Quinns Beach Long Term Coastal Management

Conceptual Options Assessment

59915802

Prepared for
City of Wanneroo

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Shaping the Future

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Executive Summary

The Quinns Beach Long Term Coastal Management Study was established by the City of Wanneroo with the goal to assess potential coastal management options to mitigate the ongoing trend of erosion present at Quinns Beach. Erosion and coastal management has a long history at Quinns Beach; early anecdotal evidence suggests that Quinns Beach has been experiencing erosion since at least the 1940's.

This report summarises Stage 2 of the Quinns Beach Long Term Coastal Management Study. The purpose of Stage 2 is to assess the coastal management options put forward in the Stage 1 study (Cardno, 2015): Coastal Processes and Preliminary Options Assessment Report. These coastal management options were assessed and refined during Stage 2 through numerical modelling of longshore sediment transport over 10 years (2005 – 2014) using the model LITPACK, and short term cross-shore and longshore sediment transport using XBEACH during the three storms that occurred in September 2013. This approach involved three rounds of LITPACK modelling, one round of XBEACH modelling, and relevant iterative analysis after each round. Some preliminary analysis using headland control theory and empirical design equations for offshore break waters was also performed. To facilitate discussion Quinns Beach has been divided into six sections based on plan alignment, existing structures and historical shoreline changes, as depicted in Figure 1-1.

Overall, the longshore sediment transport modelling provided valuable insight into the long term shoreline evolution for various coastal management layout options. Due to the connectivity of the sediment transport system at Quinns Beach, no single layout modelled in LITPACK managed to address all erosion hotspots whilst simultaneously maintaining the condition of the other sections. This highlights the fact that there is no ‘free’ sediment within the system.

Applying the work undertaken in Cardno (2015) and the longshore transport assessment, Cardno and the City developed four coastal management options to take to the Multi-Criteria Assessment (MCA) stage. The MCA evaluates each option against a range of assessment criteria to determine the most desirable alternative for the City and relevant stakeholders. The options are as follows:

> MCA1 – Offshore Breakwaters (LITPACK Option 11)
  - One 120 m offshore breakwater in Section 3, two 80 m offshore breakwaters in Sections 5,

> MCA2 – Extended Groynes & Groyne 4 (LITPACK Option 12)
  - Groyne 2 extended to 120m, Groyne 3 extended to 75 m, Groyne 4 added to length 60 m.

> MCA3 – Relocated Car Park & Groyne 4 (combination of Base Case in Sections 1-4, and Option 12 for Sections 5 and 6)
  - Additional Groyne 4 of 60m, relocation of car park.

> MCA4 – Modified Groynes & Groyne 4 (similar to LITPACK Option 10)
  - Northern extending nibs added to Groynes 1 and 3. Groyne 2 extended and Y-shape nibs added. Total offshore extent of structure is 120 m. Groyne 4 constructed of length 80 m.

To assist with the MCA, a detailed storm erosion assessment using XBEACH was performed for each of the options, excluding MCA3. The XBEACH simulations were performed without any renourishment. The results from the XBEACH modelling were assessed in light of the LITPACK modelling and the following conclusions drawn for each option:

> MCA1 – Offshore Breakwaters (LITPACK Option 11)
  - The LITPACK results indicate this option improves Section 2, 4, 5 and 6; Sections 1 and 3 are negatively impacted, although Section 1 is predicted to recede less than the existing case. The shoreline in Section 3 is predicted to recede by 10 m, which is 5 m more than the existing case. Discussions with the City indicate the two sections they are most interested in protecting, and providing an amenable beach, are Sections 3 (the car park and public amenity) and 5 (the dog beach). Detrimental effects to other sections are to be avoided. This option, whilst predicting improved amenity at Section 5, does not provide that improvement at Section 3, according to the LITPACK results.

- The XBEACH results indicate that although this option performs the best of the three in terms of average beach width across Section 3, it also predicts significant erosive pressure on the car park in Section 3. Section 2 also experiences a significant sediment deficit as a result of this option. Section 5 was predicted to improve but not consistently throughout the section when compared to the base case. Given these simulations were for storms, appropriate renourishment could provide a buffer that might mean Sections 2, 3 and 5 are suitably improved under this option.
- In summary, MCA1 predicts improvement at Section 5, but does not provide adequate protection of Section 3 seaward of the car park, and results in negative impact on Section 2. Maintenance renourishment could assist with improving this option

> MCA2 – Extended Groynes & Groyne 4 (LITPACK Option 12)

- The LITPACK results indicate a significant improvement in Section 3. As a result, Section 4 is predicted to recede, but this is limited to an average of 3-4 m across the section and appears to stabilise after 4 years. The beach width in Section 5 is predicted to improve by 5-8 m on average and appears to stabilise. The narrow beach width observed at the southern end of the section during the summer months indicates that maintenance renourishment in Section 5, and perhaps Section 4, could improve the outcomes of this option.
- The XBEACH results indicate that this option performs adequately throughout the study area: it protects the beach in front of the car park and the dog beach without putting as much pressure on erosion pinch points compared with the other layouts. Erosion does occur in the north of Section 3, however this could be minimised by capital and maintenance renourishment. The longer Groyne 2 allows for a significant sediment buffer to be placed in the northern end of Section 3 that would contribute significantly to erosion mitigation under storm conditions.
- In summary, this option is the most suited for achieving the City's goals. Renourishment will be necessary to provide suitable buffers during storms.

> MCA3 – Relocate Car Park & Groyne 4

- The LITPACK results were interpreted from the existing case, combined with MCA2 for Sections 5 and 6. The results indicate 5-10 m recession of Section 1 by the end of the 10 year simulation. This is the greatest recession compared to Options 9 to 12. This recession appears to be stable for the last 5 years, subject to seasonal variations. Section 2 is predicted to improve by 5-10 m; this is comparable to MCA1 and MCA4. Section 3 is predicted to recede by approximately 5 m; this is stable for the last 6 years of the simulation. This recession is significantly less than for MCA1 and MCA4. Section 4 is predicted to accrete by 5 m, similar to MCA1. The beach width in Section 5 is predicted to improve by 5-8 m on average and appears to stabilise. The narrow beach width observed at the southern end of the section during the summer months indicates that maintenance renourishment in Section 5, and perhaps Section 4, could improve the outcomes of this option.
- The XBEACH results indicate that this option performs better or comparable to the other options for Sections 1 and 2. Whilst the average increase in beach width is lower than MCA1 for this option, less erosion occurs at the southern end of the Section 2. There is less erosion in Section 2 compared to all other options. Accretion is predicted across all of Section 4 under the storm sequence. The dog beach is protected by the presence of Groyne 4.
- In summary, if maintenance renourishment is undertaken in a targeted manner, using the beach monitoring and modelling to predict the optimal volumes and placement, this option could provide a suitable alternate option for achieving the City's goals. Whilst this option does not allow for the retention of the car park, it does reduce the erosive pressure in Section 3, at the same time as providing alternative parking and beach amenity in Section 1.

> MCA4 – Modified Groynes & Groyne 4 (similar to LITPACK Option 10)

- The LITPACK results indicate this option does not provide protection to Section 3; the results indicate recession. Section 5 is predicted to improve however. Section 4 is predicted to recede by 10-20m; this recession does not stabilise by the end of the 10 year simulation.

  - The XBEACH results show Section 3 slightly improves in the southern half of the section; however erosion is increased in the northern half. Significant erosive pressure is placed on the GSC revetment immediately south of Groyne 1. Erosion occurs in the north of Section 4 and 5. Some of these impacts could be minimised by capital and maintenance renourishment.
  - In summary, the presence of the nibs gives potential for greater buffer storage of sediment; however the volumes required to fill these buffers would likely be significant. This would need to be investigated further during detailed design. Improvements to Section 5 are predicted for this option. The improvement to Section 3 is not conclusive.

A conceptual design was completed for each option, including preliminary drawings and a cost estimate. This fed into the MCA, which considered:

> Public perception
> Environmental impacts / impact on adjacent coastline
> Likely effectiveness
> Capital cost
> Maintenance cost
> Safety
> Adaptability for climate change

MCA3 scored the highest in the MCA, mainly due to its low capital and maintenance cost, and the alternative amenity provided in Section 1. MCA2 received the second highest score, mostly due to its predicted ability to best protect Sections 3 and 5 (the car park and dog beach respectively). The public perception scores were added following the MCA workshop held in December 2015.

During the MCA Workshop, a fifth option, MCA5, was recommended to be assessed. This consists of the following:

> Upgrade the existing car park so that it meets Australian Standards.
> Revetment seaward of the car park in Section 3.
> Groyne 4 installed to 60 m in length, crest level of 6.5 m AHD;
> No modifications to the existing structures

Whilst this option does allow for retention of the existing car park, it is the most likely to reduce beach amenity in Section 3. This option received a score that placed it in the middle rankings of the five options assessed.

There are still uncertainties regarding the specifics of the mitigation option and these should be assessed further during detailed design. Specifically, the capital and maintenance renourishment volumes should be refined, as well as the crest levels of the proposed structures. The selected design life can also be modified should that provide cost savings in construction, or alternative options for future management

At this stage of the project, MCA3 is the option recommended to take to detailed design due to its highest score in the multi-criteria analysis.

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1 Introduction

Quinns Beach is an iconic region of the City of Wanneroo and has a long history of beach-side culture; its public amenity and recreational value are a focal point for the community. The history of Quinns Beach is characterised by a key challenge facing coastal communities – shoreline erosion and recession. Early reports of erosion date back to the 1940s and have continued through to present times. This ongoing erosion at Quinns Beach is a challenging issue that the City is keen to resolve.

The Quinns Beach Long Term Coastal Management Study was established by the City of Wanneroo with the goal of assessing potential coastal management options that would mitigate the ongoing trend of erosion present at Quinns Beach. The study area extends from the southernmost section of Quinns Beach, approximately 1 km north of the Mindarie Keys marina entrance, to the northernmost rocky outcrop approximately 2.2 km northwest of Groyne 3 (the northern-most existing groyne at Quinns Beach). This study area essentially includes all sandy coastlines from Mindarie Keys in the south to Alkimos Beach in the north, and includes several coastal protection structures, including the most recent (geotextile sand containers) works adjacent to Frederick Stubbs Park (Figure 1-1). To facilitate discussion Quinns Beach has been divided into six sections based on plan alignment, existing structures and historical shoreline changes, as depicted in Figure 1-1.

The overall study is split into five stages:

> Stage 1 – Undertake a detailed coastal processes assessment based on existing studies and recently collected data

> Stage 2 – Assess coastal management options and identify a preferred option based on a multi criteria analysis

> Stage 3 – Provide detailed design drawings and technical specifications (suitable for tendering purposes) for the preferred coastal management option

> Stage 4 – Provide technical advice during tendering and construction phases of the project

> Stage 5 – Provide technical advice and coastal engineering services post construction

This report summarises Stage 2 of the Quinns Beach Long Term Coastal Management Study. The purpose of Stage 2 is to assess the coastal management options put forward in the Stage 1 study (Cardno, 2015): Coastal Processes and Preliminary Options Assessment Report. These coastal management options were assessed and refined through numerical modelling of longshore sediment transport over 10 years (2005 – 2014) using the model LITPACK, and short term cross-shore and longshore sediment transport using XBEACH during the three storms that occurred in September 2013. This approach involved three rounds of LITPACK modelling, one round of XBEACH modelling, and relevant iterative analysis after each round. Some preliminary analysis using headland control theory and empirical design equations for offshore break waters was also performed. Following the modelling assessment of the options, four options were selected through discussions with the City and Department of Transport (DoT) to be assessed by means of a multi-criteria assessment.

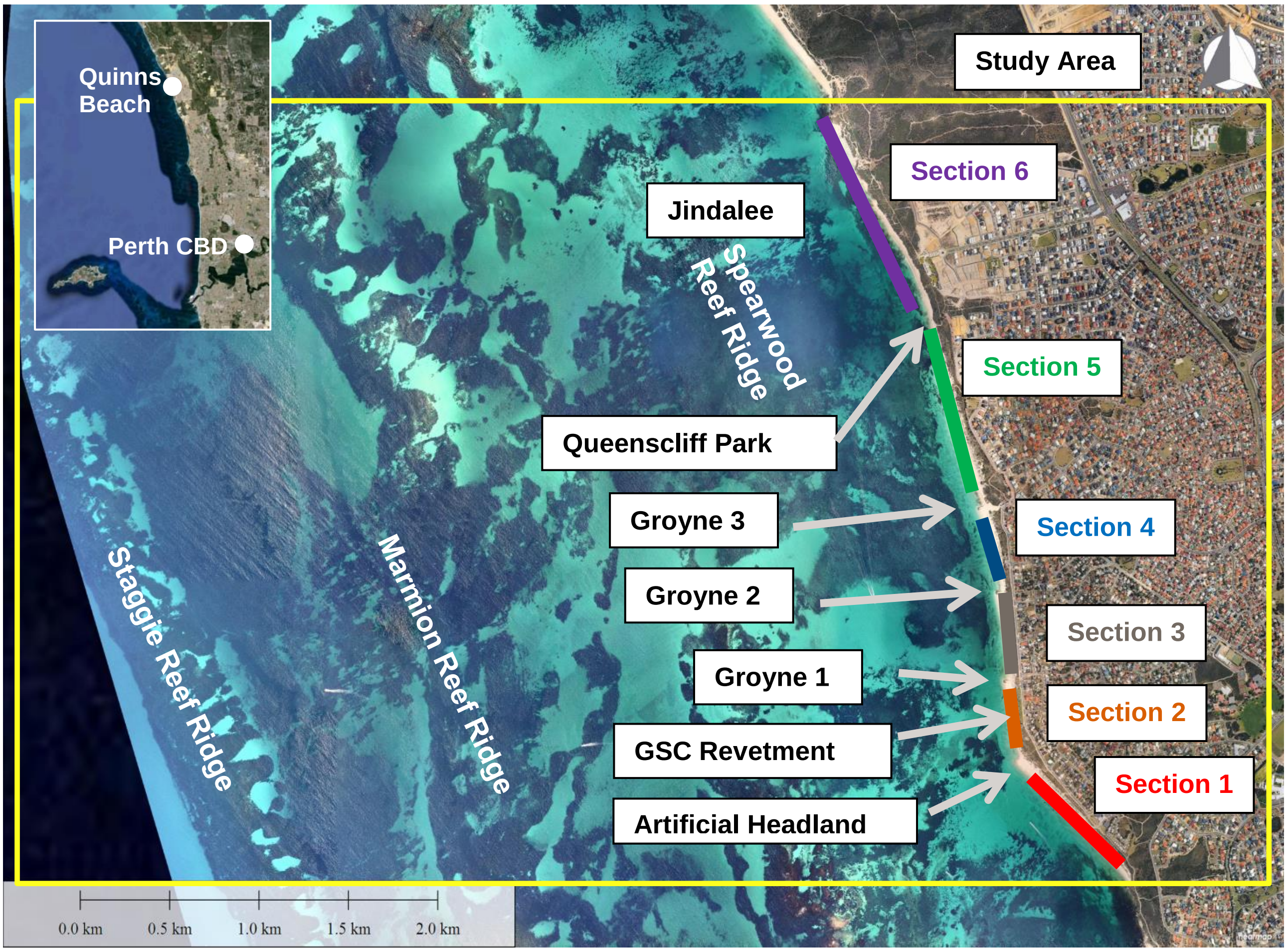

Figure 1-1 The Study Area; Quinns Beach within the City of Wanneroo, 35 km north of Perth

2 Longshore Sediment Transport Assessment

The longshore sediment transport assessment was undertaken to analyse, in further detail, four of the options identified in Cardno (2015). On the basis of a preliminary Multi-Criteria Assessment (MCA) completed in Cardno (2015) the options chosen for further assessment were options 3, 4, 5, and 6.

This longshore sediment transport assessment was undertaken using LITPACK in three rounds to further refine the layouts of proposed coastal structures. The LITPACK models simulated a period of 10 years, from 2005 to 2014, to assist in identifying long term shoreline movement trends for each option. The preliminary assessment rounds were conducted as follows:

1. Assessment of Options 3, 4, 5, & 6;
   a. Review of outcomes with the City and the DoT;
2. Development and assessment of Options 7, 8, 9, & 10;
   a. Review of outcomes with the City and the DoT;
3. Additional assessment of Options 11 & 12;
   a. Review and confirmation of final options for multi-criteria assessment and storm erosion (XBEACH) modelling (Chapter 3, 4 and 6).

The four coastal management options discussed in this chapter are options 9, 10, 11, and 12. The earlier conceptual options 3 through 8 are summarised briefly below, and discussed in more detail in Appendix A.

2.1 Preliminary LITPACK Options Description

2.1.1 Options 3 to 8

Options 3, 4, 6, 7 and 8 were modelled with LITPACK; Mepbay was applied for the artificial headland in Option 3 and the Y-shaped groynes in Option 5 to determine the likely equilibrium beach profile (refer Appendix A).

> Option 3
  - Layout: Shift the existing headland 75 m to the northwest. Construct Groyne 4, 80 m in length, in Section 5. Small artificial headland (length roughly 40-50 m) to be constructed in the centre of Section 3, approximately 10 m offshore from the 0 m AHD contour. This would be a similar structure to the existing artificial headland.
  - Results: Shifting the artificial headland provided benefits to the northern sections; however Section 1 was predicted to erode. The new artificial headland was predicted to provide some protection immediately landward of the structure, but would likely lead to increased erosion pockets in its lee. Groyne 4 provided sand retaining capacity in Section 5 at the northern end of the section; erosion in the lee of Groyne 3 would require renourishment.

> Option 4
  - Layout: Construct two offshore breakwaters of approximately 50 m in length, 50 m offshore, in each of Sections 3 and 5 to protect the car park and dog beach respectively. The groynes were lengthened by 30 m (total length 80 m).
  - Results: The model indicated the offshore breakwaters do not provide the desired effects. Almost no salient was formed; the only significant changes observed were erosion in the lee of these structures. Lengthening of the groynes appeared to improve the volumes of sand retained in all beach sections.

> Option 5
  - Layout: Similar to Option 4, but instead of lengthening the groynes, Y nibs would be added to Groynes 1 to 3 such that the overall distance extending offshore matches the length achieved in Option 4. The

aim of the nib is to create a headland that shifts the control point of the groyne out to the 'headland' rather than back near the base of the groyne. Offshore breakwaters as per Option 4 above.

- Results: The results indicated that this groyne-end form may improve the sediment holding capacity of the groynes, but only in the areas very near to the structures. Future iterations of this option should assess just adjusting Groyne 1 and Groyne 3. As with Option 4, the model did not predict the growth of a salient behind the offshore breakwaters.

> Option 6
  - Layout: Option 6 is the same as Option 4, but with the addition of the suggested artificial headland shift, as per Option 3.
  - Results: Similar to Option 4, with the added erosion in Section1 due to the shift in the artificial headland.

> Option 7
  - Layout: Another test of the offshore breakwaters, using a smaller 'distance offshore' to 'breakwater length' ratio to investigate if this would lead to accretion in their lee. In Section 3, the breakwaters are 60 m in length, 30 m offshore. In section 5, they are 80 m and 40 m respectively. Capital renourishment of 35,000 m^3 was included. This option also included extending Groynes 1 to 3 by approximately 30 m, and construction of Groyne 4.
  - Results: Offshore breakwaters had a positive effect in Section 5, but still did not improve the shoreline in Section 3. Groyne extension appeared to lead to accretion in Section 2 and 5. Section 1 and 4 were unchanged. Section 3 receded by 5-10m.

> Option 8
  - Layout: Tested the effect of extending Groynes 1 to 3 by approximately 30 m, adding in Groyne 4 and capital renourishment of 33,600 m^3.
  - Results: Section 1 and 4 unchanged, Section 3 receded by 5-10 m, Section 5 accreted by 5-10 m.

2.2 Final LITPACK Options Description

2.2.1 Option 9 – Extended Artificial Headland & Groyne 4

This option tested the effect of extending the artificial headland to the northwest to a total of approximately 120 m in length, in conjunction with capital renourishment of 10,800 m^3 in the vicinity of the headland. The conceptual layout of Option 9 is shown in Figure 2-1a; the present location of the artificial headland is at the intersection of Sections 1 and 2. The renourishment for this option aims to minimise the negative impacts immediately surrounding the extension of the artificial headland by shifting the 0 m AHD contour seaward immediately adjacent to the structure, by approximately 10 m in Section 1 and 30 m in Section 2. The extended artificial headland is represented in LITPACK as a revetment. Whilst the inclusion of the artificial headland as a revetment means that erosion cannot occur behind the structure, qualitatively it reproduced the behaviour typical for such a structure. In reality, due to the low profile of the headland, significant overtopping and sediment bypass would occur around this structure during storm conditions.

In addition, a fourth proposed groyne was included in the model in the vicinity of Queenscliff Park. This groyne is around 20 to 30 m longer than the existing groynes (total length 80 m). The renourishment breakdown across the beach sections is outlined below.

Table 2-1 Modelled nourishment volumes for Option 9

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
1,900 m^3	8,900 m^3	-	-	-	-

2.2.2 Option 10 – Modified Groynes

This option investigated the impact of angled nibs at the end of the groynes to determine their effect on sediment transport between the sections. Y-shaped nib extensions were added to Groyne 1 and a single nib extension was added to the northern side of Groyne 3 (see Figure 2-1b for the spatial layout). To model these groyne shapes in LITPACK, multiple groynes were included that extended to the vicinity of the proposed nib end; the angled nib itself was not included in the model. The multiple groynes were specifically:

> Three groynes close together at Groyne 1 to represent the Y-shape;

> Extension of Groyne 2 to 80 m length total;

> Two groynes close together at Groyne 3 to represent northwards pointing angled L-shape;

Renourishment was included in the vicinity of the modified groynes. The total capital renourishment volume was 23,000 m^3 for this option. This aimed to shift the 0 m AHD contour seaward by approximately 30 m in the applied sections, allowing for the offshore movement of the control point due to the presence of the nibs. Groyne 4 was not included in this option.

Table 2-2 Modelled nourishment volumes for Option 10

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
-	3,600 m^3	9,300 m^3	-	10,100 m^3	-

2.2.3 Option 11 – Offshore Breakwaters

This option includes the addition of three offshore breakwaters, one centred in Section 3 and two situated north of Groyne 3. All other structures are modelled as they exist at the present. The offshore breakwaters have been placed at approximately -3 m AHD. The larger breakwater in Section 3 extends for 120 m, while the smaller breakwaters extend for 80 m and are spread approximately 130 m apart from Groyne 3 and each other. The full spatial layout is presented in Figure 2-2a. The existing groynes were not modified in any way and Groyne 4 was not included in this option.

Renourishment was included in this option in the vicinity of the breakwaters to limit any potential down drift impacts of the structures. A smaller amount of renourishment was also placed at the northern end of Section 2. This aims to provide a buffer for Section 2, and allow for the reduction in bypassing from the north when the structures are first constructed. The volumes are outlined in the table below.

Table 2-3 Modelled nourishment volumes for Option 11

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
-	3,800 m^3	9,800 m^3	-	21,500 m^3	-

2.2.4 Option 12 – Extended Groynes & Groyne 4

Option 12 was developed as a modified version of Option 8 – Extended Groynes (see Appendix A) in an attempt to equalise the sediment bypassing rates around each of the groynes. An analysis of the sediment bypassing each of the groynes indicated significantly more sediment bypassed Groyne 2 than the other two groynes. To reduce this volume, and perhaps assist in retaining more sediment in Section 3, Groyne 1 was left at its existing length, and Groyne 2 lengthened significantly. The existing length of the three groynes is approximately 55 to 60 m. The final layout selected for the groynes was as follows:

> Groyne 1 existing length;

> Groyne 2 lengthened to 120 m;

> Groyne 3 lengthened to 80 m;

> Additional Groyne 4 length 60 m;

Renourishment was the same as Option 8 to allow for direct comparison between the two options. It included a total of 33,600 m^3 placed adjacent to the groynes as shown in the model layout in Figure 2-2b and as described in the table below.

Table 2-4 Modelled nourishment volumes for Option 12

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
-	3,800 m^3	10,600 m^3	-	10,800 m^3	8,400 m^3

Figure 2-1 Conceptual Layouts for (a) Option 9. Groynes 1 to 3 are unchanged in length; extended artificial headland extended shown by the purple line; Groyne 4 new structure. (b) Option 10. Red lines indicate modelled structures

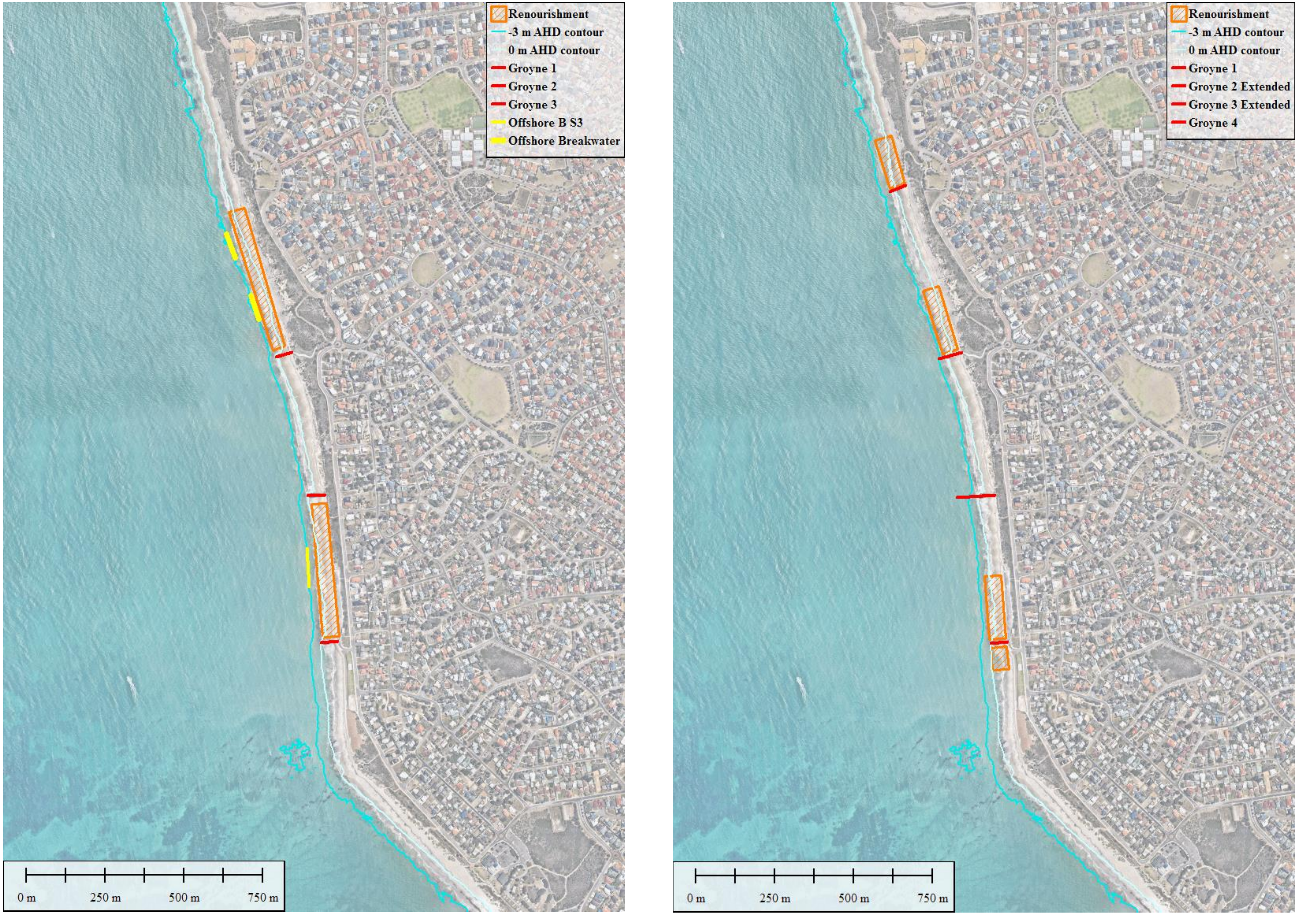

Figure 2-2 Conceptual Layouts for (a) Option 11. Groynes 1 to 3 are unchanged in length; offshore breakwaters shown in yellow. (b) Option 12. Groyne 1 unchanged in length, Groynes 2 and 3 lengthened. Groyne 4 new structure.

2.3 Model Results

The LITPACK model was used to undertake simulations for a period of 10 years. Results were extracted in May (end of summer) and September (end of winter) for each year and the shoreline plotted. Appendix B presents the shoreline results from Options 9, 10, 11, and 12 by section over an aerial photograph from February 2008. All investigations are based on 10 years of modelled wave data. This 10 year period was selected due to the availability of measured directional wave data from the Rottnest Island wave buoy. The LITPACK model results are plotted with the existing case outcomes (undertaken in Stage 1 of the project (Cardno, 2015)) for comparison.

A time series of the average beach width in each section over the 10 years is presented in Figure 2-3. The beach width was calculated by determining the position of the 0 m AHD contour line relative to a baseline and finding the average distance between the two lines for each time step. The shoreline within 20 m of a modelled structure was not included in the calculation, in order to exclude the significant variability around each structure and to focus on the overall trend of the shoreline within each section.

Results are discussed below; each layout is compared to the existing case simulation. Reference is also made to the earlier assessment rounds to highlight the effects of changes to the structure layouts.

2.3.1 Option 9 – Extended Artificial Headland & Groyne 4

The primary difference between Option 9 and the other options discussed earlier in this chapter is the extension of the artificial headland. The intended effect of this structure is to recreate the natural cuspate shape of the shoreline in this area, and trap more sediment within Section 1 without significant detriment to Section 2. A summary of the headland's effects with respect to the existing case is outlined below:

> The shoreline width in Section 1 increases by up to 5 m. This is better than the existing case and all other options, which result in an overall decrease in Section 1's width, with the existing case eroding by approximately 10 m.

> Option 9 only experiences minor erosion in the vicinity of the Surf Life Saving Club (SLSC) that appears to stabilise by the end of the simulation. All other options experience erosion from the SLSC to the south.

> The layout leads to a decrease in beach width in Section 2 by 5-15 m, with an average width decrease of 10 m, which stabilises after 3 years. The beach doesn't erode back to the GSC structure, except immediately adjacent to Groyne 1 during the September model output (end of winter).

> The option reduces average beach width by about 5-10 m in Section 3. This is likely due to the reduced supply from the south as there is an increase in sediment retained in Section 1. This option performs similarly in this section to the existing case and all other options except Option 12.

> The option performs the same as the existing case in Section 4 (~5 m accretion).

> The addition of Groyne 4 promotes a small and steady increase in the width of Section 5, averaging to 5 m over the 10 years. Section 6 remains relatively stable.

2.3.2 Option 10 – Modified Groynes

This option includes Y-shaped nibs on the end of Groyne 1 and an angled L-shape nib on the north side of Groyne 3. The intended effect is to reduce sediment transport around these structures to hold sand in the desired sections. A summary of the outcomes are as follows:

> Minimal effect on Section 1 and Section 2 compared to the existing case.

> Section 3 recedes by 5-15 m, depending on season, roughly stabilising after 6 years.

> Section 4 recedes by approximately 10-20 m. Recession is slightly greater adjacent to the groynes, at the north for May and the south for September. This is significantly worse for this section than any other option and does not appear to stabilise after 10 years.

> Section 5 is widened by 5-10 m depending on season and location along section, whilst Section 6 increases in width by about 5 m on average. This is the best performing option for both of these northern sections.

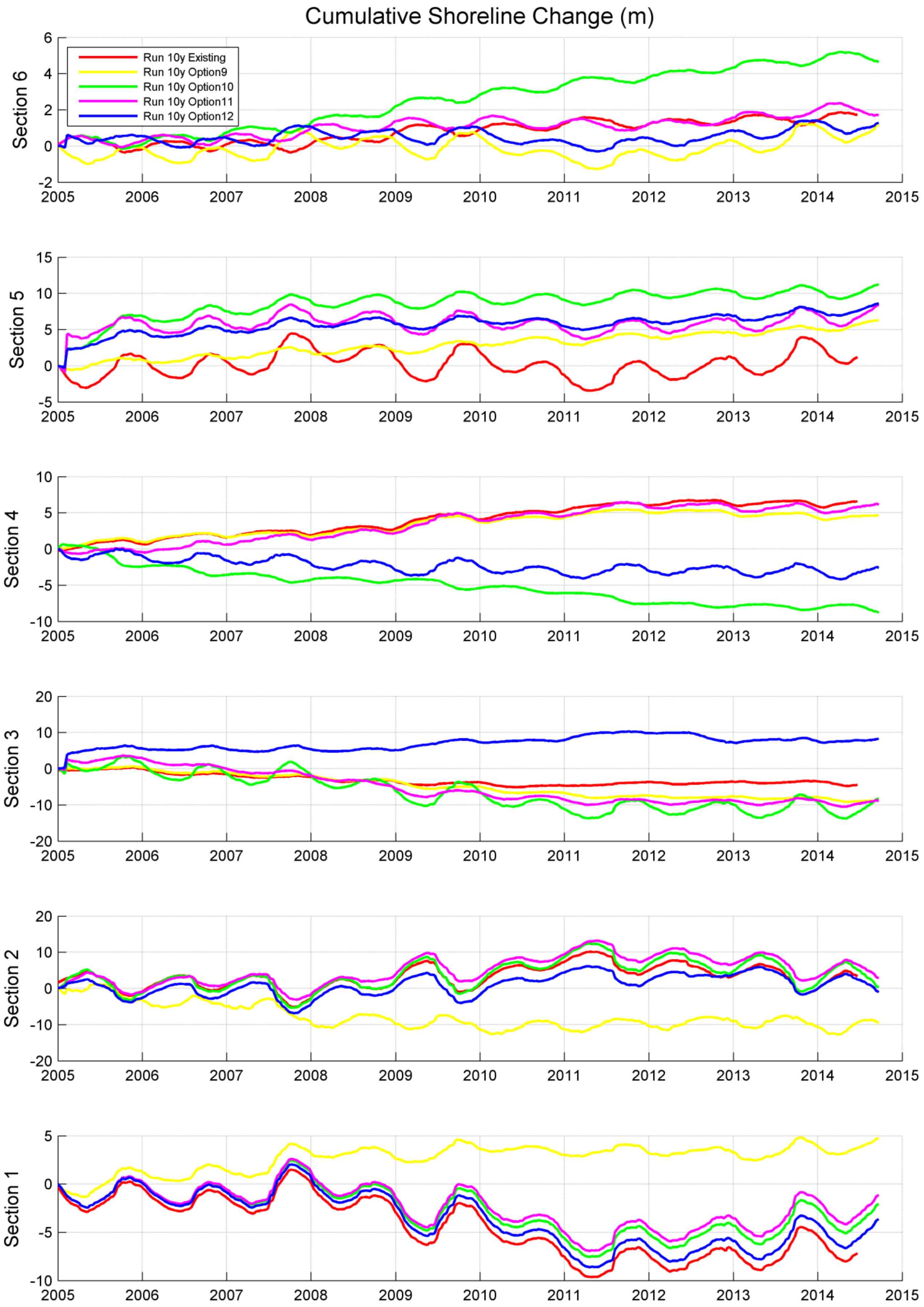

Figure 2-3 Cumulative movement of the average beach width across each section in metres

The effect of the nibs is similar to that of extending the groynes. The lengthened structure at Groyne 1 results in greater accretion in Section 2. However, the accretion in Section 2 is not significant, and on average the shoreline width moves back to 0 m change after the 10 years. Correspondingly, there is a recession in Section 3 due to a reduced sediment supply from the south. This shoreline movement is persistent, remaining at around 10 m on average for the last four years.

It appears that only adjusting Groynes 1 and 3 also results in Section 4 moving out of equilibrium, and therefore results in erosion in this previously stable section. A similar yet less significant effect was observed in Option 12 through the lengthening of the groynes, but every other option had no detrimental effect on this section.

2.3.3 Option 11 – Offshore Breakwaters

The distance offshore, length and spacing of the breakwaters for the initial application of offshore breakwaters in LITPACK were calculated using the method employed in Silvester & Hsu (1999). These empirical calculations give an indication of the predicted accretion of the salient behind the breakwater, and the likely erosion either side.

The first LITPACK round, Options 4, 5 and 6, included offshore breakwaters of length 50 m, approximately 40-50 m offshore (refer Appendix A). The empirical calculations indicated the peak of the accretion in the lee of the structure would be approximately 13-15 m. A tombolo could form, but it would be more likely that depths in the lee of the structure would be small. These values were selected as it was not the goal to form a tombolo, rather to induce accretion behind the structure. The LITPACK results showed some accretion in the lee of the breakwaters in Section 5, but no significant change to the shoreline in Section 3.

The offshore breakwaters were assessed again in the second LITPACK round; Options 7 and 8 (refer Appendix A). The empirical calculations were applied again, but to test the response in LITPACK, the distance offshore and length were set such that accretion in the lee of the structure would be 14-19 m. Two lengths (and therefore distances offshore) were tested: 60 m length and 30 m offshore in Section 3, and 80 m length and 40 m offshore in Section 5. The salient was therefore predicted to extend halfway offshore to the offshore breakwaters. The LITPACK results again indicated that Section 3 did not change from the presence of the offshore breakwaters. Section 5 however, showed 5 - 7 m of accretion, and therefore offshore breakwaters in this section could potentially be successful.

Option 11 was then selected through discussions with the City and DoT to provide a final test in LITPACK of the offshore breakwaters in Section 3, and refine the proposed offshore breakwaters in Section 5. The lack of response in Section 3 was thought to be due to a limitation of LITPACK resolving the interaction between the groynes and the offshore breakwater. The model results are discussed in this chapter; limitations on modelling the offshore breakwaters in LITPACK are discussed in Chapter 2.4. The main observations from the model were:

> Reduced erosion on average in Section 1 by 5 m, compared to the existing case. The section still saw seasonal shoreline movements similar to all options except Option 9, reaching a maximum average shoreline movement of 7 m inland in early 2011, before stabilising and slightly recovering for the last four years.

> Section 2 was not significantly affected by the offshore breakwaters, with accretion in this section only just exceeding the results of the existing case.

> The large offshore breakwater in Section 3 did not appear to have a significant impact. Results for this option show the average shoreline position move seaward 2-3 m due to the initial sand nourishment in the section, followed by a recession of approximately 10 m which stabilised after 10 years, compared with a recession of 5 m in the existing case model.

> Section 4 was unchanged due to the offshore breakwaters, with accretion in the area closely matching the existing case.

> The resultant shoreline in Section 5 under this option is improved by 5-15 m, depending on the season, with an average improvement across the section of 7.5 m by 2014. The initial increase in shoreline width due to the capital renourishment was held, and width slightly improved over the simulation period, with the section holding beach width and reducing seasonal variability compared with the existing case model.

2.3.4 Option 12 – Extended Groynes & Groyne 4

This layout was the result of analysis of several earlier simulations that included groyne lengthening. Analysis of the annual integrated longshore drift was undertaken to examine the movement of sediment throughout the model domain. A summary of the main observations from the model results for this option are:

> Minimal effect on Section 1 compared to the existing case. Slightly more erosion in Section 1 compared with Option 8 (all groynes lengthened) due to the increased sediment bypassing around Groyne 1.

> Section 2 shows no improvement on average over the 10 years, similar to the existing case. Accretion occurs in the southern area just to the north of the artificial headland at both the May and September outputs, indicating that the erosive shadow effect to the north of the headland may not be captured as strongly in the model results. Significant erosion occurs immediately south of Groyne 1 during winter, limiting the average section width and producing the same seasonal variability seen in all other options for the section.

> Section 3 beach width increases by 5 m from capital nourishment, and then steadily accretes to a maximum of 10 m additional total beach width over the 10 year simulation. This is the only final round simulation that effectively holds and stabilises Section 3, which is confirmed by Figure 2-3, indicating the significantly reduced longshore drift past Groyne 2.

> As expected, the reduction in sediment bypassing around the lengthened Groyne 2 results in a reduction in the average beach width in Section 4. However the reduction is limited to an average of 3-4 m across the section and appears to stabilise after 4 years. Given the good condition of this section at present this could potentially be considered an acceptable reduction by the City.

> The beach width in Section 5 is improved by 5-8 m on average and appears to stabilise. This varies depending on season and location within the section, with the beach at the southern end near Groyne 3 and the vehicle access path expected to remain relatively narrow during the summer months due to down drift impacts.

> The fourth groyne appears to effectively stabilise the compartment in Section 5 without creating significant erosion to the north that could negatively affect the pedestrian access path in the area.

2.4 Discussion

Three rounds of longshore sediment transport modelling have broadly determined the following:

> Addition of Groyne 4 has positive influence on Section 5 without significant detriment to both Sections 4 and 6.

  - The effect in Section 6 will be confirmed following the data collection at this site and re-calibration of the wave and sediment transport modelling.
  - The ability of the shoreline to accommodate the additional erosion that may occur in Section 6 due to the installation of Groyne 4 will need to be examined further.

> Sections 1 and 2 are strongly linked, with a change in one section always being inversely experienced in the other section to a similar magnitude.

> The offshore breakwaters in Section 5 have a positive influence on the section.

> Altering Groynes 1 and 3 without Groyne 2 also has positive influence on Sections 5 and 6, at the detriment of Sections 3 and 4.

> Only the significant extension of Groyne 2 modelled in Option 12 produces a positive effect on Section 3. All other final round options fail to outperform the existing case with regards to average beach width across the section. Preliminary Options 3 and 6 also outperformed the existing layout; however the results were not as strong as Option 12.

Overall, the modelling provided valuable insight into the long term shoreline evolution for various coastal management layout options. Options 9 and 10 provided some unexpected results around modified coastal structures, such as increased erosion in Section 2 and the destabilisation of Section 4 respectively. However limitations with representing certain structures in the LITPACK model are likely to have contributed somewhat to this. Due to the connectivity of the sediment transport system at Quinns Beach, no single layout manages to address all erosion hotspots whilst simultaneously maintaining the condition of the other sections. This highlights the fact that there is no ‘free’ sediment within the system.

Whilst LITPACK appeared to poorly reproduce the anticipated shoreline evolution in the lee of the offshore breakwaters, it is important to note that LITPACK only models the longshore transport generally as a result of non-storm conditions. Due to this, shoreline evolution is dependent on sufficient longshore sediment supply. Section 3 is known to have limited supply, from both the north and the south due to the presence of Groynes 1 and 2, so the building of a salient in this section is only possible through local erosion (or initial nourishment) in the section, resulting in limited change in mean shoreline position within the section. This is what is predicted by the XBEACH model for MCA1 (refer Chapter 4.1.6). Where the longshore supply is not limited, as is the case for the northern offshore breakwater in Section 5, expected shoreline effects of the offshore breakwater are observed in LITPACK.

Whilst there may be localised short comings of both LITPACK and XBEACH (refer Chapter 4.1.6 and 5.2.3), in the absence of a unified alternative, each aids in understanding the possible shoreline response to changes to existing coastal structures and new structures for long term coastal management.

Cardno (2015) highlighted that the summer periods of 2011/12 through 2013/14 (the final four years of the assessment period) had reduced northward wind stress (due to reduced southerly winds) as compared to the first 6 years of the simulation period. The effect of this climatic variability is clearly seen for all options with a change in the observed trend leading up to this time. These conditions give the impression that erosion (or accretion) stabilises over the final 4 years of the modelled period. Equally, the shorelines will also progressively move towards a dynamic equilibrium over time for the combination of structures present, with the observed stabilisation also being due somewhat to this process. Had stronger northward wind stress been maintained for the full 10 years, the trend from 2004 through 2011 would likely continue, however at a reduced rate.

3 Multi-Criteria Assessment Options

Applying the work undertaken up to this point, (Cardno (2015) and Chapters 1 to 2 of this report) Cardno, DoT and the City developed four coastal management options to take to the Multi-Criteria Assessment (MCA) stage. The MCA, discussed in Chapter 6, evaluates each option against a range of assessment criteria to determine the most desirable option for the City and relevant stakeholders.

The four options were determined based on the work by Cardno (2015) and the longshore transport assessment described above. Each option is described in detail in the following subchapters. To assist with the MCA, a detailed storm erosion assessment was performed for each of the options, excluding MCA3, for which results could be interpreted from the other simulations. A conceptual design was completed for each option, including preliminary drawings and a cost estimate, also outlined below. The conceptual design drawings are presented in Appendix C.

3.1 Design Criteria

All of the coastal mitigation structures described in the MCA have been developed for a 50 year design life. To decrease the likelihood of severe damage during the proposed design life, the 100 year Average Recurrence Interval (ARI) wave and water level design criteria have been utilised to determine each structures' required characteristics. The 100 year ARI has approximately a 40% chance of being reached or exceeded within the next 50 years, disregarding the impact of sea level rise on the design water level. For the concept design Cardno has not considered the effect of sea level rise, expected to be a 0.35 m rise over the next 50 years. However, the structure design has been relatively conservative at this stage.

Design wave heights were determined in Cardno (2015) at various model output locations along the study area. The bed level for each model output location varies between 3.1 m and 4.1 m below AHD and produced 100 year ARI wave heights from 1.5 to 1.6 m. The wave heights from the closest output points to each proposed structure were applied as the design wave heights for said structure.

Water-level data was obtained from the Department of Transport (DoT) at Two Rocks from 1994 to 2014 inclusive, and also the National Tide Centre for Hillarys from 1992 to 2014 inclusive. Extremal analysis of the Two Rocks and Hillarys water level data sets was undertaken to determine the 100-year ARI design water level for the study area. A Weibull fit was selected as the most appropriate method of determination. The 100 year design water level was determined to be 1.34 m AHD for the study area. MRA (1999) estimated the 50 year ARI still water level for the study area as 1.2 m AHD.

At each model output point, a scatter plot of modelled significant wave height (H_S) versus the mean wave period (Tp) was generated to determine the design wave period. A conservative period was selected that best matched the design wave height at each location. The design periods ranged from 7 to 15 seconds.

3.2 Design Parameters

The range of design wave heights, wave periods, structure depths and beach slopes were applied to the Van der Meer rock sizing formulae, as per Van der Meer (1988, 1992, and 1998) and Demirbilek & Vincent (2002) to provide an envelope of rock sizing. A conservative rock size was then selected from this envelope to cover the range of conditions.

The calculated Primary Armour median diameter (D_{50}) ranged from 1.2 to 1.36 m depending on the structure location. For ease of design at the concept stage, a conservative D_{50} of 1.36 m was applied as the Primary Armour size for all proposed rock armoured structures. This equates to an approximate median mass (M_{50}), at a density of 2000 kg/m^3, of 5.0 tonnes. This is similar to the 5.5t Class 1 armour recommended for the head of the original groynes by MRA (as per as-constructed design drawings provided by the City for Cardno (2013)).

The Secondary Armour was calculated again using the Van der Meer formulae to determine an appropriate armour size. The formulae produced a range of recommended design sizes ranging from 0.50 to 0.70 m in diameter. However, given that the largest calculated Primary Armour D_{50} was used, the corresponding

Secondary Armour design D_{50} of 0.60 m was considered appropriate. This corresponds to an M_{50} of 0.45 tonnes.

The recommended geotextile for all structures is the Texcel (formerly Elcomax) 600R. However, this selection requires review at the detailed design stage. The design requirements are summarised in the following table.

Table 3-1 Rock armour structure design requirements

	Primary Armour	Secondary Armour	Geotextile type
D_{50} (m)	1.36	0.60	Texcel 600R
M_{50} (t)	5.0	0.45	

A conservative crest level was applied for groyne extensions (6.5 m AHD) and offshore breakwaters (4.3 m AHD). This crest level was assessed by applying the design conditions discussed above, and using the method provided by Burcharth & Hughes (2006). According to this method, a crest level of 6.5 m AHD will be uncomfortable but not dangerous for pedestrians under the 5 year ARI conditions. The volume of overtopping is not predicted to lead to damage of the structure. Under 100 year ARI conditions, it is predicted the crest will be unsafe for vehicles and pedestrians; however damage is not predicted to be caused by overtopping alone. The volume of overtopping predicted under these conditions is 1 L / s per metre of structure.

Significantly higher overtopping has been allowed for during design storm conditions for the offshore breakwaters as the structures will have an armoured crest and are not designed for public access. This crest level is predicted to lead to damage at the crest if it is not protected, i.e. if it is not armoured. The predicted overtopping volume is 20 L /s per metre of structure for the 100 year ARI design conditions.

The as-constructed design drawings indicate the crest level for the existing groynes is 4 m AHD at the head, and 2 m AHD along the trunk. The crest level of the groynes taken from a survey carried out in 2008 by McMullen Nolan was a maximum of 3.98 m AHD, which matches the as-constructed drawings. Using the method provided in Burcharth & Hughes (2006), the level of overtopping predicted to occur in a design storm with a crest level of 4 m AHD will be very dangerous to pedestrians or vehicles on the groyne, and may lead to structural damage on the crest of the groyne, particularly as the crest is not fully armoured. As discussed in Cardno (2013), significant damage to the crest of the groynes, with a slumping of the structure at the head, is likely due to a combination of the low crest level, which leads to a significant amount of overtopping, and the lack of a filter layer, which increases the permeability of the structure and allows smaller rocks to be washed out from within the core of the structure.

The design presented in this report aims to reduce future damage by raising the crest level, and including secondary armour and geotextile fabric to reduce the likelihood of crest damage and wash-out of fines. Extended and new structures will consist of core, geotextile fabric, secondary and primary armour.

