PORT OTAGO WAVE AND SEDIMENT DYNAMICS STUDY

Recommendations on the long term strategy for inshore dredging disposal

Prepared for Port Otago Limited

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MetOcean Solutions Ltd: Report P0140-04

April 2016

Report status

Version	Date	Status	Approved by
RevA	05/02/2016	Draft for internal review	Weppe
RevB	06/02/2016	Draft for client review	McComb
RevC	02/03/2016	Updated draft for internal review	Weppe
RevD	14/02/2016	Draft for consultation	McComb
RevE	19/04/2016	Updated draft for consultation	McComb
Rev0	24/06/2016	Approved for release	McComb

It is the responsibility of the reader to verify the currency of the version number of this report.

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1. INTRODUCTION

Port Otago Ltd has commissioned MetOcean Solutions Ltd (MSL) to undertake a program of measurements and numerical modelling of the waves, currents and sediment dynamics at the Otago Harbour entrance. These studies are required to support a resource consent application for the future deposition of material from dredging operations. The annual maintenance and incremental capital dredging required for safe navigation in the Otago Harbour averages out at approximately 200,000 m^3/year, and historically, Port Otago has used three nearshore grounds to deposit the dredged material (Figure 1.1). The maximum permitted annual volume for disposal has been 450,000m^3 across three inshore sites. The purpose of the present studies is to identify the optimum nearshore sites for long term, sustainable

The field measurement program has been described in MSL Report P0140-02, while the numerical modelling methodology and validation results are provided in MSL Report P0140-03. The present report applies the validated model solutions to determine the optimum nearshore grounds for long term disposal of the dredged material and the recommendations for adaptive management of those grounds over a 35-year consent period.

This report is structured as follows. An overview of the existing sediment dynamics is provided in Section 2, based on the prior model studies and the historical dredging records. In Section 3, consideration is given to the future dynamics including a deepened shipping channel (i.e. NextGen) and the recommendations for sustainable deposition of the dredged material.

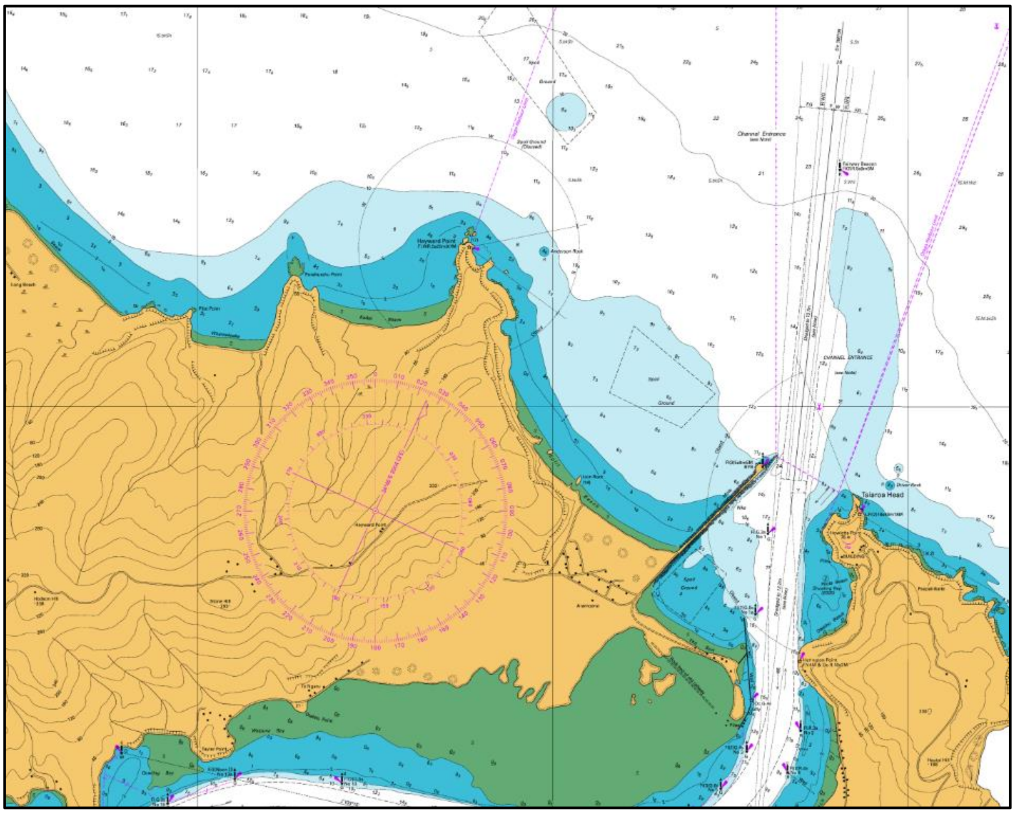


Figure 1.1 Nautical chart of the study area (portion of NZ 6612 Otago Harbour chart) showing the Harbour channel, delta bar, existing disposal grounds at Heyward Point, Aramoana Beach and Shelly Beach (dotted polygons).

2. AN OVERVIEW OF THE DYNAMICS

The coastal and nearshore region of interest encompasses the mostly sandy shoreline from Taiaora Head to Purakaunui, including the Otago Harbour Entrance, Aramoana Beach, also known as “The Spit”, Heyward Point and Whareakeake Point, also known as Murdering Beach (Figure 1.1). This region lies within Blueskin Bay, north of the Otago peninsula and is exposed to a range of oceanographic forces at regional and local scales.

The wave climate along the southeast coast of New Zealand consists of frequently energetic southerly swells combined with locally-generated events from the northeast, as well far-field swells from the northeast. The position on the north side of the Otago Peninsula provides a degree of shelter from the southerly swells but the site remains directly exposed to northeast wave events. The average wave height near Aramoana Beach is around 1.0 m. The regional hydrodynamic regime is influenced by a north-directed geostrophic current that flows up the South island’s eastern coast, known as the Southland Current (e.g. Heath, 1972). The model simulations presented in MSL Report P0140-03 showed that the Southland current can extend to influence the study region, modulated by the formation of a counter-clockwise eddy in Blueskin Bay due to the Southland Current bifurcation past Cape Saunders.

The combination of the Southland Current and frequent southerly swells is expected to drive a north-directed drift of sand along a narrow zone of inner shelf (Single and Kirk, 1994, Single et al., 2010). The predominant source of sediment feeding this littoral drift is the Clutha River (~3Mt/year) with additional contributions from Taieri River (~0.6 Mt/year) and Southland Shelf (0.4 Mt/year) (Carter, 1986). The configuration of the Blueskin Bay region, set back from the Outer Otago shelf, combined with relatively low wave energy due to sheltering from the Peninsula make the Bay a depositional environment within this predominant northward sediment drift. The dominance of a single source of sediment along this coast results in a relatively homogenous sediment type throughout the Otago Harbour Entrance region; consisting of well-sorted fine to medium sand with size range 0.2-0.3 mm (Single and Kirk, 1994, Single et al., 2010). Note that coarser and finer material are also present throughout the region, although in much smaller proportions, likely due to reworking of relict sea floor deposits (i.e. the coarser fraction) and inputs from river borne suspended sediment and locally derived stripping from the loess cover off the Otago Peninsula (i.e. the finer fraction) (Kirk,1980).

Within this regional pattern, a range of key morphological features interact with the local wave and sediment transport processes to govern the local dynamics. Key functional features of the coastal system are outlined as follows:

- The magnitude of the regional northward (longshore) sediment transport drift, which is the main source of sediment feeding the coastal system was estimated to be at least of order 450-500,000 m^3/year by Kirk (1980). The general order of magnitude was confirmed in the regional sediment budget of Carter (1986) which suggested a northward sediment drift magnitude reaching the Otago peninsula of approximately 1.1 Mt/year, which is equivalent to ~700,000 m^3/year (assuming a dry sand density of 1600 kg/ m^3). When reaching the Otago Harbour Entrance region, this sediment transport flux interacts with the strong Harbour flows with a fraction ducted into the harbour and another bypassing the entrance and feeding the northern beaches (i.e. Aramoana Beach and further north). Note on a larger scale, the Blueskin Bay is expected

to act as a relative trap to the sediment moving northward (Single and Kirk, 1994, Single et al., 2010).

- The large tidal compartment within the Otago Harbour combined with a constricted throat result in strong tidal current regime in the entrance region, notably with a strong ebb jet during flushing (e.g. Old and Vennel, 2001). The interaction of the tidal hydrodynamics with the ambient sediment drift was found to be a dominant cause for lower harbour sedimentation with sediment being ducted within the harbour basin by strong flood flows. On another hand, the strong ebb jet locally disrupts the ambient longshore sediment transport and formed a large submerged ebb delta bar (2 km long) just east of the entrance. Kirk (1980) estimates that this feature captures ~10-15% of the incoming sediment transport flux. The shipping channel partially truncates this delta bar and the locally deeper waters generally act as a trap for sediment transported along the coast. The outer channel is thus subject to sediment accumulation over time and requires regular maintenance dredging, notably along its margins with the ebb delta bar. The annual maintenance dredging volume over the outer channel region is 60,000-70,000 m^3 over the last decade.

- Maintenance and incremental capital dredging volumes have been historically disposed of at three disposal sites near the harbour entrance, at Aramoana (Spit) Beach, Shelly Beach and Heyward grounds (Figure 1.1). Over the last 30 years, the Aramoana ground received 3.4 M m^3 (average 111,000 m^3/year), the Shelly ground received ~0.5 M m^3 (average 17,000 m^3/year) and the Heyward ground received 2.1M m^3 (average 70,000 m^3/year). In the last 5 years, disposal has occurred predominantly at the Heyward ground (~130,000 m^3/year) with reduced volumes disposed at Aramoana ground (~15-20,000 m^3/year). Over time, the cumulative sediment disposal has created distinct sediment mounds, which change with time and deposition rates. These mounds are key morphological features as they interact with the local wave and sediment transport fields.

A detailed characterisation of the local wave and sediment dynamics at the disposal sites was provided in MSL Report P0140-03, based on empirical analysis of historical bathymetries combined with numerical model studies of the wave and sediment transport. That study provides an important quantitative understanding of the morphological behaviour of the mounds over the last 10-15 years; providing key baseline data that can be applied to the future management. The main findings are summarised below for Aramoana and Heyward grounds.

- The Aramoana ground has been used for regular disposal over the last 30 years. The sequence of historical bathymetries shows a prominent mound from 2002 to 2007 progressively migrating onshore and welding to the nearshore zone from 2007 to 2013, with the mound concurrently smoothing out (Figure 2.1 and Figure 2.2). This behaviour coincides with the progressive reduction of disposal volumes from 80-100,000 m^3/year from 2002-2007 down to ~15,000 m^3/year (Table 2.1). Estimations of the volumes dispersed from the ground are ~100,000 m^3/year from 2002 to 2009, reducing to ~50,000 m^3/year in 2010-2013 and further reducing to ~20,000 m^3/year for 2013-2015 (Table 2.2). The onshore migration of disposed sediment nourishes the beach system and adds to the natural supply of sediment from the east. It is noted that the dredged sediments are sourced from the littoral system, which have a relatively homogenous sediment texture, and therefore the disposal activities have not significantly changed the textural sediment from the surrounding seabed (Single and

Kirk, 1994. Bunting et al., 2003). This sediment supply has led to a beach state that has shown an accretion trend over the years since the mole construction (e.g. Single et al., 2010). That being said, the morphological model studies showed that the system can be subject to energetic wave conditions and wave-driven circulation, with strong westward transport fluxes developing past Heyward Point. Analysis of sediment transport at key transects along Aramoana Beach indicates that storm activity can readily remove sediment from the Aramoana Beach system and transport it west, past Heyward Point.

- Historical disposal at the Heyward ground was done predominantly in its southeast corner, which formed a distinct circular mound. Historical bathymetries clearly indicate the mobilization of sediment over the shallower parts of the mound, and the sediments are actively transported westwards and onshore (Figure 2.1 and Figure 2.2). Recent disposal records indicate an average disposal rate of ~35-40,000 m^3/year from 2002-2009 increasing to ~150,000 m^3/year over the last 5 years. Estimates of the volumetric changes yields sediment losses of ~30,000 m^3/year from 2002 to 2009, increasing to ~50-70,000 m^3/year more recently (Table 2.2).

Another key feature of the coastal system is the development of intense wave focusing over the ebb delta bar and over the disposal mounds. The wealth of studies to date has confirmed that these features are conducive to the formation of high quality surfing waves at Aramoana Beach and Whareakeake Point. These are both surf breaks of national significance under Policy 16 of the New Zealand Coastal Policy Statement 2010.

- For Aramoana Beach, the intense wave refraction and focusing developing over the submerged delta bar and channel margins directs a zone of focused wave energy towards the beach (Figure 2.3). Some additional wave focusing/shoaling can develop over the ground when a distinct mound is present (see Kilpatrick, 2005; Scarfe et al., 2009). During the wave refraction over the delta bar, the wave crests develop a phase offset, effectively meaning the crests snap and exhibit a segmented character, which propagates toward the beach. The combined process of wave energy focusing and wave crest snapping are the two key processes responsible for the high-quality surfing waves at Aramoana (see MSL Report P0068).

- Intense wave focusing also develops over the shallow circular mound at the Heyward ground. Similar to the process occurring over the delta bar, the wave focusing results in a distinct beam of increased wave energy in the lee of the mound. Interestingly, this area of enhanced wave energy coincides with Whareakeake Point during typical surfing wave events; providing locally increased wave heights and thereby benefiting the surf conditions.

- The preservation of the functional aspects of the swell corridors and the conservation of the key morphological features is an important concern within the sustainable management of the disposal activities. It is noted here that the recent sediment disposal at the Heyward ground has applied an adaptive disposal management regime with regular assessment of the effects of disposal on surfing conditions to ensure conservation of the key features and wave processes (MSL Reports P0140-05 a,b,c,d,e).

