BEFORE THE ENVIRONMENTAL PROTECTION AUTHORITY
AT WELLINGTON

IN THE MATTER	of the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012
AND	
IN THE MATTER	of a decision-making committee appointed to hear a marine consent application by Trans Tasman Resources Limited to undertake iron ore extraction and processing operations offshore in the South Taranaki Bight

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EXPERT EVIDENCE OF DR IAIN MACDONALD ON BEHALF OF TRANS TASMAN RESOURCES LIMITED

17 DECEMBER 2016

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EXECUTIVE SUMMARY

1. I report on a field programme that collected an oceanographic data set that supports the development of numerical models of current flows, waves, sediment transport and suspended-sediment plume dispersion in the South Taranaki Bight (STB).

2. The results from the field studies are contained within three reports: (1) Oceanographic measurements data report, (2) Nearshore optical water quality report, and (3) Shoreline monitoring report.

3. I report in the oceanographic measurements data report results from comprehensive current, wave and suspended-sediment measurements collected during a 7-month period from 9 September 2011 to 1 July 2012. Winds experienced during the field programme were typical of the long-term wind climate and included a "weather bomb" event.

4. In the nearshore optical water quality report I characterise the optical water quality and suspended-mud concentrations (SSCm) in the nearshore region (within 2.5 km of the shore) of the STB.

5. I report in the shoreline monitoring report results from 11 surveys that measured 352 profiles (100% data capture) over an 11-month period from June 2011 to April 2012.

6. The collected field datasets provide a coherent picture of currents, waves and suspended sediment concentrations in the STB. The datasets, which have been carefully calibrated to produce accurate measures, were used with confidence in the development of numerical models of current flows, waves and suspended-sediment plume dispersion in the STB.

7. Planned sand extraction operations in STB will result in elongated lanes about 1 m deep with mounds less than 10 m high and pits less than 10 m deep at different ends of each

of the lanes. The pits and mounds will be left to naturally infill and deflate. I present predictions of the time that pits will infill and mounds will deflate naturally under waves and currents in the STB.

8. A "pit" is defined as a hole 300 m wide, 300 m long and between 2 and 10 m deep. A "mound" is defined as an accumulation of sediment 300 m wide, 300 m long and between 2 and 10 m high.

9. Table 1 shows predicted pit infilling times for different combinations of initial pit depth (2 to 10 m, in 1-m increments) and mean water depth (20, 35 and 45 m) where the pit is located. I interpret the predictions as showing that, broadly, pit infilling will occur over decades at the smallest water depth (20 m) in the STB and over centuries at the greatest water depth (45 m).

10. Table 2 shows predicted mound deflation times for different combinations of initial mound height (2 to 10 m, in 1-m increments) and mean water depth (20, 35 and 45 m) where the mound is located. I predict that mounds will deflate faster than pits will infill.

11. From published values the rate of pit migration is estimated to be around 10 m per year. The direction of migration is the direction of residual sediment transport, which for the proposed mining area, is towards the southeast.

12. Results from a calibrated wave model show that the offshore bathymetry modifications results in changes to the nearshore wave climate that will not adversely affect surfing in the STB.

INTRODUCTION

Qualifications and experience

13. My name is Iain Thomas MacDonald. I am a scientist with the Coastal and Estuarine Physical Processes Group at the

National Institute of Water and Atmospheric Research Limited (NIWA), where I have been employed since 2010.

14. I was awarded a Bachelor of Engineering from the University of Auckland in 1997, a Master of Science with First Class Honours in mathematics from the University of Waikato in 2004, and a PhD in Civil and Environmental Engineering from the University of Auckland in 2009. During my PhD I carried out research relating to the transport of cohesive sediments. Prior to starting my PhD, I was employed at NIWA for six years as a technician. During this time I was predominately involved in the collection and processing of oceanographic and coastal datasets. Between 2008 and coming back to work for NIWA in 2010, I conducted postdoctoral research at the University of East Anglia, United Kingdom, where I investigated the acoustic scattering characteristics of flocculated sediments using an Acoustic Backscatter Sensor (ABS).

15. I have expert knowledge in the field of sediment transport by waves and currents, including field measurement, interpretation of field data, numerical modelling, development of theory, and application of equations to solve practical problems. I have published peer reviewed research papers on sediment transport, waves, currents and acoustics. These include articles on: estuary infilling by marine sediments under waves (Marine Geology); the role of wind-waves in macrofaunal recovery (Marine Ecology Progress Series); the influence of wave and sediment dynamics on cordgrass growth on an exposed intertidal flat (Estuaries); sediment re-mobilization from decomposing cordgrass patches on a wave-exposed intertidal flat (New Zealand Journal of Marine and Freshwater); the role of hydrodynamics (currents) on the distribution of macrofaunal colonists (Marine Ecology Progress Series); the development of novel measurements techniques for sediment transport

studies (Journal of Atmospheric and Oceanic Technology); the influence freshwater flow on estuarine sediment transport (Estuarine, Coastal and Shelf Science) and acoustic scattering from a suspension of flocculated sediments (Journal of Geophysical Research, Continental Shelf Research (2014), Continental Shelf Research (2015)). The citations for these articles are included in the reference list at the end of this document.

