PORT OTAGO DREDGE DISPOSAL GROUNDS

Functional effects of the Heyward Ground on wave dynamics and a proposed dumping plan

Prepared for Port Otago Limited

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1. INTRODUCTION

The morphological features of the Heyward disposal ground affect the local wave dynamics, and these are investigated using the nearshore wave models SWAN and CGWAVE, with a particular focus on how it influences the surfing conditions at Whareakeake.

The SWAN model was validated against field measurements, and was found to successfully reproduce the complex transformations of the wave field from the open ocean to the coast, including focusing processes over the mounds and delta bar. The complete validation details are presented in MetOcean Solutions report P0140-03.

In a first stage, idealized wave events with range of directions and periods have been simulated over the 2010 and 2013 bathymetries using SWAN to identify the main characteristics of the focusing process developing over the mound and variations with morphology. The phase-resolving CGWAVE model was then used to investigate the wave crest patterns developing over the ground and towards Whareakeake.

The identification of the key wave processes provides guidance to define a disposal program for up to 100,000 m^3 of sediment to be disposed over the first two quarters of 2014. To test the plan, considered wave events were re-simulated with a new bathymetry including an estimation of the post dumping ground morphology to assess modifications of the wave dynamics. The plan was progressively refined by repeating the procedure to ensure minimal adverse effects on the existing processes that currently benefit the surfing conditions.

2. METHODS

2.1.1. SWAN

SWAN is a third generation ocean wave propagation model, which solves the spectral action density balance equation for wavenumber-direction spectra. This means that the growth, refraction, and decay of each component of the complete sea state, each with a specific frequency and direction is solved, giving a complete and realistic description of the wave field as it changes in time and space. Physical processes that are simulated include the generation of waves by surface wind, dissipation by white-capping, resonant nonlinear interaction between the wave components, bottom friction and depth limited breaking. A detailed description of the model equations, parameterizations, and numerical schemes can be found in Holthuijsen *et al*. (2007) or the online SWAN documentation[1]. All 3rd generation physics are included. The Collins friction scheme is used for wave dissipation by bottom friction (f=0.015).

Idealized wave condition were applied as boundary condition of a large scale domain which provided nested boundary for a higher resolution model including the Harbour Entrance, delta bar, and disposal grounds. The regional and local grids are shown in Figure 2.1. The regional grid was rectangular with a resolution of ~250 m and the local grid was curvilinear with cell sizes ranging from 50 to 20 meters. The measurement sites A0, WRB and W1 shown in Figure 2.1 were used as reference points to characterize the wave transformation from the offshore region to Murdering Bay and the Whareakekae surf break.

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

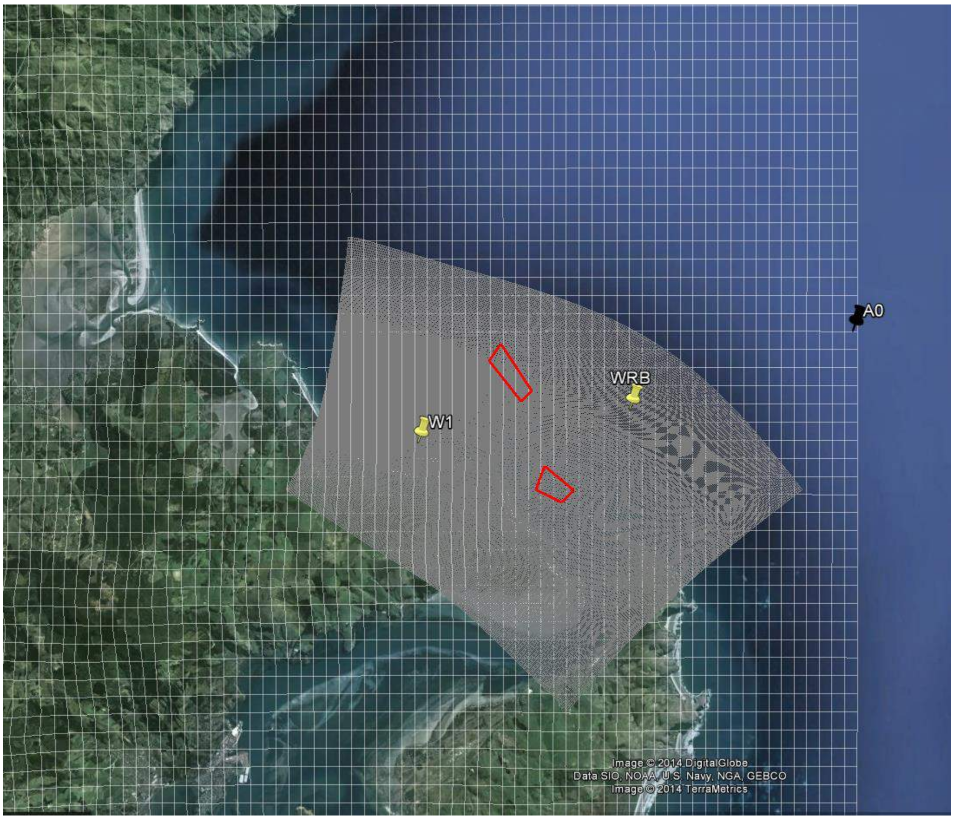

Figure 2.1 Regional and nested grid, with A0, WRB and W1 site positions. The existing disposal grounds are shown in red. (Image: Google Earth).

2.1.2. CGWAVE

The CGWAVE model was used to simulate monochromatic wave transformations from the offshore region into Aramoana Beach and the adjacent coastline. CGWAVE is an industry-standard tool for use in harbours and coastal regions with complex bathymetry. The model uses a finite-element (triangular) mesh which allows increased resolution of complex bathymetric features such as channels and structures. CGWAVE simulates the combined effects of wave refraction-diffraction and includes the effects of wave dissipation by friction, breaking, nonlinear amplitude dispersion and wave reflection (Demirbilek and Panchang, 1998). Wave - current interaction are not accounted for in the model. Note that unlike SWAN, CGWAVE is a phase-resolving model thus allowing investigations of individual wave crests patterns. The model mesh is shown in Figure 2.2.

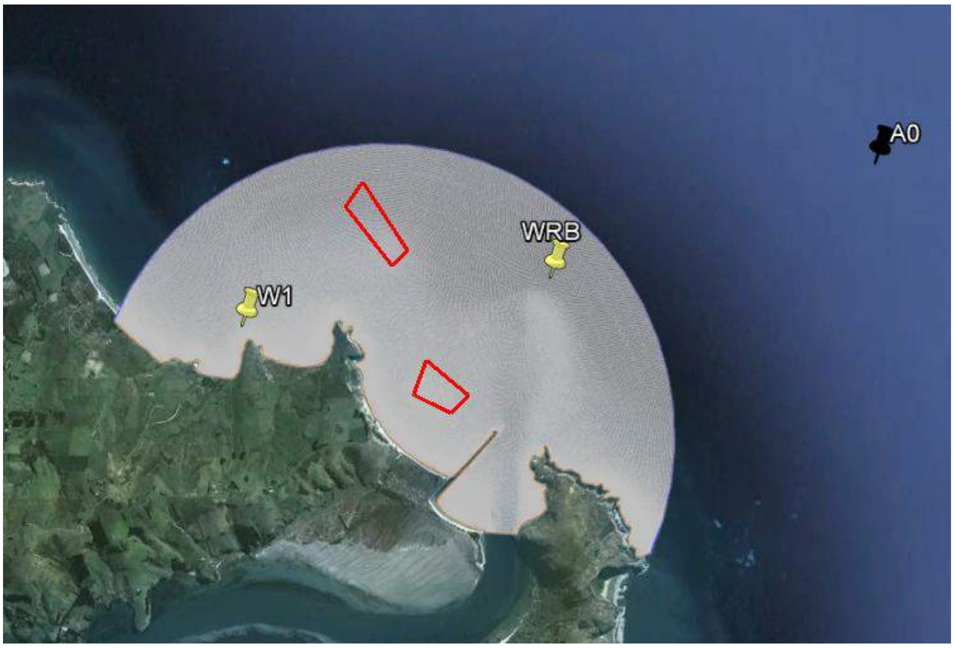

Figure 2.2 CGWAVE model mesh with A0, WRB and W1 site positions. The existing disposal grounds are shown in red. (Image: Google Earth).

2.2. Bathymetry

The bathymetric dataset used for the development of the regional and local model domain bathymetries combined data from several sources including soundings and digitized nautical chart contours. This was supplemented by high-resolution soundings of the disposal grounds and surroundings from 2010 and 2013 (October) to accurately represent the nearshore bathymetry and mound features. Model bathymetries are shown in Figure 2.3.

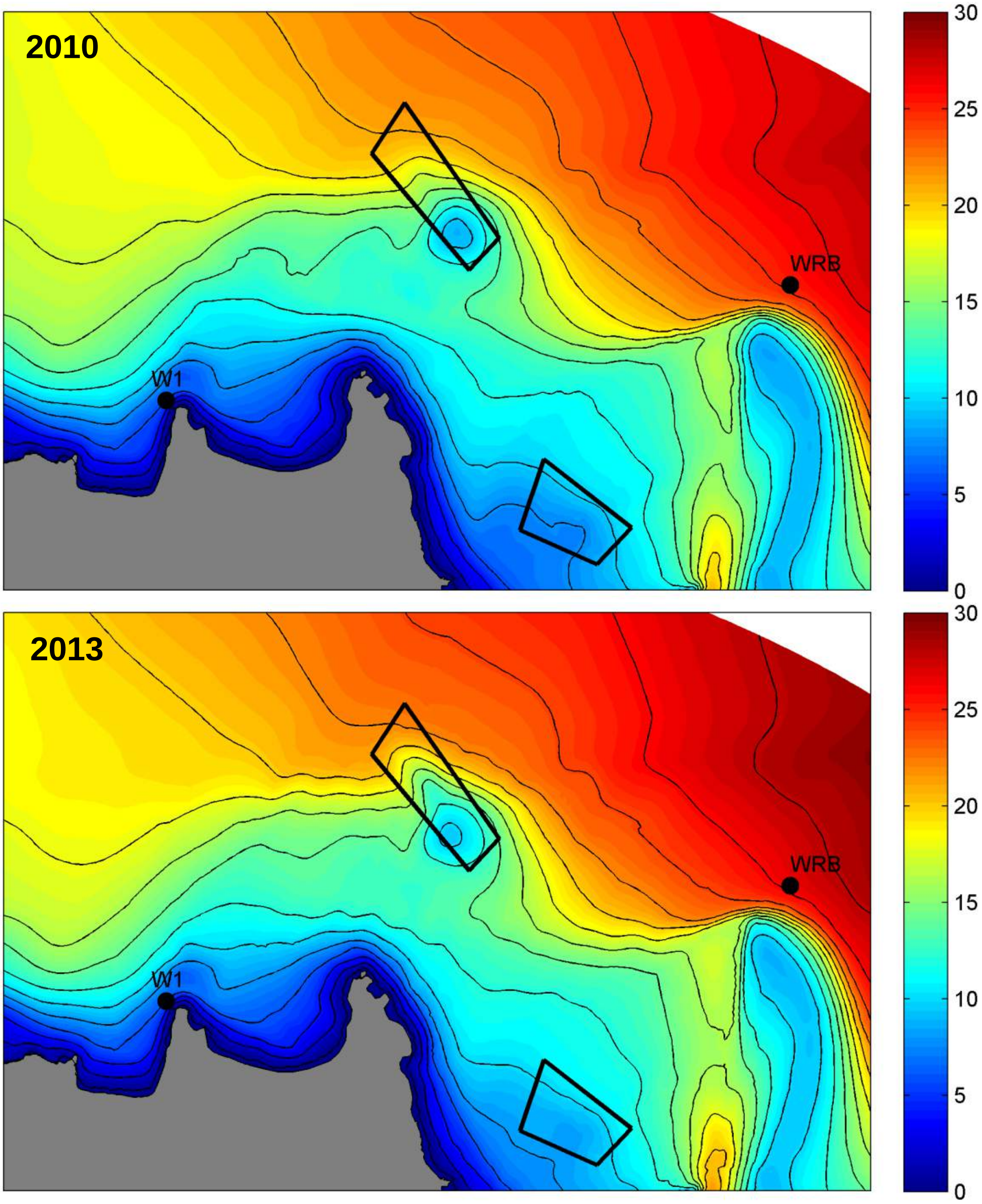

Figure 2.3 2010 and 2013 bathymetries, with WRB and W1 site positions. The existing disposal grounds are shown in black.

3. RESULTS

3.1. Existing wave dynamics

Recent bathymetries (Figure 2.3) show that cumulative sediment volumes disposed over the last decade have created prominent circular mound located on the south-eastern half of the Heyward Point ground. Depths over the ground are currently ~ 10 m MSL over the mound and up to 22 m on the northwest half. This relatively shallow circular mound has a significant effect on the local wave dynamics and resulting wave conditions at Whareakake.

The local wave fields developing in response to different offshore wave directions are presented in Figures 3.1 and 3.2 for the 2010 and 2013 bathymetries. Idealized wave events and resulting wave conditions at the WRB and W1 sites are described in Tables 3.1 and 3.2.

The overall wave transformation patterns are very similar for the two bathymetries. Intense wave focusing develops over the submerged delta bar east of the shipping channel and over the mound at the Heyward ground. Note that “beams” of increased wave energy are paired with regions of smaller wave energy that become relatively shadowed during refraction and focusing. A pure northeast incidence results in a focusing of the wave energy directed to Heyward Point, while the submerged bar increases wave heights over the central parts of Aramoana Beach. Note that some local wave refraction and focusing naturally develops off Murdering Bay due to the underlying curved bathymetric contours just off the headland. For a pure easterly incidence, the delta bar focuses wave energy along the northern half of the beach, and the Heyward mound results in increased heights almost in an east-west axis, thus missing the coast. Wave heights along the 6 meter depth contour (Figure 3.3) are shown in Figure 3.4 for the simulated events. The wave energy levels along the coast are significantly modulated by the offshore wave incidence. This modulation is present in the successive wave conditions at the A0, WRB, and W1 provided in Tables 3.1 and 3.2 for the 2010 and 2013 bathymetries.