The crest levels of the proposed structures can be refined during detailed design. The City might be comfortable accepting a higher level of overtopping at the crest of the structures, which would reduce the cost of construction. Similarly, if the design life is reduced (e.g.: from 50 to 20 years), the crest level could be reduced as the likelihood of overtopping during the design life will also be reduced.

The rock size might also be reduced, if, for example, the duration of the design wave event were reduced in the calculations. Alternatively the level of permeability used in the calculations could also be adjusted (at present a conservative value has been applied). These would both reduce the rock size required. The design rock size does match the existing breakwater head rock size, so perhaps this does not need to be adjusted. These factors can be discussed with the City during detailed design.

3.3 Option Description

3.3.1 MCA1 – Offshore Breakwaters (LITPACK Option 11)

This option is based on the offshore breakwater option (Option 11) assessed in the final LITPACK modelling round. This option is presented in Figure 3-1a. The layout summary is:

> A large offshore breakwater centred in Section 3 and extending for 120 m along the beach;

> Two smaller offshore breakwaters extending for 80 m each spaced 130 m apart, starting 130 m north of Groyne 3;

> All three breakwaters are centred on the -3 m AHD contour line and have a crest level of 4.3 m AHD;

> No modifications to the existing structures.

Table 3-2 Recommended nourishment volumes for MCA1 (not included in XBEACH model)

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Total
-	3,800 m^3	9,800 m^3	-	13,000 m^3	8,400 m^3	35,000 m^3

3.3.2 MCA2 – Extended Groynes & Groyne 4 (LITPACK Option 12)

This option is based on Option 12 from the final LITPACK round and includes the same modifications to the groyne field (refer Figure 3-1b). The layout summary is:

> Groyne 1 as existing;

> Groyne 2 lengthened to 120 m (from 60 m);

> Groyne 3 lengthened to 80 m (from 60 m);

> Groyne 4 installed to 60 m in length;

> All groyne additions have a crest level of 6.5 m AHD.

Table 3-3 Recommended nourishment volumes for MCA2 (not included in XBEACH model)

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Total
-	3,800 m^3	10,600 m^3	-	10,800 m^3	8,400 m^3	33,600 m^3

3.3.3 MCA3 – Relocated Car Park & Groyne 4

This option is based on the recommendation of the State Coastal Planning Policy that managed retreat of assets and / or infrastructure should be considered before the construction of hard shoreline defences. This option involves the removal of the existing car park (approximately 3,500 m^2) in Section 3 with the area reinstated back to natural revegetated dune. A potential car park replacement area (approximately 2,300 m^2) has been allocated just off Ocean Drive, inland of the artificial headland. All other existing structures are left in place. To stabilise Section 5, Groyne 4, to 60 m in length, is also included in this option. The layout for this option is presented in Figure 3-2a. The area over the proposed car parks (described below) is presented in Figure 3-2b. The design drawing for Groyne 4 is included in the MCA 2 drawing set in Appendix C, as it is the same for both options.

The proposed car park layout is also presented in Appendix C; this includes 76 car bays. In addition, the on-street car parking could be extended parallel to this car park (15 bays), as well as along the street parallel to the existing car park (46 bays) but at an angle of 45°. Noting the 45° parking encroaches further into the existing dune than parallel parking would. This increases the cost of construction, but results in 22 more bays than if street-parallel. The addition of street parking to MCA3 results in an extra 51 bays; a total of 137 car bays would be created for MCA3. The existing car park does not have formal marked parking bays; however it would fit approximately 95 vehicles at present, based on the AS2890 dimensions for parking bays. The proposed new car park is approximately 30 m from the start of Frederick Stubbs Park, and 150 m from the playground. The exact location could be refined during detailed design.

Should the City wish to provide additional public amenity, a new toilet block could be constructed at the south-eastern corner of Frederick Stubbs Park; this location is displayed in Figure 3-2b. A provisional cost for a toilet block has been included in the cost for MCA3.

As well as complying with the planning policy, this option makes use of the stable Section 1, focussing the public amenity to Section 1, where infrastructure already exists to cater for public use, whilst also maintaining parking and access to Fredrick Stubbs Park. Section 1 is also longer than Section 3, allowing greater visitation numbers. A beach access path to the northern end of Section 1 is already in place at the proposed new car park location. An access path of the required length to allow a universally compliant gradient is displayed in Figure 3-2b.

An estimated 33,000m^3 of capital renourishment is included for this option to reinstate the dune upon car park removal, and renourish other sections as required. It is assumed that the City will renourish annually to maintain the present beach condition and minimise further erosion of the dune.

3.3.4 MCA4 – Modified Groynes & Groyne 4 (similar to LITPACK Option 10)

This option is based on the groyne modifications investigated as part of the LITPACK Option 10 model layout (refer Figure 3-2b for layout). Based on the results of Option 10, as well as the other options, the following layout was determined in conjunction with the City and the DoT:

> Angled L-shape nibs added to the northern side of Groyne 1 and Groyne 3; nib length is 50 m. Total offshore extent of structures is 85 m.

> Y-shaped nibs added to an extended Groyne 2; structure is extended by 30 m and 50 m nibs added. Total offshore extent of structure is 120 m.

> Groyne 4 installed to 80 m in length;

> All groyne additions have a crest level of 6.5 m AHD.

Table 3-4 Recommended nourishment volumes for MCA4 (not included in XBEACH model)

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Total
-	3,800 m^3	10,600 m^3	-	10,800 m^3	8,400 m^3	33,600 m^3

3.3.5 MCA5 – Car Park Upgrade, Car Park Revetment & Groyne 4

This option was created as a result of the MCA Workshop held in December 2015. It was noted that the existing car park does not meet Australian Standards. As a comparison to MCA3, it was suggested that the existing car park be upgraded to meet the Australian Standards. As this would likely be a significant investment, a revetment seaward of the car park should also be constructed so as to ensure the car park remained in place. One aim of this option is to enable direct comparison of the protection and upgrade of the existing car park, with the car park relocation of MCA3. A summary of the layout is as follows:

> Upgrade the existing car park so that it meets Australian Standards.

> Revetment seaward of the car park in Section 3.

> Groyne 4 installed to 60 m in length, crest level of 6.5 m AHD;

> No modifications to the existing structures

The proposed layout for this option is presented in Figure 3-3b and detailed plans are located in Appendix C. As discussed in Cardno (2013) and Cardno (2015), an exposed seawall (in the active section of the beach) often suffers from terminal scour and erosion, leading to loss of the beach directly in front and to both sides of the structure. During heavy storm events waves can reflect off the seawall, potentially leading to additional erosion. Seawalls can be found at many popular beaches; however they are almost always constructed well back from the existing shoreline, as they are not intended to be reached even in significant storm events, for example the seawall bounding the limit of the beach at City Beach.

An exposed seawall also needs to be keyed in to the surrounding dune system to reduce the risk of scour around the ends of the structure (terminal scour) outflanking the structure. Given the proximity of the car park and foredune at Quinns Beach to the shoreline, it is likely by the end of summer that the seawall will become exposed each year, potentially increasing erosion within Section 3. The seawall will not reduce the local sediment deficit that is present in Section 3 (compared to MCA3) and as such, it is likely that over time the seawall will become exposed to a greater degree for increasing amounts of the year. Loss of the beach and reduction in the visual amenity could be substantial with an uncovered seawall. This is further discussed in Section 5.1.5. Whilst this option has not been modelled directly, there is a significant body of knowledge on the behaviour of beaches in front of seawalls. Discussion of the pros and cons are based on coastal engineering knowledge, and interpretation of the other simulations.

MCA5 includes an allowance for 33,000 m^3 of renourishment. The majority of this would be placed near to Groyne 4 similar to MCA2, 3, and 4. The rest would be placed seaward and also to the south of the proposed revetment to maintain beach amenity in the area.

Table 3-5 Recommended nourishment volumes for MCA5 (not modelled)

Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Total
-	3,800 m^3	10,000 m^3	-	10,800 m^3	8,400 m^3	33,000 m^3

3.4 Beach Access

A new beach access point at Groyne 1 near Frederick Stubbs Park has been conceptually designed as part of this Stage. This has been presented to the City prior to this report; it is provided in Appendix C for completeness. Two options are provided: both options provide beach access via a timber path and stairs commencing from Ocean Drive at the entry to the car park. The first option provides access to the beach either side of Groyne 1 via timber access stairs, allowing access to beaches in Section 2 and 3. The second option provides access to just Section 2, to the south of Groyne 1.

Two specialist boardwalk manufacturers were consulted to obtain a cost estimate for both options. To construct the first beach access option the cost is $322,000 ex-GST. For the second option it is $214,000 ex-GST. It is recommended a 20% contingency be added to these costs to allow for latent conditions, site works etc.

Beach access is considered for each option below:

- The beach access proposed above will be suitable for MCA1. The existing beach access points will not interfere with MCA1.
- The beach access proposed above will be suitable for MCA2. The existing beach access points will not interfere with this MCA2.
- The second beach access option presented above would be suitable for MCA3. As discussed in Chapter 3.3.3, the beach access point at the northern end of Section 1 could be utilised from the proposed new car park. This could be upgraded to be universal access compliant. Other existing beach access points will not interfere with MCA3.
- The second beach access option proposed above will be suitable for MCA5. The existing beach access points will not interfere with MCA5. It is recommended that there is no public access along the car park revetment, only at the southern and northern extents. An alternative beach access point at the north of the car park could potentially be constructed for MCA5.

A pedestrian bypass at the landward end of Groyne 4 should be included in detailed design to allow access to Section 5 from the north and to Section 6 from the south. The beach access at Queenscliff Park (just north of Groyne 4) could be modified to be universally compliant, and potentially widened to allow for maintenance vehicles.

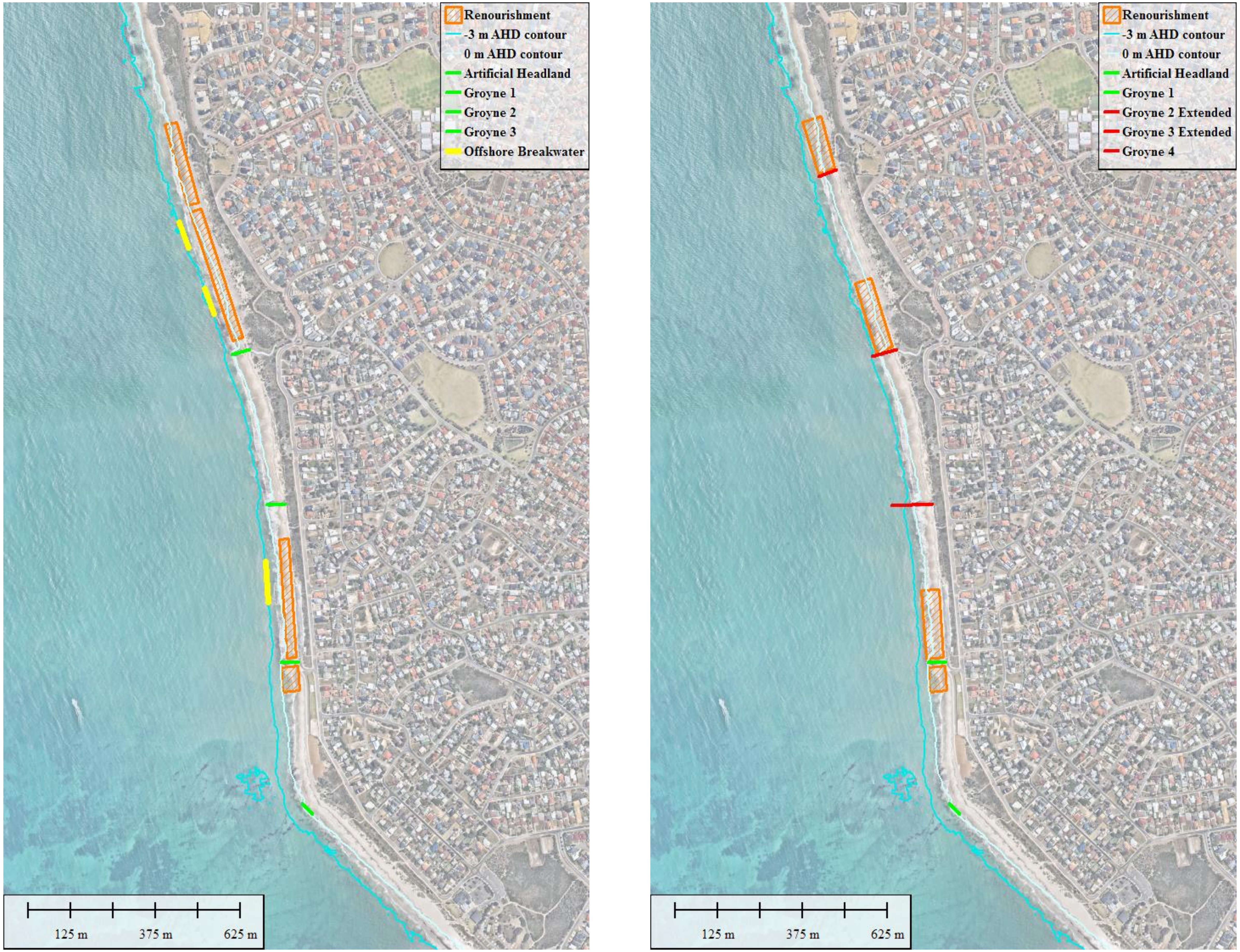

Figure 3-1 Conceptual Layouts for (a) MCA1 and (b) MCA2. Structures shown in green are existing structures; yellow are offshore breakwaters; red are new / adapted structures

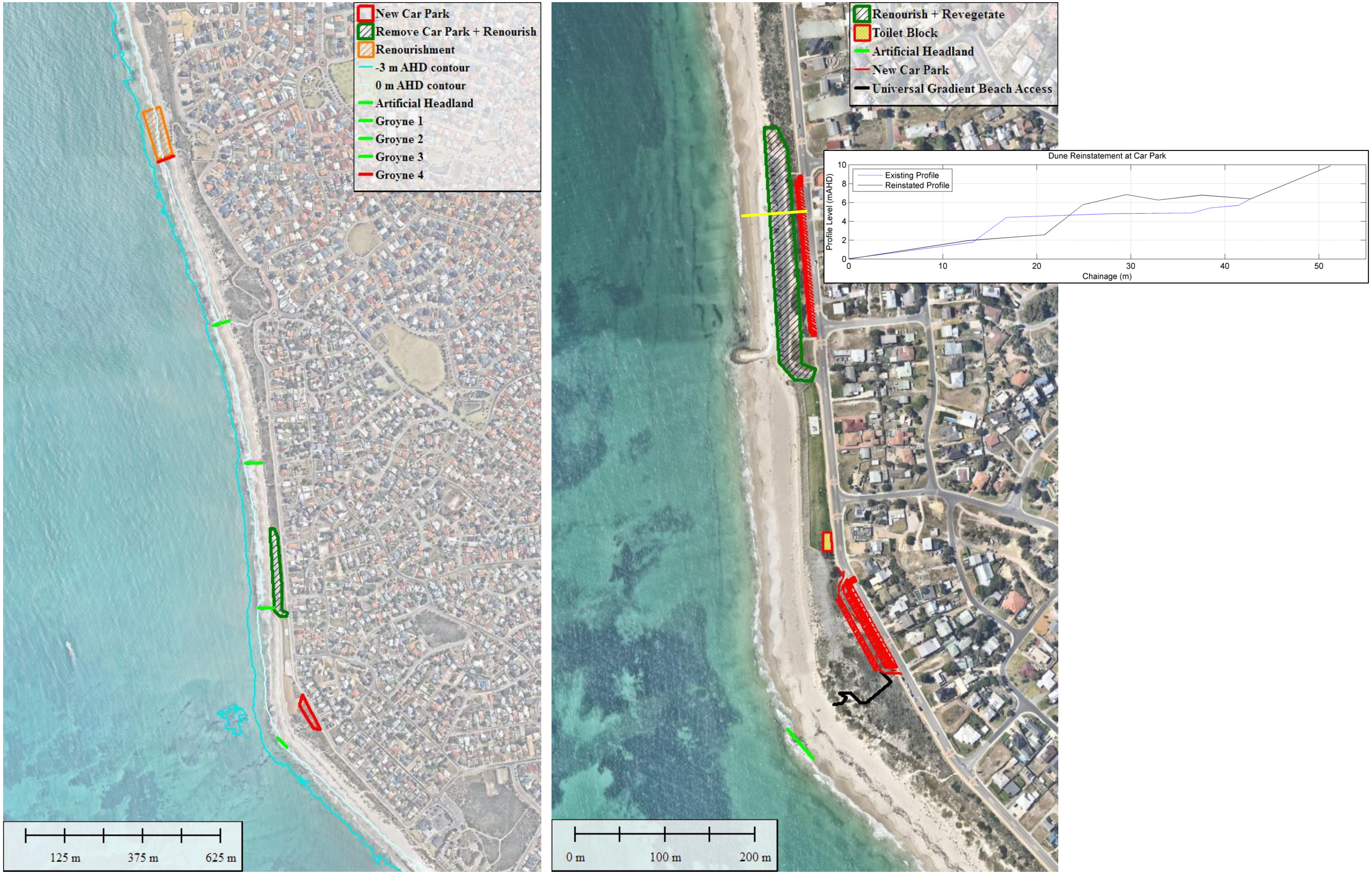

Figure 3-2 Conceptual Layouts for (a) MCA3 and (b) MCA3 zoomed in around car parks with typical dune reinstatement profile inset (profile location shown in yellow). Structures shown in light green are existing structures.

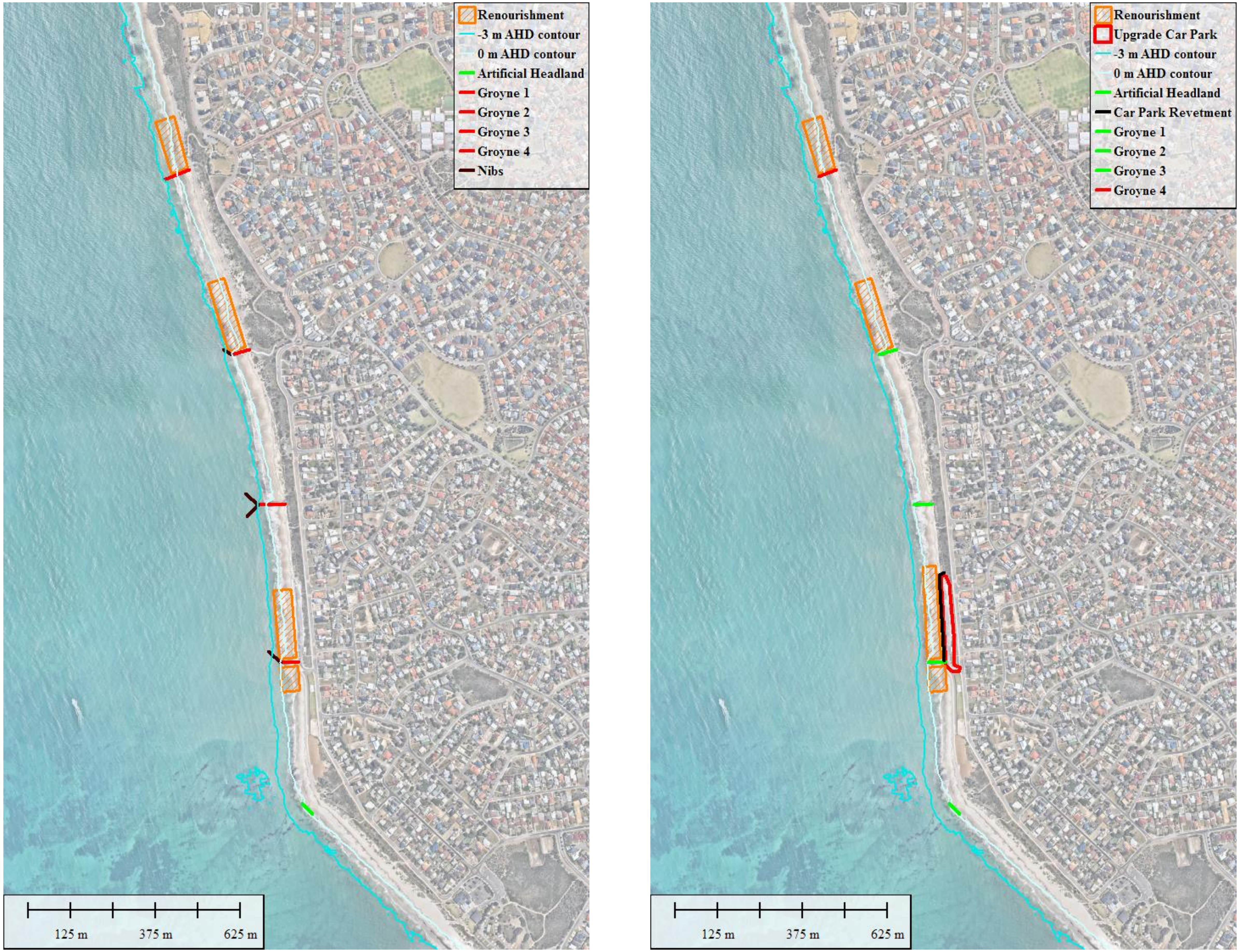

Figure 3-3 Conceptual Layouts for (a) MCA4 and (b). MCA5. Structures shown in green are existing structures; red are new / adapted structures; dark brown are breakwater nibs

3.5 Cost Estimate

3.5.1 Capital Cost Estimate

Cardno engaged two experienced contractors to provide preliminary capital cost estimates for each of the four MCA options, presented in Table 3-6. The costs are basic in nature and require refinement at the detailed design stage. However, they provide an indication of the difference in price between each option and are suitable for use in the MCA. Note that none of these prices include any allowance for renourishment. The recommended renourishment volumes have been added into the net present value calculations in Section 3.5.3 and are costed separately in Table 3-8, using an estimate of $35/m^3. Full breakdowns of both contractors' costs (not including renourishment) are shown in Appendix E. Costs in Table 3-6 have been rounded to the nearest $10,000; costs presented in Appendix E are the raw cost breakdowns supplied by the contractors.

Table 3-6 Estimated costs for rock armour structure design requirements

MCA Option	All Civils WA	WA Limestone	Contractor + Cardno Estimate
MCA 1	$4,550,000	$5,720,000	N/A
MCA 2	$4,230,000	$4,220,000	N/A
MCA 3	N/A	N/A	$2,500,000
MCA 4	$9,190,000	$8,320,000	N/A

The WA Limestone price supplied for MCA1 includes the cost of materials to build a temporary access bund to construct the offshore breakwaters. MCA3 includes $990,000 for the installation of Groyne 4 (plus 10% contingency), extracted from All Civils' breakdown of MCA 2 costs, as well as the relocation of the car park and toilet block, and an allowance for a retaining wall around the new car park. All Civils' costs presented above include an estimate contingency of 10%, as per the recommendation provided with their quote. MCA3 also includes a cost of $350,000 to construct angled parking along Ocean Drive including fill and retaining wall works.

The MCA5 costs are presented separately below in Table 3-7. It is assumed that in order to construct the revetment in MCA5, the car park would need to be partially removed and re-instated; this has been included in the capital cost estimate. The cost to construct Groyne 4 is assumed to be the same as for the other options that include Groyne 4. The cost for the car park upgrade, which includes some minimal works to the entrance ramp and layout, was costed by Cardno's Civil Infrastructure team. The total costs are presented in Table 3-7. Due to the similar structure layouts, the recommended capital renourishment for MCA5 is the same as MCA3.

Table 3-7 Estimated capital costs MCA5

Optional	
Car park revetment	$1,590,000
Car park upgrade	$510,000
Groyne 4	$1,090,000
MCA5 Total	$3,190,000

Table 3-8 Summary of recommended capital renourishment volumes and estimated costs at $35/m^3

MCA Option	Volume (m^3)	Cost
MCA 1	35,000	$1,225,000
MCA 2	33,600	$1,176,000
MCA 3	33,000	$1,155,000
MCA 4	33,000	$1,155,000
MCA 5	33,000	$1,155,000

3.5.2 Maintenance Cost Estimate

The expected maintenance costs for each of the MCA options have been calculated for the 50 year design life. The net present value (NPV) of each time series of maintenance costs was calculated to allow for comparison between each option. The NPV for each option is presented in Table 3-11. A summary of the estimation of maintenance costs is discussed below.

For the existing groyne structures, maintenance has occurred around every 6 years at a cost of $55,000 per groyne ($165,000 total), as indicated by the City. For MCA3 it is assumed that this maintenance requirement will continue for the next 50 years. Costs are expected to increase at an average of 4% per annum, the nominated inflation rate for this study. The next maintenance is assumed to occur in 2020.

For MCA2 and MCA4, the significant capital expenditure and increase in crest level is expected to reduce maintenance frequency, with both options estimated to require maintenance in 20 years and then every 10 years thereafter. However, based on the additional length of groynes, maintenance costs per occurrence are expected to be double for MCA2 ($330,000), and triple for MCA4 ($495,000). Due to the design of the breakwaters in MCA1, they are only expected to require one performance assessment by technical specialist's midway through the design life. This has been priced at $10,000 to adjust for inflation in 2041. MCA1 also includes the maintenance costs for the existing groynes as described for MCA3. If the groynes are maintained at regular intervals as outlined in the maintenance requirements, the structures will most likely remain useful and intact beyond the 50 year design life. However, due to the potential impacts of climate change, it is possible that the groynes may require more substantial improvement works to extend the design life.

The other main component of maintenance is expected to be the renourishment required to maintain the present condition of the beach. Cardno (2015) estimated the existing deficit in the study area to be 20,000 m^3 ($700,000 at $35/m^3) per annum. This deficit was described as a loss to the nearshore areas during storms, and as a result is not captured in the LITPACK modelling. The offshore movement of sediment is captured in the XBEACH model (refer Chapter 4), however the metocean conditions during the model runs are not representative of the long term conditions and hence the calculated volume of sediment lost offshore is most likely an overestimate of the long term sediment requirements. A significant percentage of the sediment moved offshore during the XBEACH simulations is expected to move back onshore in the weeks and months following a severe storm event, as has been observed at Quinns Beach in the past.

As such, the net volume of sediment lost during the XBEACH simulations (presented subsequently in Chapter 4) above the 0 m AHD contour was calculated over each section for each option. This is presented in Table 3-9. The volumes for MCA3 were calculated from the base case for Sections 1 to 4 and from MCA2 for Sections 5 and 6. The results indicate that MCA3 loses the least sediment during the simulations. However, modification of the structures means that the simulations' initial bed level is not in (or close to) the new equilibrium beach plan form. For MCA1, 2, and 4 the lost volumes could potentially be reduced (or at least their impact) if the capital renourishment volumes indicated in the LITPACK model runs were included. As discussed in subsequent chapters of this report, although the sediment loss is less for MCA3, this option does not allow for the retention of the car park in Section 3. To retain the car park, an alternative option must be selected.

Table 3-9 Estimated sediment loss (m^3) from XBEACH simulations above 0 m AHD contour

	MCA1	MCA2	MCA3 (Base case S1-S4; MCA 2 S5-S6)	MCA4
Section 1	4,000	4,500	4,500	4,500
Section 2	7,000	5,000	5,000	7,000
Section 3	5,000	7,000	4,000	6,000
Section 4	2,500	3,000	1,000	3,500
Section 5	1,000	2,500	2,500	5,500
Section 6	2,000	1,500	1,500	1,000
TOTAL	21,500	23,500	18,500	27,500

The total annual renourishment volumes for each option were estimated using the table above, together with the LITPACK results. These volumes are presented in Table 3-10. These volumes represent the total renourishment to occur per annum at Quinns Beach. Specific sections should be targeted as required. Figure 3-4 presents the predicted cumulative shoreline change for all sections by option. Note MCA3 is represented by a combination of Existing and Option 12. This figure reflects the relative volumes provided in Table 3-9 and Table 3-10 below.

As discussed subsequently in Chapter 6 and 7, the capital and maintenance renourishment volumes should be refined during detailed design through targeted model simulations. Particularly, the annual renourishment for MCA3 should ensure that further recession does not occur that might affect Ocean Drive in the future.

For MCA5, the estimated annual renourishment volume is the same as MCA3 due to the similarity in structure layout. However, increased erosive pressure in front of the seawall due to wave reflection and reduced longshore supply is expected to result in more renourishment being required each year to maintain the same level of beach amenity. A contingency has been included to account for this by increasing the annual renourishment volume by 1% each year over the 50 year life span.

Existing structure maintenance is also expected to be the same as MCA3 for the groynes. Structural maintenance costs for the seawall are expected to be the same ($165,000 per maintenance event), however due to the design specification, maintenance is only expected on the same lifecycle as the refurbished groynes in MCA2 and MCA4 (at year 20 and every 10 years following). The final NPV for MCA5 is shown in Table 3-11.

Table 3-10 Estimated annual renourishment (m^3)

	MCA1	MCA2	MCA3	MCA4	MCA5
Annual Renourishment	11,500	13,000	10,000	15,000	10,000*

*As noted above, this annual volume will increase by 1% per year

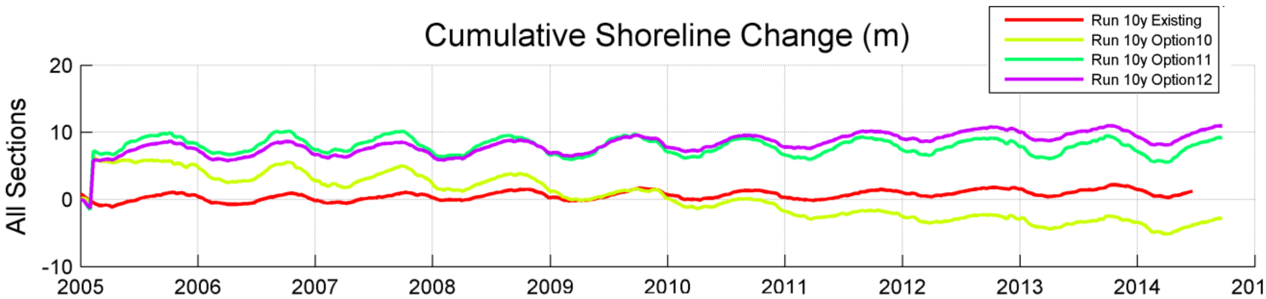

Figure 3-4 LITPACK model results: average cumulative shoreline change (in metres) for all sections, by option (MCA1: Option 11, MCA2: Option 12, MCA3: Existing / Option 12, MCA4: Option 10)

3.5.2.2 Maintenance Beach Access

To carry out the maintenance discussed above, consideration is given to the required access for each option below:

> MCA1: Groyne 1 and 2 can be accessed from the existing car park. Temporary large vehicle access can be created at the northern end of the car park. Renourishment of the area would occur from the same location. The universal access path at Groyne 3 can be used to renourish Sections 5 and 6, and maintain Groyne 3. If the beach access path at Groyne 4 were upgraded, this could also be used for maintenance vehicle access. It is noted that due to the path dimensions at Groynes 3 and 4 this would limit the vehicle size that could be utilised at these access points.

> MCA 2: To manage the potential erosion in Section 4, heavy vehicle access over the trunk of the groyne may be necessary for large volume nourishment (with access to the beach via the car park in Section 3). Alternatively, manual bypassing of sand over the extended Groyne 2 may be necessary, and should be considered in the design of this structure.

> MCA3: Relocation of the car park would remove the vehicle access in Section 3. The existing beach access road to the trunk of Groyne 1 could be maintained, with restricted access to the beach provided for nourishment of Section 3 and maintenance of Groyne 4. If the dune area is completely reinstated, temporary vehicle access (with dune reinstatement immediately afterwards) could be created for maintenance of Groyne 1, and any renourishment of Section 3. Access to Sections 4 and 5 would be via the vehicle access path at Groyne 3. Access to Section 6 and Groyne 4 could potentially be down the adapted access path at Queenscliff Park.

> MCA4: Maintenance access for this option would be similar to MCA 1 and 2. Specific details may be necessary to support temporary heavy vehicle access across the groynes or alternative heavy vehicle access provided further north.

> MCA5: Maintenance access for this option would be similar to MCA 1 and 2. Specific details may be necessary to support temporary heavy vehicle access across the groynes or alternative heavy vehicle access provided further north. Access to the beach will likely be provided from the north of the car park in Section 3; however this would compete with the installation of pedestrian beach access path at that location.

The cost and efficiency of any beach nourishment activities can be optimised and timed to make use of the natural longshore drift process, and this is something that should be detailed during the design of any the options considered here.

3.5.3 Net Present Value

The combination of the contractor cost estimates, the recommended capital renourishment, and maintenance cost estimates were combined and the net present value calculated using a discount rate of 10% (NZ Treasury, 2015). All renourishment has been estimated at $35/m^3, adjusted for inflation as required.

Table 3-11 Net Present Value

MCA Option	NPV @ 10%
MCA 1	$13,350,000
MCA 2	$13,030,000
MCA 3	$9,790,000
MCA 4	$18,790,000
MCA5	$11,500,000

Given the long length of the design life, the annual renourishment is generally the most significant factor determining the net present value. However, due to the nature of net present value calculations, the final cost is much more sensitive to changes is the capital cost and other costs early in the project lifecycle. Given the lower construction cost and estimated renourishment requirements, MCA3 was determined to be the most economical solution over the 50 year design life. Note that the capital costs may include a contingency, if described in Appendix E; however no contingency costs have been included in the renourishment or maintenance costs.

Given that every option includes some form of car park, no allowance has been made for minor car park maintenance. This is expected to be equal for each option and has been estimated at a net present value of approximately $90,000 for yearly minor maintenance and three resurfaces over the design life.

4 Storm Erosion Assessment

The storm erosion assessment utilised the calibrated XBEACH storm erosion model detailed in Cardno (2015). The model was calibrated using measured data for a one week simulation across a storm in September 2014, when pre and post storm beach surveys were available. As part of this options assessment, the calibrated XBEACH model was used to evaluate three proposed coastal management options as well as the existing layout of coastal structures. The simulation period was for six weeks from the 19th of August 2013 to the 30th of September 2013, which included three storms that significantly impacted Quinns Beach, and at the time resulted in significant erosion in Section 2 adjacent to Frederick Stubbs Park.

The options modelled in XBEACH were designed to test in detail the coastal structure layouts assessed as part of the final LITPACK modelling round. Some minor modifications were made to the layouts where it was deemed appropriate. A full description of each layout and any modifications from the LITPACK modelling are outlined in the following chapters. The existing structures case (including the geotextile sand filled container revetment) was also modelled for comparison with the assessed options.

No renourishment was included in the initial XBEACH model bathymetry for all modelled options, as per discussions with the City and DoT. The bathymetry utilised in the models is the pre-September 2014 model calibration bathymetry.

MCA3 was not included in the XBEACH modelling options assessment stage. As MCA3 is essentially the existing structures case with the addition of Groyne 4, the results for this option were interpreted from the existing case simulation and MCA2 in the vicinity of Sections 5 and 6.

4.1 Model Results

The XBEACH model results provide detailed spatial information on the cross shore and longshore movement of sediment in the model domain under storm conditions. This chapter outlines the model results for each of the four proposed layouts. Chapter 5 below discusses the differences between the options and also any notable differences between LITPACK and XBEACH results for the corresponding simulations.

Similar to the LITPACK analysis, a time series plot showing the cumulative change in the average width of each section is presented in Figure 4-1. This first subplot shows the chosen time delineation between the three storm events (grey vertical lines), which are also shown in Table 4-1. It should be noted that there can be significant sediment transport without a significant change in the location of the 0 mAHD contour, as can be observed in some of the spatial outputs. For example, there might be significant erosion of the beach berm and dune above the 0 m AHD contour.

The majority of model result plots are presented in Appendix D. The first set of figures in Appendix D compare the accretion and erosion over four different periods as outlined in the table below. These figures do not present the cumulative sediment movement over the simulation, only the movement between each of these time frames. There is a figure for each section for all four options (including the base case). The following six figures show total accretion and erosion per section over the entire model period time frame to allow for better comparison between each model scenario.

The final set of figures in Appendix D show the locations of 19 cross shore transects along the study area, followed by a plot of the initial and final beach profiles along each transect for each option. The transects are numbered from 1 in the south of Section 1 to 19 at the northern end of Section 6.

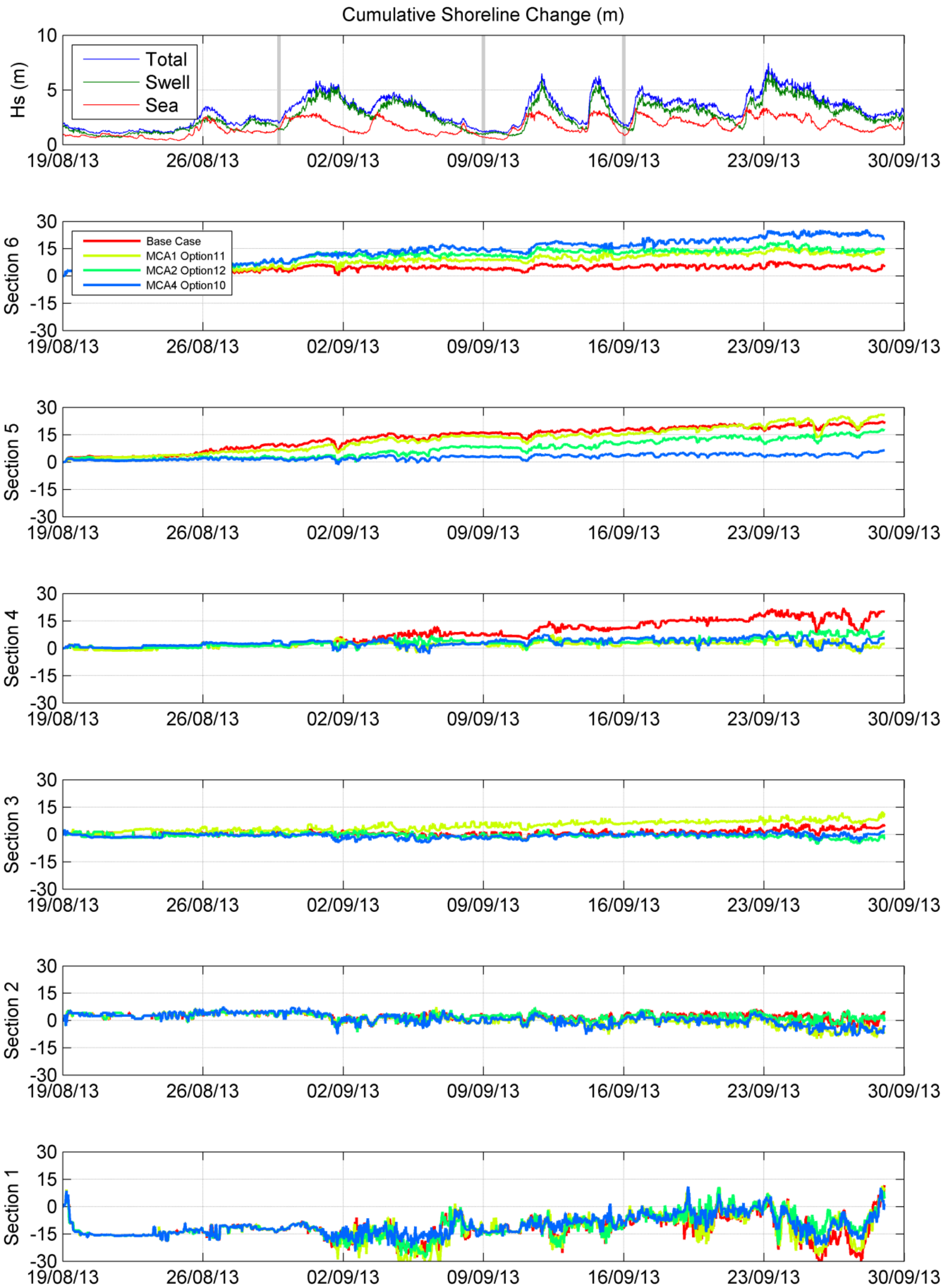

Figure 4-1 Cumulative movement of the average beach width across each section in metres

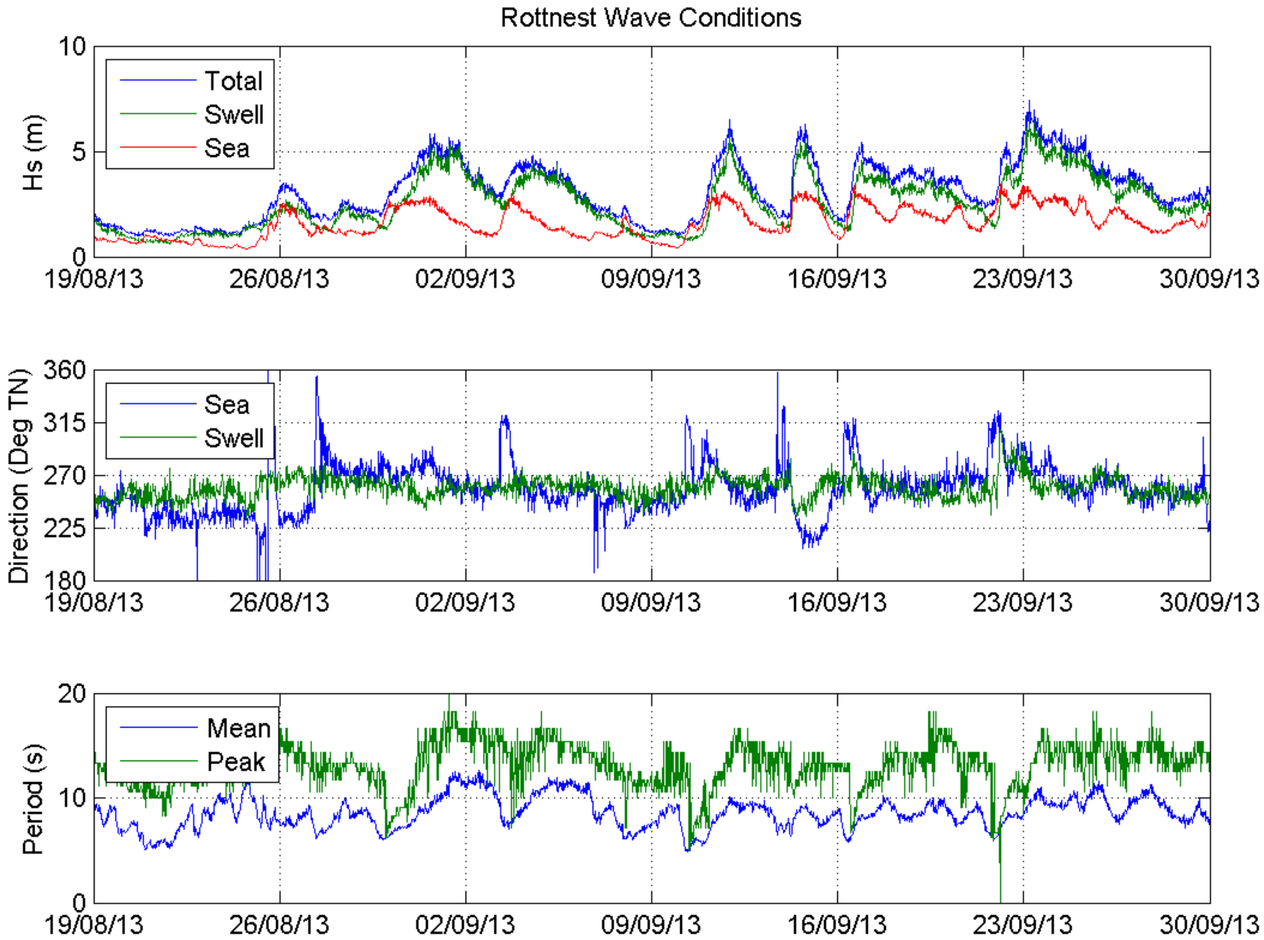

Figure 4-2 Rottnest Island wave buoy measured conditions for the duration of the XBEACH model simulations

Table 4-1 XBEACH simulation important start times

Simulation warm up	Storm 1	Storm 2	Storm 3	Simulation end
19/08/13	29/08/13 19:00	09/09/13 00:00	16/09/13 00:00	03/09/13 00:00

In general, over the simulation period, the following trends were observed:

> A significant flux of sediment from north to south, with sections experiencing a significant shoreline rotation and 'filling' of each structure on its northern side, and erosion immediately to the south.

> A smaller cross-shore flux of sediment in the offshore direction, with significant erosion occurring above the initial 0 m AHD contour in most sections, and almost no accretion occurring above the same line.

> There is virtually no significant change in the bed level outside of the range ±3 m AHD.

> The significant southward longshore sediment flux is also observed during the simulation warm up period, although significant cross shore transport was not readily observable from the spatial output maps in Appendix D. This period did experience a relatively small (~2.5 m) increase in wave height off Rottnest which included two spikes in the sea direction from the north, as shown in Figure 4-2.

> The second storm had a relatively minor impact on the study area both in terms of bed level change, with some minor recovery observed in generally eroding areas. This is consistent with anecdotal evidence reported at the time.

> All options behaved relatively the same in Sections 1 and 6 in terms of bed level change over the entire simulation. This included significant deposition immediately south of the artificial headland.

> Section 4 behaved similarly for all three options, experiencing mild accretion in the southern half and mild erosion in the northern half. The base case experienced section wide accretion here due to the lack of impediments to sediment flow from the north that were present in the three conceptual options.

> The southern end of Section 5 accretes significantly for all options and the base case.

4.1.2 MCA1 – Offshore Breakwaters (LITPACK Option 11)

In general this option provides increased beach width to the majority of the study area at the expense of two localised erosion points. Each breakwater forms its own salient that grows into a tombolo early in the simulation, indicating the modelled sediment transport is behaving as expected in the empirical calculations. The main observations of MCA1 from the analysis of the results are:

> Section 2 experienced a significant sediment deficit with erosion occurring all the way along the section during Storms 1 and 3, and only minor recovery above the 0 m AHD contour during Storm 2. However, in Section 2, the 0 m AHD contour remained relatively stable until Storm 3, when the 100 m of coast immediately south of Groyne 1 was eroded by at least 10 m, in places up to the GSC revetment.

> As expected, the offshore breakwater in Section 3 provided a significant increase to the beach width on average for the area. A significant source of this sediment appears to be the beach at the northern and southern extents of the section, which experience moderate erosion.

> MCA1 is the only option that produces significant erosive pressure on the car park during this period of net southerly transport, however slightly less erosion occurs at the northern end of Section 3.

> Section 5 accretes significantly in the south, however does not noticeably outperform the base case. The breakwaters do hold sediment in the northern half of the section and reduce erosion in the area compared to the base case scenario.

4.1.3 MCA2 – Extended Groynes & Groyne 4 (LITPACK Option 12)

In general this option performs adequately throughout the study area: it protects the beach in front of the car park and the dog beach without putting as much pressure on erosion pinch points as the other layouts. A summary of observations from the analysis figures is as follows:

> Average beach width by section is relatively stable for Sections 1 to 3, while increases of 5 to 15 m are observed in Sections 4 to 6.

> Within Section 2, the 0 m AHD contour remains within around 5 m of its starting position. However significant erosion occurs along the whole section both above and below the 0 m AHD contour.

> The extension of Groyne 2 results in significantly more erosion to the northern half of Section 3 compared with all other options. This erosion occurs at all phases of the simulation including, to a lesser extent, Storm 2.

> The addition of Groyne 4 reduces erosion to its north while only producing a very minor amount of erosion to its south.

4.1.4 MCA3 – Relocated Car Park & Groyne 4

The results for this option were taken from the existing structures case (base case) for the majority of the study area. The results from MCA2 above were utilised in the vicinity of Sections 5 and 6.

> On average across the sections, the beach width (0 m AHD contour) in Sections 1 and 2 are unaffected by the storm sequence.

- In Section 1, there is significant accretion below the 0 m AHD contour in the southern half of the section. Minor erosion occurs in the midway along the section. This is similar for all MCA options.
- Erosion in Section 2 is less than MCA1 and MCA4, and comparable, if not slightly better than MCA2.

> Minor erosion occurs in the north of Section 3; accretion occurs in the south. The average beach width increases over the storm sequence.

> Section 4 experienced accretion due to the reduced impediments to sediment supply from the north that were present in the three other options.

> The addition of Groyne 4 reduces erosion to its north while only producing a very minor amount of erosion to its south.

4.1.5 MCA4 – Modified Groynes & Groyne 4 (similar to LITPACK Option 10)

This option resulted in significant increases in beach width on the northern side of the modified groynes and corresponding erosion shadows on the southern sides. It appears that the nib additions significantly impede sediment transport for most or all of the simulation. The main observations are:

> Overall relatively stable beach for every section with the exception of Section 6 that increases by 25 m by the end of the simulation.

> Significant erosive pressure placed on the GSC revetment immediately south of Groyne 1 and along the length of the section.

> Minimal change in bed level on the seaward end of the first three groynes and stronger shoreline rotations in Sections 3 and 4 than any other modelled scenario.

> The extended Groyne 4 holds significantly more sand to the north than the breakwaters or shorter groyne, resulting in less erosion in Section 6 but increased erosion immediately to the south of the structure.

4.1.6 Validation of XBEACH results

Whilst no quantitative validation data was available for the storm period, various photographic records are available for the time and provide valuable qualitative evidence of the processes that occurred. The large flux of sediment from Section 6 to Section 5 appears to be present in available aerial photography of these sections from before (30/06/2013) and after (13/10/2013) the September 2013 period. These photographs demonstrate that this process did occur, however with uncertainty around the magnitude of the process. The calibration of the XBEACH model in Cardno (2015) identified this area as under-estimating the erosion that occurred during the September 2014 calibration period. Examination of cross-shore profiles before and after the storm reveal that the lack of representation of nearshore reefs around -1 m AHD as non-erodible structures is the likely cause of too much supply from Section 6. It is recommended that the model schematisation is improved in this area for detailed design.