Code of conduct

16. I confirm that I have read the Code of Conduct for Expert Witnesses as contained in the Environment Court Practice Note dated 1 December 2014. I agree to comply with this Code. This evidence is within my area of expertise, except where I state that I am relying upon the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

SCOPE OF EVIDENCE

17. In my evidence I report on a field programme that collected an oceanographic data set that supported the development of numerical models of current flows, waves, sediment transport and suspended-sediment plume dispersion in the South Taranaki Bight (STB).

18. I also report on an 11-month beach monitoring programme. The purpose of which was to provide background data, from which rates of change along the shore (shoreline stability) could be established, before the commencement of any offshore sand extraction.

19. The results from the field studies described above are contained within three reports that were included as part of the impact assessment. These three reports are: (1) Oceanographic measurements data report, (2) Nearshore

optical water quality report and (3) Shoreline monitoring report.

20. In my evidence I also present a prediction of the time that it will take for pits to infill and mounds to deflate under waves and currents.

21. The infill/deflation method is an adaptation of methods published in the scientific literature that involve the application of formulas for the transport of sediment under waves and currents. The method was developed in collaboration with my colleague Dr Malcom O. Green.

22. Additionally, I report on the potential impacts of the mining operation on the surfing breaks along the STB coastline. This assessment is based on the information contained in the following 2 reports: (1) Mead (2015) and (2) Gorman (2015).

EXISTING ENVIRONMENT

Oceanographic measurements

23. Full details of the measurements can be found in the oceanographic data report (MacDonald, Budd, Bremner, & Edhouse, 2015).

24. Current velocities were measured at five sites in the STB and represent a significant dataset in their own right, as few current-meter moorings have been undertaken in this region. The data show the prevailing patterns of water movements in the STB, with tides and winds being the main contributors. Tidal currents account for a significant proportion of the measured currents at all sites, with the proportion explained by the tidal constituents ranging from 40% to 78%. The peak ebb and flood current speeds of the main twice-daily lunar (M2) tide, which is an average tide, ranged between 0.13 m/s and 0.25 m/s.

25. Somewhat higher and lower tidal speeds occur on spring and neap tides, respectively. At all sites the M2 tide was oriented in the SE–NW direction (parallel with the coastline).

26. The tidal currents, however, only comprise part of the story. Currents in the STB are also substantially affected by wind conditions. Large current speeds of around 1 m/s were measured on a number of occasions during periods of high winds. Winds blowing from the W and the SE sectors had the most pronounced influence on currents. Moderate to strong winds not only increased current speeds but also greatly altered current direction. During strong winds, currents could set in a constant direction for more than 24 hours; during calm conditions, currents reversed approximately every 6.2 hours with the tides re-asserting dominance.

27. At most sites during periods of light winds the prevailing current drift was towards the SE, which is consistent with the influence of the d'Urville Current, which sweeps past Farewell Spit and turns around in the STB to head south. However, current drift directions were significantly altered by moderate to strong SE winds which reversed the drift towards the NW. During times of moderate to strong W to NW winds, the prevailing SE drift was considerably enhanced.

28. These results have implications for the hydrodynamic and sediment modelling as both tidal and meteorological forcing contributes to the observed water movements in the STB.

29. Waves were measured at eight sites in the STB, in water depths ranging from 50 m offshore to 9 m near the coast. Wave measurements in both deep and shallow water have captured the transformation of wave trains as they move from deep to shallow water and experience shoaling, frictional dissipation and, to a lesser extent refraction.

30. The collected wave data clearly confirms that the STB is a high-energy environment. At the deep sites, significant wave

heights in excess of 4.0 m were routinely observed. The highest significant wave height of 7.1 m was recorded on 3 March 2012 at 05:40 during the South Taranaki weather bomb. Local 10-minute average winds at Whanganui preceding this event were very strong (~17 m/s or 61 km/hr) with gusts up to 100 km/hr from the SSW within a deep-low depression.

31. Wave directions associated with wave heights greater than 2 m exhibit a bimodal distribution, dominated by waves arriving from either the S–SSE or from the SW–WSW sectors. There was a reduction in wave height moving from the offshore deeper sites into the shallower sites close to the shoreline, which results primarily from the balance between shoaling and frictional dissipation. There was also a reduction in wave height moving down coast in a S–SE direction, caused by sheltering of the prevailing SW to WSW swell by the tip of the South Island (Farewell Spit).

Suspended sediments

32. Concentrations in the water column of suspended sands and suspended fine sediments (clays, silts and muds) were measured at several sites and heights above the bed within the STB.