With respect to surfing conditions at Whareakeake, potential benefits of the focusing processes developing over the dump mound at Heyward are expected to be the most significant for offshore directions of 60 to 70 degrees. For these incident angle, wave refraction over the pronounced dump mound focuses energy directly towards the surf break and this area of enhanced wave energy is expected to further combine with local wave focusing due to the underlying nearshore bathymetric contours closer to shore. Note the distinct peaks in the wave height predicted at Whareakeake in Figure 3.4.

The effect of wave period was investigated for these optimal incidences. Note that wave period is another significant parameter with respect to focusing processes as it governs the depth and degree to which waves undergo refraction. Predicted wave fields for wave periods from 10 to 16 seconds are shown in Figures 3.5 and 3.6 for offshore wave directions of 60 and 70 degrees. Variations can be clearly seen on the isolines Hs=2.5 m for the different cases. For the 70 degree case (Figures 3.5), the isoline does not reach the coast past Heyward Point when wave period is 10 seconds (or smaller). Wave heights larger than 2.5 m start to reach Whareakeake for wave periods larger than 12 seconds. As the period increases, the isoline eventually spreads to Heyward Point and connects with the area of larger wave heights along Aramoana Beach resulting from the focusing over the ebb delta bar. A similar spreading of the isoline Hs=2.5 m is also visible on the Figure 3.6for a 60 degree incidence. In both cases, the increase in wave period is also associated with generally more efficient refraction and focusing processes, resulting in increased maximum wave heights over the shallower mounds and delta bar. Wave heights along the 6 m depth contour for the different wave periods are provided in Figure 3.7, and show the different level of wave energy reaching the coast. Resulting conditions at the W1 site just off Murdering Bay are quantified in Tables 3.1 and 3.2 and show an increase in wave height for increasing periods.

To determine the best outcome from future disposal activities, it is useful to investigate more closely differences between the two recent bathymetries and how associated mound shapes affect the wave focusing processes, and in turn, the surfing conditions. Over the last decade, dredged sediments were disposed predominantly within the south-eastern section of the ground, which has created the prominent circular mound feature (see 2010 bathymetry, Figure 2.3, top). In contrast, the last survey undertaken in October 2013 shows that significant volumes have been disposed of in the northwest half of the ground, with a distinct bend of bathymetric contours becoming evident (Figure 2.3, bottom). This is clearly visible in the bathymetric changes from 2010 and 2013 shown in Figure 3.8. Over this period, the circular mound in the southeast half of the ground was eroded by ~0.5 m with sediments migrating westwards, while the seabed level was raised by about 2.0 m over parts of the north-western half of the ground.

The differences between the significant wave height predicted over the 2010 and 2013 bathymetries are shown in Figure 3.9 for offshore wave directions of 70 and 60 degrees (expected to be optimal for surfing).

The 2013 morphology slightly influences the wave height patterns that develop over and westward of the ground. Smaller wave heights are predicted in the lee of the circular mound over the 2013 bathymetry due to a lower level compared to 2010. In contrast, there is an area of increased wave height originating from the shallower northwest ground half, reaching the coast between Heyward Point and Whareakeake headland. The magnitude of changes is about ±50 cm for the wave event simulated. This band of enhanced energy is bounded to the west by a region of smaller wave heights which can be attributed to the relative wave shadowing associated with the new focusing process developing over the ground northwest half.

For a 60 degree wave incidence, the area of enhanced wave energy in 2013 does not occur east of the Whareakeake headland, while smaller heights are predicted further west the beach. Here, the break appears to lie just at the limits between the two zones, but it is clear that slight changes in direction would result in the break being in either of the two zones. For a 70 degree incidence, the overall feature is shifted west and the surf break lies within the band of larger wave heights.

For reference, similar results are presented for the 50 and 80 degrees incidence in Figure 3.10. The pattern is reproduced although with shifted positions. Whareakeake headland is in line with the shadow band for the 50 degrees case, while the current mound morphology results in larger heights in the vicinity of the break for an 80 degrees incidence.

Overall, the modelling suggest that the recent modifications of the mound morphology do not substantially alter the key focusing process due to the mound, but do slightly modify the range of offshore directions that result in preferential wave focusing towards the Whareakeake surf break.

Significant wave heights predicted along the 6 meter contour in 2010 and 2013 are compared in Figure 3.11 for different offshore incidence angles. The modifications in wave heights off Whareakeake remain very low, while along Aramoana beach the maximum wave heights are consistently larger for the 2010 case due to a shallower mound within the Aramoana ground.

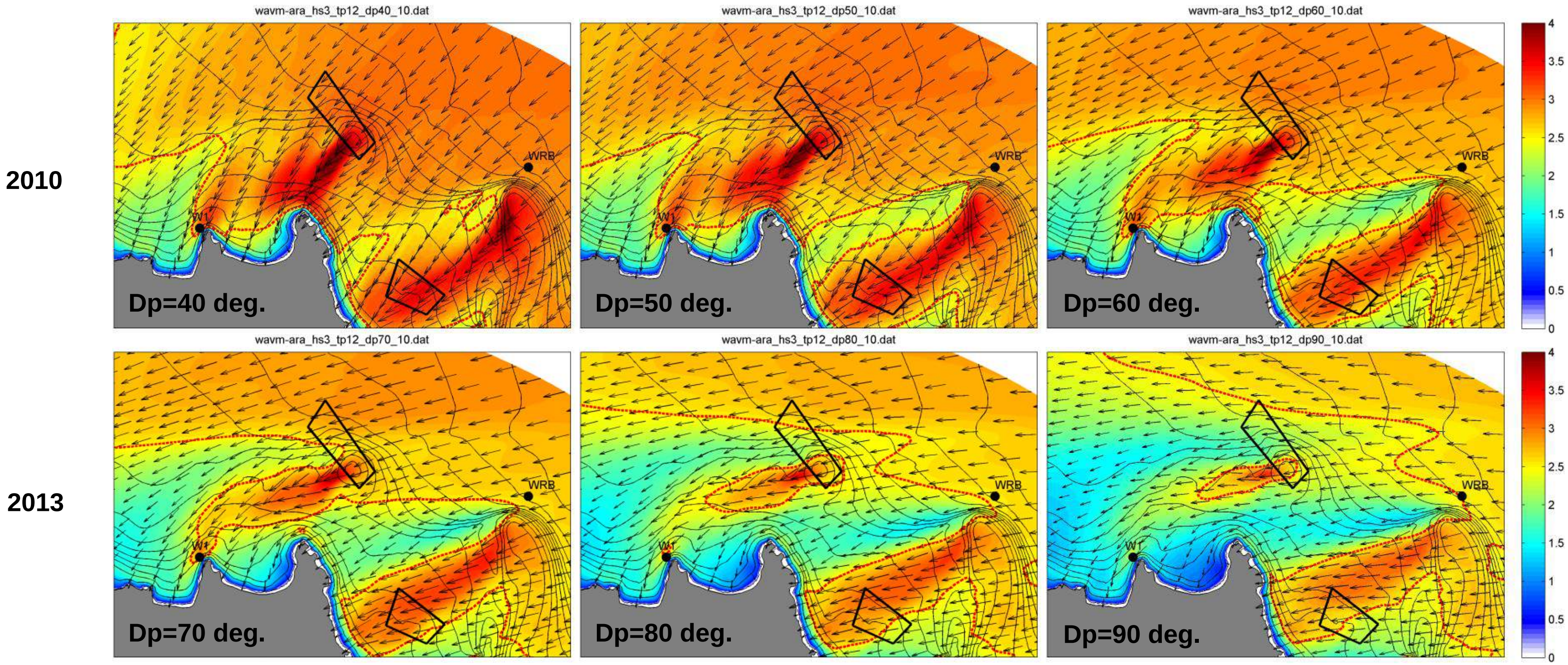

Figure 3.1 Significant wave heights and directions for a range of different offshore directions (Hs= 3 m, Tp=12 sec.) for the 2010 bathymetry. The dotted red line is the 2.5 m wave height contour. The black dots indicate the position of the wave measurements.

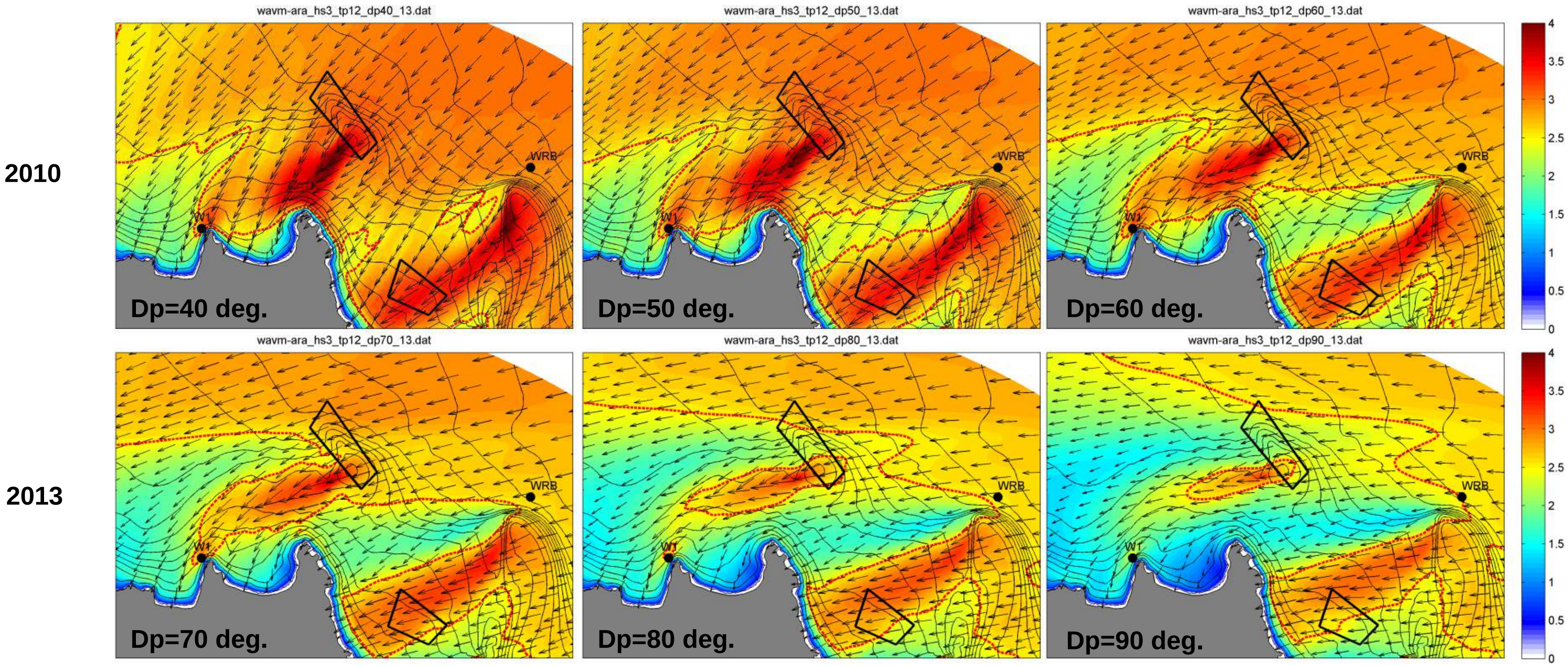

Figure 3.2 Significant wave heights and directions for a range of different offshore directions (Hs= 3 m, Tp=12 sec.) for the 2013 bathymetry. The dotted red line is the 2.5 m wave height contour. The black dots indicate the position of the wave measurements.

Table 3.1 Wave conditions at the A0, WRB and W1 sites for all the simulated idealized wave events over the 2010 bathymetry. Significant wave heights Hs are in meters, Peak direction Dp are degrees, and peak periods Tp in seconds.

2010								
A0 - Site			**WRB - Site**			**W1 - Site**		
Hs (A0)	**Dp (A0)**	**Tp (A0)**	**Hs (WRB)**	**Dp (WRB)**	**Tp (WRB)**	**Hs (W1)**	**Dp (W1)**	**Tp (W1)**
3.0	90	12.0	2.5	88	11.9	1.9	17	11.9
3.0	80	12.0	2.5	84	11.9	2.3	17	11.9
3.0	70	10.0	2.6	72	9.9	2.2	16	10.1
3.0	70	12.0	2.6	76	11.9	2.6	16	11.9
3.0	70	14.0	2.7	84	14.1	2.6	16	14.2
3.0	70	16.0	2.7	84	16.0	2.7	16	16.0
3.0	60	10.0	2.6	64	9.9	2.6	16	10.1
3.0	60	12.0	2.7	68	11.9	2.8	16	11.9
3.0	60	14.0	2.8	68	14.1	3.0	16	14.2
3.0	60	16.0	2.8	72	16.0	3.0	15	16.0
3.0	50	12.0	2.8	60	11.9	2.9	15	11.9
3.0	40	12.0	2.9	52	11.9	2.9	15	11.9

Table 3.2 Wave conditions at the A0, WRB and W1 sites for all the simulated idealized wave events over the 2013 bathymetry. Significant wave heights (Hs) are in meters, Peak direction (Dp) are degrees, and peak periods (Tp) in seconds.

