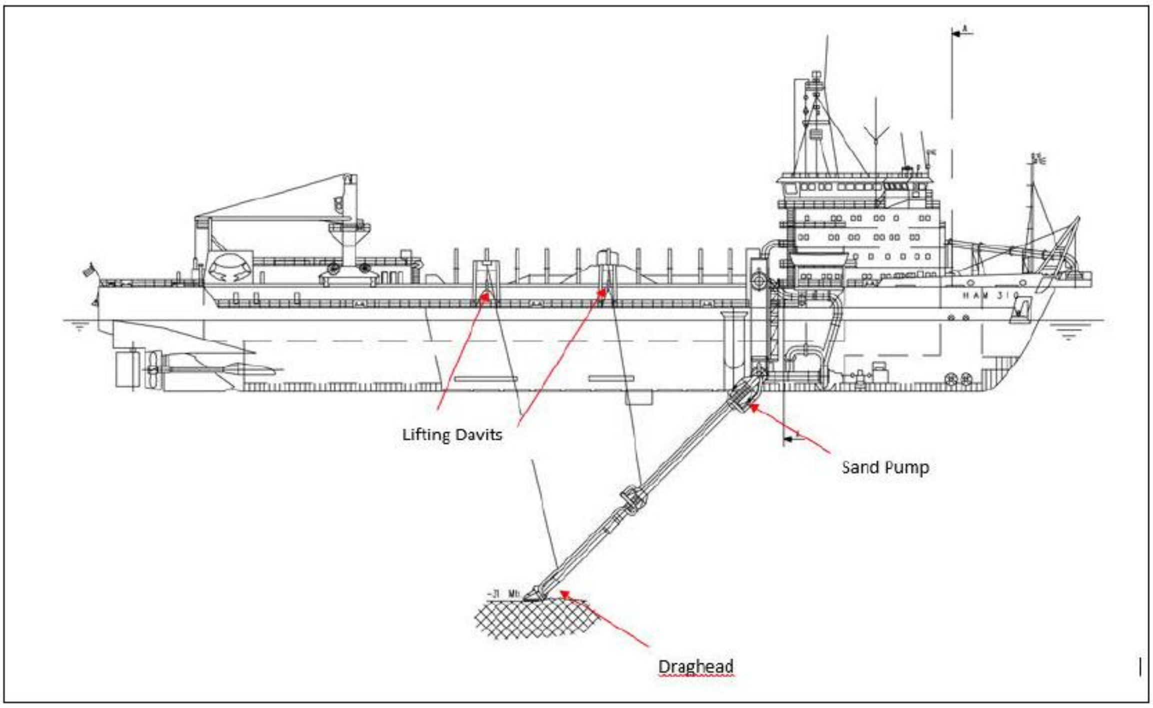

Figure 2.3 Schematic diagram of trailing suction hopper dredge (not an actual MBL vessel), figure from Jacobs (2020).

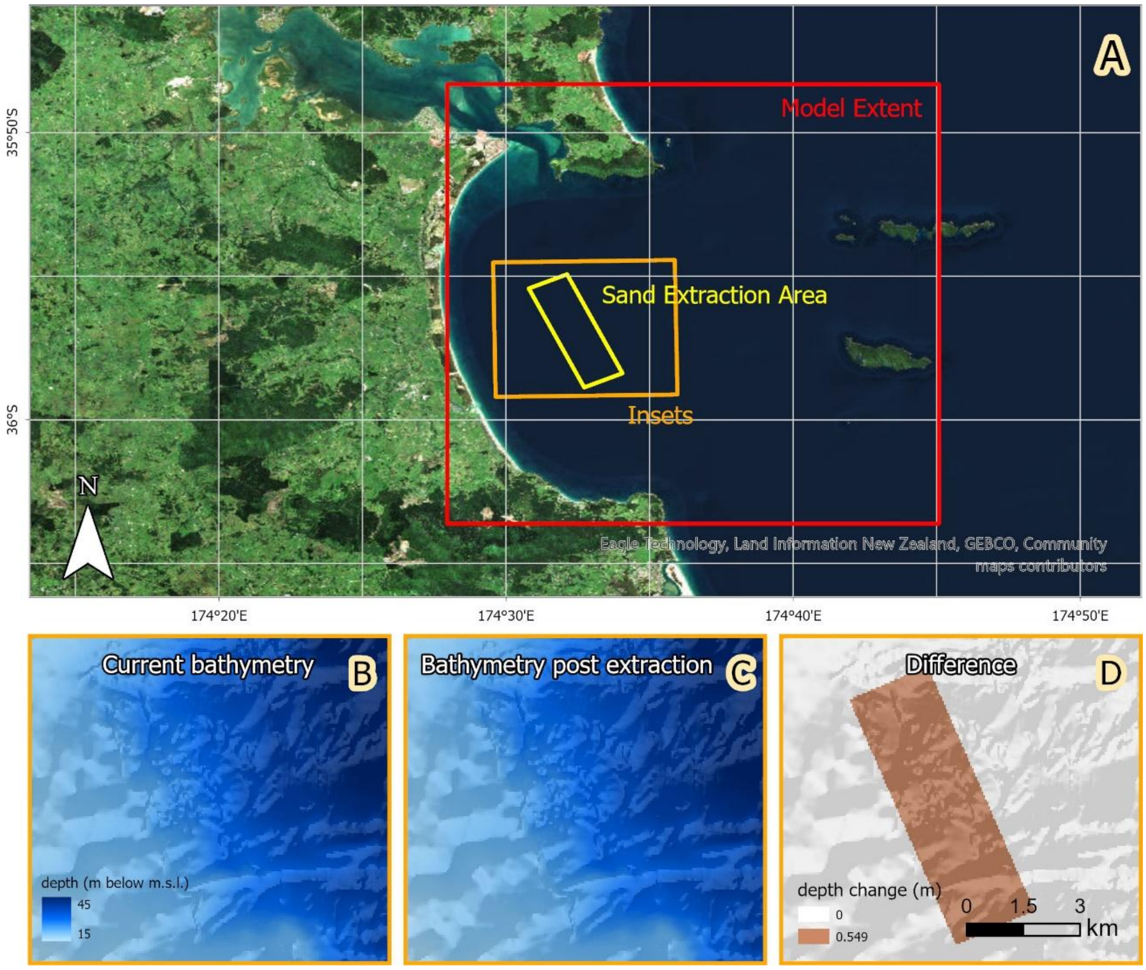

Figure 2.4 Maps illustrating the model extent and sand extraction area (A). Also shown are the current and post-extraction bathymetry (B and C, respectively) as well as the depth difference near at the extraction area (D).

2.3.4 Selected modelling year

The wave hindcast was set and run for a 1-year period (2009). This year was carefully selected based on the offshore sea state corresponding to the closest values from the 41-year (1979 - 2019) averaged conditions (Table 2.2).

Table 2.2 Annual significant wave height statistics at the offshore site (174.575467°E, 35.951263°S) from the Hauraki SWAN grid. This table is used to select the appropriate year of simulation for the finest grids, i.e., year 2009 (highlighted in grey) with mean and 95th percentile Hs closest to the averaged values.

Year	Parameter	
	Mean (m)	95th percentile(m)
1979	0.91	2.02
1980	0.85	1.88
1981	0.98	2.12
1982	0.85	1.94
1983	0.87	1.95
1984	0.96	2.06
1985	1.06	2.32
1986	0.84	1.76
1987	0.83	1.91
1988	0.97	2.35
1989	1.07	2.46
1990	0.84	1.75
1991	0.79	1.58
1992	0.82	1.80
1993	0.80	1.89
1994	0.88	1.91
1995	0.89	1.78
1996	0.94	2.18
1997	0.88	2.08
1998	1.07	2.42
1999	0.98	2.03
2000	0.96	2.28
2001	1.02	2.17
2002	0.85	1.83
2003	0.96	2.22
2004	0.84	1.82
2005	0.88	1.87
2006	0.83	1.82
2007	0.94	2.17
2008	0.99	2.19
2009	0.89	2.01
2010	0.92	2.03
2011	0.97	2.19
2012	0.96	2.12
2013	0.89	1.81
2014	0.89	2.06
2015	0.76	1.48
2016	0.93	1.94
2017	0.85	1.85
2018	0.88	1.85
2019	0.82	1.61
Average	**0.91**	**1.99**

2.3.5 Modelling scenarios

Modelling scenarios were undertaken for both existing and post extraction sea floor level surfaces to provide an indication of any changes in the sea state after the completion of the 35-year term being applied for.

All extraction areas are based on the full extraction volumes over the 35-year term of the consent and no replenishment of sand coming into the extraction area. In reality, sand is very likely to replenish the extraction areas over the life of the consent, so the present simulations represent worst-case scenarios for bathymetry changes.

Details of the simulations are provided below (also illustrated in Figure 2.4):

- **a:** Existing: Existing bathymetry.
- **b:** Post-extraction: Bathymetry including the full Te Ākau Bream Bay offshore extraction (average of 54.9 cm over time), covering the offshore proposed sand extraction area, see Figure 2.4. This represents the complete volume of sand extracted (8,450,000 m^3) over the 35-year term of the consent spread over the 15.4 km^2.

3. Analytical methods

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

$$E(f) = \int_{-\pi}^{\pi} E(f,\theta)d\theta. \tag{3.1}$$

Spectral moments were calculated as

$$m_x = \iint f^x E(f,\theta)df\, d\theta, \tag{3.2}$$

The significant wave height, H_s, mean direction, D_m, mean direction at peak energy, D_{pm}, peak wave period, T_p , and mean wave period, T_m, are defined as:

$$H_s = 4\sqrt{m_0} \tag{3.3}$$

$$D_m = \tan^{-1}\frac{\iint E(f,\theta)\sin\theta\, d\theta df}{\iint E(f,\theta)\cos\theta\, d\theta df} \tag{3.4}$$

$$D_{pm} = \tan^{-1}\frac{\int_{-\pi}^{\pi} E\left(f_p,\theta\right)\sin\theta\, d\theta}{\int_{-\pi}^{\pi} E\left(f_p,\theta\right)\cos\theta\, d\theta} \tag{3.5}$$

$$T_p = 1/f_p \tag{3.6}$$

$$T_m = \sqrt{\frac{m_0}{m_2}} \tag{3.7}$$

where f_p is the peak wave frequency of the one-dimensional spectra and $E\left(f_p,\theta\right)$ is the energy contained in the peak wave frequency band. Note that T_p and Dpm require spectral peaks within a given partition and are not defined when peaks are not identified for that partition.

4. Wave fields for typical surfing events

In this section, three large wave events from the Northeast (NE), East (E) and Southeast (SE) sectors which occurred in 2009 (the year of simulation) were investigated in terms of sea state differences between existing and post-extraction campaigns from a surfing perspective.

4.1 NE event

A snapshot of significant wave height and wave direction is provided in Figure 4.1 for a large wave event incoming from the NE sector which occurred on 05/03/2009 to illustrate typical wave field and refraction patterns in the area of interest.

The differences in significant wave height between existing and post-extraction scenarios during the NE wave event are shown in Figure 4.2, while the difference in wave direction is provided in Figure 4.3.

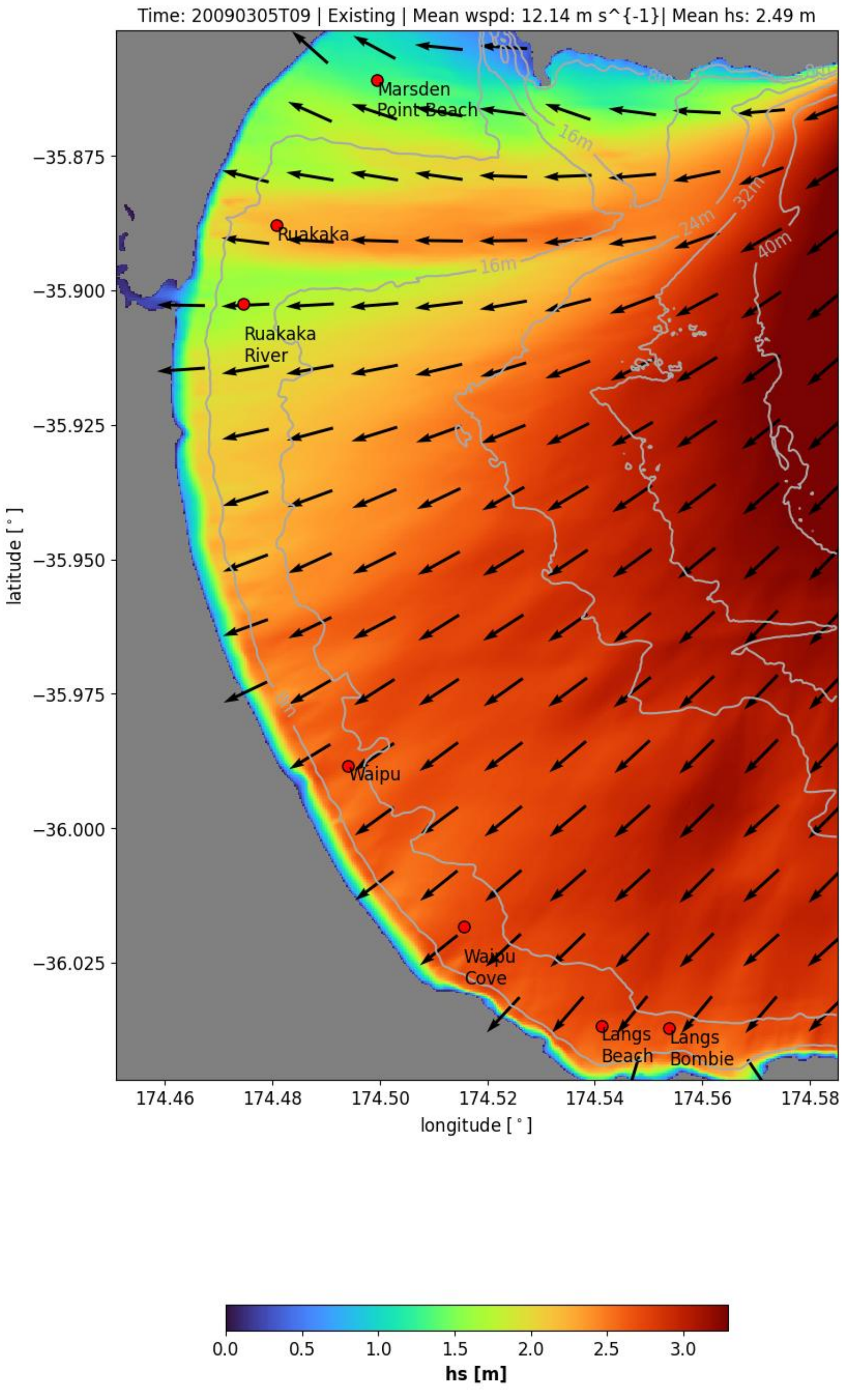

Figure 4.1 Snapshots of significant wave height from the finest SWAN grid illustrating a typical large NE wave event on 05/03/2009 09:00UTC. Surf breaks are indicated by red dots.

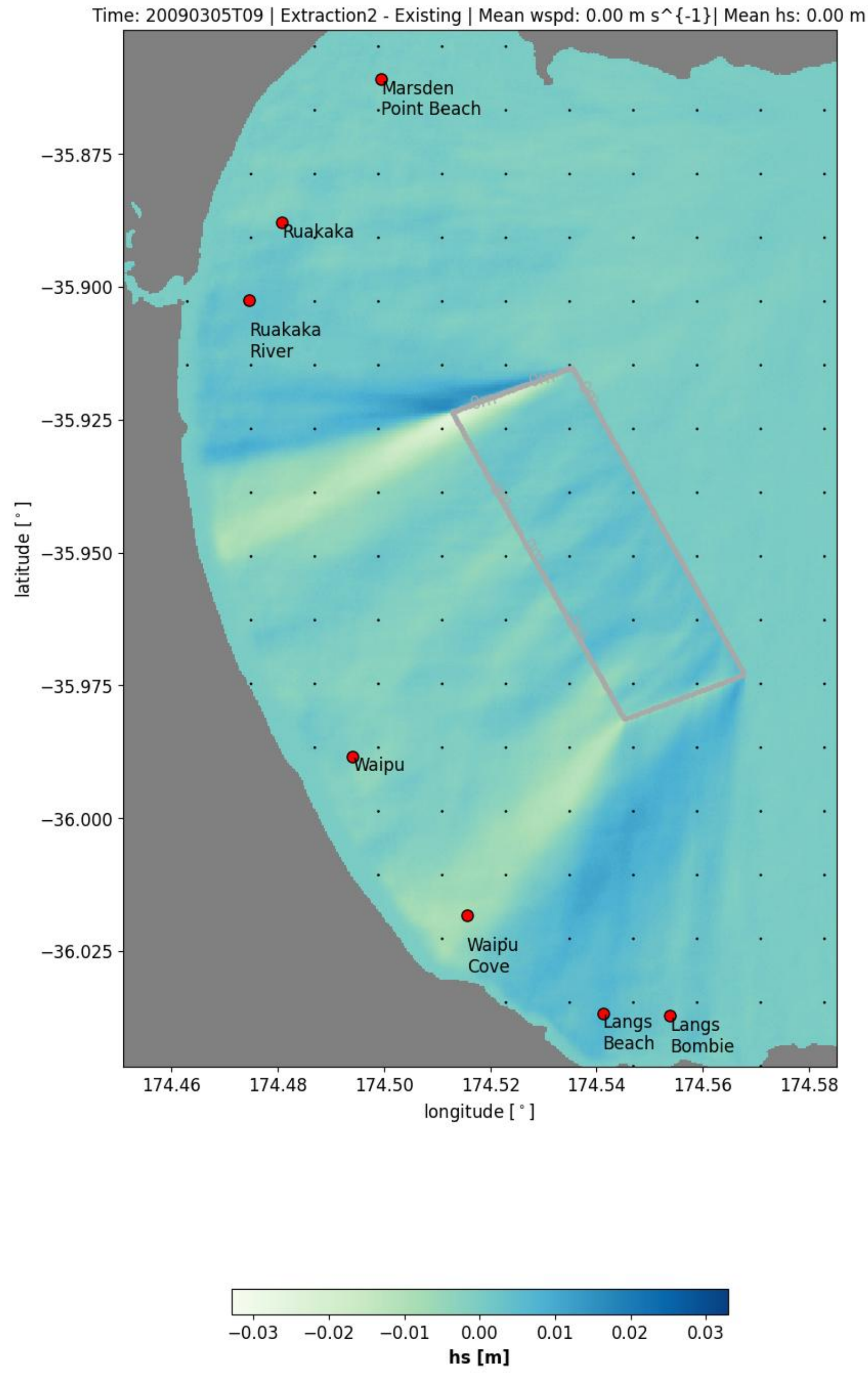

Figure 4.2 Map showing the difference in significant wave height (m) between existing and post-extraction scenarios during the NE wave event on 05/03/2009 09:00UTC. Surf breaks are indicated by red dots.

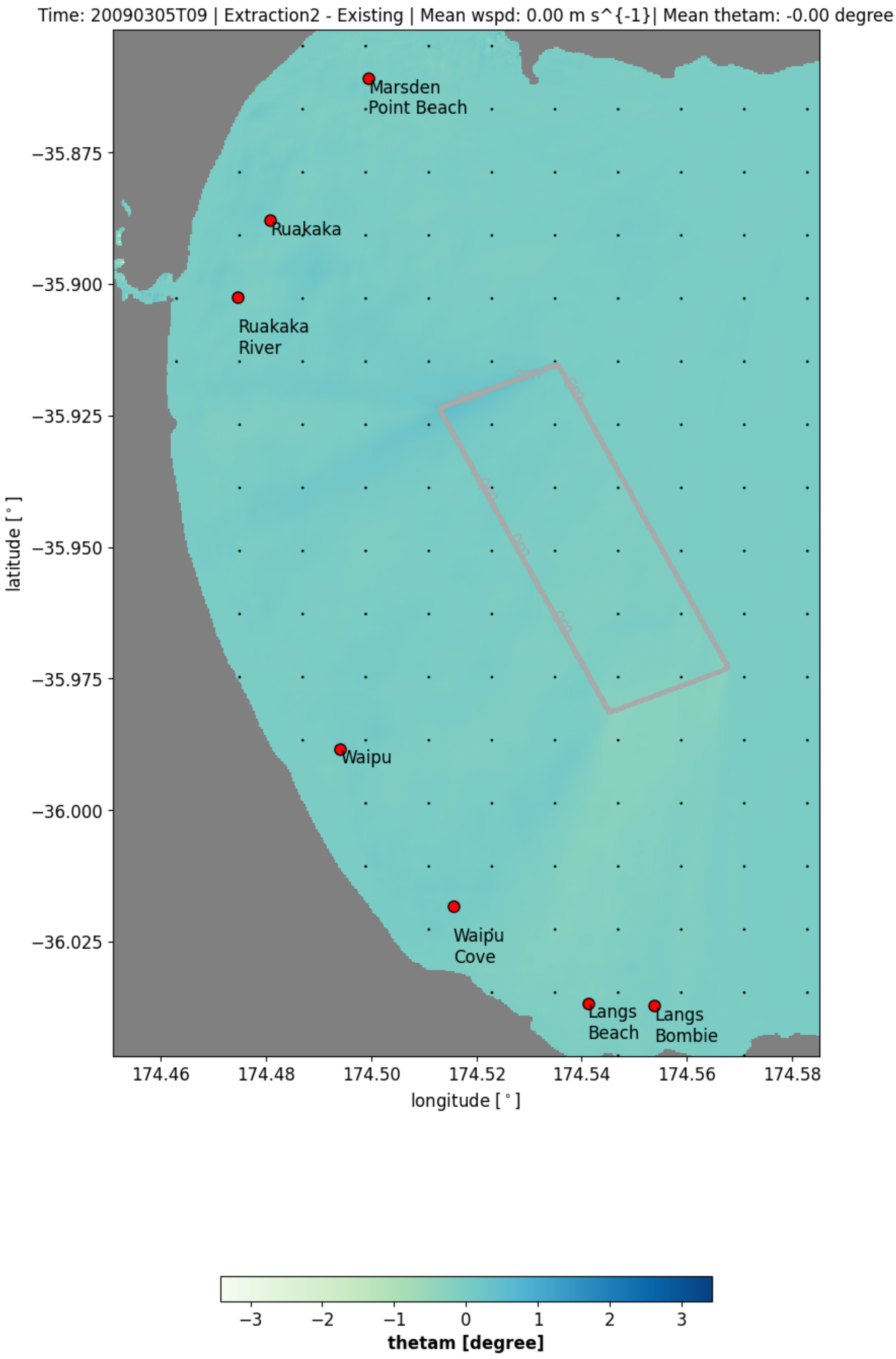

Figure 4.3 Map showing the difference in mean wave direction (deg) between existing and post-extraction scenarios during the NE wave event on 05/03/2009 09:00UTC. Positive/negative differences indicate clockwise/anticlockwise rotations. Surf breaks are indicated by red dots.