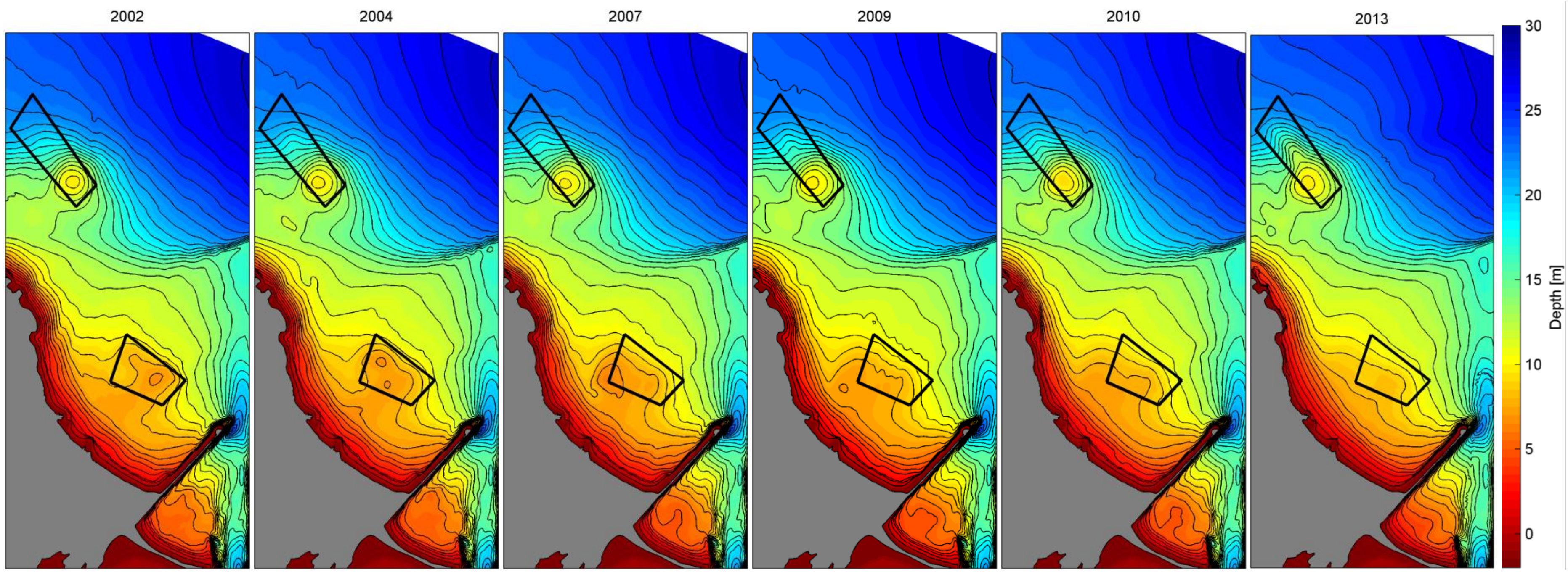


Figure 2.1 Sequence of bathymetries generated from soundings of the existing disposal grounds (shown in black) from 2002 to 2013.

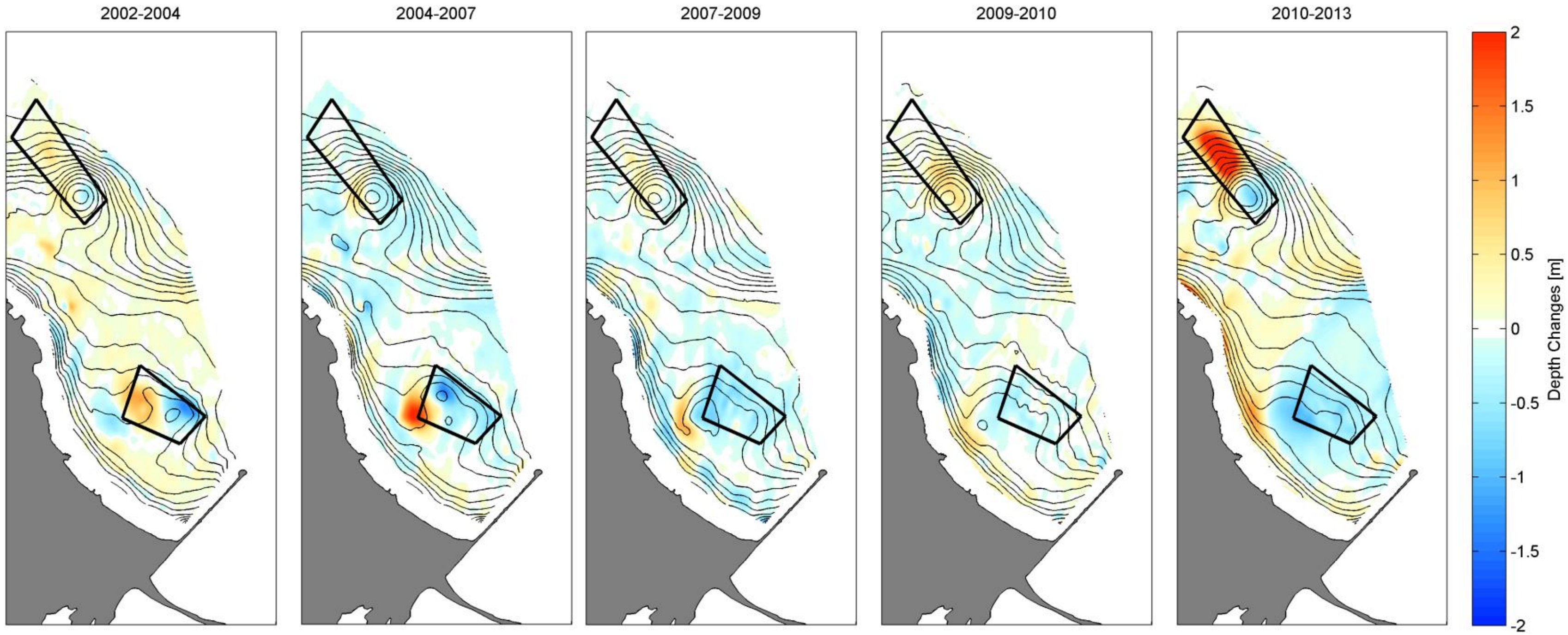


Figure 2.2 Sequence of bathymetric changes between surveys shown in Figure 2.1. Existing disposal grounds are shown in black. Negative changes indicate erosion and positive changes indicates deposition.

Table 2.1 Sediment disposal records (provided by Port Otago Ltd).

Year	Heyward [m3]	Aramoana [m3]
2002	47,455	141,406
2003	39,180	83,789
2004	35,880	89,750
2005	35,876	149,684
2006	990	43,317
2007	33,525	62,838
2008	55,019	14,665
2009	55,880	18,430
2010	109,204	23,063
2011	119,841	13,617
2012	199,590	13,269
2013	117,594	17,035
2014	173,380	3,825
Last 10 yr Total	900,899	359,743
Last 10 yr Average	90,090	35,974
Last 5 yr Total	719,609	70,809
Last yr Average	143,922	14,162

Table 2.2 Summary of the volumetric analysis of the historical bathymetry dataset. Net ground volume balances are estimated by subtracting the volumes disposed over each period from the volumetric changes defined from the successive historical bathymetries. A positive volume indicates a net gain of sediment and negative volume indicates a net loss of sediment.

		Vol. disposed Aramoana	Vol. disposed Heyward	Vol. change ground Aramoana	Vol. change ground Heyward	No of months	Vol. net change Aramoana	Vol. net change Heyward
		[m3]	[m3]	[m3]	[m3]		[m3/year]	[m3/year]
Long-term Estimations								
Sept. 2002	Jan. 2009	50,7000	225,000	-188,000	46,500	76	-110,000	-28,200
May 2010	Nov. 2013	48,100	459,000	-138,000	296,000	42	-53,000	-46,400
Nov. 2013	Nov. 2015	0	414,000	-41,400	284,000	25	-19,900	-62,600

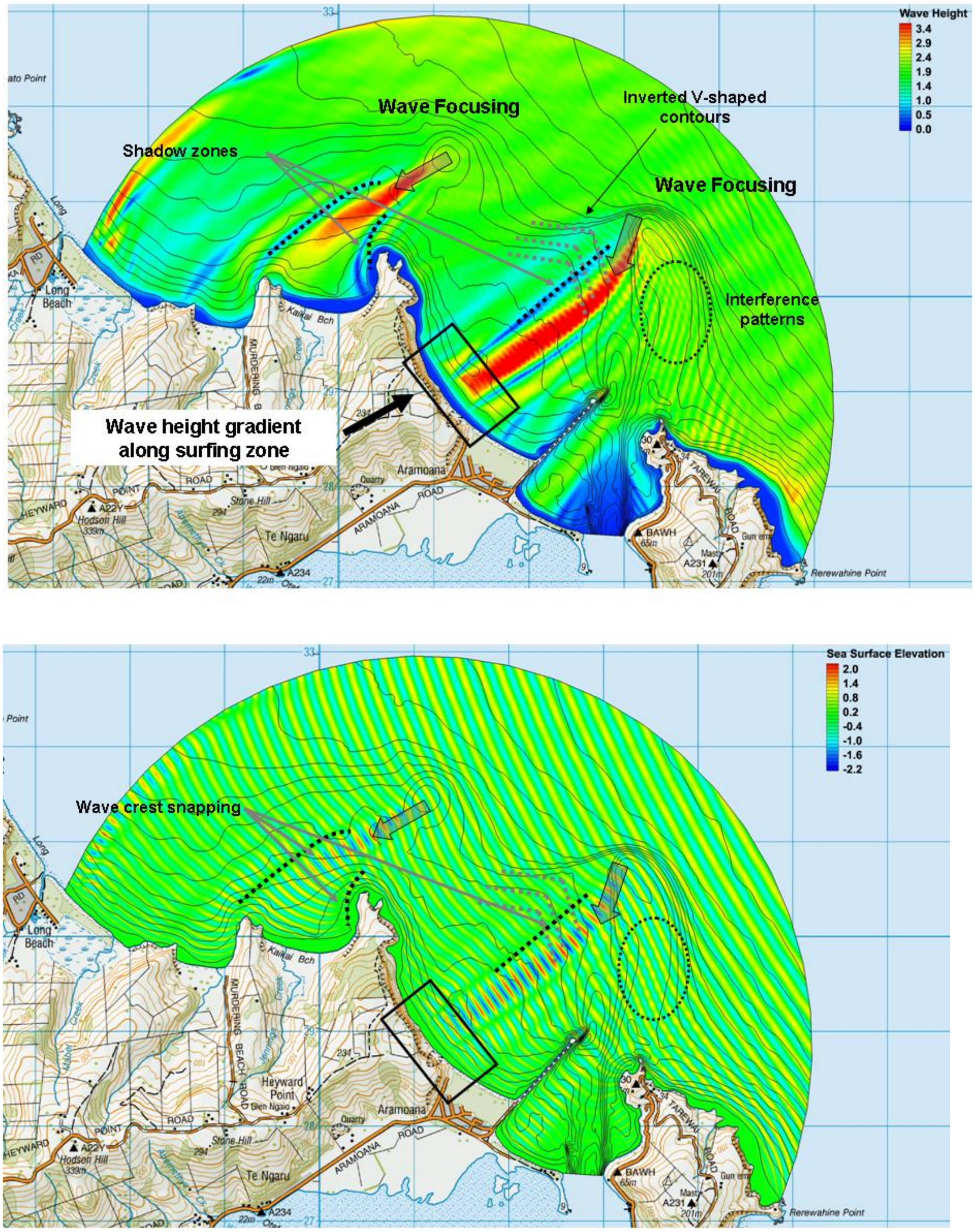


Figure 2.3 Annotated model output summarising the surfing wave dynamics.

3. RECOMMENDATIONS FOR LONG TERM DISPOSAL

To establish sustainable disposal grounds for the future inshore dredging requirements over the next 35 years, it is necessary to consider several important issues:

- The annual maintenance dredging volumes will increase as a result of the NextGen project.
- Deposition of sand sediments in the Aramoana coastal cell is necessary to maintain the sedimentary budget and beach health.
- Some of the dredged sediments are not suitable for coastal nourishment purposes (i.e. the silt and rock).
- There are two surf breaks of national significance in close proximity to the harbour entrance.

These issues are discussed in the following sub-sections. It is proposed that the existing Aramoana ground is slightly modified, while the Heyward ground is enlarged to enable more effective deposition management to be undertaken.

3.1. Effect of the shipping channel deepening

The NextGen project involves capital dredging of up to 7.2 M m^3 of sediment to widen and deepen the existing shipping channel both in the entrance region and within the Harbour (Figure 3.1). This will have an effect on the sediment and hydrodynamics at the entrance region as well as within the harbour itself (see Bell et al., 2009). The direct effects of the channel deepening are twofold. First, a deeper channel will result in increase of the sediment trapping potential, thereby increasing the maintenance dredging volumes. Second, the increase in sediment trapping will reduce the amount of sediment that naturally bypasses the channel nowadays and is transported to the west.

An assessment of the modified sediment balance due to deepening was undertaken using historical bathymetric surveys and dredging and disposal records, as well as numerical modelling (see Weppe et al., 2015, and MSL Report P0140-03). The recent monitoring and adaptive management of the disposal operations at the Heyward ground has also provided some new guidance on the ground morphological behaviour (MSL Reports P0140-05 a,b,c,d,e).

As outlined in the Section 2, the Otago harbour entrance is subject to westward flux of coastal sediments. The outer part of the shipping channel is normal to this drift, and therefore acts as a trap to a portion of those sediments, necessitating annual dredging to maintain safe navigation. The annual maintenance dredging volumes are around 60,000 – 70,000 m^3/year, with most of the volume sourced from the eastern channel margins along the ebb delta bar (Figure 3.2 and Figure 3.3).