2013										
A0 - Site				**WRB - Site**				**W1 - Site**		
Hs (A0)	**Dp (A0)**	**Tp (A0)**		**Hs (WRB)**	**Dp (WRB)**	**Tp (WRB)**		**Hs (W1)**	**Dp (W1)**	**Tp (W1)**
3.0	90	12.0		2.5	88	11.9		2.0	17	11.9
3.0	80	12.0		2.5	84	11.9		2.4	17	11.9
3.0	70	10.0		2.6	72	9.9		2.2	16	10.1
3.0	70	12.0		2.6	76	11.9		2.7	16	11.9
3.0	70	14.0		2.7	84	14.1		2.6	16	14.2
3.0	70	16.0		2.7	84	16.0		2.7	16	16.0
3.0	60	10.0		2.6	64	9.9		2.6	16	10.1
3.0	60	12.0		2.7	68	11.9		2.8	16	11.9
3.0	60	14.0		2.8	68	14.1		3.0	16	14.2
3.0	60	16.0		2.8	72	16.0		3.0	16	16.0
3.0	50	12.0		2.8	60	11.9		2.9	15	11.9
3.0	40	12.0		2.9	52	11.9		2.9	15	11.9

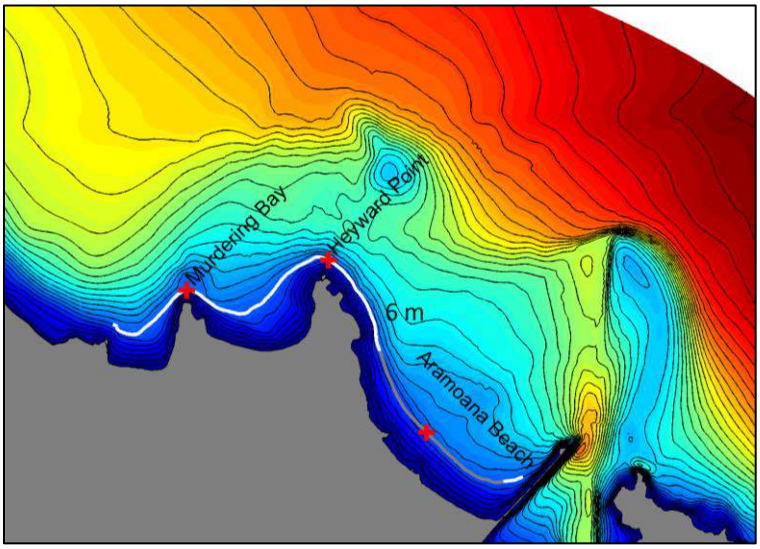

Figure 3.3 Position of 6 m contour with along the coast, with key locations.

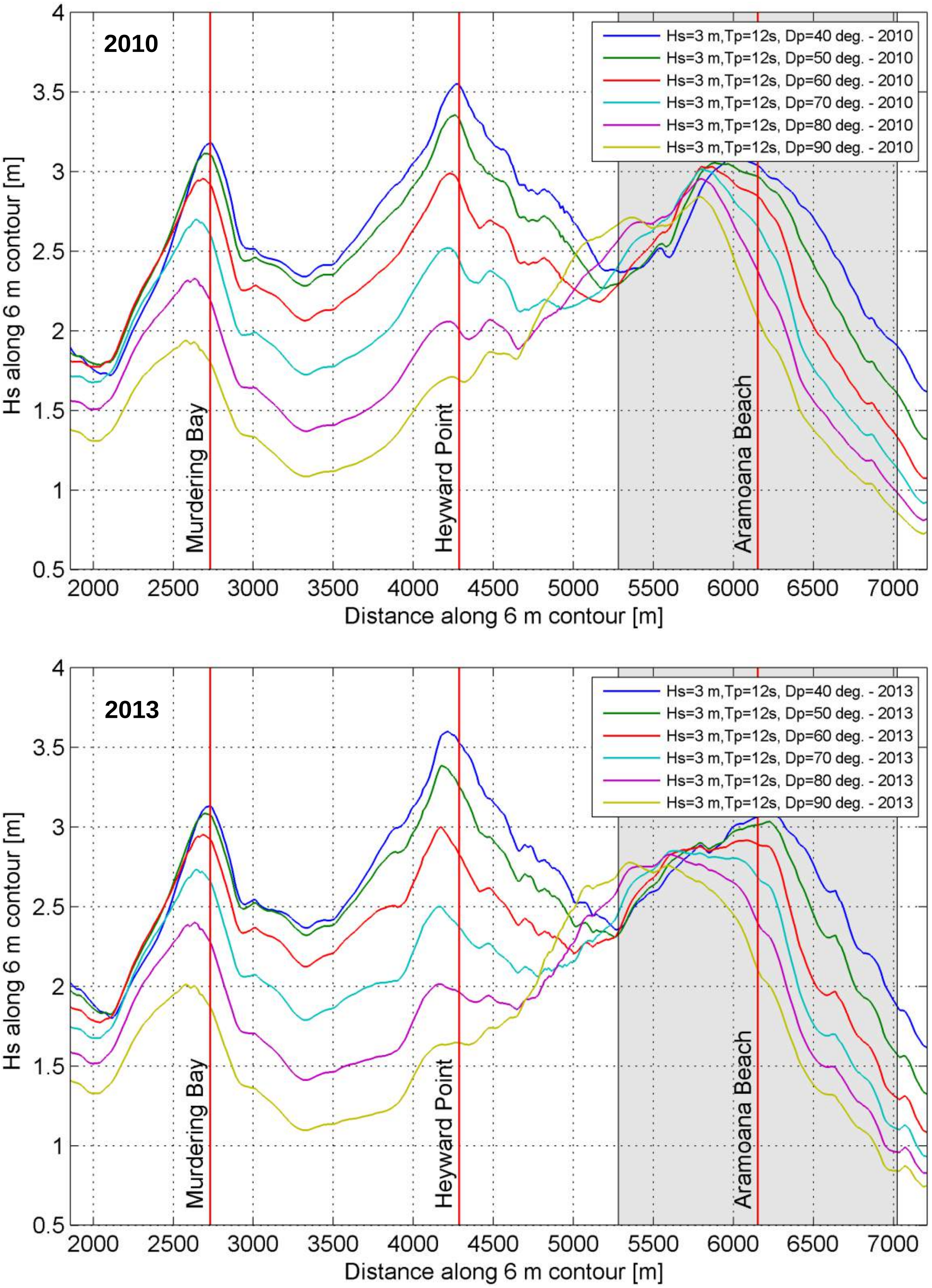

Figure 3.4 Significant wave heights along the 6 m contour for different wave directions over the 2010 and 2013 bathymetries.

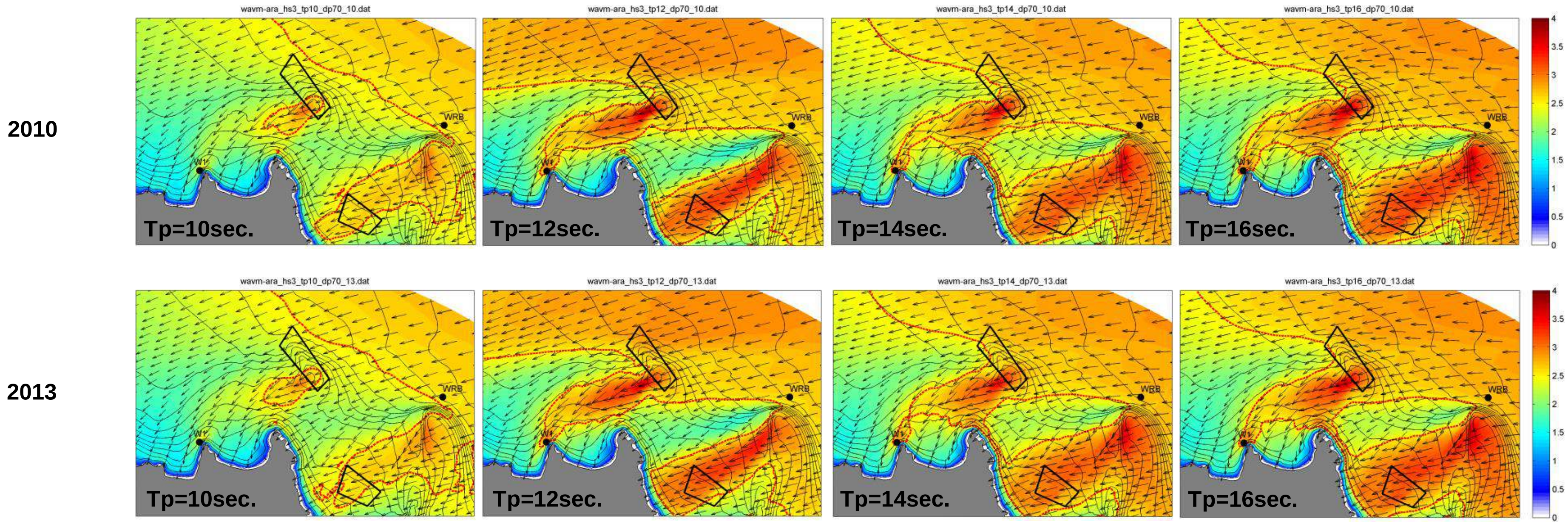

Figure 3.5 Significant wave heights and directions for different wave periods (T=10,12,14,16 sec.) with offshore conditions Hs=3 m and DirT= 70 deg, over the 2010 (top) and 2013 (bottom) bathymetry. The dotted red line is the 2.5 m wave height contour. The black dots indicate the position of the wave measurements.

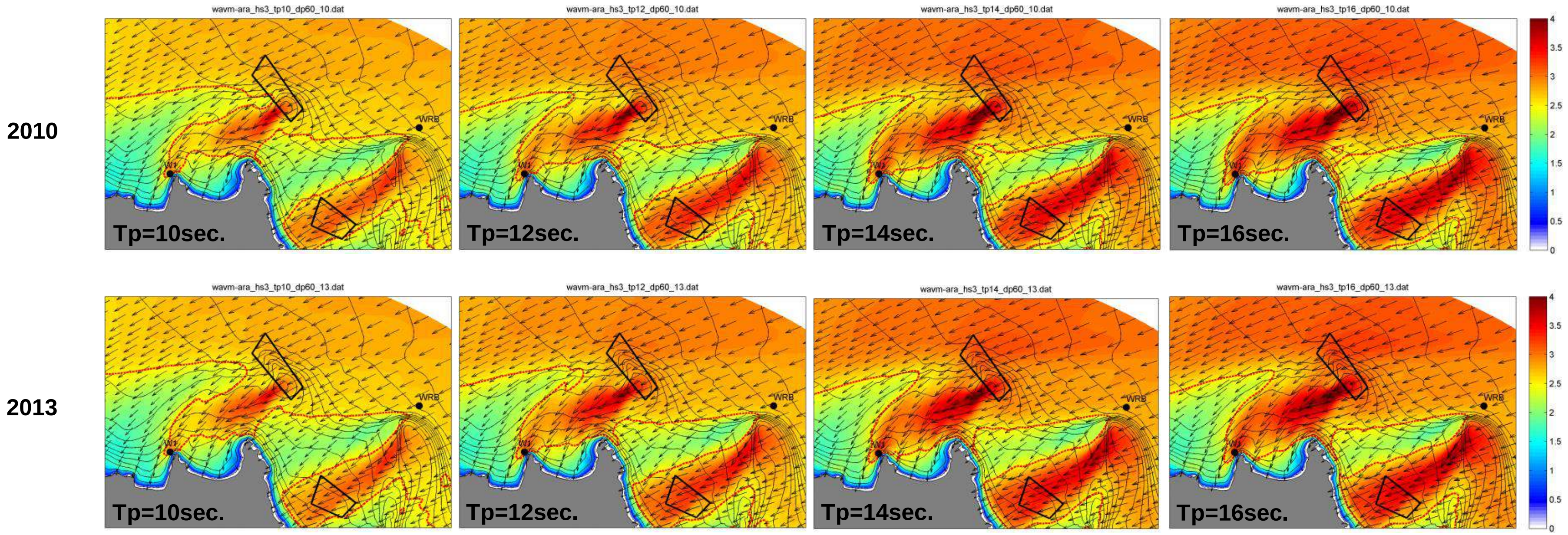

Figure 3.6 Significant wave heights and directions for different wave periods (T=10, 12, 14, 16 sec.) with offshore conditions Hs=3 m and DirT= 60 deg, over the 2010 (top) and 2013 (bottom) bathymetries. The dotted red line is the 2.5 m wave height contour. The black dots indicate the position of the wave measurements.

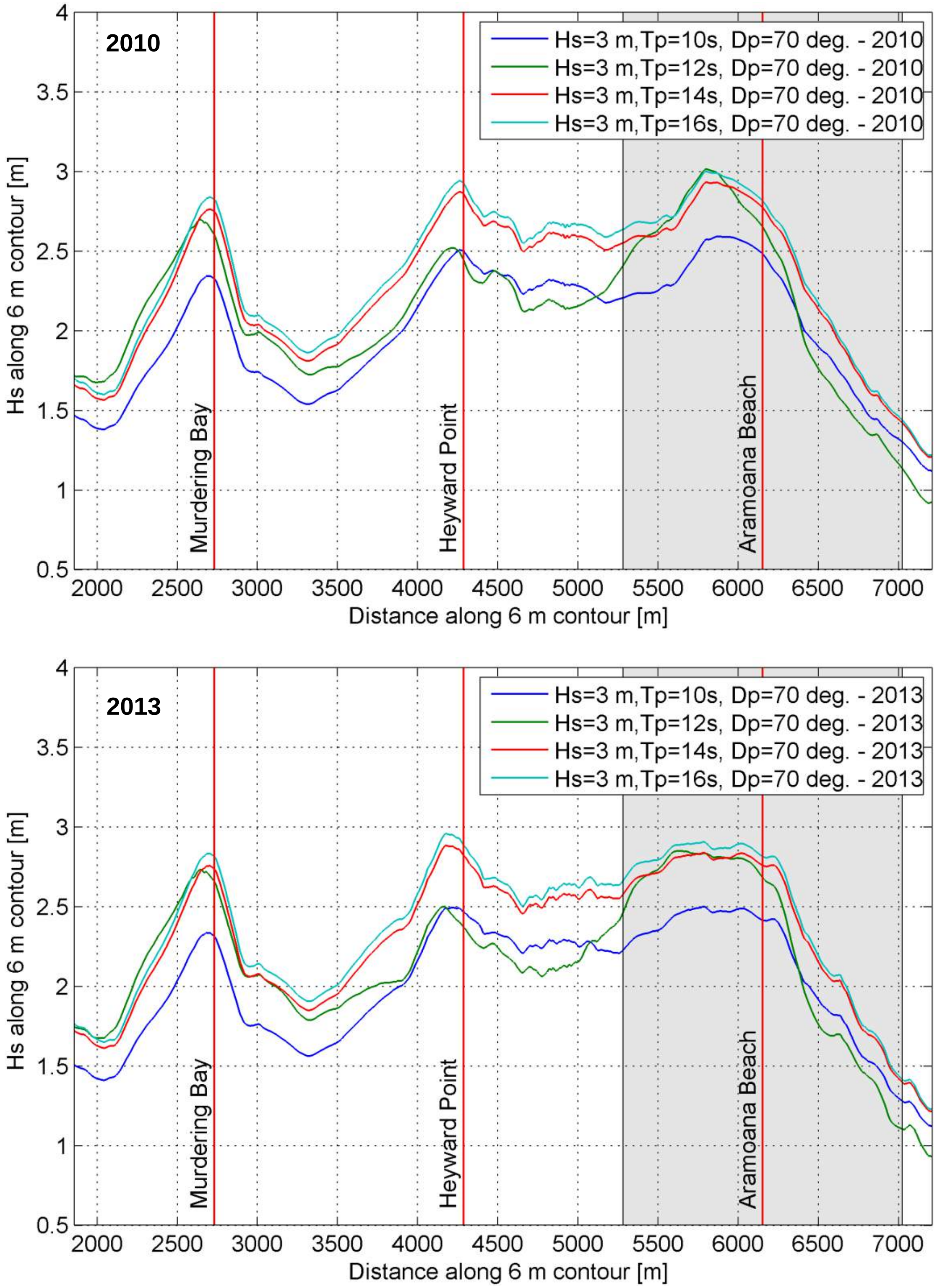

Figure 3.7 Significant wave heights along the 6 m contour for different wave periods over the 2010 (top) and 2013 (bottom) bathymetries.