33. In the near-surface waters (i.e. within 2 to 3 m of the water surface), the maximum suspended-fine-sediment concentration (*SSCm*) was 0.025 grams/litre. At some sites *SSCm* varied over the deployment period, with peaks in *SSCm* tending to occur during or just after periods of significant rainfall. At these times it is likely that rivers were discharging fine sediments into the STB, which were then being transported in suspension through the measurement site. Some of the peaks in *SSCm* also coincided with times of large waves. While it is possible that large waves resuspended fine sediments from the sea bed and increased

SSCm near the surface, it is also possible that the increase resulted from an increase in optical backscatter generated by the entrainment of air bubbles into the water column by an energetic sea. For most of the time, the near-surface background *SSCm* was typically less than 0.01 grams/litre, which is close to the lower detection limit of an optical backscatter sensor (OBS).

34. Near the sea bed (i.e. within 1m of the sea bed), the maximum *SSCm* was 0.08 grams/litre, and peaks in concentration near the bed did not always coincide with peaks in wave height. This implies that increases in concentration were not always driven by resuspension of local bed sediments. Instead, fine suspended sediment may have been advected through the measurement site from some "upstream" location. During calm periods, background suspended-fine-sediment concentration at the seabed was similar to the background concentration at the surface (~ 0.01 grams/litre).

35. When there was any sand in suspension, suspended-sand concentration (*SSCs*) close to the sea bed was typically much greater than *SSCm*. The largest suspended-sand concentration very close to the seabed was 1.9 grams/litre. At all sites, periods of increased sand concentration coincided with periods of large waves, thus highlighting the importance of waves in resuspending sand from the seabed in the STB. During calm periods, no sand was found to be in suspension.

36. Over the duration of the largest sediment-transport event, 3355 kg of sand per metre width of sea bed was transported in suspension by currents. This equates to a volume of 2.1 m^3 of sand transported per metre width of sea bed. These are gross transport rates in any direction.

37. Temperature and salinity measurements show that the water column in the STB was generally well mixed with only small vertical differences in temperature and salinity. Slightly lower salinity is likely to be found in the vicinity of major rivers in the STB (e.g., Patea, Waitotara and Whanganui).

38. Overall, the field dataset provides a coherent and comprehensive picture of currents, waves and suspended sediment concentrations in the STB. The datasets, which have been carefully calibrated to produce accurate measures, were used with confidence in the development of numerical models of current flows, waves and suspended-sediment plume dispersion in the STB.

Nearshore optical water quality

39. The nearshore optical water quality report presents results that characterise the optical water quality and suspended-mud concentrations (SSCm) in the nearshore region (within 2.5 km of the shore) of the STB. The field studies were undertaken to provide background data to help assess the potential effects of offshore sand extraction on the surrounding environment, in particular the effect of sediment plume dispersal.

40. Full details of the measurements can be found in the nearshore optical water quality report (MacDonald, Gall, & Bremner, 2015).

41. The field measurement programme was designed to include measurements of light beam attenuation (c), light absorption (b), diffuse light attenuation coefficient (k_d), nephelometric turbidity (T_n), suspended-mud concentration (SSCm), CDOM (indexed by g_{340}) and phytoplankton concentration (indexed by chlorophyll a).

42. Specifically, the field measurement programme consisted of:

(a) Two boat surveys (S1 and S2) to measure vertical profiles of optical variables and SSCm.

(b) A 6-week deployment of moored instruments at 6 nearshore sites (~10 m water depth) to assess temporal variability and to establish relationships between measured near-surface optical backscatter and certain optical variables.

(c) The collection of water samples from the surf-zone region at 11 sites along the STB. The water samples were analysed to determine variables relating to optical water quality and *SSCm*.

43. Measurements from both boat surveys showed that *SSCm* and optical variables vary significantly with distance offshore, with *SSCm* and diffuse light attenuation (k_d) being greatest closest to the shore, and visual clarity (as indexed by the horizontal black disc visibility) increasing rapidly with distance offshore. Both coloured dissolved organic matter (CDOM) and chlorophyll-a concentration also decrease with distance offshore.

44. Both boat surveys suggest a reduction in *SSCm* (and hence an increase in visual clarity and a decrease in k_d) moving down the coast in a S-SE direction. Measured *SSCm* was greater during S2 than during S1, which was probably the result of higher river flows (and sediment loads). The maximum (averaged over the water column) *SSCm* measured during S2 was 0.068 g/L near Hawera.

45. During S2, in the waters ~500m offshore, the horizontal black disc visibility (y_{BD}) was less than 1 m along the entire length of the STB, which is a rather low visual clarity.

46. Using the boat survey data, statistically robust *in-situ* relationships were determined relating turbidity (T_n) to *SSCm*,

the beam attenuation coefficient (c) at 530 nm (from which y_{BD} is derived), and k_d. These relationships were applied to the optical backscatter data collected at the six moored instrument sites.

47. The estimates of T_n, *SSCm*, k_d, and y_{BD} from the six moored instrument sites all showed considerable temporal variability. During the last two weeks of the deployment period there was a significant increase in *SSCm*, coinciding with increased river flows. At these times it is likely that the rivers were discharging fine sediments into the STB, which were then being transported in suspension through the measurement site.

48. Some of the measured peaks in *SSCm* from the moored sites also coincided with times of high wind speed but low river flows. These peaks in *SSCm* are most likely wave-driven. At these times, wave stirring is entraining fine sediments from the sea floor, which are subsequently mixed into the water column.