The morphology model studies clearly reproduce the sediment accretion pattern along the channel and delta bar margins (Table 3.1 and Figure 3.1). Although a set of surveyed channel bathymetries were available, the quantitative validation of the predicted depositional volumes was complicated by several factors including the large dredging-induced morphological changes intermediate between the surveys intervals, which cannot be included in the model. In general however, the model

simulation for the existing channel design predicts accretion of 100-125,000 m^3/year; higher than the historical dredged volumes which average at 60-70,000 m^3/year. As noted in MSL Report P0140-03, the deposition process is generally quite localised along the eastern edge of the channel that truncates the delta bar. The model clearly reproduces the trapping process but overestimates the volume and spatial extent. Therefore, to make good use of the model as a process-based tool, the absolute volume is not used. Rather, the relative increase in trapping due to channel deepening is used as the metric for an assessment of effects.

The model predicts an increase in annual maintenance dredging volume within the entrance channel by around 60%. Applying that ratio to the current average maintenance dredging rate of 60,000 m^3/year provide a predicted annual maintenance dredging requirement of 100,000 m^3/year. That is, an extra 40,000 m^3/year of sediment is expected to deposit in the entrance region, which is a volume that would normally continue past the entrance channel and progress naturally westward.

Table 3.1 Maintenance dredging volumes removed from the outer channel area. The region where most of the maintenance dredging was undertaken is shown in Figure 3.2 as a dotted black rectangle.

Years	Volume dredged from the outer channel [m^3]
2007-2008	38700
2008-2009	4800
2009-2010	107000
2010-2011	69600
2011-2012	67900
2012-2013	59600
2013-2014	44940
2014-2015	68640
MEAN	57648

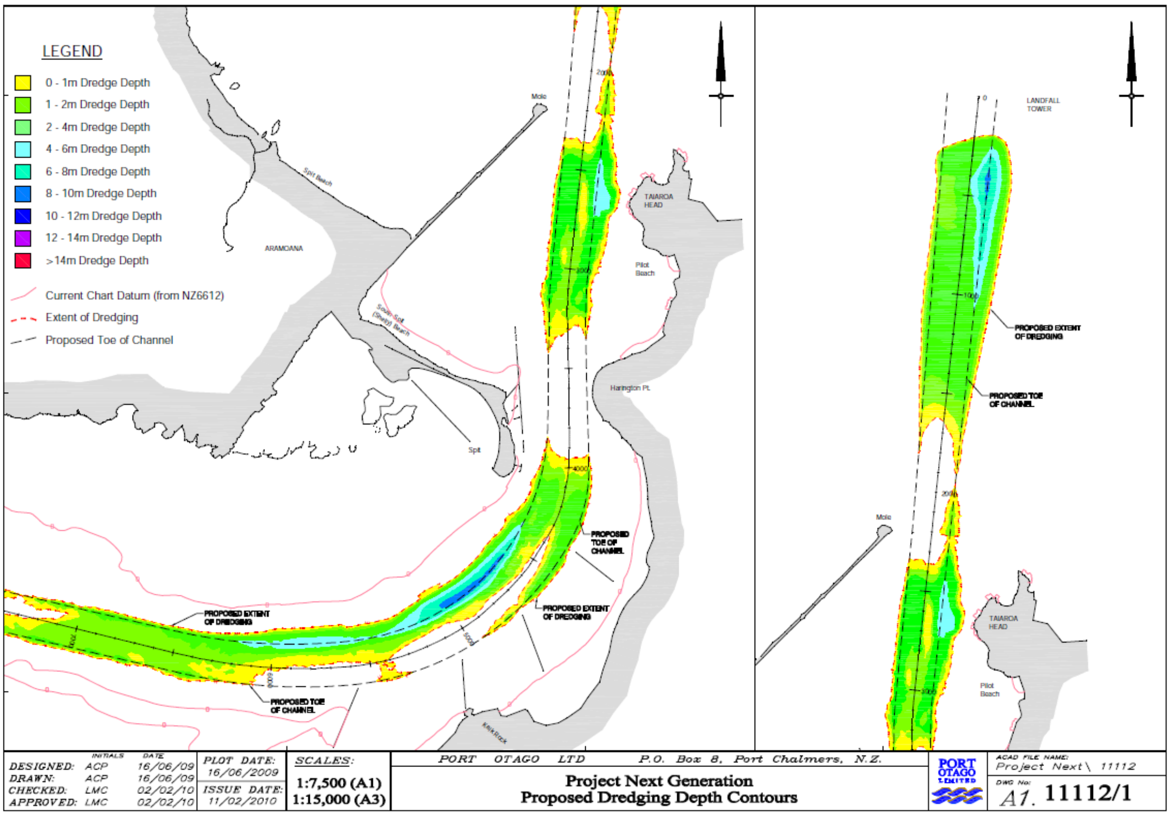


Figure 3.1 “Next Generation” channel design.

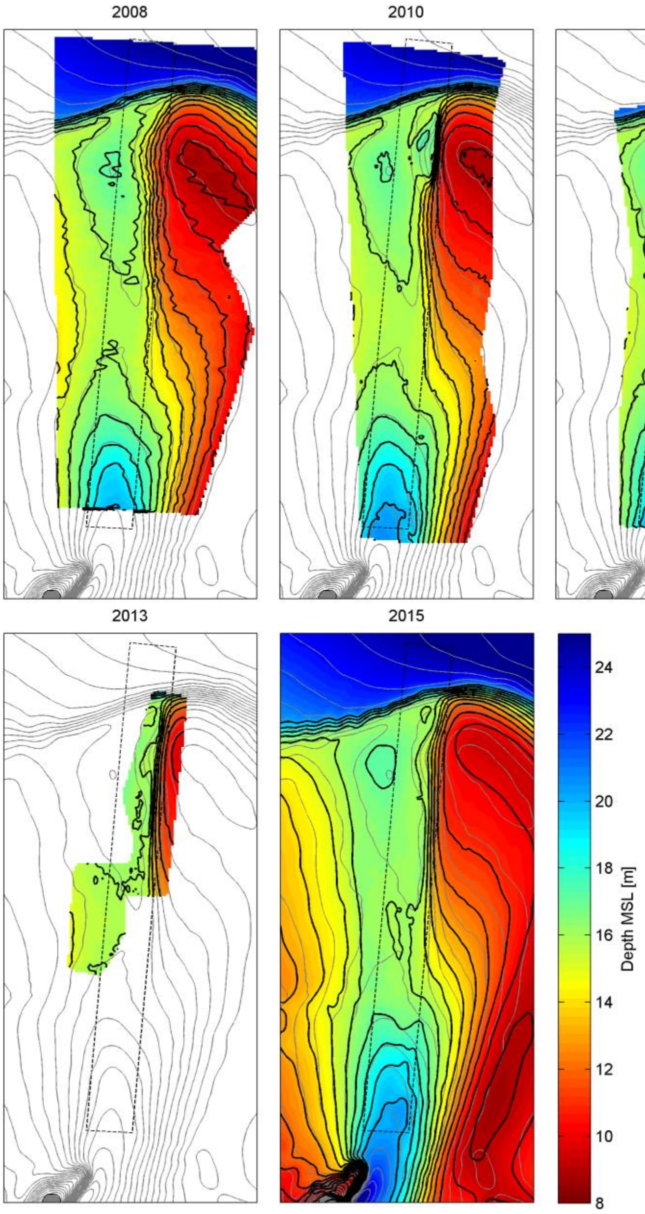


Figure 3.2 Sequence of available channel bathymetries. The dotted black rectangle is the general area where the maintenance dredging is undertaken.

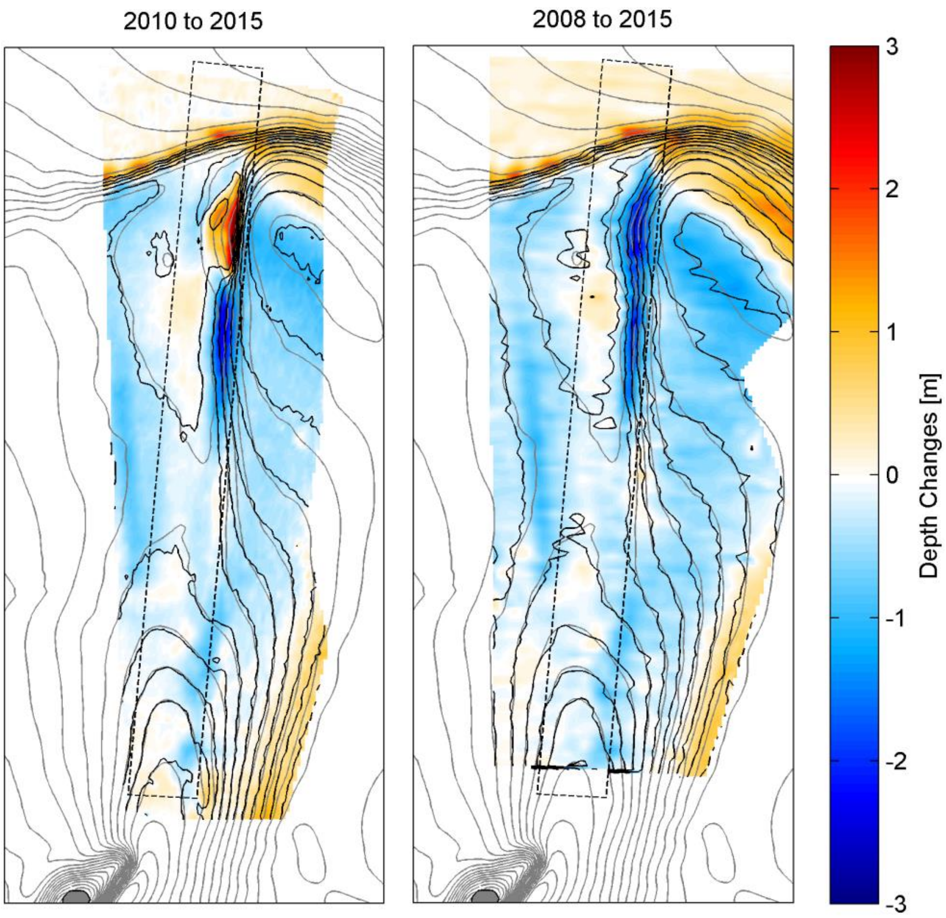


Figure 3.3 Long term bathymetric changes in the channel region over two different time intervals, 2010 to 2015 (left) and 2008 to 2015 (right).

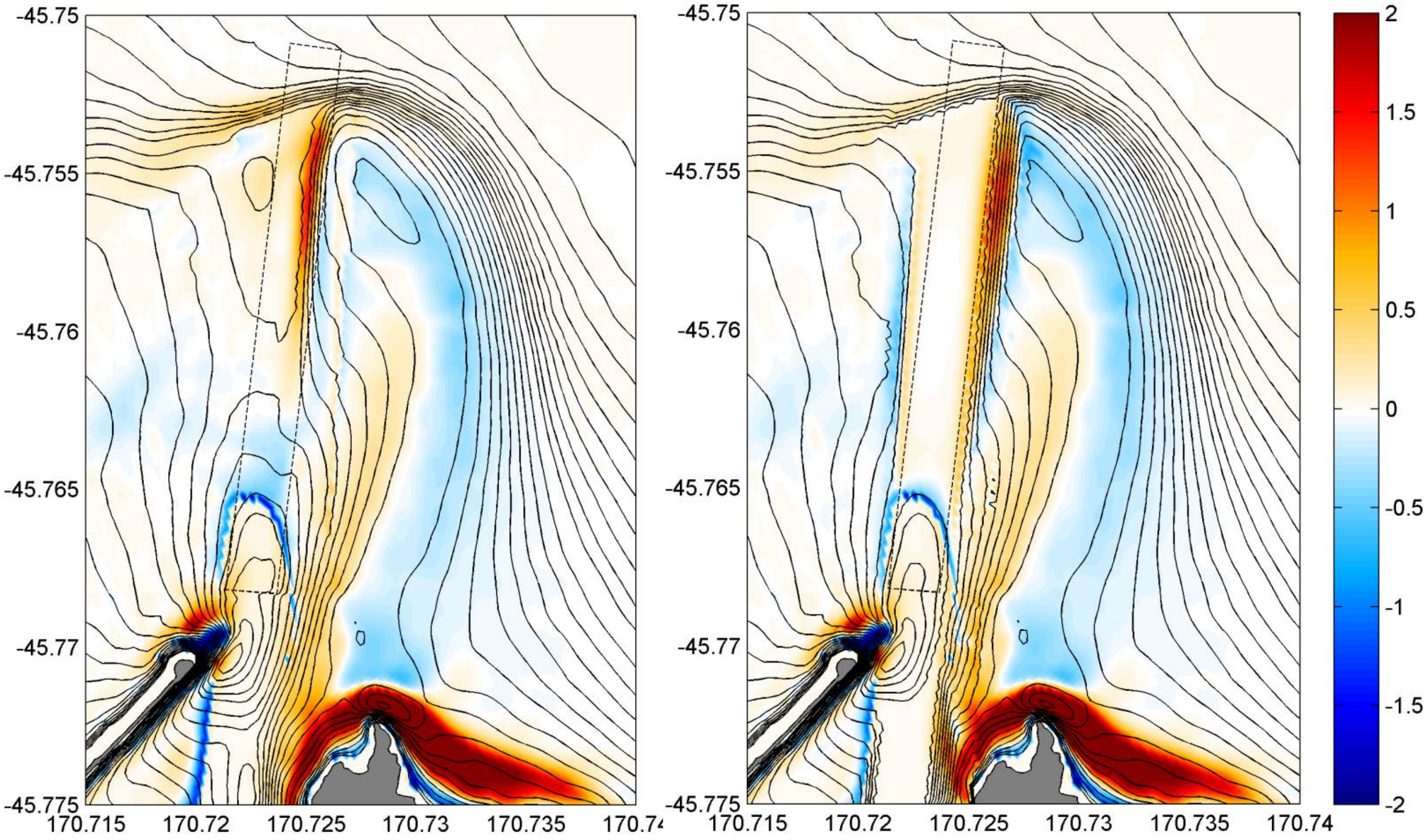


Figure 3.4 Predicted bathymetric changes in the entrance channel region after a 6 month morphological simulation. The dotted black polygon indicates the region where maintenance dredging is currently undertaken.