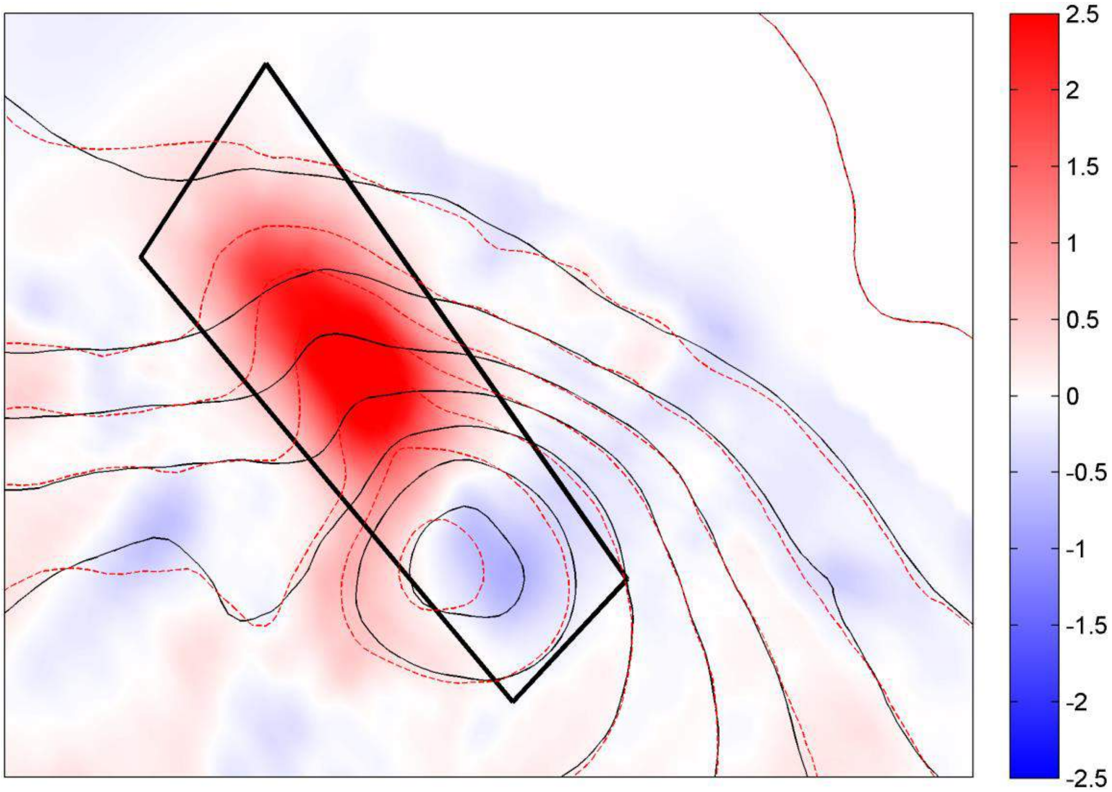

Figure 3.8 Bathymetric differences from 2010 to 2013 in the vicinity of the Heyward Point ground. Black contours are for the 2010 bathymetry and red dashed contours are for the 2013 bathymetry.

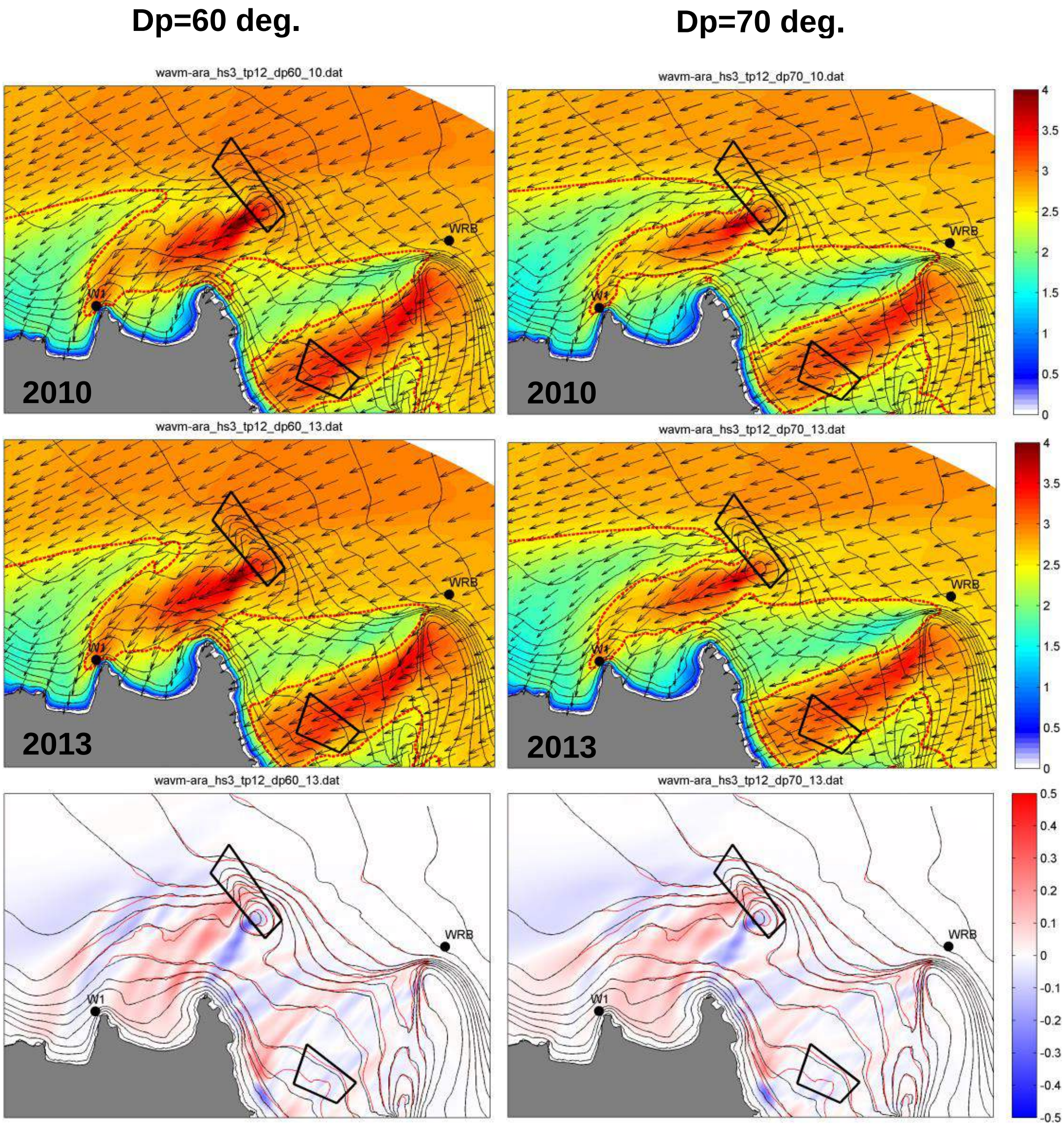

Figure 3.9 Predicted significant wave heights for offshore directions of 60 (left) and 70 (right) degrees over the 2010 (top) and 2013 (middle) bathymetries and differences (bottom). The dotted red line is the 2.5 m wave height contour (top, middle). In difference maps (bottom), positive values indicate wave height larger over the 2013 bathymetry than over the 2010 bathymetry. 2010 contours are shown in red and 2013 contours are shown in black.

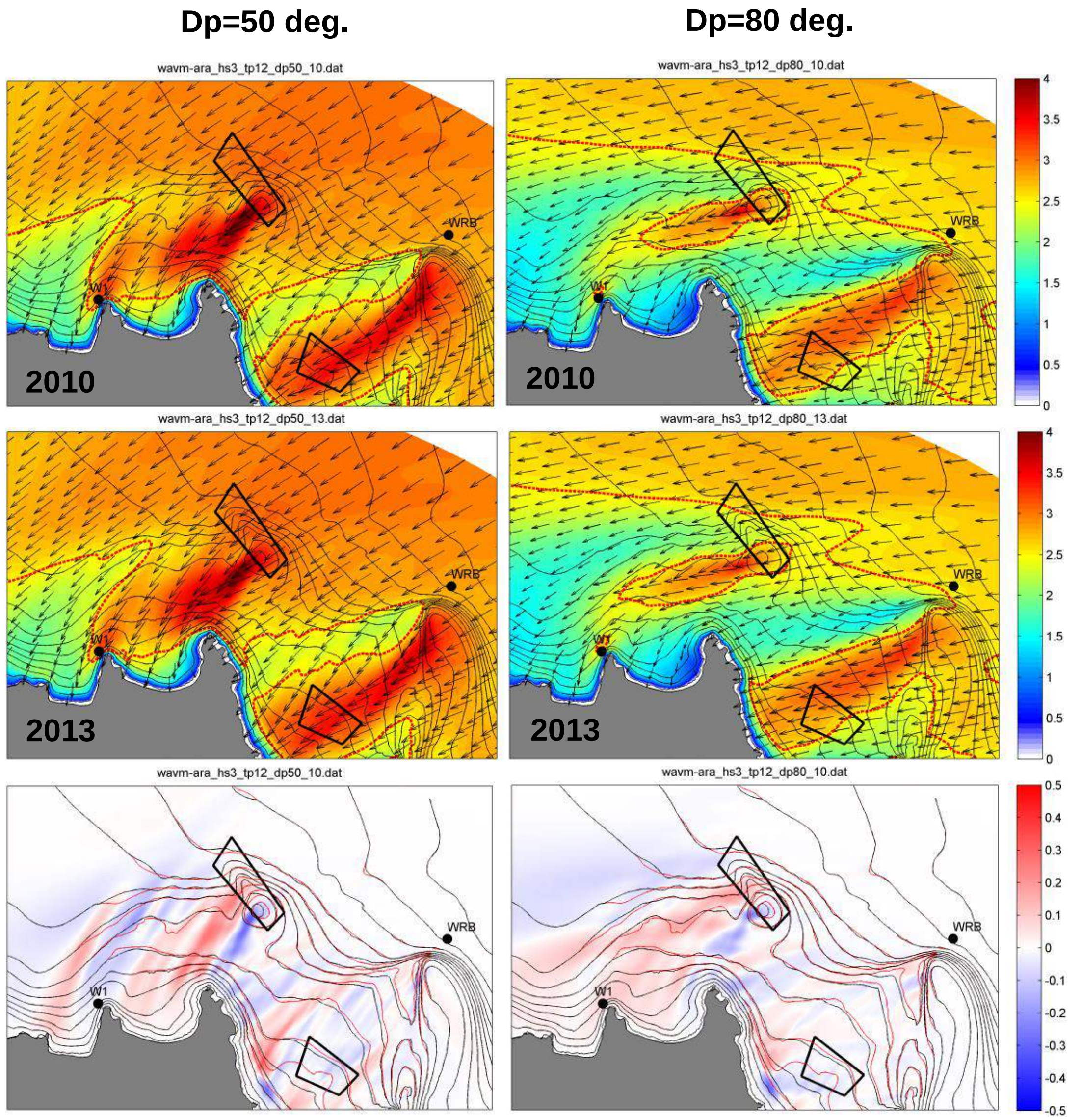

Figure 3.10 Predicted significant wave heights for offshore directions of 50 (left) and 80 (right) degrees over the 2010 (top) and 2013 (middle) bathymetries and differences (bottom). The dotted red line is the 2.5 m wave height contour (top, middle). In difference maps (bottom), positive values indicate wave height larger over the 2013 bathymetry than over the 2010 bathymetry. 2010 contours are shown in red and 2013 contours are shown in black.