49. During river and wave events, the euphotic depth (the depth at which the ambient light level drops to 1%) is less than the mean water depth at the instrument sites. This is significant, as it means that less than 1% of the ambient light is reaching the benthos at these times.

50. Rainfall data has shown that the deployment took place during a period of lower than expected rainfall for that time of year, and consequently during a period of low river flows. Since rivers are a major source of fine sediments into the STB, it is likely that the data are representative of conditions with clearer water.

Shoreline monitoring

51. A beach profile is a survey of the topography of the beach running from the base of the cliff or the top of the sand dune

to about the low water mark. The profile usually runs in a direction that is normal to the direction of the shoreline. By comparing repeat surveys the measured changes can be used to determine rates of erosion or accretion and the size of the beach volume changes.

52. A network of 32 beach profiles at eight sites was established to monitor the shoreline stability along the STB from Kai Iwi to Ohawe. The sites were selected as lying landward of potential offshore mining sites, away from rivers and headlands which may influence beach processes locally, and where there was public access to the beach.

53. The shoreline monitoring report (MacDonald, Ovenden, & Hume, 2015) presents the results from 11 surveys that measured 352 profiles (100% data capture) over an 11-month period from June 2011 to April 2012. One of the 11 surveys (survey S04) was carried out immediately after a storm.

54. The accuracy of the survey data was deemed to be at worst around 6 cm in the horizontal and 3 cm in the vertical. This level of accuracy is regarded as more than sufficient for the purposes of measuring changes in beach profiles.

55. The measured beach profiles show that the shoreline along the STB is very dynamic, with large changes in the beach profiles occurring at nearly all of the 32 profiling sites. At six of the eight sites, there is little accommodation space for beach sand, which appears to form a veneer only several meters thick over the rocky shore platform left by the retreating cliff line. Given the limited storage, potentially a large fraction of the entire beach volume is being washed off and on shore on a regular basis.

ASSESSMENT OF EFFECTS

Pits infilling and mound deflation

56. Table 1 and Table 2 show the results of the calculations, which are the predicted times of pit infilling and mound deflation. Table 1 shows predicted pit infilling times for different combinations of initial pit depth and mean water depth where the pit is located. Table 2 shows predicted mound deflation times for different combinations of initial mound height and mean water depth where the mound is located. T_{50} is the predicted time it takes for the pit depth to reduce by 50% of the initial pit depth or the mound height to reduce by 50% of the initial mound height, as the case may be. Likewise, T_{90} is the predicted time it takes for the pit depth to reduce by 90% of the initial pit depth or the mound height to reduce by 90% of the initial mound height. $T_{1\mathrm{m}}$ in the case of a pit is the predicted time it takes for the initial pit depth to reduce to 1 m. $T_{1\mathrm{m}}$ in the case of a mound is the predicted time it takes for the initial mound height to reduce to 1 m.

57. As an example of how to read Table 1: It is predicted that a pit with initial depth of 8 m located in 35 m water depth will reduce to 1 m depth in 83 years under the waves and currents experienced in the STB; the pit will reduce by 50% of its initial depth (i.e., to a pit depth of 4 m) in 44 years; and the pit will reduce by 90% of its initial depth (i.e., to a pit depth of 0.8 m) in 86 years.

58. As an example of how to read Table 2: It is predicted that a mound with initial height of 6 m located in 45 m water depth will reduce to 1 m height in 148 years under the waves and currents experienced in the STB; the mound will reduce by 50% of its initial height (i.e., to a mound height of 3 m) in 81 years; and the mound will reduce by 90% of its initial height (i.e., to a mound height of 0.6 m) in 163 years.

59. The method that was developed and used to predict pit infilling cannot account for any potential deformation and/or migration of dredged pits. Instead, it seeks to estimate only an infilling timescale based on the relatively simple sediment-trapping premise. However, from published values the rate of pit migration is estimated to be around 10 m per year. The direction of migration is the direction of residual sediment transport, which for the proposed mining area, is towards the southeast. However, the residual sediment transport direction and therefore the pit migration direction will depend on the long-term distribution of wind speed and direction.

Table 1. Predicted T_{50}, T_{90} and T_{1m} (in years) for a range of initial pit depths (2–10 m) at each of the three mean water depths 20 m, 35 m and 45 m.

Water depth (m)	Initial pit depth (m)								
	10	9	8	7	6	5	4	3	2
	T_{1m} (years)								
20	71	63	55	48	40	32	24	16	8
35	104	94	83	72	61	50	39	27	14
45	359	319	279	239	199	160	120	80	40
	T_{50} (years)								
20	39	35	31	27	24	20	16	12	8
35	53	49	44	39	35	30	25	20	14
45	199	179	160	139	120	100	80	60	40
	T_{90} (years)								
20	71	64	57	50	43	36	29	22	15
35	104	95	86	78	68	59	49	39	28
45	359	323	287	251	215	180	144	108	72

Table 2 Predicted T_{50}, T_{90} and T_{1m} (in years) for a range of initial mound heights (2–10 m) at each of the three mean water depths 20 m, 35 m and 45 m.