4.2 E event

A snapshot of significant wave height and direction is provided in Figure 4.4 for a large wave event incoming from the E sector which occurred on 11/07/2009.

The differences in significant wave height between existing and post-extraction scenarios during the E wave event are shown in Figure 4.5, while the difference in wave direction is provided in Figure 4.6.

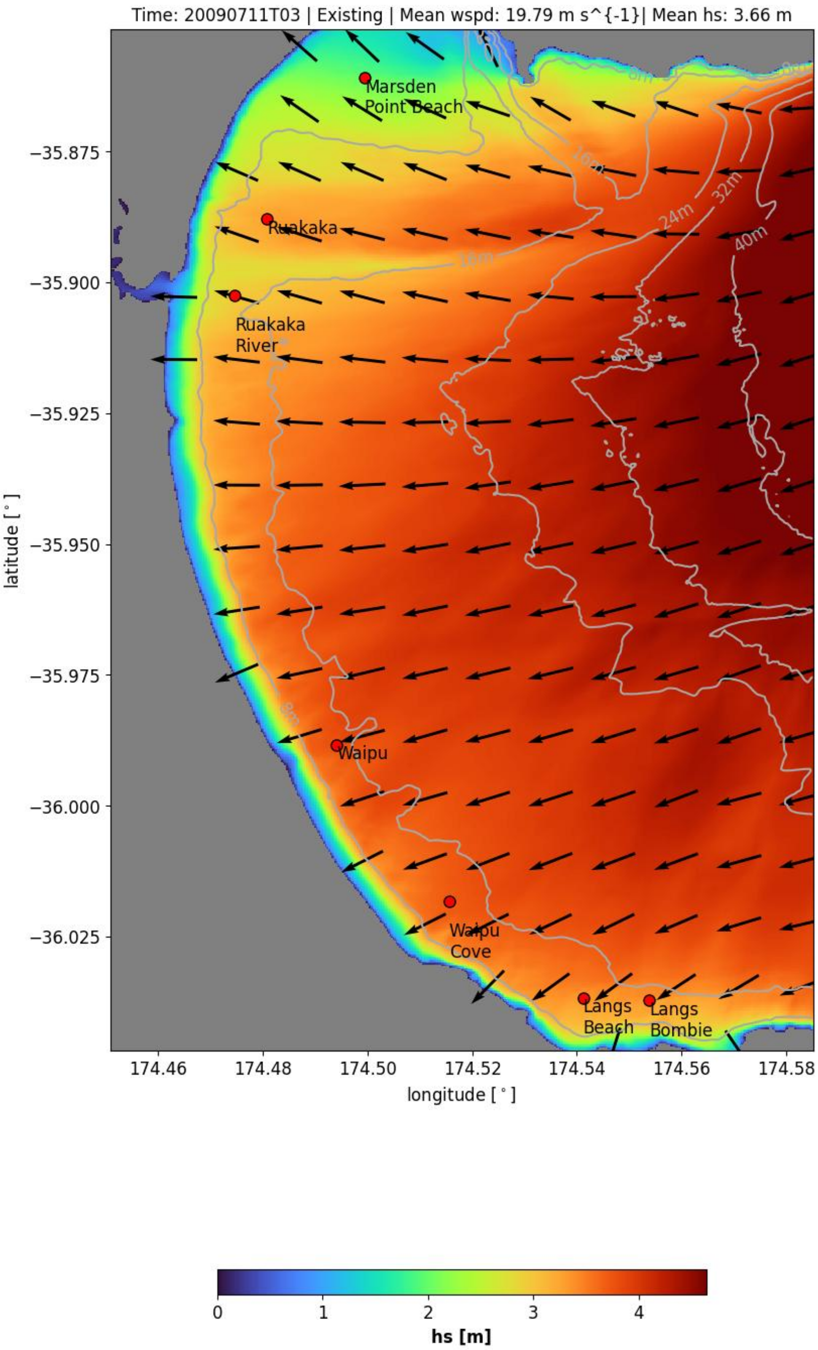

Figure 4.4 Snapshots of significant wave height from the finest SWAN grid on 11/07/2009 03:00UTC illustrating a typical large E wave event. Surf breaks are indicated by red dots.

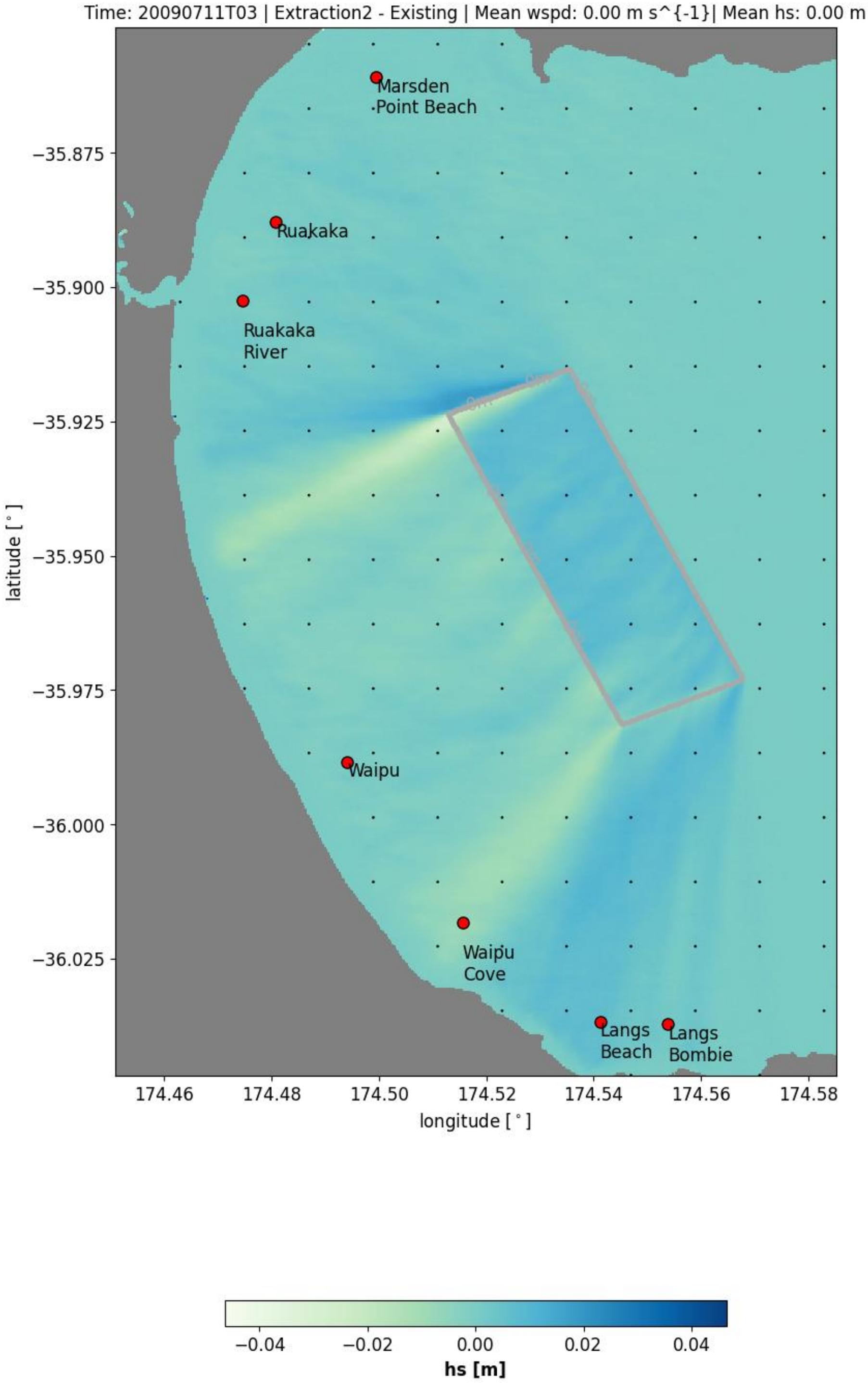

Figure 4.5 Map showing the difference in significant wave height (m) between existing and post-extraction scenarios during the E wave event on 11/07/2009 03:00UTC. Surf breaks are indicated by red dots.

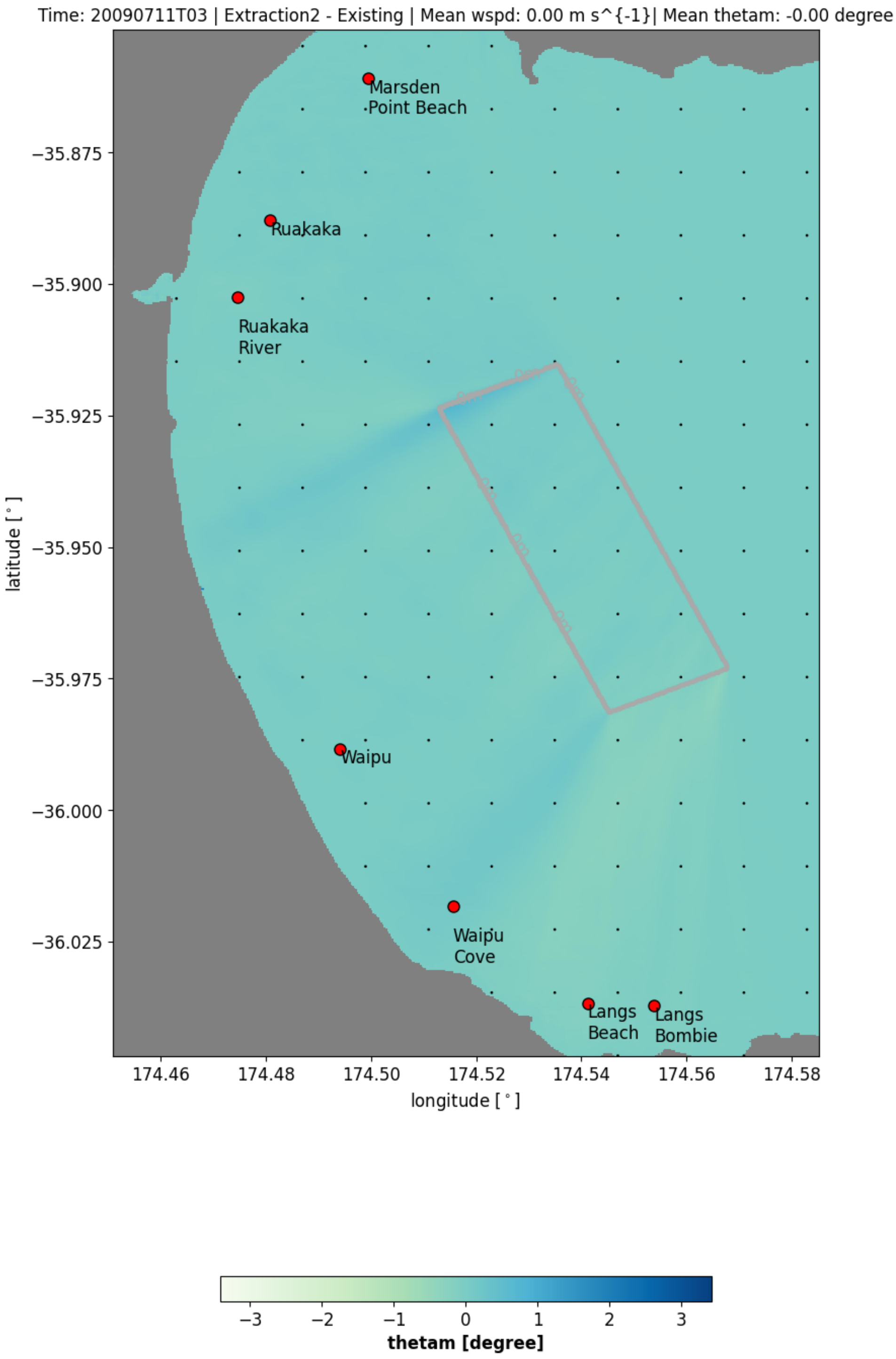

Figure 4.6 Map showing the difference in mean wave direction (deg) between existing and post-extraction scenarios during the E wave event on 11/07/2009 03:00UTC. Positive/negative differences indicate clockwise/anticlockwise rotations. Surf breaks are indicated by red dots.

4.3 SE event

A snapshot of significant wave height and direction is provided in Figure 4.7 for a large wave event incoming form the SE sector which occurred on 02/05/2009.

The differences in significant wave height between existing and post-extraction scenarios during the SE wave event are shown in Figure 4.8, while the difference in wave direction is provided in Figure 4.9.

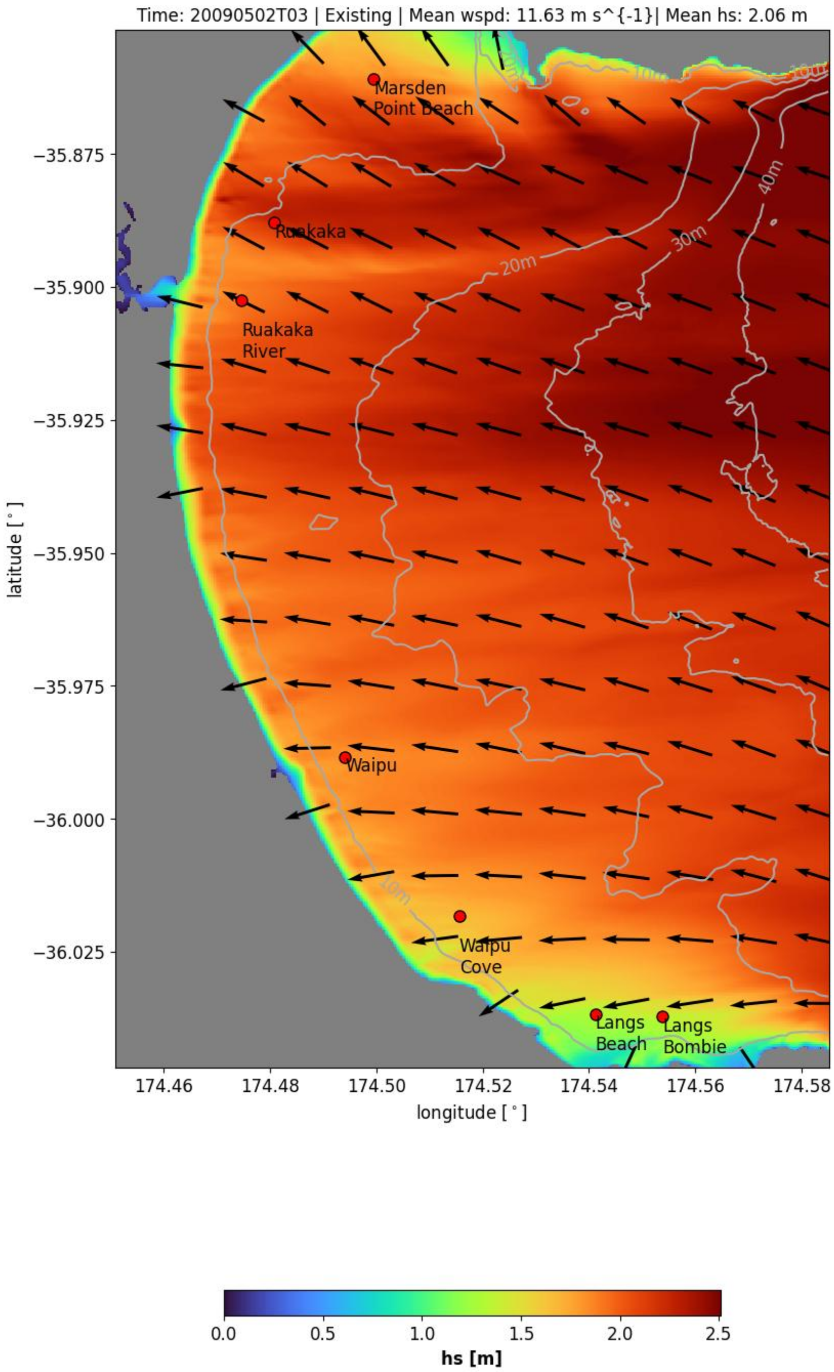

Figure 4.7 Snapshots of significant wave height from the finest SWAN grid on 02/05/2009 00:00UTC illustrating a typical large SE wave event. Surf breaks are indicated by red dots.

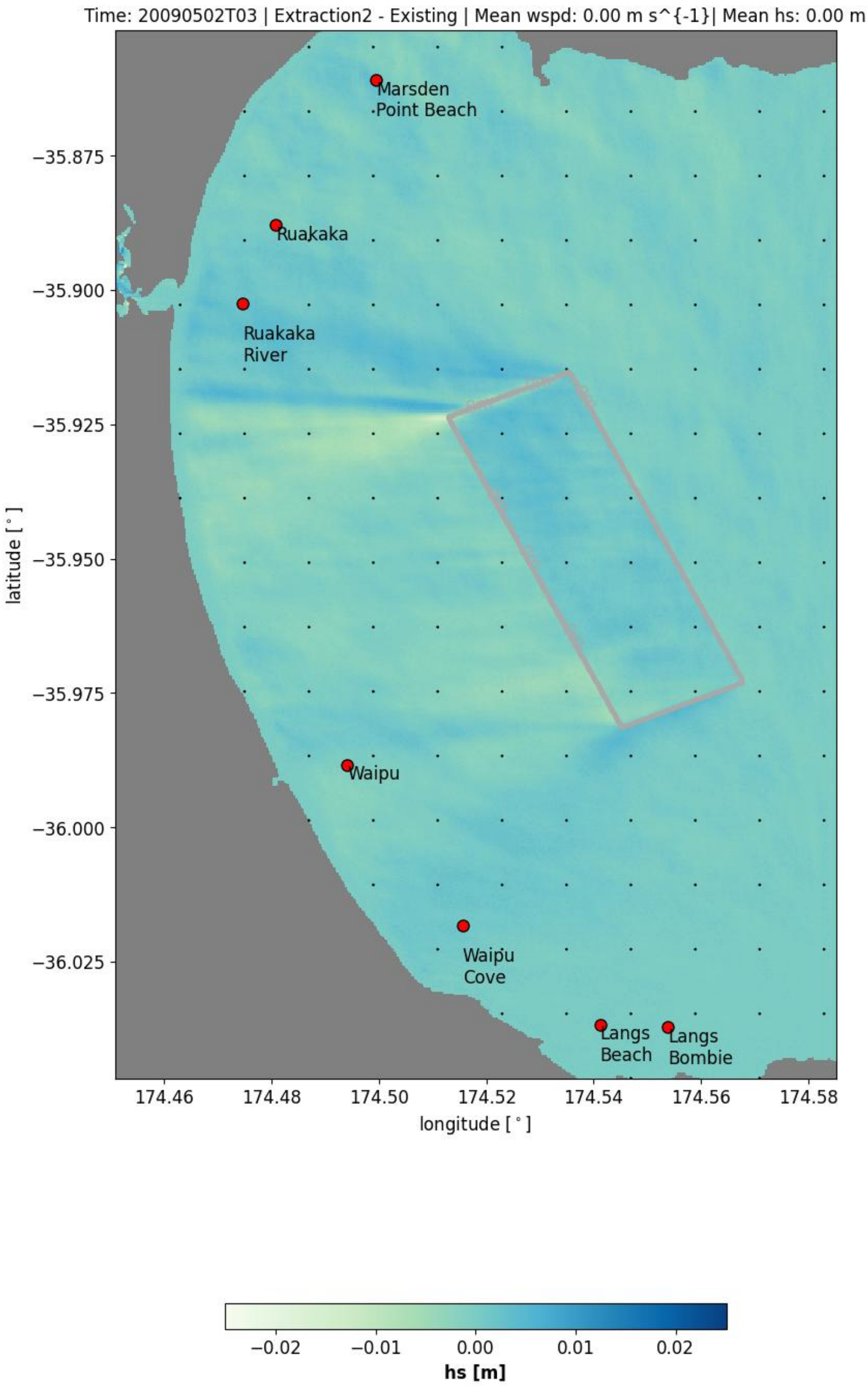

Figure 4.8 Map showing the difference in significant wave height (m) between existing and post-extraction scenarios during the SE wave event on 02/05/2009 00:00UTC. Surf breaks are indicated by red dots.