It is noted that additional wave data has been collected in the north of the study area concurrently to this stage. The data will be used to further calibrate the wave model for use in detailed design. This will then allow refinement of the XBEACH model.

All simulations result in significant erosion and lowering of the beach level in front of the geotextile sand filled container revetment and this process is exacerbated where the supply of sand from the north around Groyne 1 is further limited by additional structures further north. All simulations result in significant accumulation of sand in Section 1 which is also supported by inspection of aerial photographs. This provides confidence that the XBEACH model is able to reproduce the complex sediment transport processes during storms.

For the offshore breakwater and compound (L and Y) shape groynes, XBEACH produced morphological changes that were consistent with expectations and empirical predictions from headland control theory and offshore breakwater design. There remains some uncertainty as to the rate of sediment accumulation and persistence of the tombolo that forms behind the offshore breakwaters, as the model has been calibrated for the cross-shore profile evolution that occurs along the ‘open’ beach at Quinns, and it is likely that the calibration parameters (for wave asymmetry and skewness) would be somewhat different in the lee of these structures due to significant local changes in the wave conditions.

Figure 4-3 Aerial photographs of Sections 5 and 6 from (a) 30/06/2013 and (b) 13/10/2013

5 Discussion

5.1 Effectiveness of Options

5.1.1 MCA1 – Offshore Breakwaters (LITPACK Option 11)

The LITPACK results indicate this option improves Section 2, 4, 5 and 6; Sections 1 and 3 are negatively impacted, although Section 1 is predicted to recede less than the existing case. The shoreline in Section 3 is predicted to recede by 10 m, which is 5 m more than the existing case. Discussions with the City indicate the two sections they are most interested in protecting, and providing an amenable beach, are Sections 3 (the car park and public amenity) and 5 (the dog beach). Detrimental effects to other sections are to be avoided. This option, whilst predicting improved amenity at Section 5, does not provide that improvement at Section 3, according to the LITPACK results.

The XBEACH results indicate that although this option performs the best of the three in terms of average beach width across Section 3, it also predicts significant erosive pressure on the car park in Section 3. Section 2 also experiences a significant sediment deficit as a result of this option. Section 5 was predicted to improve but not consistently throughout the section when compared to the base case. Given these simulations were for storms, appropriate renourishment could provide a buffer that might mean Sections 2, 3 and 5 are suitably improved under this option.

In summary, MCA1 predicts improvement at Section 5, but does not provide adequate protection of Section 3 seaward of the car park, and results in negative impact on Section 2. Maintenance renourishment could assist with improving this option. If this option were selected for detailed design, the location of the offshore breakwater in Section 3 could be investigated to optimise the protection of the car park.

5.1.2 MCA2 – Extended Groynes & Groyne 4 (LITPACK Option 12)

The LITPACK results indicate a significant improvement in Section 3. As a result, Section 4 is predicted to recede, but this is limited to an average of 3-4 m across the section and appears to stabilise after 4 years. The beach width in Section 5 is predicted to improve by 5-8 m on average and appears to stabilise. The narrow beach width observed at the southern end of the section during the summer months indicates that maintenance renourishment in Section 5, and perhaps Section 4, could improve the outcomes of this option.

The XBEACH results indicate that this option performs adequately throughout the study area: it protects the beach in front of the car park and the dog beach without putting as much pressure on erosion pinch points compared with the other layouts. Erosion does occur in the north of Section 3, however this could be minimised by capital and maintenance renourishment (note the XBEACH simulations were performed without any renourishment). The longer Groyne 2 allows for a significant sediment buffer to be placed in the northern end of Section 3 that would contribute significantly to erosion mitigation under storm conditions. Equally, the longer Groyne 2, which strongly impedes littoral drift around the structure, may result in additional erosion sensitivity due to particular sequences of weather conditions. For example summers with reduced northward littoral drift (due to weakened southerly winds) may make the southern side of Groyne 2 susceptible to erosion in the subsequent winter. Similarly summers with a larger than average northward littoral drift may make the northern side of Groyne 2 susceptible to erosion by the end of summer. These conditions would need to be managed through beach monitoring and beach renourishment.

On the basis of the work undertaken to date, this option is the most suited for achieving the City's goals of increased beach amenity in Sections 3 and 5. Renourishment will be necessary to provide suitable buffers during storms.

5.1.3 MCA3 – Relocate Car Park & Groyne 4

The LITPACK results were interpreted from the existing case, combined with MCA2 for Sections 5 and 6. The results indicate 5-10 m recession of Section 1 by the end of the 10 year simulation. This is the greatest recession compared to Options 9 to 12. This recession appears to be stable for the last 5 years, subject to seasonal variations. Recall, however, that these years include reduced northward wind stresses and therefore littoral drift rates (Chapter 2.4). Section 2 is predicted to improve by 5-10 m; this is comparable to

MCA1 and MCA4. Section 3 is predicted to recede by approximately 5 m; this is stable for the last 6 years of the simulation. This recession is significantly less than for MCA1 and MCA4. Section 4 is predicted to accrete by 5 m, similar to MCA1. The beach width in Section 5 is predicted to improve by 5-8 m on average and appears to stabilise. The narrow beach width observed at the southern end of the section during the summer months indicates that maintenance renourishment in Section 5, and perhaps Section 4, could improve the outcomes of this option.

The XBEACH results indicate that this option performs better or comparable to the other options for Sections 1 and 2. Whilst the average increase in beach width is lower than MCA1 for this option, less erosion occurs at the southern end of the Section 2. Accretion is predicted across all of Section 4 under the storm sequence. The dog beach is protected by the presence of Groyne 4.

It should be noted that all options experience significant erosion in Section 2, as was observed during the September 2013 period. However the XBeach model includes the presence of the GSC revetment, so erosion landward is limited for all options. Due to MCA1, MCA2 and MCA4 all having more extensive structures northward of Section 2, these options compared to MCA3 have a larger deficit in longshore sediment supply and hence greater erosion in front of the GSC revetment.

In summary, if maintenance renourishment is undertaken in a targeted manner, using the beach monitoring and modelling to predict the optimal volumes and placement, this option could provide a suitable alternate option for achieving the City's goals. Whilst this option does not allow for the retention of the car park, it does reduce the erosive pressure in Section 3, at the same time as providing alternative parking and access to beach amenity in Section 1.

5.1.4 MCA4 – Modified Groynes & Groyne 4 (similar to LITPACK Option 10)

The LITPACK results indicate this option does not provide protection to Section 3; the results indicate recession. Section 5 is predicted to improve however. Section 4 is predicted to recede by 10-20 m; this recession does not stabilise by the end of the 10 year simulation.

The XBEACH results show Section 3 slightly improves in the southern half of the section; however erosion is increased in the northern half. Significant erosive pressure is placed on the GSC revetment immediately south of Groyne 1. Erosion occurs in the north of Section 4 and 5. Some of these impacts could be minimised by capital and maintenance renourishment.

In summary, the presence of the nibs gives potential for greater buffer storage of sediment; however the volumes required to fill these buffers would likely be significant. Improvements to Section 5 are predicted for this option. The improvement to Section 3 is not conclusive.

5.1.5 MCA5 – Car Park Upgrade, Car Park Revetment& Groyne 4

As discussed in Section 3.3.5, if the car park is upgraded to meet Australian Standards, a revetment along Section 3 would be required to ensure the investment is protected. The potential for a revetment to protect the car park as a last line of defence was discussed in Cardno (2013) and Cardno (2015). Revetments typically result in a lowering of the beach in front of the revetment and potential flanking erosion due to limitation of longshore drift once the structure interacts with the active beach. This is likely to occur frequently by the end of summer with the current configuration of coastal structures, and may lead to additional erosion in Section 3. The purpose of a car park close to the beach is in order to access beach amenity (i.e. sand and safe swimming conditions). In its present location, the car park provides potential access to Sections 2 and 3. If none of the alternative MCA options are able to maintain a beach in front of the car park, the use of a revetment to protect the car park, as a last line of defence, would, over time, somewhat diminish the value of having a car park at this location and include ongoing increases in maintenance costs (either through additional beach nourishment to maintain beach amenity or through structure maintenance costs). Whilst beach amenity may be reduced in Section 3, due to the seasonal rotation of the beach, beach amenity may be maintained in Section 2 by December each year as sand builds on the southern side of Groyne 1.

5.2 Uncertainty and Limitations

5.2.1 Climatic Variability

The coastal processes assessment undertaken in Cardno (2015) demonstrated that there is significant inter-annual and decadal variability in metocean conditions which result in significant changes in the overall alignment and sediment storage along Quinns Beach. The time periods investigated with the numerical models in this study and Cardno (2015) were selected on the basis of the quality and availability of data to calibrate the models. Offshore measured directional wave data is only available from the Rottnest Island wave buoy from 2004 onwards. Figure 5-1 presents a time series plot of monthly mean wave height, monthly mean alongshore wind stress and vegetation line movements. Whilst the period 2004 through 2014 appears reasonably representative of the 20 years of available measurements, the following differences are of particular note:

- The very stormy winter of 1996, with significant southward wind stress
- The inclusion of the succession of comparatively reduced northward wind stress (during summer) from 2011/12 through 2014.

Additional discussion is presented in Cardno (2015); however it is important to note that the results presented in this study must be considered within the context of the conditions used to assess the various options. Whilst appropriate for a comparative study (comparing between options), each option may potentially exacerbate erosion (or accretion) in particular locations when subjected to different climatic conditions.

5.2.2 Climate Change and Sea Level Rise

The International Panel for Climate Change's (IPCC) report AR4 (2007) has provided projections for sea level rise based on historical sea level rise and future emission scenarios. Based on the IPCC's projections, the DoT recommended a vertical sea level rise of 0.9 m be adopted when considering the impact of coastal processes over the next 100 years (2010 to 2110) (Bicknell 2010). Hunter's (2009) decadal representation of the recommended sea level rise scenario is presented in Figure 5-2, extended to 2110. These recommendations were formally adopted by the West Australian Planning Commission (WAPC). The more recently updated IPCC AR5 Report (2013) provided updated predictions of sea level rise due to a range of global emissions scenarios and the DoT (2010) recommendation remains consistent with these updated estimates.

The response of Quinns Beach to climate change and sea level rise is likely to be complex and spatially variable due to the complex nearshore reefs and dune geology. An increase in sea level will potentially lead to an increase in wave energy penetration to the beach and alterations of the nearshore wave climate. It is broadly accepted that sea level rise will lead to shoreline recession; however the character of that recession will be a result of the local geology, with the presence and durability of limestone within the dunes at Quinns Beach playing a key role. During detailed design it is recommended that consideration of the potential changes to the nearshore wave climate be considered in the design of the preferred coastal management option. In addition, for areas where shoreline recession is expected, an assessment of the presence of bedrock beneath the dunes should be undertaken to inform assessment of the sensitivity of the areas to sea level rise.

In addition to the predicted changes in sea level, climate change may also result in changes in the frequency, intensity, duration and direction of storms that may result in significantly different responses than can be predicted by the use of historical data. These changes in storm parameters are unknown at this time, and cannot be assessed as part of this study.

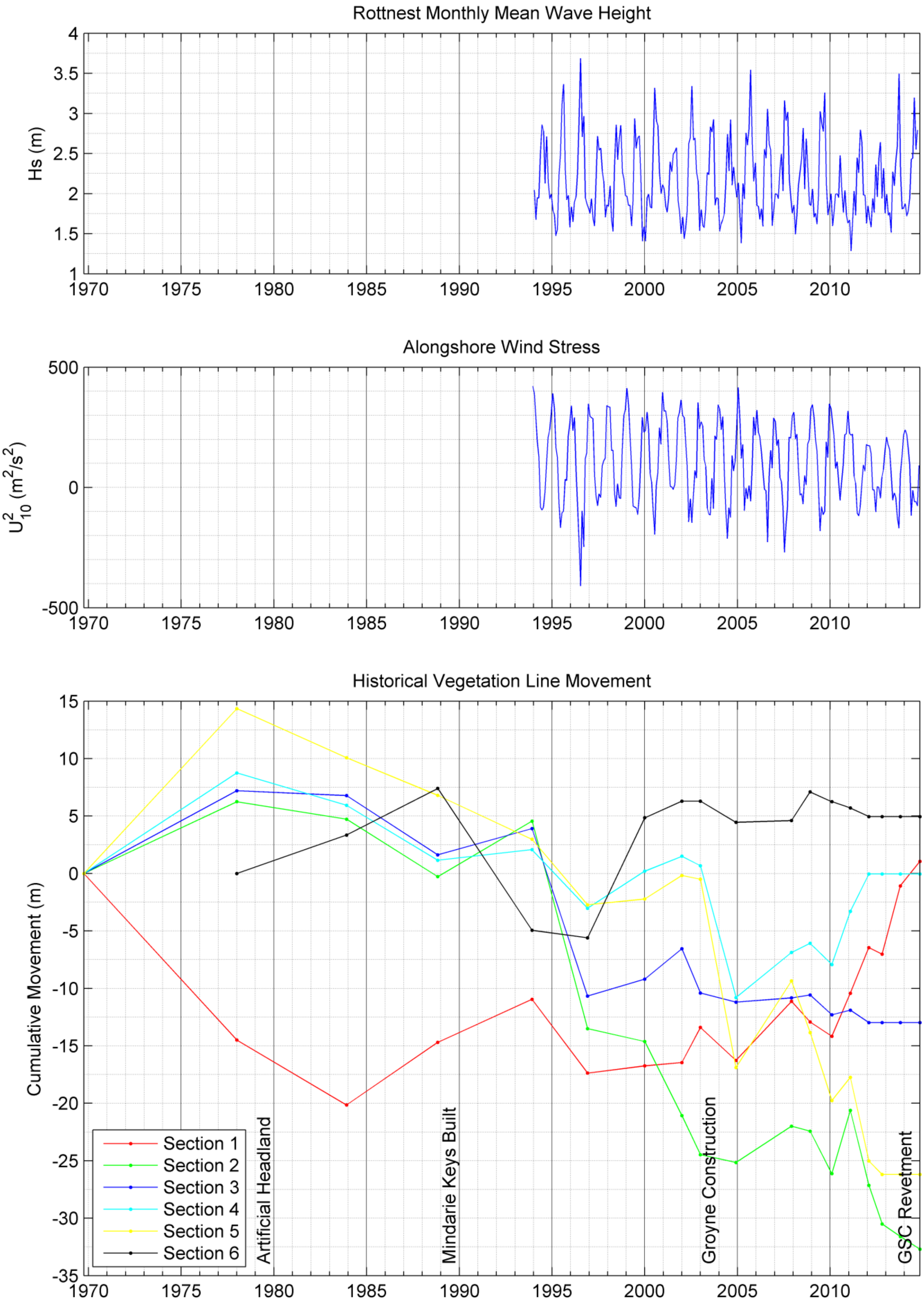

Figure 5-1 Quinns beach measured metocean conditions and vegetation line movement along the study area, plotted cumulatively from 1969 to November 2014

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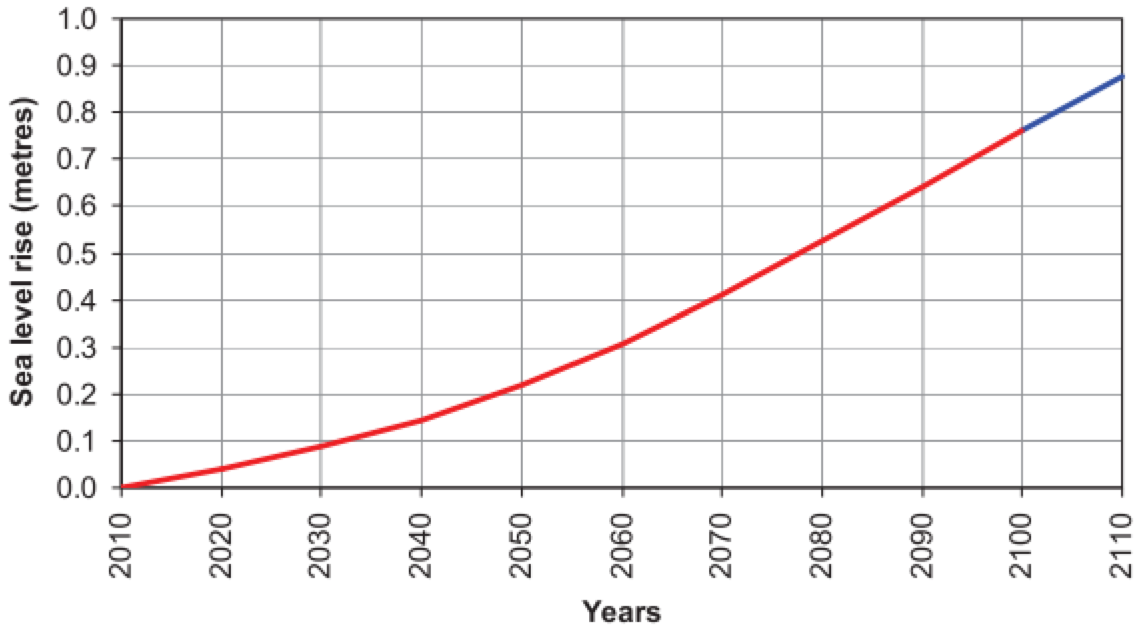

Figure 5-2 The DoT's recommended allowance for sea level rise in coastal planning for WA (DoT 2010)

5.2.3 Numerical Model Limitations

Numerical models inherently include assumptions and simplifications in order to model the complex natural world. The LITPACK model is a computationally efficient model that allows simulations of beach morphology to be undertaken over several years (ten years in this study). LITPACK (and other similar shoreline evolution models) only model longshore transport, in essence assuming that cross shore losses during storms are subsequently recovered post storms over a time scale short enough to avoid significantly influencing supply to the littoral drift process. The model formulations for longshore transport have been developed for long straight sandy coast lines and the influence of coastal structures is incorporated parametrically and assuming no interaction between the structures. Clearly these assumptions do not hold for Quinns Beach, and as such significant model calibration effort was completed in Cardno (2015) in order to reproduce the observed shoreline changes at Quinns Beach. This study has highlighted the limitations of LITPACK in resolving shoreline changes where multiple coastal structures interact, and as such the results must be carefully considered in the assessment of the various options.

XBeach is a 2D morphological model developed specifically to assess the time varying response of coastlines to storm and tropical cyclone conditions. It has specific formulations for dune erosion, over wash and breaching. Whilst the model itself includes fewer assumptions and limitations compared to LITPACK, this comes at the cost of computational expense and significantly greater data requirements for the set-up of the model. The model requires a significantly more detailed representation of the beach and non-erodible reefs. If gaps in this data exist, then significant changes can occur very rapidly as the model adjusts during the model warm up period. As noted in Cardno (2015) there is limited representation of the nearshore reefs in Sections 5 and 6, which may result in an overestimation of the supply of sand from this area. In addition, particularly important for Quinns Beach is the modelling of wave dissipation across the reefs (as discussed in Cardno (2015). Additional wave data has been collected by the City offshore from Section 5 whilst this stage of the study (Conceptual Options Assessment) was carried out. Validation of the wave model in this location is currently being undertaken. The sediment transport modelling in this area may be subsequently updated, depending on the outcomes of the validation.

6 Multi-Criteria Assessment

6.1 Assessment Criteria

Each of the five options was evaluated according to the following criteria:

> Public perception
  - A higher score means the public views the option more favourably.

> Environmental impacts / impact on adjacent coastline (denoted negative impacts in Table 6-1 below)
  - Potential for problem erosion or accretion as a result of implementing the option.

> Likely effectiveness
  - The ability of the option to protect Sections 3 and 5, whilst minimising adverse effects on other sections. These are the sections the City has identified with ongoing erosion issues.

> Capital cost
  - Upfront cost of implementing the option, including any capital renourishment. A high cost receives a lower score.

> Maintenance cost
  - Includes maintenance costs for structures, as well as renourishment costs. A high cost receives a low score.

> Safety
  - Options' potential to impact swimmer safety or public safety on structures themselves.

> Adaptability for climate change
  - This is mainly the potential for the option to respond to sea level rise.

Each criterion was given a score out of 5, as described in Table 6-1.

Table 6-1 Evaluation rating criteria

Negative Impacts, Capital & Maintenance Cost,		Public Perception, Effectiveness, Safety, Climate Change Adaptability	
Rating	**Description**	**Rating**	**Description**
1	Very High	1	Very low
2	High	2	Low
3	Moderate	3	Moderate
4	Low	4	High
5	Very Low	5	Very High

6.2 Risk Identification

Throughout the design process, the options were considered in line with the assessment criteria described in the Chapter 6.1. Potential environmental, social and financial pros and cons for each option are considered below. The designs presented for assessment represent those that present the lowest risk in terms of effectiveness. Financial risk is addressed by obtaining cost estimates which are captured by the scores assigned in Chapter 6.3 below.

Additional risks associated with each option have been identified in the following tables. These risks (or ‘cons’), together with their respective ‘pros’ have been used to assist in determining the evaluation rating for each criteria. The XBEACH modelling indicates renourishment would be required in some areas to provide a buffer for storms. Continual beach monitoring will enable an understanding of the buffer required to maintain adequate beach width in storms. The modelling undertaken to date and through detailed design will assist in informing the renourishment regime so as to minimise the amount of sand required.

Table 6-2 Pros and Cons – MCA1

MCA1	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Adaptability
Pros	▪ Allows dog walking access from Section 5 to 6	▪ Northern sections predicted to improve	▪ Improves amenity in Section 5	▪ Third cheapest option	▪ Roughly equal to second best NPV cost (fractionally more expensive than MCA2)	▪ Can provide calmer areas protected from waves during typical conditions ▪ Existing car park does not meet current safety standards and is difficult to upgrade due topographic relief. ▪ Unsafe pedestrian crossing at existing car park entrance due to steep access road	▪ Structures' levels could be raised to maintain effectiveness during SLR
Cons	▪ May interfere with some community members' desired use of the beach (e.g.: swimming alongshore) ▪ May reduce aesthetic beach amenity	▪ Section 1 predicted to recede ▪ Section 3 predicted to recede ▪ Section 2 predicted to recede.	▪ Does not provide adequate protection of Section 3 seaward of the car park.	▪ Reasonably expensive capital cost	▪ Reasonably expensive maintenance cost	▪ Potential to generate dangerous currents around structures ▪ Potential for members of the public to cause harm to themselves by swimming to or climbing on the breakwater	▪ Increased renourishment would be required to minimise shoreline recession. ▪ Costly to modify structure due to location offshore ▪ Car park in Section 3 would need to be removed in the future.
Score	2	2.5	2.5	2.5	2.5	1.5	2

Table 6-3 Pros and Cons – MCA2

MCA2	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Adaptability
Pros	▪ Numerical models predict greatest potential to maintain beach in front of car park	▪	▪ Provides beach amenity in Sections 3 and 5	▪ Second cheapest option	▪ Roughly equal to second best NPV cost (fractionally cheaper than MCA2)	▪ Existing car park does not meet current safety standards and is difficult to upgrade due topographic relief ▪ Unsafe pedestrian crossing at existing car park entrance due to steep access road	▪ Structures' levels could be raised to combat SLR
Cons	▪ May interfere with some community members desired use of the beach (e.g.: swimming alongshore) ▪ May reduce aesthetic beach amenity ▪ If the extended Groyne 2 is not able to protect the car park, this option will be seen as a failure	▪ Significantly increased interruption of longshore sediment transport may result in greater down drift effects that were not able to be sufficiently modelled	▪ Renourishment required to provide suitable buffer in storms ▪ Susceptible to inter-annual changes in longshore sediment transport.	▪	▪ Reasonably expensive maintenance cost	▪ Potential to generate dangerous currents around structures ▪ Structure head will be in deeper water with exposure to larger wave conditions	▪ Increased renourishment would be required to minimise shoreline recession.
Score	4	2.5	4	3	2	3	2

Table 6-4 Pros and Cons – MCA3

MCA3	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Adaptability
Pros	▪ Relocation of the car park may reduce the public's sensitivity to erosion	▪ Erosion of present situation is well understood due to measurements and modelling undertaken to date. ▪ Rehabilitating the dune in Section 3	▪ Will utilise additional beach amenity provided in Section 1 ▪ Provide improved amenity in Section 5 ▪ Proposed car park partially protected by the GSC revetment and artificial headland ▪ Relocation of car park removes present erosion pressure in Section 3	▪ Cheapest option	▪ Cheapest NPV	▪ Additional visibility of car park may reduce potential for anti-social behaviour ▪ Improved safety of pedestrian crossings at car park entrance due to improved visibility and level with road	▪ Structures' levels could be raised to combat SLR ▪ Car park would have already been relocated, reducing exposure of existing infrastructure
Cons	▪ Relocation of the car park may not align with the community's desires ▪ Loss of car park heritage value	▪ Relocation of the car park could lead to further recession (based on historic rates of recession) in Section 3, potentially threatening Ocean Drive in the future ▪ Clearing dune area in Section 2 for new car park	▪ May not provide the desired beach amenity (a wide beach in Section 3)	▪ Some additional details of capital costs required	▪ Risk of erosion in Section 3 continuing, resulting in higher levels of renourishment or additional work	▪ Existing structures are prone to damage which could lead to instability and a hazard to public access ▪ Overtopping during storms could be a hazard	▪ Increased renourishment would be required to minimise shoreline recession
Score	2	2.5	3.5	4.5	4	4	3

Table 6-5 Pros and Cons – MCA4

MCA4	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Adaptability
Pros	▪ Extension of existing structures, building on past work.	▪	▪ Presence of the nibs gives potential for greater buffer storage of sediment ▪ Improvements to Section 5	▪	▪	▪ Existing car park does not meet current safety standards and is difficult to upgrade due topographic relief ▪ Unsafe pedestrian crossing at existing car park entrance due to steep access road	▪ Structures' levels could be raised to combat SLR
Cons	▪ May interfere with some community members desired use of the beach (e.g.: swimming alongshore) ▪ May reduce aesthetic beach amenity	▪ Significantly increased interruption of longshore sediment transport may result in greater down drift effects that were not able to be sufficiently modelled	▪ Capital / renourishment volumes in lee of nibs required would be significant. ▪ Improvement of Section 3 not conclusive – further investigation regarding nourishment volumes required. ▪	▪ Most expensive option	▪ Most expensive NPV	▪ Potential to generate dangerous currents around structures	▪ Increased renourishment would be required to minimise shoreline recession ▪ Car park may need to be relocated as a result of shoreline recession.
Score	4	2.5	2.5	1	1	3	2

Table 6-6 Pros and Cons – MCA5

MCA4	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Adaptability
Pros	▪ Allows retention of car park in existing location	▪ Limits shoreline erosion immediately seaward of the structure	▪ Existing car park is protected	▪ Second cheapest option	▪	▪	▪ Structures' levels could be raised to combat SLR
Cons	▪ Reduces beach amenity in Section 3 ▪ Reduced visual amenity of the coastline	▪ Scour at toe and erosion ends of structure	▪ May not provide amenable swimming beach ▪ Protection is the least recommended option to accommodate shoreline erosion ▪ Erosion issues in sections south of Section 5 are not addressed	▪ Unlikely to receive funding assistance from the state government	▪ Will not receive funding assistance from the state government ▪ Uncertainty for beach in front of revetment, costs may increase beyond expectations and beach may not be able to be maintained	▪ Potential danger to public climbing on structure ▪ Potential danger to public being 'trapped' between waves and revetment at higher tides	▪ Expensive to upgrade structure to allow for climate change ▪ Increased renourishment would be required to minimise shoreline recession
Score	4	2.5	2	4	2.5	2.5	1

6.3 Ranking Assessment Summary

This section presents the evaluation rating score for each criterion, shown in Table 6-7, extracted from each of the tables presented in the previous section. Each criterion is weighted equally. The scores have been totalled to provide an indication of which option is best overall. The public perception scores were added following the MCA workshop held in December 2015. These scores were agreed with all attendees at the workshop.

The effectiveness score was applied based on the ability of the option to protect Sections 3 and 5, whilst minimising adverse effects on other sections. As discussed in Chapter 5.1, MCA2 provides the most suitable protection of Sections 3 and 5. Options MCA1 and MCA4 provide various levels of protection to these sections, and are scored lower accordingly. Whilst MCA3 does not improve the amenity in Section 3, it does provide beach amenity in Section 1, and reduces the erosive pressure on Section 3. MCA5 provides protection of the car park, but may not provide adequate beach amenity in Section 3.

The remaining criteria were scored according to the following rationale. All scores were discussed with attendees at the MCA Workshop; values were confirmed and updated as required:

> The impacts score was based on all options affecting the environment in different ways, but with approximately the same overall effect.

> The capital and maintenance costs were both normalised over the scale of 1 to 5; the corresponding score was applied for each option.

> A relative safety score based on the pros and cons included in the tables above was applied. For example, MCA3 was considered the safest as no additional structures were to be constructed. MCA5 was considered the least safe due to the proximity of the car park revetment to the swimming beach.

> MCA5 was considered least able to adapt to climate change as extensive upgrade of the car park revetment would be required to combat SLR. MCA1, MCA2 and MCA4 would require an equal level of structure upgrade due to similar structure requirements. MCA3 involves the least structures. This, combined with the fact that relocation of the at-risk car park allows for shoreline recession due to SLR, results in the highest score.

After examining the options presented in this report and the evaluation matrix below, combined with the coastal hazards facing this section of coastline, the best overall solution is MCA3. MCA2 scored second best, and provides the most suitable protection of Sections 3 and 5.

Table 6-7 Evaluation matrix

Solution Option	Protection Solution							
	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Adaptability	Total
MCA 1	2	2.5	2.5	2.5	2.5	1.5	2	15.5
MCA 2	4	2.5	4	3	2	3	2	20.5
MCA 3	2	2.5	3.5	4.5	4	4	3	23.5
MCA 4	4	2.5	2.5	1	1	3	2	16
MCA5	4	2.5	2	4	2.5	2.5	1	18.5

Note that the scores for the capital and maintenance costs have been adjusted since the MCA workshop to allow for the inclusion of MCA5.

7 Conclusions & Recommendations

The purpose of Stage 2 of the Quinns Beach Long Term Coastal Management Study was to assess the coastal management options put forward in the Stage 1 study (Cardno, 2015): Coastal Processes and Preliminary Options Assessment Report. In this stage, these coastal management options were assessed and refined through numerical modelling of longshore sediment transport over 10 years (2005 – 2014) using the model LITPACK, and short term cross-shore and longshore sediment transport using XBEACH during the three storms that occurred in September 2013. This approach involved three rounds of LITPACK modelling, one round of XBEACH modelling, and relevant iterative analysis after each round.

Following the longshore modelling assessment, Cardno and the City developed four coastal management options to take to the Multi-Criteria Assessment (MCA) stage. Discussions with the City indicated that the overall goals of the mitigation options are to provide an amenable beach at Section 3 seaward of the car park, as well as at the dog beach in Section 5, whilst avoiding detrimental effects to other sections. The options are as follows:

- MCA1 – Offshore Breakwaters (LITPACK Option 11)
- MCA2 – Extended Groynes & Groyne 4 (LITPACK Option 12)
- MCA3 – Relocated Car Park & Groyne 4
- MCA4 – Modified Groynes & Groyne 4 (similar to LITPACK Option 10)

To assist with the MCA, a detailed storm erosion assessment using XBEACH was performed for each of the options, excluding MCA3, for which results could be interpreted from the other simulations. The results from the XBEACH modelling were assessed in light of the LITPACK modelling and the following conclusions drawn for each option:

- MCA2 provides suitable protection of Sections 3 and 5.
- MCA3 provides suitable protection of Section 5, and alternative beach amenity to Section 3 in Section 1 and 2. It also reduces the immediate maintenance pressure in Section 3 due to erosion in front of the car park.
- Options MCA1 and MCA4 provide various levels of protection to these sections, which could be improved through capital and maintenance renourishment and fine tuning of the structure through detailed design.

As discussed in the body of the report, there remain some uncertainties regarding the model results. Assessing both the LITPACK and XBEACH results to determine the relative effectiveness of the options does allow some mitigation of these uncertainties, and these should be investigated further during detailed design. Specifically, the capital and maintenance renourishment volumes should be refined through targeted modelling, as well as the crest levels of the proposed structures. The selected design life can also be modified should that provide cost savings in construction, or alternative options for future management.

Following the MCA workshop held in December 2015, an additional option, MCA5, was assessed. This option, containing the revetment along the length of the existing car park, was found to have a relatively low capital cost (2nd) and a similar renourishment cost to MCAs 1, 2, and 3. This option is favoured by the community however its low adaptability, likelihood of reducing beach amenity and low effectiveness as a long term coastal management strategy resulted in an average score (3rd).

The MCA evaluated each option against a range of assessment criteria to determine the most desirable option for the City and relevant stakeholders for long term coastal management. MCA3 received the highest score mainly due to its low capital and maintenance cost, and the alternative amenity provided in Section 1. MCA2 received the second highest score, mostly due to its predicted ability to best protect Sections 3 and 5 (the car park and dog beach respectively).

At this stage of the project, MCA3 is the option recommended to take to detailed design due to its highest score in the multi-criteria analysis.

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Conceptual Options Assessment

APPENDIX

A

PRELIMINARY LONGSHORE ASSESSMENT

Cardno
Shaping the Future

A. Preliminary Longshore Transport Assessment

As outlined in the main body of the report, the longshore transport assessment was undertaken in three rounds. The model setups and results for the first two rounds are outlined in this appendix. The final four options (9 to 12) have been discussed in the report.

A.1 Round 1 - Options Assessed

The four options assessed in Round 1 are displayed in Figure A-1 and Figure A-2. These correspond to Options 3, 4, 5 and 6 from Cardno's Coastal Processes and Preliminary Options Assessment Report (Cardno, 2015). Options 3, 4 and 6 were assessed using LITPACK. The same model set-up was used as previously by Cardno, with the addition of the new and modified structures specific to each option; as well as the GSC revetment. No renourishment was included in the Round 1 assessment.

The existing artificial headland at the cusp of Quinns Beach is not a structure that can be included in LITPACK because it is generally too close to the shoreline and 'engulfed' by sand. In the Cardno (2015) study, the wave climate, principally local wave direction, was adjusted and the model calibrated such that the shoreline in this location matched the existing shoreline behaviour according to this artificial headland. This adjustment was shifted in LITPACK to represent the shifted artificial headland in Options 3 and 6.

The new offshore breakwater in Option 3 (in line with the car park in Section 3) and the effects of the Y-shaped groynes in Option 5 were also modelled using Mepbay (Model for Equilibrium Planform of Bay beaches, Klein et al 2003). Mepbay uses headland control theory to calculate the idealised shoreline planform of a headland-bay beach in static equilibrium based on the parabolic model. This was applied to various coastal structures (modelled as a headland) using the dominant summer and winter wave conditions described by Cardno (2015).

This appendix has been included because it provides background information on the option selection process in a succinct manner.

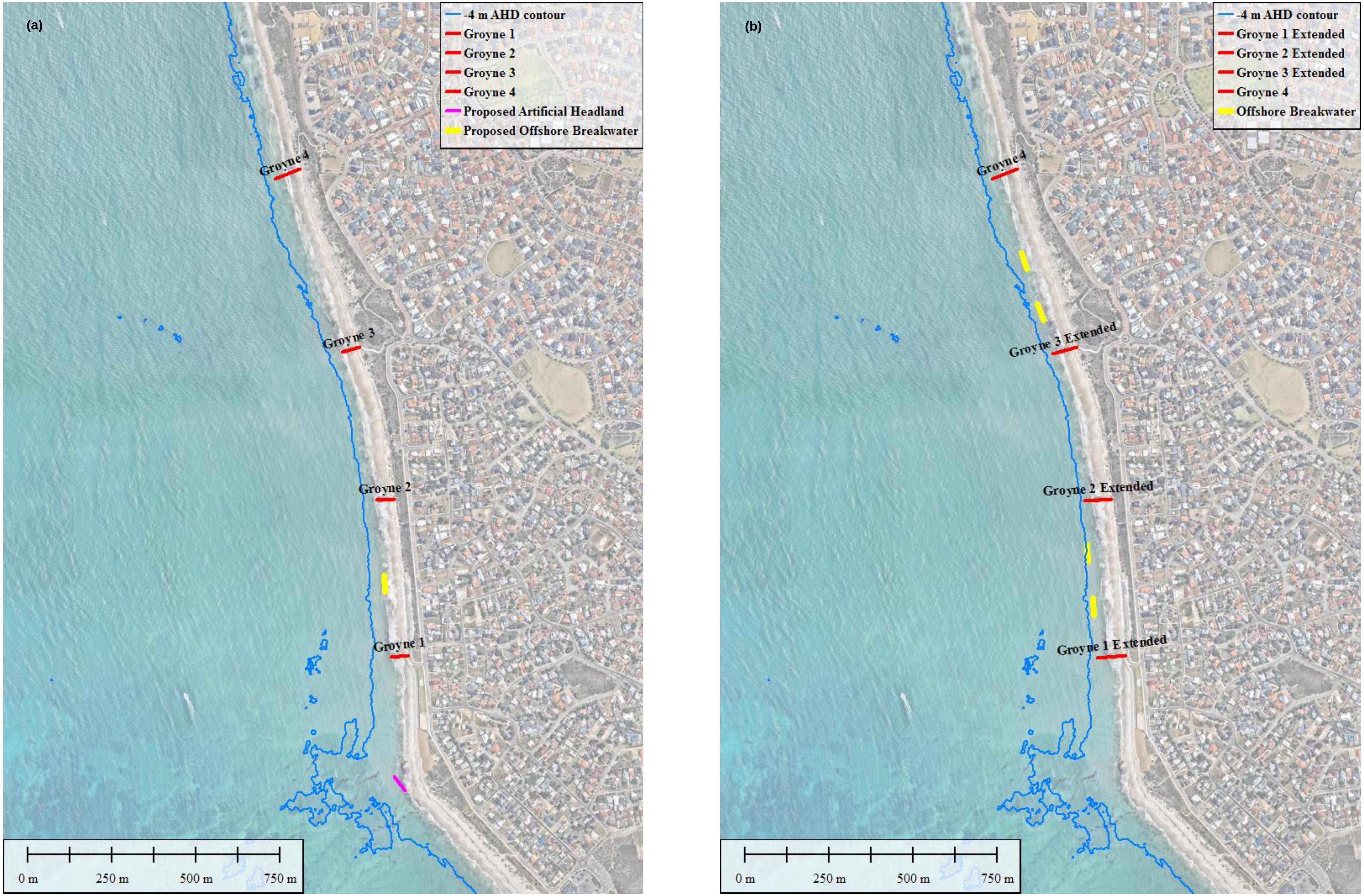
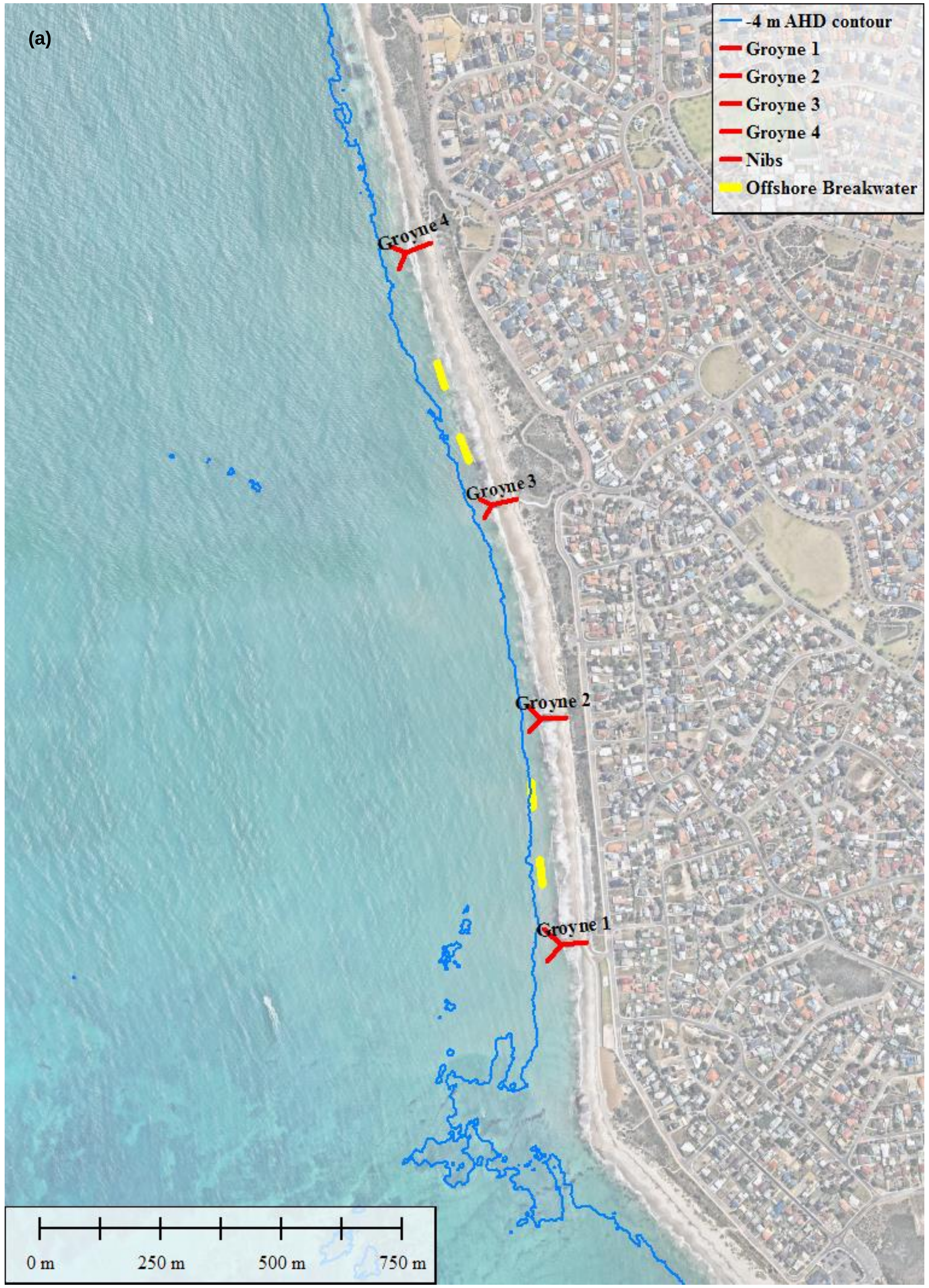


Figure A-1 Conceptual Layouts (a) Option 3 (b) Option 4



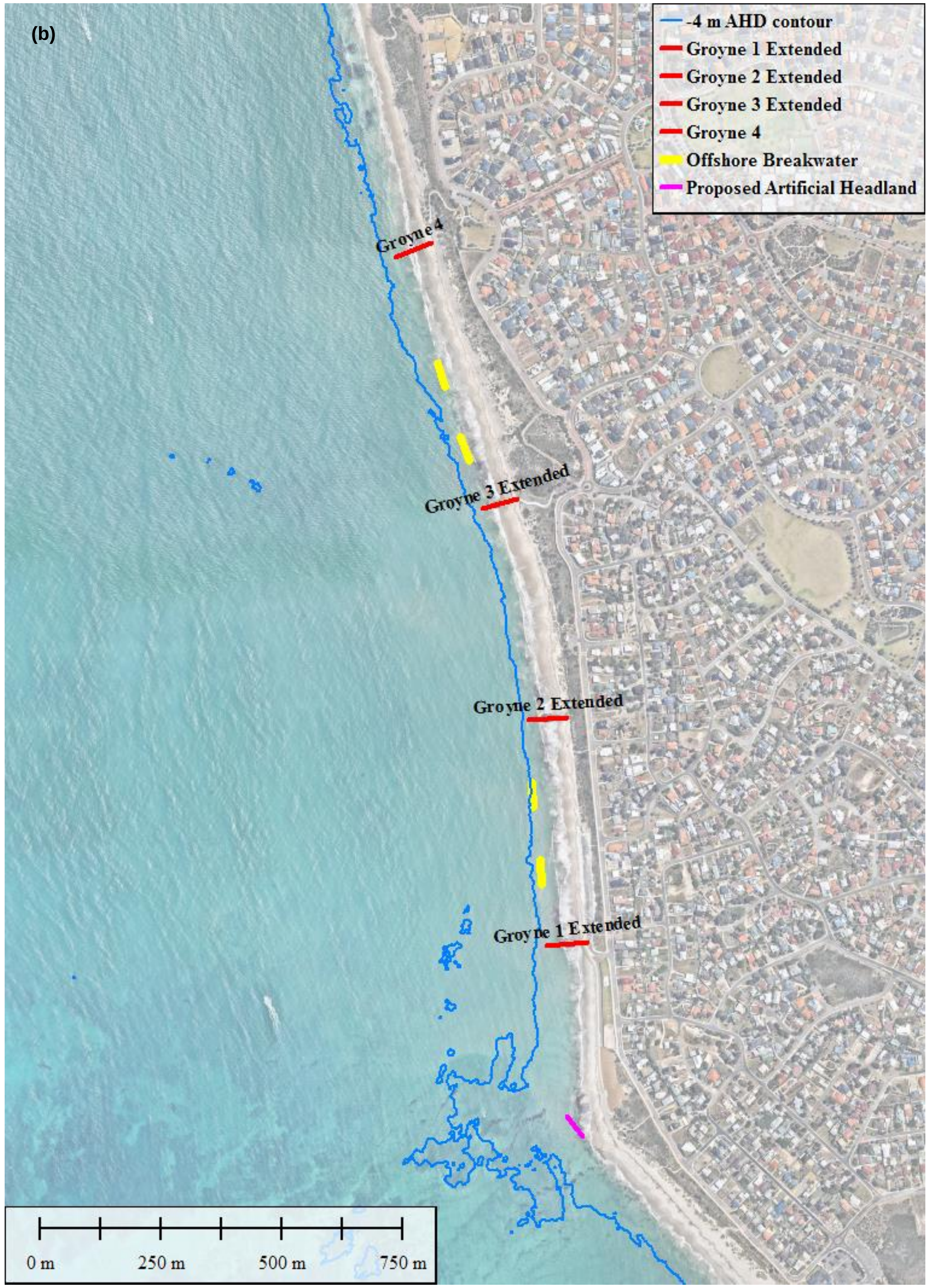


Figure A-2 Conceptual Layouts (a) Option 5 (b) Option 6

A.2 Round 1 – Model Results

A.2.1 LITPACK

The model was used to undertake simulations for a period of 10 years. Results were extracted in May (end of summer) and September (end of winter) for each year and the shoreline plotted – in terms of the MSL contour.

Figure A-3 presents the results from Option 3. Figure A-3a and Figure A-3b show Option 3 with the inclusion of shifting the artificial headland; Figure A-3c and Figure A-3d show Option 3 with the artificial headland in its existing location, and the inclusion of the geotextile sandbag revetment (GSC revetment). This result shows that the shoreline does not erode back to the GSC structure for these cases, so it is not included in the other simulations. Figure A-4 presents the results for Options 4 and 6.

For ease of selecting the options to simulate for the next round of modelling, the effect of each component is noted in the subsequent chapters.

A.2.2 Mepbay

The mean weighted wave directions for summer and winter were applied separately; the resultant equilibrium planforms output from the Mepbay model are presented in Figure A-5 and Figure A-6 for Options 3 and 5, respectively.

A.2.3 Effect of Shifting the Artificial Headland – Options 3 and 6

> Significantly improves Sections 2 and 3 and also has improved shoreline flow-on effects further north.

> Section 1 suffers more erosion than the existing case – in front of the caravan park and surf club at the southern end of the section.

  - This could potentially be mitigated with renourishment. Note it would be easier to renourish Section 1 with the material from the sandbar offshore near the Mindarie Marina.

> It is recommended that an option be modelled that leaves the artificial headland where it is, but adds an additional structure at the new modelled location. This may alleviate the erosion in Section 1 that occurs with this option.

> Possible subsequent modelling option: include some form of renourishment in Section 1.

A.2.4 Effect of Small Offshore Breakwater – Option 3

The results from the Mepbay analysis indicate that the small offshore breakwater in Section 3 will provide some protection immediately landward of the structure, but will likely lead to increased erosion pockets in its lee. It is unlikely that it would be an appropriate solution, but can be investigated further if required.

A.2.5 Effect of Offshore Breakwaters – Options 4, 5 and 6

> The offshore breakwaters do not provide the desired effects. Almost no salient is formed; the only significant changes observed are erosion in the lee of these structures. This could be due to the longshore processes dominating the site.

> It is not recommended that these structures are investigated further.

A.2.6 Effect of Lengthening Groynes

> Lengthening of the groynes appears to improve the volumes of sand retained in all Beach Sections.

> It is recommended that a simulation be conducted with just the lengthened groynes, plus groyne 4, with the existing artificial headland. This will confirm (we expect) the very low value of incorporating offshore breakwaters.

A.2.7 Effect of Groyne 4

> Groyne 4 provides some sand retaining capacity in Section 5 at the northern end of the section. However, the erosion in the lee of Groyne 3 is quite pronounced. Renourishment would be required to minimise this.

> North of Groyne 4, there do not appear to be any negative effects. However, it is noted that the wave model has not been calibrated as effectively in this area so this outcome should be viewed with this in mind – mainly because of the lack of directional wave data in that area. Because little or no shoreline erosion occurs here presently, the model was calibrated to produce that observation. However, inclusion of Groyne 4 may change that condition.