3.2. Aramoana ground

The morphological behaviour of the Aramoana Beach system over the last 10-15 years is illustrated in Figure 2.1. A prominent disposal mound is present within the ground from 2002-2007 with concurrent disposal volumes averaging at ~100,000 m^3/year (Table 2.2). There is clear evidence of onshore transport of this deposited sediment, due to the direct effect the orbital asymmetry of waves. The reduction of disposal volumes to ~20,000 m^3/year from 2007 onwards and continued onshore sediment transport resulted in the progressive onshore migration of the mound and eventual welding to the surf zone. Sediment transport by waves is enhanced in shallow waters and therefore there is more dispersion from the ground during the years of high deposition when there was a prominent mound. Dispersal rates ranged from ~100,000 m^3/year during 2002-2009, reducing to ~50,000 m^3/year in 2010-2013 and further decreasing to ~20,000 m^3/year (Table 2.2) as the disposal activities progressively reduced (see Table 2.1).

The time history nearshore bathymetry contours (Figure 3.5) indicates that the beach in the lee of the ground indeed went through an accretion period as the mound migrated onshore, with an offshore migration of depth contours from a *relatively* eroded state (e.g. 2002-2007) to a *relatively* accreted state in the 2013-2014. Note that the year 2010 seems to be a transition period, with 5 and 6 m contours close to 2002-2007 positions, but with a clear progradation of the 7 m contours. Interestingly, the recent 2015 surveys (May, September and November) indicate a new onshore translation of the nearshore contours and thus relative erosion. This suggests the beach system is currently showing the adjustment following several years with very low deposition rates.

Sediment budget estimations derived from the numerical model studies show that the strong westwards flows that develop past Heyward Point during storms can drive significant volumes of sediment out of the Aramoana Beach cell (MSL Report P0140-03). While quantitative model predictions of sediment transport need to be interpreted with care, the predicted magnitudes of sediment transported past Heyward Point were of order 50-100,000 m^3/year. This is an important mechanism and it highlights the need to maintain a sediment supply to the Aramoana Beach cell to ensure the sandy character is preserved.

The optimum annual volume required to maintain a sediment equilibrium supply for Aramoana Beach is difficult to estimate. However some guidance can be obtained from the historical surveys and recorded dredging history. The envelopes of beach states presented in Figure 3.5 are a baseline of the morphology, covering a 15-year period during which time an average of 35,000 m^3 /year was deposited. This is useful proxy for a reference volume of what is needed to sustain the system.

However, as outlined in Section 3.1, the dredging of the channel will increase its trapping potential, and it is estimated that a deeper channel may trap an additional 40,000 m^3/year. This is a volume that would likely otherwise by-pass the Harbour Entrance to naturally supply the adjacent coast. To compensate this potential deficit, a future disposal strategy will need to factor in this increase. Accordingly, an expected sediment requirement for Aramoana Beach after NextGen is 70-90,000 m^3/year.

An adaptive management approach to the Aramoana ground is recommended, with an annual allowance of up to 100,000 m^3/year, calculated over 5-year period (i.e. not per calendar year). The envelopes of the surveyed 5,6,7 m (msl) bathymetric contours can be used as the baseline morphology, which will provide practical

indicators to regularly assess the sedimentary budget of the wider Aramoana cell, rather than just the sandy intertidal beach. Effective management of the disposal volumes should aim to conserve of the 5, 6, and 7 m (msl) contours within the historical baseline envelopes.

The deeper bathymetric contours lying within the disposal ground area (7 to 10 m, msl) are also useful and easily obtained proxies which should be used to manage the seabed morphology and ensure the beach system remains in a stable state. In order to assist the management of the future disposal operations, a revised disposal ground is proposed (Figure 3.6). The new rectangular ground includes most of the existing ground and is gridded in 50 by 50 m square cells to facilitate the comparison with the baseline morphologies and attribution of specific sediment loads throughout the ground in the future.

The set of historical contours (Figure 3.7) indicates a maximum mound level within the ground at ~7m msl (2002) while the 9 and 10m contours for that time essentially follow of the offshore edge of the ground. In contrast, the recent morphological states (2015) show 9 and 10m contours shifted onshore by 100 to 250 m relative to the 2002 positions and the shallowest level is ~8 m msl.

The bathymetric dataset was processed to capture the minimum and maximum depth levels within each cell throughout the study period and provide an overall envelope of the morphological states that should not be exceeded due to excessive or insufficient disposal. For example, the 9 m contour should be kept in the vicinity of the offshore edge of the ground (I cells) in a relatively “full” ground, while it should not move further onshore than the cell lines E to B in a relatively “empty” ground. The shallowest seabed level within the ground should not exceed ~7 m msl to prevent any adverse impacts on the primary wave focusing process developing further offshore on the ebb delta bar (e.g. wave breaking on the mound). Given the clear transfer of sediment from the disposal ground to the nearshore beach (e.g. Figure 2.1, Figure 2.2), these maps should be used alongside the 5-6-7 m msl contours envelopes to monitor the state of the beach system and modulate the sediment loading of the disposal ground accordingly.

With respect to the surfing amenity, the key process creating high-quality surfing waves is the intense refraction over the ebb delta bar and channel margins which redirects energy towards the beach and causes offset crests. The conservation of the surf break requires preserving both the existing swell corridor as well as the underlying morphological features. It is evident that the deepening of the channel will modify the refraction process over the delta bar head due to the modified depth gradients, however wave modelling suggests that the overall mechanics of the process will be conserved (Figure 3.10). The modelling of an idealized surfing wave event post channel dredging indeed shows the conservation of a distinct area of focused wave energy toward the beach, however there is a slight change in its position. This means that there may be a slight shift in the optimal swell direction window for the focused wave area to align with the mound area and the typical surfing region along the beach (northwest half). However, the key process generating the focus is not altered.

Other studies have shown that the presence of a dump mound may have beneficial effects on surf - further rotating and focusing the wave crests (Kilpatrick, 2005; Scarfe et al., 2009). However, local surfer observations of degraded surf quality as a migrating mound moved shoreward and began to weld to the surf zone suggest that oversupply (short or long term) can have detrimental effects. These effects will be avoided by the maintaining the contours as outlined.

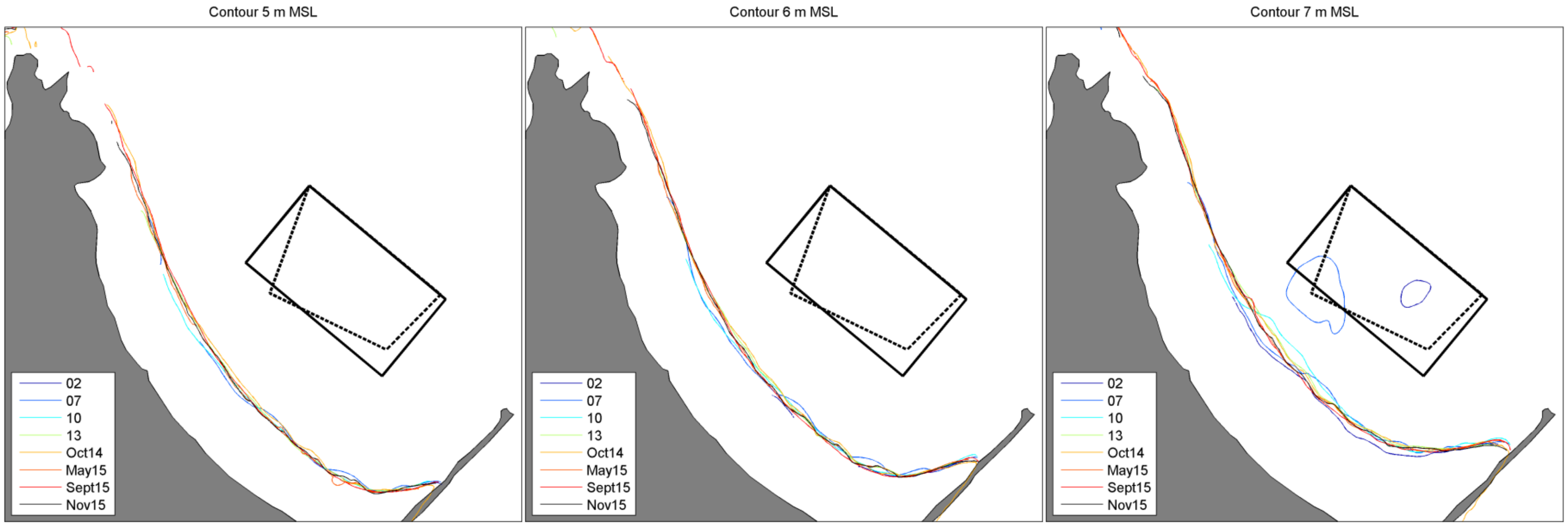


Figure 3.5 Sequence of surveyed nearshore contours at 5, 6, and 7 m relative to mean sea level. The existing Aramoana Beach disposal ground is shown as a black dashed line and the proposed new ground is shown as a continuous line.

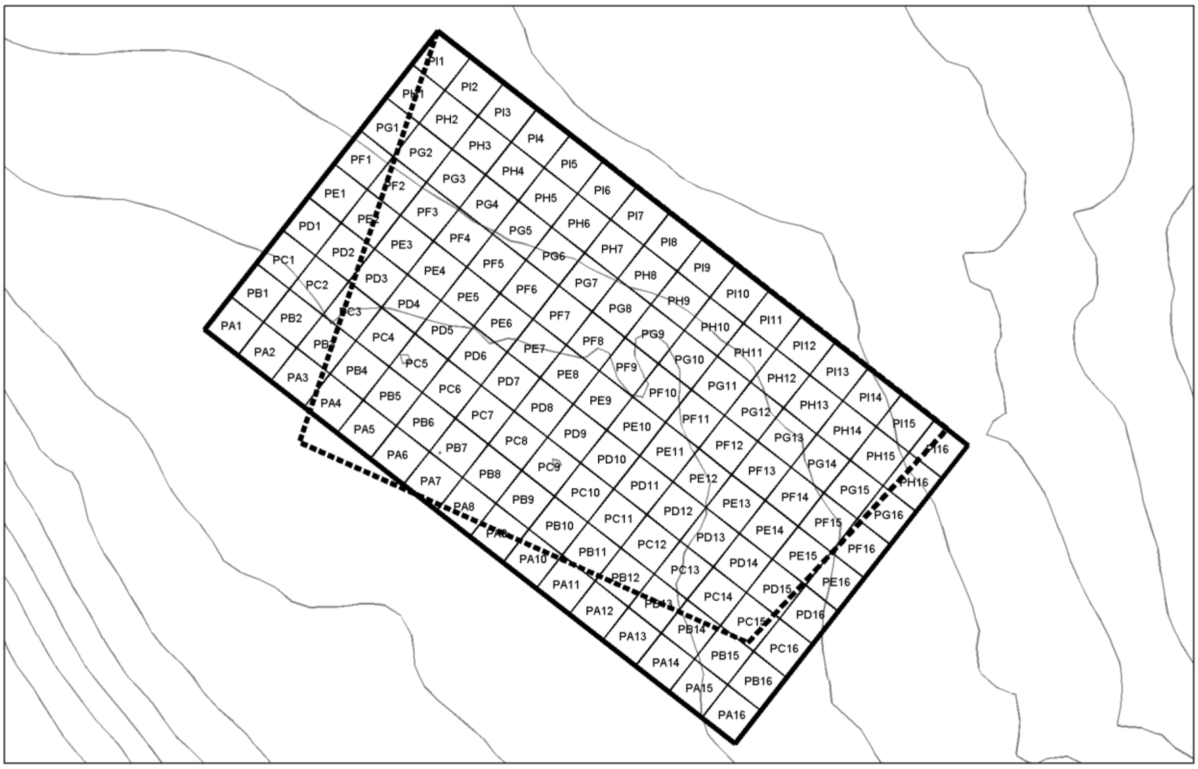


Figure 3.6 Proposed Aramoana Beach disposal ground delimitation. There are 144 identical square cells of 50 by 50 m. The existing ground is shown as a dotted black polygon. Existing and proposed ground areas are 0.28 and 0.36 km^2 respectively.