Water depth (m)	Initial mound height (m)								
	10	9	8	7	6	5	4	3	2
	T_{1m} (years)								
20	22	20	19	18	16	13	11	8	4
35	20	18	17	15	13	11	9	7	4
45	227	210	191	171	148	123	96	67	35
	T_{50} (years)								
20	8	9	9	8	8	7	7	6	4
35	8	8	8	8	7	7	6	4	4
45	104	100	95	89	81	72	61	49	35
	T_{90} (years)								
20	22	21	20	19	18	16	13	11	8
35	20	19	18	17	15	13	11	9	7
45	227	214	198	182	163	142	119	93	65

60. Full details of the methods and calculations can be found in Hume, Gorman, Green, and MacDonald (2015).

61. van Rijn, Soulsby, Hoekstra, and Davies (2005) provided a summary of infilling rates of existing extraction pits in the coastal waters of the USA, Japan, UK and the Netherlands, which is reproduced in Table 3. My work predicts that, broadly, pit infilling will occur over decades at the smallest water depth (20 m) in the STB and over centuries at the greatest water depth (45 m), which is somewhat faster than the infilling rates reported in van Rijn's summary. This might be because the wave and current climate of the STB is substantially more energetic than the cases reported in the summary.

Table 3:.van Rijn et al. (2005) summary of observations of infilling rates of existing extraction pits in the coastal waters of the USA, Japan, UK and the Netherlands.

Pit location	**Infill characteristics**
Pit at foot of beach face (2 to 5 m depth contour)	Infill from beachside and from seaside (annual infill rate is not more than about 3% of initial pit volume; infill rates are between 5 and 15 m^3/m/yr, depending on wave climate; filling time scale is 20 to 30 years).
Pit in upper shore face zone (5 to 15 m depth contour)	Relatively rapid infill of extraction pit with sediments from landside (beach zone); annual infill rates up to 20% of Initial pit volume in shallow water (filling time scale is 5 to 10 years).
Pit in middle shore face zone (15 to 25 m depth contour)	Infill of extraction pit mainly from landside with sediments eroded from upper shore face by near-bed offshore-directed currents during storm events; annual infill rate is about 1% of initial pit volume (filling time scale is 100 years).
Pit in lower shore face zone (beyond 25 m depth contour)	Minor infill of sand in extraction pit; only during super storms.

Surfing breaks

62. Changes to the seabed morphology can potentially affect waves by refraction, diffraction and shoaling. These in turn can potentially impact on surfing breaks along the coast.

63. The two main wave parameters that could be potentially affected are wave height and direction. Which in turn can impact on key surfing wave quality parameters, such as wave peel angles and breaking intensity (Hutt, Black, & Mead, 2001; Mead & Black, 2001).

64. In order to determine the impacts on surfing breaks inshore of the proposed mining operations, the following approach was adopted:

(a) Identify the location(s) of the surfing breaks that could potentially be affected;

(b) At each identified site determine the wave and wind conditions that produce favourable surfing conditions;

(c) Using a calibrated wave model predict nearshore (~10 m water depth) changes in wave height and direction that results from the modified offshore bathymetry (pits and mounds).

65. Using the New Zealand Surfing Guide (NZSG), 10 surfing breaks along STB where identified that could be potentially affected. The 10 selected surfing breaks are shown in Figure 1 and further details are given in Table 4. Given the classification scheme presented in the NZSG was used to select the 17 Surfing Breaks of National Significance (as listed in the New Zealand Coastal Policy Statement 2010 (Policy 16)) it was deemed appropriate to be used here. In the NZSG surf breaks are rated between 1 (poor) and 10 (nationally significant). The 10 breaks of interest here are rated between 3 (Kai-iwi) and 8 (The Point/Fences and South Break).