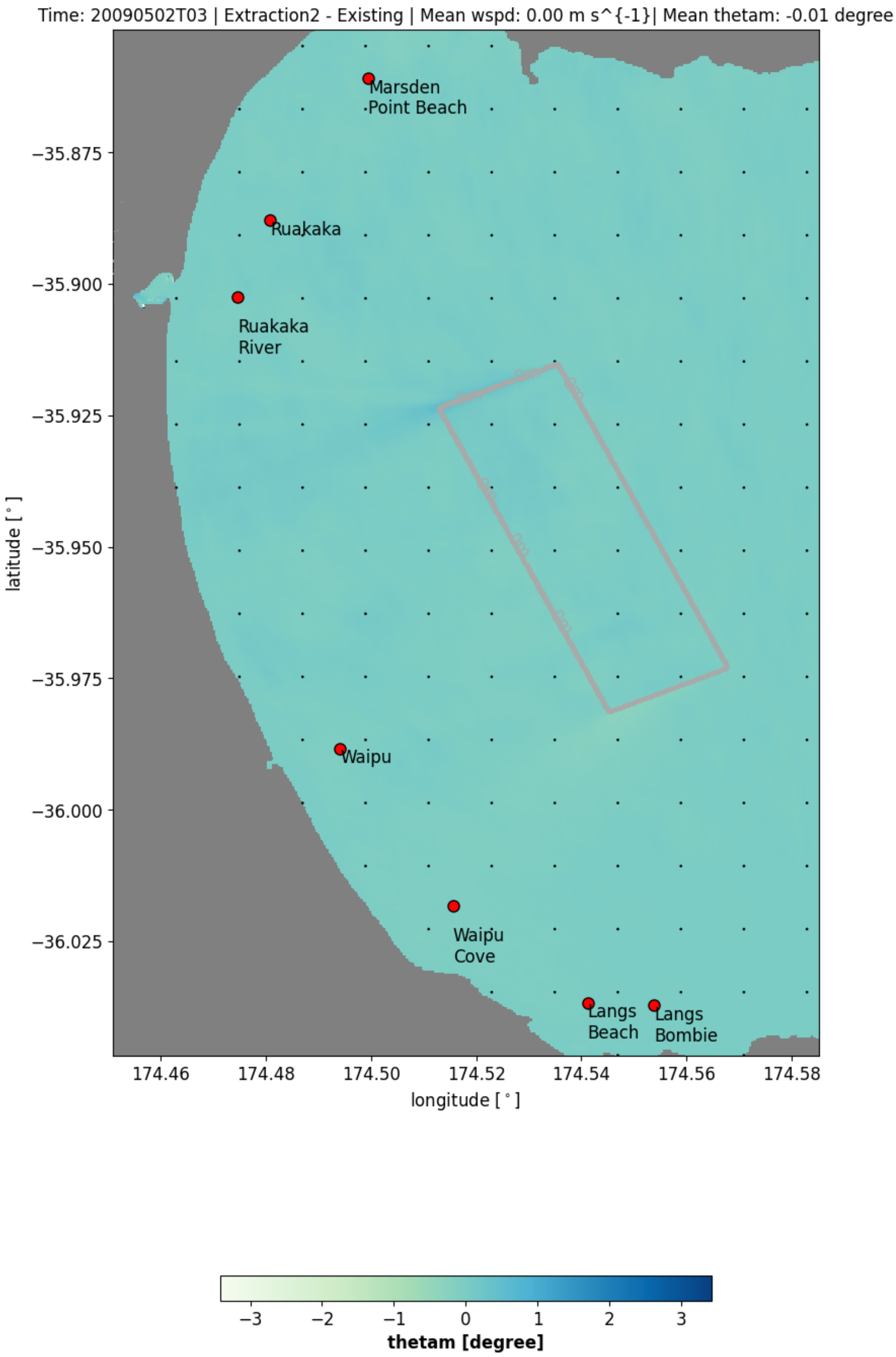

Figure 4.9 Map showing the difference in mean wave direction (deg) between existing and post-extraction scenarios during the SE wave event on 02/05/2009 00:00UTC. Positive/negative differences indicate clockwise/anticlockwise rotations. Surf breaks are indicated by red dots.

5.Site statistics

This section provides ambient wave statistics for the existing conditions and time series of wave parameters illustrated for Waipū River Mouth, as an example of surf breaks in the embayment, together with the difference in wave parameters between existing and after the extraction campaign (see Section 2.3.5). The results for all other surf breaks are available in Appendix A (Section 9).

5.1 Waipū River Mouth

5.1.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Waipū River Mouth is provided in Table 5.1.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 5.2.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 5.3. Assuming that surfable conditions[4] are met when $H_s \geq 0.5$ and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 45.8 % of the time at Waipū River Mouth. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[5]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 5.1, showing the predominance of waves incoming from the ENE sector.

[4] inclusive of poor to average conditions, which can still be attractive to beginner surfers.
[5] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 5.1 Annual and monthly total significant wave height statistics at Waipū River Mouth.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics [(1)]															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main [(2)] Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.22	1.39	0.53	0.23	0.28	0.32	0.34	0.48	0.53	0.55	0.60	0.88	1.05	1.31	1.33	NE E
February	0.40	3.12	0.75	0.41	0.40	0.43	0.45	0.62	0.75	0.81	0.92	1.21	1.54	2.15	2.75	NE
March	0.23	3.09	0.71	0.49	0.23	0.29	0.33	0.54	0.78	0.81	0.85	1.26	1.89	2.33	2.77	NE E
April	0.24	2.51	1.08	0.49	0.25	0.28	0.35	1.07	1.24	1.29	1.50	1.75	1.94	2.18	2.33	NE E
May	0.23	1.85	0.62	0.33	0.24	0.30	0.33	0.52	0.64	0.71	0.77	1.13	1.36	1.63	1.77	E
June	0.13	2.29	0.67	0.47	0.15	0.18	0.22	0.55	0.82	0.93	0.99	1.28	1.61	2.16	2.22	NE E
July	0.15	4.31	0.72	0.76	0.16	0.23	0.29	0.48	0.62	0.69	0.78	1.20	2.44	4.02	4.20	NE E
August	0.16	2.56	0.94	0.56	0.17	0.25	0.28	0.83	1.18	1.30	1.40	1.88	2.00	2.24	2.36	NE E
September	0.19	1.52	0.77	0.33	0.20	0.36	0.44	0.66	0.95	1.03	1.11	1.28	1.39	1.45	1.47	NE E
October	0.16	1.38	0.44	0.19	0.17	0.22	0.24	0.41	0.48	0.53	0.58	0.71	0.80	0.92	1.08	NE E
November	0.17	0.89	0.32	0.10	0.17	0.19	0.22	0.31	0.35	0.36	0.37	0.41	0.47	0.58	0.76	NE E
December	0.22	1.19	0.41	0.12	0.24	0.30	0.32	0.37	0.42	0.44	0.46	0.50	0.61	0.71	1.01	NE E
Winter	0.13	4.31	0.78	0.62	0.16	0.21	0.27	0.57	0.90	0.99	1.10	1.54	1.99	2.39	3.65	NE E
Spring	0.16	1.52	0.51	0.30	0.17	0.21	0.24	0.41	0.56	0.61	0.68	0.98	1.21	1.37	1.43	NE E
Summer	0.22	3.12	0.56	0.31	0.28	0.32	0.33	0.47	0.57	0.61	0.64	0.91	1.14	1.41	1.61	NE E
Autumn	0.23	3.09	0.80	0.48	0.24	0.29	0.34	0.64	0.97	1.06	1.14	1.51	1.80	2.08	2.32	NE E
All	0.13	4.31	0.66	0.47	0.17	0.24	0.28	0.50	0.72	0.81	0.94	1.24	1.58	2.00	2.29	NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 5.2 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Waipū River Mouth. The same data are represented in the form of a rose plot in Figure 5.1.

H_s (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	0.17	28.27	20.95	0.08	-	-	-	0.01	49.48	100.00
0.5-1	0.09	18.40	14.31	0.01	-	-	-	-	32.81	50.52
1-1.5	-	7.72	4.35	-	-	-	-	-	12.07	17.70
1.5-2	-	2.47	1.14	-	-	-	-	-	3.61	5.64
2-2.5	-	1.24	0.08	-	-	-	-	-	1.32	2.03
2.5-3	-	0.30	-	-	-	-	-	-	0.30	0.71
3-3.5	-	0.14	-	-	-	-	-	-	0.14	0.41
3.5-4	-	0.09	-	-	-	-	-	-	0.09	0.27
4-4.5	-	0.18	-	-	-	-	-	-	0.18	0.18
Total	0.26	58.81	40.83	0.09	-	-	-	0.01	100.00	

Table 5.3 Annual joint probability distribution (in %) of the total significant wave height and peak period at Waipū River Mouth. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
0-0.5	0.02	0.84	1.05	1.97	15.76	18.79	7.45	1.73	1.13	0.65	0.07	49.46	100.00
0.5-1	-	0.54	2.88	3.86	11.77	7.32	5.28	0.99	0.17	0.01	-	32.82	50.52
1-1.5	-	0.01	1.07	0.96	4.22	3.85	1.83	0.13	-	-	-	12.07	17.70
1.5-2	-	-	0.24	0.97	1.53	0.73	0.14	-	-	-	-	3.61	5.64
2-2.5	-	-	-	0.39	0.60	0.33	-	-	-	-	-	1.32	2.03
2.5-3	-	-	-	0.01	0.22	0.07	-	-	-	-	-	0.30	0.71
3-3.5	-	-	-	-	0.10	0.03	-	-	-	-	-	0.13	0.41
3.5-4	-	-	-	-	0.03	0.06	-	-	-	-	-	0.09	0.27
4-4.5	-	-	-	-	0.01	0.17	-	-	-	-	-	0.18	0.18
Total	0.02	1.39	5.24	8.16	34.24	31.35	14.70	2.85	1.30	0.66	0.07	100.00	
Exceed%	100.00	99.98	98.58	93.35	85.18	50.93	19.59	4.89	2.03	0.73	0.07		

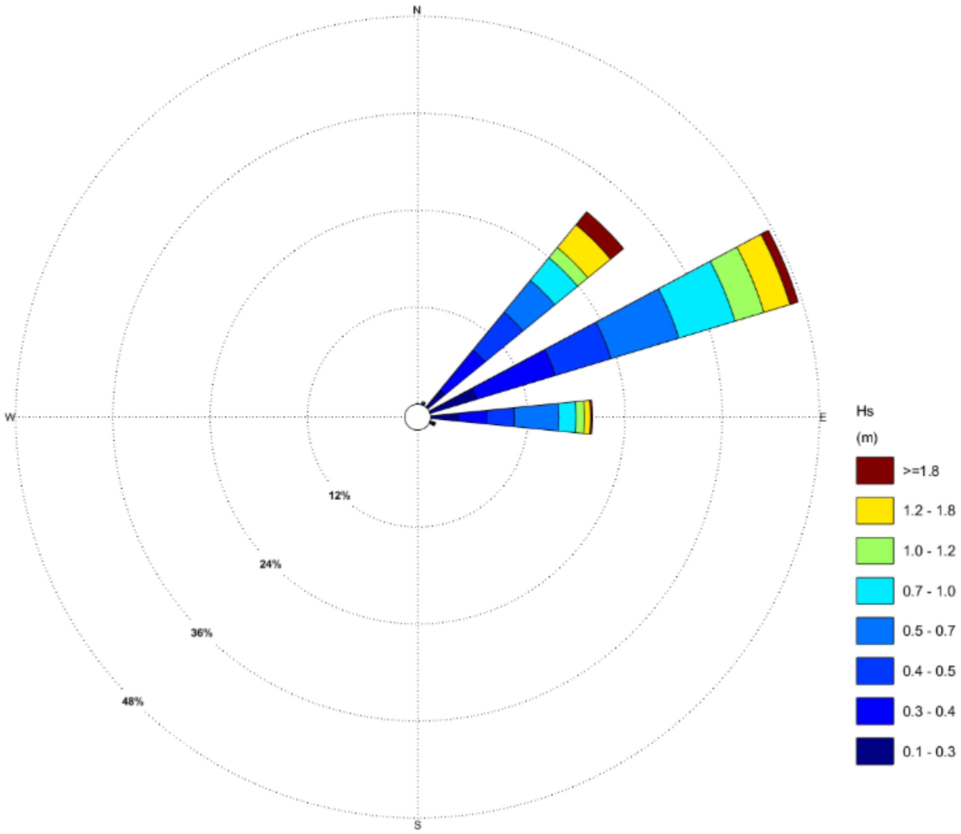

Figure 5.1 Annual wave rose plot for the total significant wave height at Waipū River Mouth. Sectors indicate the direction from which waves approach.

5.1.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Waipū River Mouth considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 5.2, Figure 5.3 and Figure 5.4, respectively.

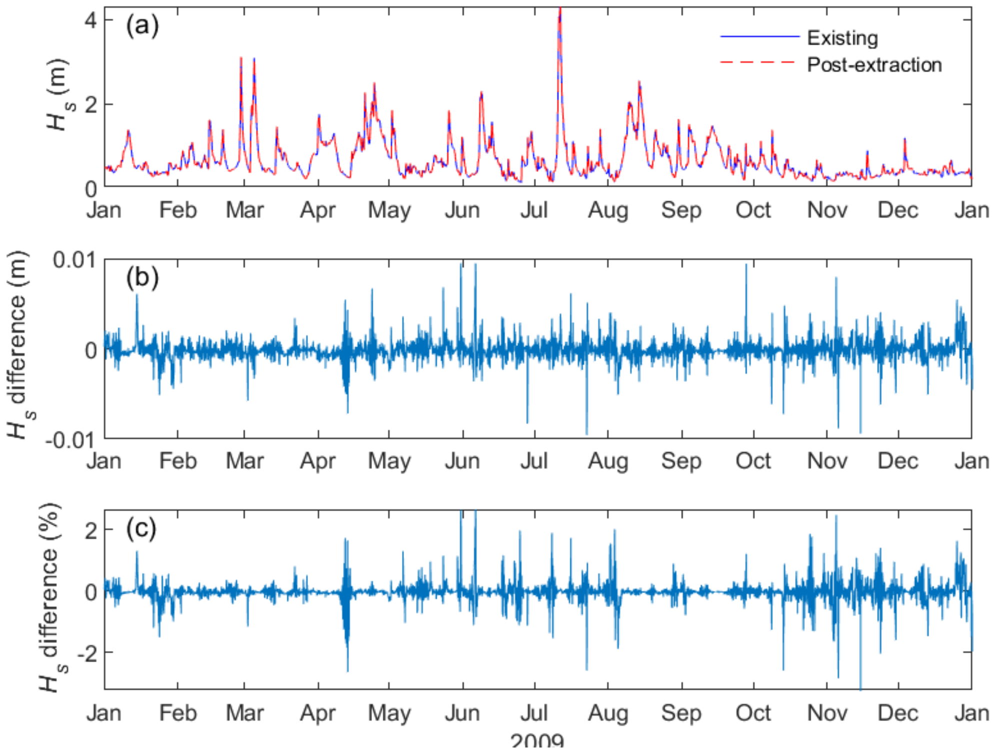

Figure 5.2 Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Waipū River Mouth.

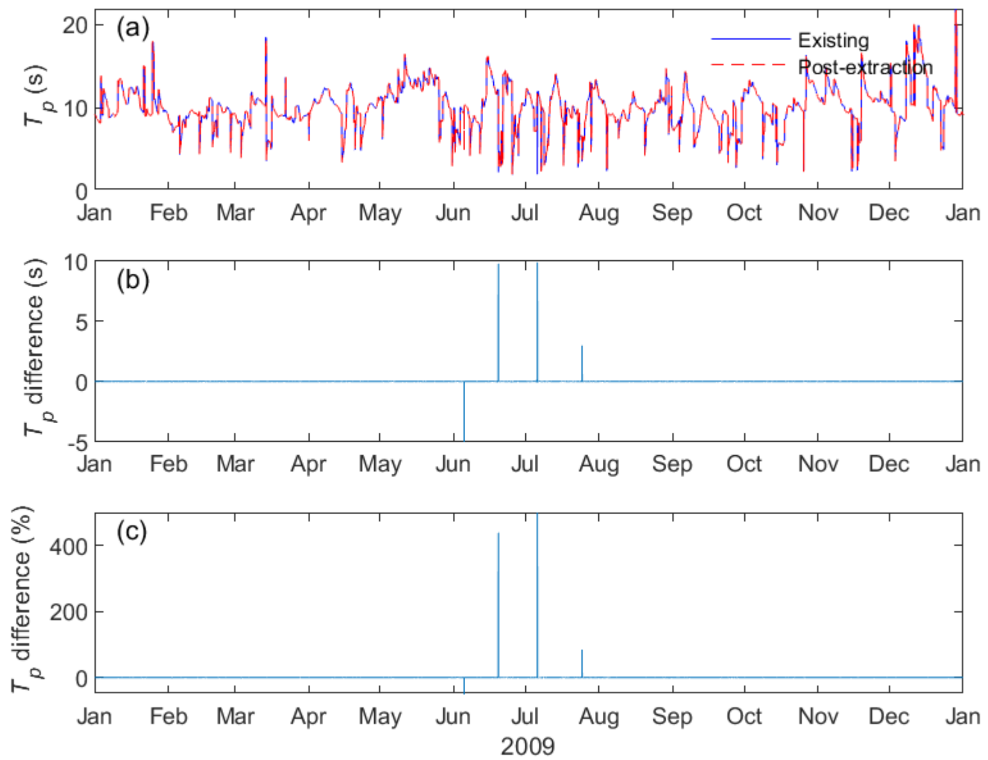

Figure 5.3 Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Waipū River Mouth.

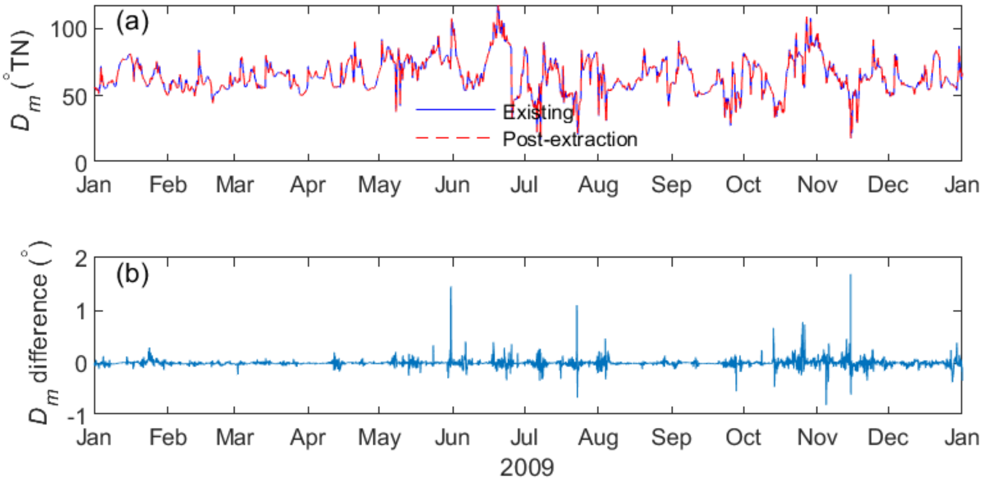

Figure 5.4 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Waipū River Mouth.

6.Surfability assessment

This section investigates the potential effects of the extraction on annual surfing conditions. The estimated percentage of time of surfable conditions for the existing and post-extraction scenarios are presented in Table 6.1 for all surf breaks of interest. Also provided in these tables are the differences in percentage of time of surfable conditions between existing and post-extraction scenarios, which do not exceed 0.2% in absolute value for all sites and thresholds considered. For reference, a 0.1% increase represents an additional 8.8 hours per year with surfable conditions, while a decrease of -0.1% represents a diminution of 8.8 hours per year. In practice, surfing activities nearly always take place during daylight hours. As a result, the actual value of 8.8 hours is effectively reduced by around half, or 4.4 hours, for a 0.1% change.

To present the largest changes within the year of simulation, the maximum increase and decrease of several wave parameters for a post-extraction scenario are provided as value and percentage differences in Table 6.2 to Table 6.5, respectively. These results represent the tabulated summary of all time series presented in Sections 5 and 9, focusing on the maximum differences. However, note that the differences are insignificant most of the time.

The maximum increases in H_s and D_m do not exceed 0.02 m (or 3.5% relative increase) and 1.29 degrees clockwise, respectively, while the maximum decreases in H_s and D_m are -0.01 m (corresponding to -1.2% relative decrease) and 2.06 degrees anticlockwise, respectively, for all scenarios and thresholds considered (Table 6.2 to Table 6.5).

The maximum increases and decreases in T_p exhibit large values (with up to 9.76 s increase and down to –11.15 s decrease). However, T_p values are highly sensitive to minor changes in the wave spectra during bi-modal wave conditions (i.e., when the wind seas and swell energy are of similar amplitude). Large abrupt jumps/drops in T_p from wind sea periods to swell periods (and vice versa) are common during these events but are not necessarily occurring at the exact same time during the existing and post-extraction scenarios. Therefore, we added the result for mean period T_m in Table 6.2 to Table 6.5, which is a more stable wave parameter during these bi-modal sea state conditions and provides a more realistic estimate of the maximum rate of change between existing and post-extraction conditions (within +/- 1 s maximum change, i.e. between -12.2% and +10.1% relative change considering thresholds used by Mead et al., 2004, and Black et al., 2004). We note that, for conservative surfable conditions, the absolute changes increase to +/- 2 s, i.e. between -25.5% and +22.0% relative change. However, these conditions are considered by an experienced surfer to not be surfable.

To further demonstrate these jumps/drops in T_p are not representative of significant surfability changes, the difference in the annual joint probability distribution of H_s and T_p between existing and post-extraction scenarios are presented for Waipū River Mouth in Table 6.6. The results indicate the few abrupt T_p drops/jumps from wind sea periods to swell periods (and vice versa) are rare and do not significantly affect the annual statistics. All other surf breaks considered in this study similarly exhibit very small differences.