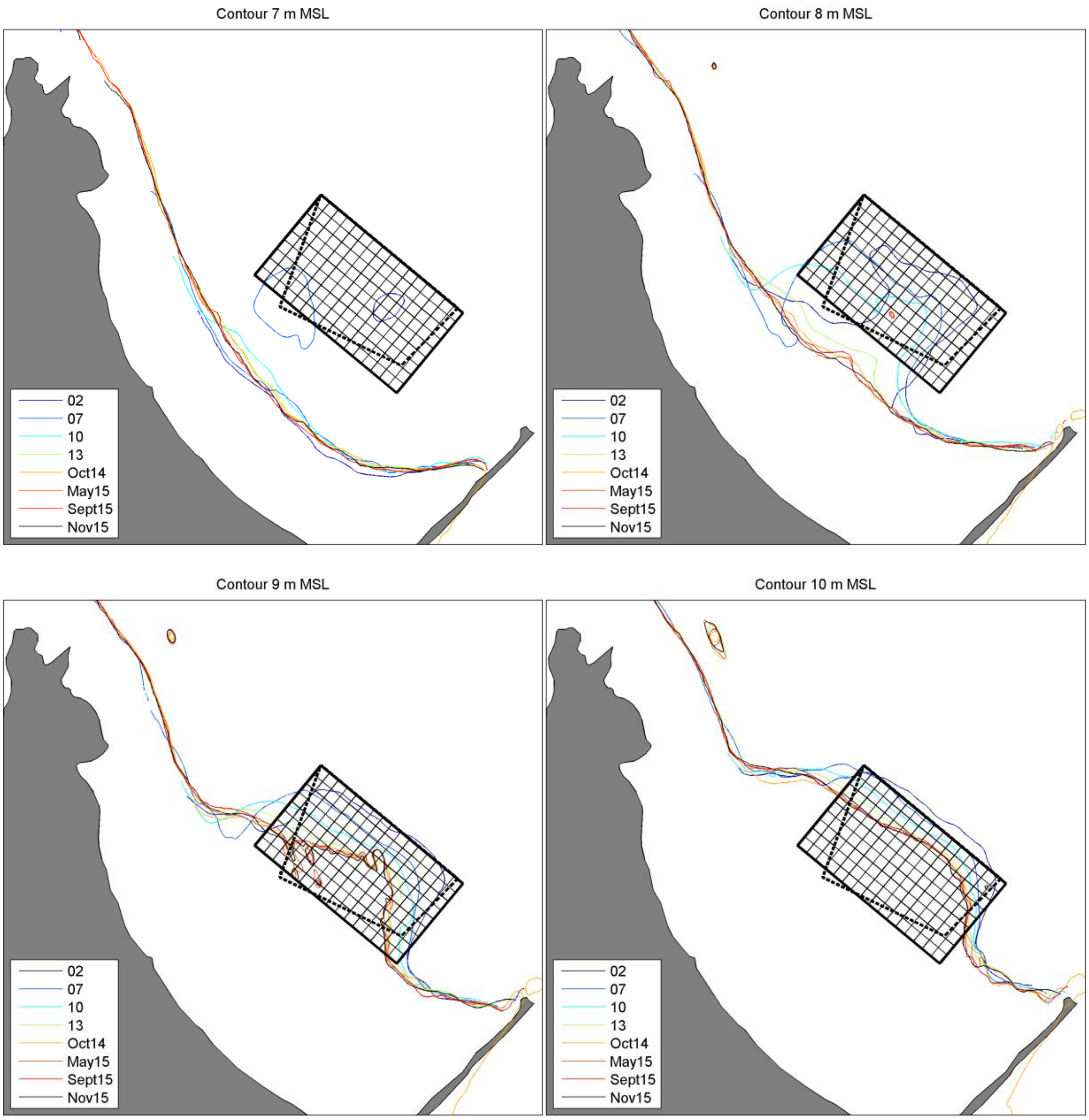


Figure 3.7 Sequence of surveyed nearshore contours at 7, 8, 9, and 10 m relative to mean sea level, with the existing (dashed) and proposed (solid) Aramoana Beach disposal grounds.

3.3. Heyward ground

An effective long term disposal strategy for Heyward ground includes retaining the existing wave focusing feature and undisturbed swell corridor as well as addressing sustainable disposal volumes, including for silts and rock. The existing ground is too small to accommodate all the modern needs, but the general ground position is appropriate. The revised ground includes most of the historical ground, but is increased in very specific dimensions to facilitate the future management of disposal volumes and sediment textures. The proposed extent is shown in Figure 3.8. Here, the ground has been gridded into cells of 150 by 150 m size (Figure 3.9) to facilitate sediment volume attribution - in a similar way to the adaptive management regime of the existing Heyward ground over the previous 2 years (Figure 3.10).

The circular mound that has been present in the disposal ground morphology over the last 15 years is a key feature to preserve the wave focusing process that benefits the surf at Whareakeake. The analysis of the historical bathymetric dataset, as well as recent monitoring (MSL Report P0140-05 a,b,c,d,e) indicates that dispersion from the ground averaged ~50,000 m^3/year from 2009-2014. The circular mound itself is the most active region of the ground for sediment transport, due to its relatively shallow level and larger interaction with the waves. Overall, it was estimated that dispersion rates around 30-40,000 m^3/year can be attributed to the mound area only for the period 2002-2010. Significant volumes have been disposed in the ground over the last 2 years (~400,000 m^3, see Table 2.2) and the sequence of surveyed contours clearly shows how the mound has grown, with its maximum level rising from 9.5 m (msl) to ~8.5 m (msl) (Figure 3.11). Volumetric analysis of the recent 2014 and 2015 survey data suggests an increase in dispersal rate from the ground to around 70,000 m^3/year, of which some 50,000 m^3/year can attributed to the mound area alone.

The disposal of sediment volumes of the same order of magnitude of what is naturally lost needs to be sustained to conserve the mound. Accordingly, it is recommended that disposal of up to 50,000 m^3/year is maintained in the mound region, which is cells PB567, PD567, and PC567 (see Figure 3.10 for cell delimitation). This should be managed relative to the envelope of historical contours. Notably it is recommended to keep the 12 m msl contour within the mound area (i.e. cells PB567, PC567, PD567), which means not extending the mound base further that what it is today. Shallower contours should be centred around cell PC6; maximum level should not exceed the current level of 8.5 m msl, but should be kept at least at ~ 10 m msl as it was 2002. This loading of the mound should be combined with the cessation of disposal over the spur currently present in the cells PC 1234, and PD 1234, to prevent any disturbance of the primary wave focusing process developing over the circular mound.

The selective placement sediment volumes elsewhere in the ground should be guided by the effective potential for mobilisation. Sediment becomes mobilised when the shear stress at the seabed exceeds the sediment critical bed shear stress. The shear stress depends on both the flow and wave conditions as well as the water depth, plus the critical bed shear stress is a function of the sediment size. To serve as a guide to allocate the sediment deposition, a map of the ambient bed shear stress regime was determined. A one-year timeseries of wave and flow conditions at each of the future grounds was extracted and used to compute the bed shear stress statistics due to combined waves and currents. Computations were made following the approach of Soulsby (1997) using depth-averaged currents and a generic Chezy coefficient of 65 $m^{1/2}$/s assuming a sandy seabed.

Mean, median and 90th percentile shear stress maps (Figure 3.12) Figure 3.12 clearly illustrate the gradients experienced throughout the new ground. These should be interpreted relative to the critical shear stress of the sediment to be disposed which include both sand and silt and possibly a rock fraction. Fine to medium sands as found within the Otago beach system (d_{50} ~200 µm) have typical critical shear stress in the 0.2 N/m^2 range. Critical stress levels are more complicated to estimate for the silt (d_{50}<63 µm) because cohesive forces that aggregate individual particles cannot be neglected, however silt is expected to be more easily mobilized than sand, especially in the context of disposal when consolidation will be limited. Van Rijn (2007) reports a range of order 0.05-0.3 N/m^2 for weakly consolidated mud. The upper region of the ground (lines F to J) experiences bed shear stress levels that are about an order of magnitude lower that in the mound vicinity and it is therefore recommended to dispose the silt fraction there. Accordingly, the southwestern half of the ground, including the mound area, should receive the sandy material.

A key requirement for the preservation of the Whareakeake surf break is the conservation of its swell corridor, including the pre-focusing ramp with relatively linear bathymetric contours whose parts are now within the new ground. In that sense, the future disposed volumes should be predominantly directed to the northwest and southeast corners. Since rock volumes will be static once disposed and will therefore durably modify the morphology, they should be directed to the deepest cells to the northwest. Remaining sand and silt volumes should be directed to areas with larger ambient shear stress levels and thus an increased potential for dispersion. As an example, a generic annual plan allowing disposal of up to 200,000 m^3 is included in Figure 3.13.

The annual morphological simulations were reproduced using the existing and estimated post-disposal bathymetries. Bathymetric changes (Figure 3.14) show very similar patterns, albeit with slightly larger magnitudes, to the post-disposal bathymetry due to shallower levels and large interactions with waves. The annual depth changes in each cell of the ground clearly show an important mobilisation of the sediment over the circular mound which is pushed westwards and onshore while very limited sediment transport is predicted elsewhere (i.e. in the deeper cells of the ground). It is evident that the depth of the seabed is a critical parameter with respect to the sediment dynamics.

The morphological simulations provide useful information on the expected dispersal potential of the ground, which can be used to estimate behaviour over the next 35 years. The annual dispersion of sediment as a function of the initial depth of the seabed throughout the disposal ground (Figure 3.15) shows a clear acceleration of seabed changes for shallower depths, with magnitudes of changes tapering down to around zero at depths of 18-20 m. The magnitude of the seabed erosion was fitted as function of the initial seabed depth using the least square method to provide an empirical tool to assess the bathymetry state following 35-years of disposal activities and the likely ongoing sediment dispersion.

Assuming that the ground will receive an average of 200,000 m^3/year (subject to adaptive management), the total volume disposed over 35 years is 7,000,000 m^3. Applying a worse-case scenario without transport and considering a simple homogeneous spreading of the volume throughout the ground would result in a seabed increase of 3.1 m (Figure 3.16). The potential for the annual sediment dispersal in each cell of the ground based on the fitted relationship is illustrated in Figure 3.17. An estimate of the bathymetry after 35 years can be estimated by successively applying the mean annual dispersion magnitudes to the bathymetry

on Figure 3.17. The resulting morphology is shown on Figure 3.18 The purpose of this exercise is to demonstrate that the ground has sufficient extent to manage the expected sediment volumes over a long term, with areas of high and low dispersal that allow the important and valued aspects of the morphology to be preserved.

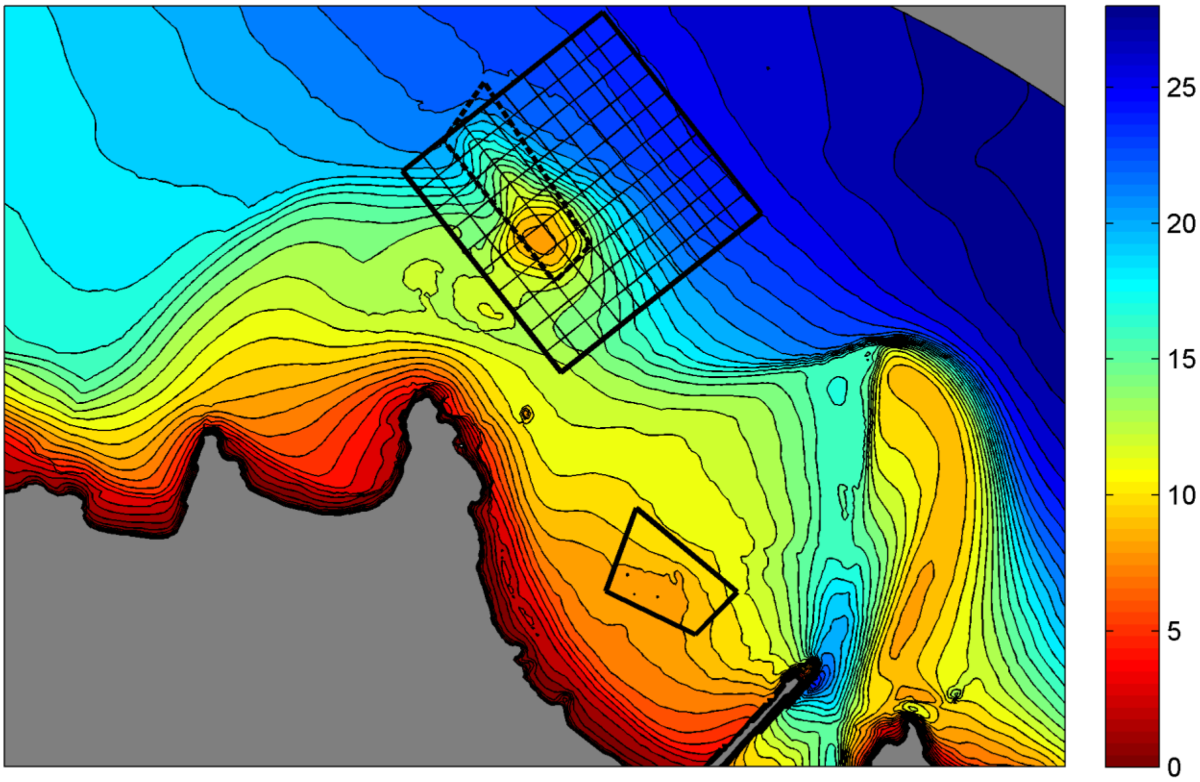


Figure 3.8 Proposed Heyward ground. The existing ground is shown as a dotted black polygon.

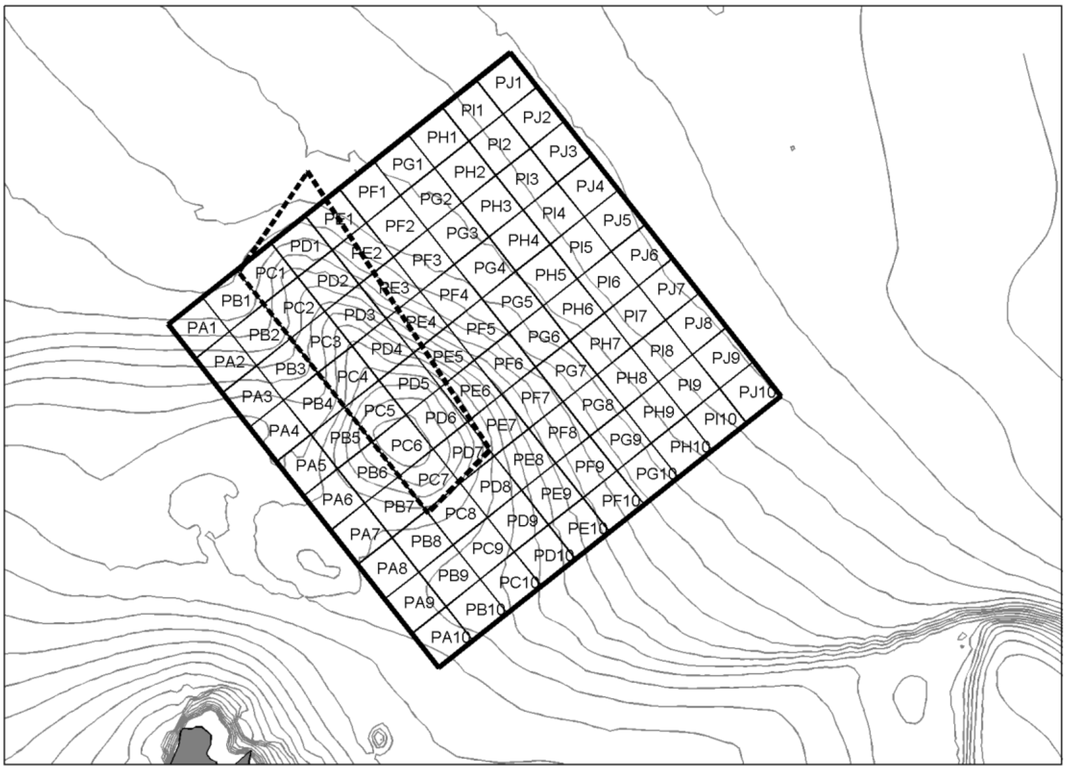


Figure 3.9 Proposed disposal ground delimitation. There are 100 identical square cells of 150 by 150 m. The existing ground is shown as a dotted black polygon. The proposed ground area is 2.25 km^2.