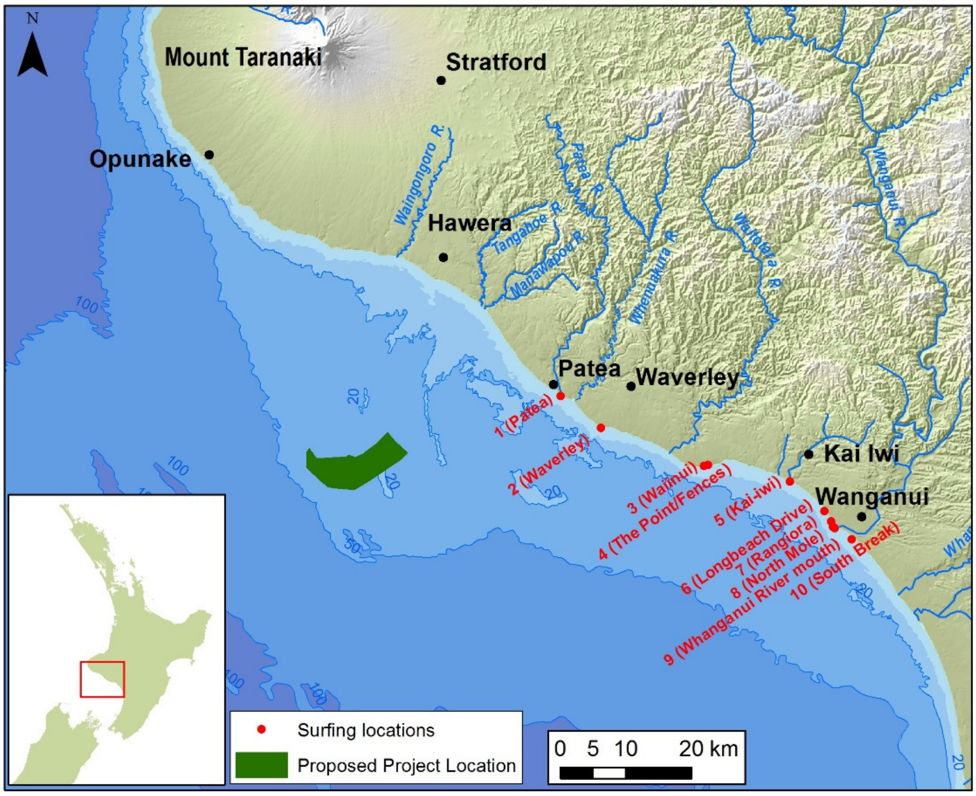

Figure 1: Location map showing the10 surfing breaks identified for use in this study.

Table 4: 10 surfing locations along STB that could be potentially affected by the proposed mining activities.

ID	Name	Rating	Wave direction	Wind	Tide
1	Patea River mouth	7	SW	NE	All
2	Waverley	6	SW	NE	MTH
3	Wainui	6	SW	NE	All
4	The Point (Fences)	8	SW	NE	MTH
5	Kai-iwi	3	SW	NE	MT
6	Longbeach Drive	4	SW	NE	HT
7	Rangiora Street	4	SW	NE	HT
8	North Mole	6	SW	NE	LTM
9	Whanganui River mouth	5	SW	NE	LT
10	South Break	8	SW	NE	LTM

66. From the NZSG and consultation with local surfers, it was determined that long period (>12 s), clean swells from the south-west to west-southwest that coincide with light offshore (NE) winds (or no winds) results in good surfing conditions. Furthermore, it was established that incident wave height and water depth were also important factors.

67. From this 24 combinations of wave height, wave period, wave direction and water levels (corresponding to low, mid

and high tide) were selected to cover the range of scenarios that produce the best surfing conditions. The 24 combinations are shown in Table 5.

Table 5: Selected wave and water level conditions that cover the range of conditions that produce the best surfing conditions.

	Tide	Wave height (m)	Wave period (s)	Wave direction (˚T)
1	Low	1.5	12	225
2	Mid	1.5	12	225
3	High	1.5	12	225
4	Low	1.5	12	247
5	Mid	1.5	12	247
6	High	1.5	12	247
7	Low	1.5	16	225
8	Mid	1.5	16	225
9	High	1.5	16	225
10	Low	1.5	16	247
11	Mid	1.5	16	247
12	High	1.5	16	247
13	Low	3.0	12	225
14	Mid	3.0	12	225
15	High	3.0	12	225
16	Low	3.0	12	247
17	Mid	3.0	12	247
18	High	3.0	12	247
19	Low	3.0	16	225
20	Mid	3.0	16	225
21	High	3.0	16	25
22	Low	3.0	16	247
23	Mid	3.0	16	247
24	High	3.0	16	247

68. Using a calibrated wave model, the 24 wave scenarios presented in Table 5 above were simulated over the existing (undisturbed) seabed <u>and</u> for eight hypothetical test cases in which the seabed was modified by the addition of pits and mounds (216 simulations in total (24 x 9)). The eight modified seabed configurations were selected from Gorman (2015) which represent a selection of possible states of the seabed

during the mining operations. The eight cases are shown in Figure 2 below.