Table 6.1 Percentage of surfable conditions and difference between existing and post-extraction scenarios at surf breaks considering the conservative threshold of $H_s \geq 0.5$ m and $T_p \geq 6$ s, the threshold used by Mead et al. (2004) and Black et al. (2004) of $H_s \geq 0.75$ m and $T_p \geq 6$ s, and for average to good conditions ($H_s \geq 0.75$ m and $T_p \geq 8$ s).

		Probability of surfable conditions (%)		
Surfable conditions		**Conservative conditions (including poor conditions)**	**Threshold used by Mead et al. (2004) and Black et al. (2004)**	**Average to good conditions**
Sea state criteria		**$H_s \geq 0.5$ m and $T_p \geq 6$ s**	**$H_s \geq 0.75$ m and $T_p \geq 6$ s**	**$H_s \geq 0.75$ m and $T_p \geq 8$ s**
Te Poupouwhenua Marsden Point Beach	**Existing**	23.2	8.2	7.0
	Post-extraction	23.2	8.2	7.1
	Difference*	0.0	0.0	0.0
Ruakākā	**Existing**	49.6	27.6	23.8
	Post-extraction	49.6	27.6	23.9
	Difference*	0.0	0.0	0.0
Ruakākā River Mouth	**Existing**	28.2	12.8	11.6
	Post-extraction	28.4	13.0	11.7
	Difference*	0.2	0.1	0.1
Waipū River Mouth	**Existing**	45.8	25.4	21.8
	Post-extraction	45.7	25.4	21.8
	Difference*	-0.1	0.0	0.0
Waipū Cove	**Existing**	45.8	25.8	21.7
	Post-extraction	45.8	25.8	21.7
	Difference*	0.0	0.0	0.0
Wairahi Langs Beach	**Existing**	44.0	24.4	19.6
	Post-extraction	44.0	24.4	19.7
	Difference*	0.1	0.0	0.0
Langs Bombie	**Existing**	45.8	25.0	20.3
	Post-extraction	45.8	25.0	20.3
	Difference*	-0.1	0.0	0.0

*Positive value indicates an increase in the percentage of annual surfable conditions. (values rounded to one decimal point)

*Table 6.2 Maximum **value increase** of several wave parameters between existing and post-extraction scenarios at surf breaks considering the conservative threshold of $H_s \geq 0.5$ m and $T_p \geq 6$ s, the threshold used by Mead et al. (2004) and Black et al. (2004) of $H_s \geq 0.75$ m and $T_p \geq 6$ s, and for average to good conditions ($H_s \geq 0.75$ m and $T_p \geq 8$ s).*

Surfable conditions			Conservative conditions (including poor conditions)	Threshold used by Mead et al. (2004) and Black et al. (2004).	Average to good conditions
Sea state criteria			$H_s \geq 0.5$ m & $T_p \geq 6$ s	$H_s \geq 0.75$ m & $T_p \geq 6$ s	$H_s \geq 0.75$ m & $T_p \geq 8$ s
Increase	Te Poupouwhenua Marsden Point Beach	H_s (m)	0.01	0.01	0.01
		T_p (s)	9.76	6.53	6.53
		T_m (s)	1.00	0.41	0.41
		D_m (°)	0.40	0.19	0.19
	Ruakākā	H_s (m)	0.02	0.00	0.00
		T_p (s)	9.72	9.72	9.72
		T_m (s)	1.28	0.68	0.68
		D_m (°)	1.29	0.22	0.22
	Ruakākā River Mouth	H_s (m)	0.01	0.01	0.01
		T_p (s)	8.30	5.88	5.88
		T_m (s)	1.28	0.14	0.14
		D_m (°)	0.55	0.42	0.42
	Waipū River Mouth	H_s (m)	0.01	0.01	0.00
		T_p (s)	2.98	0.02	0.01
		T_m (s)	1.17	0.22	0.22
		D_m (°)	0.34	0.19	0.19
	Waipū Cove	H_s (m)	0.01	0.01	0.00
		T_p (s)	4.99	0.05	0.05
		T_m (s)	0.65	0.20	0.20
		D_m (°)	0.26	0.22	0.22
	Wairahi Langs Beach	H_s (m)	0.01	0.01	0.01
		T_p (s)	2.06	1.80	1.80
		T_m (s)	1.43	0.53	0.53
		D_m (°)	0.31	0.11	0.11
	Langs Bombie	H_s (m)	0.01	0.01	0.00
		T_p (s)	0.01	0.01	0.01
		T_m (s)	1.33	0.50	0.50
		D_m (°)	0.31	0.23	0.23

Table 6.3 *Maximum* ***value decrease*** *of several wave parameters between existing and post-extraction scenarios at surf breaks considering the conservative threshold of $H_s \geq 0.5$ m and $T_p \geq 6$ s, the threshold used by Mead et al. (2004) and Black et al. (2004) of $H_s \geq 0.75$ m and $T_p \geq 6$ s, and for average to good conditions ($H_s \geq 0.75$ m and $T_p \geq 8$ s).*

Surfable conditions			Conservative conditions (including poor conditions)	Threshold used by Mead et al. (2004) and Black et al. (2004).	Average to good conditions
Sea state criteria			**$H_s \geq 0.5$ m & $T_p \geq 6$ s**	**$H_s \geq 0.75$ m & $T_p \geq 6$ s**	**$H_s \geq 0.75$ m & $T_p \geq 8$ s**
Decrease	**Te Poupouwhenua Marsden Point Beach**	**H_s (m)**	-0.01	-0.01	-0.01
		T_p (s)	-0.04	-0.04	0.00
		T_m (s)	-1.14	-0.21	-0.21
		D_m (°)	-0.33	-0.25	-0.25
	Ruakākā	**H_s (m)**	-0.01	0.00	0.00
		T_p (s)	-0.03	-0.03	-0.03
		T_m (s)	-2.00	-0.92	-0.92
		D_m (°)	-2.06	-0.17	-0.17
	Ruakākā River Mouth	**H_s (m)**	0.00	0.00	0.00
		T_p (s)	-0.03	-0.01	-0.01
		T_m (s)	-1.62	-0.99	-0.99
		D_m (°)	-0.31	-0.23	-0.23
	Waipū River Mouth	**H_s (m)**	-0.01	-0.01	-0.01
		T_p (s)	-0.02	-0.02	-0.01
		T_m (s)	-0.50	-0.17	-0.17
		D_m (°)	-0.54	-0.54	-0.14
	Waipū Cove	**H_s (m)**	-0.01	-0.01	-0.01
		T_p (s)	-7.92	-0.55	-0.55
		T_m (s)	-0.40	-0.32	-0.32
		D_m (°)	-0.56	-0.31	-0.16
	Wairahi Langs Beach	**H_s (m)**	-0.01	0.00	0.00
		T_p (s)	-1.66	-1.66	-1.66
		T_m (s)	-1.57	-0.44	-0.44
		D_m (°)	-0.37	-0.21	-0.21
	Langs Bombie	**H_s (m)**	0.00	0.00	0.00
		T_p (s)	-11.15	-0.01	-0.01
		T_m (s)	-1.02	-0.90	-0.90
		D_m (°)	-0.26	-0.16	-0.13

Table 6.4 *Maximum **percentage of increase** of several wave parameters between existing and post-extraction scenarios at surf breaks considering the conservative threshold of $H_s \geq 0.5$ m and $T_p \geq 6$ s, the threshold used by Mead et al. (2004) and Black et al. (2004) of $H_s \geq 0.75$ m and $T_p \geq 6$ s, and for average to good conditions ($H_s \geq 0.75$ m and $T_p \geq 8$ s).*

Surfable conditions			Conservative conditions (including poor conditions)	Threshold used by Mead et al. (2004) and Black et al. (2004).	Average to good conditions
Sea state criteria			$H_s \geq 0.5$ m & $T_p \geq 6$ s	$H_s \geq 0.75$ m & $T_p \geq 6$ s	$H_s \geq 0.75$ m & $T_p \geq 8$ s
Increase	Te Poupouwhenua Marsden Point Beach	H_s (m)	1.2	0.5	0.5
		T_p (s)	336.3	99.9	99.9
		T_m (s)	13.9	5.5	5.5
		D_m (°)	-	-	-
	Ruakākā	H_s (m)	3.5	0.4	0.4
		T_p (s)	219.0	219.0	219.0
		T_m (s)	21.6	10.1	10.1
		D_m (°)	-	-	-
	Ruakākā River Mouth	H_s (m)	1.8	1.1	1.1
		T_p (s)	183.7	137.8	137.8
		T_m (s)	19.0	1.9	1.9
		D_m (°)	-	-	-
	Waipū River Mouth	H_s (m)	1.2	1.2	0.2
		T_p (s)	84.8	0.3	0.1
		T_m (s)	21.7	3.4	3.4
		D_m (°)	-	-	-
	Waipū Cove	H_s (m)	1.2	0.7	0.4
		T_p (s)	210.8	0.4	0.4
		T_m (s)	11.0	3.1	3.1
		D_m (°)	-	-	-
	Wairahi Langs Beach	H_s (m)	1.5	0.5	0.5
		T_p (s)	28.8	24.8	24.8
		T_m (s)	22.0	7.2	7.2
		D_m (°)	-	-	-
	Langs Bombie	H_s (m)	0.9	0.6	0.6
		T_p (s)	0.2	0.1	0.1
		T_m (s)	19.5	7.3	7.3
		D_m (°)	-	-	-

Table 6.5 *Maximum **percentage of decrease** of several wave parameters between existing and post-extraction scenarios at surf breaks considering the conservative threshold of $H_s \geq 0.5$ m and $T_p \geq 6$ s, the threshold used by Mead et al. (2004) and Black et al. (2004) of $H_s \geq 0.75$ m and $T_p \geq 6$ s, and for average to good conditions ($H_s \geq 0.75$ m and $T_p \geq 8$ s).*

Surfable conditions			Conservative conditions (including poor conditions)	Threshold used by Mead et al. (2004) and Black et al. (2004).	Average to good conditions
Sea state criteria			$H_s \geq 0.5$ m & $T_p \geq 6$ s	$H_s \geq 0.75$ m & $T_p \geq 6$ s	$H_s \geq 0.75$ m & $T_p \geq 8$ s
Decrease	Te Poupouwhenua Marsden Point Beach	H_s (m)	-0.7	-0.7	-0.7
		T_p (s)	-0.6	-0.6	-0.1
		T_m (s)	-11.5	-2.3	-2.3
		D_m (°)	-	-	-
	Ruakākā	H_s (m)	-1.2	-0.5	-0.5
		T_p (s)	-0.2	-0.2	-0.2
		T_m (s)	-25.5	-11.8	-11.8
		D_m (°)	-	-	-
	Ruakākā River Mouth	H_s (m)	-0.4	-0.3	-0.3
		T_p (s)	-0.3	-0.1	-0.1
		T_m (s)	-20.2	-11.6	-11.6
		D_m (°)	-	-	-
	Waipū River Mouth	H_s (m)	-1.2	-0.6	-0.6
		T_p (s)	-0.3	-0.3	-0.1
		T_m (s)	-8.3	-2.6	-2.6
		D_m (°)	-	-	-
	Waipū Cove	H_s (m)	-1.0	-1.0	-0.8
		T_p (s)	-39.6	-6.4	-6.4
		T_m (s)	-8.1	-4.3	-4.3
		D_m (°)	-	-	-
	Wairahi Langs Beach	H_s (m)	-1.1	-0.5	-0.3
		T_p (s)	-12.5	-12.5	-12.5
		T_m (s)	-23.3	-6.9	-6.9
		D_m (°)	-	-	-
	Langs Bombie	H_s (m)	-0.6	-0.5	-0.5
		T_p (s)	-55.5	-0.1	-0.1
		T_m (s)	-14.6	-12.2	-12.2
		D_m (°)	-	-	-

Table 6.6 Difference in annual joint probability distribution (in %) of the significant wave height and peak period between existing and post-extraction scenarios at Waipū River Mouth. Positive value indicates an increase in percentage of occurrence for post-extraction scenario. The green cells indicate H_s and T_p ranges corresponding to "surfable conditions". The results indicate the few abrupt T_p drops/jumps from wind sea periods to swell periods (and vice versa) are rare and do not significantly affect the annual statistics. All other surf breaks considered in this study exhibit similar very small differences.

H_s (m)	Peak period (s)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	Total
0-0.5	-0.01	-0.01	0.01	0.03	0.00	0.02	-0.01	0.03	0.00	0.00	0.00	0.06
0.5-1	-	-0.01	0.00	0.01	-0.04	-0.01	0.00	0.00	0.00	0.00	-	-0.05
1-1.5	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
1.5-2	-	-	0.01	-0.01	0.00	0.00	0.00	-	-	-	-	0.00
2-2.5	-	-	-	0.00	0.00	0.00	-	-	-	-	-	0.00
2.5-3	-	-	-	0.00	0.00	0.00	-	-	-	-	-	0.00
3-3.5	-	-	-	-	0.00	0.00	-	-	-	-	-	0.00
3.5-4	-	-	-	-	0.00	0.00	-	-	-	-	-	0.00
4-4.5	-	-	-	-	0.00	0.00	-	-	-	-	-	0.00
Total	-0.01	-0.02	0.02	0.03	-0.04	0.01	-0.01	0.03	0.00	0.00	0.00	0.00

7.Summary

The surfability of regionally significant surf breaks (as defined by the New Zealand Surfing Guide Book and Northland Regional Council) within Te Ākau Bream Bay was examined with the proposed sand extraction consent expected to be in the swell corridor for seven surf breaks (see Table 1.1). Hindcast wave data for the year 2009 (as it was closest to the yearly average and the 95th percentile wave height conditions) was chosen to characterise the wave conditions at these surf breaks and estimate the level of change in surfable conditions as well as several standard wave parameters (focusing on worst-case events).

We investigated the effects on surfability of waves based on extracting of the total proposed volume over the full term of the consent areas with no replenishment of sand infilling the area. These are considered worst-case scenarios as they cause maximum changes in bathymetry. They are unlikely to occur due to the sand pathways replenishing extraction areas over the life of the consent.

The seven surf breaks of interest in this study consist of a combination of sites listed in the New Zealand Surfing Guide Book and the Northland Regional Council online portal[6].

We investigated the change in wave field for typical good surfing events with incoming waves from the NE, E and SE and found generally little variation in terms of wave heights and directions between existing and post-extraction conditions. However, some local variations were generated from the edges of the consent areas (away from the surf breaks of interest), with significant wave height (H_s) and mean wave direction (D_m) changes of up to ±0.04 m and ±1 degree, respectively, during the selected N, NE and SE swell events.

In this report, the effects of extraction are investigated only after extraction of the full licence volume for the full term of the consent is undertaken. Changes in wave parameters tend to be more pronounced near the edges of the extraction areas. Therefore, the wave fields are likely to be locally and temporarily affected during the extraction campaigns in locations where the extraction stops until the following permitting weather window for extraction.

Conservative surfable conditions (i.e., inclusive of poor to average conditions which can still be attractive to beginner surfers) are defined as $H_s \geq 0.5$ m and peak wave period (T_p)

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[6] https://data-nrcgis.opendata.arcgis.com/datasets/NRCGIS::regionally-significant-surf-breaks-1/explore?location=-35.978003%2C174.610447%2C11.00

≥ 6 s. These conditions occur annually on average 23.2-49.6% of the time at the seven surf breaks of interest. Applying less conservative thresholds as used by Mead et al. (2004) and Black et al. (2004) (i.e. H_s > 0.75, and T_p > 6 s – conditions that advanced surfers would target) suggest surfable conditions occur 8.2-27.6% of the time. Average to good surfable conditions (i.e., $H_s \geq 0.75$ m and $T_p \geq 8$ s) are expected to occur 7.0-23.8% of the time. Results show that the change in surfable conditions only varies between -0.1 to 0.2% (positive value indicating an increase in surfable conditions).

Even for the worst-case changes within the simulation year, the maximum differences in H_s ranged between -0.01 m (-1.2% relative decrease) and 0.02 m (3.5% relative increase), while the maximum D_m differences were ±2 degree for all scenarios and thresholds considered at the seven reporting sites. Some T_p instabilities noted were judged non-representative of the actual wave period change due to common abrupt jumps from the modelled T_p time series during bi-modal wave conditions. The maximum differences in the more representative mean period (T_m) showed less than ±1 s maximum change, which is -12.2% and +10.1% relative change considering thresholds used by Mead et al., 2004, and Black et al., 2004 (which exclude poor surfing conditions).

Surf quality typically increases with increasing wave height and period, while the effect of changes in wave direction depends on the bathymetry and coastal features in the vicinity of each surf break. In this study, we show that the extraction may lead to a slight increase or decrease in the wave height and surf quality, but these changes would be hard to detect by a surfer. Given the morphology of the coastline (with no sheltered surf breaks or embayments), we consider that the small changes in wave direction are unlikely to affect the surf quality at the seven surf breaks of interest. Changes in wave periods may temporarily slightly deteriorate or improve the surf quality when the mean period T_m decreases or increases, respectively.

While it is recognised that there is uncertainty associated with any future sediment transport and bathymetry evolution, this study provides initial estimates of the consequences of the proposed extraction scenarios and associated bathymetric changes in terms of nearshore surfability based on the worst-case scenario.

Wind data were not included in the estimation of surfable conditions. Strong wind events from the NE, E and SE octants may deteriorate the surf quality, therefore further decreasing the percentage surfable conditions. However, the decrease in the number of surfable days would be the same when compared to existing vs full extraction, so there is no need to include it in the analysis.

Based on the worst-case bathymetry change scenarios, the impact on surfability at the seven surf breaks close to the extraction areas was found to be less than minor to negligible. Based on our results, it is unlikely that a surfer on site would be able to perceive a difference (increase or decrease) in wave height or period resulting from the proposed extraction. Our study was based on results for the year 2009; however, interannual variation of wave heights (including highest swell year) are not expected to have any significant impact on the results.

Although this is beyond the purpose of this study, it is worth mentioning the potential for changes in wave-induced rip currents (caused by changes in wave patterns) are likely to be less than minor to negligible.

Table 7.1 Summary of changes in surfable conditions and several standard wave parameters for all surf breaks considered. Also presented are the maximum levels of changes associated with the extraction area edges during typical NE, E and SE swell events.

	Difference criteria	Summary of changes
At surf breaks	Annual change in surfable conditions	-0.1% to 0.2%*
	Maximum H_s changes during surfable conditions	-0.01 m (-1.2%) and +0.02 m (+3.5%)
	Maximum D_m changes during surfable conditions at surf breaks	±2 degree
	Maximum T_m changes during surfable conditions at surf breaks	±2 s (between -25.5% and and +22.0%)
Near extraction area edges	Maximum H_s changes associated with extraction area edges during typical N, NE and SE swell events	±0.04 m (<7%)
	Maximum D_m changes associated with extraction area edges during selected N, NE and SE swell events	±1 degree

*Positive value indicates an increase in percentage of annual surfable conditions.

7.1 Consideration of climate change

The projected impacts of climate change on wave dynamics in the NZ waters include potential changes in wave heights, periods, and directions due to shifting wind patterns and increased storm activity (Hemer et al., 2013; Morim et al., 2019). Rising sea levels may also interact with wave propagation, potentially leading to greater wave energy reaching the shoreline (IPCC, 2021). However, despite these potential changes, the level of change in surfability at Te Akau Bream Bay is expected to remain very similar (i.e., less than minor to negligible) under both present-day conditions and future climate change scenarios, given that the dominant swell and wind patterns influencing surf conditions are not projected to shift dramatically (Vousdoukas et al., 2018; Morim et al., 2019).

This conclusion is consistent with the more detailed conclusions reached in Tonkin and Taylors' Te Ākau Bream Bay Sand Extraction: Coastal Process Effects Assessment as to the generally negligible cumulative impact of climate change on the effects of sand extraction in Te Ākau Bream Bay. It follows that there is a negligible prospect that climate change would exacerbate the effects of sand extraction on surf breaks in the Bay.

8. References

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9. Appendix A (detailed statistics at all surf breaks)

This section provides ambient wave statistics for the existing conditions and time series of wave parameters for all surf breaks (except Waipū River Mouth, which is already provided in Section 5.1) together with the difference in wave parameters between existing and after the extraction campaigns (see Section 2.3.5).

9.1 Te Poupouwhenua Marsden Point Beach

9.1.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Te Poupouwhenua Marsden Point Beach is provided in Table 9.1.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 9.2.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 9.3. Assuming that surfable conditions are met when $H_s \geq 0.5$ and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 23.2% of the time at Te Poupouwhenua Marsden Point Beach. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[7]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 9.1, showing the predominance of waves incoming from the SE sector.