A.2.8 Effect of Y-shape Groynes

> The Mepbay results indicate that this groyne-end form may improve the sediment holding capacity of the groynes, but only in the areas very near to the structures; other than if the Y feature also lengthens the groyne, which is a separate issue.

> It is likely only needed in some sections – perhaps just adjusting Groyne 1 and the northern side of Groyne 3.

> A possible future investigation option could be to insert 2 groynes close together into LITPACK to attempt to replicate the behaviour of this shape – effectively two outer groyne ends.

A.3 Round 1 – Recommendations

As discussed above, the following options were recommended for simulation in Round 2:

> Extended Groynes 1 to 3, addition of Groyne 4, existing artificial headland

> As above, but with the addition of a new artificial headland to the north of the existing headland structure.

> Optional: Model Y-shape in LITPACK by putting 2 groynes close together – only for Groyne 1 and 3 (may not produce useable results).

> Optional: Some form of renourishment, or change to the existing beach plan-profile to represent capital renourishment – specifically in Section 1 and Section 5 adjacent to Groyne 3 and south of Section 4.

Optional: Use Mepbay to assess the Y-shape in Section 3 and 5 without the presence of the offshore breakwaters.

Figure A-3 LITPACK Results – Option 3 (a) Shifted Artificial Headland, May Output; (b) Shifted Artificial Headland, September Output; (c) GSC Revetment Included, May Output; (b) GSC Revetment Included, September Output

Figure A-4 LITPACK Results – (a) Option 4, May Output; (b) Option 4, September Output; (c) Option 6, May Output; (d) Option 6, September Output;

Figure A-5 Mepbay results: Option 3, Section 3 – summer and winter equilibrium planforms

Figure A-6 Mepbay results: Option 5, Sections 2, 4 and 6 – summer and winter equilibrium planforms

A.4 Round 2 – Options Assessed

The four options to be assessed in Round 2 are Options 7 to 10. Options 7 and 8 are displayed in Figure A-7; options 9 and 10 are described in the body of the report. All options were assessed using LITPACK. The same model set-up was used as in Cardno (2015), with the addition of the new and modified structures specific to each option as well as specified beach nourishment volumes.

A.4.1 Option 7 – Offshore Breakwaters

Option 7 involved another test of the offshore breakwaters (Figure A-7a). Empirical calculations were undertaken to determine the length and distance offshore for the breakwaters using the method of Silvester & Hsu (1999). A smaller 'distance offshore' to 'breakwater length' ratio (S/B=0.5) was applied for this round of modelling, which allows the breakwaters to be closer inshore. A higher value was used in Round 1 as these lower values theoretically give a continuously growing tombolo, and the aim of the offshore breakwaters was salient accretion rather than tombolo formation. This resulted in the following:

> Two 60 m long offshore breakwaters in Section 3, 30 m offshore from the 0 m AHD contour (previously these were 50 m offshore with a length of 50 m);

> In Section 5, two 80 m long offshore breakwaters, 40 m offshore from the 0 m AHD contour. The -3 m AHD contour is closer to the shoreline in Section 5, indicating it was reasonable for the longer structures to be located in this section, as the longer structures must be further offshore according to the applied S/B value.

This option also includes extending Groynes 1 to 3 by approximately 30 m, the addition of Groyne 4, and capital renourishment.

The total design capital renourishment volume for this option is 35,000 m^3. The purpose was to initially shift the 0 m AHD contour seaward by approximately 30 m in the applied sections, allowing for the offshore movement of the control point due to the extended groyne length. The distribution was:

> 3,800 m^3 Section 2

> 9,800 m^3 Section 3

> 13,000 m^3 Section 5

> 8,400 m^3 Section 6

A.4.2 Option 8 – Extended Groynes

This option tested the effect of extending Groynes 1 to 3 by approximately 30 m, adding in Groyne 4 and capital renourishment (Figure A-7b). The total capital renourishment volume for this option is 33,600 m^3. This aims to initially shift the 0 m AHD contour seaward by approximately 30 m in the applied sections, allowing for the offshore movement of the control point due to the extended groyne length.

> 3,800 m^3 Section 2

> 10,600 m^3 Section 3

> 10,800 m^3 Section 5

> 8,400 m^3 Section 6

A.4.3 Option 9

This option tested the effect of extending the artificial headland to a total of approximately 120 m in length, in conjunction with capital renourishment of 10,800 m^3. The renourishment for this option aims to minimise the negative impacts immediately surrounding the extension of the artificial headland by shifting the 0 m AHD contour seaward by 10 m in Section 1 and 30 m in Section 2 immediately adjacent to the structure. The extended artificial headland is represented in LITPACK as a revetment.

> 1,900 m^3 Section 1

> 8,900 m^3 Section 2

A.4.4 Option 10

Model the nib extensions (Y ends) to the groynes in LITPACK by including multiple groynes in the vicinity of the nibs, with associated capital renourishment. Specifically:

> Represent Y-shape as 3 groynes close together at Groyne 1

> Extension of Groyne 2 to 80 m length total

> Represent northwards pointing L-shape as 2 groynes close together at Groyne 3

Groyne 4 is not included in this option. Total capital renourishment volume is 23,000 m^3 for this option. This aims to shift the 0 m AHD contour seaward by approximately 30 m in the applied sections, allowing for the offshore movement of the control point due to the presence of the nibs.

> 3,600 m^3 Section 2

> 9,300 m^3 Section 3

> 10,100 m^3 Section 5

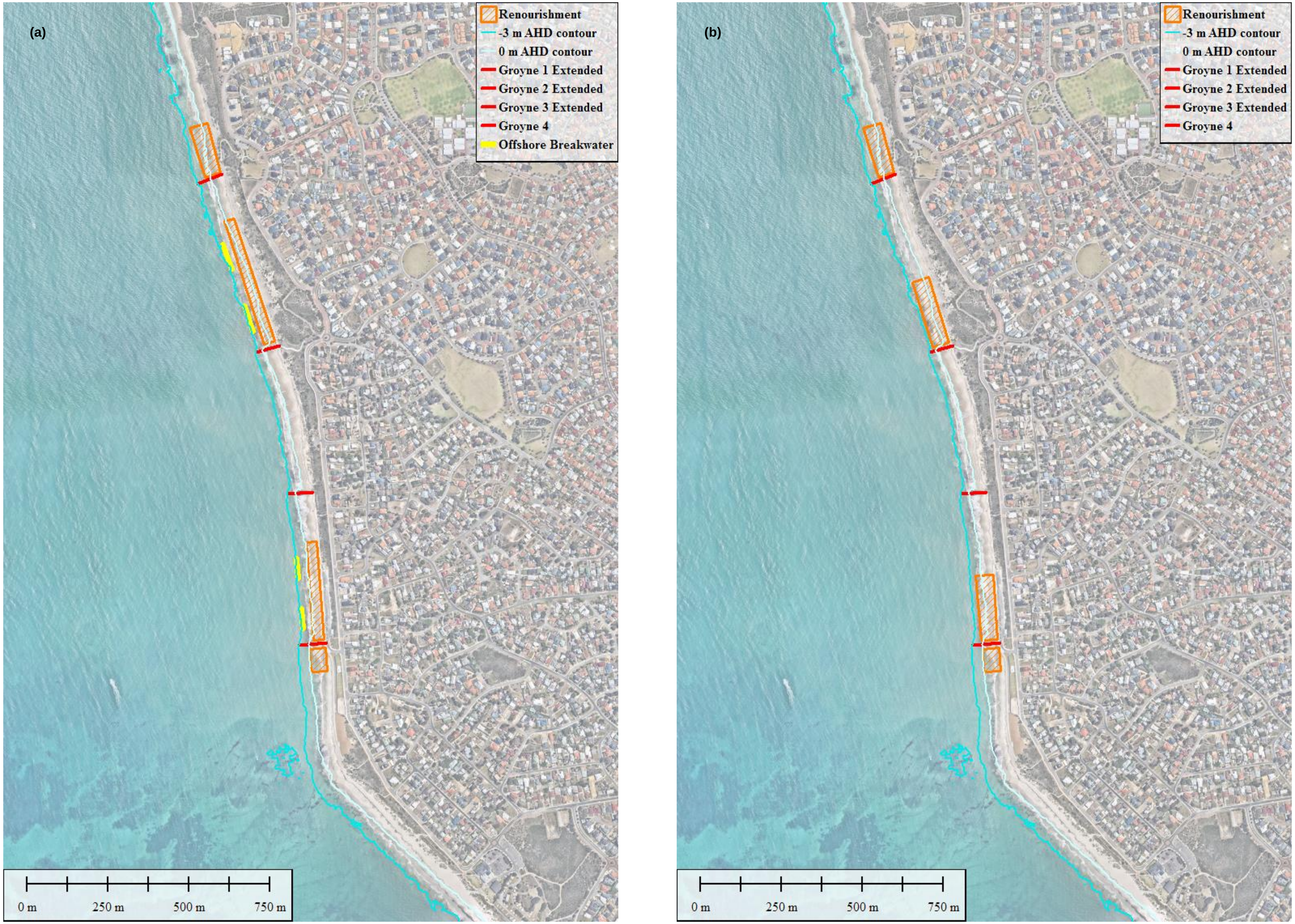


Figure A-7 Conceptual Layouts (a) Option 7 (b) Option 8

A.5 Round 2 – Model Results

The LITPACK model was used to undertake simulations for a period of 10 years. Results were extracted in May (end of summer) and September (end of winter) for each year and the shoreline plotted. Figure A-7 presents the results from Options 7 and 8. All investigations are based on 10 years of modelled wave data.

For ease of selecting the options to simulate for the next round of modelling, the effect of each component is noted in the subsequent sections. Results are compared to the existing case simulation undertaken in Stage 1 of the project (Cardno, 2015). Because this is an interim, summary document, this information is presented in brief dot point form (will be expanded subsequently for the final report).

A.5.1 Effect of Offshore Breakwaters – Option 7

- Minimal effect on Section 1 compared to the existing case.
- Section 2 not affected by offshore breakwaters. Improvement to this section in this option (5-10 m) is due to the extension of the groynes.
- Offshore breakwaters in Section 3 do not appear to have any impact. Results for this option indicate the shoreline recedes by approximately 5-10 m. This is the same as for only extending the groynes.
- Section 4 is unchanged due to the offshore breakwaters.
- The resultant shoreline in Section 5 under this option is improved by 5-15 m, depending on the season. Comparing this result to that of Option 8, it appears the effect purely from the offshore breakwaters, and not the extended groynes, is roughly 5-10 m.
- Optional additional modelling scenario – move the offshore breakwaters to the north so that they are centred within the section (could be undertaken in detailed design if this option is selected) to test whether this results in a more even accretion across Section 5.
- Optional additional modelling scenario – model one much larger offshore breakwater in Section 3 to see if this has any effect.
- It is not clear why the offshore breakwaters result in accretion in Section 5 and not in Section 3. One reason could be the greater wave heights experienced in Section 5, or a difference in wave approach angle relative to the shoreline. Noting there doesn't seem to be an obvious difference in the relative mean weighted wave directions presented in Cardno (2015). Tests could be undertaken to determine if longer and / or more landward structures could have an effect if the City wishes to investigate this further.

A.5.2 Effect of Extended Groynes – Option 8

- Minimal effect on Section 1 compared to the existing case.
- Section 2 improved on average across the section by 5 -10 m. Accretion is greatest in the northern part of the section.
- Section 3 beach width reduced by approximately 5-10 m. Recession is roughly the same across the section. The recession is likely due to the reduction in bypassing around the lengthened groynes. Increased capital renourishment may assist with this recession.
- Section 4 is unchanged due to extension of groynes.
- The beach width in Section 5 is improved by 5-10 m. This varies depending on season and location within the section.

A.5.3 Effect of Groyne 4

- Groyne 4 assists with accretion in Section 5 by approximately 5-10 m.
- In Section 6, the impacts to the north appear to only be felt approximately 200 m north of Groyne 4. Depending on season, this is either erosion or accretion approximately 5-10m.
- Further investigation would assist with optimising the length of Groyne 4

> Further calibration of the wave and sediment transport modelling is required following the completion of the data collection in this area in order to provide confidence in the effects of Groyne 4 in Section 6. The modelling may be under-estimating the effects to the north of the groyne.

> Optional additional modelling: test the offshore breakwaters in Section 5 without Groyne 4

> Optional additional modelling: test the offshore breakwaters in Section 5 with Groyne 4 at a similar length to the existing groynes.

A.6 Round 2 – Summary & Recommendations

The modelling conducted over these two rounds has determined the following:

> Addition of Groyne 4 has positive influence on Section 5
  - Effect in Section 6 will be confirmed following the data collection at this site and re-calibration of the wave and sediment transport modelling.

> The offshore breakwaters in Section 5 have a positive influence on Section 5.

> Altering Groynes 1 and 3 without Groyne 2 also has positive influence on Section 5, at the detriment of Section 4.

> None of the options modelled to date has improved the beach width at Section 3. Extension of the groynes could still be a viable option if simulations are conducted to test the results with a greater capital renourishment.

One overall mitigation solution, subject to detailed design, could involve the extension of the artificial headland, combined with greater capital renourishment volumes (than has been modelled) in Section 3 to combat the minor recession observed in the modelling in that Section. The car park in Section 3 could be removed and the dune rehabilitated. A new car park could be created in Section 1 near the cusp where there is a greater buffer zone. Due to the positive effect of the artificial headland extension on Section 1, this beach could then be identified as the City's public amenity beach. It is also longer than Section 3, which allows greater public visitation, and has existing disabled access. If the City wishes, this option could be discussed as part of the multi-criteria analysis workshop to gauge community response. This solution would also involve Groyne 4 and possibly the offshore breakwaters in Section 5 so that the dog beach amenity is improved and retained.

If the beach amenity at Section 3 is still to be the focus for the City, then the following could be investigated as an additional LITPACK round:

> One long offshore breakwater in Section 3, perhaps 100 m in length or longer. This could be undertaken with extended groynes or leaving at the existing length.

> Extended groynes with a much greater capital renourishment.

At this stage, the recommended options for XBEACH are:

> Extended artificial headland

> Groyne 4

> Offshore breakwaters in Section 5

> Extended groynes with greater capital renourishment

> Some combination so as to arrive at two scenarios

Differing groyne lengths and offshore breakwater spacing can be determined during detailed design.

Note: The actual options selected for XBEACH model assessment differ to the above recommendations due to further analysis and consultation with the City and the DoT.

Figure A-8 LITPACK Results - (a) Option 7 Offshore Breakwaters, May Output (b) Option 7 Offshore Breakwaters, September Output (c) Option 8 Extended Groynes, May Output (d) Option 8 Extended Groynes, September Output

Conceptual Options Assessment

APPENDIX B

FINAL LONGSHORE ASSESSMENT RESULT PLOTS

Cardno
Shaping the Future

B. Appendix B

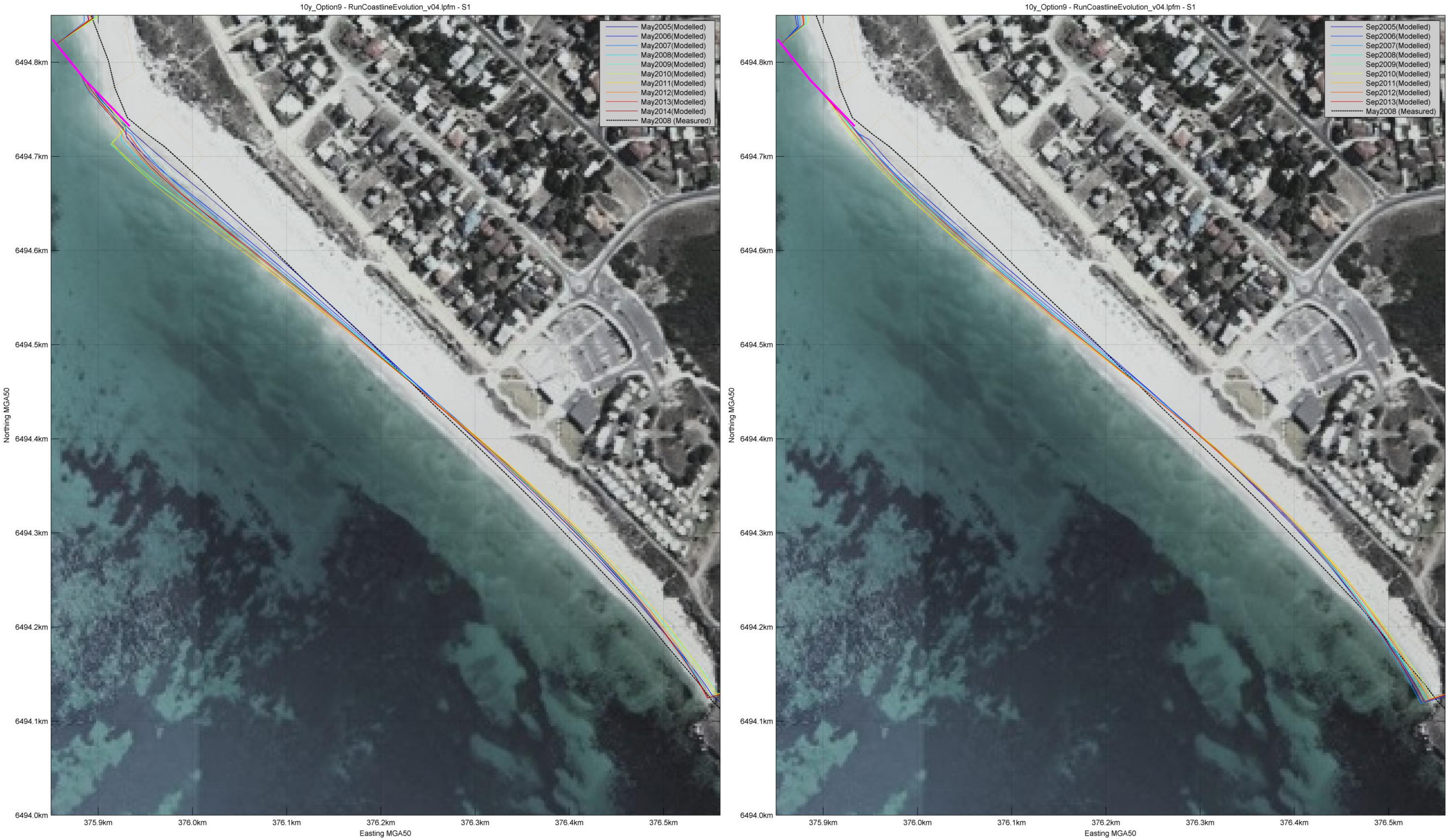
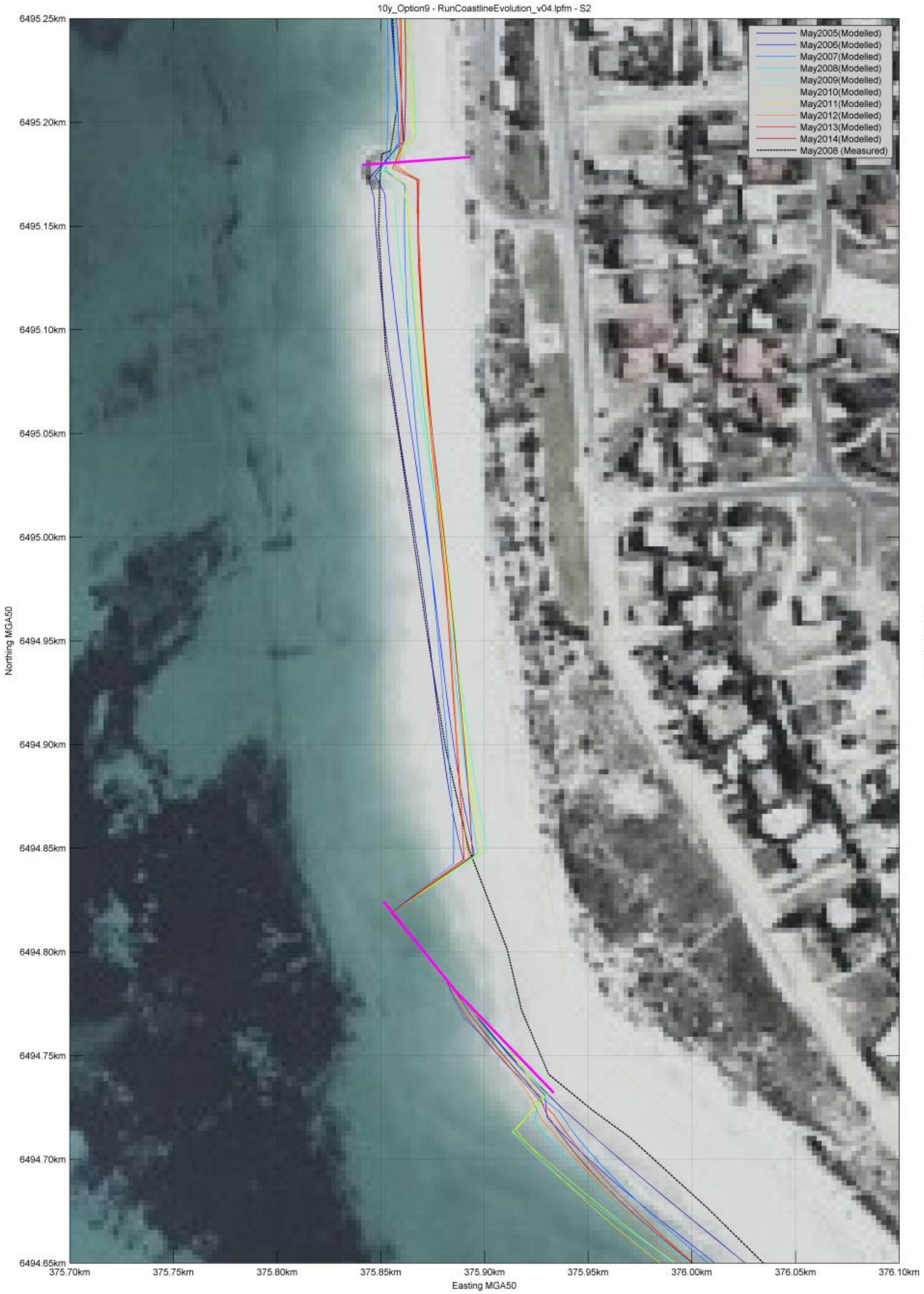


Figure B-1 Option 9 – Section 1: Shoreline evolution for (a) May and (b) September



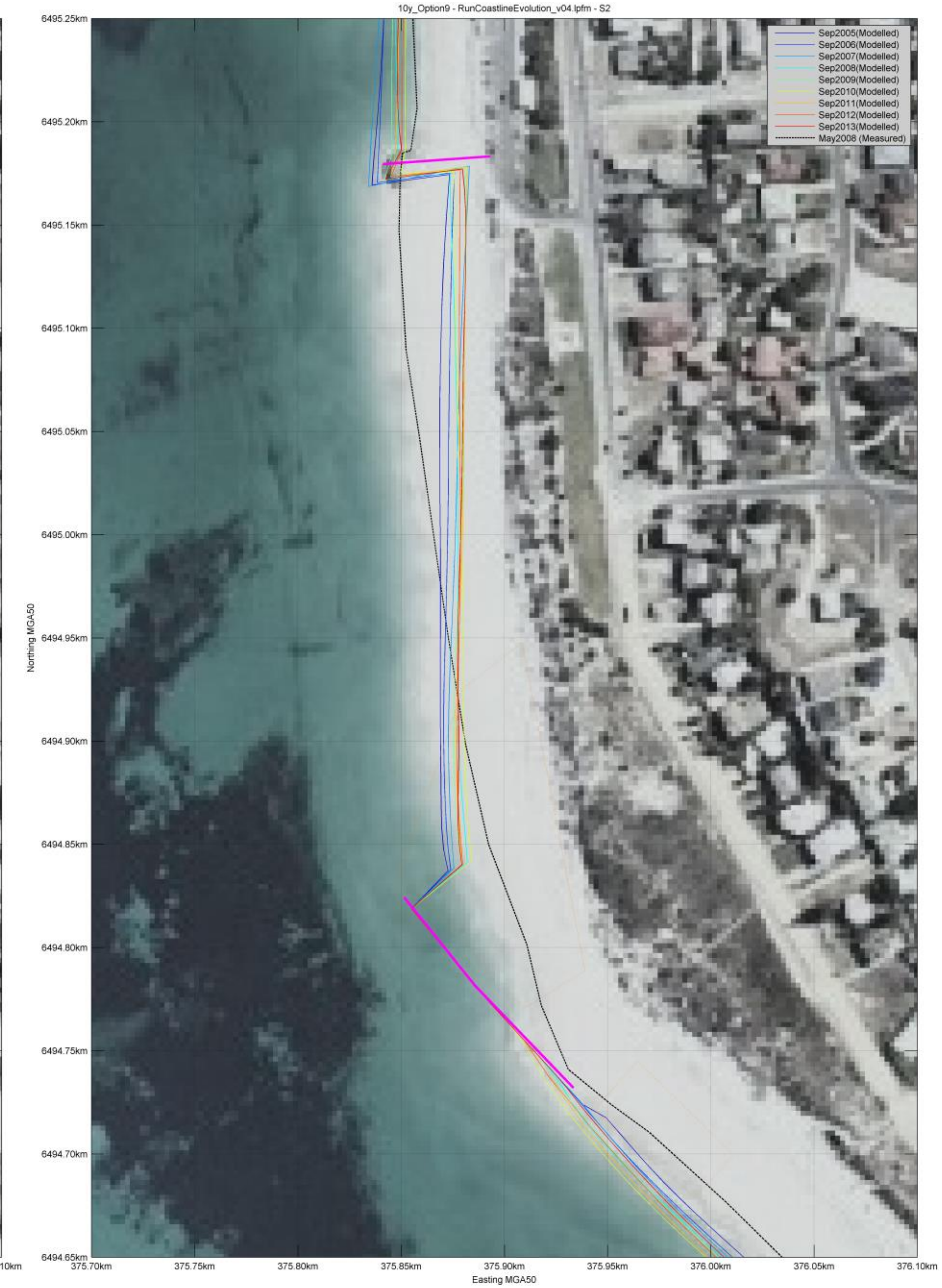
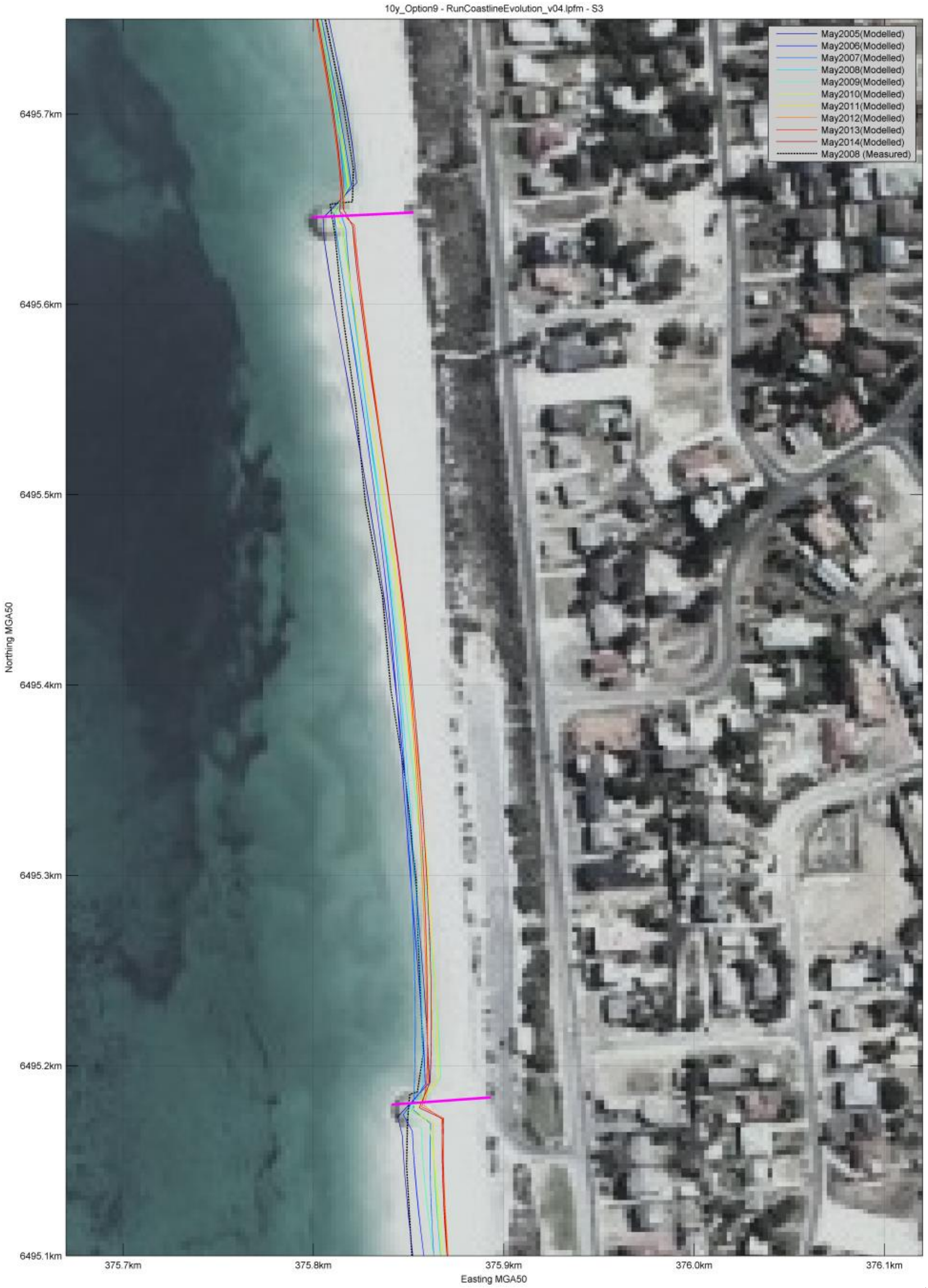


Figure B-2 Option 9 – Section 2: Shoreline evolution for (a) May and (b) September



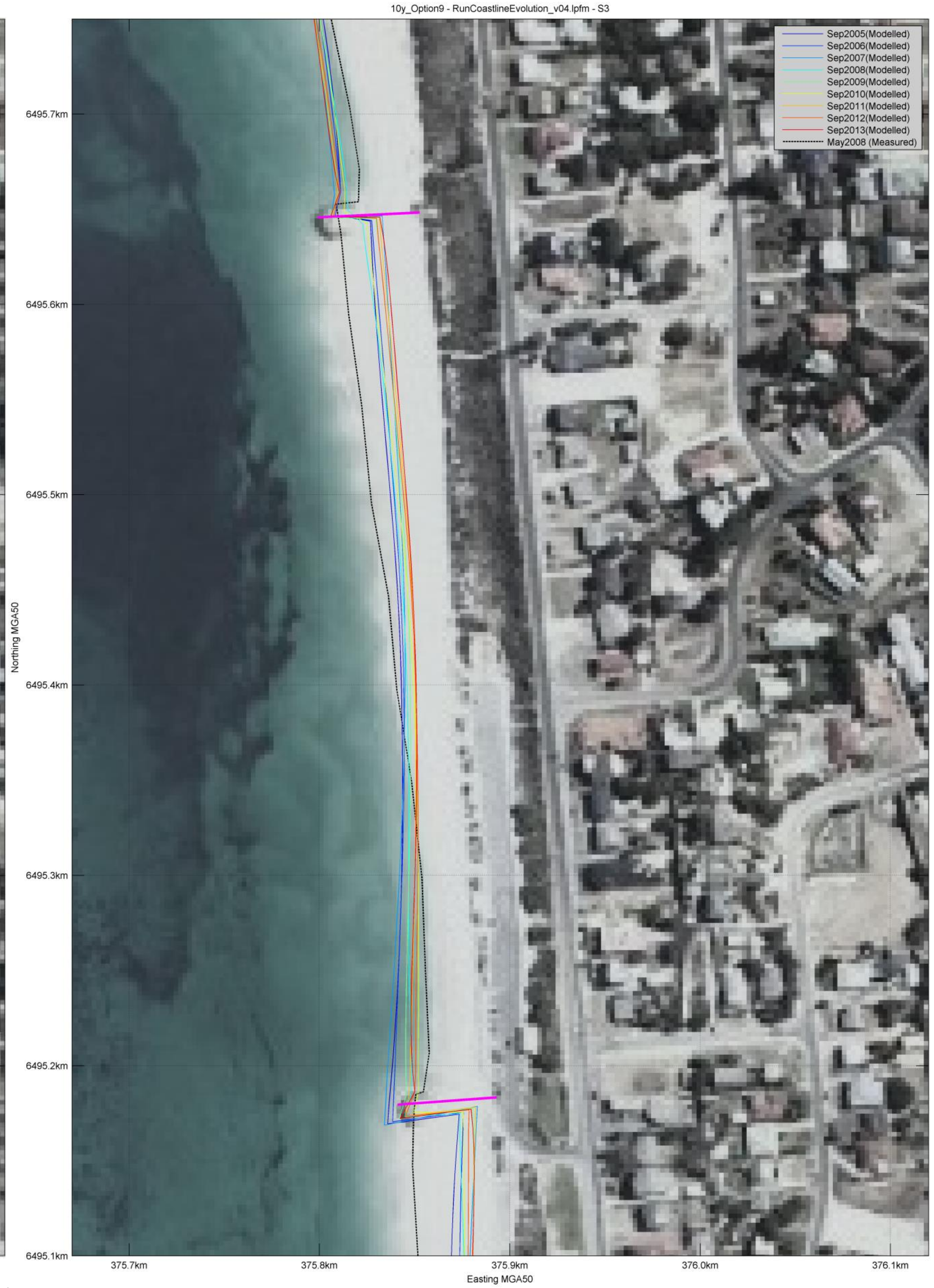


Figure B-3 Option 9 – Section 3: Shoreline evolution for (a) May and (b) September

Figure B-4 Option 9 – Section 4: Shoreline evolution for (a) May and (b) September

Figure B-5 Option 9 – Section 5: Shoreline evolution for (a) May and (b) September

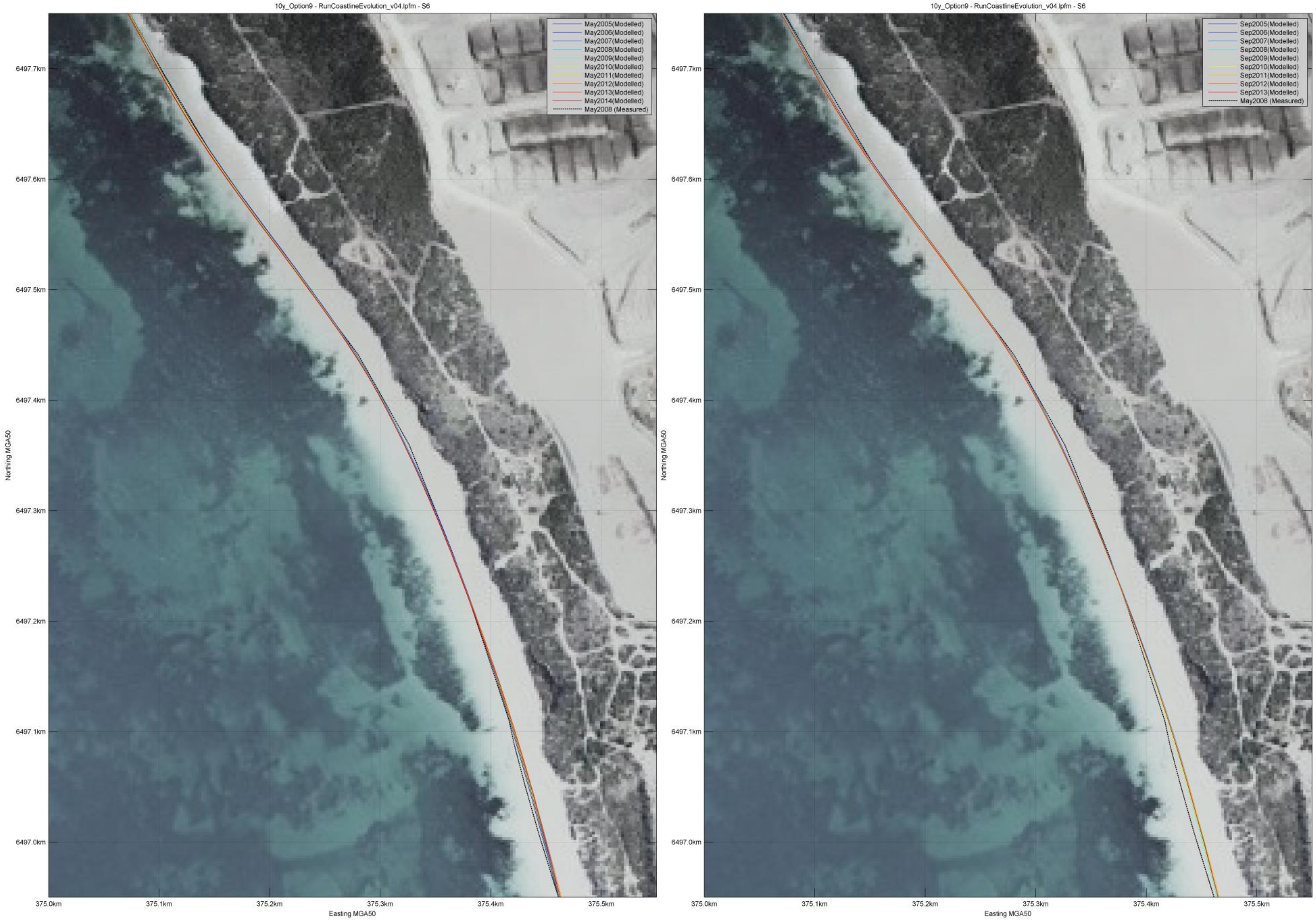


Figure B-6 Option 9 – Section 6: Shoreline evolution for (a) May and (b) September

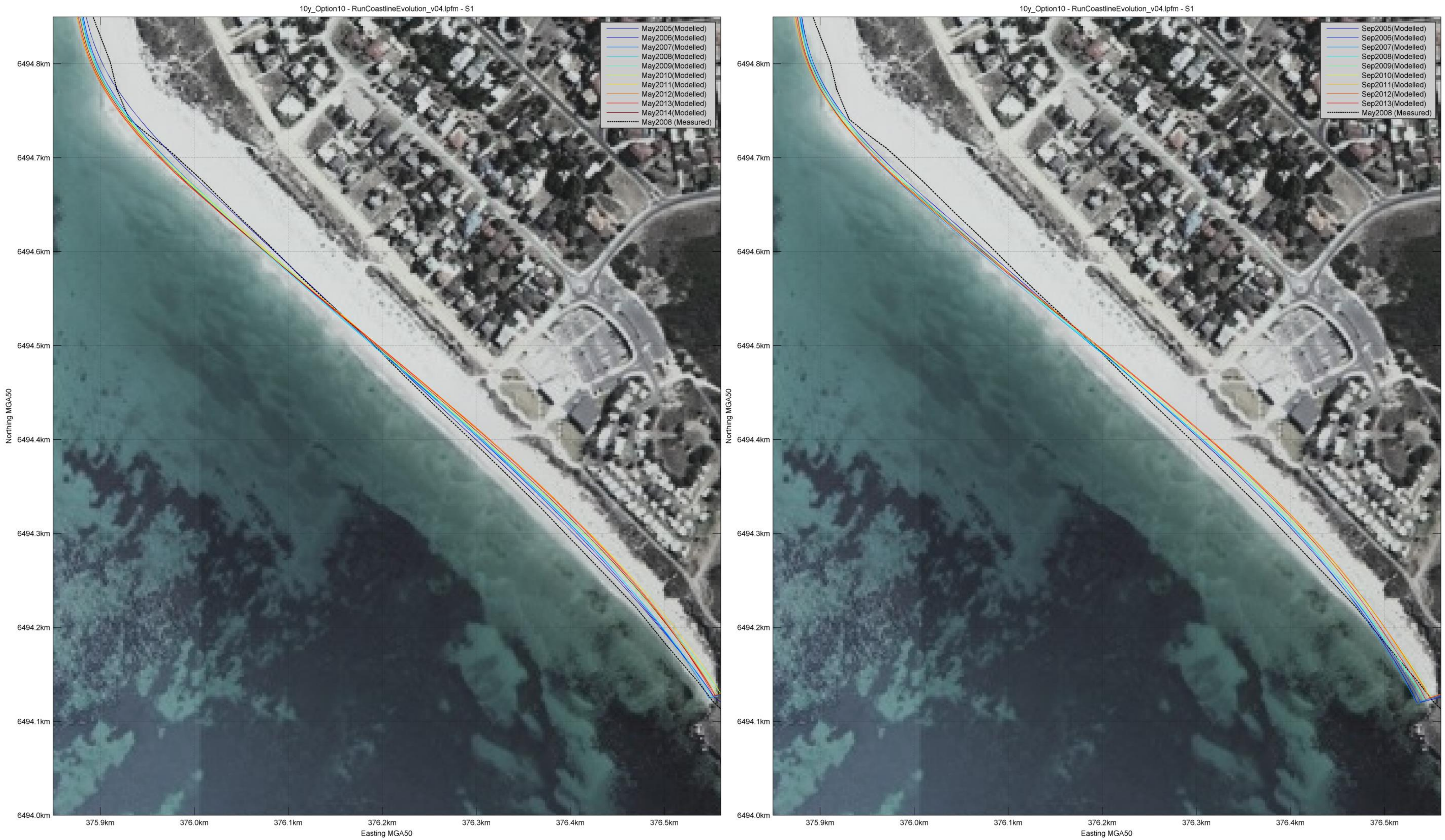


Figure B-7 Option 10 – Section 1: Shoreline evolution for (a) May and (b) September

Figure B-8 Option 10 – Section 2: Shoreline evolution for (a) May and (b) September

Figure B-9 Option 10 – Section 3: Shoreline evolution for (a) May and (b) September

Figure B-10 Option 10 – Section 4: Shoreline evolution for (a) May and (b) September

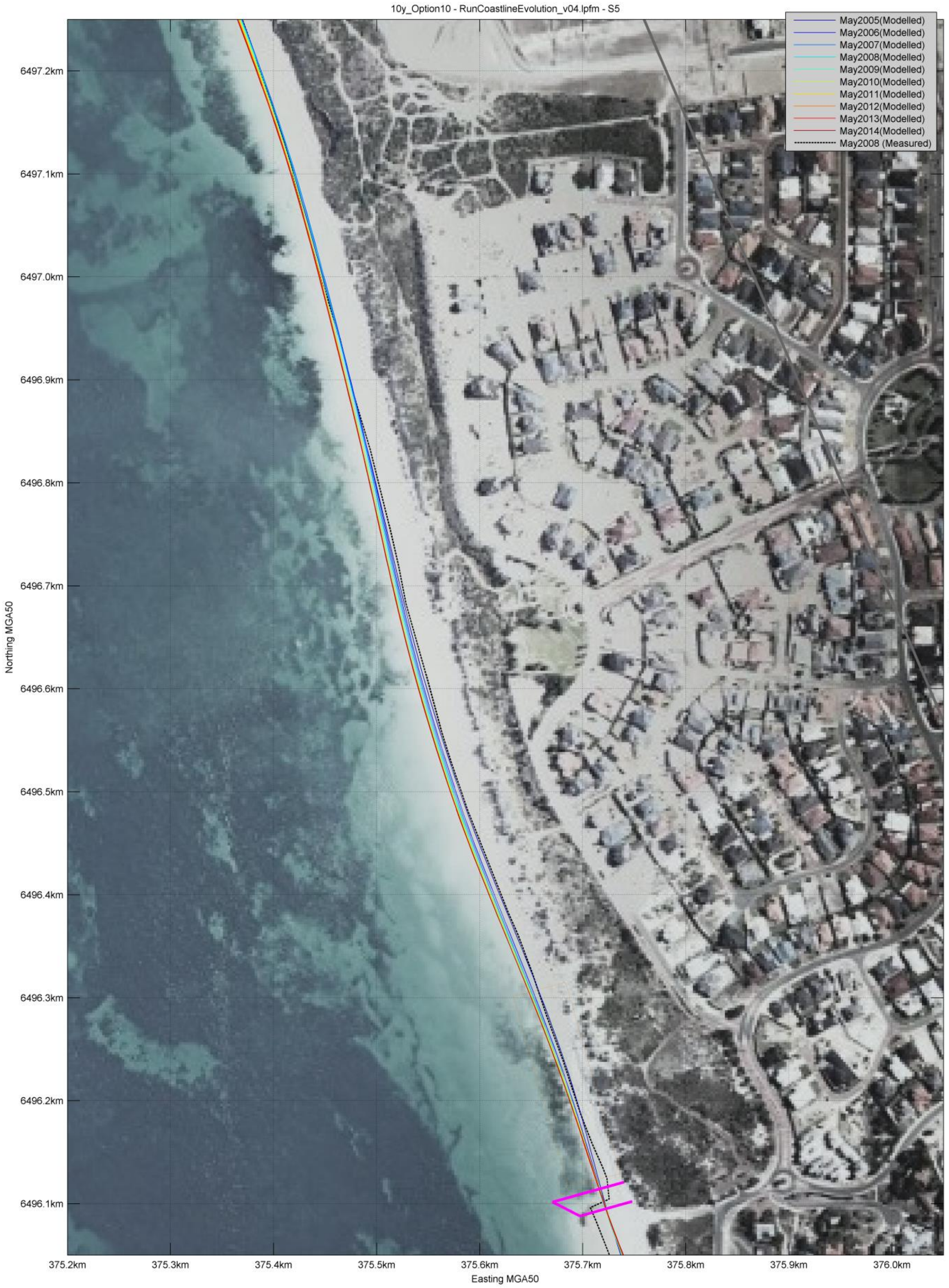


Figure B-11 Option 10 – Section 5: Shoreline evolution for (a) May and (b) September

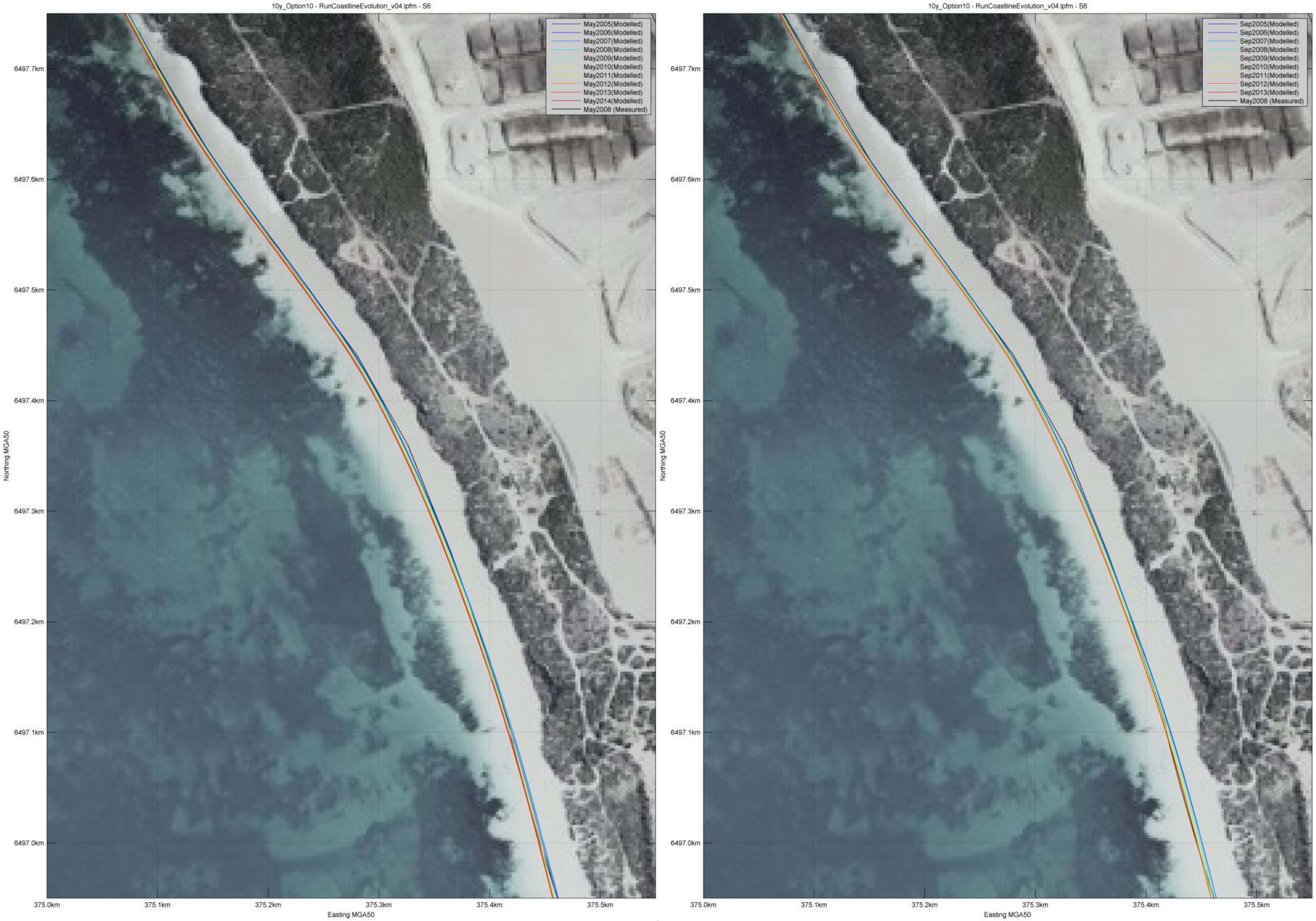


Figure B-12 Option 10 – Section 6: Shoreline evolution for (a) May and (b) September