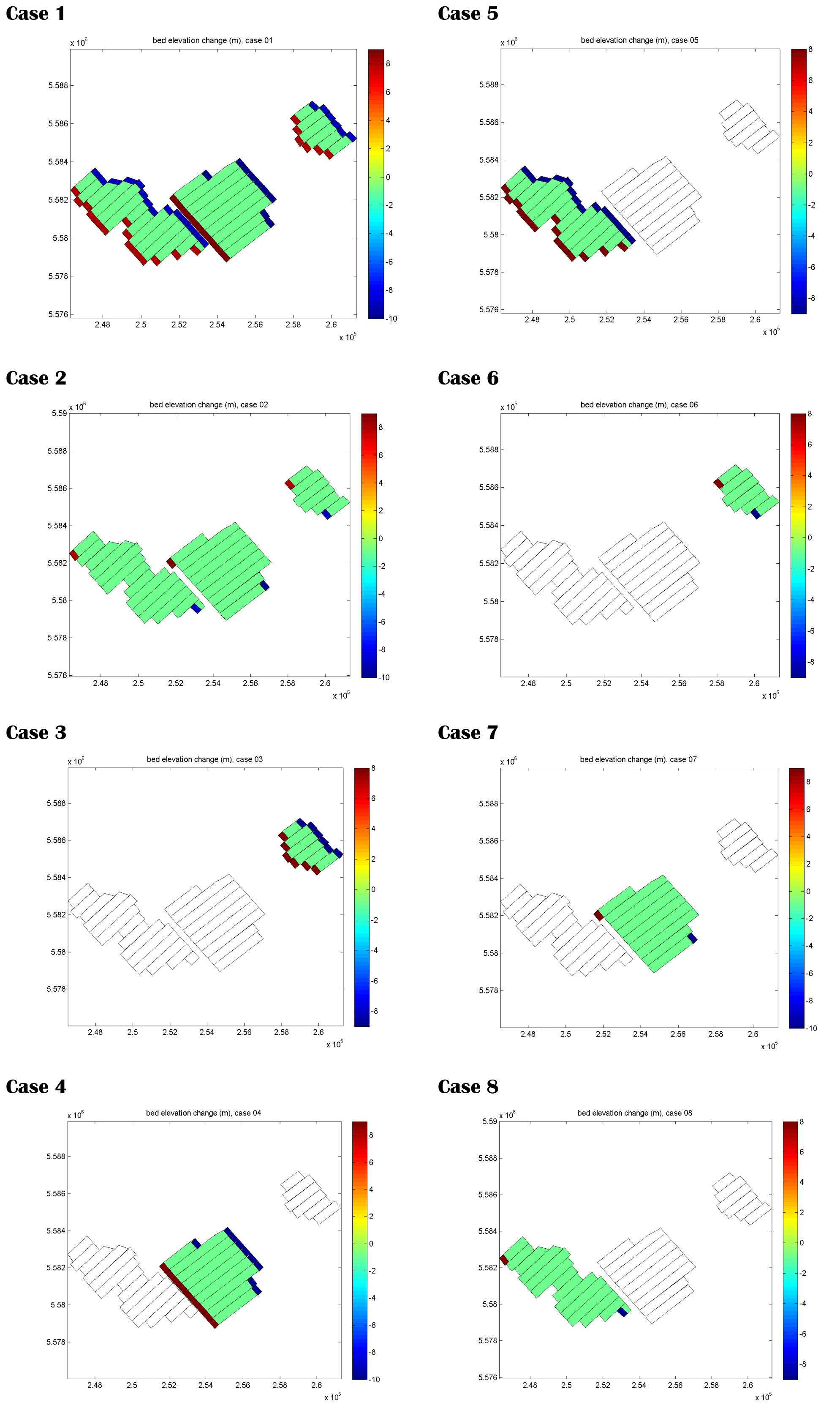

Figure 2: Hypothetical bathymetry changes used. Remnant mounds (maroon) have heights of 8m or 9m, remnant pits have depths of 9m or 10m, while refilled areas (light green) are assumed to have a depth of 1m

69. The numerical wave simulations were carried out using the SWAN (Simulating WAves Nearshore) model, which was developed for shallow water applications in coastal and estuarine environments. SWAN is the most widely-accepted model for simulating wind-generated wave processes at regional scales, and its ongoing development is supported by many leading members of the global wave modelling community. The SWAN model used here was calibrated and verified against a comprehensive set of field measurements, see Gorman (2015) for details.

70. By computing the differences between model results from the modified and undistributed seabed the impact on the nearshore wave climate resulting from the offshore seabed modifications can be assessed. The results from this analysis are shown in Appendix 2 and 3 of Mead (2015). These results are summarised herein.

71. In terms of wave height, the largest predicted change in the nearshore wave height is less than 0.03 m. In this case the incident wave height was 3 m, so a change of ~1%. This level of change is deemed insignificant and will not adversely affect surfing along the STB coast line.

72. In terms of wave direction, the largest predicted change in the nearshore wave direction is less than 2°. This level of change is deemed insignificant and will not adversely affect surfing along the STB coast.

RESPONSE TO SUBMISSIONS

73. In her submission Jacqui Malpas's stated: "To quote from the Geological Desktop Summary, pg. 15 there is 'little oceanographic data for Taranaki". The desktop study that is referred to here was written before an extensive oceanographic measurements programme was conducted.

74. In her submission Jacqui Malpas's argues that "Studies of the longshore sediment transport were undertaken for 7 months. Why only 7 months & not a full year? Which 7 months? These are incomplete". In the oceanographic measurements data report (MacDonald, Budd, et al., 2015) I present results from comprehensive current, wave and suspended-sediment measurements collected during a 7-month period from 9 September 2011 to 1 July 2012. In this report, I show that the distribution of wind speeds and directions encountered during the field deployment was similar to the long-term distribution. Therefore, the range of winds conditions experienced during the field programme were representative of the long-term wind climate. I am therefore confident that we have measured current velocities, waves and sediment transport over a representative range of conditions, including periods of strong on-shore winds.