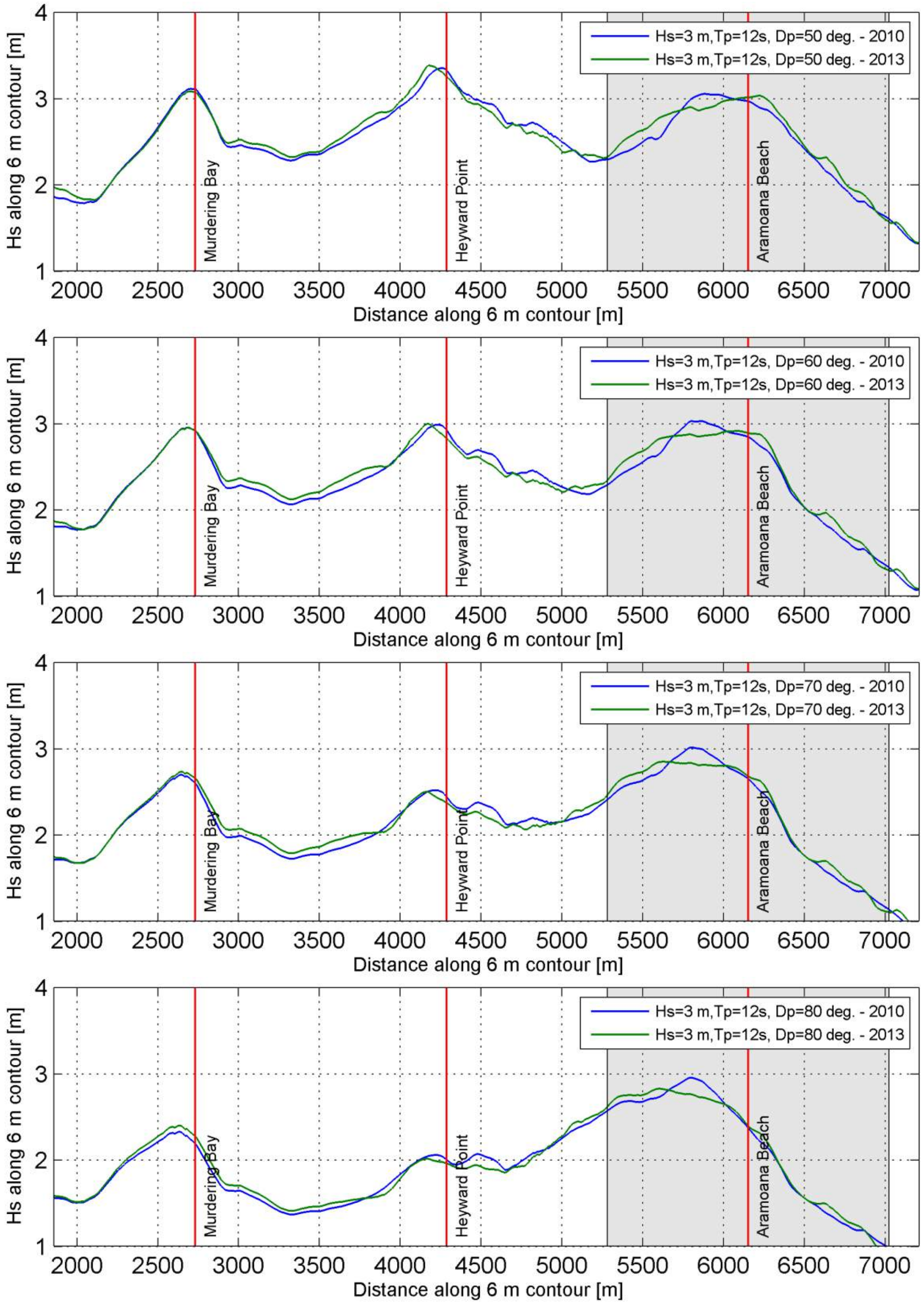

Figure 3.11 Significant wave heights along the 6 m contour for wave incidences of 50, 60, 70, and 80 degrees over the 2010 and 2013 bathymetries.

The SWAN simulations discussed here provide useful information on the distribution of wave energy in the lee of the dump site. However, as SWAN is a phase-averaged model, no information is available on individual wave crests and how they may be affected. Accordingly, another model has been used to examine the evolution of wave crests as they propagate over the mound and towards the coast to the Whareakeake surf break.

The phase-resolving CGWAVE model was used to simulate monochromatic wave events over the 2010 and 2013 bathymetries. The event with an offshore direction of 70 degrees (Hs=3m, Tp=12 seconds) was considered as test case and the conditions transformed at the WRB site (Table 3.1) were applied to the CGWAVE model boundary (see mesh Figure 2.2).

Monochromatic simulations are idealized cases that assume a single wave component with one period, and one direction for the totality of the wave energy. These simulations have limitations since they do not reproduce the typical combination of wave components with different periods and direction of realistic sea states but they are very useful to investigate the behaviour of clean, long-lined swells that are of particular interest since these swells most likely produce quality waves at Whareakake.

Predicted wave crest patterns over the 2010 and 2013 bathymetries are presented in Figure 3.12. These results identify the key wave processes developing at the study site and the functions of various bathymetric features, including the distinctive morphology within the Heyward ground. As they approach the coast, incident wave crests first reach the submerged delta bar east of the shipping channel. The tip of the delta bar and adjacent channel produces large depth gradients that locally refract incident wave crests towards Aramoana Beach. However, the portion of crests north of the bar continues to propagate undisturbed, which results in different directions occurring along individual wave crests. This is initially sustained over some distance, but eventually the crests snap and a phase difference of around 180 degrees is obtained (i.e. trough adjacent to crest).

The incident wave crests passing north of the delta bar continue to propagate freely towards the Heyward ground. These waves are progressively affected by curved bathymetric contours that extend some distance before the ground, but the most significant shoaling and refraction occurs and develops directly over the circular mound in the SE corner of the ground. This process directs focuses wave energy in the lee of the mound, and also introduces a delay in wave phase and occasions with crest-snapping also. While this effect is reproduced in both the 2010 and 2013 bathymetries, some variations in wave phase patterns are visible. Notably the shallower northwest half of the ground in 2013 slows down incident crests more, thereby reducing the shift in wave phase and delaying the snapping of the crests in the lee of that zone.

The model results indicate that the circular mound located in the southeast corner of the Heyward ground plays has a key function in the focusing of the incident wave energy towards Whareakeake, and those functional aspects need to be conserved to ensure the swell corridor is not fundamentally changed. The shallower ridge adjacent to the circular mound in northwest half of the ground that is present in the latest bathymetry from October 2013 introduces a slight delay in the wave phases but does not significantly alter the overall refraction patterns that develop over the ground. The spatial extent of the ridge feature in the direction of wave propagation remains relatively limited, and new depth gradients are not sharp enough to drive major crest bifurcation or snapping.

Effective management of the Heyward ground over the next few years needs to conserve these functional components and avoid adverse impact on the surf quality. A key point to the disposal strategy is to maintain a circular mound within the south-eastern half of the ground. In that context, the sediment volumes required to sustain the mound are expected to be much less than the total volumes to be dumped, so other parts of the ground will have to be used for that capacity.

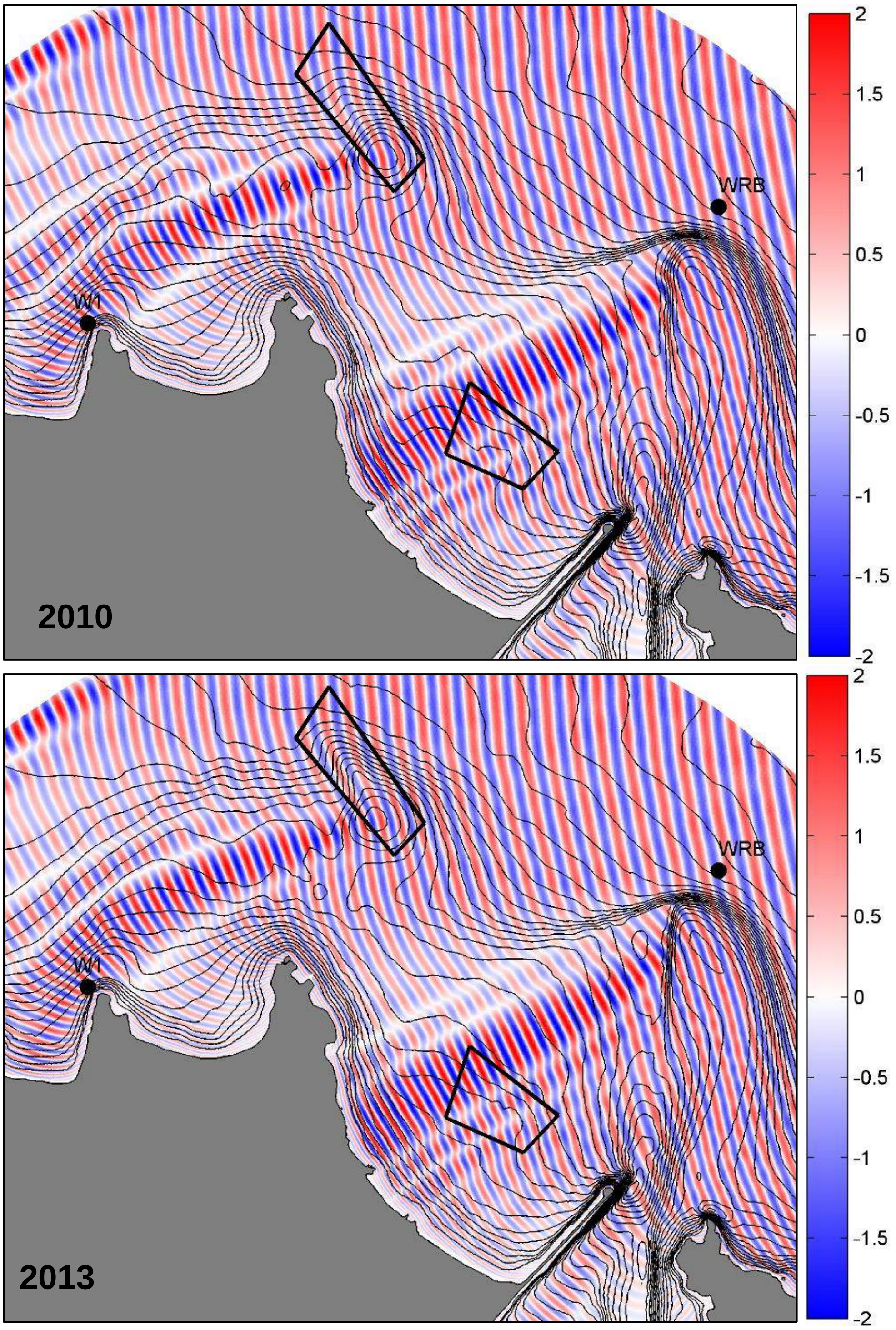

Figure 3.12 Predicted wave crest patterns for a monochromatic wave event Hs=2.6 m Dir=75 deg, Tp=12 sec., over the 2010 (top) and 2013 (bottom) bathymetries.

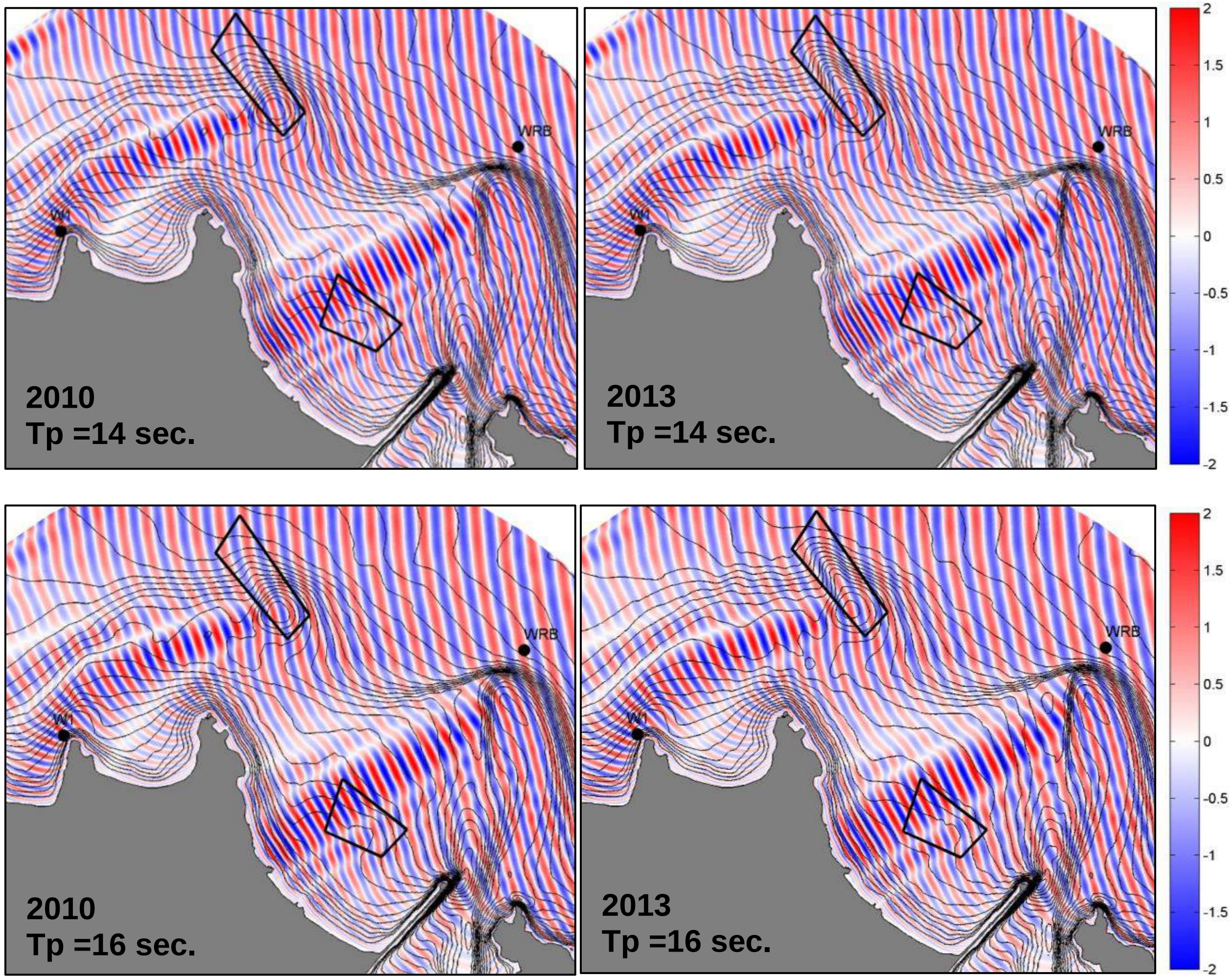

Figure 3.13 Predicted wave crest patterns for the same monochromatic wave event as presented in Figure 3.12 (Hs=2.6 m Dir=75 deg), with longer wave periods of 14 (top) and 16 (bottom) seconds, over the 2010 (left) and 2013 (right) bathymetries.