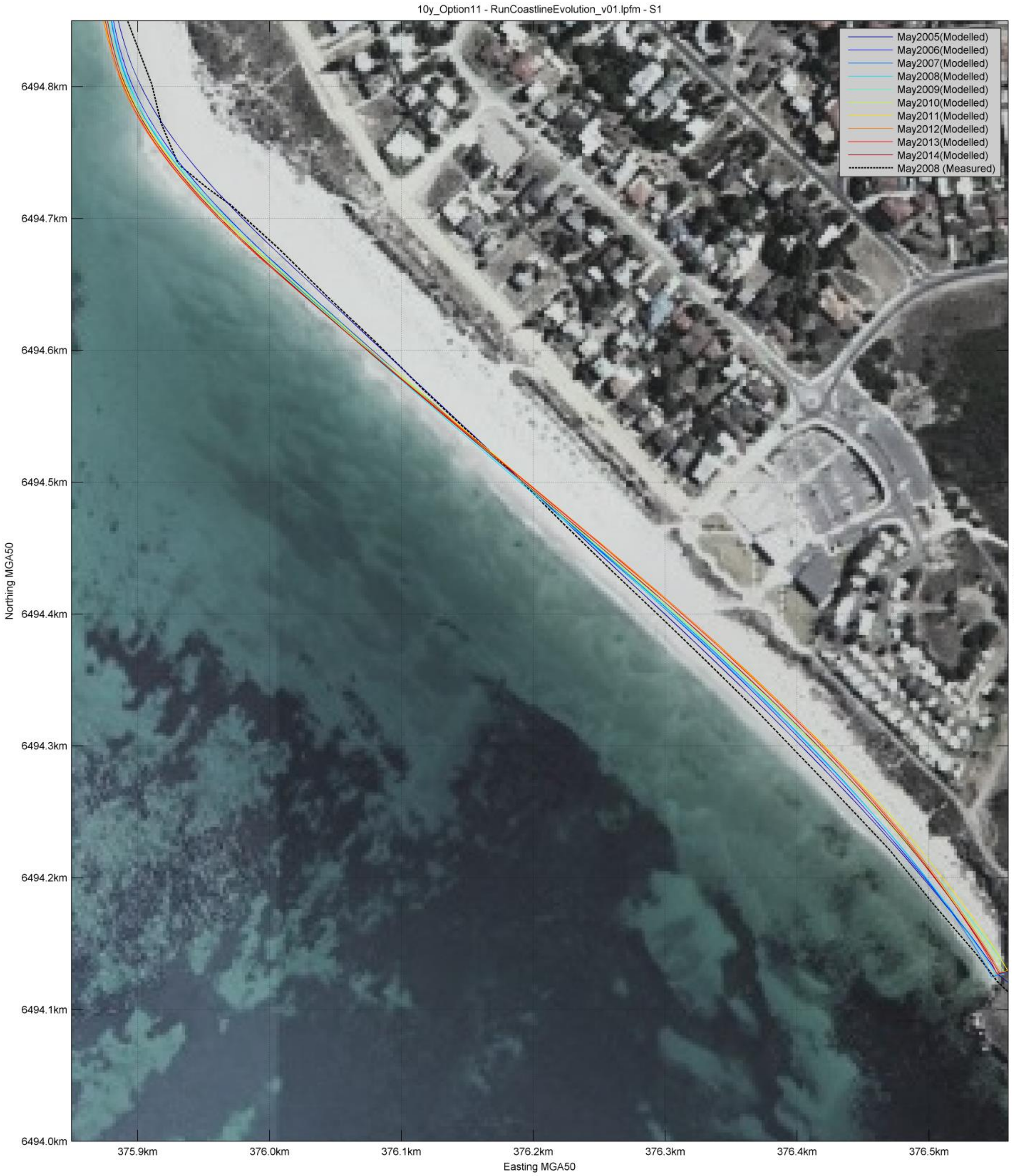


Figure B-13 Option 11 – Section 1: Shoreline evolution for (a) May and (b) September

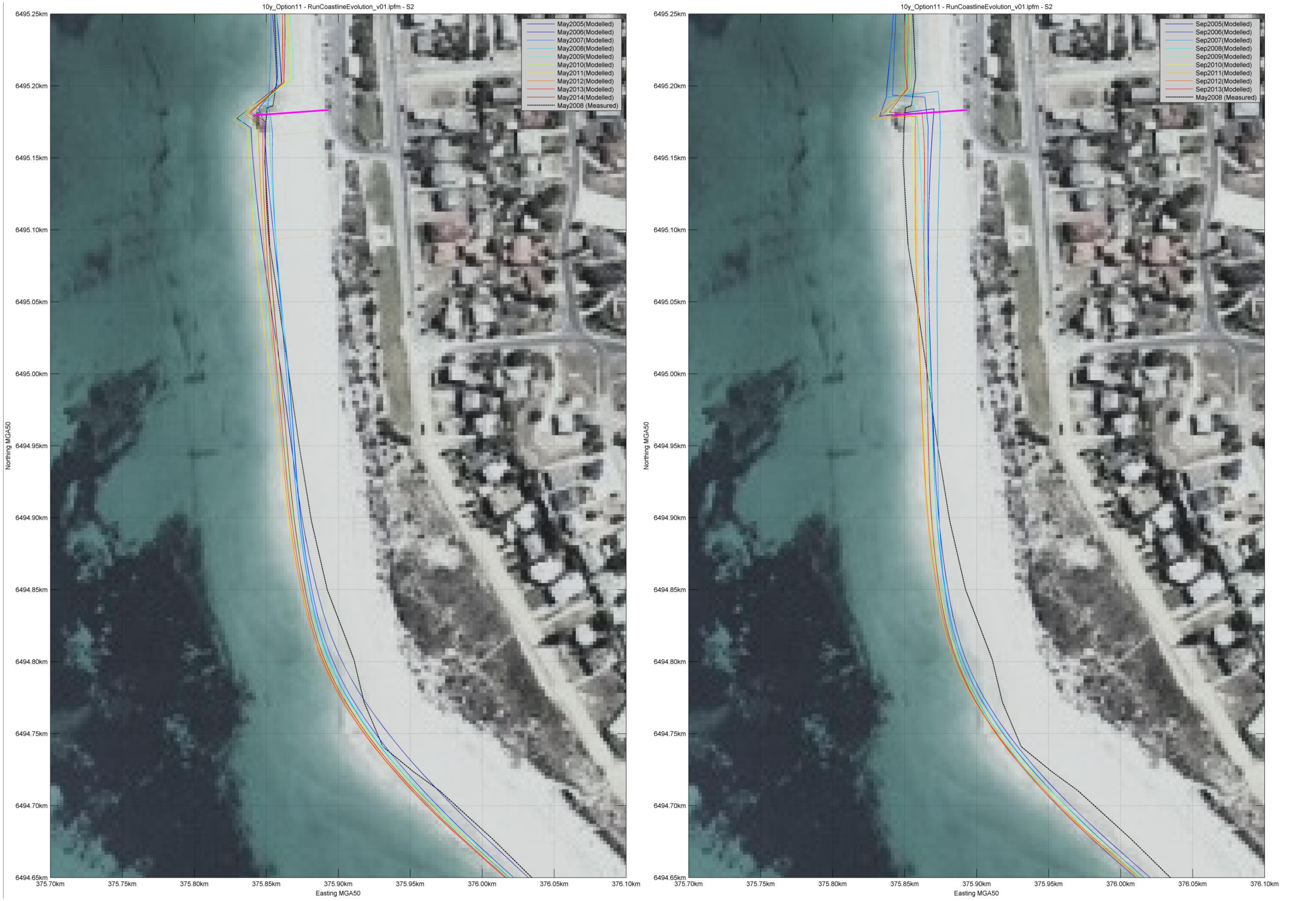


Figure B-14 Option 11 – Section 2: Shoreline evolution for (a) May and (b) September

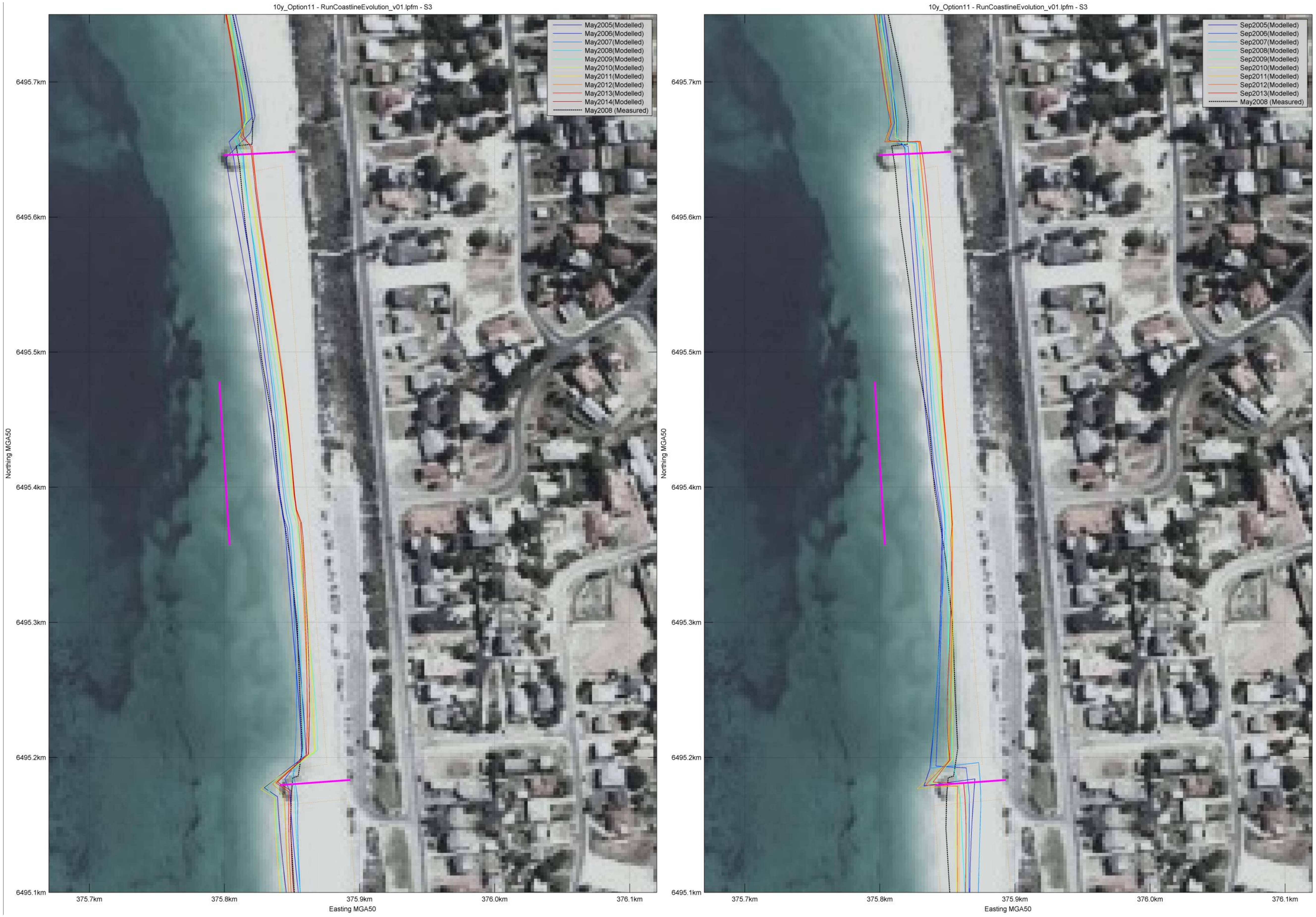


Figure B-15 Option 11 – Section 3: Shoreline evolution for (a) May and (b) September

Figure B-16 Option 11 – Section 4: Shoreline evolution for (a) May and (b) September

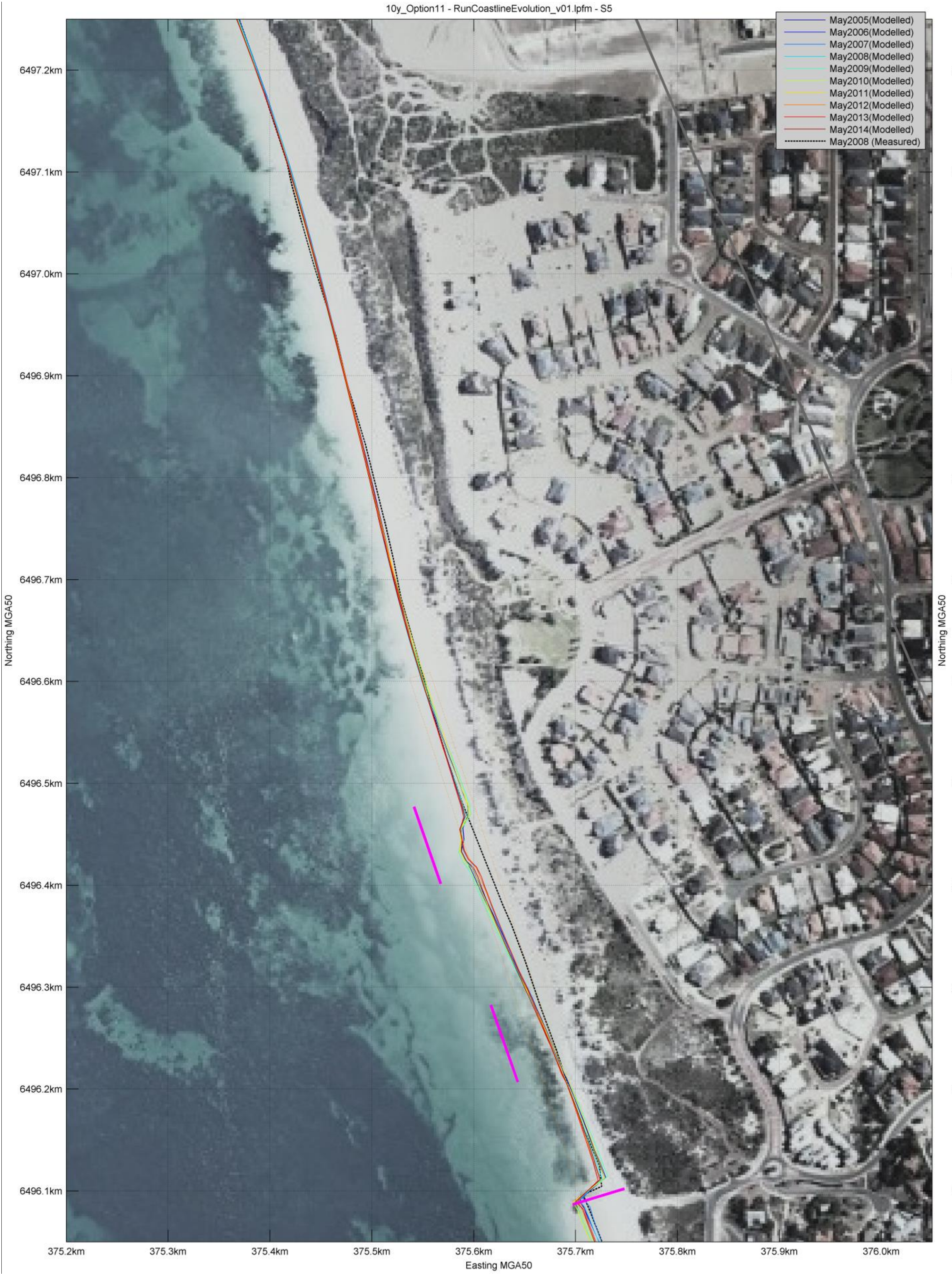


Figure B-17 Option 11 – Section 5: Shoreline evolution for (a) May and (b) September

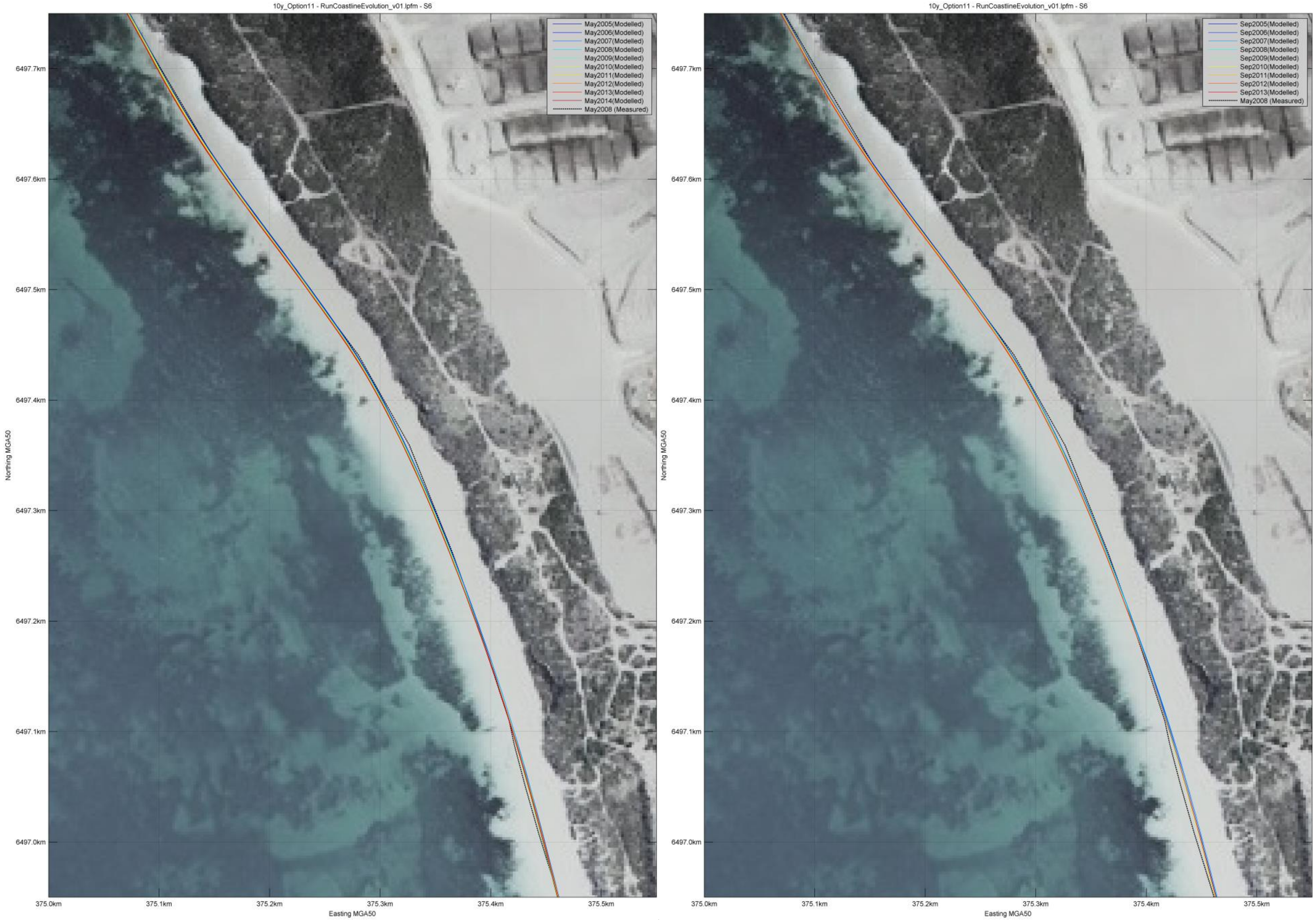


Figure B-18 Option 11 – Section 6: Shoreline evolution for (a) May and (b) September

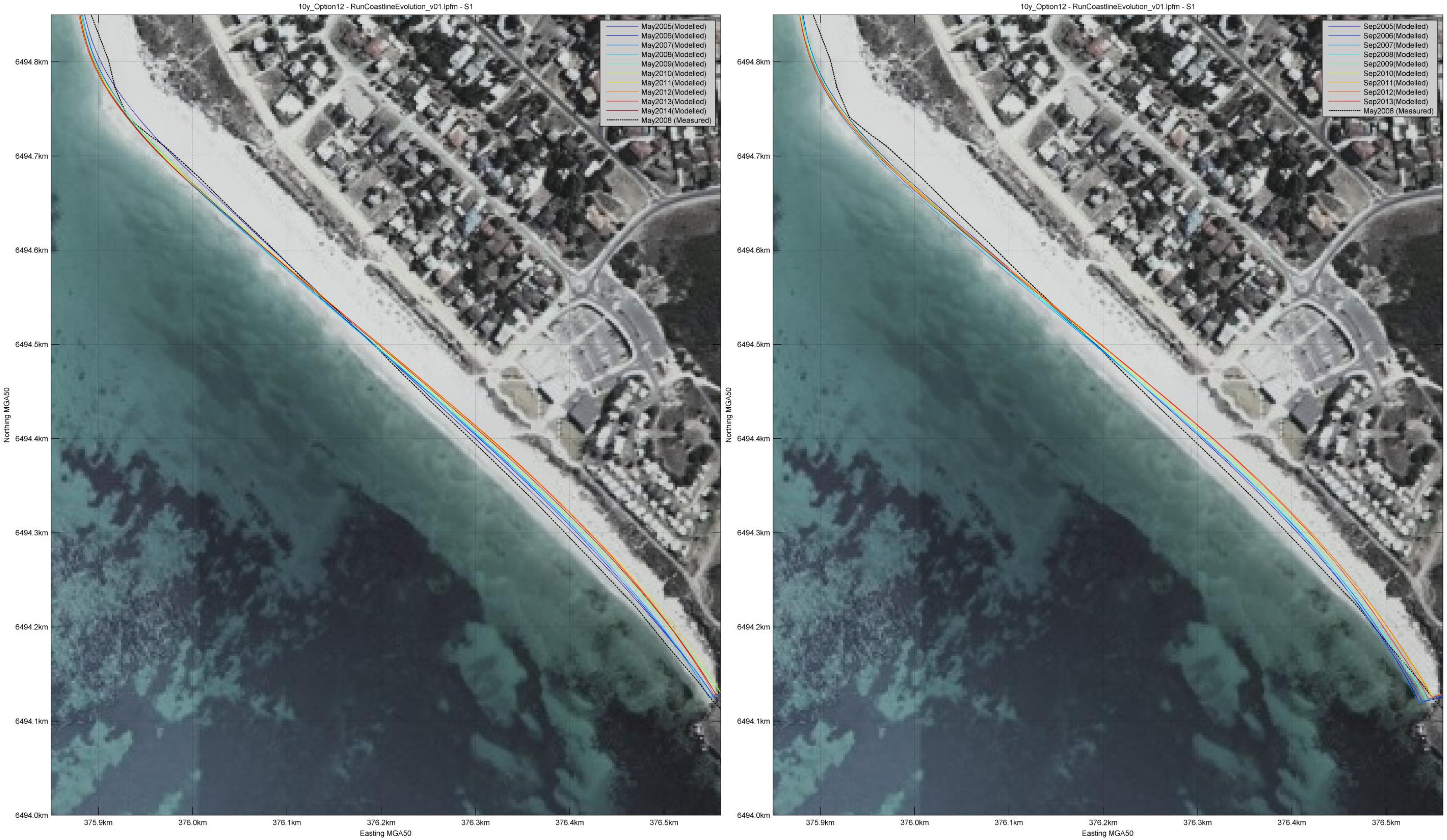
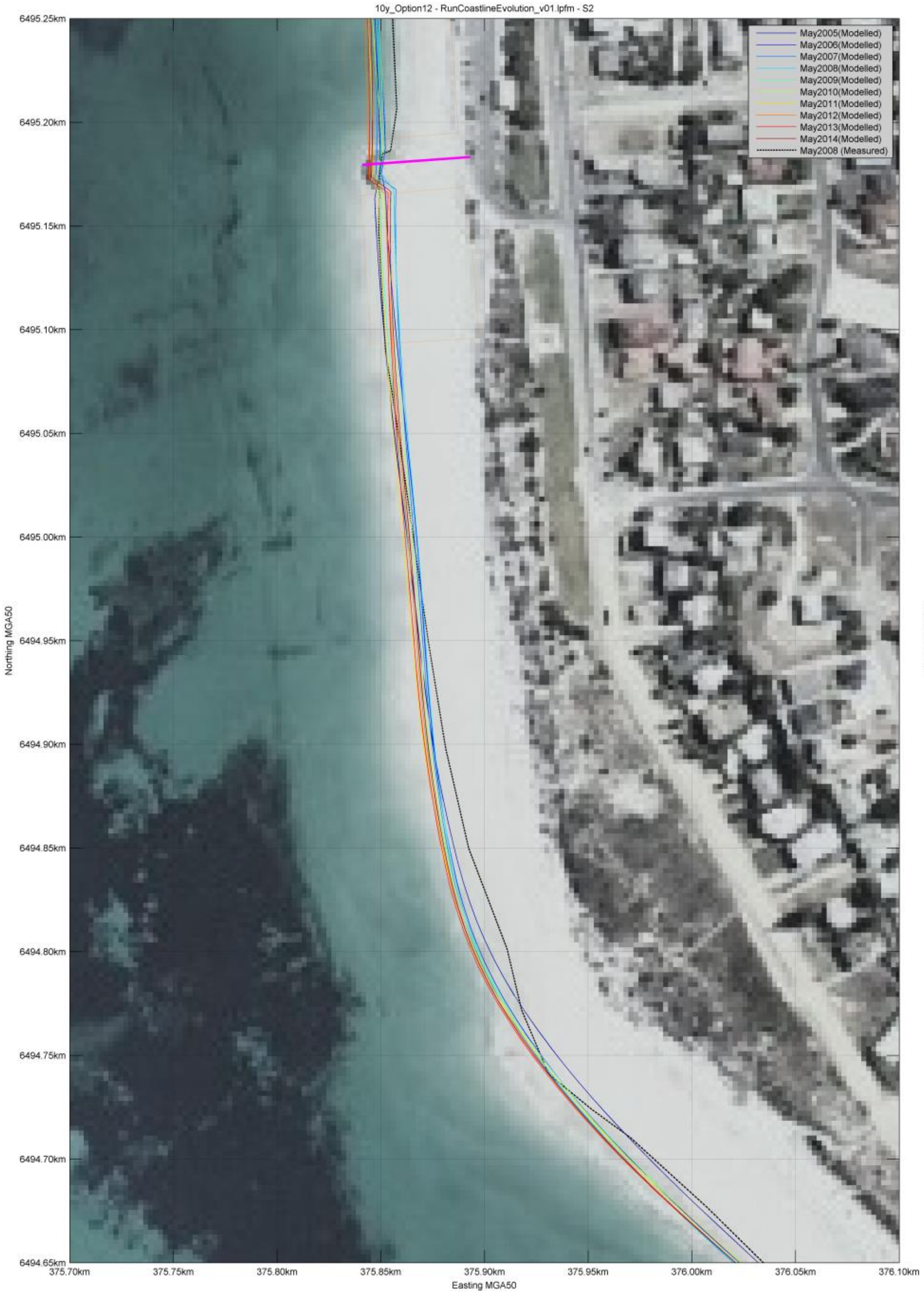


Figure B-19 Option 12 – Section 1: Shoreline evolution for (a) May and (b) September



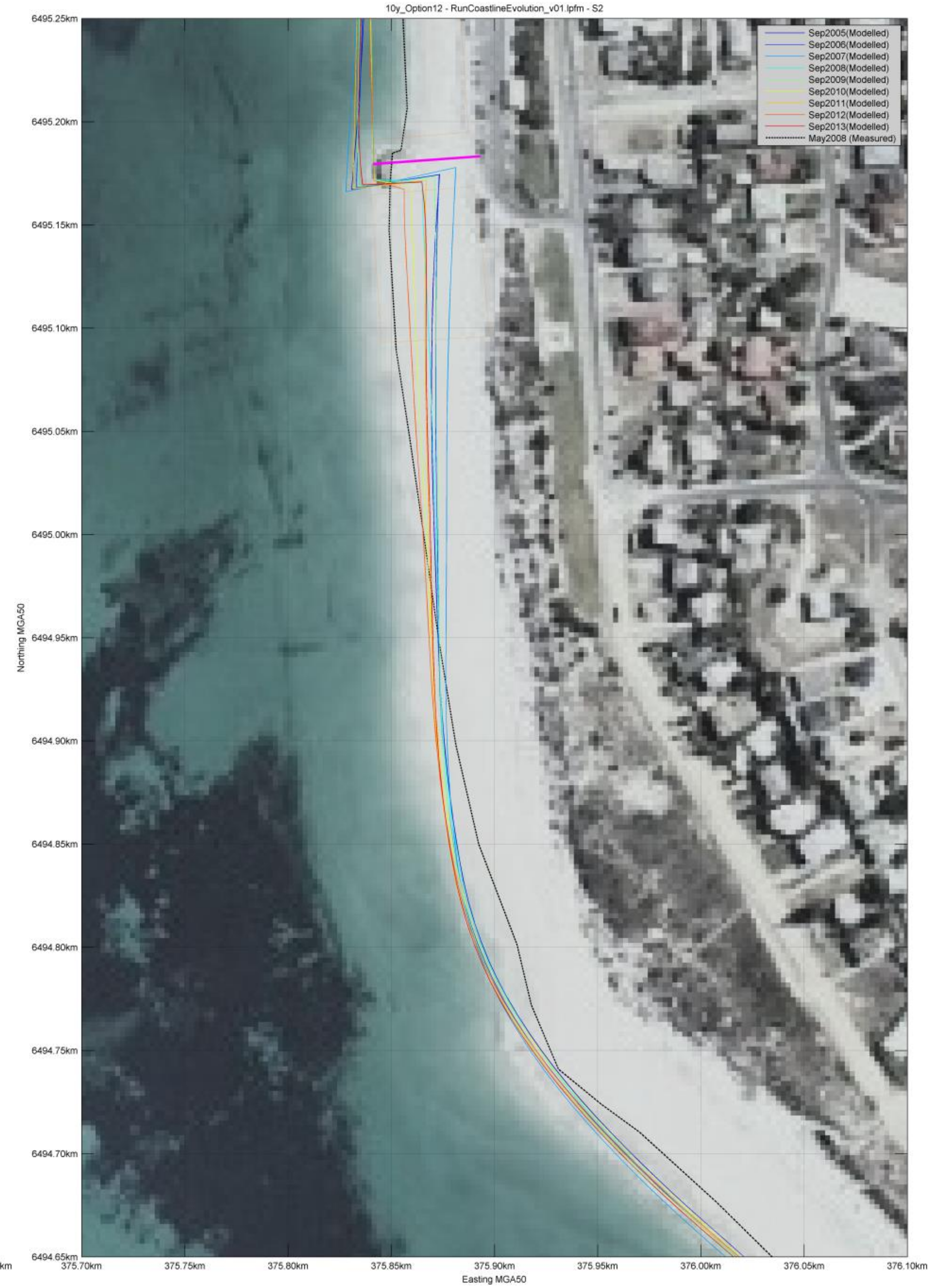


Figure B-20 Option 12 – Section 2: Shoreline evolution for (a) May and (b) September

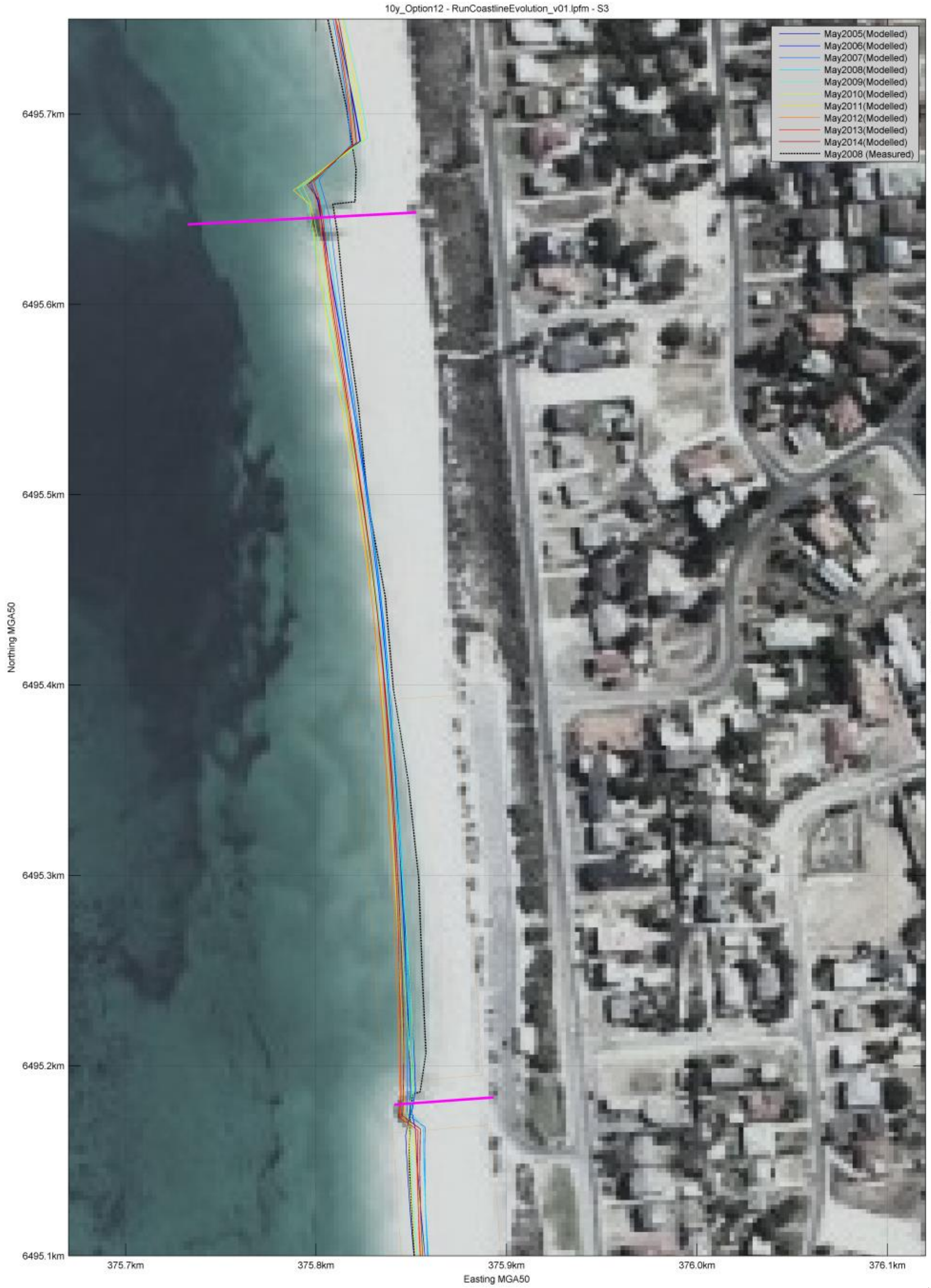


Figure B-21 Option 12 – Section 3: Shoreline evolution for (a) May and (b) September

Figure B-22 Option 12 – Section 4: Shoreline evolution for (a) May and (b) September

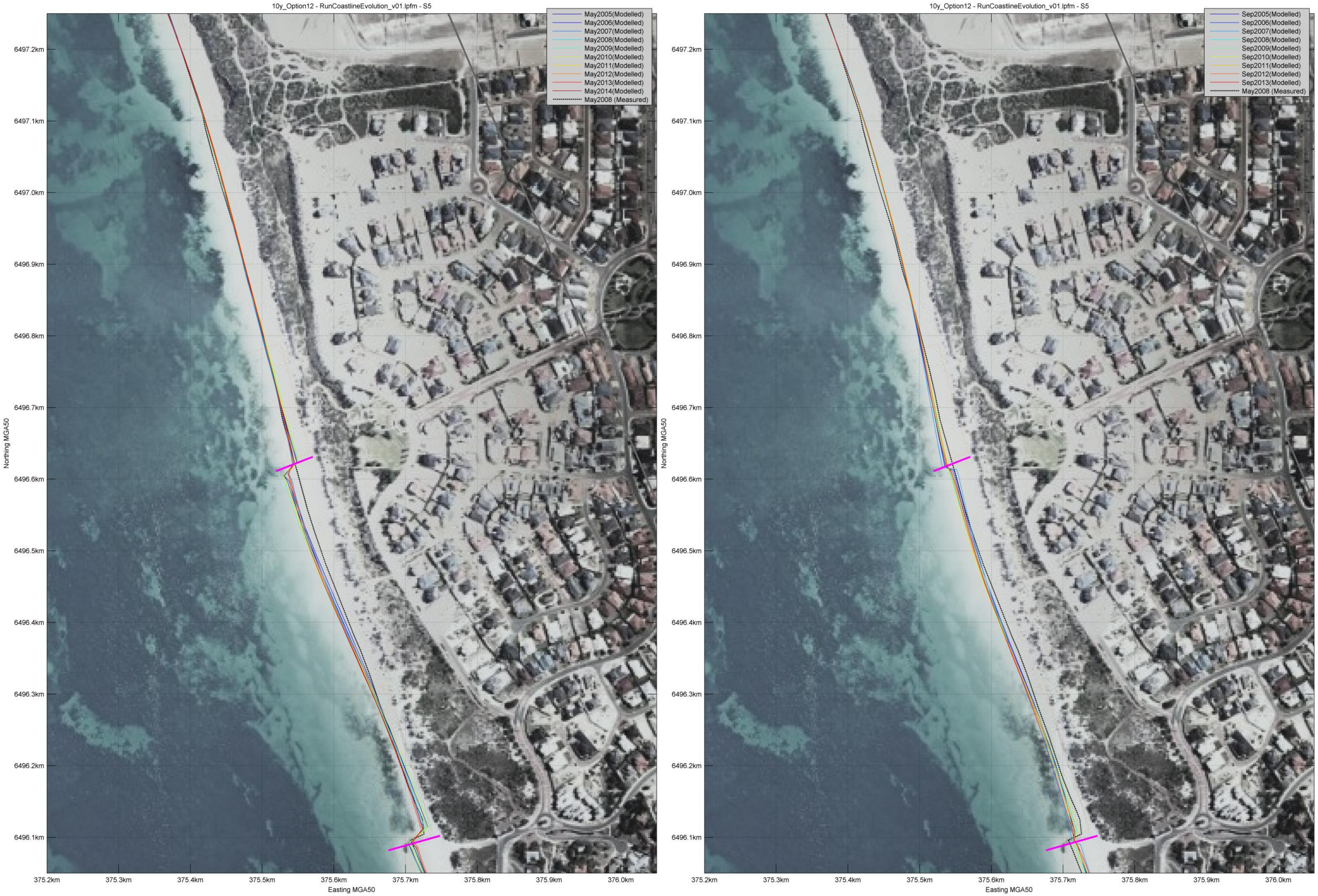
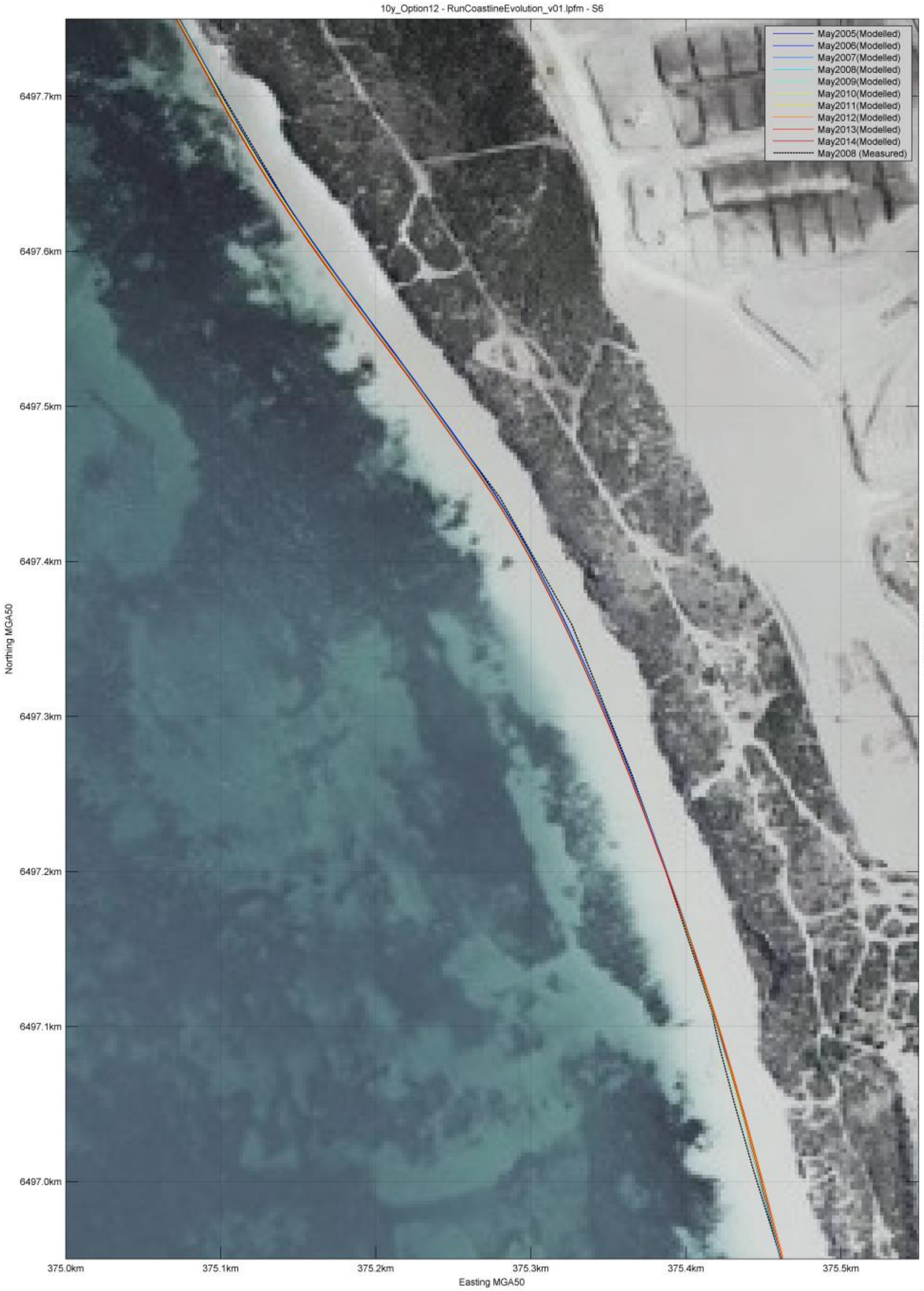


Figure B-23 Option 12 – Section 5: Shoreline evolution for (a) May and (b) September



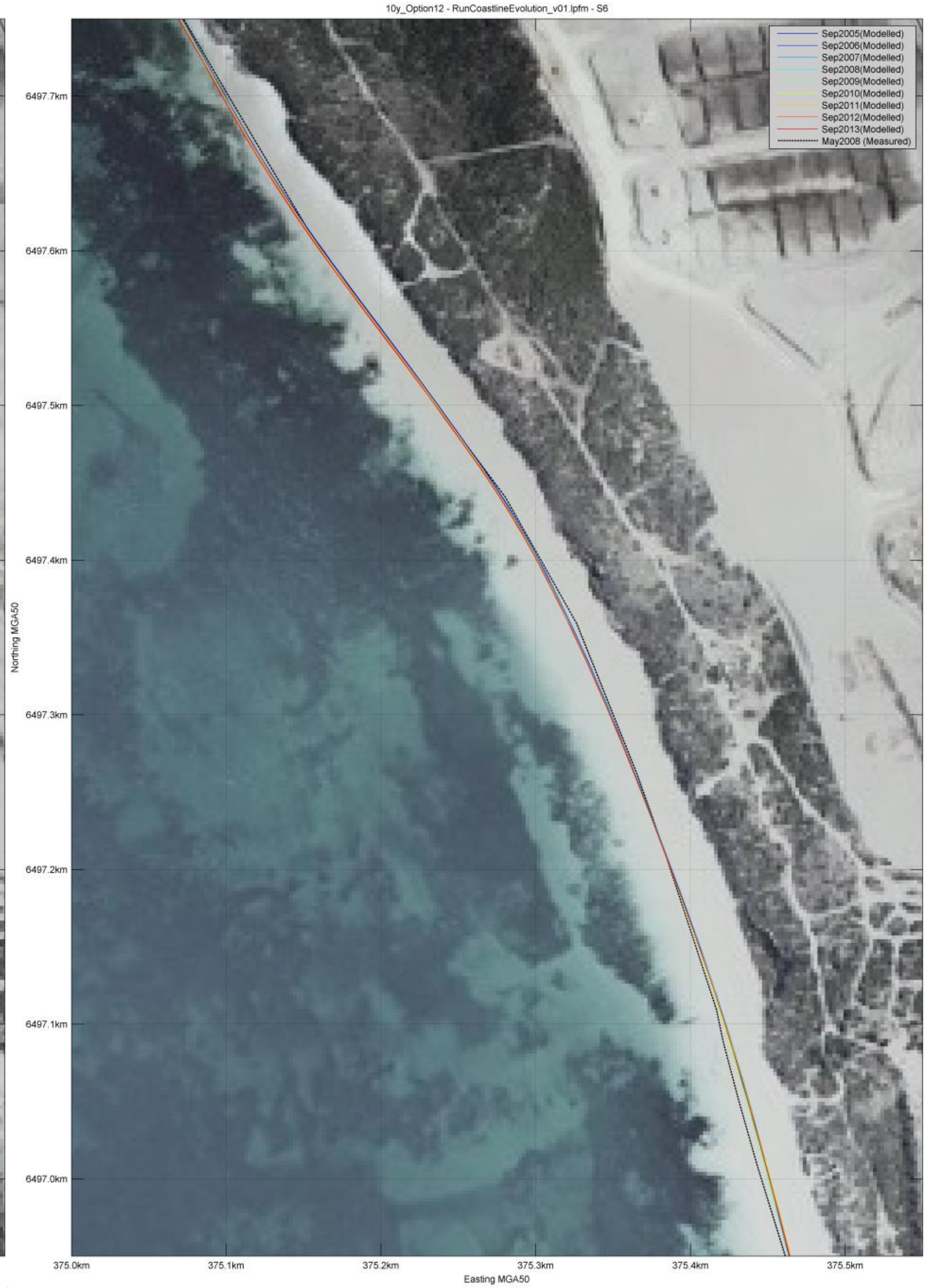


Figure B-24 Option 12 – Section 6: Shoreline evolution for (a) May and (b) September

Conceptual Options Assessment

APPENDIX

C

MCA OPTION CONCEPT DESIGN DRAWINGS

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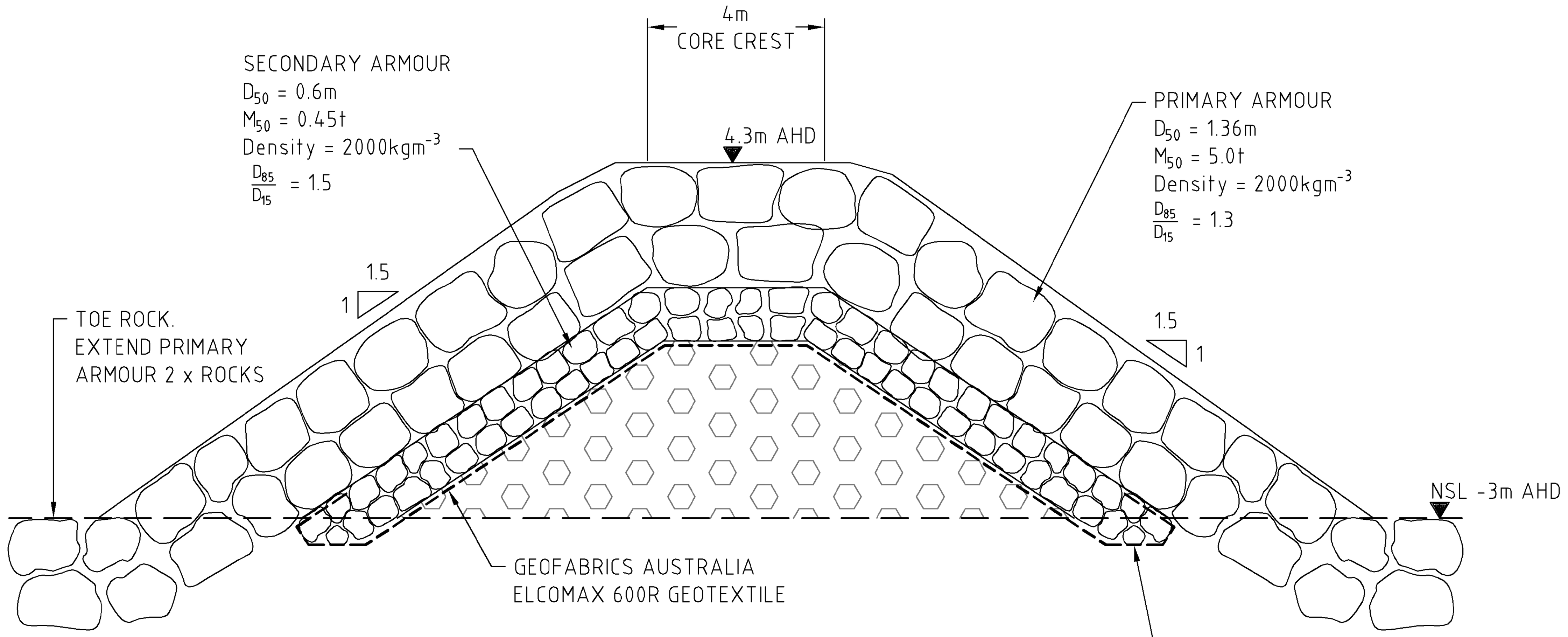
2. SETOUT COORDINATES ARE SHOWN IN: UTM - ZONE 50, GDA94.