[7] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 9.1 Annual and monthly total significant wave height statistics at Te Poupouwhenua Marsden Point Beach.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics [1]															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main [2] Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.14	1.05	0.37	0.19	0.14	0.16	0.18	0.34	0.42	0.45	0.49	0.58	0.78	0.98	1.01	SE
February	0.15	1.64	0.38	0.26	0.16	0.17	0.18	0.30	0.38	0.43	0.49	0.62	0.98	1.27	1.53	SE
March	0.10	1.70	0.44	0.31	0.11	0.14	0.15	0.37	0.45	0.48	0.55	0.81	1.24	1.46	1.52	SE
April	0.11	2.12	0.67	0.34	0.12	0.14	0.22	0.63	0.77	0.85	0.93	1.15	1.28	1.51	1.71	SE
May	0.23	1.90	0.59	0.31	0.24	0.28	0.30	0.51	0.65	0.70	0.76	1.05	1.24	1.54	1.68	SE
June	0.11	1.30	0.46	0.27	0.13	0.15	0.17	0.41	0.59	0.64	0.68	0.81	1.02	1.23	1.27	SE
July	0.10	2.58	0.51	0.47	0.11	0.14	0.18	0.36	0.49	0.54	0.60	0.92	1.90	2.22	2.43	SE
August	0.08	1.36	0.55	0.28	0.10	0.17	0.19	0.55	0.66	0.70	0.73	1.02	1.09	1.16	1.19	SE
September	0.12	1.42	0.43	0.25	0.15	0.21	0.22	0.35	0.44	0.48	0.53	0.74	1.01	1.23	1.30	SE
October	0.06	0.99	0.37	0.20	0.08	0.12	0.14	0.33	0.47	0.51	0.55	0.65	0.77	0.85	0.94	SE
November	0.08	0.87	0.29	0.13	0.10	0.14	0.17	0.27	0.33	0.35	0.38	0.45	0.53	0.66	0.73	SE
December	0.14	0.89	0.29	0.14	0.14	0.15	0.16	0.25	0.32	0.35	0.39	0.51	0.58	0.64	0.74	SE
Winter	0.08	2.58	0.51	0.36	0.11	0.15	0.18	0.43	0.60	0.64	0.70	0.92	1.13	1.51	2.08	SE
Spring	0.06	1.42	0.36	0.20	0.09	0.14	0.17	0.31	0.41	0.44	0.49	0.60	0.78	1.00	1.19	SE
Summer	0.14	1.64	0.35	0.20	0.14	0.16	0.17	0.30	0.39	0.42	0.46	0.57	0.72	0.99	1.15	SE
Autumn	0.10	2.12	0.56	0.33	0.12	0.15	0.22	0.48	0.65	0.70	0.77	1.04	1.27	1.49	1.63	SE
All	0.06	2.58	0.45	0.30	0.12	0.15	0.18	0.36	0.51	0.56	0.62	0.81	1.05	1.29	1.52	SE

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 9.2 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Te Poupouwhenua Marsden Point Beach. The same data are represented in the form of a rose plot in Figure 9.1.

H_s (m)	**Mean wave direction at peak energy (degT)**									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	1.05	0.22	1.43	61.66	2.12	1.16	0.68	0.80	69.12	100.00
0.5-1	0.05	0.18	0.09	23.30	1.29	0.07	-	-	24.98	30.89
1-1.5	-	-	-	4.82	-	-	-	-	4.82	5.90
1.5-2	-	-	-	0.71	-	-	-	-	0.71	1.08
2-2.5	-	-	-	0.33	-	-	-	-	0.33	0.38
2.5-3	-	-	-	0.05	-	-	-	-	0.05	0.05
Total	1.10	0.40	1.52	90.87	3.41	1.23	0.68	0.80	100.00	

Table 9.3 Annual joint probability distribution (in %) of the total significant wave height and peak period at Te Poupouwhenua Marsden Point Beach. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	Total	Exceed%
0-0.5	2.63	7.02	0.74	3.48	18.46	25.93	10.35	0.42	0.09	-	-	69.12	100.00
0.5-1	-	3.06	2.09	0.58	2.99	7.73	7.00	1.44	0.09	-	-	24.98	30.89
1-1.5	-	-	2.44	0.43	0.64	0.59	0.56	0.15	-	-	-	4.81	5.90
1.5-2	-	-	0.13	0.39	0.06	0.11	0.02	-	-	-	-	0.71	1.08
2-2.5	-	-	-	0.14	0.16	0.03	-	-	-	-	-	0.33	0.38
2.5-3	-	-	-	-	0.05	-	-	-	-	-	-	0.05	0.05
Total	2.63	10.08	5.40	5.02	22.36	34.39	17.93	2.01	0.18	-	-	100.00	
Exceed%	100.00	97.37	87.30	81.90	76.87	54.53	20.12	2.19	0.18	-	-		

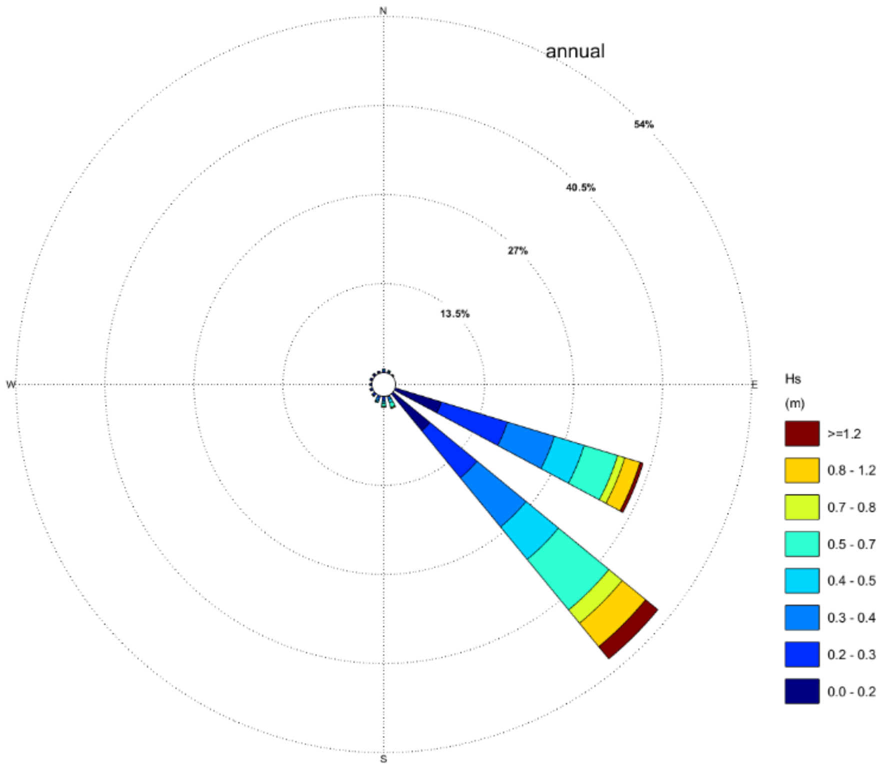

Figure 9.1 Annual wave rose plot for the total significant wave height at Te Poupouwhenua Marsden Point Beach. Sectors indicate the direction from which waves approach.

9.1.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Te Poupouwhenua Marsden Point Beach considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 9.2, Figure 9.3 and Figure 9.4, respectively.

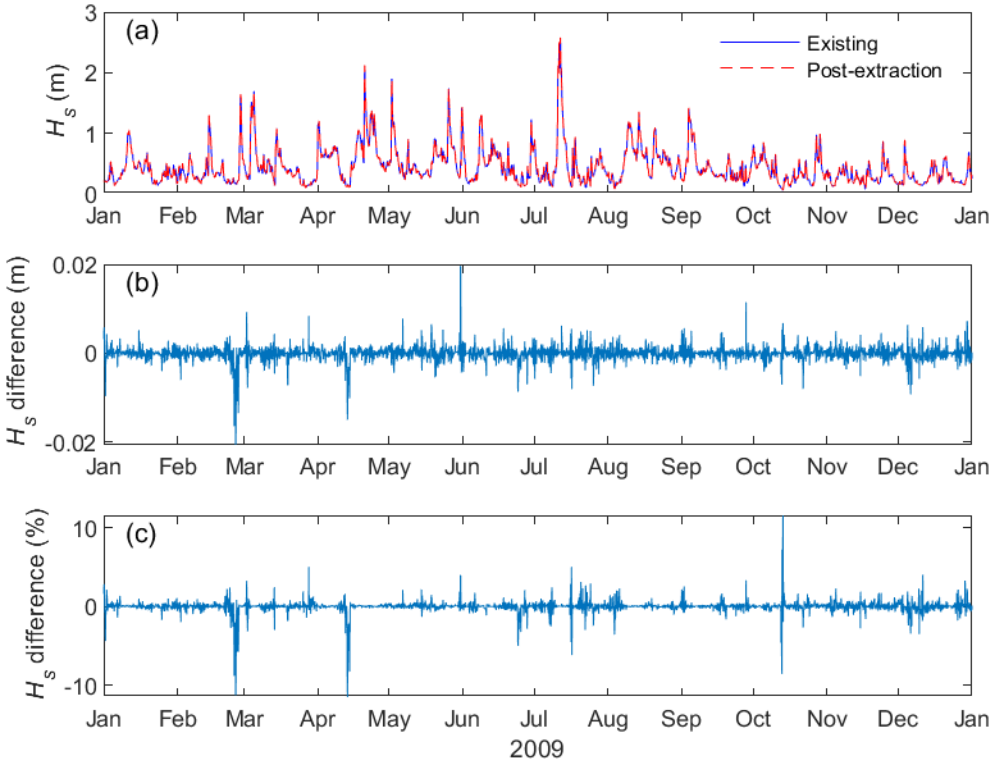

Figure 9.2 *Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Te Poupouwhenua Marsden Point Beach.*

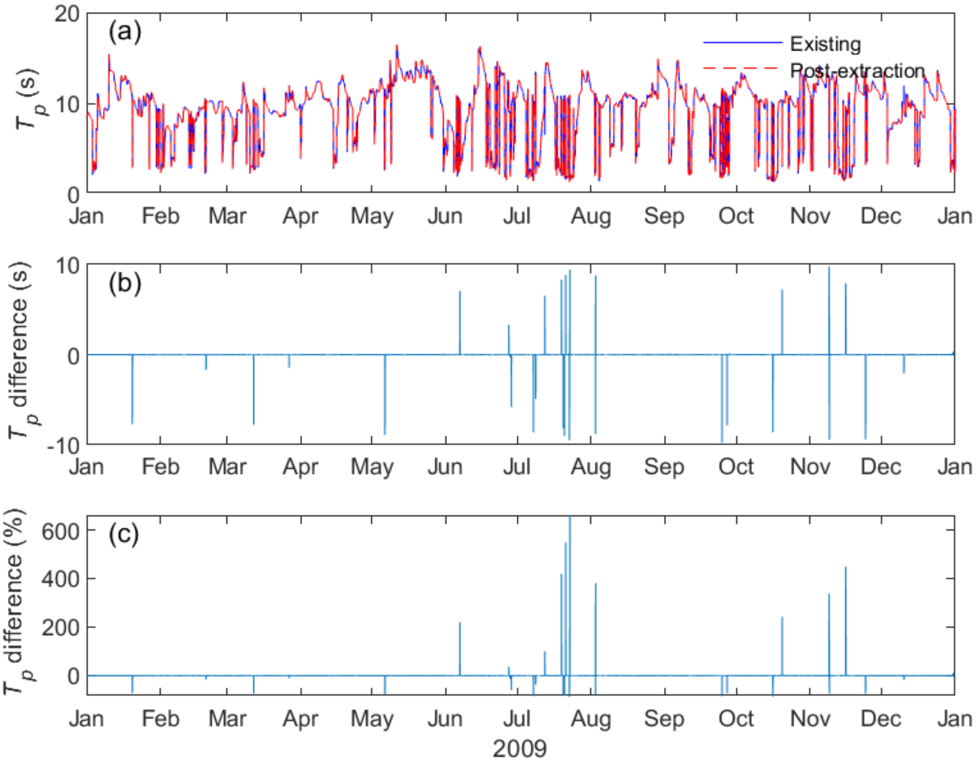

Figure 9.3 *Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Te Poupouwhenua Marsden Point Beach.*

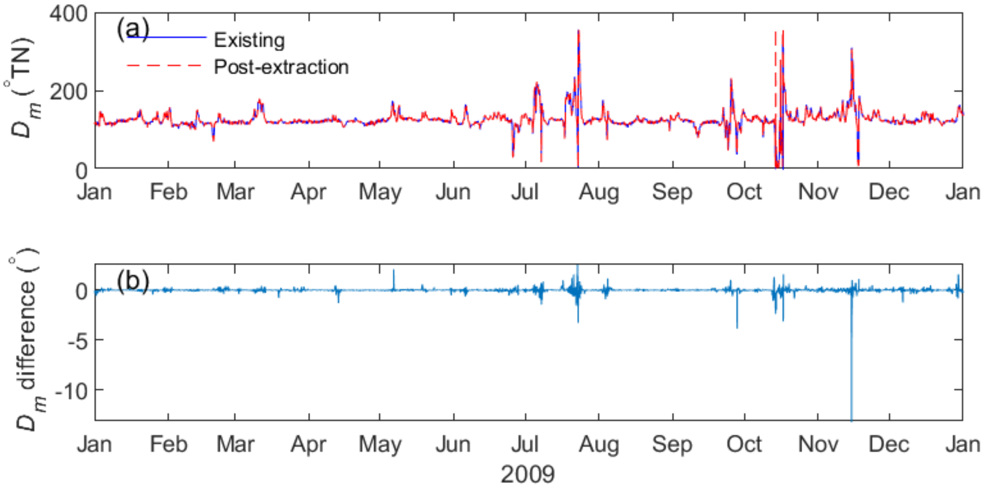

Figure 9.4 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Te Poupouwhenua Marsden Point Beach.

9.2 Ruakākā

9.2.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Ruakākā is provided in Table 9.4.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 9.5.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 9.6. Assuming that surfable conditions are met when $H_s \geq 0.5$ and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 49.6% of the time at Ruakākā. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[8]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 9.5, showing the predominance of waves incoming from the E sector.

[8] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 9.4 Annual and monthly total significant wave height statistics at Ruakākā.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics (1)															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main (2) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.25	1.56	0.56	0.27	0.26	0.28	0.32	0.47	0.59	0.61	0.66	0.93	1.24	1.50	1.52	E SE
February	0.33	2.63	0.70	0.38	0.34	0.37	0.43	0.59	0.69	0.75	0.81	1.13	1.56	1.93	2.39	E
March	0.20	2.72	0.73	0.46	0.20	0.24	0.31	0.60	0.78	0.87	0.94	1.31	1.85	2.15	2.42	E
April	0.21	2.47	1.14	0.48	0.22	0.24	0.32	1.22	1.35	1.38	1.46	1.75	1.91	2.05	2.13	E
May	0.25	2.24	0.72	0.41	0.27	0.34	0.37	0.59	0.79	0.87	0.97	1.32	1.68	1.85	2.01	E SE
June	0.14	1.97	0.65	0.41	0.16	0.22	0.27	0.49	0.84	0.89	0.94	1.22	1.58	1.87	1.89	E SE
July	0.15	3.85	0.67	0.71	0.16	0.18	0.23	0.45	0.63	0.70	0.79	1.22	2.50	3.52	3.63	E SE
August	0.17	2.22	0.89	0.48	0.18	0.23	0.28	0.86	1.14	1.22	1.30	1.62	1.76	1.86	1.94	E
September	0.23	1.74	0.69	0.32	0.24	0.34	0.37	0.62	0.82	0.87	0.90	1.00	1.42	1.60	1.67	E
October	0.16	0.99	0.47	0.20	0.18	0.20	0.22	0.42	0.59	0.62	0.65	0.78	0.85	0.89	0.92	E
November	0.16	0.82	0.33	0.11	0.17	0.19	0.20	0.30	0.38	0.40	0.42	0.46	0.53	0.65	0.71	E
December	0.24	1.11	0.41	0.14	0.24	0.28	0.29	0.36	0.46	0.49	0.51	0.60	0.68	0.72	0.95	E
Winter	0.14	3.85	0.74	0.56	0.16	0.21	0.26	0.58	0.88	0.96	1.08	1.41	1.77	2.18	3.27	E SE
Spring	0.16	1.74	0.50	0.27	0.18	0.20	0.24	0.41	0.59	0.63	0.68	0.85	0.96	1.40	1.58	E
Summer	0.24	2.63	0.55	0.30	0.26	0.29	0.31	0.47	0.59	0.62	0.66	0.86	1.16	1.52	1.75	E
Autumn	0.20	2.72	0.86	0.49	0.22	0.28	0.34	0.72	1.12	1.20	1.27	1.54	1.84	2.06	2.17	E
All	0.14	3.85	0.66	0.45	0.18	0.24	0.27	0.52	0.73	0.83	0.92	1.28	1.57	1.89	2.12	E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 9.5 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Ruakākā. The same data are represented in the form of a rose plot in Figure 9.5.

H_s (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	0.08	0.18	42.02	5.55	0.03	0.08	-	-	47.94	100.00
0.5-1	0.06	0.07	30.74	3.78	0.10	-	-	0.01	34.76	52.06
1-1.5	-	-	10.87	0.62	-	-	-	-	11.49	17.30
1.5-2	-	-	4.26	0.11	-	-	-	-	4.37	5.82
2-2.5	-	-	0.76	0.13	-	-	-	-	0.89	1.45
2.5-3	-	-	0.25	-	-	-	-	-	0.25	0.56
3-3.5	-	-	0.11	-	-	-	-	-	0.11	0.31
3.5-4	-	-	0.19	-	-	-	-	-	0.19	0.19
Total	0.14	0.25	89.20	10.19	0.13	0.08	-	0.01	100.00	

Table 9.6 Annual joint probability distribution (in %) of the total significant wave height and peak period at Ruakākā. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
0-0.5	0.01	1.26	0.96	2.09	20.77	16.01	6.55	0.24	0.05	-	-	47.94	100.00
0.5-1	-	0.67	1.11	3.09	13.32	8.74	6.16	1.43	0.23	-	-	34.75	52.06
1-1.5	-	-	0.58	0.48	4.12	4.27	1.68	0.35	-	-	-	11.48	17.30
1.5-2	-	-	0.11	1.35	1.78	0.73	0.30	0.10	-	-	-	4.37	5.82
2-2.5	-	-	-	0.34	0.41	0.11	0.02	-	-	-	-	0.88	1.45
2.5-3	-	-	-	0.03	0.13	0.09	-	-	-	-	-	0.25	0.56
3-3.5	-	-	-	0.03	0.05	0.03	-	-	-	-	-	0.11	0.31
3.5-4	-	-	-	-	0.05	0.15	-	-	-	-	-	0.20	0.19
Total	0.01	1.93	2.76	7.41	40.63	30.13	14.71	2.12	0.28	-	-	100.00	
Exceed%	100.00	99.99	98.06	95.30	87.88	47.25	17.11	2.40	0.27	-	-		

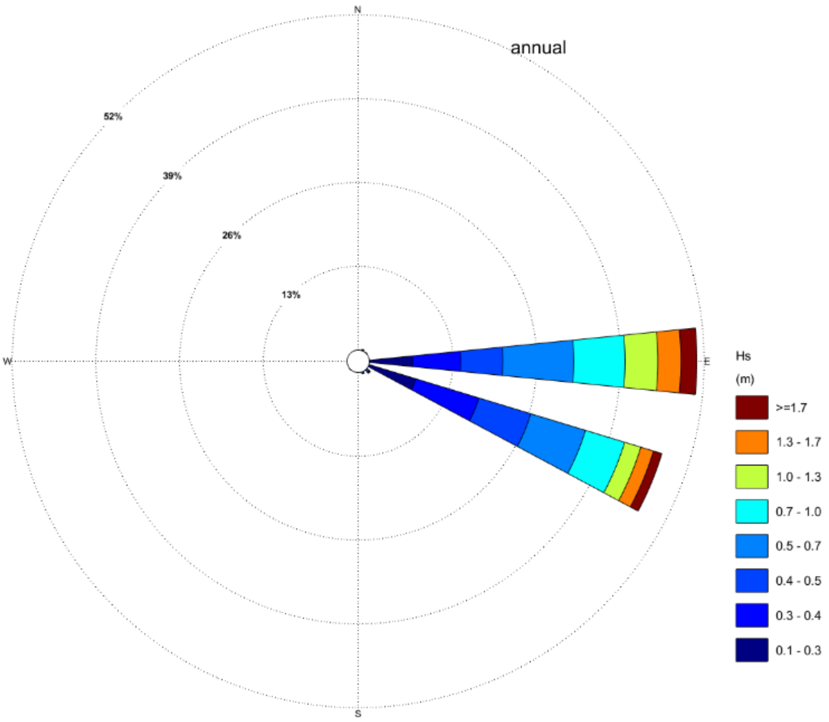

Figure 9.5 Annual wave rose plot for the total significant wave height at Ruakākā. Sectors indicate the direction from which waves approach.

9.2.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Ruakākā considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 9.6, Figure 9.7 and Figure 9.8, respectively.

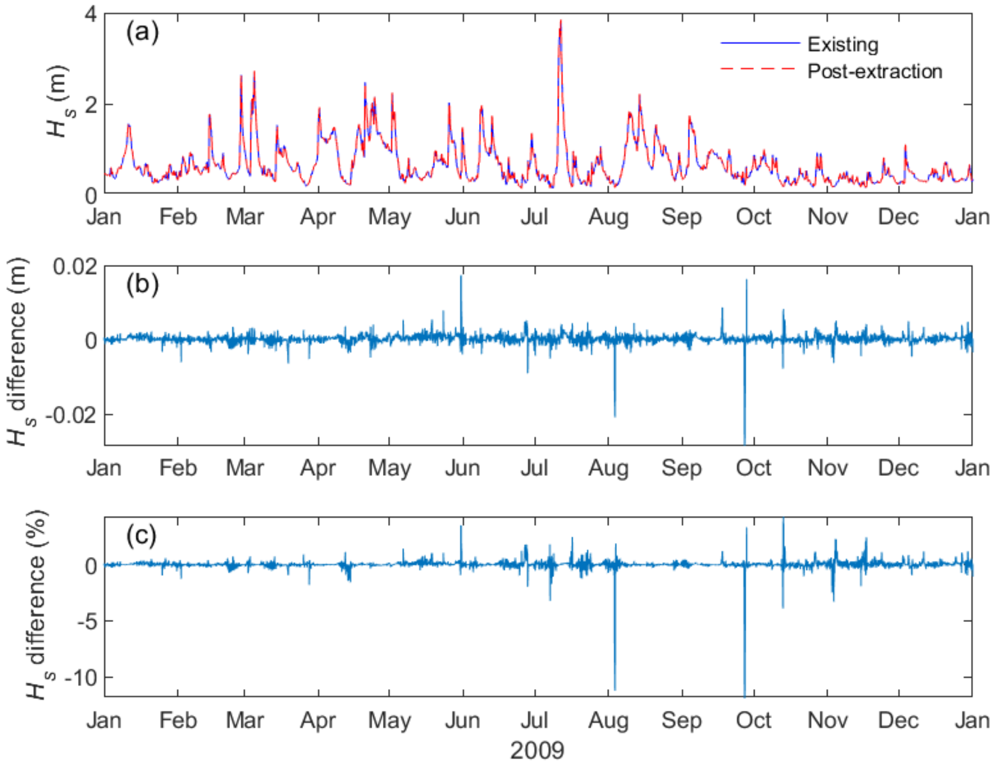

Figure 9.6 Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Ruakākā.