3.2. Proposed disposal regime for Q1-Q2 2014

The first step in the management plan for a volume up to 100,000 m^3 to be placed at Heyward ground was to sector the area into 50 cells (10 by 5) of approximately 70 by 70 meters (see Figure 3.14). The coordinates of each cell centre, as a 'target' for the dredge, are given in Table 3.2.

The bathymetric changes from 2010 and 2013 bathymetries (Figure 3.8) show that much of the recent sediment disposal was northwest of the circular mound, thus forming a ridge that was not present in 2010. Associated volumetric changes per cell are quantified in Figure 3.15 and Table 3.4 for reference. To date, this feature does not appear to significantly disturb the wave focusing processes or negatively affect the surf conditions at Whareakeake.

The plan conserves the well-defined mound and focusing process as a key requirement. The proposed program for the first half of 2014 is provided in Tables 3.5 and 3.6 and Figures 3.16 and 3.17. The quantities are expressed as actual sediment volumes and number of loads (assuming 600 m^3 per load). The existing circular mound is loaded by ~60,000 m^3. The remaining volumes are placed predominantly in the northwest end of the mound ground in relatively deep water (~20-22 m, ~25,000 m^3), with some sediment also placed along the northern and southernmost cells. No additional sediment is to be placed over the central cells to avoid a build-up of the existing ridge feature.

The circular mound is known to be highly dynamic due to sediment mobilization by wave action, and it is expected that active erosion will occur. Analysis of historical bathymetries and long-term model simulations indicates that the feature tends to migrate westwards (and thus out of the ground) with estimated annual ground volumetric losses ranging from 10,000 to 40,000 m^3/year, depending on the prominence of the feature. The proposed volume is expected to be sufficient to sustain a well-defined mound but is low enough to avoid any adverse impact on the focusing process such as sharp wave redirection or wave breaking (except perhaps under extreme storm conditions). A smaller fraction of the total volume is allocated to the north-western half of the ground to account for the reduced potential for sediment mobilization in deeper water of ~20-22 m.

An estimation of the Heyward Point bathymetry after disposal of 100,000 m^3 of sediments (at once) according to the disposal program is provided in Figure 3.18. However, this estimation will not represent the actual final morphology, particularly over the mound, as intermediate morphological adjustments will occur in response to the wave climate. This bathymetry should rather be considered as a worst case scenario, and used to assess potential modifications of the wave focusing processes.

The predicted wave fields for the existing and post-disposal bathymetries are compared in Figures 3.19 and 3.20. The shallower circular mound post-disposal locally narrows and enhances the focusing process directly over the ground, but this generally tends to results in slightly smaller heights in its lee, due to the additional friction. The effective reduction remains very limited, around 10 cm, and is progressively attenuated moving closer to the shore. Note that this should be considered as an upper limit since simulated depth levels over the mound are unlikely to be reached due to progressive morphological adjustments. Actual wave height modifications are therefore expected to be an order of magnitude smaller than those redicted here.

Some new refraction and focusing develops over the relatively shallower northwest half of the ground post-disposal, with a band of slightly enhanced wave heights (~ +10 cm) in the lee of the ground, progressively dissipating towards the coast. The resulting wave conditions along the 6 m depth contour for the different bathymetries and events are compared in Figure 3.21. Predicted wave heights for the existing and post-disposal bathymetries are very similar, with slight magnitude differences of the order of centimetres. The successive wave conditions at the A0, WRB and W1 sites are provided in Table 3.7 (see Table 3.2 for existing bathymetry). Overall, modifications of the wave conditions at Whareakeake are expected to be insignificant.

A new CGWAVE model including the post-disposal bathymetry was implemented to investigate the wave crest patterns. The predictions for the existing and post-disposal bathymetries for the same surfing event as modelled in Section 3.1 are compared in Figure 3.22. The key focusing process over the mound is conserved, although slightly narrowed. Modifications of the northwest part of the ground morphology are not marked enough to force any significant direction or height gradient along individual crests and do not appear to affect the primary focusing over the circular mound.

Overall, the model results suggest that the proposed program for the disposal of 100,000 m^3 of sediment into the Heyward ground allows conservation of the key wave processes responsible for improved surfing conditions at Whareakeake. To account for the different degrees of sediment mobility over the ground due to the depth-dependent wave action, it is recommended to initially focus the disposal activities over the circular mound. It is suggested to complete about half of the disposal planned over the circular mound before starting to progressively load the deeper cells. The disposal of new sediment should ideally happen relatively homogenously over the ground. It should generally be avoided to dispose successive loads over the same cell but rather progressively load each cell 1 load at a time, to ensure smooth adjustment of the ground morphology.

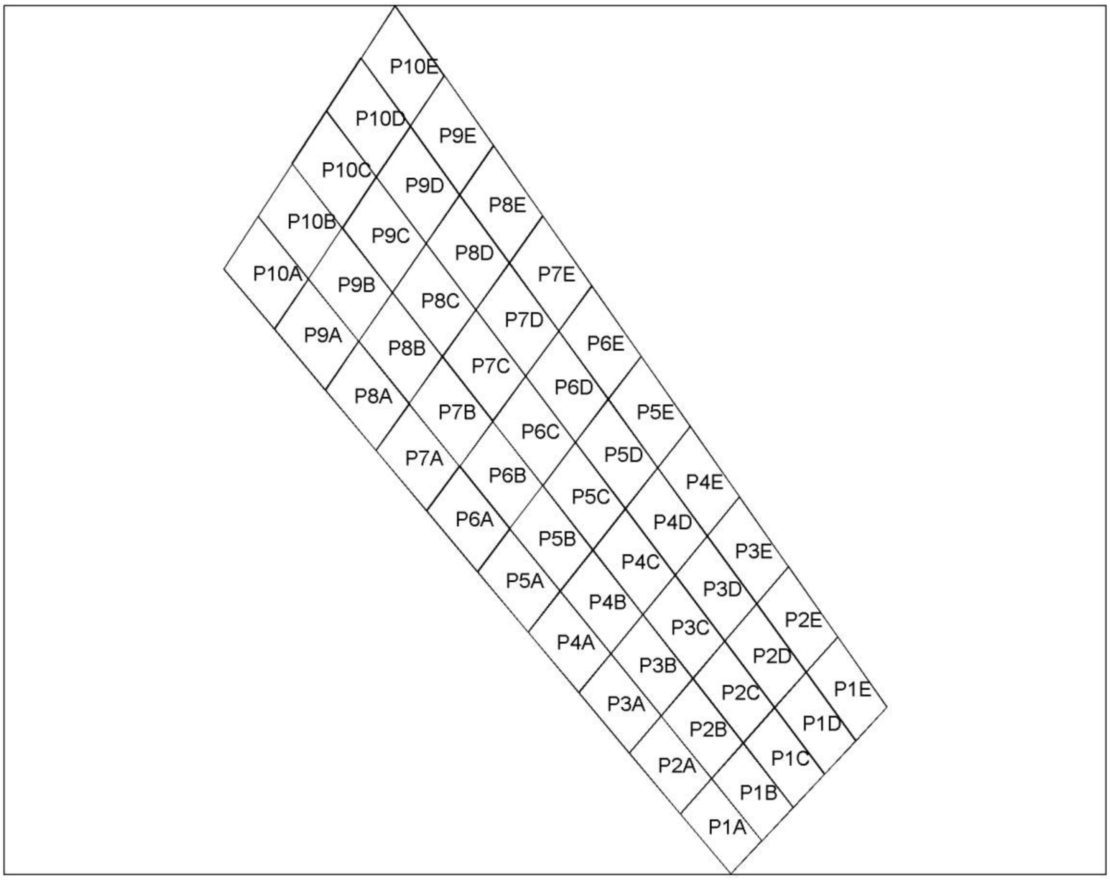

Figure 3.14 Delimitation of the 50 cells considered over the Heyward disposal ground.

Table 3.3 Coordinates of cell centres. Cell delimitation is shown in Figure 3.14.

Cell Name	Centre Longitude	Centre Latitude
P1A	170.7014	-45.7489
P1B	170.7019	-45.7485
P1C	170.7025	-45.7481
P1D	170.7030	-45.7477
P1E	170.7036	-45.7473
P2A	170.7005	-45.7482
P2B	170.7011	-45.7477
P2C	170.7016	-45.7473
P2D	170.7022	-45.7469
P2E	170.7028	-45.7465
P3A	170.6997	-45.7474
P3B	170.7003	-45.7470
P3C	170.7008	-45.7465
P3D	170.7014	-45.7461
P3E	170.7020	-45.7456
P4A	170.6989	-45.7467
P4B	170.6994	-45.7462
P4C	170.7000	-45.7457
P4D	170.7006	-45.7453
P4E	170.7011	-45.7448
P5A	170.6980	-45.7459
P5B	170.6986	-45.7454
P5C	170.6992	-45.7449
P5D	170.6998	-45.7444
P5E	170.7003	-45.7439
P6A	170.6972	-45.7452
P6B	170.6978	-45.7446
P6C	170.6984	-45.7441
P6D	170.6989	-45.7436
P6E	170.6995	-45.7431
P7A	170.6963	-45.7444
P7B	170.6969	-45.7439
P7C	170.6975	-45.7433
P7D	170.6981	-45.7428
P7E	170.6987	-45.7422
P8A	170.6955	-45.7436
P8B	170.6961	-45.7431
P8C	170.6967	-45.7425
P8D	170.6973	-45.7420
P8E	170.6979	-45.7414
P9A	170.6947	-45.7429
P9B	170.6953	-45.7423
P9C	170.6959	-45.7417
P9D	170.6965	-45.7411
P9E	170.6971	-45.7405
P10A	170.6938	-45.7421
P10B	170.6945	-45.7415
P10C	170.6951	-45.7409
P10D	170.6957	-45.7403
P10E	170.6963	-45.7397

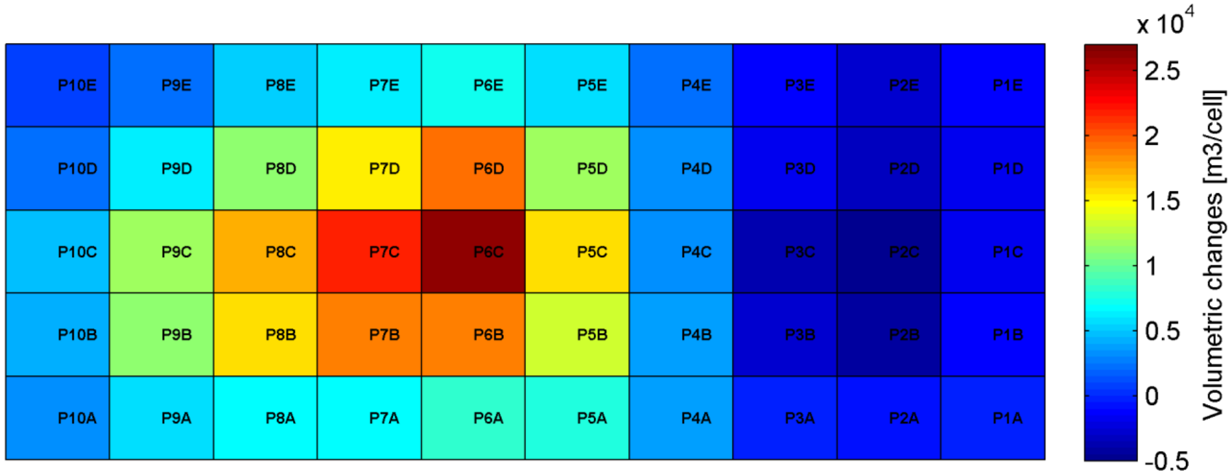

Figure 3.15 Volumetric changes of each cell from 2010 to 2013. The cell extents are shown in Figure 3.14.

Table 3.4 Volumetric changes of each cell from 2010 to 2013. The cell extents are shown in Figure 3.14.