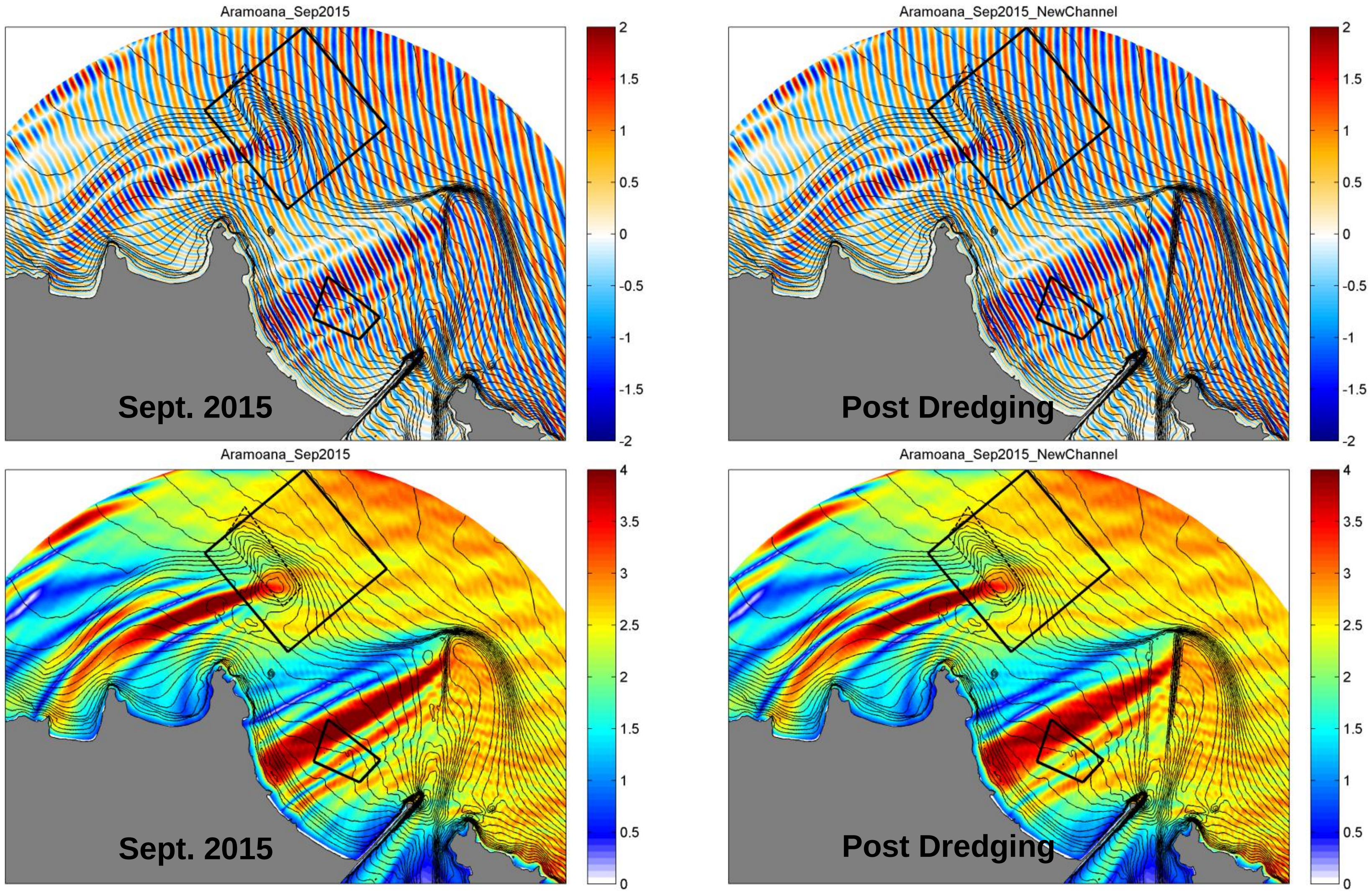


Figure 3.10 Predicted wave crest patterns and significant wave heights for an idealized surfing event (Hs=2.6 m Dir=75 deg, Tp=12 sec.) over the September 2015 (left) and post dredging (right) bathymetries.

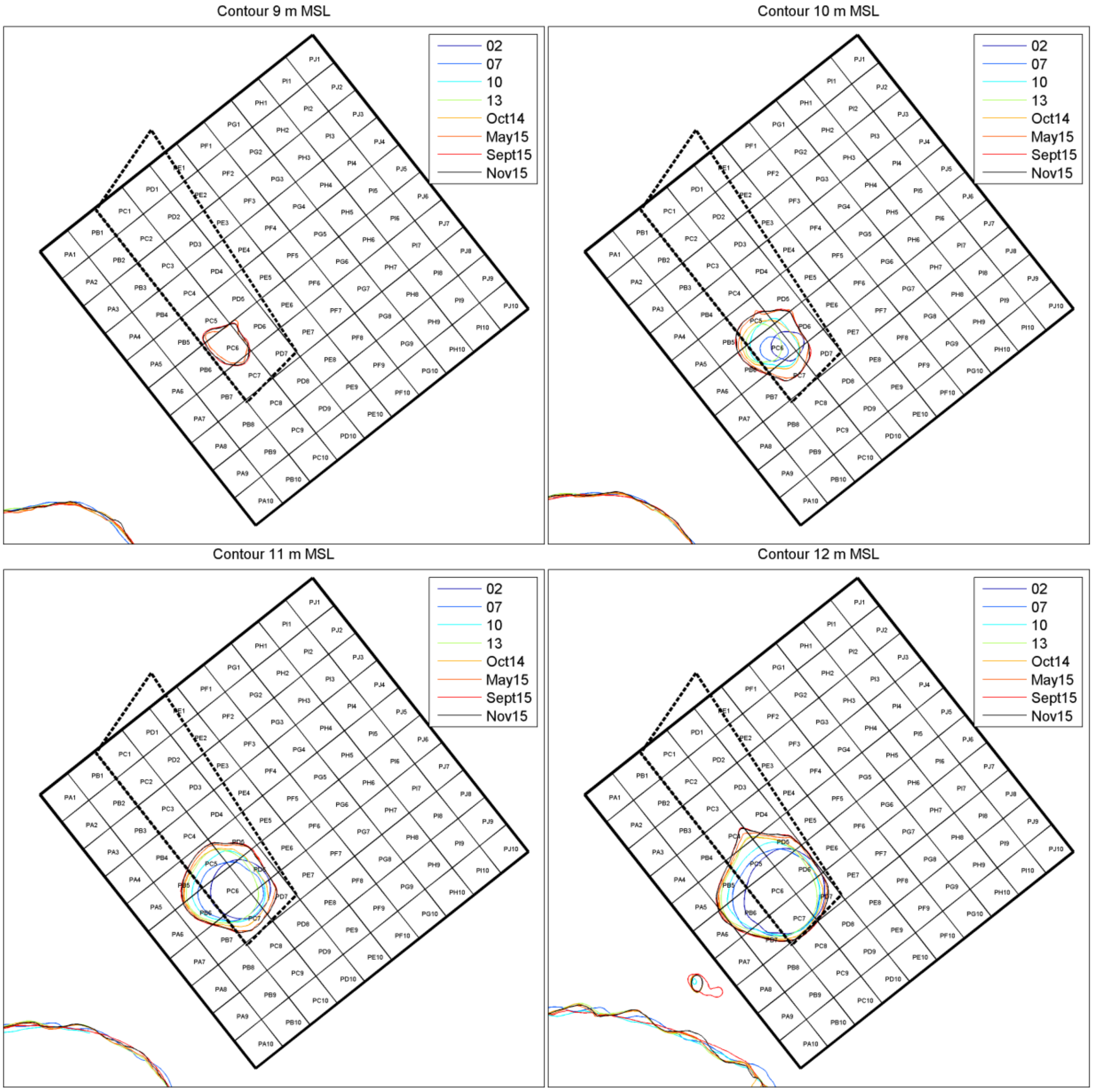


Figure 3.11 Sequence of surveyed nearshore contours at 9, 10, 11 and 12 m relative to mean sea level, with the new ground cells overlaid.

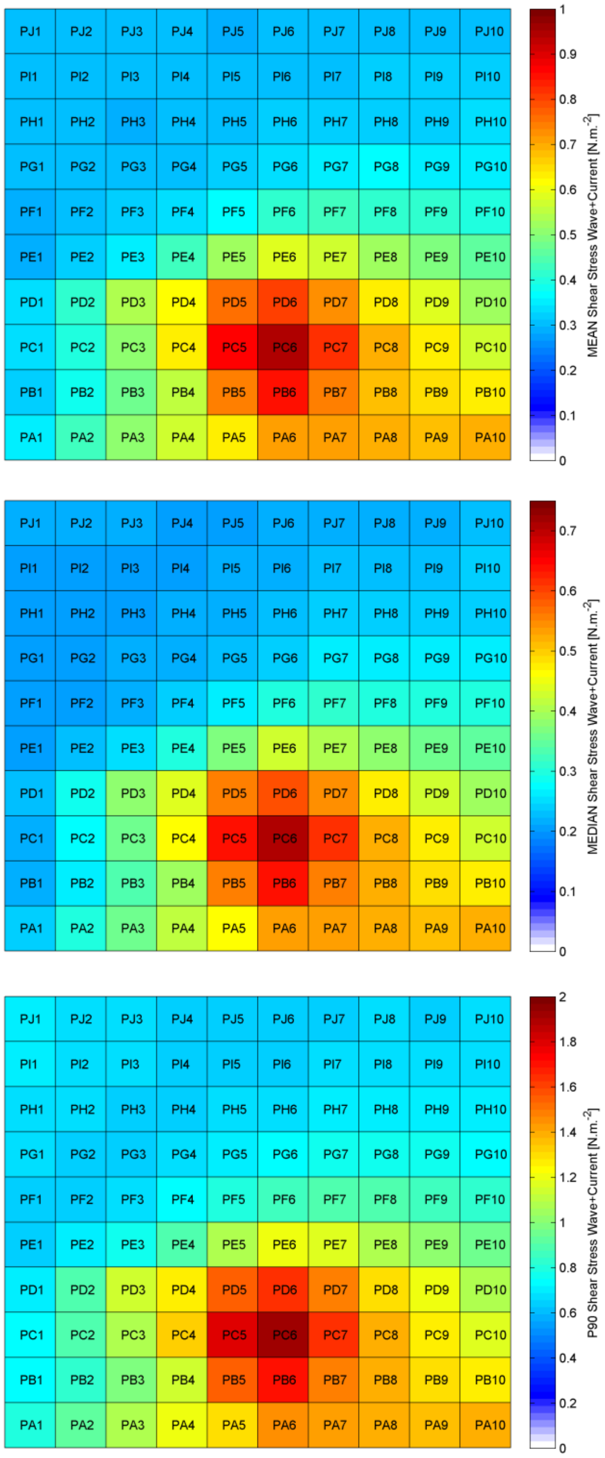


Figure 3.12 Mean, median, and 90th percentile shear stresses due to combined wave and currents throughout the proposed disposal ground (top to bottom). Note this grid is representative. Actual cell positions are shown in Figure 3.9.