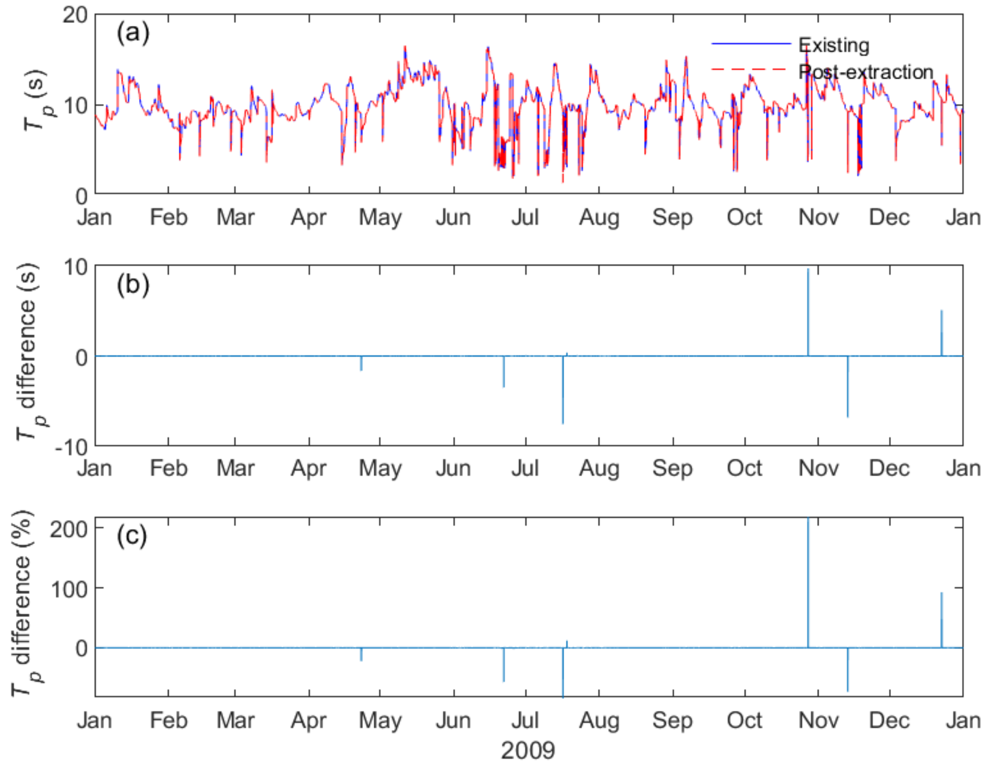

Figure 9.7 Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Ruakākā.

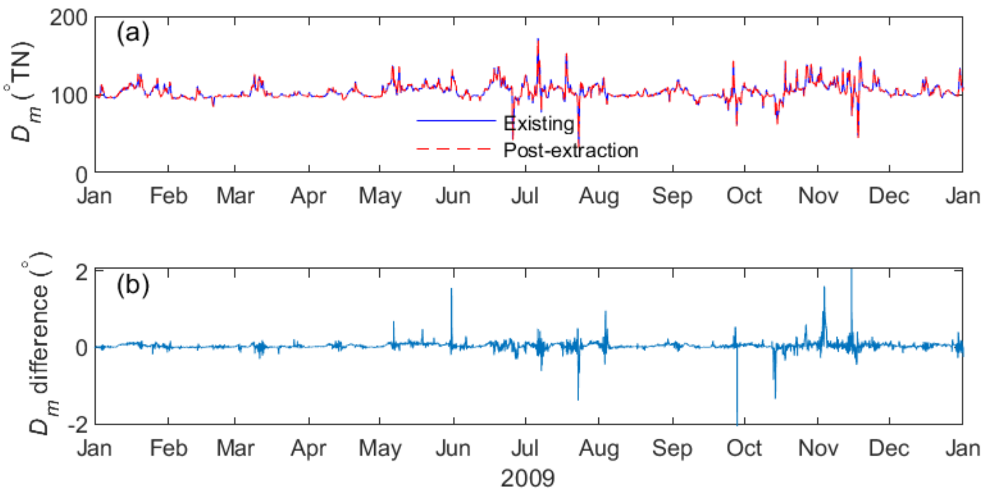

Figure 9.8 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Ruakākā.

9.3 Ruakākā River Mouth

9.3.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Ruakākā River Mouth is provided in Table 9.7.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 9.8.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 9.9. Assuming that surfable conditions are met when $H_s \geq 0.5$ and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 28.2% of the time at Ruakākā River Mouth. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[9]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 9.9, showing the predominance of waves incoming from the E sector.

[9] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 9.7 Annual and monthly total significant wave height statistics at Ruakākā River Mouth.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics [(1)]															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main [(2)] Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.19	1.12	0.42	0.19	0.19	0.22	0.24	0.36	0.47	0.51	0.53	0.63	0.88	1.08	1.11	E
February	0.20	2.11	0.49	0.32	0.20	0.24	0.25	0.40	0.49	0.54	0.63	0.80	1.20	1.50	1.92	E
March	0.14	2.23	0.52	0.37	0.15	0.18	0.22	0.41	0.52	0.56	0.61	0.98	1.49	1.76	1.91	E
April	0.13	2.20	0.81	0.40	0.14	0.15	0.23	0.78	0.91	1.01	1.10	1.37	1.58	1.74	1.81	E
May	0.21	1.93	0.59	0.34	0.23	0.29	0.30	0.48	0.62	0.69	0.77	1.14	1.32	1.65	1.81	E
June	0.12	1.67	0.53	0.31	0.14	0.21	0.24	0.45	0.64	0.69	0.75	0.88	1.13	1.59	1.62	E
July	0.10	3.62	0.56	0.62	0.11	0.14	0.17	0.38	0.54	0.58	0.64	0.97	2.05	3.07	3.39	E
August	0.11	1.76	0.66	0.37	0.12	0.18	0.21	0.64	0.82	0.88	0.94	1.21	1.39	1.48	1.50	E
September	0.14	1.49	0.52	0.26	0.15	0.26	0.28	0.45	0.55	0.58	0.64	0.85	1.09	1.37	1.42	E
October	0.10	0.88	0.38	0.17	0.11	0.16	0.19	0.35	0.45	0.48	0.52	0.62	0.71	0.80	0.83	E
November	0.12	0.75	0.27	0.10	0.13	0.14	0.17	0.25	0.31	0.32	0.34	0.41	0.47	0.57	0.64	E
December	0.17	1.02	0.32	0.14	0.17	0.18	0.20	0.26	0.34	0.37	0.42	0.50	0.58	0.64	0.87	E
Winter	0.10	3.62	0.58	0.46	0.12	0.16	0.21	0.45	0.67	0.74	0.81	1.07	1.40	1.73	2.92	E
Spring	0.10	1.49	0.39	0.21	0.12	0.16	0.19	0.34	0.45	0.47	0.51	0.64	0.77	1.07	1.32	E
Summer	0.17	2.11	0.41	0.24	0.18	0.20	0.22	0.34	0.44	0.47	0.51	0.64	0.85	1.12	1.40	E
Autumn	0.13	2.23	0.64	0.39	0.14	0.19	0.25	0.55	0.77	0.81	0.87	1.23	1.49	1.74	1.83	E
All	0.10	3.62	0.51	0.36	0.14	0.18	0.21	0.40	0.56	0.61	0.70	0.91	1.23	1.56	1.76	E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 9.8 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Ruakākā River Mouth. The same data are represented in the form of a rose plot in Figure 9.9.

H_s (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	0.26	0.56	59.98	1.83	0.37	0.39	0.46	0.47	64.32	100.00
0.5-1	-	0.39	25.53	1.36	0.06	0.03	-	-	27.37	35.69
1-1.5	-	-	5.62	0.46	-	-	-	-	6.08	8.32
1.5-2	-	-	1.58	0.07	-	-	-	-	1.65	2.25
2-2.5	-	-	0.26	0.01	-	-	-	-	0.27	0.60
2.5-3	-	-	0.09	-	-	-	-	-	0.09	0.33
3-3.5	-	-	0.19	-	-	-	-	-	0.19	0.24
3.5-4	-	-	0.05	-	-	-	-	-	0.05	0.05
Total	0.26	0.95	93.30	3.73	0.43	0.42	0.46	0.47	100.00	

Table 9.9 Annual joint probability distribution (in %) of the total significant wave height and peak period at Ruakākā River Mouth. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
0-0.5	1.34	3.45	2.48	4.41	23.19	21.04	8.10	0.25	0.06	-	-	64.32	100.00
0.5-1	-	1.91	3.09	1.46	5.88	8.41	5.97	0.65	-	-	-	27.37	35.69
1-1.5	-	-	1.72	0.45	1.80	0.92	1.18	-	-	-	-	6.07	8.32
1.5-2	-	-	0.73	0.43	0.26	0.17	0.05	-	-	-	-	1.64	2.25
2-2.5	-	-	0.07	0.07	0.07	0.07	-	-	-	-	-	0.28	0.60
2.5-3	-	-	-	0.03	-	0.06	-	-	-	-	-	0.09	0.33
3-3.5	-	-	-	0.13	0.05	0.02	-	-	-	-	-	0.20	0.24
3.5-4	-	-	-	0.01	0.01	0.02	-	-	-	-	-	0.04	0.05
Total	1.34	5.36	8.09	6.99	31.26	30.71	15.30	0.90	0.06	-	-	100.00	
Exceed%	100.00	98.66	93.31	85.22	78.23	46.97	16.25	0.96	0.06	-	-		

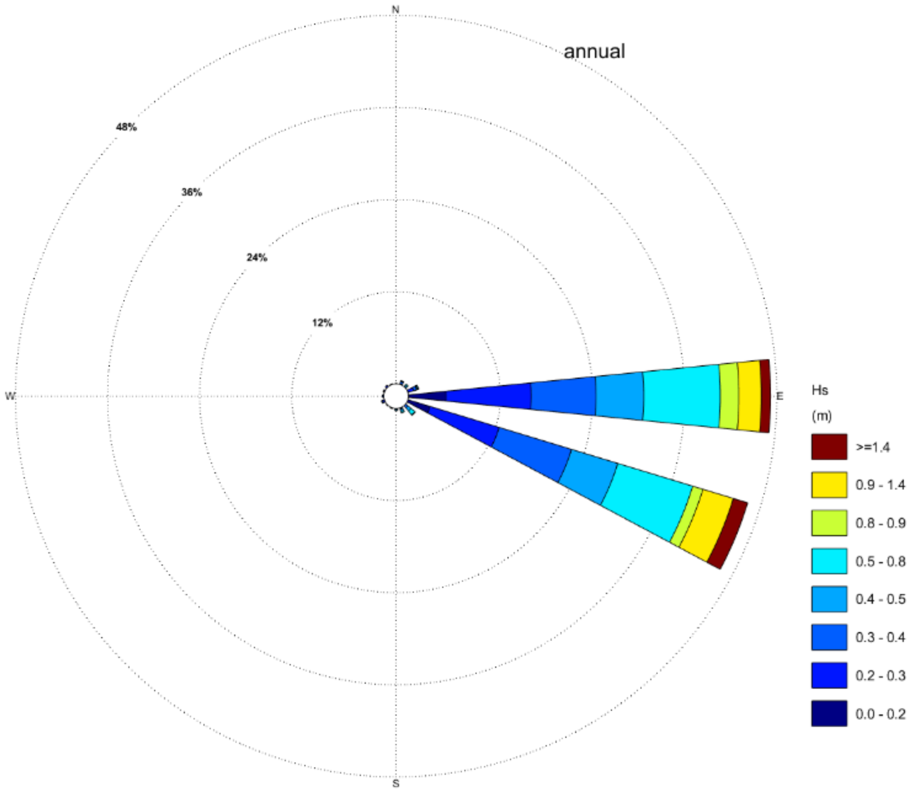

Figure 9.9 Annual wave rose plot for the total significant wave height at Ruakākā River Mouth. Sectors indicate the direction from which waves approach.

9.3.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Ruakākā River Mouth considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 9.10, Figure 9.11 and Figure 9.12, respectively.

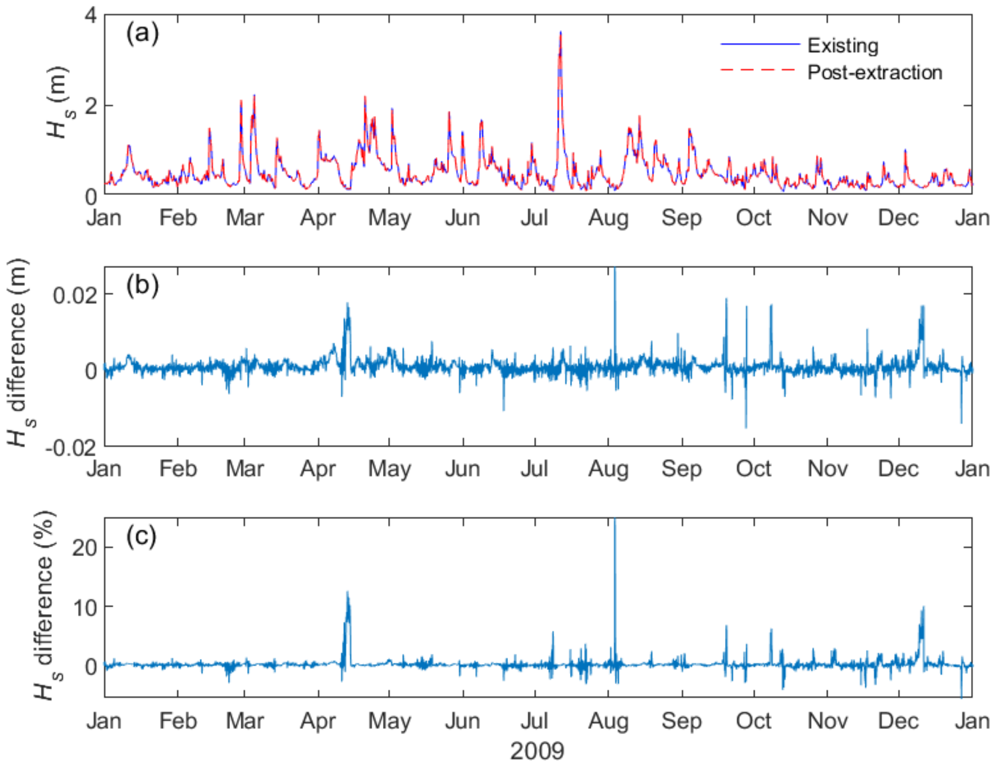

Figure 9.10 Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Ruakākā River Mouth.

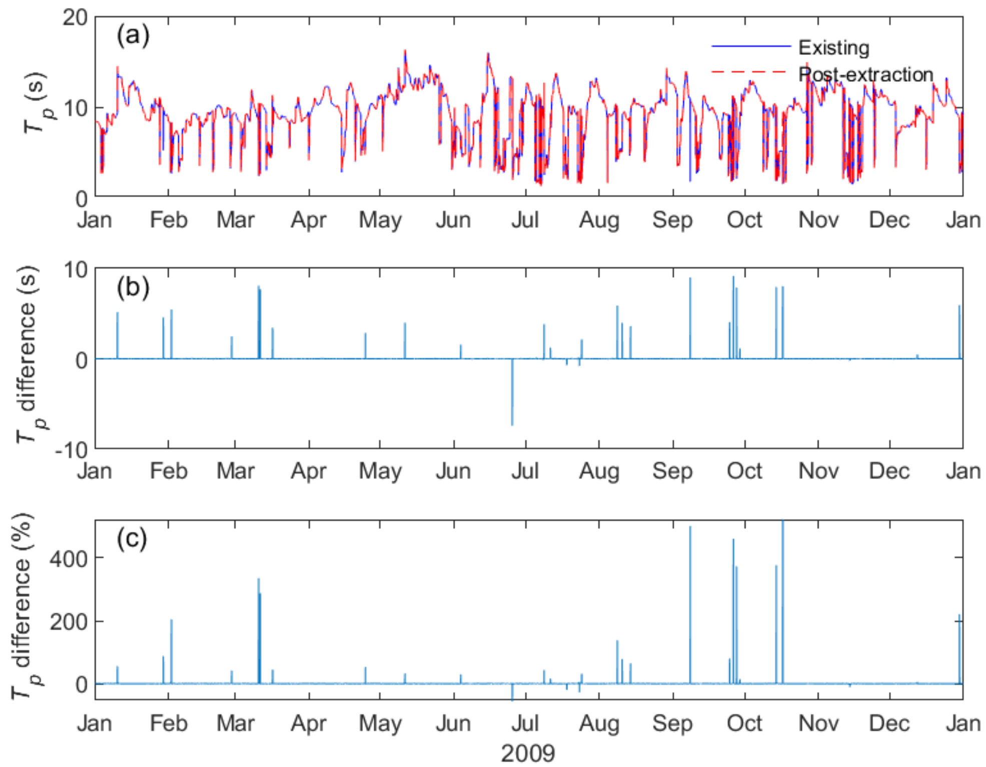

Figure 9.11 Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Ruakākā River Mouth.

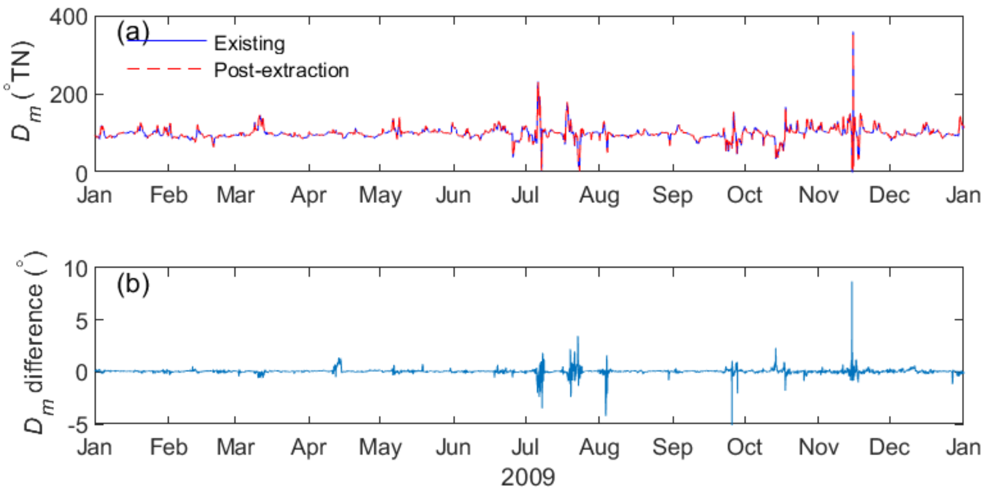

Figure 9.12 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Ruakākā River Mouth.

9.4 Waipū Cove

9.4.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Waipū Cove is provided in Table 9.10.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 9.11.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 9.12. Assuming that surfable conditions are met when $H_s \geq 0.5$ and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 45.8% of the time at Waipū Cove. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[10]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 9.13, showing the predominance of waves incoming from the ENE sector.

[10] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 9.10 Annual and monthly total significant wave height statistics at Waipū Cove.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics (1)															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main (2) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.22	1.40	0.52	0.23	0.28	0.31	0.33	0.47	0.52	0.56	0.59	0.88	1.09	1.34	1.35	NE E
February	0.40	3.16	0.75	0.41	0.40	0.43	0.44	0.62	0.74	0.81	0.92	1.23	1.50	2.21	2.79	NE
March	0.24	3.07	0.71	0.48	0.24	0.29	0.36	0.53	0.77	0.79	0.82	1.24	1.84	2.37	2.83	NE E
April	0.24	2.56	1.06	0.48	0.25	0.27	0.35	1.05	1.21	1.26	1.43	1.70	1.91	2.19	2.41	NE E
May	0.24	1.68	0.61	0.30	0.25	0.32	0.36	0.53	0.64	0.70	0.76	1.01	1.30	1.52	1.64	E
June	0.13	2.37	0.65	0.50	0.15	0.16	0.20	0.53	0.81	0.90	1.01	1.26	1.65	2.21	2.29	NE E
July	0.15	4.00	0.74	0.72	0.16	0.24	0.30	0.51	0.65	0.75	0.83	1.20	2.39	3.85	3.92	NE E
August	0.16	2.67	0.97	0.59	0.17	0.27	0.30	0.84	1.20	1.29	1.48	1.94	2.06	2.37	2.50	NE E
September	0.19	1.68	0.79	0.34	0.19	0.38	0.46	0.71	0.93	1.00	1.10	1.30	1.44	1.62	1.66	NE E
October	0.16	1.46	0.45	0.21	0.18	0.21	0.24	0.40	0.50	0.55	0.59	0.76	0.86	1.00	1.21	NE E
November	0.16	1.04	0.33	0.11	0.16	0.19	0.22	0.32	0.35	0.36	0.38	0.41	0.47	0.70	0.87	NE
December	0.22	1.18	0.42	0.11	0.24	0.31	0.33	0.39	0.44	0.46	0.48	0.53	0.60	0.69	1.00	NE E
Winter	0.13	4.00	0.79	0.62	0.15	0.20	0.26	0.58	0.90	1.00	1.13	1.59	2.05	2.48	3.51	NE E
Spring	0.16	1.68	0.52	0.31	0.17	0.21	0.24	0.42	0.57	0.64	0.73	0.97	1.23	1.40	1.55	NE E
Summer	0.22	3.16	0.56	0.31	0.28	0.32	0.35	0.47	0.57	0.60	0.64	0.91	1.16	1.43	1.57	NE E
Autumn	0.24	3.07	0.79	0.47	0.25	0.29	0.36	0.65	0.96	1.03	1.11	1.44	1.72	2.08	2.39	NE E
All	0.13	4.00	0.67	0.46	0.17	0.25	0.28	0.51	0.73	0.81	0.94	1.23	1.58	2.05	2.36	NE E

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 9.11 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Waipū Cove. The same data are represented in the form of a rose plot in Figure 9.13.