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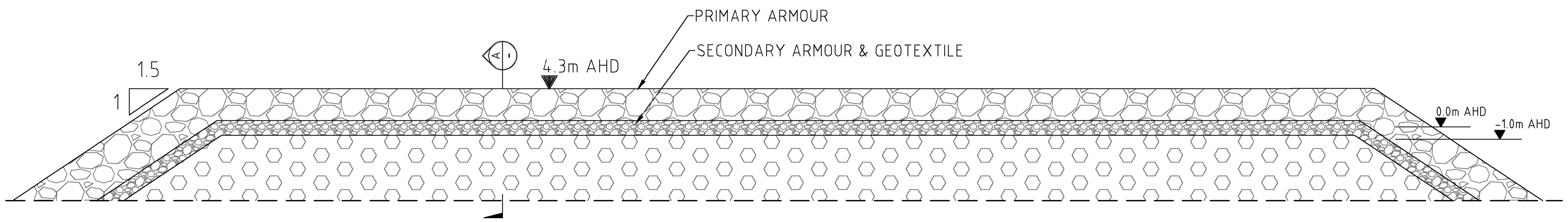

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Rev	Date	Description	Drawn	Appr.
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Drawn: RML	Date: 29/10/2015	Client: CITY OF WANNEROO
Designed: JGW	Date: 29/10/2015	Project: QUINNS BEACH LONG TERM COASTAL MANAGEMENT QUINNS ROCKS, WA
Checked: WCE	Date: 29/10/2015	
Reviewed: JGW	Date: 29/10/2015	Title: MCA 1 OFFSHORE BREAKWATER IN SECTION 3
Approved: JGW	Date: 29/10/2015	

Status			
NOT FOR CONSTRUCTION			
Date: 29/10/2015	Datum: A.H.D.	Scale: AS SHOWN	Size: A1
Drawing Number: 59915802-001			Revision: V1

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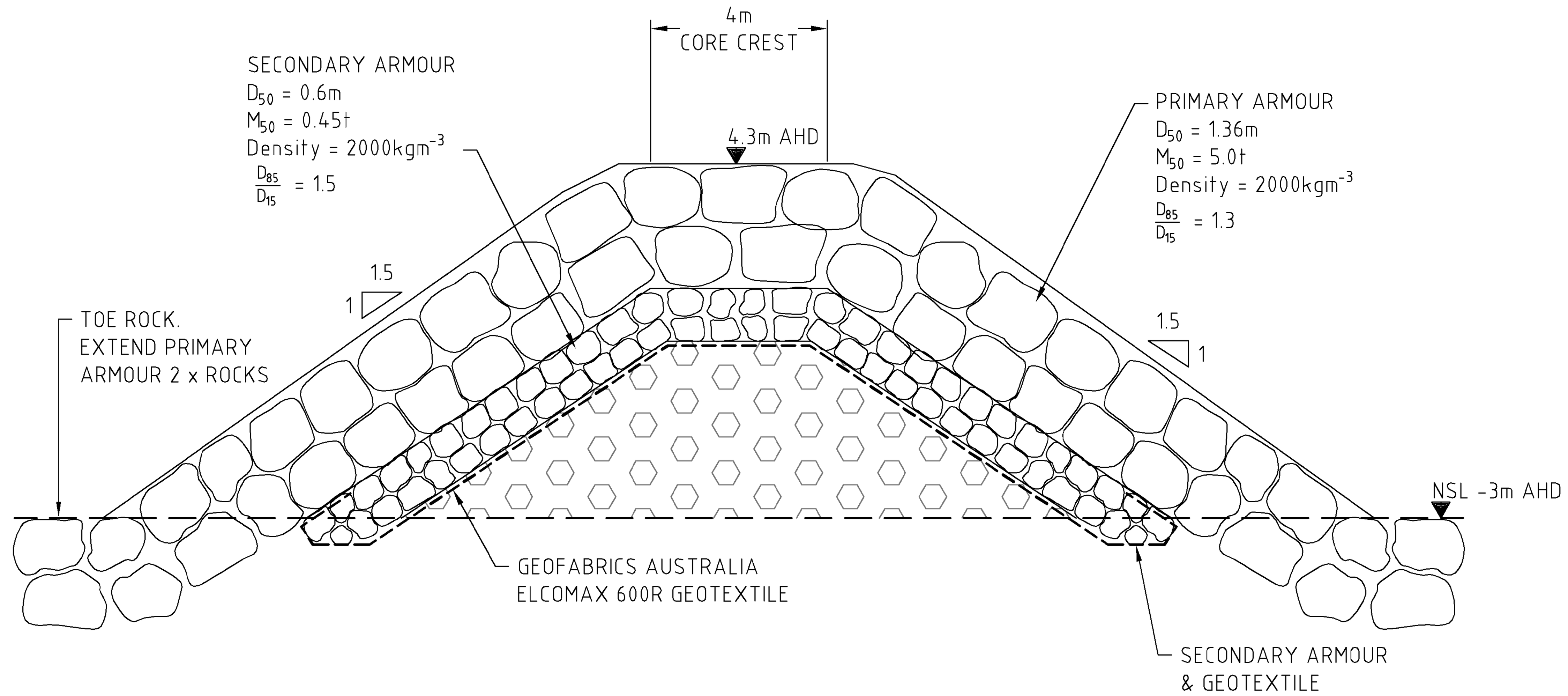

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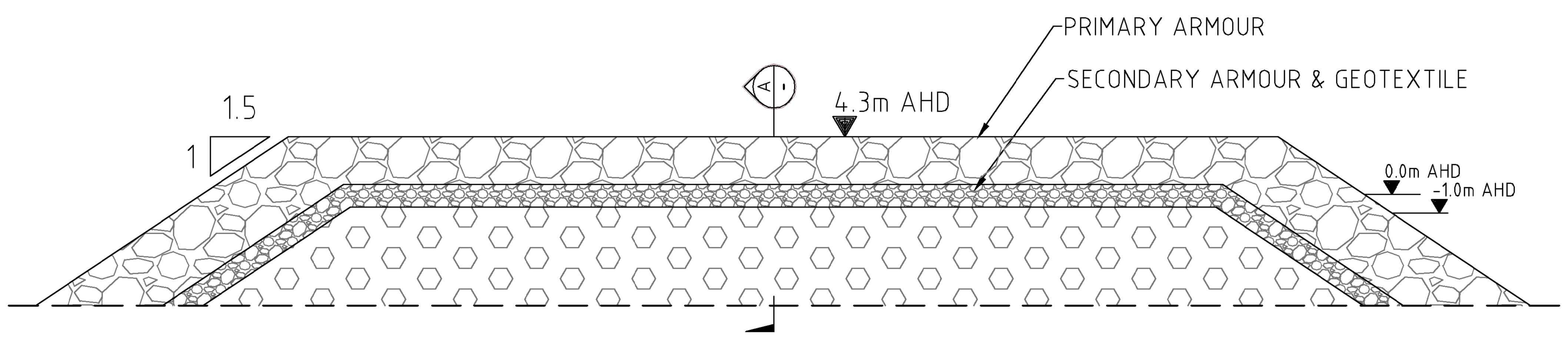

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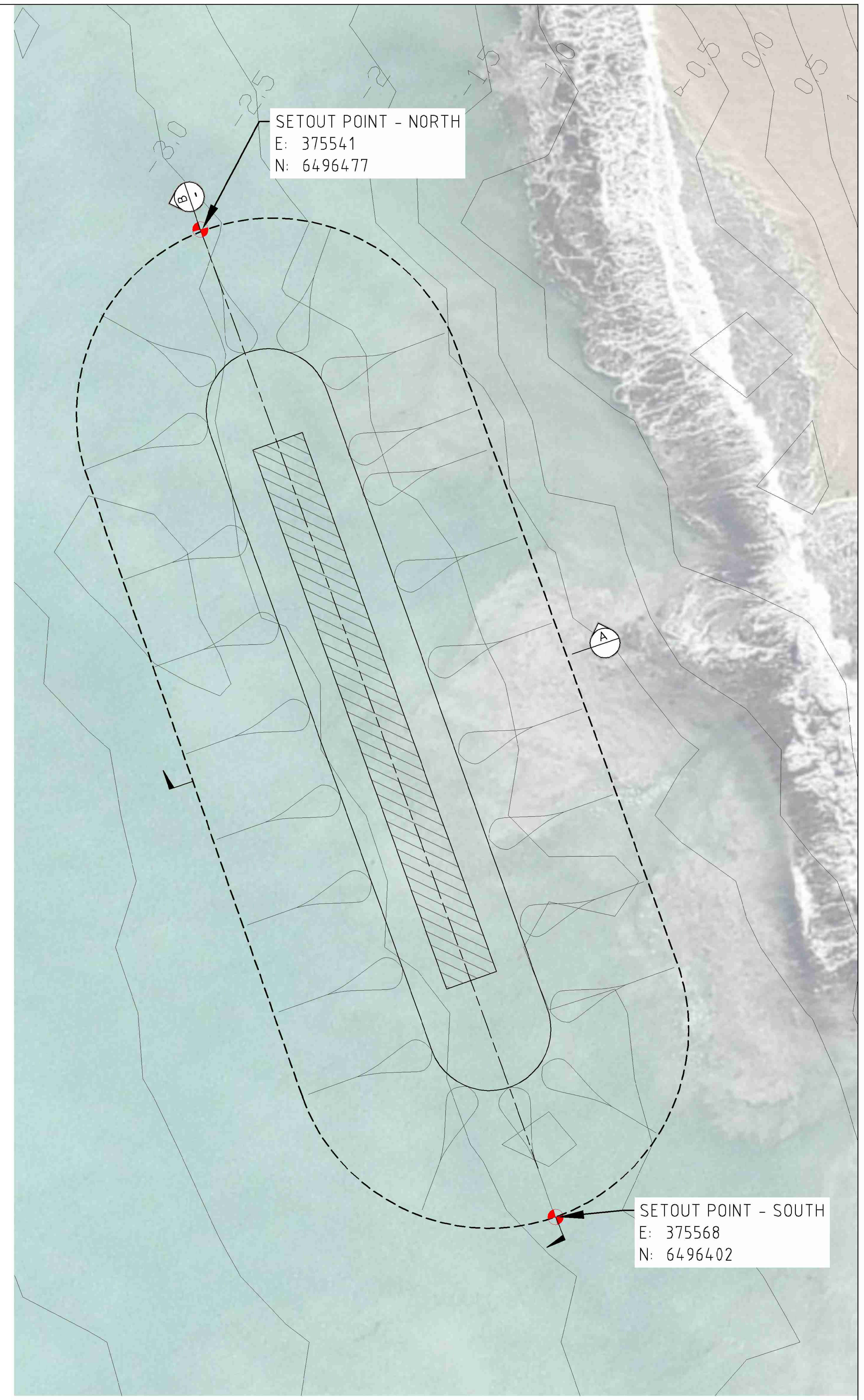

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NORTH

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Drawn	RML	29/10/2015
Designed	JGW	29/10/2015
Checked	WCE	29/10/2015
Reviewed	JGW	29/10/2015
Approved	JGW	29/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 1
NORTHERN OFFSHORE BREAKWATER
IN SECTION 5

Status: NOT FOR CONSTRUCTION

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Drawing Number: 59915802-002
Revision: V1

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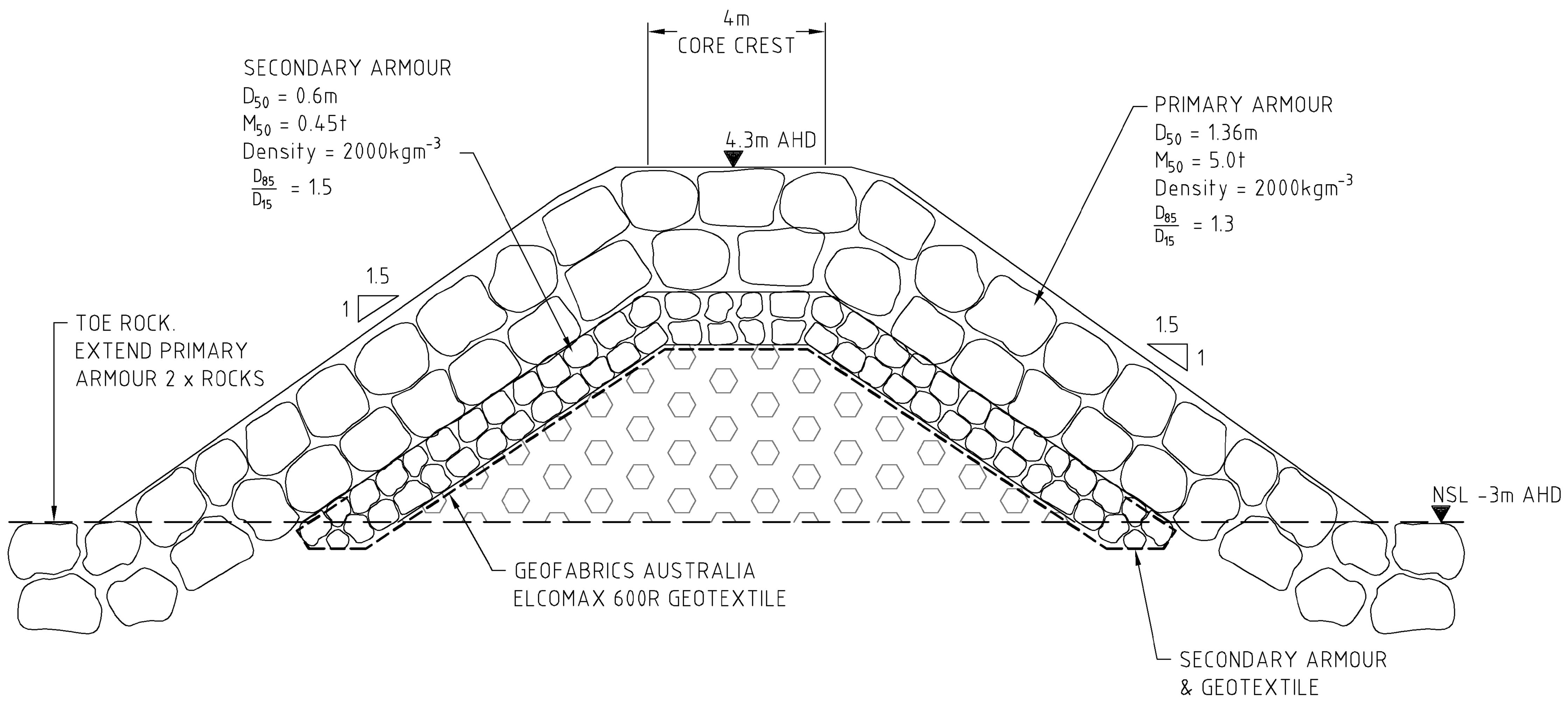

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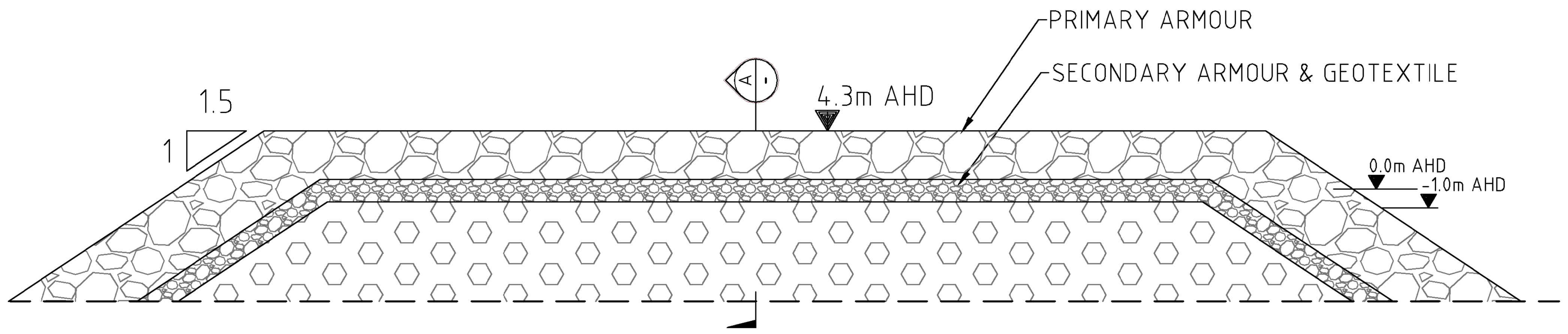

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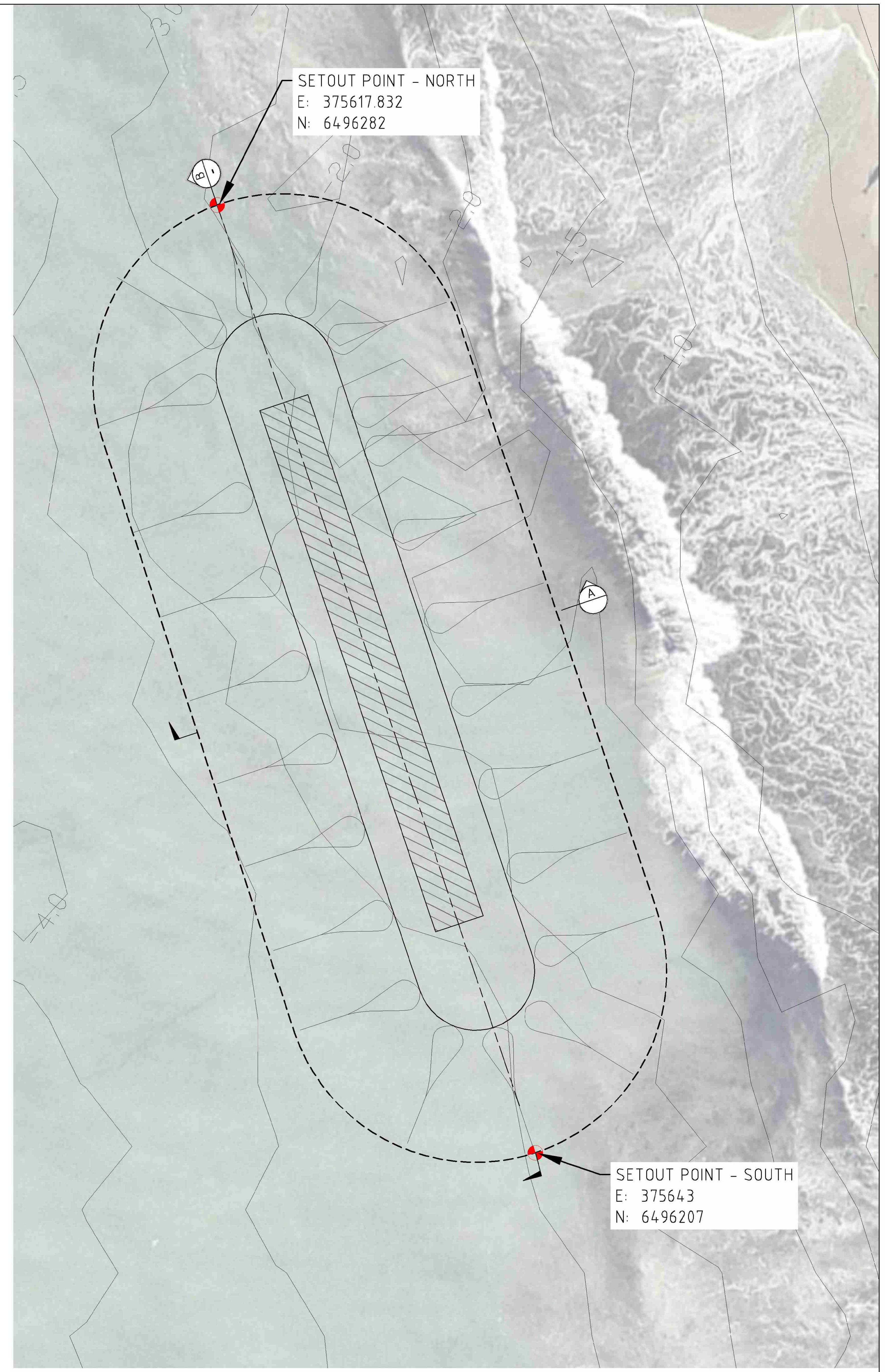

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NORTH

Drawn	RML	29/10/2015
Designed	JGW	29/10/2015
Checked	WCE	29/10/2015
Reviewed	JGW	29/10/2015
Approved	JGW	29/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 1
SOUTHERN OFFSHORE BREAKWATER
IN SECTION 5

Status: NOT FOR CONSTRUCTION

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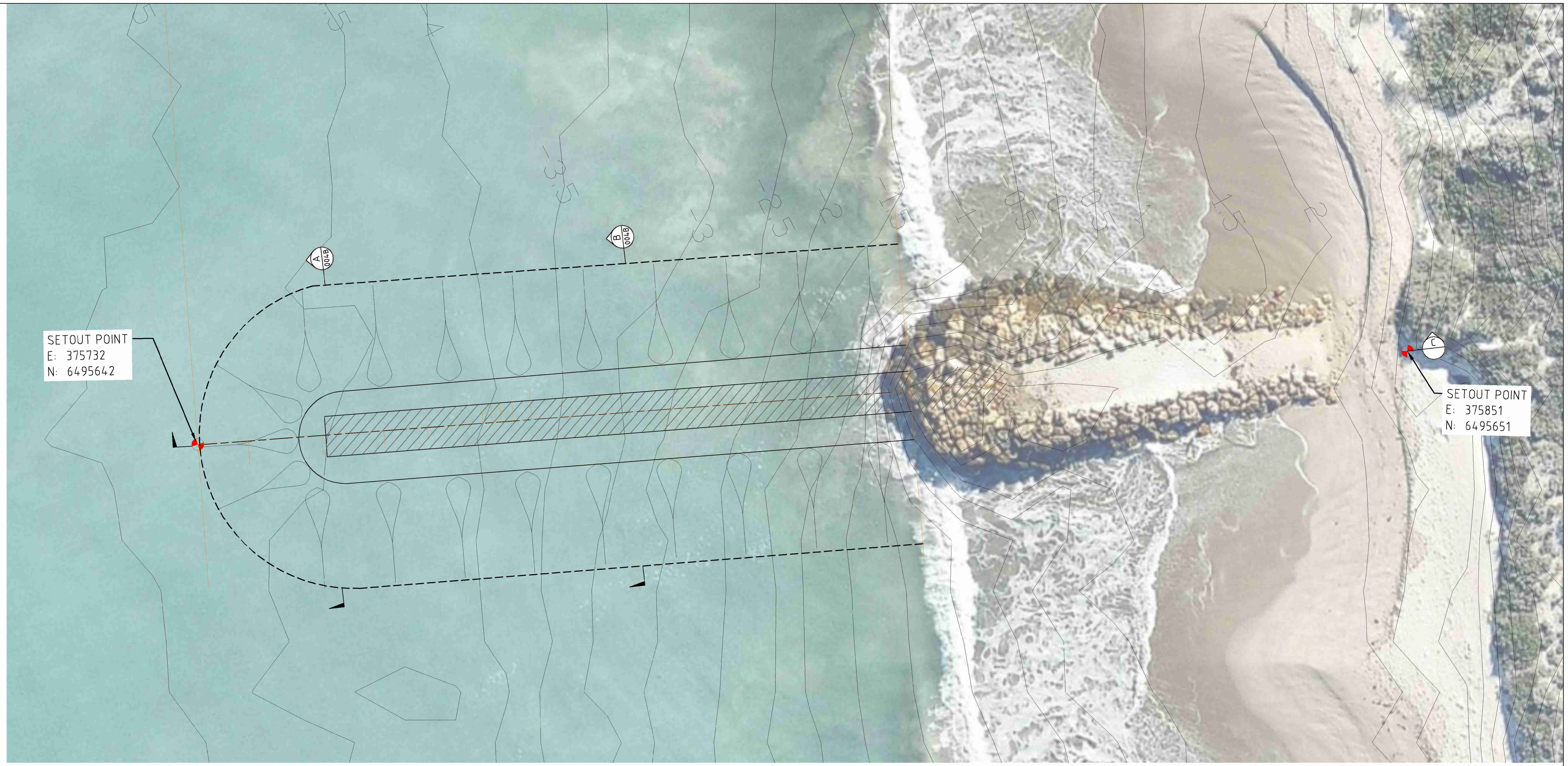

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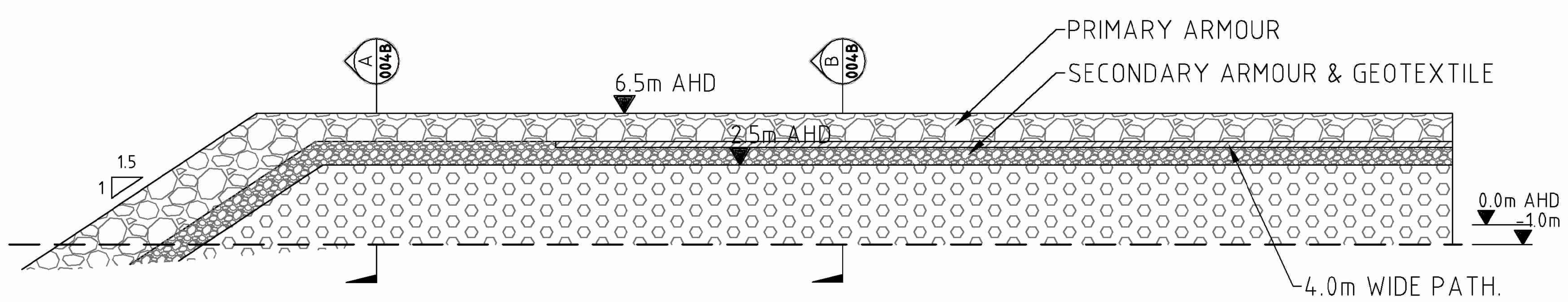

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NORTH

		Date
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Designed	JGW	22/10/2015
Checked	WCE	22/10/2015
Reviewed	JGW	22/10/2015
Approved	JGW	22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 2
GROYNE 2 EXTENSION
PLAN & SECTION

Status: NOT FOR CONSTRUCTION

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Drawing Number: 59915802-004A
Revision: V1

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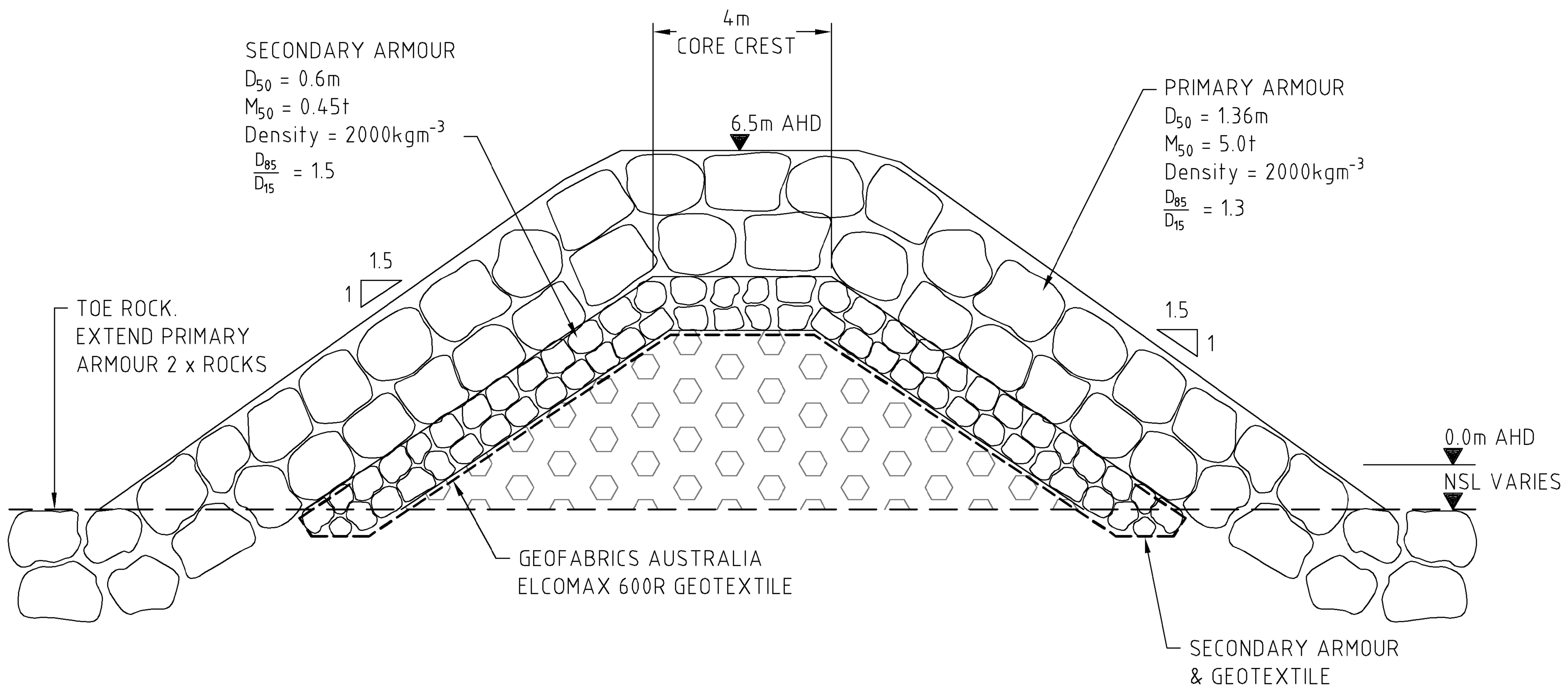

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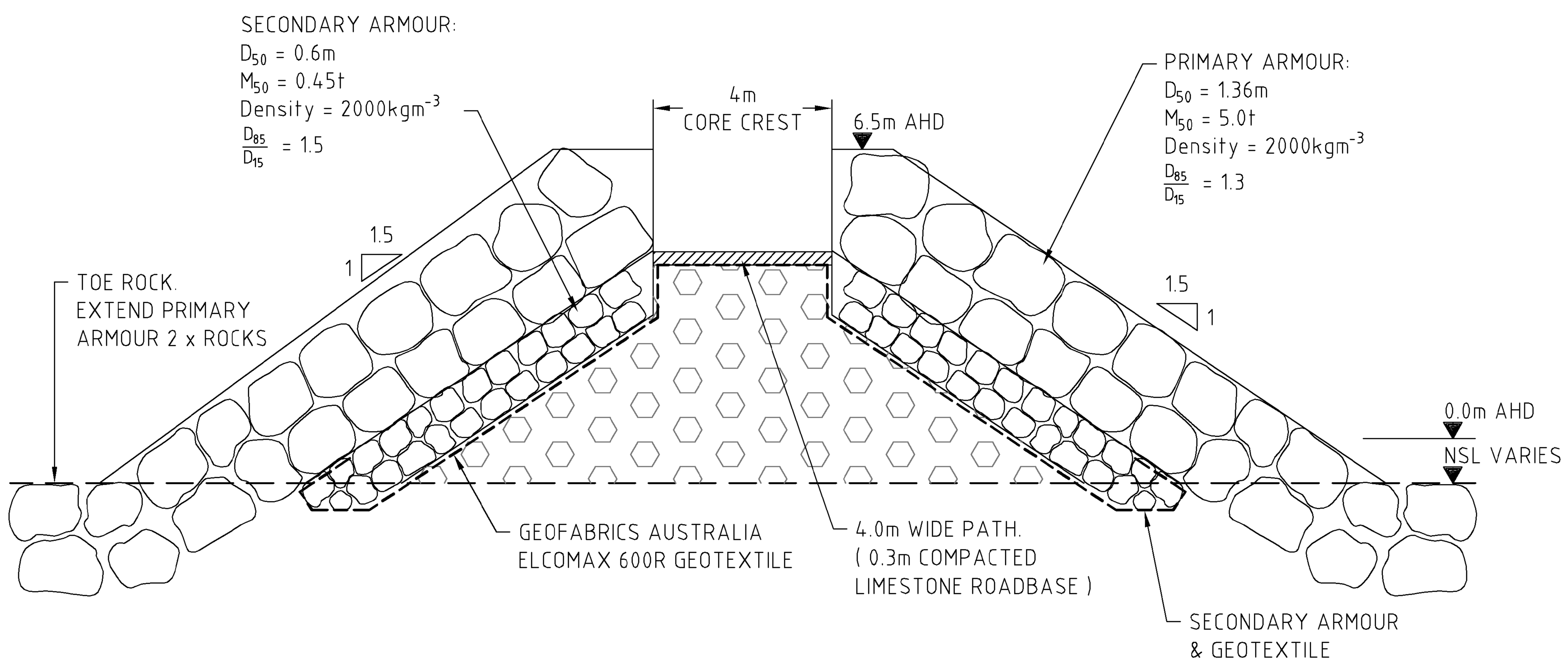

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Designed	JGW	22/10/2015
Checked	WCE	22/10/2015
Reviewed	JGW	22/10/2015
Approved	JGW	22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 2
GROYNE 2 EXTENSION
SECTIONS

Status: NOT FOR CONSTRUCTION

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Drawing Number: 59915802-004B

Revision: V1

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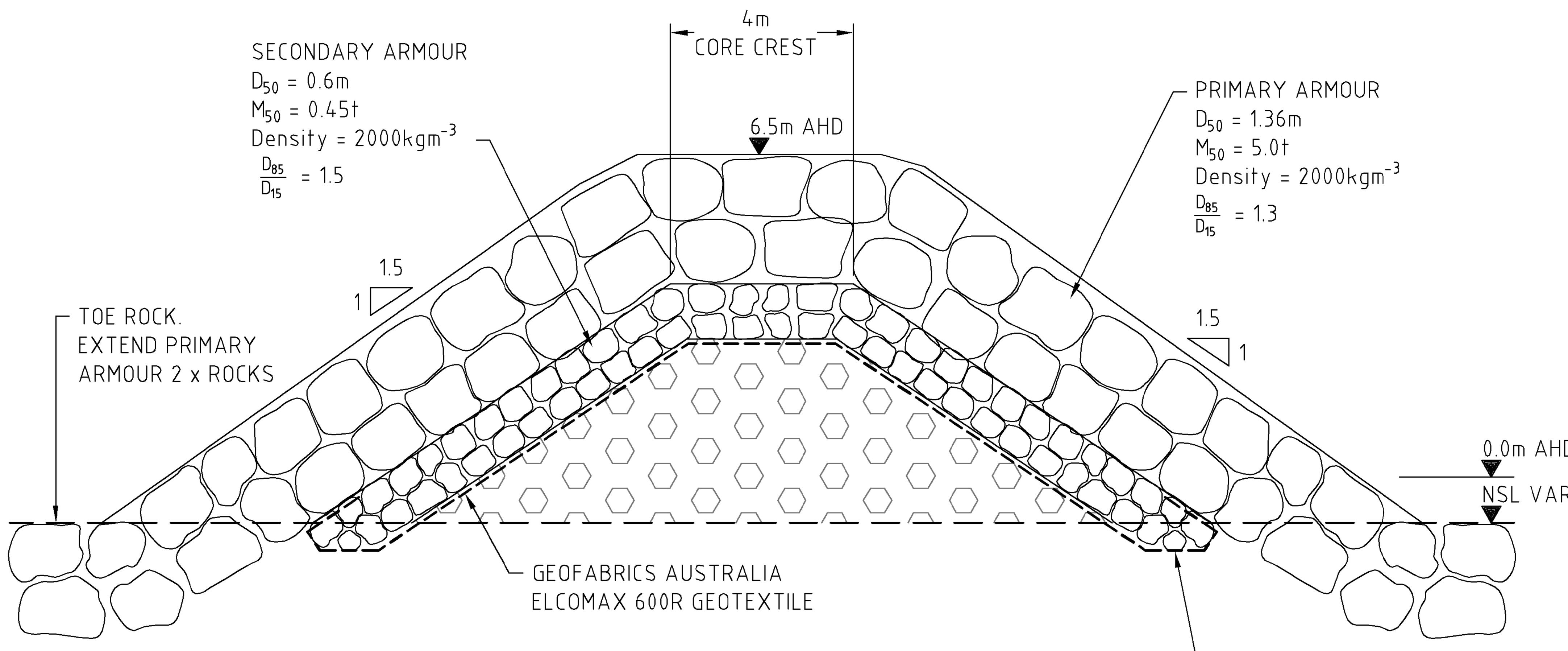

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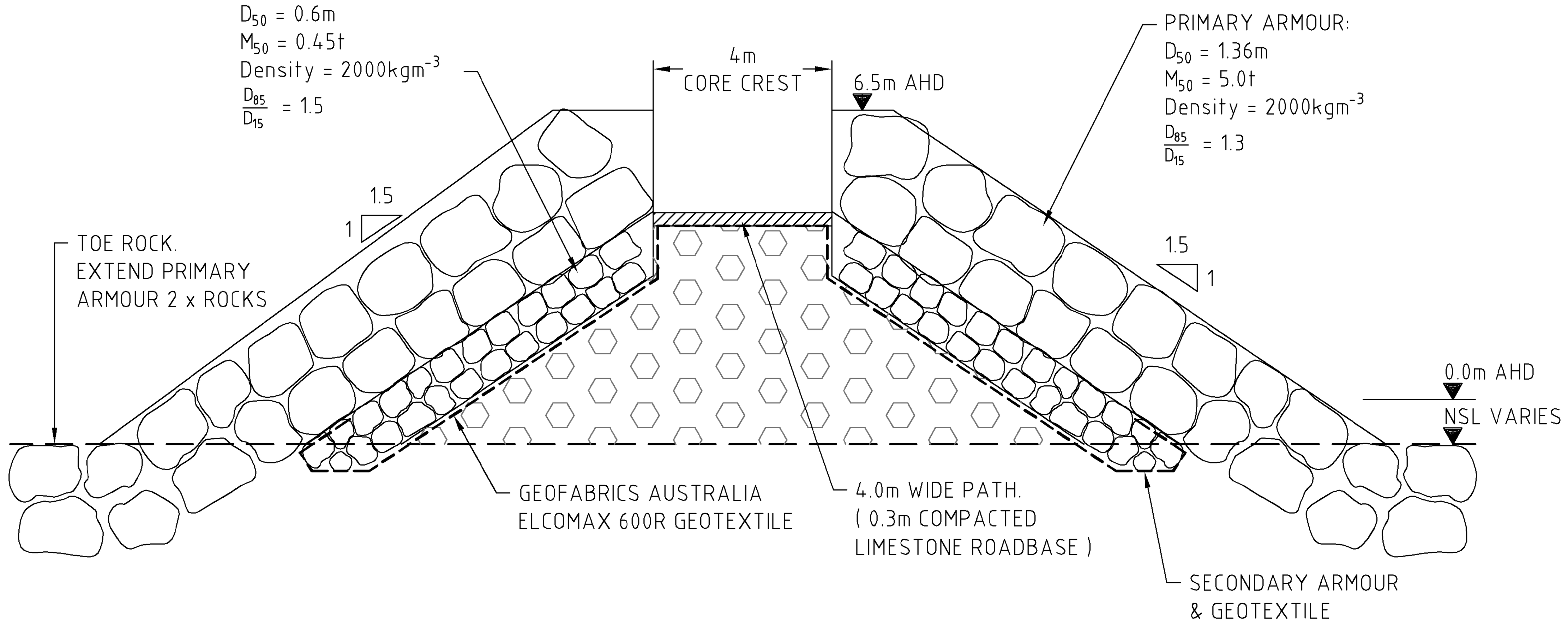

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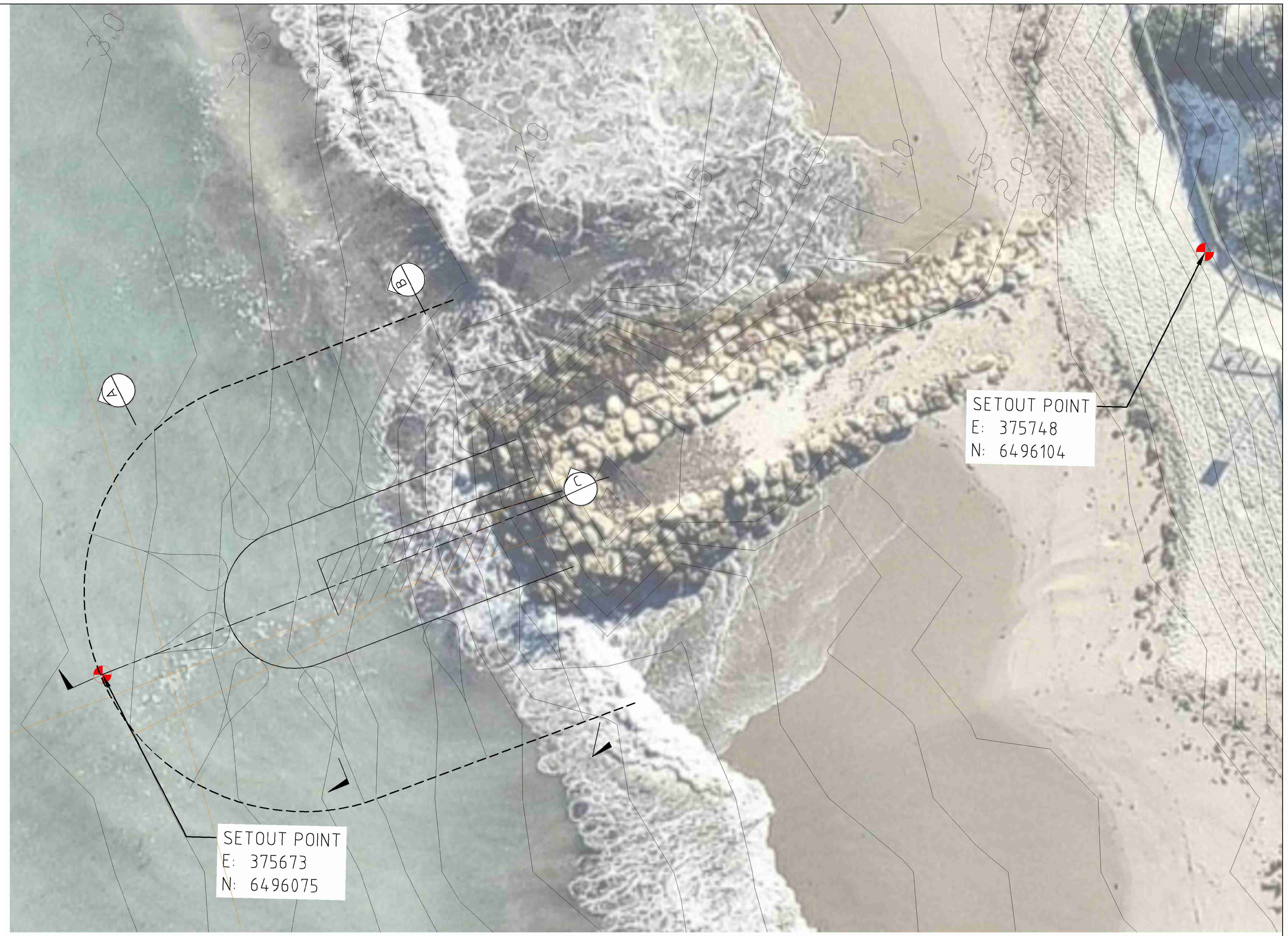

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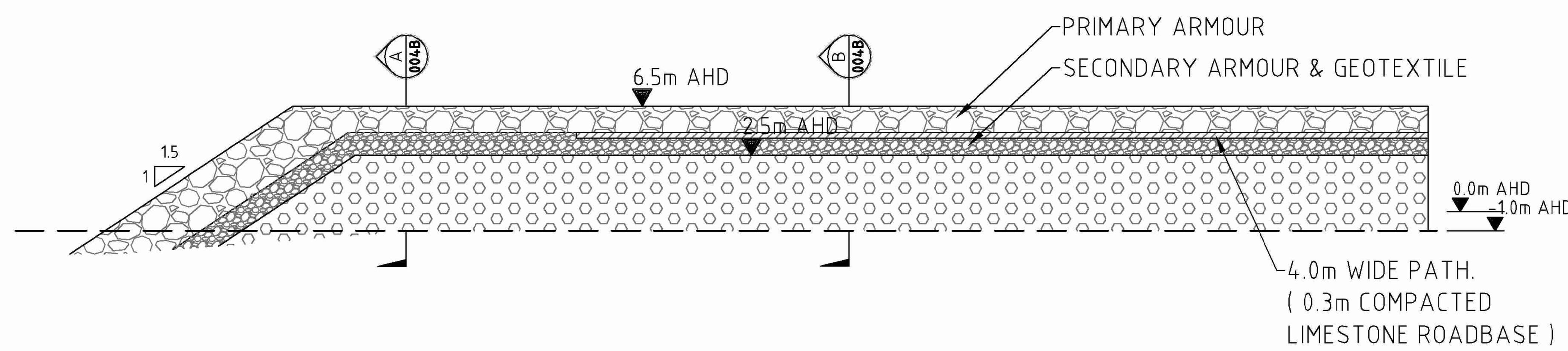

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Designed	JGW	22/10/2015
Checked	WCE	22/10/2015
Reviewed	JGW	22/10/2015
Approved	JGW	22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 2
GROYNE 3 EXTENSION

Status: NOT FOR CONSTRUCTION

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Revision: V1

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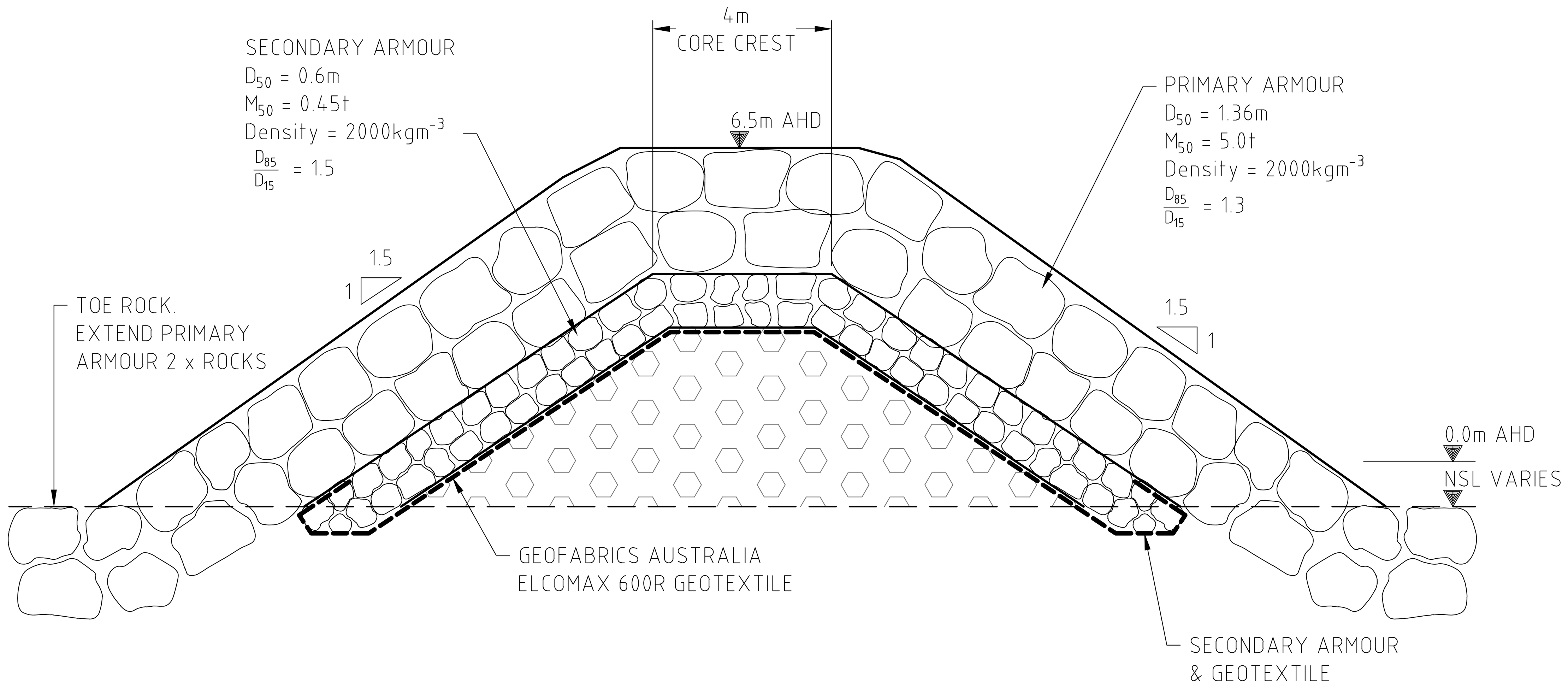