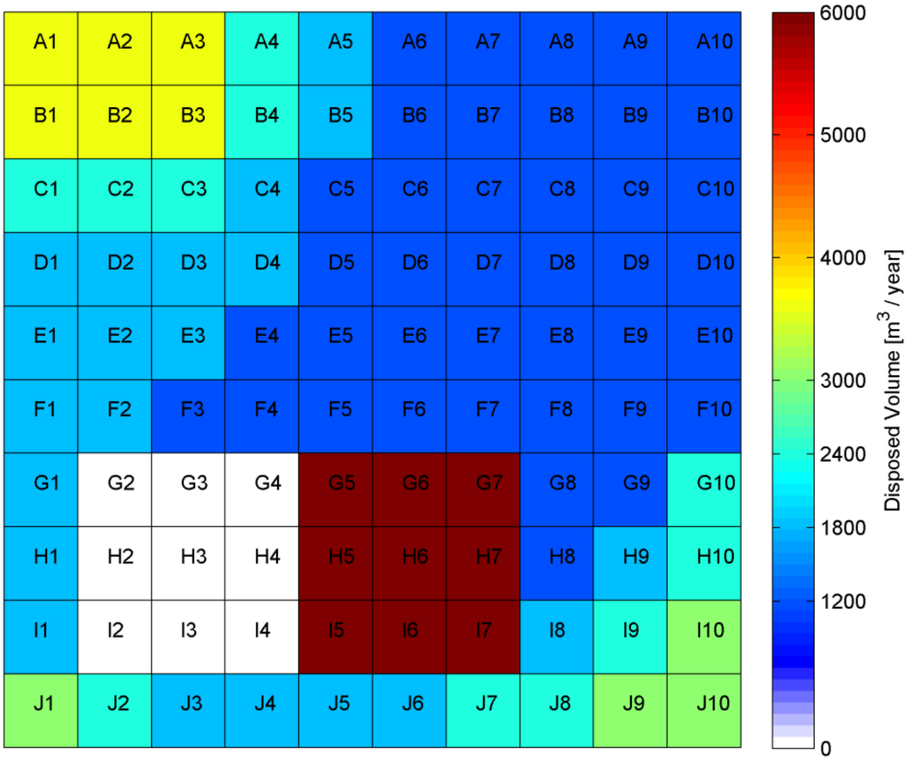
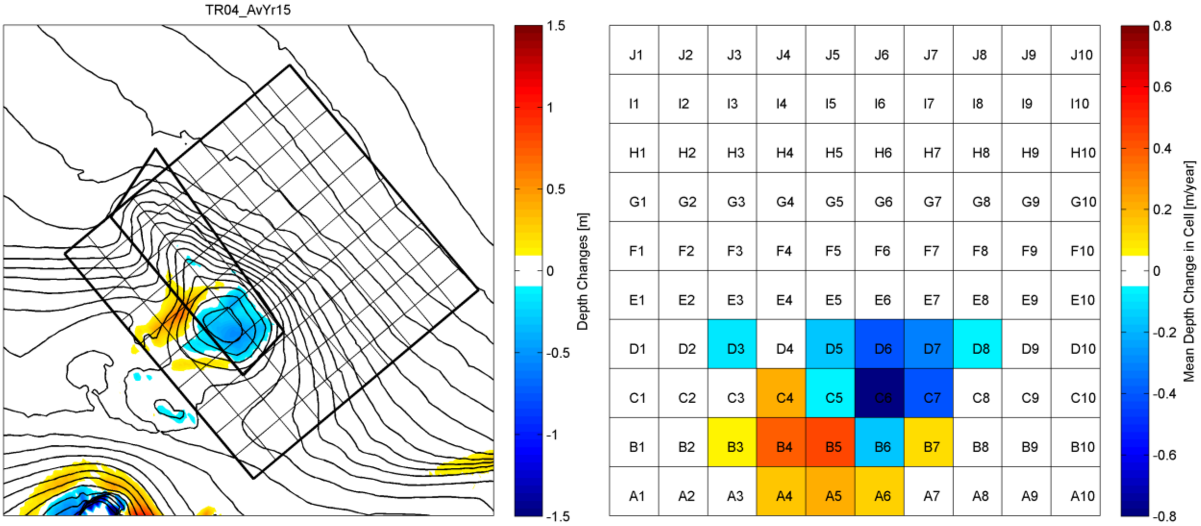


Figure 3.13 Example of an annual disposal plan allowing disposal of up 200,000 m^3. Actual cell positions are shown in Figure 3.9.

Existing (Nov 2015).



Post-disposal

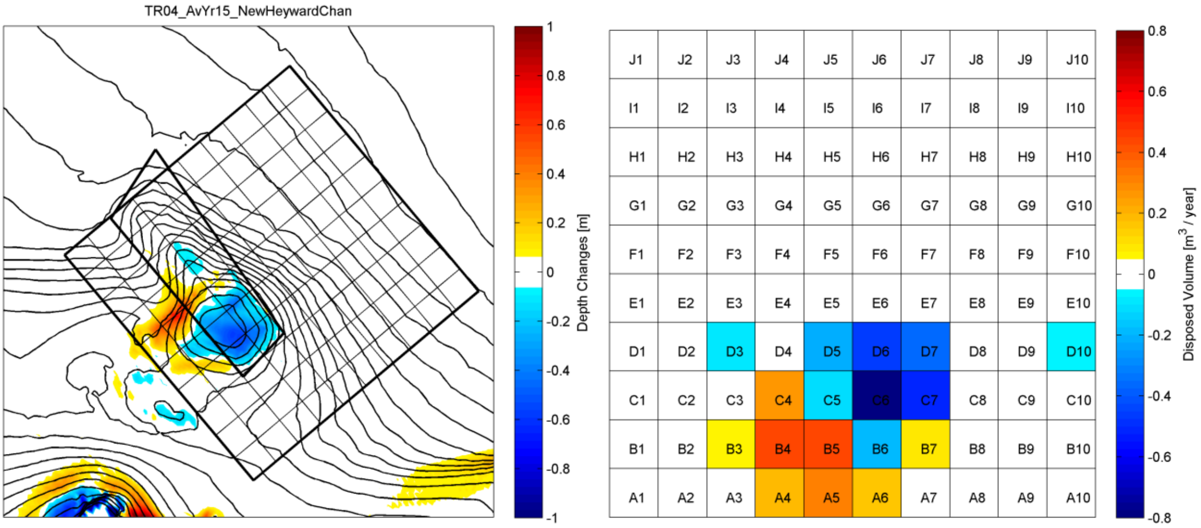


Figure 3.14 Predicted bathymetric changes after an accelerated 6-month morphological simulation and equivalent annual depth changes in each cells of the new ground.

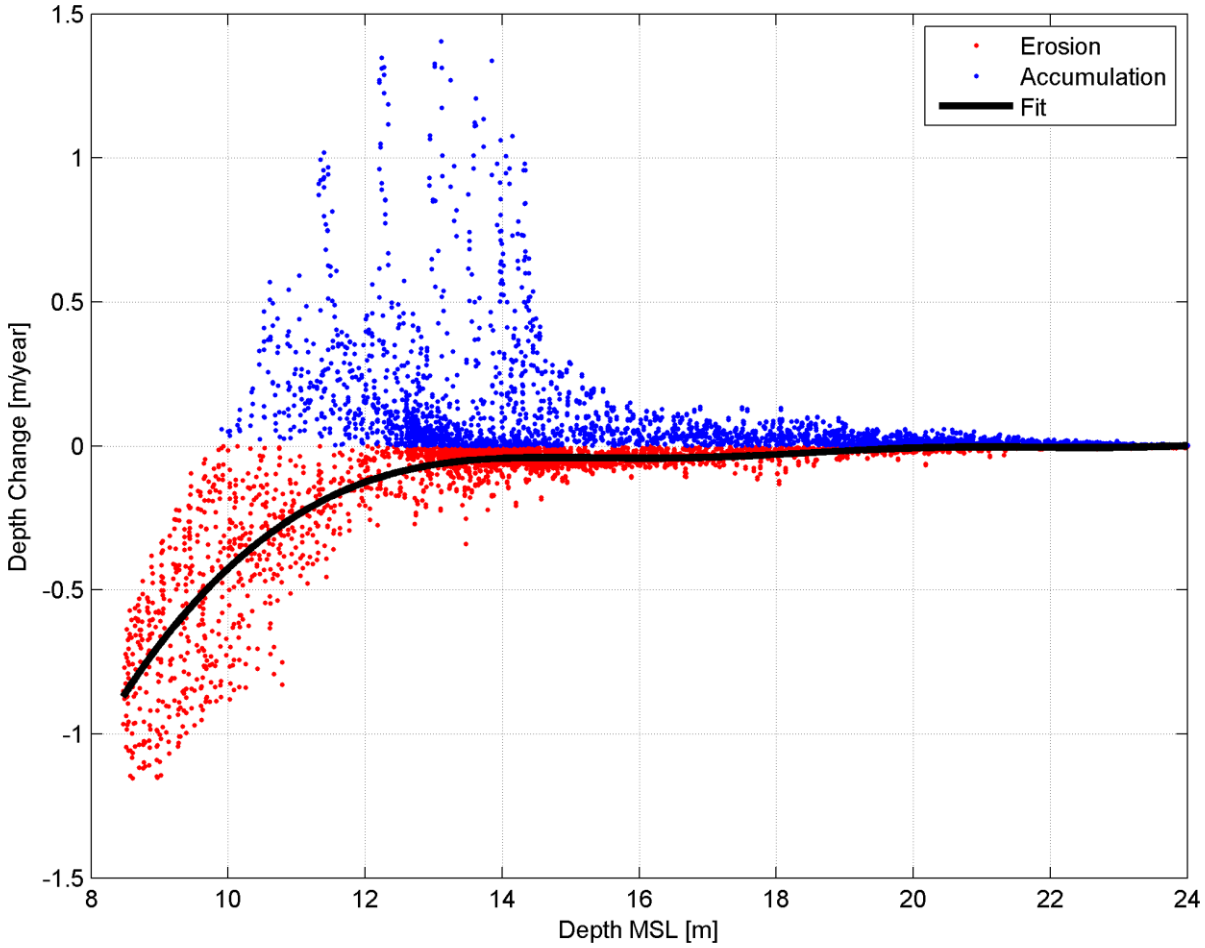


Figure 3.15 Depth changes as a function of the initial seabed depth in the proposed ground. A negative change indicates erosion and vice-versa. Note positive depth changes are due to the deposition of sediment mobilized in erosive cells. The black line shows an empirical relationship between the erosion magnitudes and initial seabed depth (least square fitting).

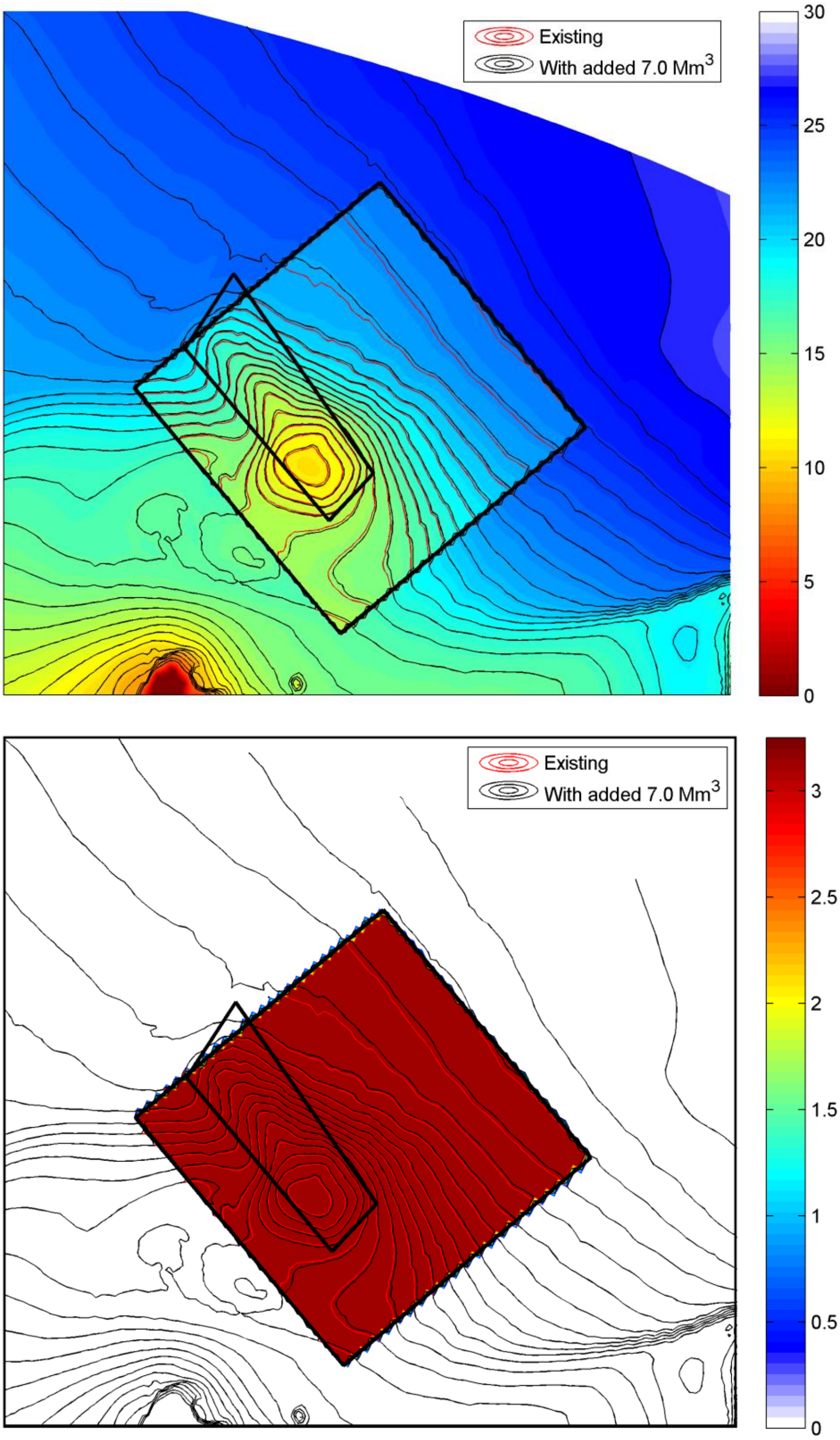


Figure 3.16 Disposal ground bathymetry assuming a homogeneous spreading of the total 35-year allowance of sediment volumes (200,000 m^3/year; total 7,000,000 m^3) (top), and difference with existing bathymetry (bottom).

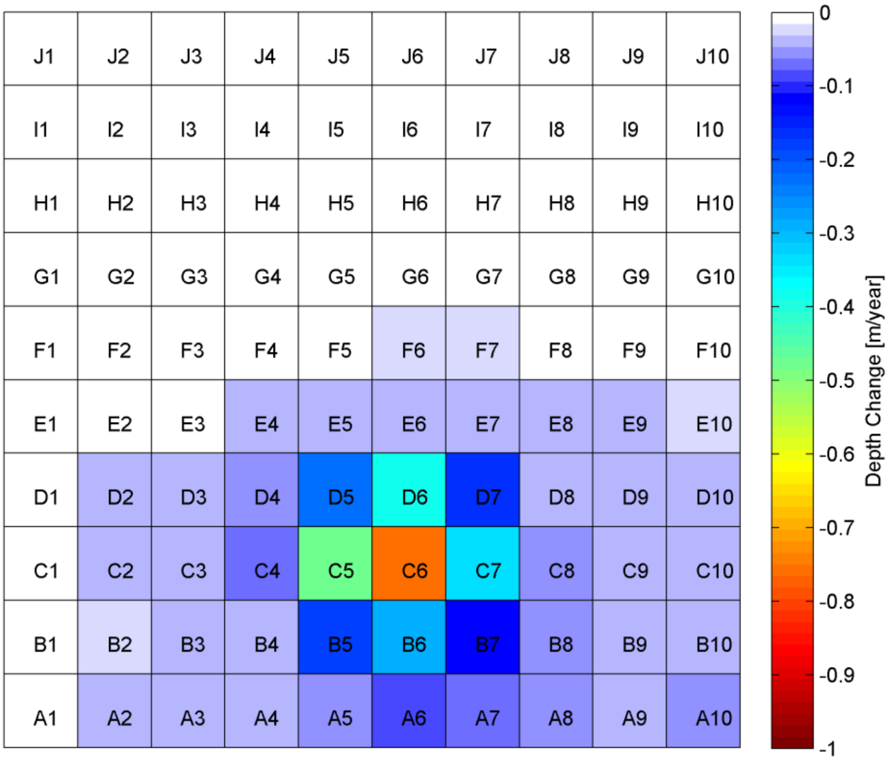


Figure 3.17 Potential for annual depth change in each cell of the ground according to the fitted relationship shown in Figure 3.15.