H_s (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	0.25	33.49	15.47	0.02	-	-	-	-	49.23	100.00
0.5-1	0.33	21.12	12.13	-	-	-	-	0.01	33.59	50.77
1-1.5	0.03	7.53	3.74	-	-	-	-	-	11.30	17.18
1.5-2	-	2.81	0.75	-	-	-	-	-	3.56	5.87
2-2.5	-	1.53	0.02	-	-	-	-	-	1.55	2.31
2.5-3	-	0.35	-	-	-	-	-	-	0.35	0.75
3-3.5	-	0.14	-	-	-	-	-	-	0.14	0.40
3.5-4	-	0.24	-	-	-	-	-	-	0.24	0.26
4-4.5	-	0.02	-	-	-	-	-	-	0.02	0.02
Total	0.61	67.23	32.11	0.02	-	-	-	0.01	100.00	

Table 9.12 Annual joint probability distribution (in %) of the total significant wave height and peak period at Waipū Cove. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
0-0.5	0.01	0.88	1.18	2.51	11.84	17.35	9.72	2.81	1.81	0.92	0.19	49.22	100.00
0.5-1	-	0.65	3.12	5.06	10.85	7.16	5.02	1.18	0.35	0.11	0.09	33.59	50.77
1-1.5	-	-	1.05	1.16	3.87	3.26	1.75	0.22	-	-	-	11.31	17.18
1.5-2	-	-	0.18	0.94	1.19	1.08	0.17	-	-	-	-	3.56	5.87
2-2.5	-	-	-	0.31	0.88	0.29	0.08	-	-	-	-	1.56	2.31
2.5-3	-	-	-	-	0.21	0.15	-	-	-	-	-	0.36	0.75
3-3.5	-	-	-	-	0.11	0.02	-	-	-	-	-	0.13	0.40
3.5-4	-	-	-	-	0.03	0.21	-	-	-	-	-	0.24	0.26
4-4.5	-	-	-	-	-	0.02	-	-	-	-	-	0.02	0.02
Total	0.01	1.53	5.53	9.98	28.98	29.54	16.74	4.21	2.16	1.03	0.28	100.00	
Exceed%	100.00	99.99	98.46	92.93	82.96	53.98	24.44	7.69	3.49	1.32	0.29		

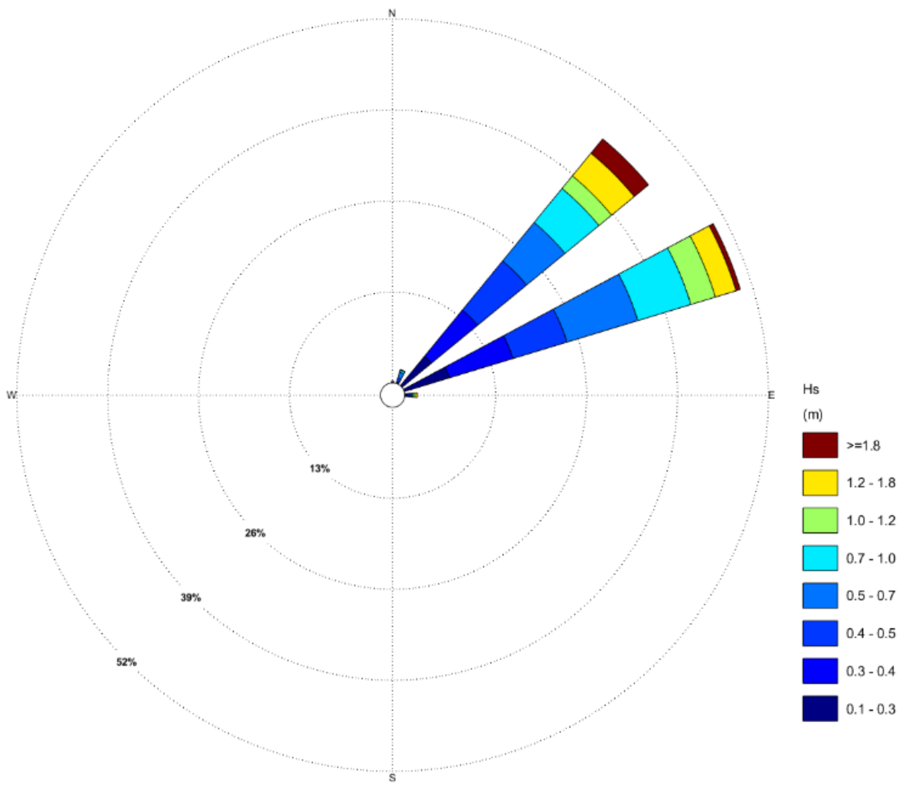

Figure 9.13 Annual wave rose plot for the total significant wave height at Waipū Cove. Sectors indicate the direction from which waves approach.

9.4.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Waipū Cove considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 9.14, Figure 9.15 and Figure 9.16, respectively.

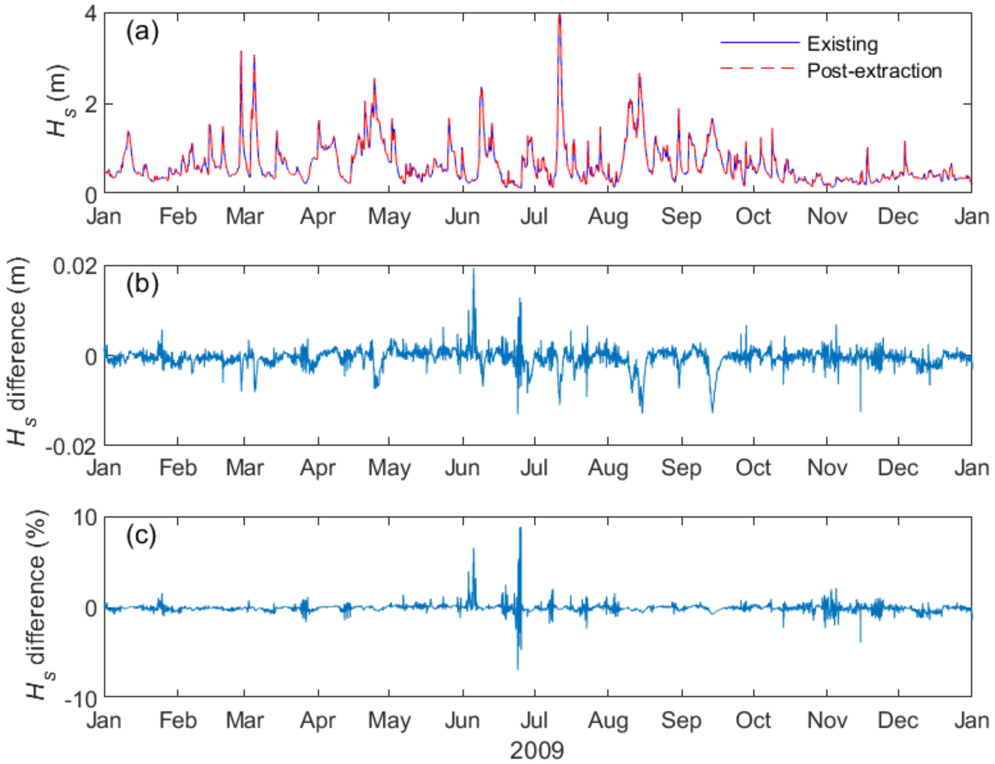

Figure 9.14 Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Waipū Cove.

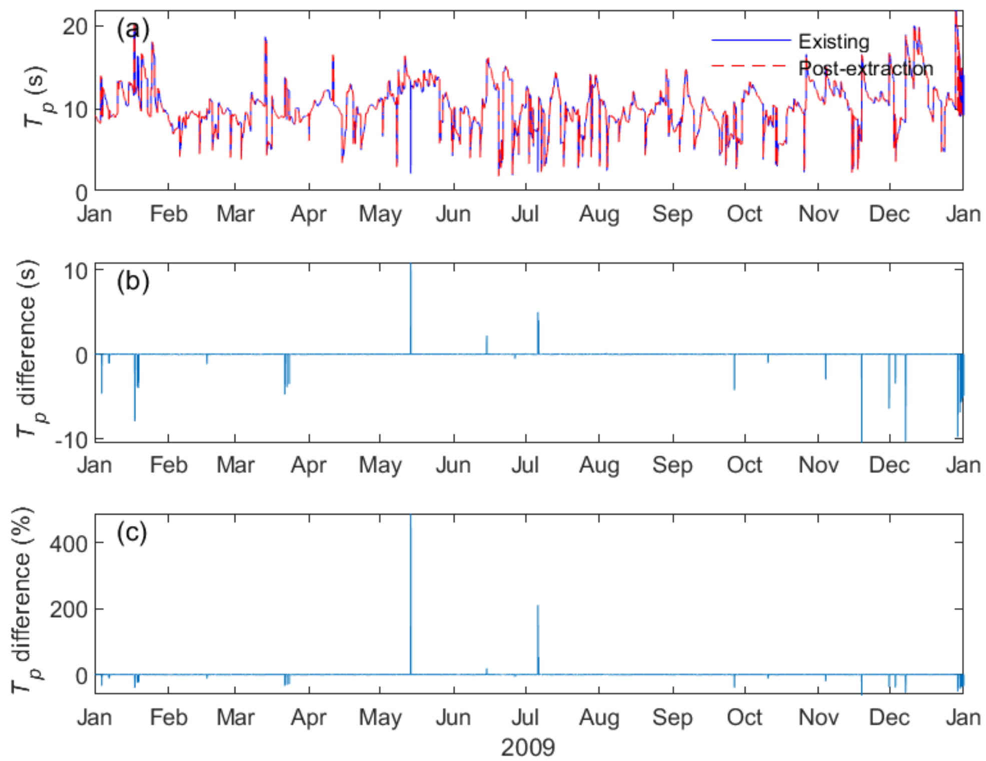

Figure 9.15 Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Waipū Cove.

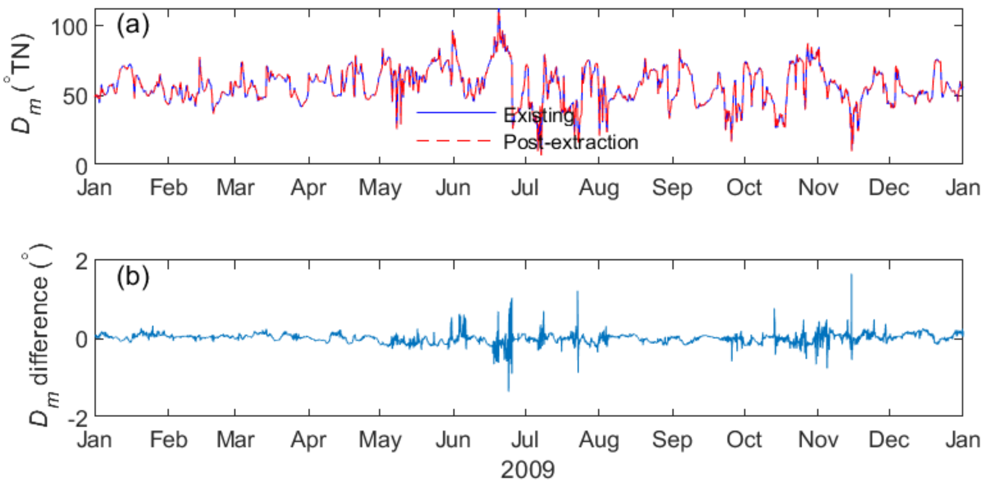

Figure 9.16 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Waipū Cove.

9.5 Wairahi Langs Beach

9.5.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Wairahi Langs Beach is provided in Table 9.13.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 9.14.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 9.15. Assuming that surfable conditions are met when $H_s \geq 0.5$ and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 44.0% of the time at Wairahi Langs Beach. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[11]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 9.17, showing the predominance of waves incoming from the NE sector.

[11] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 9.13 Annual and monthly total significant wave height statistics at Wairahi Langs Beach.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics [1]															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main [2] Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.22	1.28	0.50	0.21	0.28	0.31	0.34	0.43	0.50	0.54	0.58	0.81	1.00	1.21	1.24	NE
February	0.37	3.03	0.71	0.40	0.37	0.38	0.39	0.59	0.71	0.80	0.88	1.16	1.39	2.09	2.65	NE
March	0.24	2.87	0.67	0.45	0.24	0.29	0.35	0.51	0.70	0.72	0.75	1.14	1.65	2.30	2.68	NE
April	0.23	2.51	0.97	0.45	0.23	0.26	0.34	0.94	1.10	1.14	1.26	1.57	1.77	2.21	2.39	NE
May	0.23	1.39	0.57	0.23	0.24	0.33	0.37	0.50	0.61	0.65	0.70	0.86	1.13	1.25	1.32	NE
June	0.14	2.36	0.63	0.50	0.15	0.17	0.19	0.45	0.80	0.90	0.98	1.27	1.61	2.22	2.31	NE E
July	0.14	3.60	0.73	0.65	0.17	0.25	0.30	0.53	0.69	0.80	0.91	1.33	2.22	3.35	3.51	NE
August	0.16	2.73	0.94	0.60	0.17	0.28	0.31	0.81	1.12	1.32	1.49	1.92	2.08	2.45	2.58	NE
September	0.17	1.85	0.77	0.35	0.19	0.38	0.40	0.70	0.89	0.94	0.98	1.26	1.55	1.75	1.82	NE
October	0.16	1.49	0.45	0.23	0.17	0.21	0.23	0.37	0.52	0.56	0.62	0.79	0.93	1.05	1.25	NE
November	0.14	1.16	0.33	0.13	0.15	0.19	0.22	0.30	0.35	0.36	0.37	0.43	0.52	0.80	0.99	NE
December	0.22	1.10	0.42	0.11	0.23	0.30	0.31	0.40	0.47	0.48	0.50	0.54	0.59	0.68	0.93	NE
Winter	0.14	3.60	0.77	0.60	0.16	0.19	0.24	0.60	0.88	0.96	1.10	1.56	2.03	2.50	3.08	NE
Spring	0.14	1.85	0.51	0.31	0.16	0.21	0.24	0.40	0.58	0.65	0.75	0.94	1.12	1.49	1.69	NE
Summer	0.22	3.03	0.54	0.29	0.28	0.31	0.34	0.46	0.56	0.58	0.63	0.86	1.09	1.34	1.55	NE
Autumn	0.23	2.87	0.73	0.43	0.24	0.28	0.36	0.61	0.86	0.93	1.01	1.26	1.59	2.00	2.35	NE
All	0.14	3.60	0.64	0.44	0.17	0.24	0.28	0.49	0.70	0.80	0.89	1.15	1.51	2.02	2.36	NE

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 9.14 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Wairahi Langs Beach. The same data are represented in the form of a rose plot in Figure 9.17.

H_s (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	0.42	48.18	2.09	-	0.14	0.01	-	0.01	50.85	100.00
0.5-1	0.64	33.61	0.51	-	-	-	-	-	34.76	49.15
1-1.5	0.05	8.75	0.43	-	-	-	-	-	9.23	14.38
1.5-2	-	3.00	0.01	-	-	-	-	-	3.01	5.15
2-2.5	-	1.39	-	-	-	-	-	-	1.39	2.13
2.5-3	-	0.45	-	-	-	-	-	-	0.45	0.74
3-3.5	-	0.21	-	-	-	-	-	-	0.21	0.30
3.5-4	-	0.09	-	-	-	-	-	-	0.09	0.09
Total	1.11	95.68	3.04	-	0.14	0.01	-	0.01	100.00	

Table 9.15 Annual joint probability distribution (in %) of the total significant wave height and peak period at Wairahi Langs Beach. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
0-0.5	0.15	1.00	2.27	3.70	8.80	16.28	11.08	3.97	2.43	0.95	0.22	50.85	100.00
0.5-1	-	1.03	3.08	6.33	9.99	7.04	3.86	2.13	0.88	0.33	0.09	34.76	49.15
1-1.5	-	-	0.95	1.38	3.40	2.43	1.02	0.02	0.03	-	-	9.23	14.38
1.5-2	-	-	0.11	0.87	1.03	0.86	0.15	-	-	-	-	3.02	5.15
2-2.5	-	-	-	0.13	0.88	0.25	0.14	-	-	-	-	1.40	2.13
2.5-3	-	-	-	-	0.24	0.17	0.03	-	-	-	-	0.44	0.74
3-3.5	-	-	-	-	0.03	0.17	-	-	-	-	-	0.20	0.30
3.5-4	-	-	-	-	-	0.09	-	-	-	-	-	0.09	0.09
Total	0.15	2.03	6.41	12.41	24.37	27.29	16.28	6.12	3.34	1.28	0.31	100.00	
Exceed%	100.00	99.85	97.82	91.41	79.00	54.63	27.34	11.06	4.93	1.59	0.31		

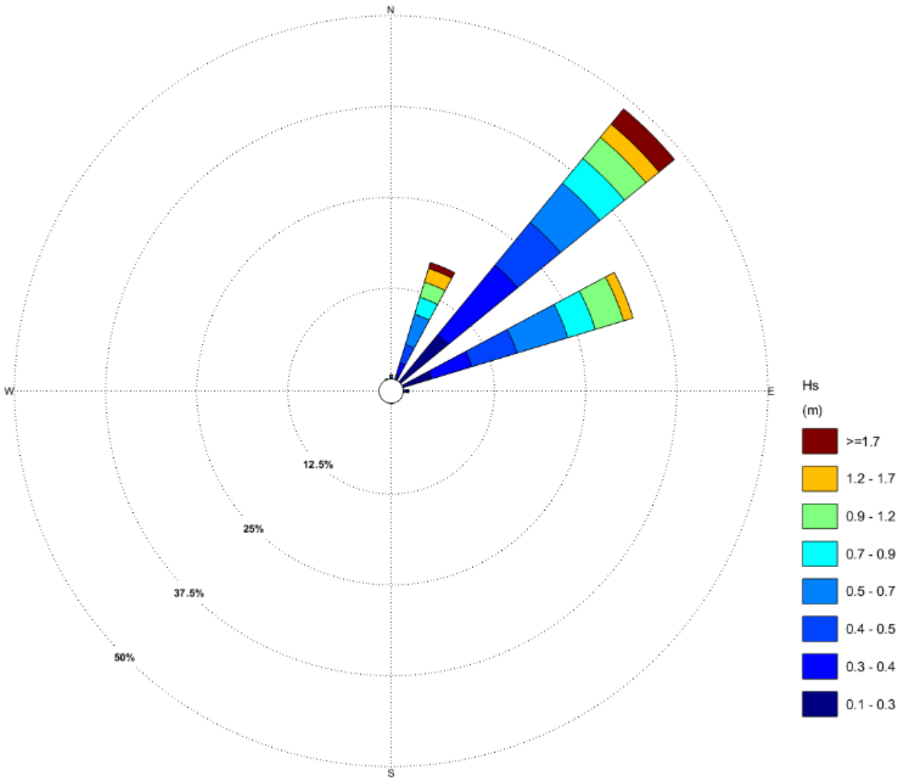

Figure 9.17 Annual wave rose plot for the total significant wave height at Wairahi Langs Beach. Sectors indicate the direction from which waves approach.

9.5.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Wairahi Langs Beach considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 9.18, Figure 9.19 and Figure 9.20 respectively.