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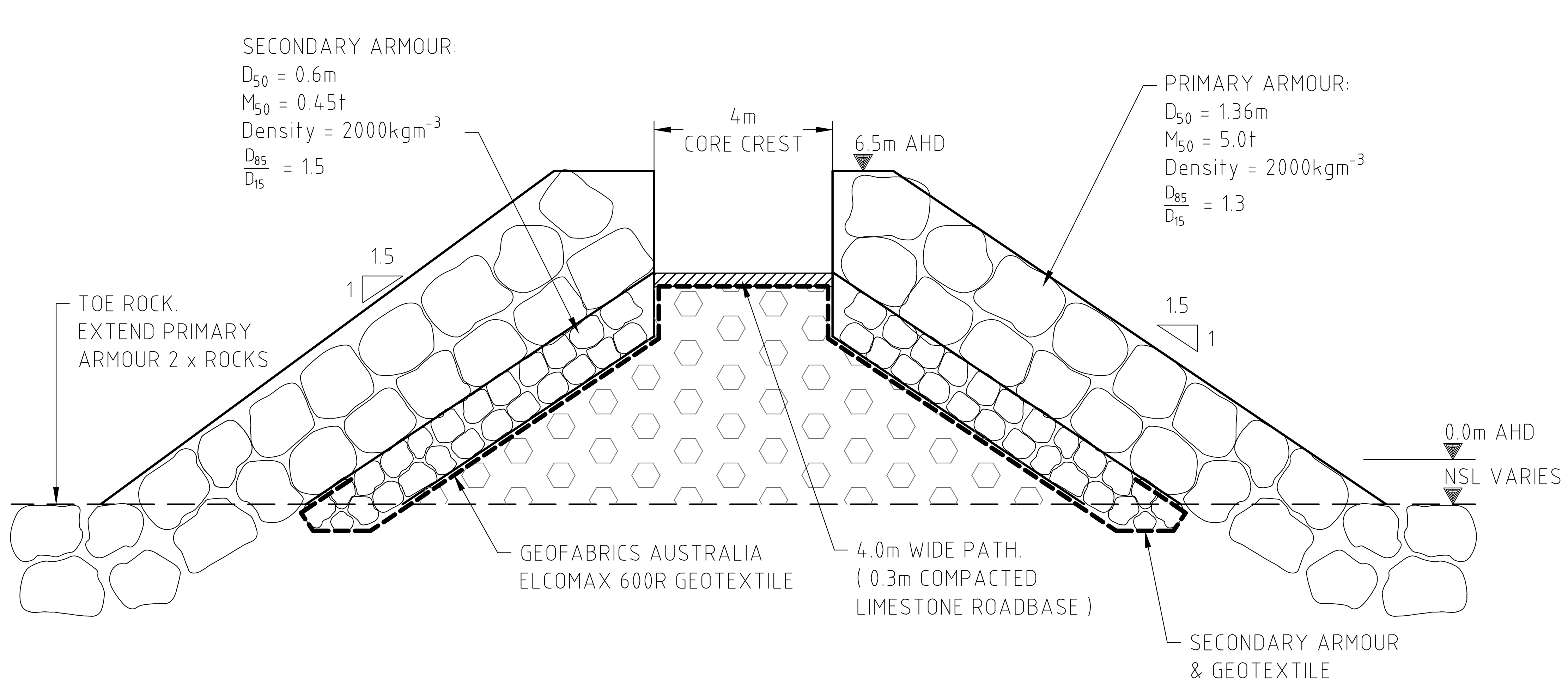
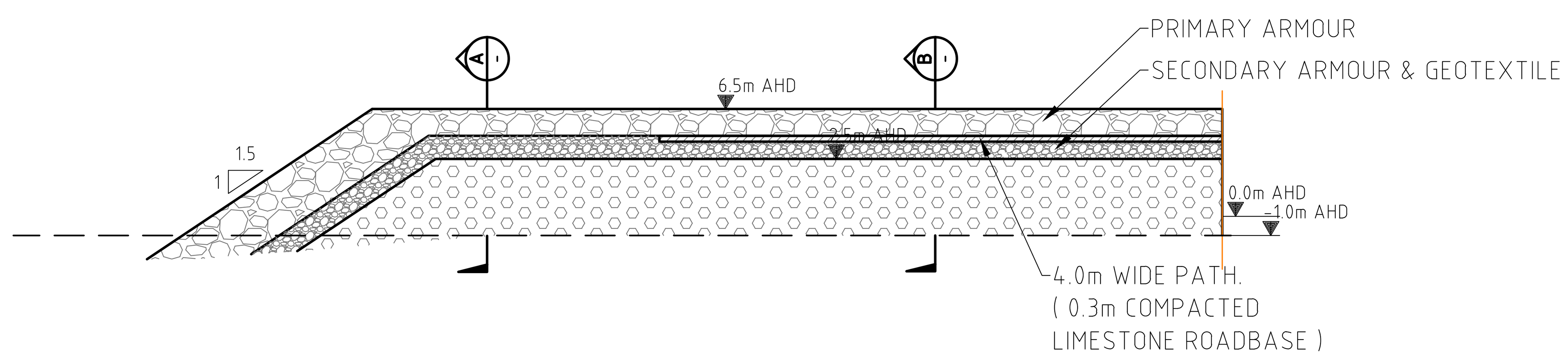
SCALE 1:100



SECTION B
SCALE 1:100

PLAN
SCALE 1:250



SECTION C
SCALE 1:250

NOTES

1. CONTOURS SHOWN ARE APPROXIMATE ONLY.
2. SETOUT COORDINATES ARE SHOWN IN: UTM - ZONE 50, GDA94.

DATE PLOTTED: 23 November, 2015 - 9:10am

XREF's: bathyContoursAHD
CAD FILE: C:\Temp_Cad\AcPublish_5608\Unsaved Drawing1.dwg

Rev	Date	Description	Drawn	Appr.
B	23/11/2015	PRELIMINARY ISSUE	RML	JGW
A	29/10/2015	PRELIMINARY ISSUE	RML	JGW

NORTH

		Date
Drawn	RML	23/11/2015
Designed	JGW	29/10/2015
Checked	WCE	29/10/2015
Reviewed	JGW	23/11/2015
Approved	JGW	23/11/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA2 & MCA3
GROYNE 4, 60m IN LENGTH

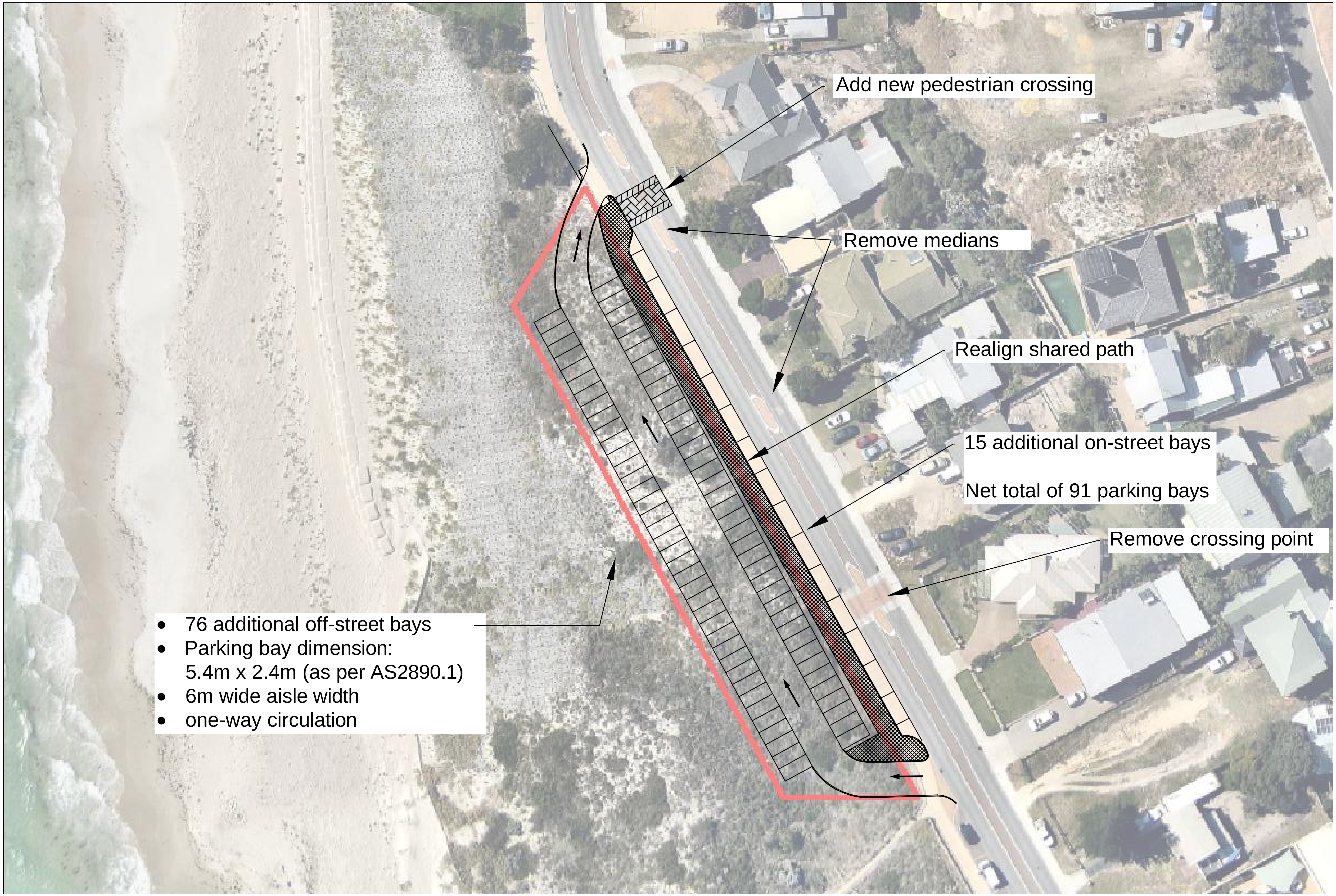
Status: NOT FOR CONSTRUCTION

Date	Datum	Scale	Size
23/11/2015	A.H.D.	AS SHOWN	A1

Drawing Number: 59915802-006
Revision: V2

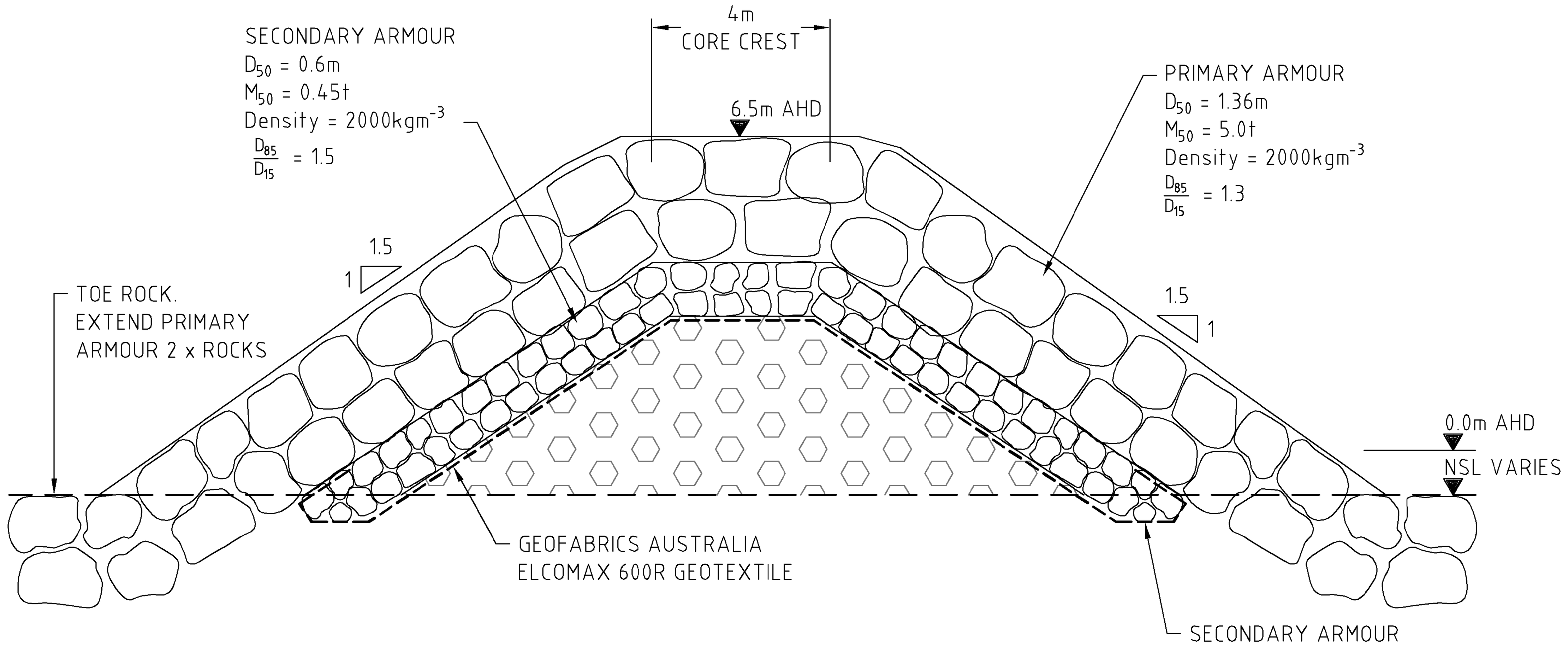
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150mm ON A1 ORIGINAL

Realign shared path (Earthworks would be required)
46 on-street bays
Bay size according to AS 2890.5
3.5m wide parallel to kerb
4.8m deep perpendicular to kerb
Remove pedestrian crossing


Add new pedestrian crossing
Remove medians
Realign shared path
15 additional on-street bays
Net total of 91 parking bays
Remove crossing point
76 additional off-street bays
Parking bay dimension:
5.4m x 2.4m (as per AS2890.1)
6m wide aisle width
one-way circulation

NOTES

1. CONTOURS SHOWN ARE APPROXIMATE ONLY.
2. SETOUT COORDINATES ARE SHOWN IN: UTM - ZONE 50, GDA94.



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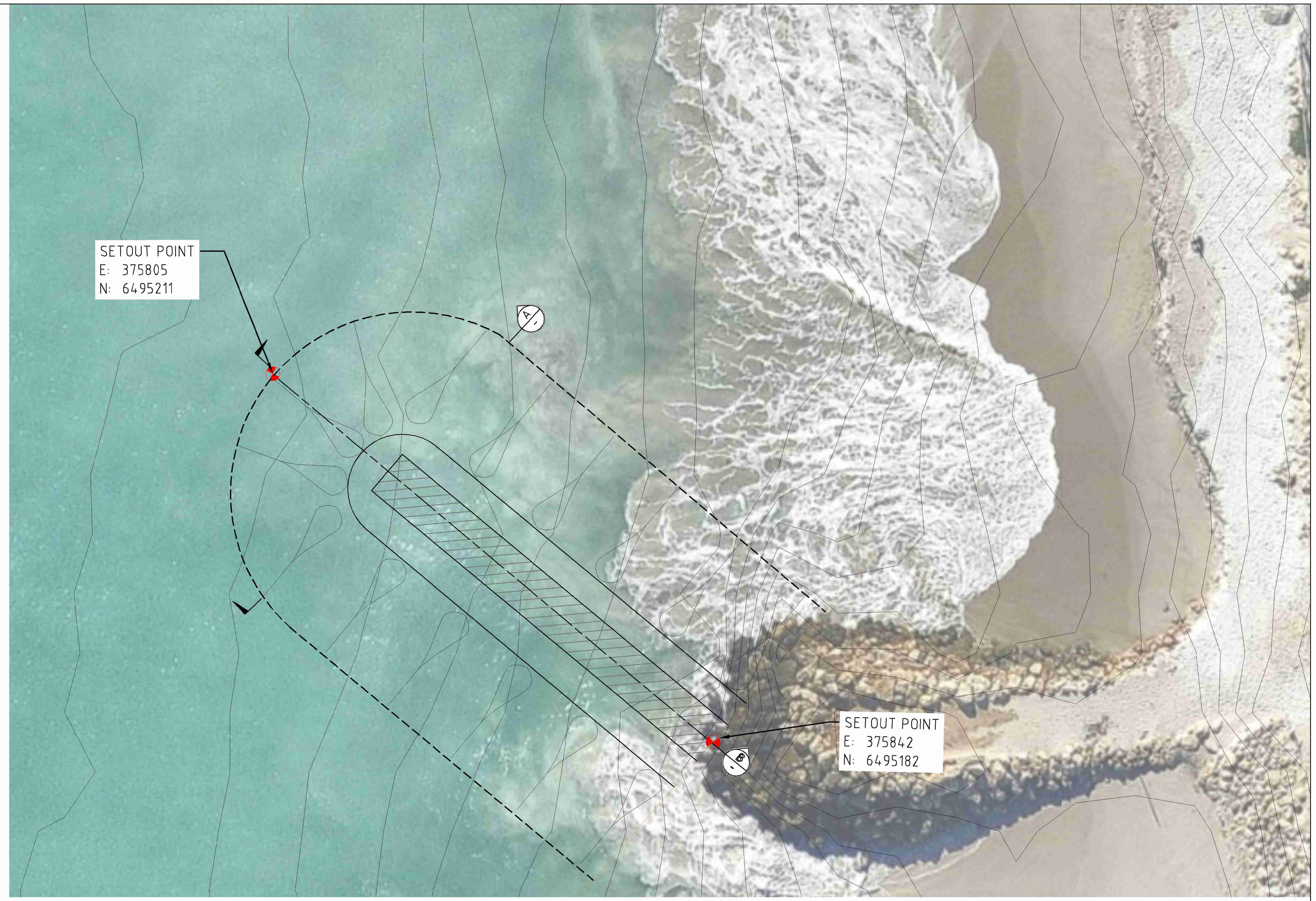
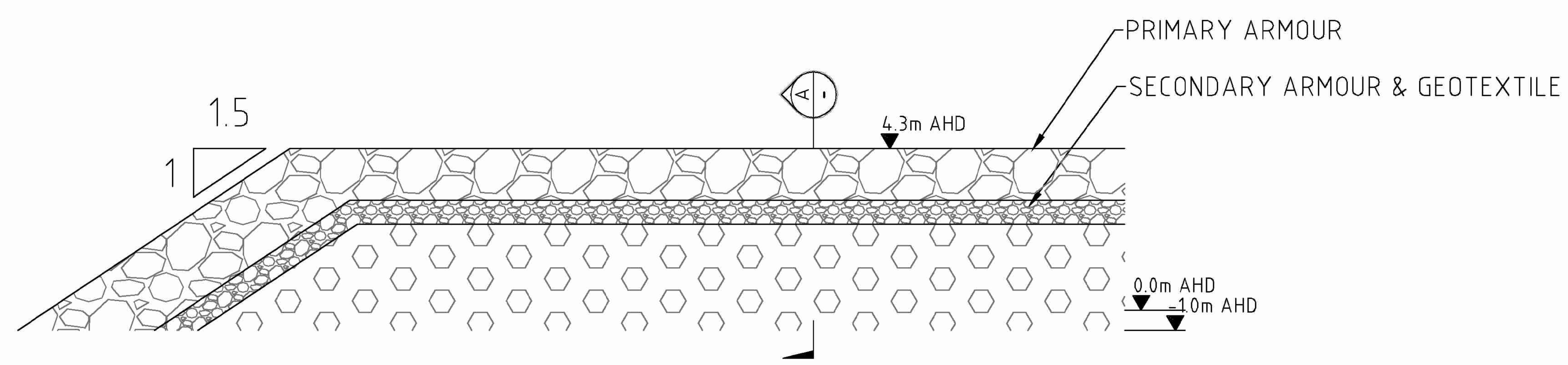


PLAN
SCALE 1:250



SECTION B
SCALE 1:250

DATE PLOTTED: 22 October, 2015 - 7:09pm

XREF's: bathyContoursAHD
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Rev	Date	Description	Drawn	Appr.
A	22/10/2015	PRELIMINARY ISSUE	RML	JGW

NORTH

Drawn	RML	Date 22/10/2015
Designed	JGW	Date 22/10/2015
Checked	WCE	Date 22/10/2015
Reviewed	JGW	Date 22/10/2015
Approved	JGW	Date 22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 4
GROYNE 1 NIB

Status: NOT FOR CONSTRUCTION

Date	Datum	Scale	Size
22/10/2015	A.H.D.	AS SHOWN	A1

Drawing Number: 59915802-007
Revision: V1

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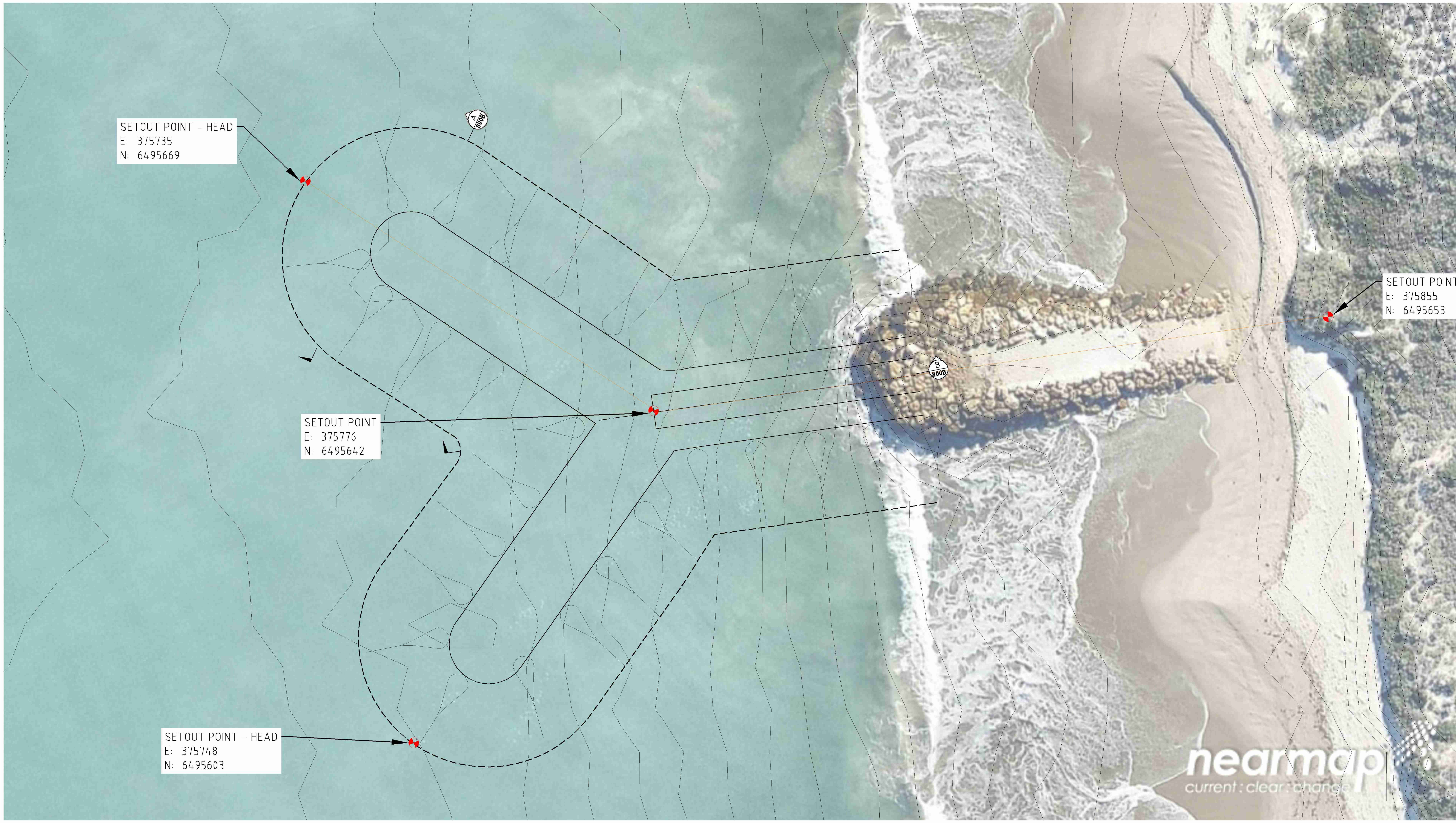

PLAN
SCALE 1:250

DATE PLOTTED: 22 October, 2015 - 7:10pm
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Rev	Date	Description	Drawn	Appr.
A	22/10/2015	PRELIMINARY ISSUE	RML	JGW

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		Date
Drawn	RML	22/10/2015
Designed	JGW	22/10/2015
Checked	WCE	22/10/2015
Reviewed	JGW	22/10/2015
Approved	JGW	22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 4
GROYNE 2 EXTENSION AND NIB
PLAN

Status: NOT FOR CONSTRUCTION

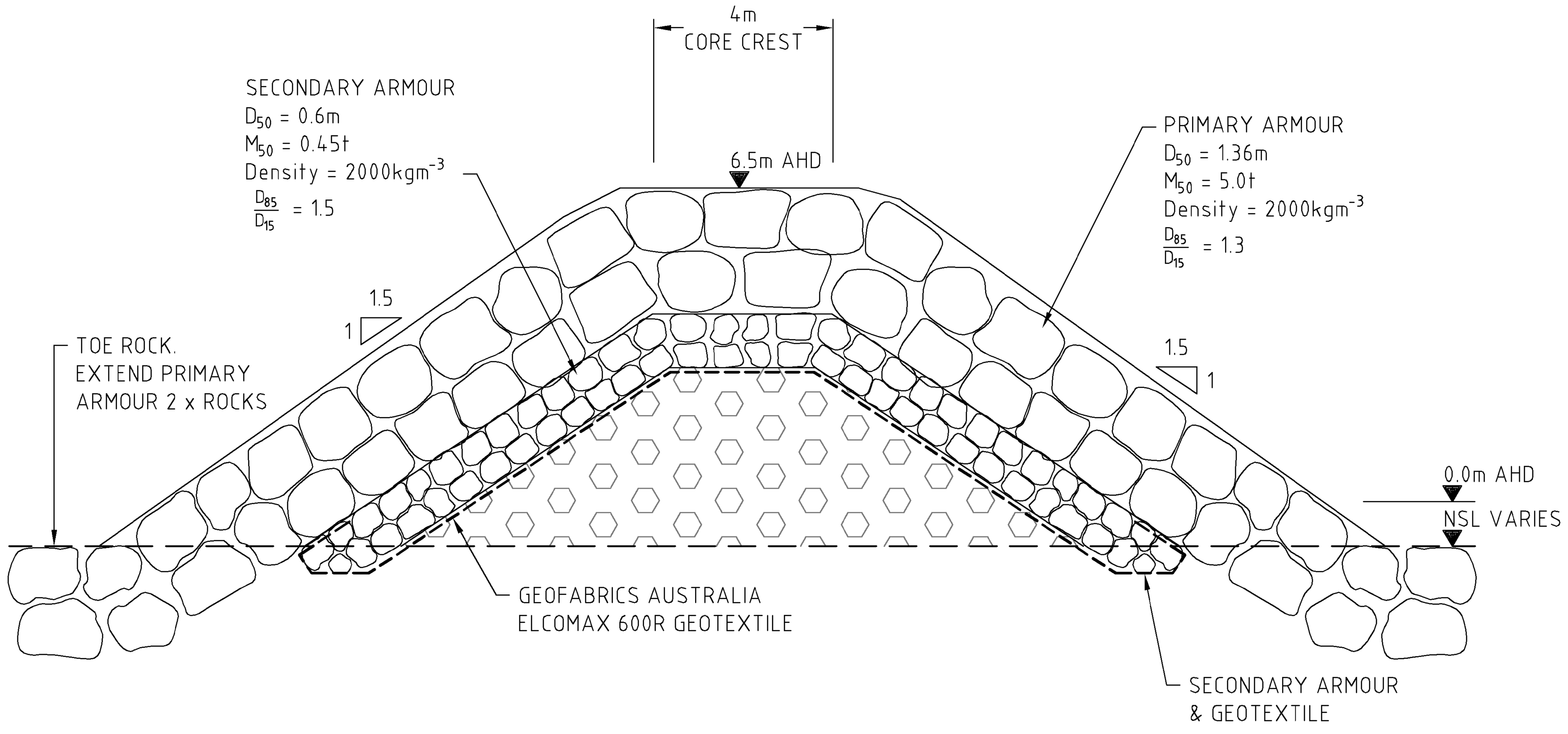
Date	Datum	Scale	Size
22/10/2015	A.H.D.	AS SHOWN	A1

Drawing Number: 59915802-008A
Revision: V1

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150mm ON A1 ORIGINAL

NOTES

1. CONTOURS SHOWN ARE APPROXIMATE ONLY.
2. SETOUT COORDINATES ARE SHOWN IN: UTM - ZONE 50, GDA94.



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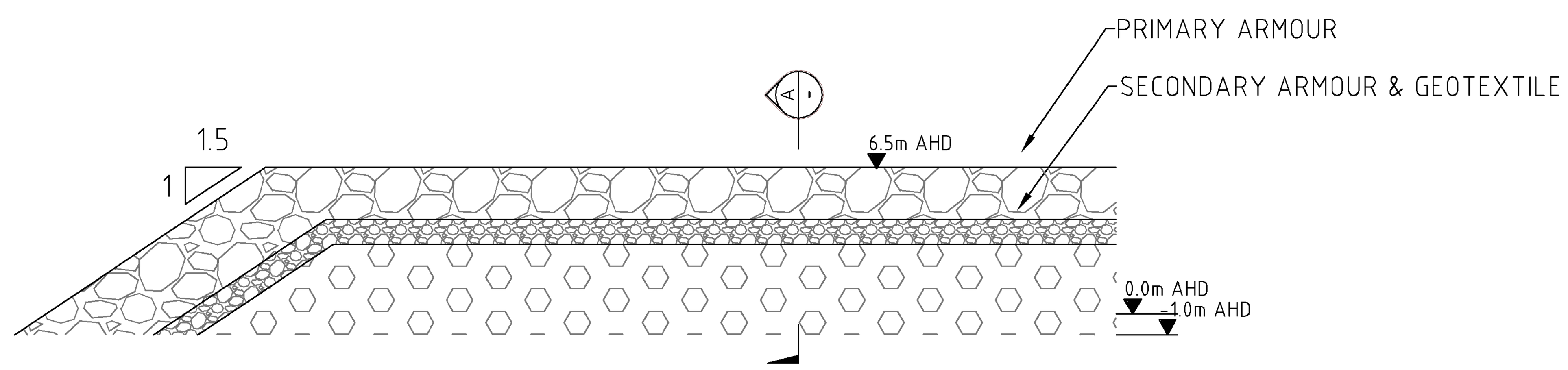

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DATE PLOTTED: 22 October, 2015 - 7:11pm

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Rev	Date	Description	Drawn	Appr.
A	22/10/2015	PRELIMINARY ISSUE	RML	JGW

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		Date
Drawn	RML	22/10/2015
Designed	JGW	22/10/2015
Checked	WCE	22/10/2015
Reviewed	JGW	22/10/2015
Approved	JGW	22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 4
GROYNE 2 EXTENSION AND NIB
SECTIONS

Status: NOT FOR CONSTRUCTION

Date	Datum	Scale	Size
22/10/2015	A.H.D.	AS SHOWN	A1

Drawing Number: 59915802-008B
Revision: V1

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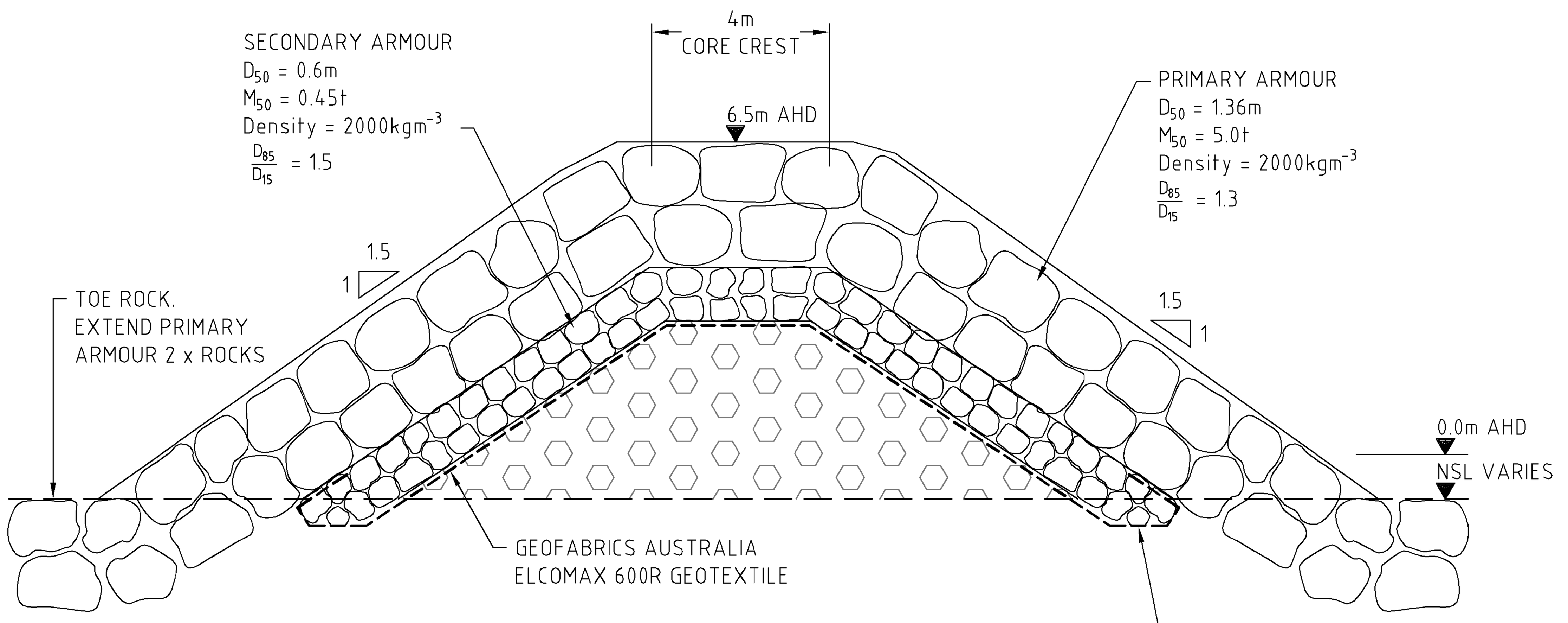

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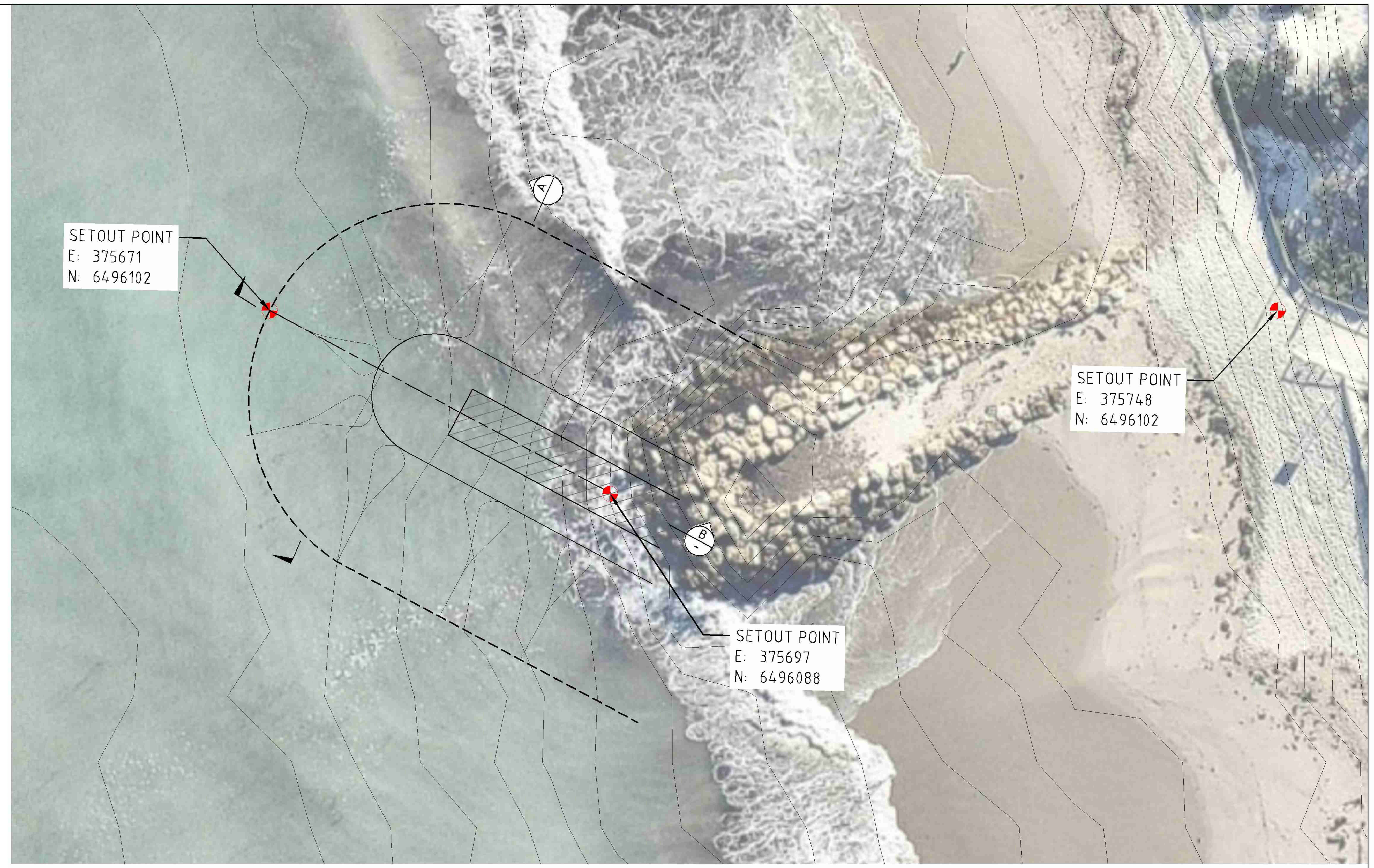

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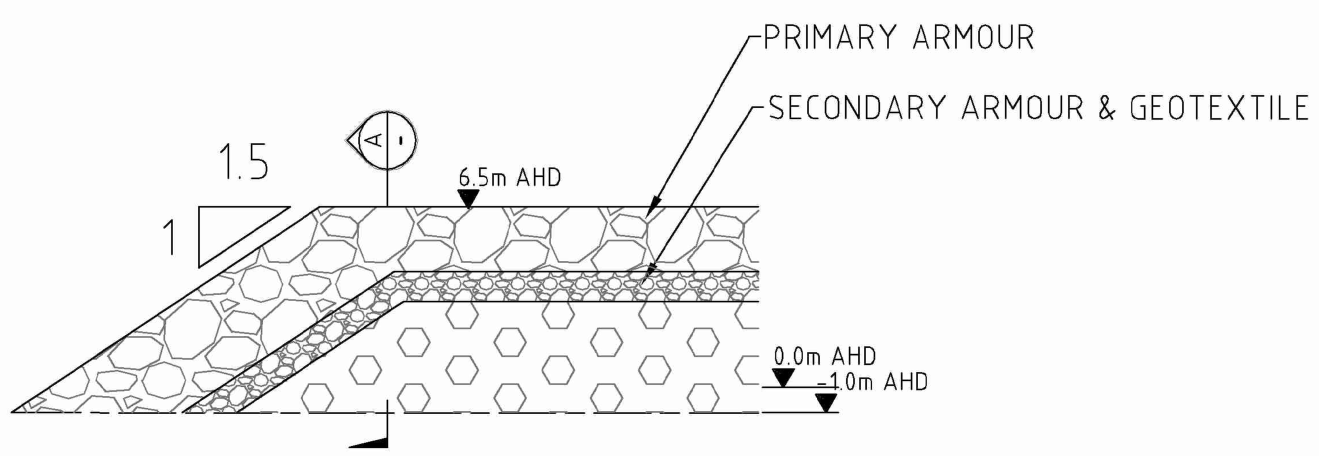
SCALE 1:250



SECTION B
SCALE 1:250

Rev	Date	Description	Drawn	Appr.
A	22/10/2015	PRELIMINARY ISSUE	RML	JGW

NORTH

		Date
Drawn	RML	22/10/2015
Designed	JGW	22/10/2015
Checked	WCE	22/10/2015
Reviewed	JGW	22/10/2015
Approved	JGW	22/10/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA 4
GROYNE 3 NIB

Status: NOT FOR CONSTRUCTION

Date	Datum	Scale	Size
22/10/2015	A.H.D.	AS SHOWN	A1

Drawing Number: 59915802-009
Revision: V1

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DATE PLOTTED: 22 October, 2015 - 7:11pm
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NOTES

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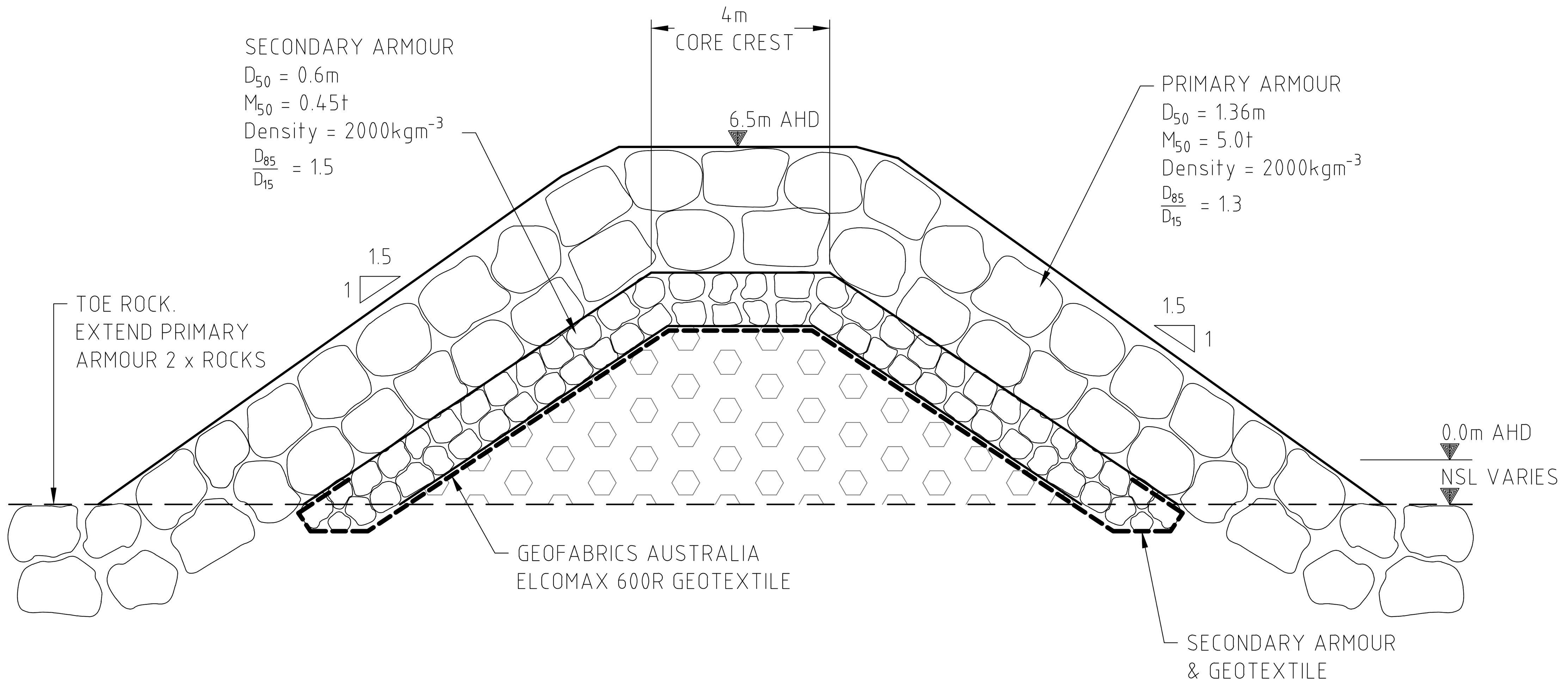
2. SETOUT COORDINATES ARE SHOWN IN: UTM - ZONE 50, GDA94.