Volumetric Changes per cell [m^3]									
P10E	P9E	P8E	P7E	P6E	P5E	P4E	P3E	P2E	P1E
P10D	P9D	P8D	P7D	P6D	P5D	P4D	P3D	P2D	P1D
P10C	P9C	P8C	P7C	P6C	P5C	P4C	P3C	P2C	P1C
P10B	P9B	P8B	P7B	P6B	P5B	P4B	P3B	P2B	P1B
P10A	P9A	P8A	P7A	P6A	P5A	P4A	P3A	P2A	P1A
830.33	2045.23	5026.44	6492.38	7069.88	5821.72	2091.09	-1085.50	-2574.51	-1305.91
2339.24	6038.04	11204.49	15383.03	19101.89	11542.13	3460.14	-1573.46	-3336.52	-1612.83
4652.56	11767.37	17320.46	21919.39	26231.41	15652.06	3215.11	-3716.51	-5021.39	-1981.38
4489.12	11145.06	15944.50	18752.21	18511.25	13494.85	3584.26	-2885.82	-4174.27	-1292.44
3171.17	5955.41	6959.76	6958.89	8424.40	7832.12	3829.54	-260.52	-846.71	-186.93

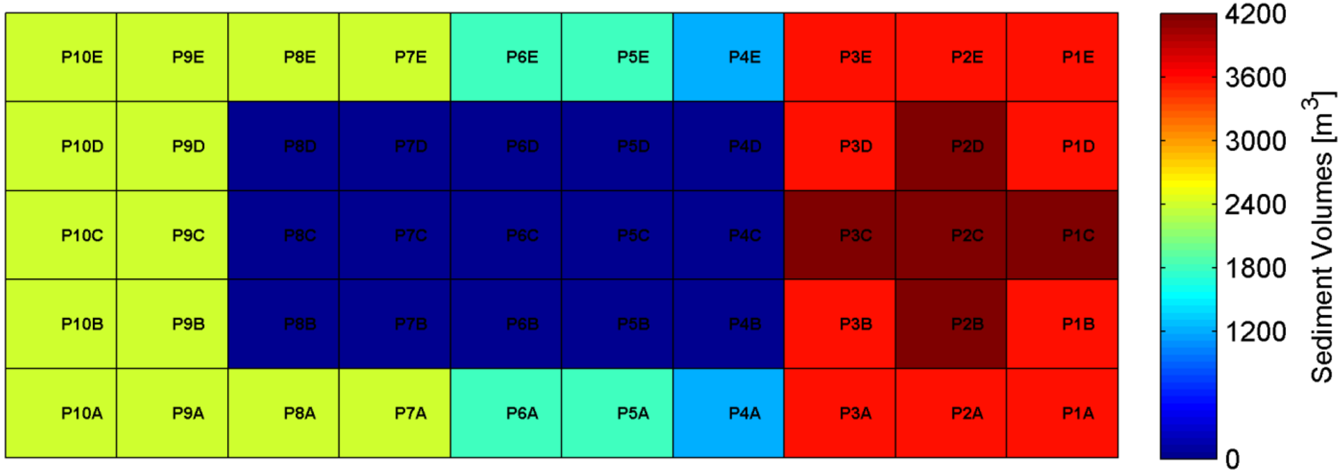

Figure 3.16 Proposed dumping plan for 100,000 m^3, for Q1 and Q2 of 2014.

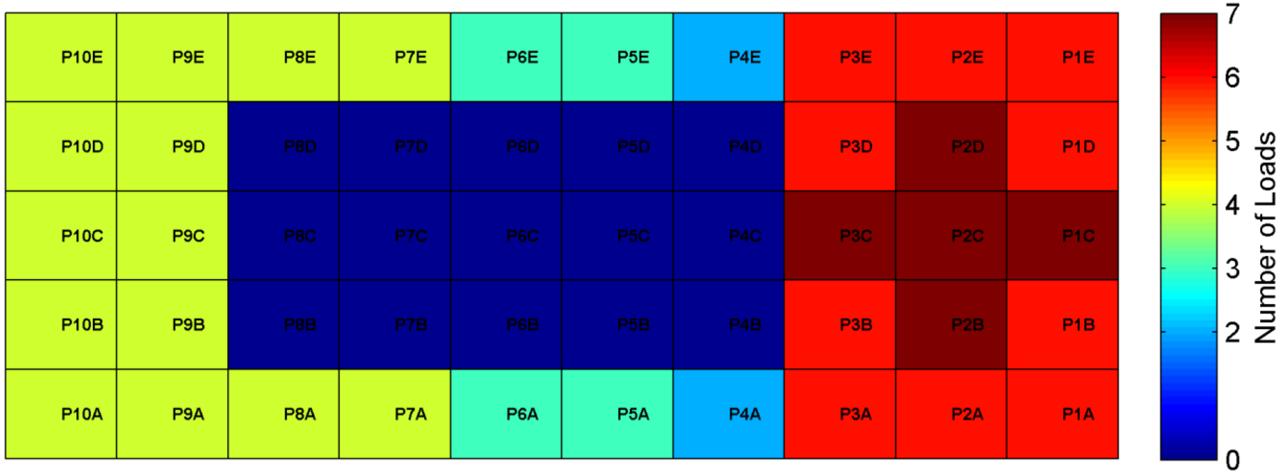

Figure 3.17 Proposed dumping plan for 100,000 m^3, for Q1 and Q2 of 2014 expressed in number of boat loads, assuming 1 load is 600 m^3. .

Table 3.5 Proposed dumping plan for 100,000 m^3, for Q1 and Q2 of 2014.

Volumetric Changes per cell [m^3]									
P10E	P9E	P8E	P7E	P6E	P5E	P4E	P3E	P2E	P1E
P10D	P9D	P8D	P7D	P6D	P5D	P4D	P3D	P2D	P1D
P10C	P9C	P8C	P7C	P6C	P5C	P4C	P3C	P2C	P1C
P10B	P9B	P8B	P7B	P6B	P5B	P4B	P3B	P2B	P1B
P10A	P9A	P8A	P7A	P6A	P5A	P4A	P3A	P2A	P1A
2400	2400	2400	2400	1800	1800	1200	3600	3600	3600
2400	2400	0	0	0	0	0	3600	4200	3600
2400	2400	0	0	0	0	0	4200	4200	4200
2400	2400	0	0	0	0	0	3600	4200	3600
2400	2400	2400	2400	1800	1800	1200	3600	3600	3600

Table 3.6 Proposed dumping plan for 100,000 m^3, for Q1 and Q2 of 2014, expressed in number of boat loads, assuming 1 load is 600 m^3. .

Number of loads (1 load =600 m^3)									
P10E	P9E	P8E	P7E	P6E	P5E	P4E	P3E	P2E	P1E
P10D	P9D	P8D	P7D	P6D	P5D	P4D	P3D	P2D	P1D
P10C	P9C	P8C	P7C	P6C	P5C	P4C	P3C	P2C	P1C
P10B	P9B	P8B	P7B	P6B	P5B	P4B	P3B	P2B	P1B
P10A	P9A	P8A	P7A	P6A	P5A	P4A	P3A	P2A	P1A
4	4	4	4	3	3	2	6	6	6
4	4	0	0	0	0	0	6	7	6
4	4	0	0	0	0	0	7	7	7
4	4	0	0	0	0	0	6	7	6
4	4	4	4	3	3	2	6	6	6

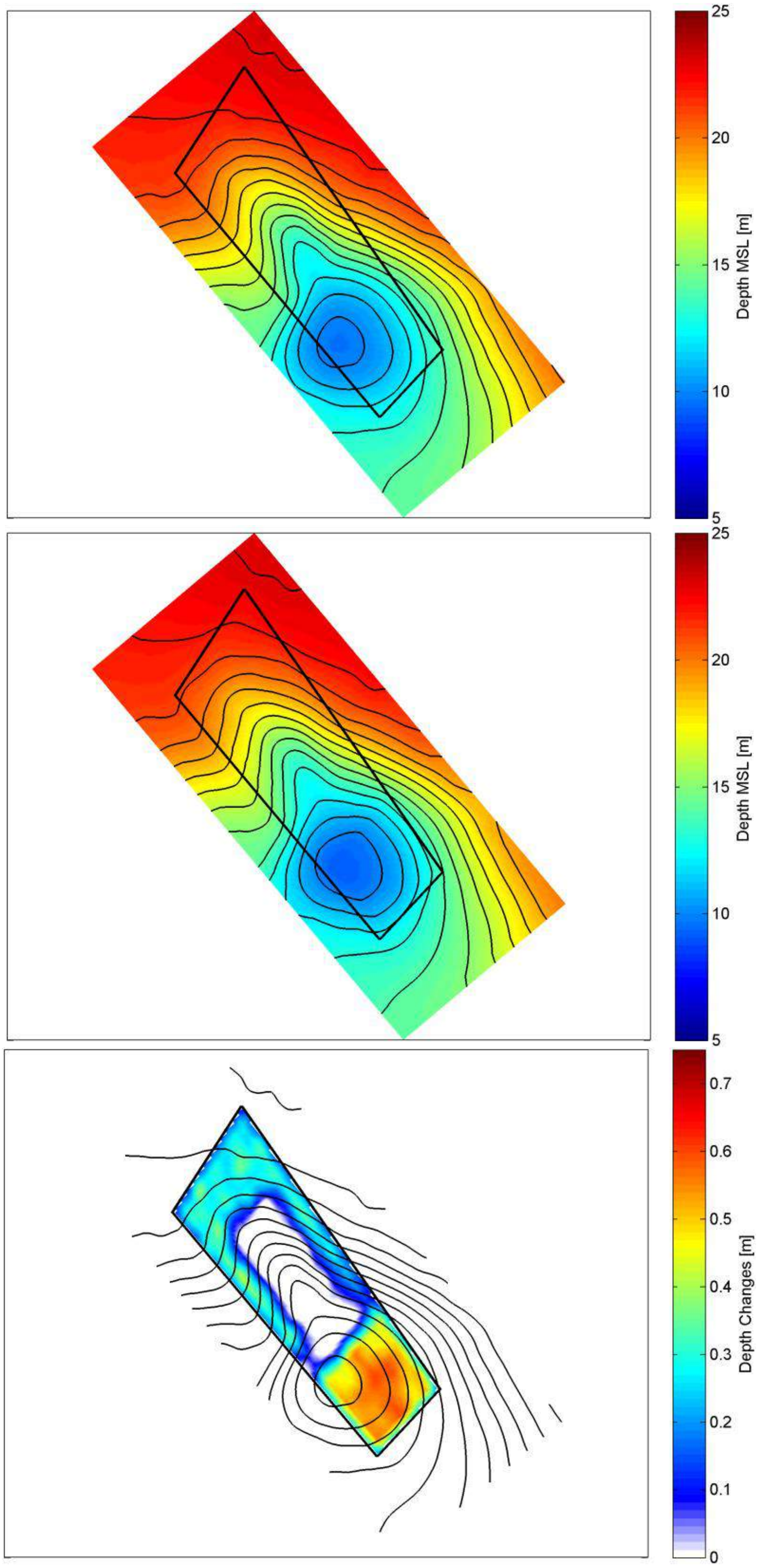

Figure 3.18 Comparison of existing bathymetry (top) and bathymetry with the 100,000 m^3 of sediment added over the ground following the dumping plan (middle). The bottom picture shows the depth difference.

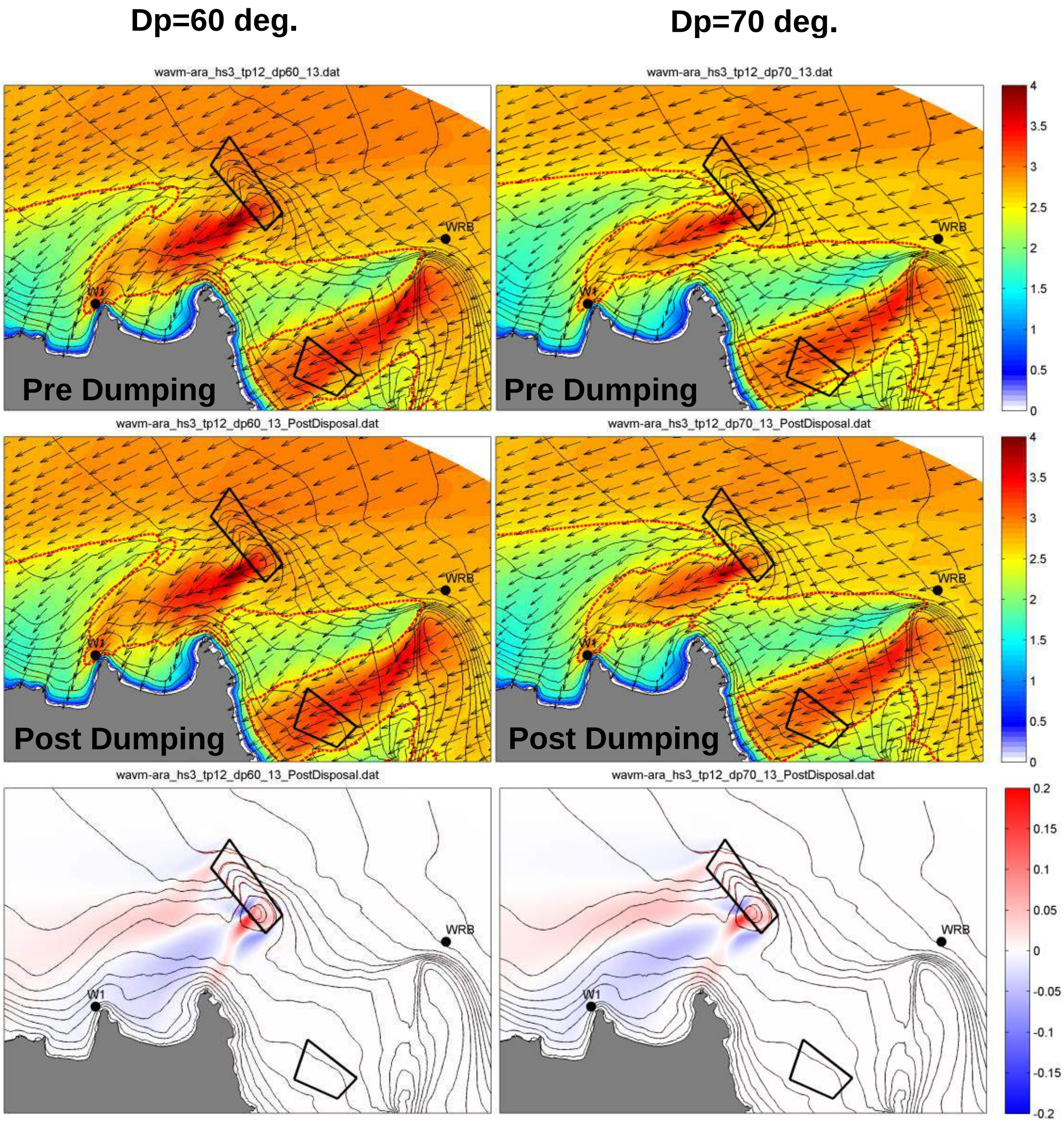

Figure 3.19 Predicted significant wave heights for offshore directions of 60 (left) and 70 (right) degrees over the existing (2013, top) and post-disposal (middle) bathymetries and differences (bottom). The dotted red line is the 2.5 m wave height contour (top, middle). In difference maps (bottom), positive values indicate wave height larger over the 2013 bathymetry than over the 2010 bathymetry. Existing contours are shown in black and post-disposal contours are shown in red.