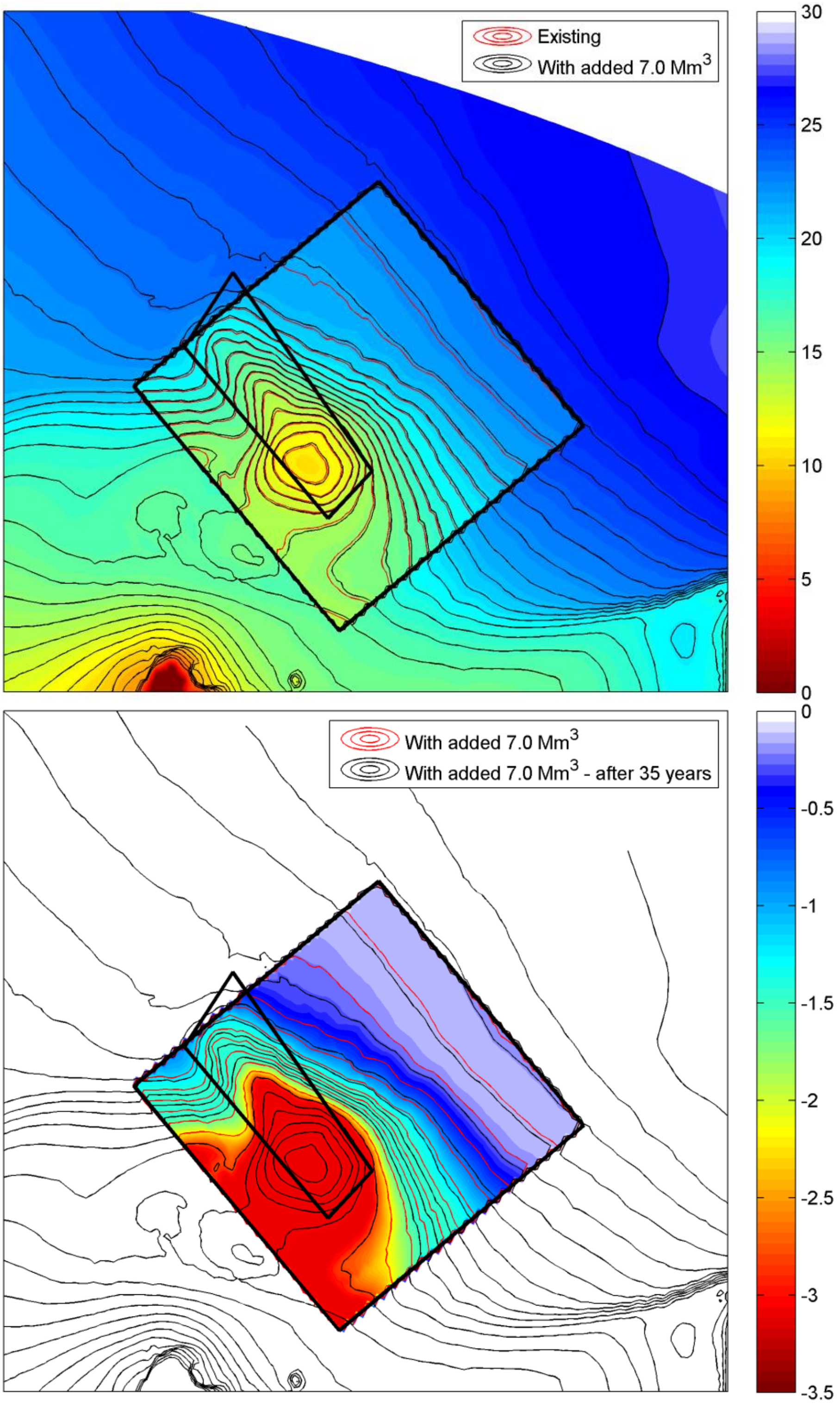


Figure 3.18 Top – post disposal bathymetry after 35-years of sediment dispersion (200,000 m^3/year ; total 7,000,000 m^3). Bottom - difference with initial post disposal bathymetry

4. RECOMMENDATIONS

Defining a sustainable disposal strategy for the next 35 years requires due consideration of the sediment dynamics from a coastal supply context, as well as the local surfing wave dynamics and effects on the adjacent breaks. The ecological impacts of the disposal activities are considered elsewhere. Two disposal grounds are recommended for future use (Figure 4.1).

4.1. Aramoana ground

A supply of sand immediately west of the entrance is necessary to maintain and nourish the Aramoana coastal system. The dredging of the harbour entrance channel interrupts the natural sediment transport, and a disposal ground here is required to replicate the natural sand bypassing and thereby maintain the sandy character of Aramoana Beach.

The recommendation is to site the future ground in the same place as the historical ground, but increase the size slightly to square the ground off and align the margins with the seabed contours in this area. This resizing will also facilitate the adaptive management from year to year.

The studies undertaken to date suggest that after the NextGen channel deepening project, an annual bypassing volume of 50,000 - 100,000 m^3 per year will be needed to maintain the supply to Aramoana Beach. Accordingly, it is proposed that up to 100,000 m^3/year of sand can be deposited at the new Aramoana ground, averaged over a rolling 5-year period. This will allow effective management of the ground and the ability to respond to changes in the wave climate and the beach response.

Bathymetric contours will be used as proxies to monitor the system nourishment and ensure it remains in a stable state, consistent with the morphologies surveyed over the last 15 years. The envelope of the 5, 6 and 7 m depth contour will be used as the metric, which will be monitored through yearly bathymetric survey. Where there is a departure from the specified contours, an expert review should be undertaken to identify the potential for adverse wave and sediment transport, and thereafter as recommended by the expert. The recommended envelopes for monitoring are provided on Figure 4.2.

4.2. Heyward ground

An extension of the existing disposal ground is required to better manage the future maintenance dredging volumes and the mixture of materials for disposal (i.e. sand, silt and rock), while not adversely affecting the swell wave conditions to the Whareakeake surf break. The new ground encompasses the old ground, but extends eastward to include deeper water and align with the native bathymetric contours. The new ground is shown on Figure 4.1. The expectation is for up to 200,000 m^3/year to be deposited in this ground, averaged over a 5-year rolling average. However, if for any reason disposal at Aramoana is not available, then up to 300,000 m^3/year can be accommodated in this ground, averaged over a 5-year rolling average, provided that disposal ceases at Aramoana during the same period. Areas for sand, silt and rock disposal should be further delineated (Figure 4.3).

Disposal in the ground will be carried out in a manner to avoid the creation of wave interference patterns and wave crest disruptions at Whareakeake. There are several ways to achieve this, and a simple technique is recommended. As a guideline, the existing prominent circular disposal mound should not become less than 9.5 m in depth (below MSL) and the surrounding 12 m depth contour not less than 300 m in diameter.

Monitoring should include annual bathymetry survey. Where there is a departure from the specified contours, an expert review should be undertaken to identify the potential for adverse wave and sediment transport effects, and thereafter as recommended by the expert.

Figure 4.1 The proposed new inshore disposal grounds.

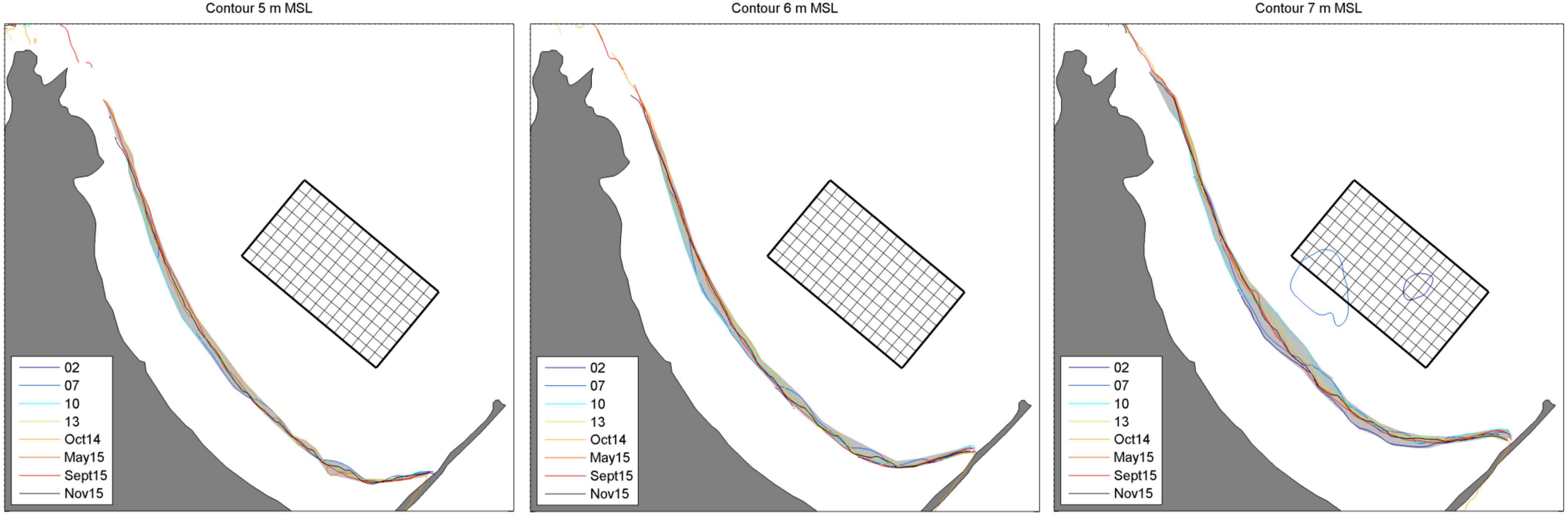


Figure 4.2 The recommended method for monitoring the nourishment of Aramoana coastal system is to maintain the 5, 6 and 7 m isobaths within the historical envelope since 2002.

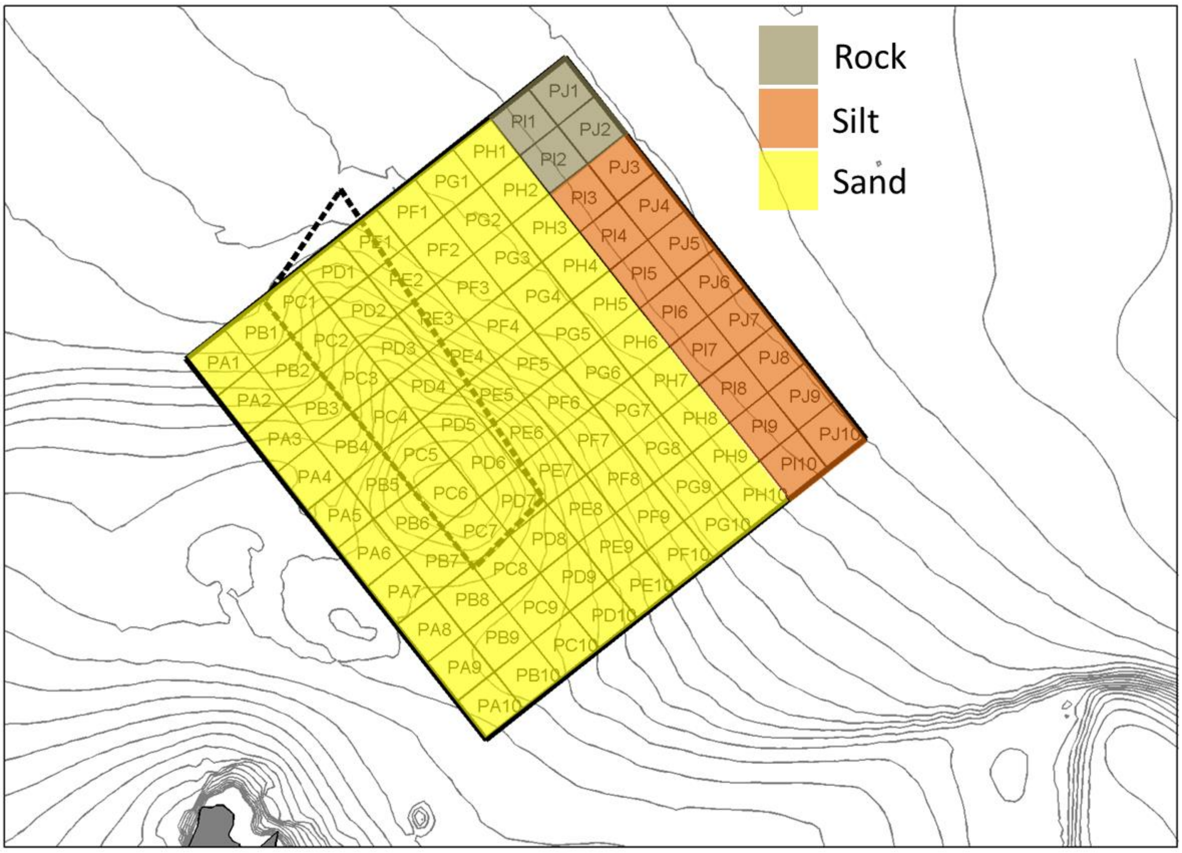


Figure 4.3 Recommendations for the use of the new Heyward ground include partitioning to allow discrete areas for disposal of rocky material, slits and sands.

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