75. Jacqui Malpas and Hinemaria Ward-Holmes also raised concerns about potential impacts on surfing along the STB coastline. I have addressed these concerns in my evidence above.

76. Ms Pratt suggests that, if lined up in some way, pits formed in the STB as a result of the sand extraction operations may have an effective width footprint that is greater than the 300 m that was assumed in the predictions, and that the pits could deepen, in parts, and migrate. However, in response, I note that TTR does not anticipate the pits being lined up to have an effective width that is greater than 300 m, but if they were, then the predicted values represent the minimum time scales associated with infilling. Also, as I noted in paragraph 59, my method cannot account for any potential deformation and/or migration of dredged pits. Instead, it seeks to estimate only an infilling timescale based on the relatively simple sediment-trapping premise.

77. Ms Pratt suggests that a morphodynamic model should have been used. While such models can resolve small scale features (such as a better representation of the hydrodynamics) within the pit, it is not correct to assume that they will provide better predictions than those based on the sediment-trapping premise approach which I adopted. On this point, van Rijn et al. (2005) noted that the "modelling of morphodynamics is not very accurate due to the absence of accurate field data of sand transport processes. In the absence of such data the uncertainty margins are relatively large (up to factor 5)".

78. In their submission Origin Energy Resources Kupe NZ Ltd (OERKL) raised concerns about the geo-stability of the region and the potential impact on their operations. My evidence addresses the natural reinstatement of the seabed morphology: I present predictions of the time that pits will take to infill and mounds will take to deflate under waves and currents in the STB. Pit infilling will occur over decades at the smallest water depth (20 m) and over centuries at the greatest water depth (45 m). Furthermore, I predict that mounds will deflate faster than pits will infill. Pit migration is estimated from published data to be around 10 m per year. I am not aware of any mitigation methods that have been tried and tested as increasing the speed of recovery of the seabed.

79. Dr A O MacLennan also raised a similar issue about the "disruption of the sea and seabed with risks of lasting damage". As discussed in paragraph 78 above, my evidence addresses the natural reinstatement of the seabed morphology.

CONDITIONS

80. The oceanography and sediment plume monitoring proposed in TTR's monitoring and management framework

looks sensible to me. I believe the proposed measurement programme targets the right set of parameters at a suitable spatial and temporal resolution

81. Under TTR's proposed monitoring and management framework, bathymetric surveys will be conducted quarterly. The results from repeat surveys will be used to assess the accuracy of the pit infilling and mound deflation predictions. The bathymetric measurements could also be used to establish the rates of pit migration.

CONCLUSIONS

Oceanographic measurements

82. The oceanographic measurements represent a comprehensive set of current, wave and suspended-sediment measurements collected during a 7-month period from 9 September 2011 to 1 July 2012. Winds experienced during the field programme were typical of the long-term wind climate and included a weather bomb event.

83. The collected field dataset provides a coherent picture of currents, waves and suspended sediment concentrations in the STB. The datasets, which have been carefully calibrated to produce accurate measures that were used with confidence in the development of numerical models of current flows, waves and suspended-sediment plume dispersion in the STB.

Nearshore optical water quality

84. Rainfall data has shown that the optical water quality and suspended-mud concentration measurements took place during a period of lower than expected rainfall for that time of year, and consequently during a period of low river flows. Since rivers are a major source of fine sediments into the STB, it is likely that the data are representative of conditions with clearer water.

85. The results show a consistent gradient in suspended sediment concentration extending offshore, with *SSCm* decreasing with increasing distance offshore. This was also reflected in an offshore gradient in optical parameters.

86. The field measurements provide the background optical water quality and *SSCm* in the nearshore region of the STB. These results were used with confidence to help assess the potential effects of offshore sand extraction on the surrounding environment, and in particular the effect of sediment plume dispersal in the nearshore environment.

Pit infilling and mound deflation

87. My work predicts that, broadly, pit infilling will occur over decades at the smallest water depth (20 m) in the STB and over centuries at the greatest water depth (45 m). Furthermore, I predict that mounds will deflate faster than pits will infill.

88. Mounds deflate faster than pits infill, for two reasons. Firstly, the mound stands above the seabed and so it is subject to stronger wave-orbital motions than a pit at the same mean water depth. This difference reduces as the simulation proceeds and the mound is deflated. Secondly, the rate of deflation of the mound is not reduced by any trapping efficiency (in contrast to the rate of pit infilling, which is reduced by a trapping efficiency.

89. Pit migration is estimated to be around 10 m per year in the direction of residual sediment transport, which for the proposed mining area is towards the southeast.

Surf breaks

90. Of the 216 modelled simulations, only four resulted in a detectable change in wave height and direction, and only at the Patea and Waverley breaks. However, these changes

are small, with less than a 1 % change in height and less than a 2° change in direction.

91. These small changes in wave height and direction are deemed insignificant and will not adversely affect surfing at the 10 sites investigated along the STB coast line. This result is consentient with the results from a similar study looking at the impact on surfing from the disposal of spoil from a dredging programme at Port of Otago (Bell et al., 2009).

Dr Iain MacDonald

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