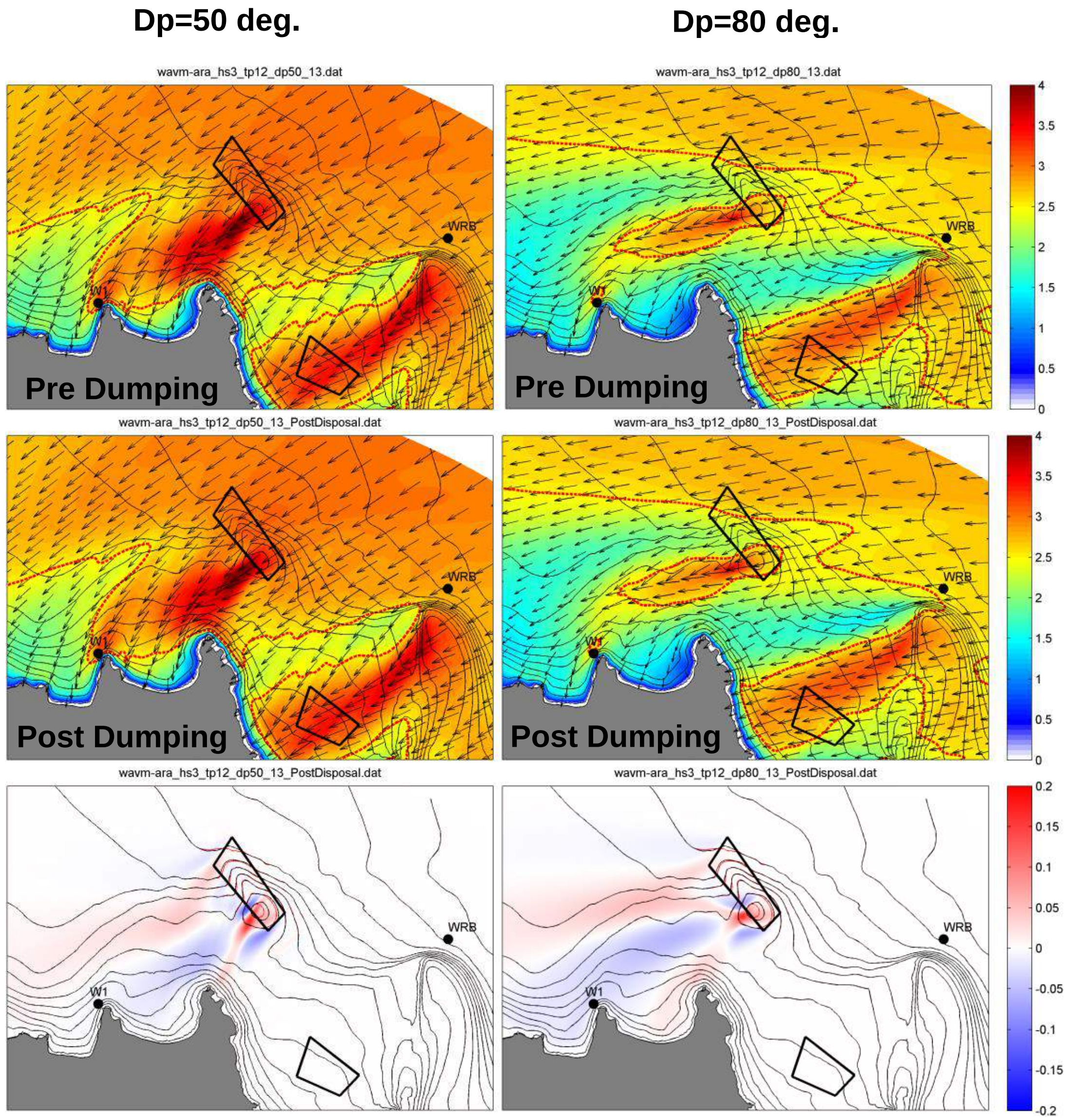

Figure 3.20 Predicted significant wave heights for offshore directions of 50 (left) and 80 (right) degrees over the existing (2013, top) and post-disposal (middle) bathymetries and differences (bottom). The dotted red line is the 2.5 m wave height contour (top, middle). In difference maps (bottom), positive values indicate wave height larger over the 2013 bathymetry than over the 2010 bathymetry. Existing contours are shown in black and post-disposal contours are shown in red.

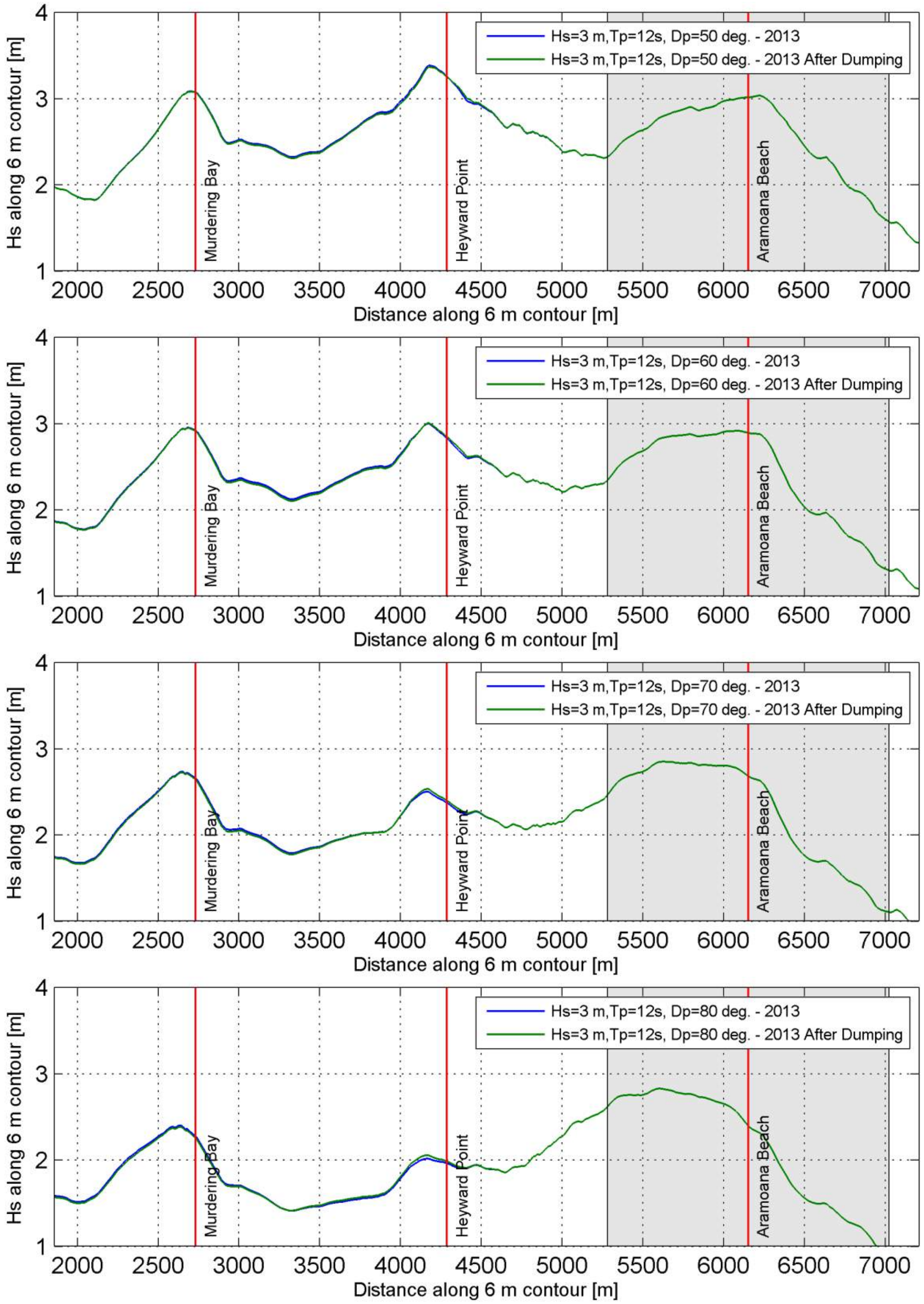

Figure 3.21 Significant wave heights along the 6 m contour for a wave incidence of 50, 60, 70, and 80 degrees over the existing (2013) and post-disposal bathymetries.

Table 3.7 Wave conditions at the A0, WRB and W1 sites for all the simulated idealized wave events over the post-disposal bathymetry. The wave conditions over the existing (2013) bathymetry are provided in Table 3.2. Significant wave heights Hs are in meters, Peak direction Dp are degrees, and peak periods Tp in seconds.

2013 post-disposal										
A0 - Site				**WRB - Site**				**W1 - Site**		
Hs (A0)	**Dp (A0)**	**Tp (A0)**		**Hs (WRB)**	**Dp (WRB)**	**Tp (WRB)**		**Hs (W1)**	**Dp (W1)**	**Tp (W1)**
3.0	90	12.0		2.8	88	11.9		2.0	17	11.9
3.0	80	12.0		2.5	84	11.9		2.3	17	11.9
3.0	70	10.0		2.6	72	9.9		2.2	16	10.1
3.0	70	12.0		2.6	76	11.9		2.7	16	11.9
3.0	70	14.0		2.7	84	14.1		2.6	16	14.2
3.0	70	16.0		2.7	84	16.0		2.7	16	16.0
3.0	60	10.0		2.6	64	9.9		2.6	16	10.1
3.0	60	12.0		2.7	68	11.9		2.8	16	11.9
3.0	60	14.0		2.8	68	14.1		3.0	16	14.2
3.0	60	16.0		2.8	72	16.0		3.0	16	16.0
3.0	50	12.0		2.8	60	11.9		2.9	15	11.9
3.0	40	12.0		2.9	52	11.9		2.9	15	11.9

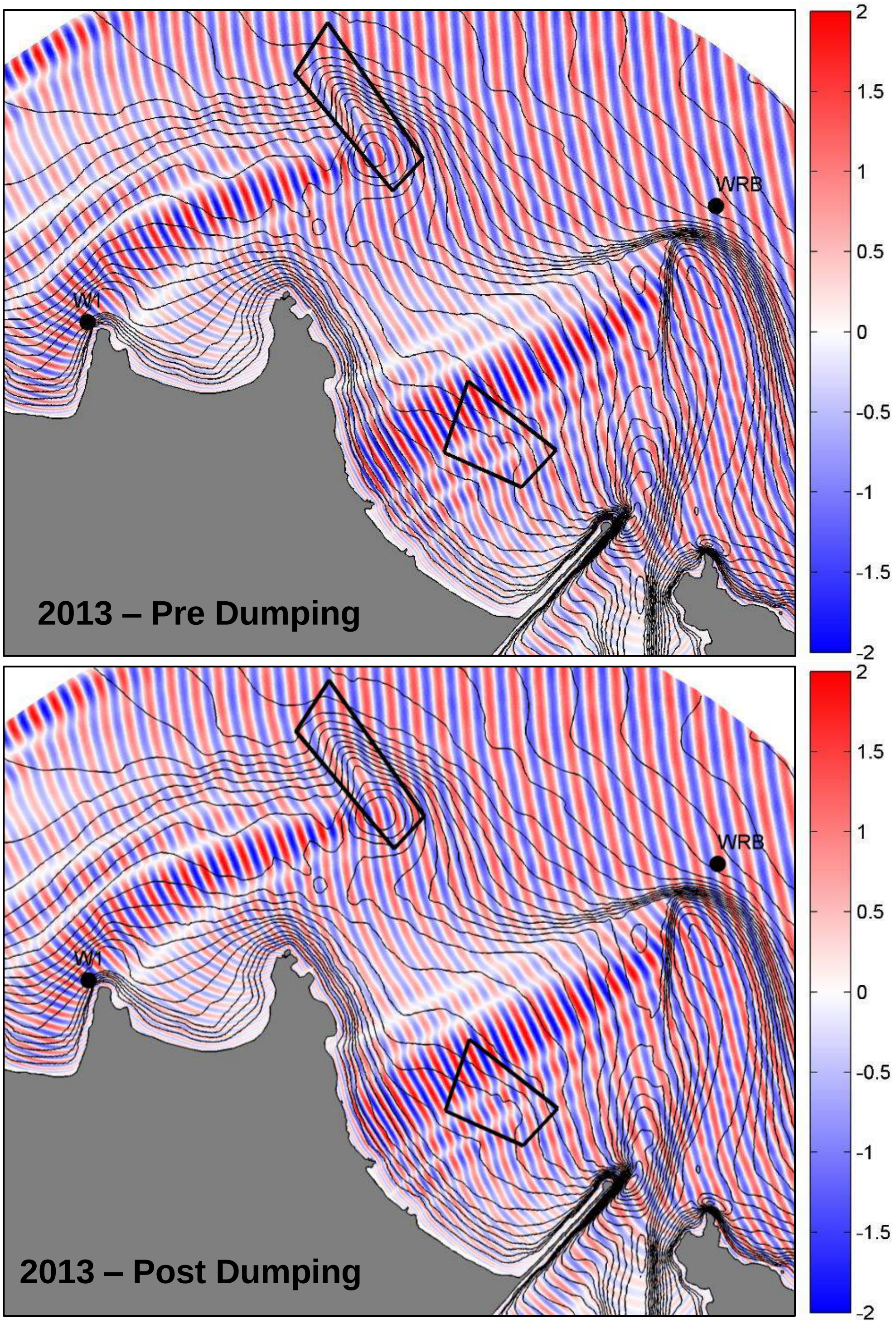

Figure 3.22 Predicted crest patterns for a monochromatic wave event Hs=2.6 m Dir=75 deg, Tp=12 sec., over the existing (top) and post dumping (bottom) bathymetries.

4. REFERENCES

Demirbilek, Z. and Panchang, V. (1998). “CGWAVE: A coastal surface water wave model of the mild slope equation,” Technical Report CHL-98-26.

Holthuijsen, L., 2007. Waves in Oceanic and Coastal Waters. Cambridge University Press. ISBN 0521860288, 9780521860284.