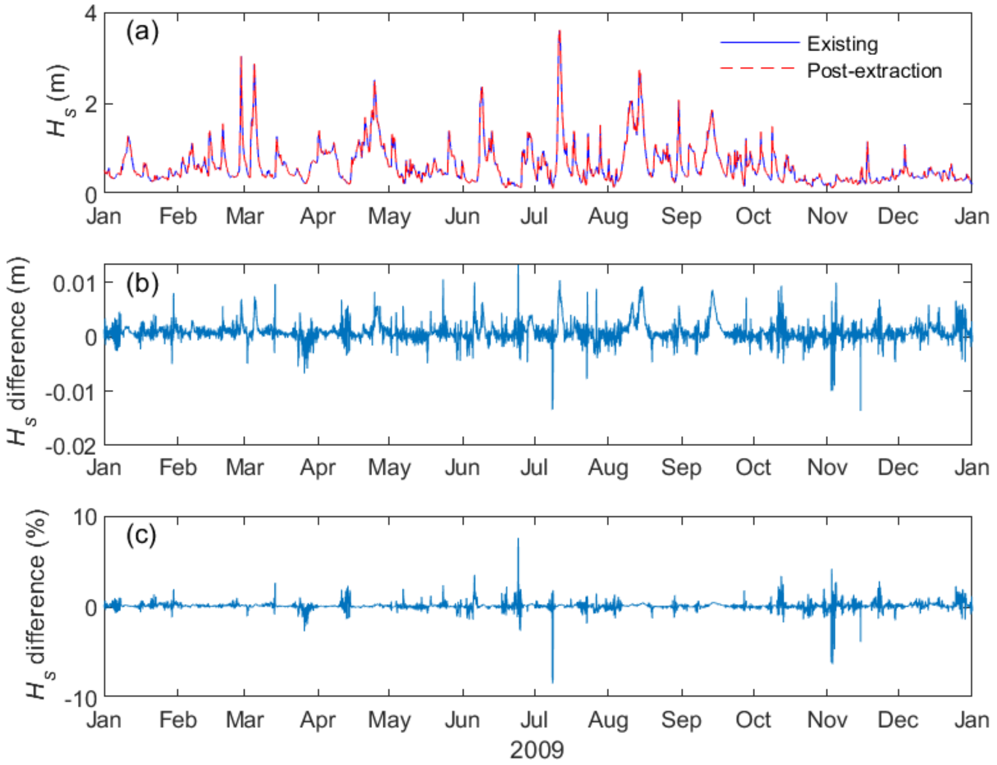

Figure 9.18 Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Wairahi Langs Beach.

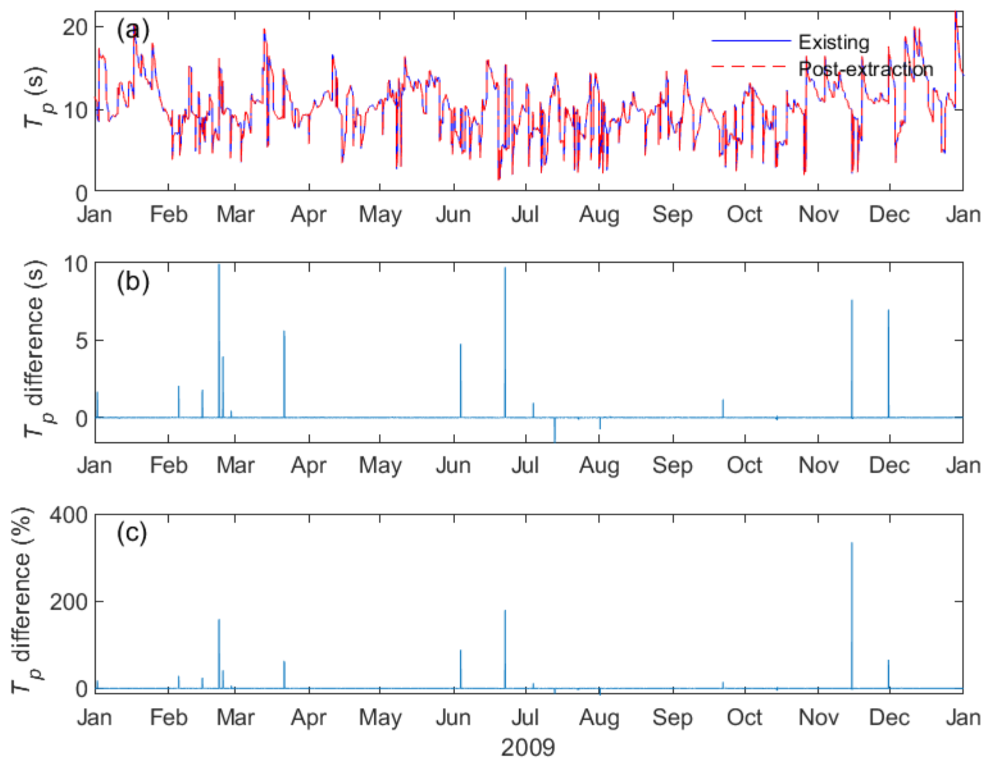

Figure 9.19 Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Wairahi Langs Beach.

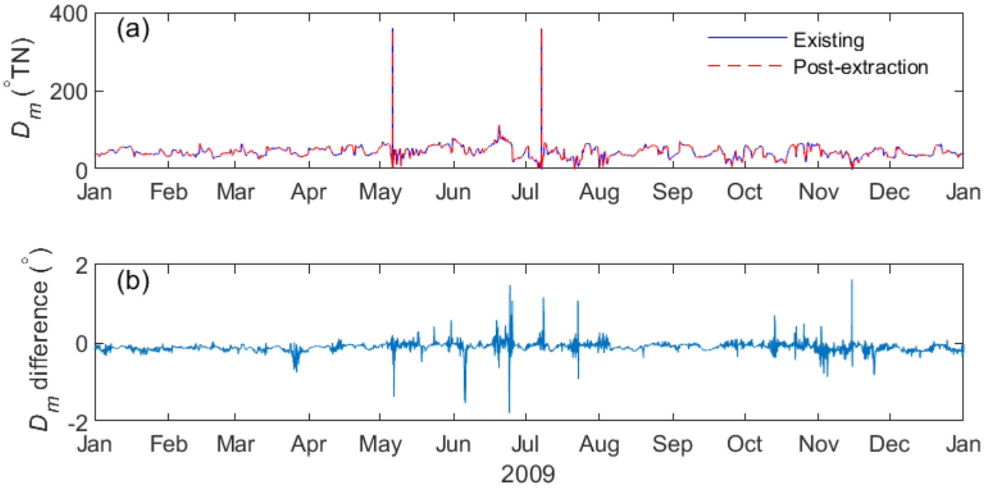

Figure 9.20 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Wairahi Langs Beach.

9.6 Langs Bombie

9.6.1 Existing conditions

A summary of the total significant wave height statistics (H_s) at Langs Bombie is provided in Table 9.16.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 9.17.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 9.18. Assuming that surfable conditions are met when $H_s \geq$ 0.5 and $T_p \geq 6$ s, the statistics indicate that these conditions occur on average 45.8% of the time at Langs Bombie. These values are considered conservative, as in reality wave periods of $T_p < 8$ s or $H_s < 0.75$ m are considered poor to average surfing conditions[12]. As such, Mead et al., (2004) used a threshold of $H_s > 0.75$, and $T_p > 6$ s, and Black et al., (2004) used similar wave height and period limitations while limiting the directional spreading to less than 40, which effectively increased the period (T_p) threshold.

The annual wave rose is presented in Figure 9.21, showing the predominance of waves incoming from the ENE sector.

[12] https://www.surfertoday.com/surfing/9116-the-importance-of-swell-period-in-surfing

Table 9.16 Annual and monthly total significant wave height statistics at Langs Bombie.

Period (01 Jan – 31 Dec 2009)	Total significant wave height statistics (1)															
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)											Main (2) Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p70	p75	p80	p90	p95	p98	p99	
January	0.22	1.30	0.51	0.21	0.28	0.31	0.34	0.43	0.51	0.55	0.59	0.81	1.03	1.25	1.27	NE
February	0.35	3.03	0.71	0.40	0.36	0.37	0.38	0.59	0.70	0.79	0.87	1.15	1.38	2.09	2.66	NE
March	0.23	2.85	0.66	0.45	0.23	0.28	0.35	0.53	0.68	0.71	0.75	1.14	1.64	2.29	2.68	NE
April	0.22	2.52	0.97	0.45	0.22	0.25	0.34	0.95	1.10	1.16	1.25	1.56	1.76	2.21	2.39	NE
May	0.26	1.41	0.60	0.24	0.27	0.35	0.39	0.53	0.63	0.68	0.73	0.89	1.15	1.30	1.35	NE
June	0.14	2.38	0.64	0.50	0.15	0.17	0.20	0.46	0.81	0.91	0.99	1.28	1.59	2.24	2.32	NE E
July	0.12	3.63	0.75	0.65	0.15	0.24	0.30	0.55	0.73	0.82	0.94	1.36	2.27	3.39	3.52	NE
August	0.16	2.76	0.95	0.59	0.17	0.28	0.32	0.82	1.12	1.31	1.49	1.92	2.05	2.48	2.61	NE
September	0.18	1.85	0.77	0.35	0.20	0.38	0.40	0.70	0.90	0.95	1.00	1.24	1.55	1.76	1.82	NE
October	0.16	1.50	0.47	0.24	0.17	0.21	0.23	0.40	0.54	0.58	0.63	0.82	0.96	1.07	1.27	NE
November	0.14	1.18	0.34	0.13	0.15	0.20	0.23	0.32	0.37	0.38	0.40	0.45	0.54	0.83	1.00	NE
December	0.23	1.11	0.43	0.11	0.25	0.30	0.32	0.40	0.48	0.49	0.51	0.56	0.59	0.68	0.93	NE
Winter	0.12	3.63	0.78	0.60	0.16	0.20	0.24	0.61	0.90	0.97	1.12	1.56	2.02	2.54	3.12	NE
Spring	0.14	1.85	0.53	0.31	0.16	0.22	0.24	0.42	0.59	0.66	0.76	0.96	1.11	1.50	1.69	NE
Summer	0.22	3.03	0.54	0.29	0.28	0.31	0.34	0.46	0.56	0.59	0.63	0.86	1.10	1.34	1.55	NE
Autumn	0.22	2.85	0.74	0.42	0.23	0.29	0.36	0.63	0.88	0.93	1.01	1.27	1.57	1.99	2.36	NE
All	0.12	3.63	0.65	0.44	0.17	0.24	0.28	0.51	0.71	0.81	0.90	1.16	1.51	2.01	2.38	NE

Notes: (1) All statistics derived from hindcast wave data for the period 01 January to 31 December 2009.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 9.17 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at Langs Bombie. The same data are represented in the form of a rose plot in Figure 9.21.

H_s (m)	Mean wave direction at peak energy (degT)									
	337.5-22.5	**22.5-67.5**	**67.5-112.5**	**112.5-157.5**	**157.5-202.5**	**202.5-247.5**	**247.5-292.5**	**292.5-337.5**	**Total**	**Exceed%**
0-0.5	0.74	46.31	1.60	-	0.09	0.03	0.07	0.21	49.05	100.00
0.5-1	0.91	34.89	0.41	-	-	-	-	0.05	36.26	50.95
1-1.5	0.05	9.15	0.41	-	-	-	-	-	9.61	14.69
1.5-2	-	2.93	0.01	-	-	-	-	-	2.94	5.08
2-2.5	-	1.37	-	-	-	-	-	-	1.37	2.13
2.5-3	-	0.47	-	-	-	-	-	-	0.47	0.76
3-3.5	-	0.21	-	-	-	-	-	-	0.21	0.30
3.5-4	-	0.09	-	-	-	-	-	-	0.09	0.09
Total	1.70	95.42	2.43	-	0.09	0.03	0.07	0.26	100.00	

Table 9.18 Annual joint probability distribution (in %) of the total significant wave height and peak period at Langs Bombie. The green cells indicate "surfable conditions".

H_s (m)	Peak period (s)											
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**Total**	**Exceed%**
0-0.5	0.15	1.12	1.70	3.44	8.61	15.04	11.24	4.38	2.42	0.75	0.19	49.04	100.00
0.5-1	-	1.15	2.91	6.07	10.02	7.66	4.79	2.25	0.91	0.39	0.10	36.25	50.95
1-1.5	-	0.01	0.92	1.38	3.44	2.44	1.34	0.06	0.02	-	-	9.61	14.69
1.5-2	-	-	0.14	0.87	1.00	0.79	0.15	-	-	-	-	2.95	5.08
2-2.5	-	-	-	0.11	0.87	0.25	0.14	-	-	-	-	1.37	2.13
2.5-3	-	-	-	-	0.25	0.18	0.03	-	-	-	-	0.46	0.76
3-3.5	-	-	-	-	0.03	0.17	-	-	-	-	-	0.20	0.30
3.5-4	-	-	-	-	-	0.09	-	-	-	-	-	0.09	0.09
Total	0.15	2.28	5.67	11.87	24.22	26.62	17.69	6.69	3.35	1.14	0.29	100.00	
Exceed%	100.00	99.85	97.57	91.90	80.03	55.80	29.17	11.48	4.79	1.44	0.30		

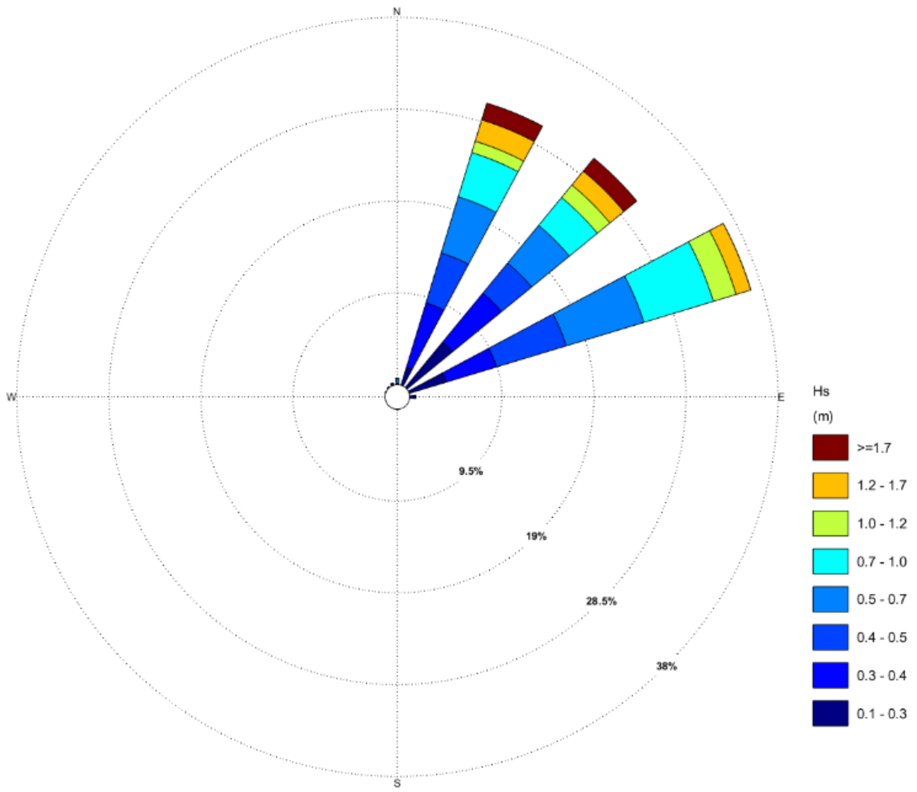

Figure 9.21 Annual wave rose plot for the total significant wave height at Langs Bombie. Sectors indicate the direction from which waves approach.

9.6.2 Post-extraction

Co-temporal time series of H_s, peak wave period (T_p) and mean wave direction (D_m) at Langs Bombie considering existing and post-extraction scenarios (as well as differences and relative differences for each parameter) are presented in Figure 9.22, Figure 9.23 and Figure 9.24 respectively.

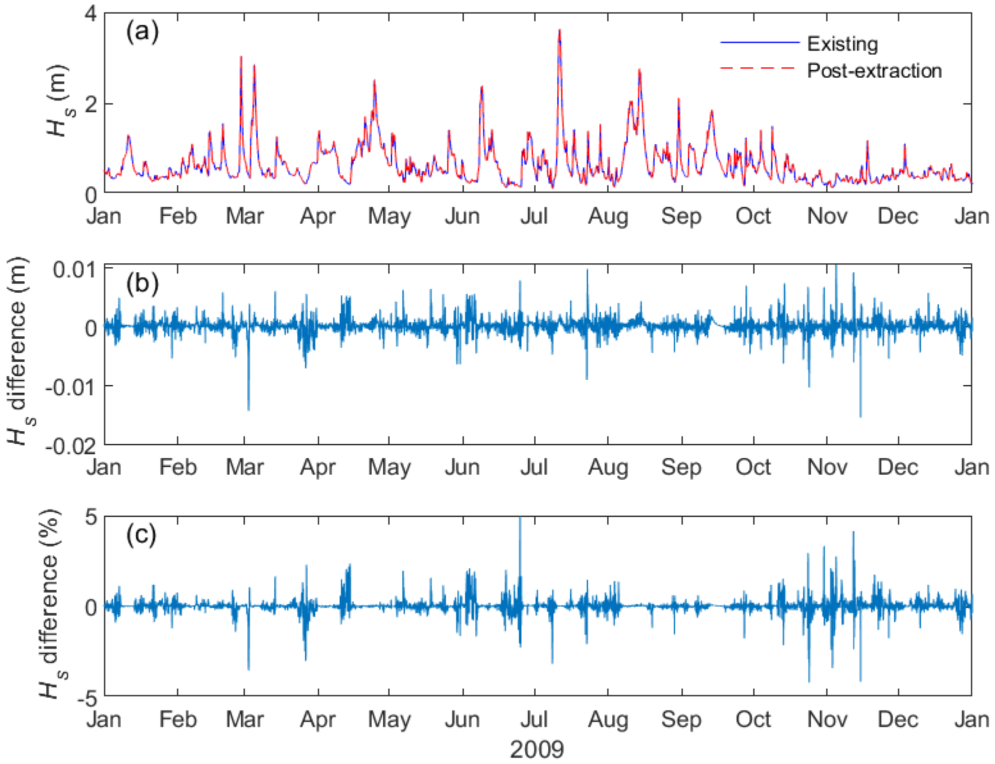

Figure 9.22 Co-temporal time series of (a) H_s, (b) difference in H_s and (c) relative difference in Hs between existing and post-extraction scenarios at Langs Bombie.

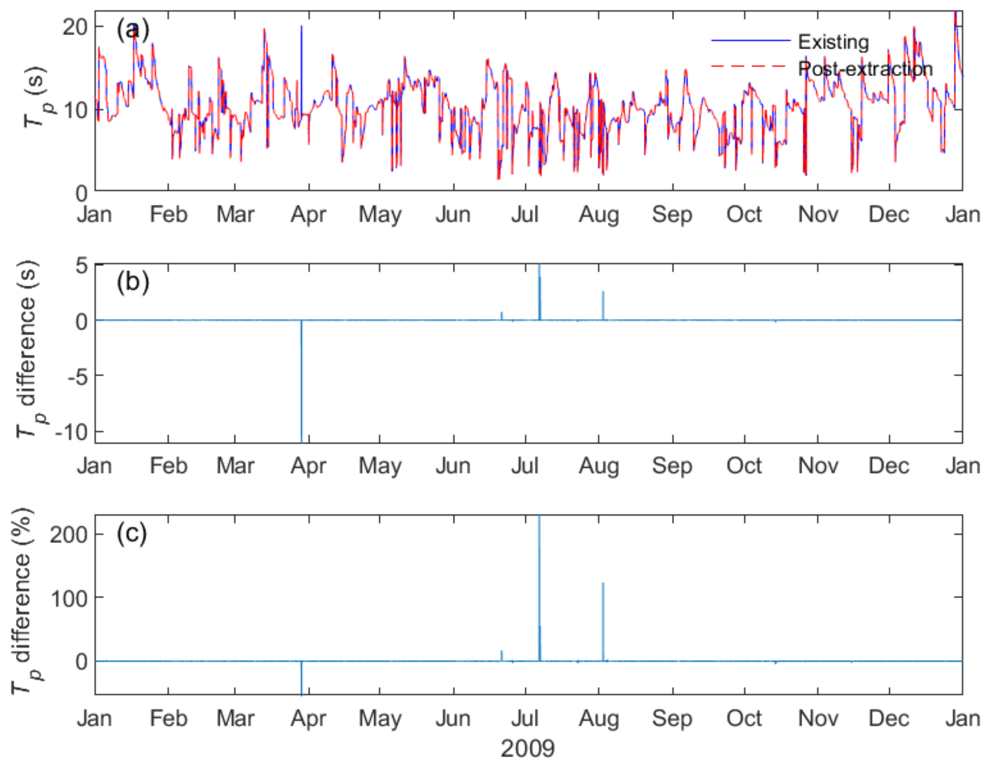

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Figure 9.23 Co-temporal time series of (a) T_p, (b) difference in T_p and (c) relative difference in T_p between existing and post-extraction scenarios at Langs Bombie.

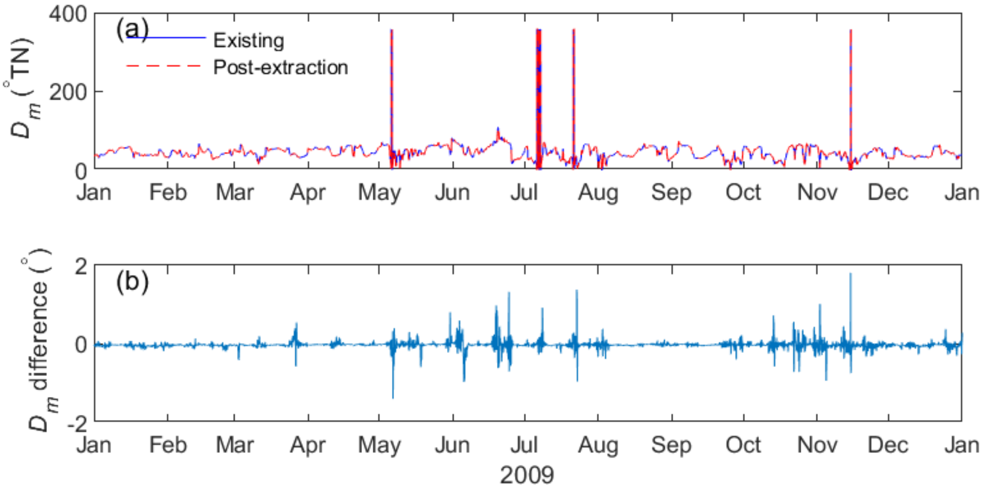

Figure 9.24 Co-temporal time series of (a) D_m and (b) difference in D_m between existing and post-extraction scenarios at Langs Bombie.