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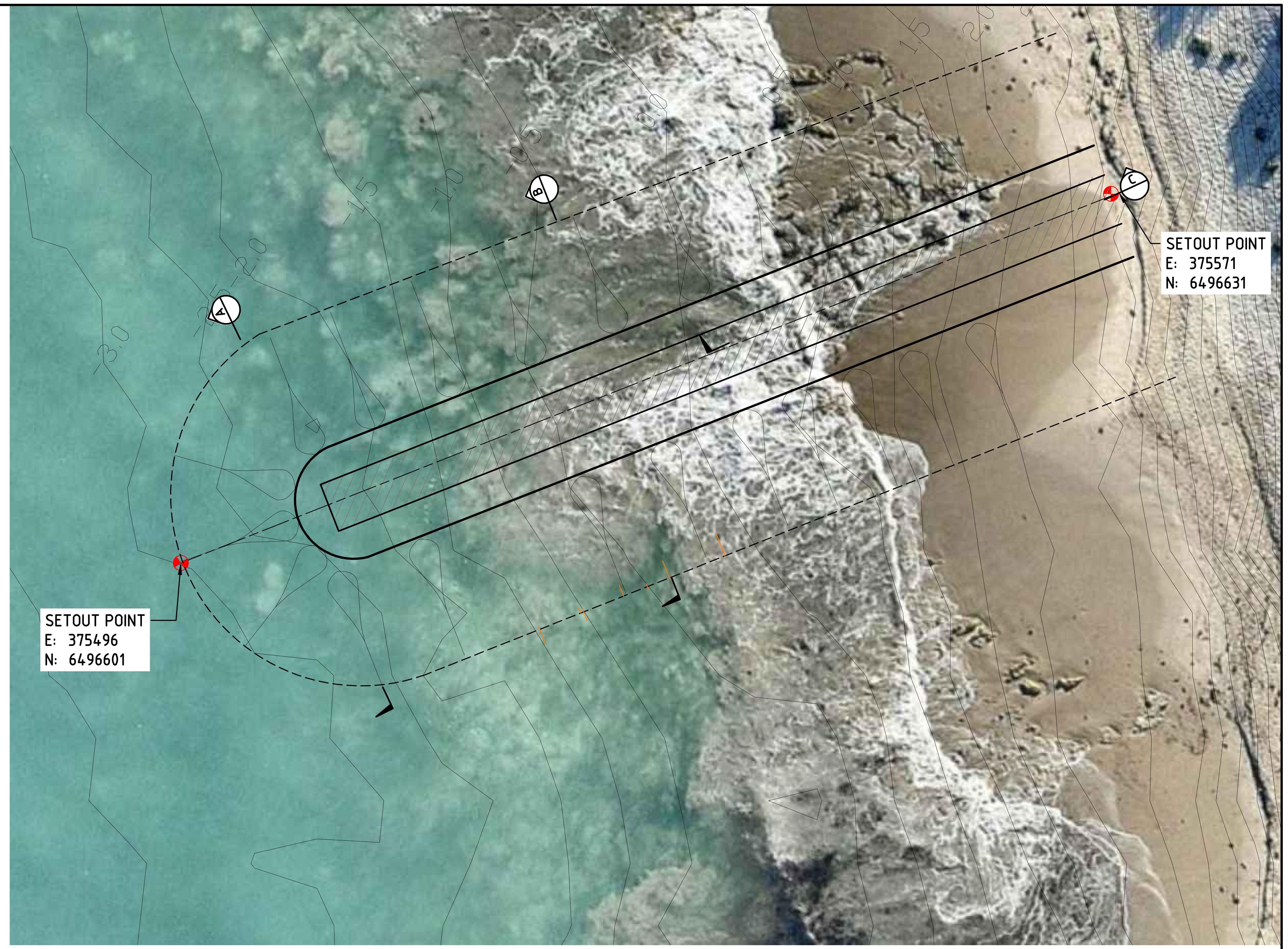

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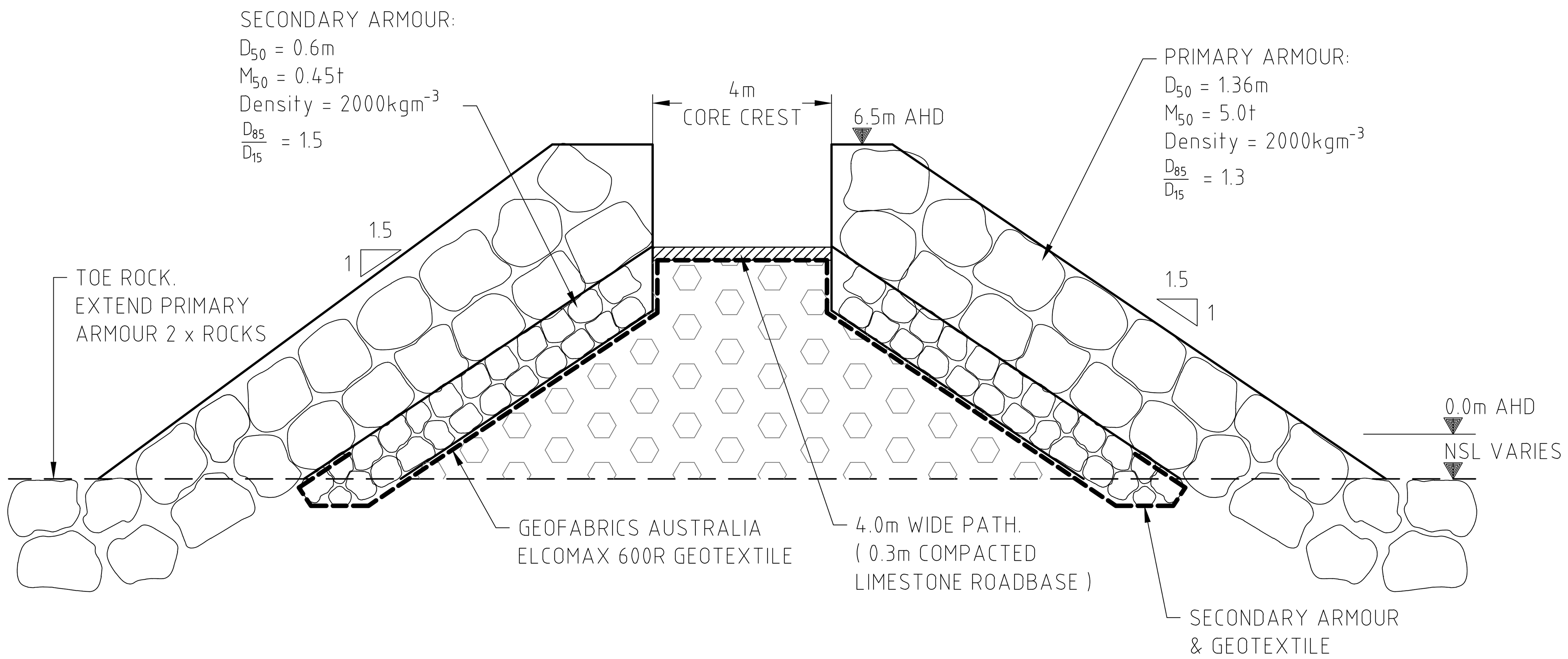

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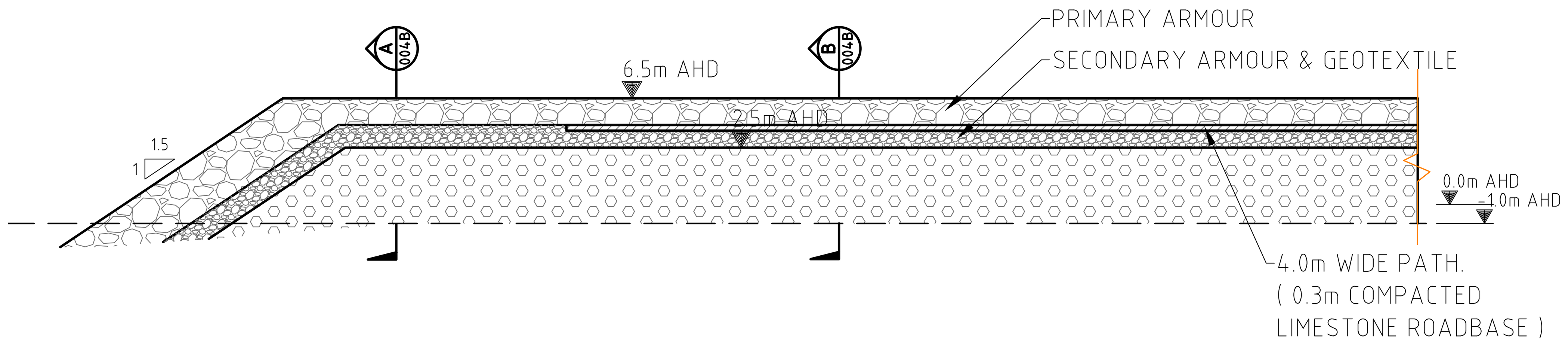

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SCALE 1:250

Rev	Date	Description	Drawn	Appr.
B	23/11/2015	PRELIMINARY ISSUE	RML	JGW
A	29/10/2015	PRELIMINARY ISSUE	RML	JGW

NORTH

		Date
Drawn	RML	23/11/2015
Designed	JGW	29/10/2015
Checked	WCE	29/10/2015
Reviewed	JGW	23/11/2015
Approved	JGW	23/11/2015

Client: CITY OF WANNEROO

Project: QUINNS BEACH
LONG TERM COASTAL MANAGEMENT
QUINNS ROCKS, WA

Title: MCA4:
GROYNE 4, 80m IN LENGTH

Status: NOT FOR CONSTRUCTION

Date	Datum	Scale	Size
23/11/2015	A.H.D.	AS SHOWN	A1

Drawing Number: 59915802-010 Revision: V2

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DATE PLOTTED: 23 November, 2015 - 9:10am

XREF's: bathyContoursAHD
CAD FILE: C:\Temp_Cad\AcPublish_5608\Unsaved Drawing2.dwg

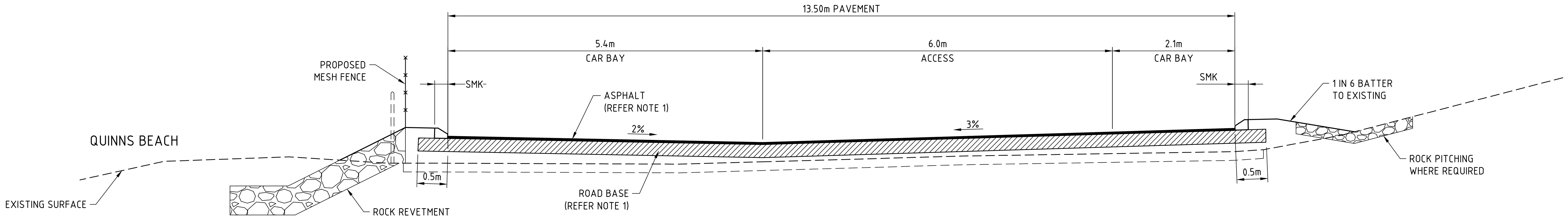
PLAN

SCALE = 1:500

LEGEND

- 6.73 — PROPOSED PAVEMENT LEVEL
- 26.0 — EXISTING SURFACE CONTOUR
- SMK — PROPOSED KERBING
- EXISTING KERBING
- TIE-INTO EXISTING PAVEMENT
- PROPOSED LINEMARKING
- S — EXISTING GRAVITY SEWER PIPE
- W — EXISTING WATER MAIN
- T — EXISTING COMMS
- E — EXISTING UNDER GROUND POWER
- G — EXISTING GAS

REFER TO ROADWORKS PLAN - FOR KERB TYPES REQUIRED.
WHEN NOT CLEAR - KERB TYPES SHOWN ON THIS DWG:
MK - MOUNTABLE KERB
SMK - SEMI-MOUNTABLE KERB



SECTION A

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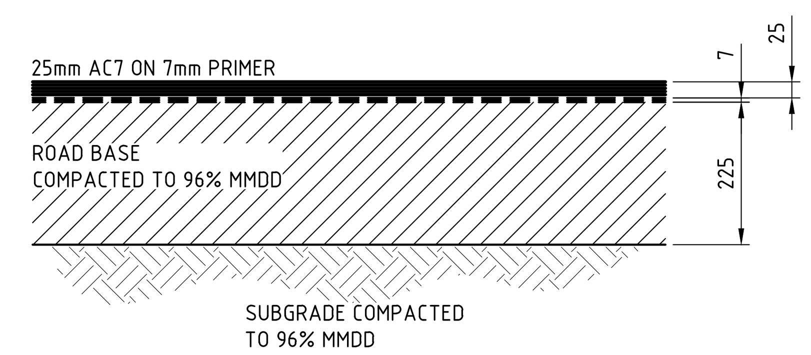

TYPICAL PAVEMENT DESIGN DETAIL

SCALE 1:10

DATE PLOTTED: 22 January, 2016 - 11:03am

XREF's: 59915802_QuinnsBeachLongTerm_0A
CAD FILE: V:\Jobs\59915802_QuinnsBeachLongTerm\Des_An\Engineering\Stage2 Options Assessment\Design&Costing&Sketches\MCAS_Civil\Civil\CAD\59915802-CI-CP1.dwg

Rev	Date	Description	Drawn	Appr.
A	15.01.2016	INITIAL ISSUE	JYY	NT

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Unit 2, 89 Duchess Street, PO Box 713, Busselton Western Australia 6280
Phone (08) 9781 1444 Fax (08) 9752 2471

Drawn	JYY	Date 15.01.2016
Designed		Date
Checked		Date
Reviewed		Date
Approved	SH	Date 22.01.2016

Client:

Project: QUINNS BEACH LONG TERM COASTAL MANAGEMENT
OCEAN DR QUINNS ROCKS

Title: CAR PARK PLAN

Status: NOT FOR CONSTRUCTION

Date	Datum	Scale	Size
15.01.2016	A.H.D	AS SHOWN	A1

Drawing Number: 59915802-CI-CP1
Revision: A

ON A1 ORIGINAL

CITY OF WANNEROO | QUINNS BEACH ACCESS | ACCESS CONCEPT 1

scale: 1:500 @ A4 | date: 08/09/2015 | drawing no: 59915802-LA-004 | issue: A

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CITY OF WANNEROO | QUINNS BEACH ACCESS | ACCESS CONCEPT 2

scale: 1:500 @ A4 | date: 08/09/2015 | drawing no: 59915802-LA-005 | issue: A

11 Harvest Terrace, West Perth, Western Australia 6005 Australia | Phone +61 8 9273 3888 | Web www.cardno.com

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Conceptual Options Assessment

APPENDIX D

XBEACH MODEL RESULTS

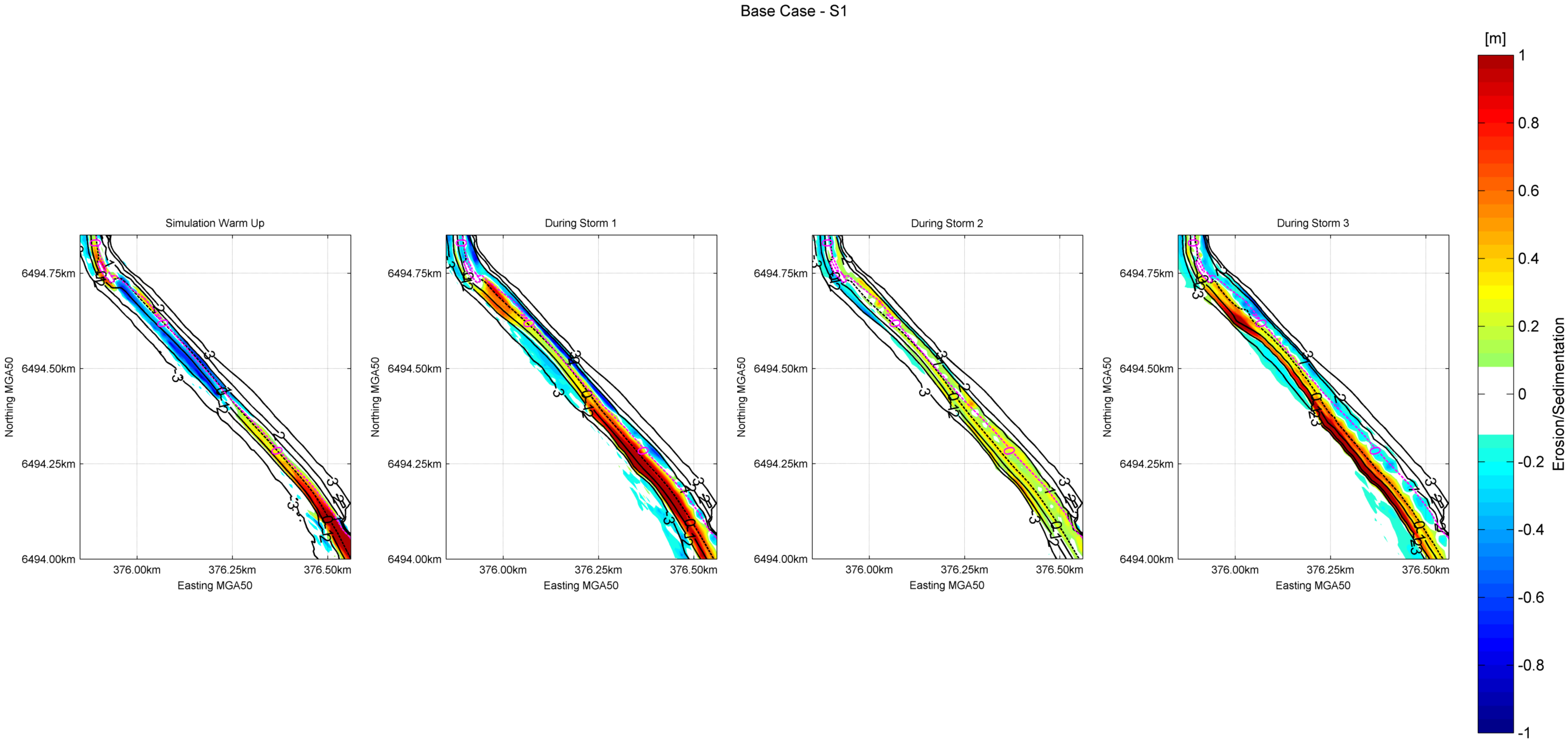


Figure D-1 XBEACH Base Case Section 1: Sedimentation & Erosion

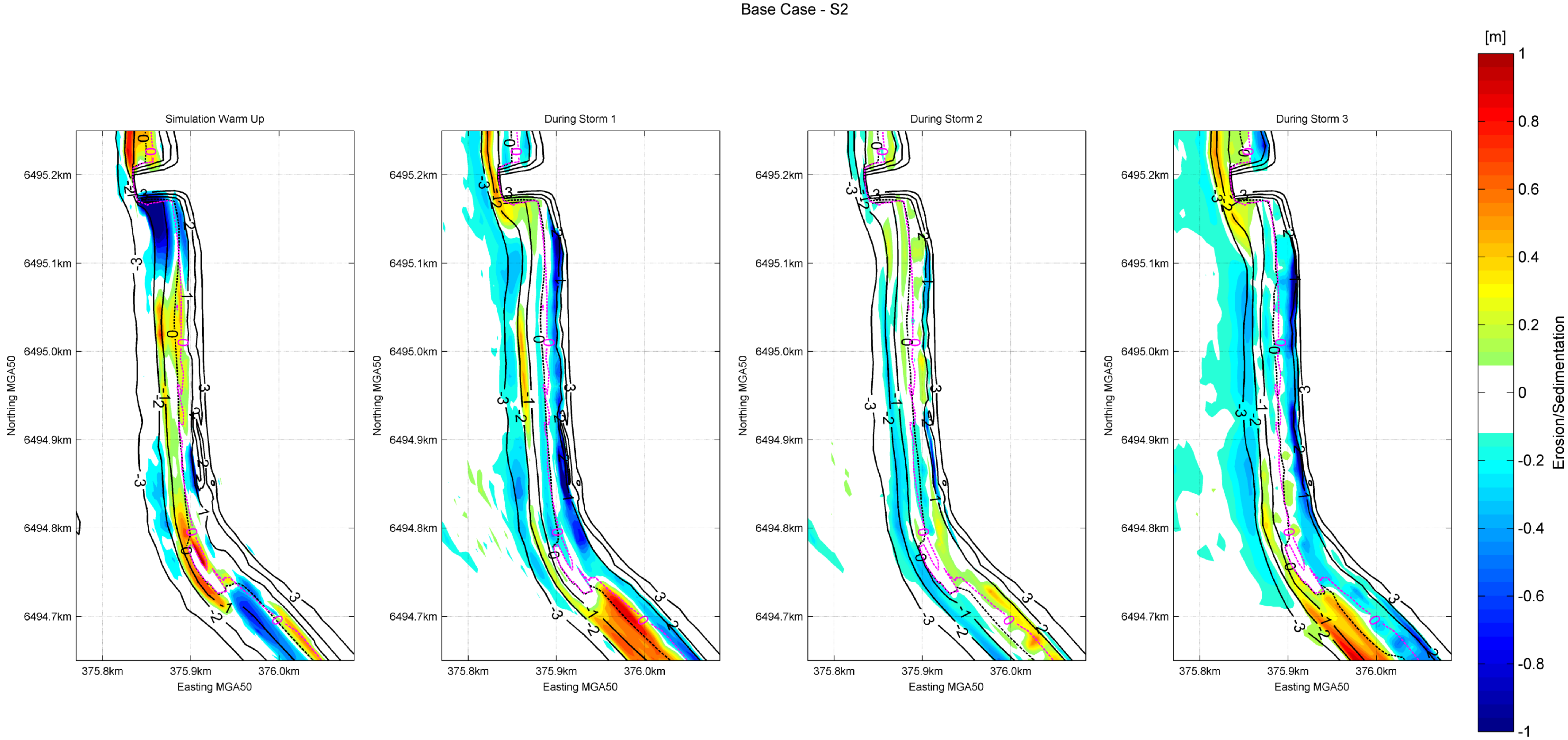


Figure D-2 XBEACH Base Case Section 2: Sedimentation & Erosion

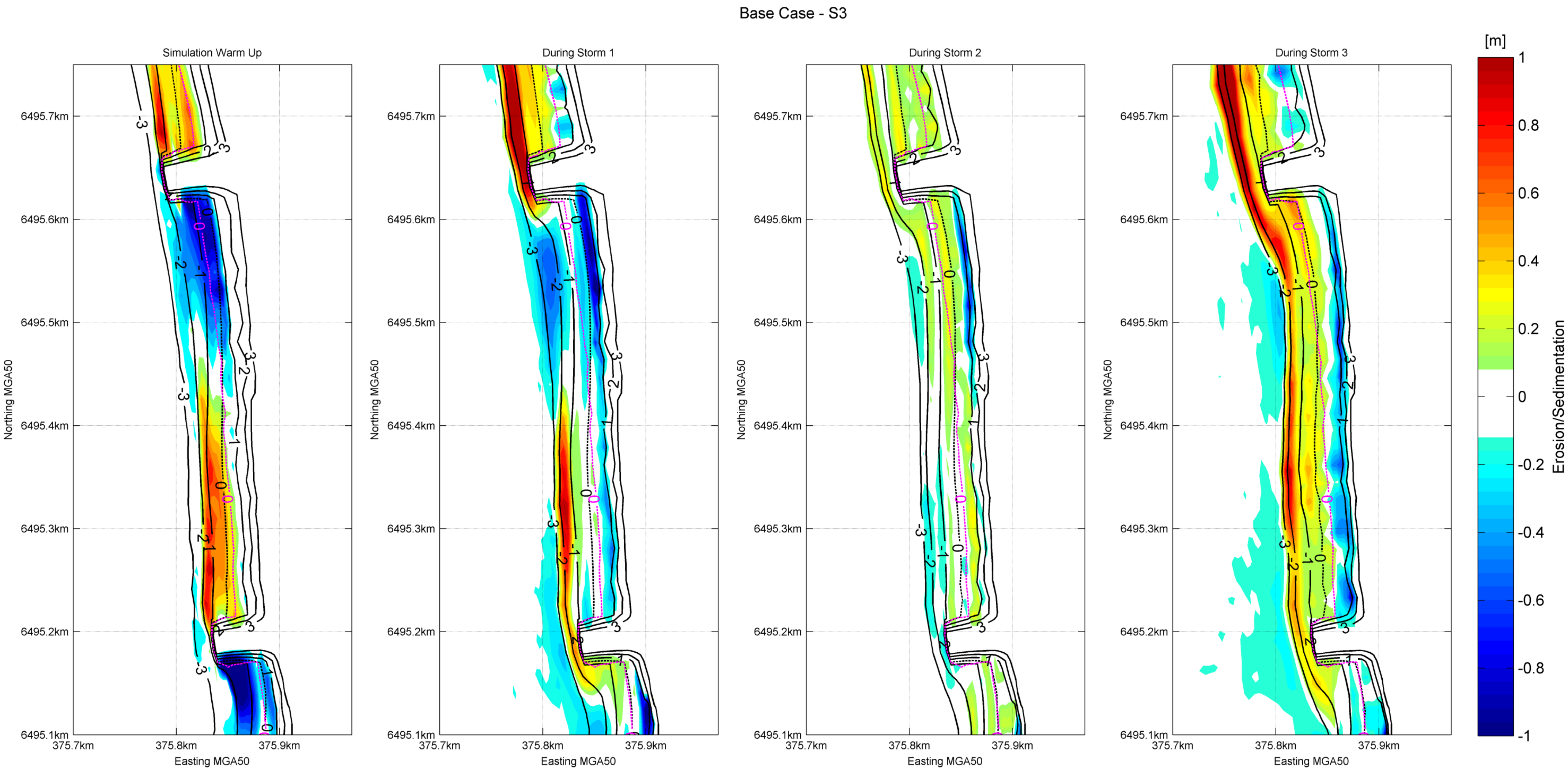


Figure D-3 XBEACH Base Case Section 3: Sedimentation & Erosion

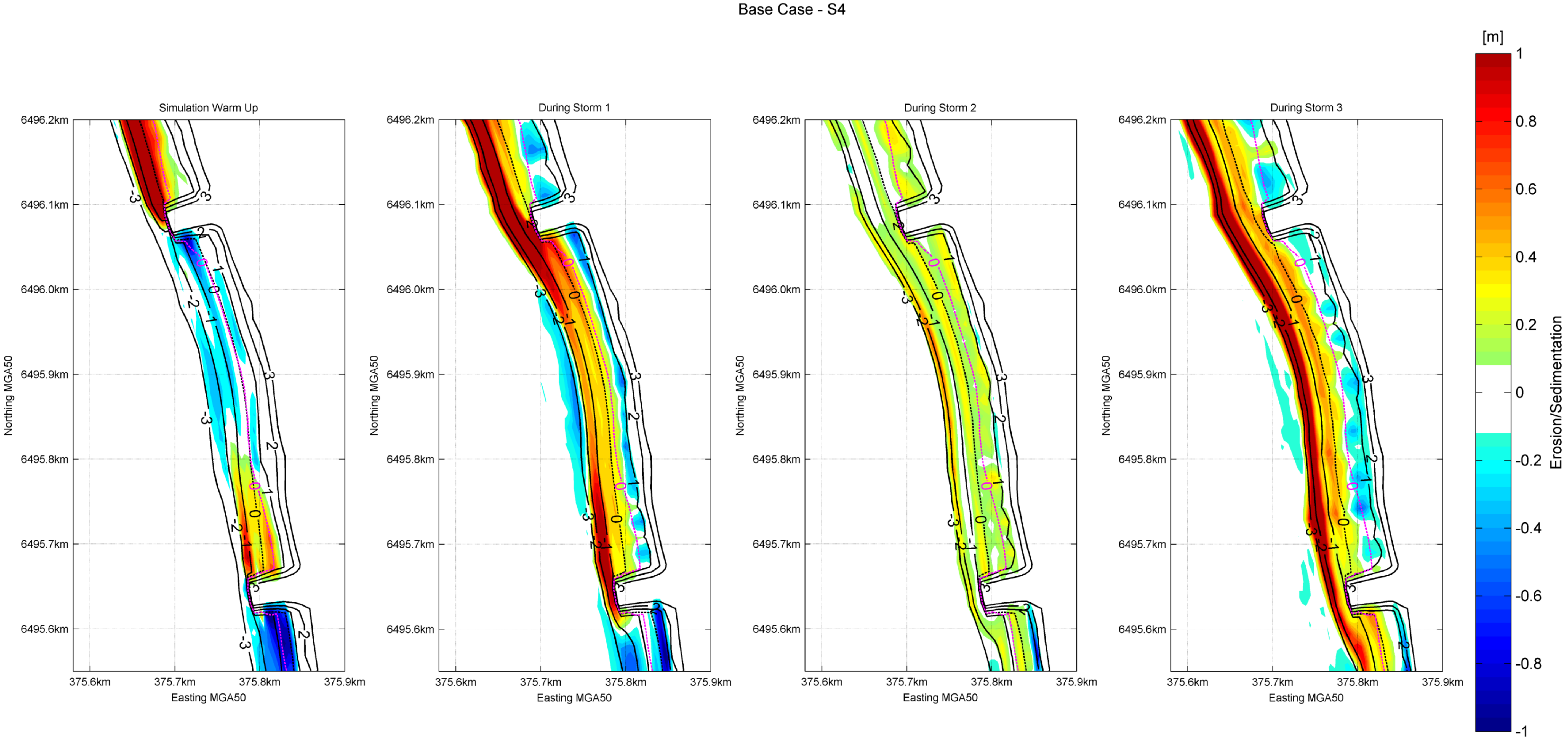


Figure D-4 XBEACH Base Case Section 4: Sedimentation & Erosion

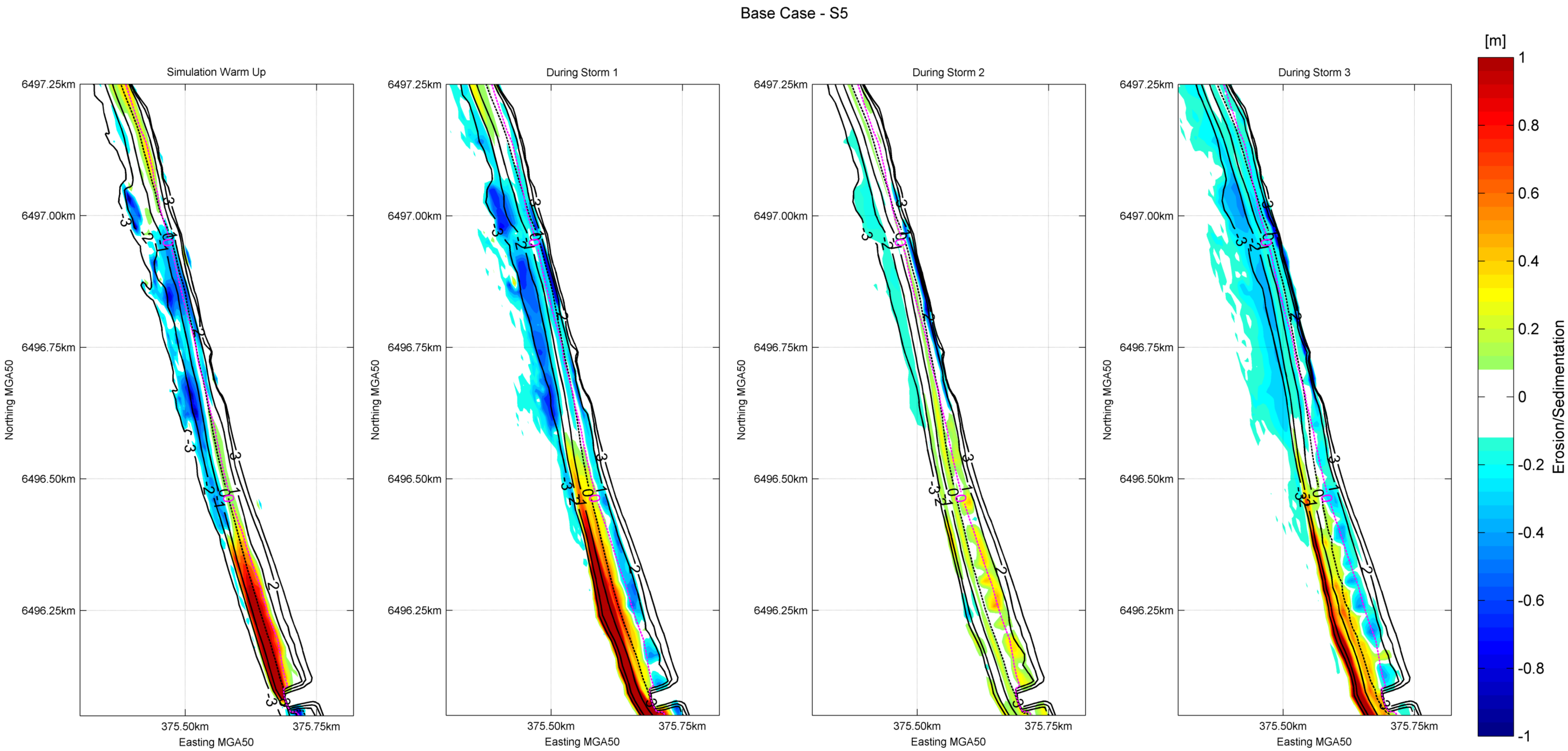


Figure D-5 XBEACH Base Case Section 5: Sedimentation & Erosion

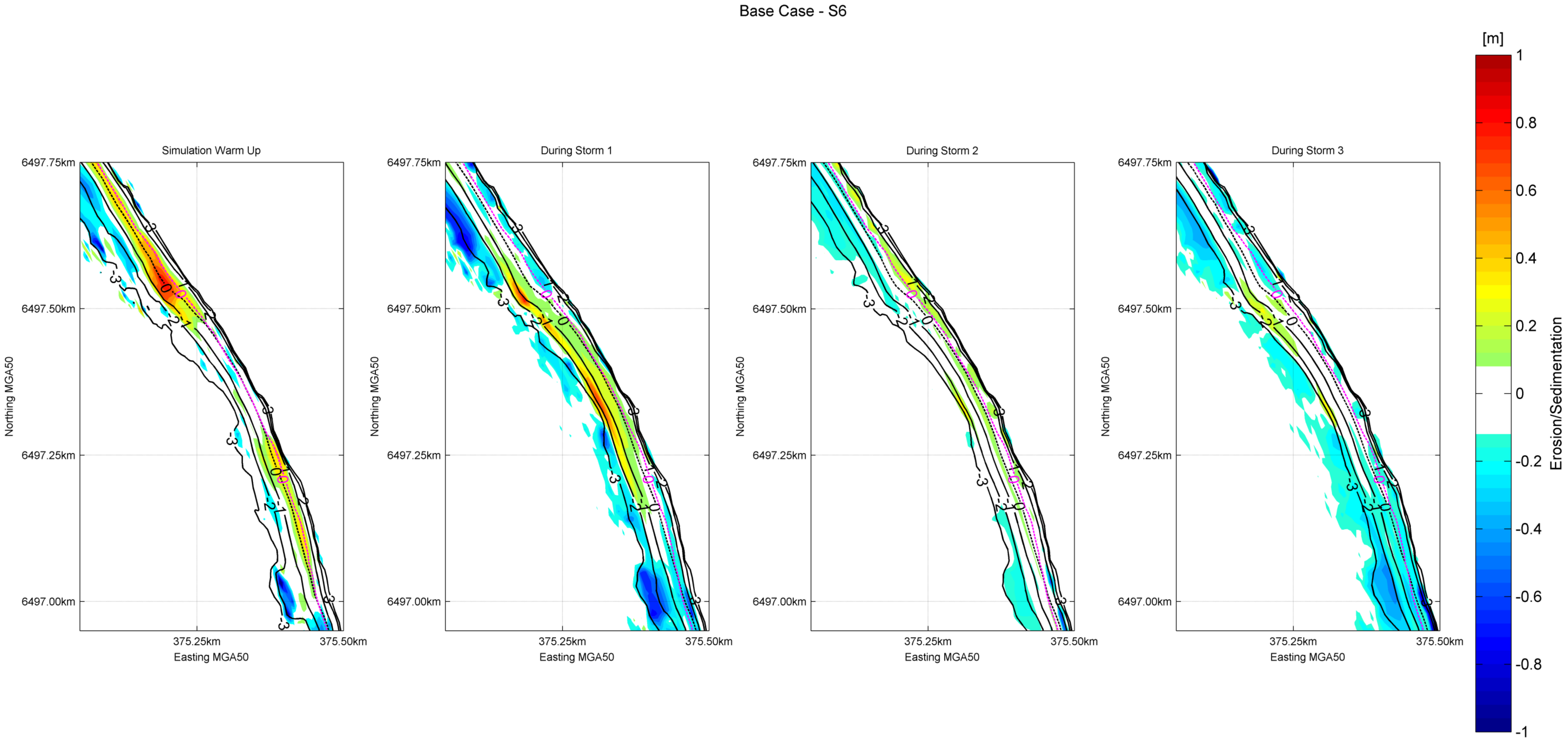


Figure D-6 XBEACH Base Case Section 6: Sedimentation & Erosion

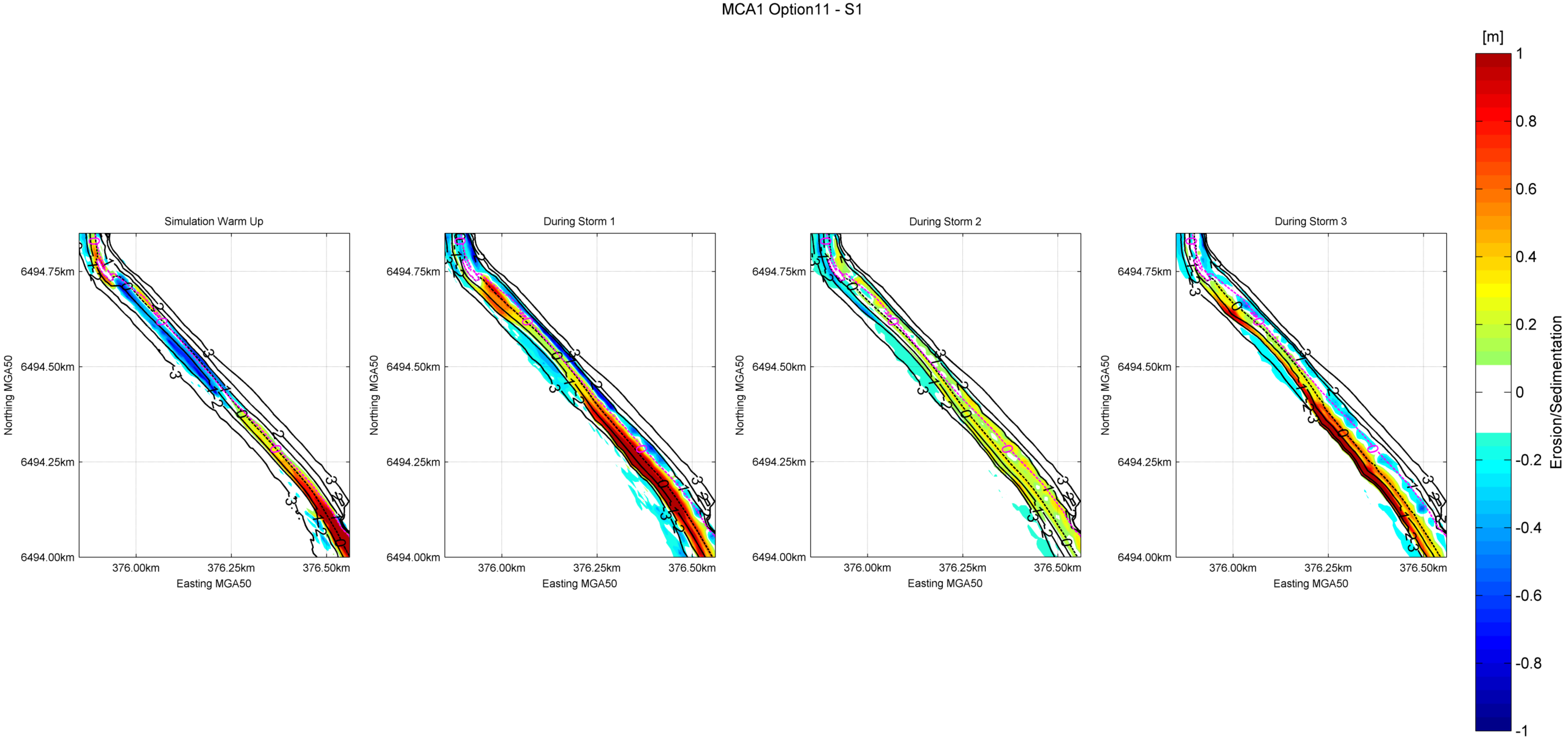


Figure D-7 XBEACH MCA1 Section 1: Sedimentation & Erosion

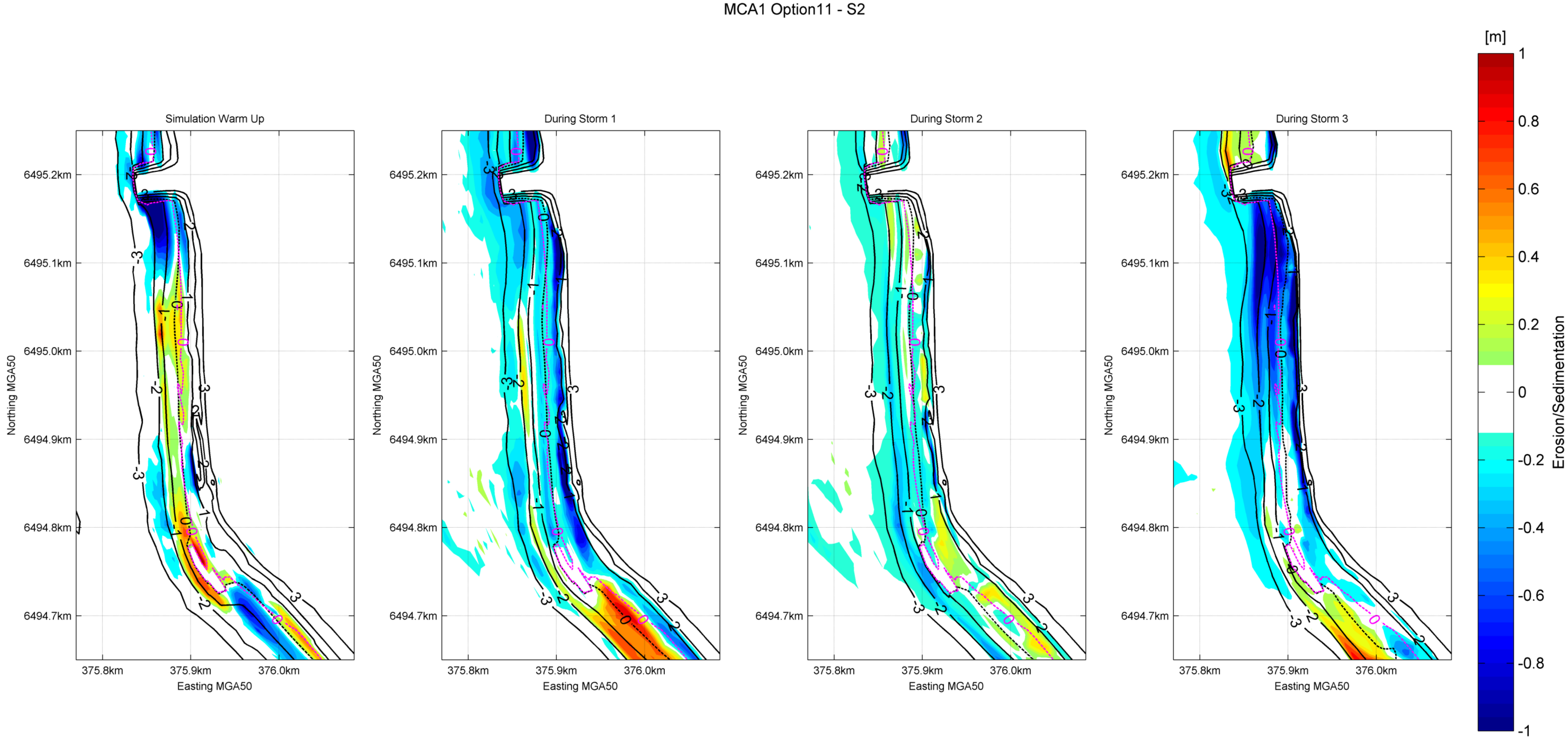


Figure D-8 XBEACH MCA1 Section 2: Sedimentation & Erosion

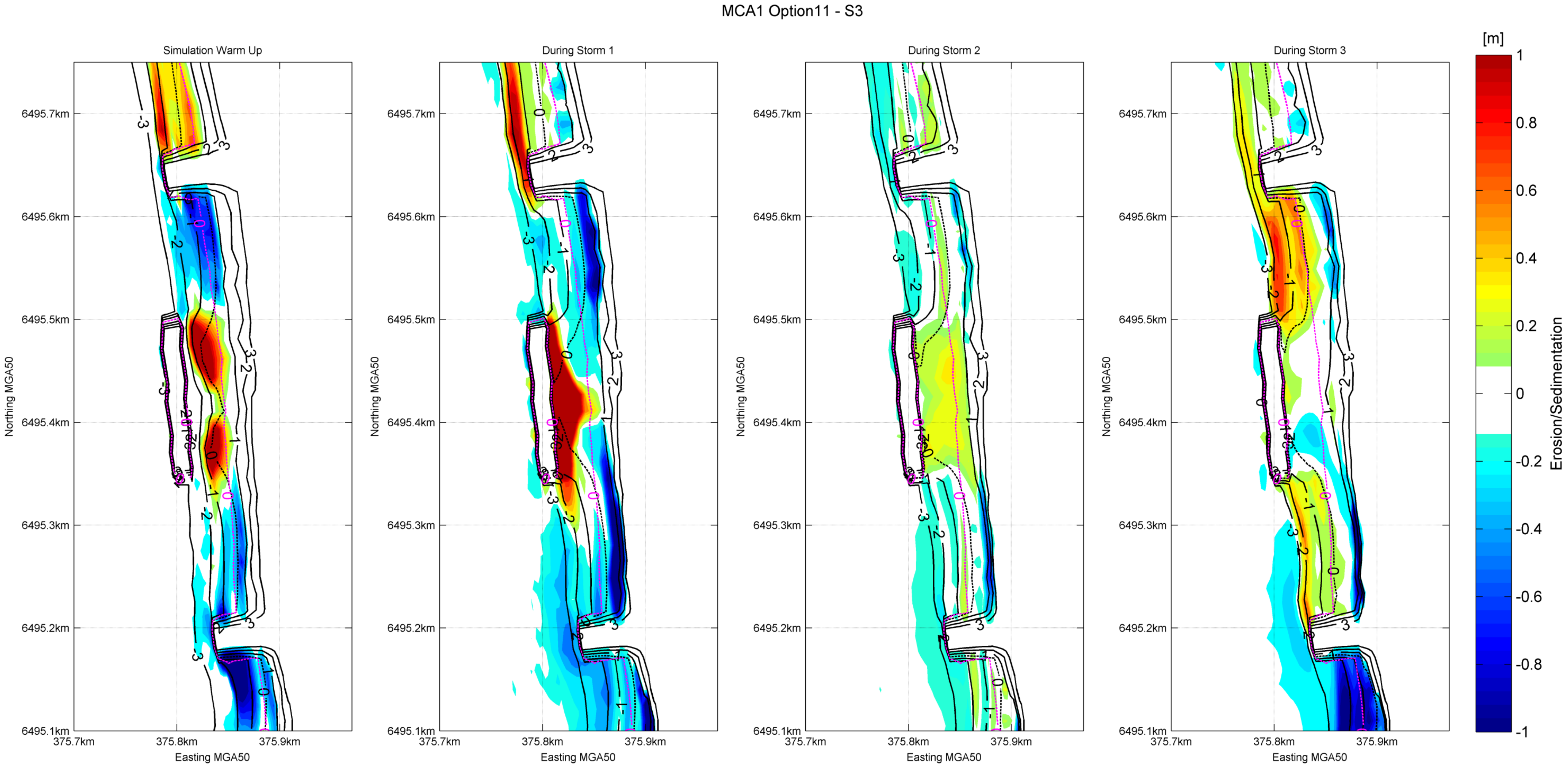


Figure D-9 XBEACH MCA1 Section 3: Sedimentation & Erosion

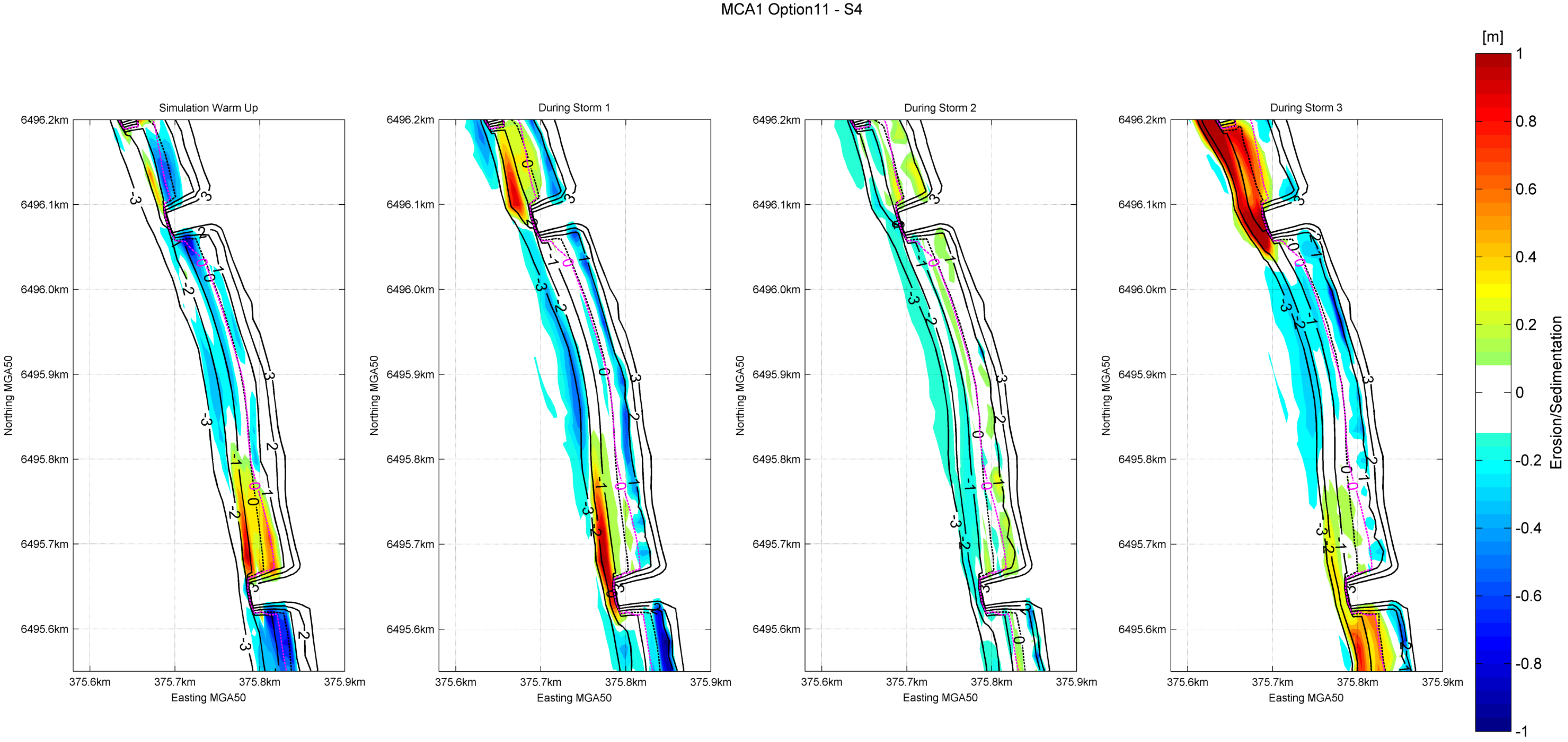


Figure D-10 XBEACH MCA1 Section 4: Sedimentation & Erosion

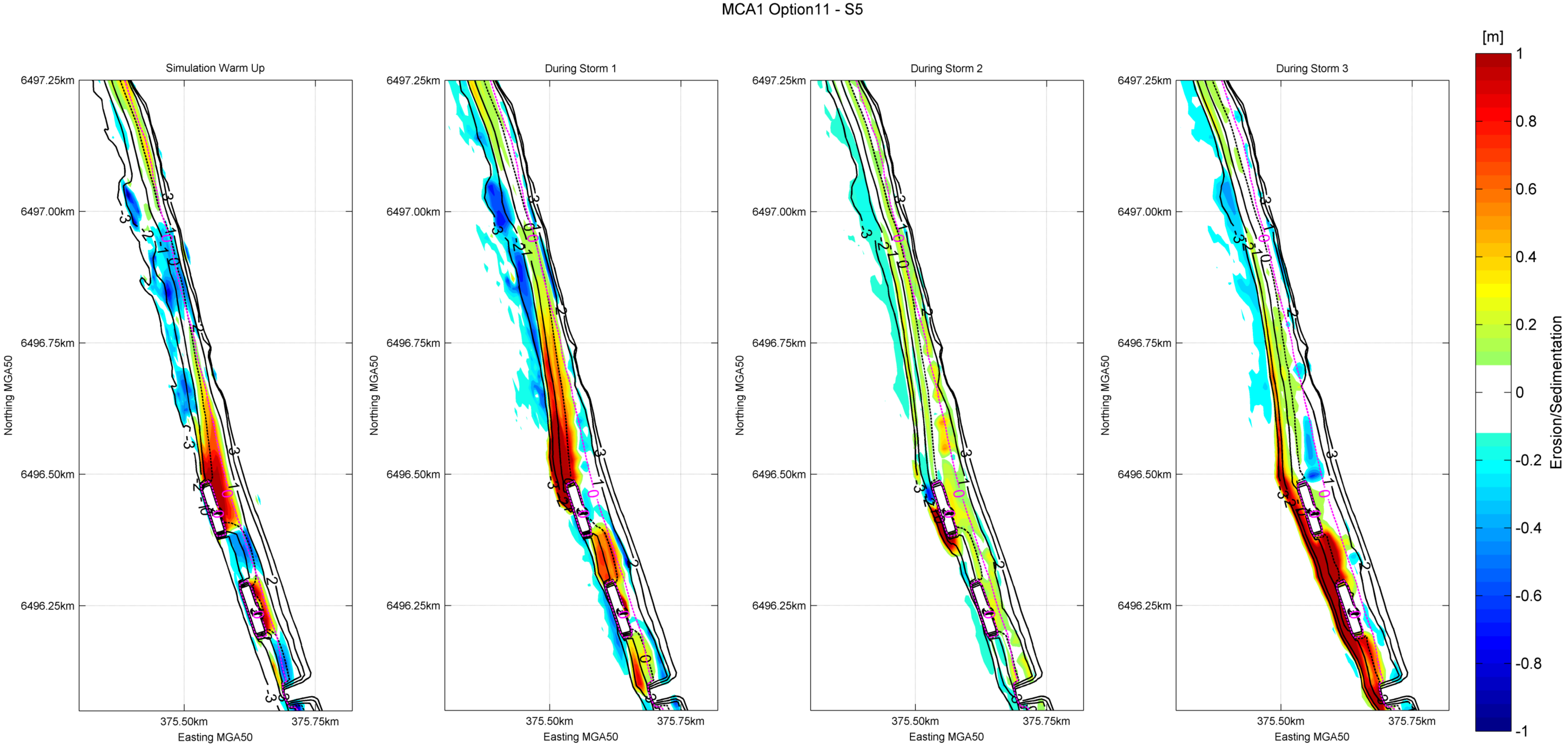


Figure D-11 XBEACH MCA1 Section 5: Sedimentation & Erosion

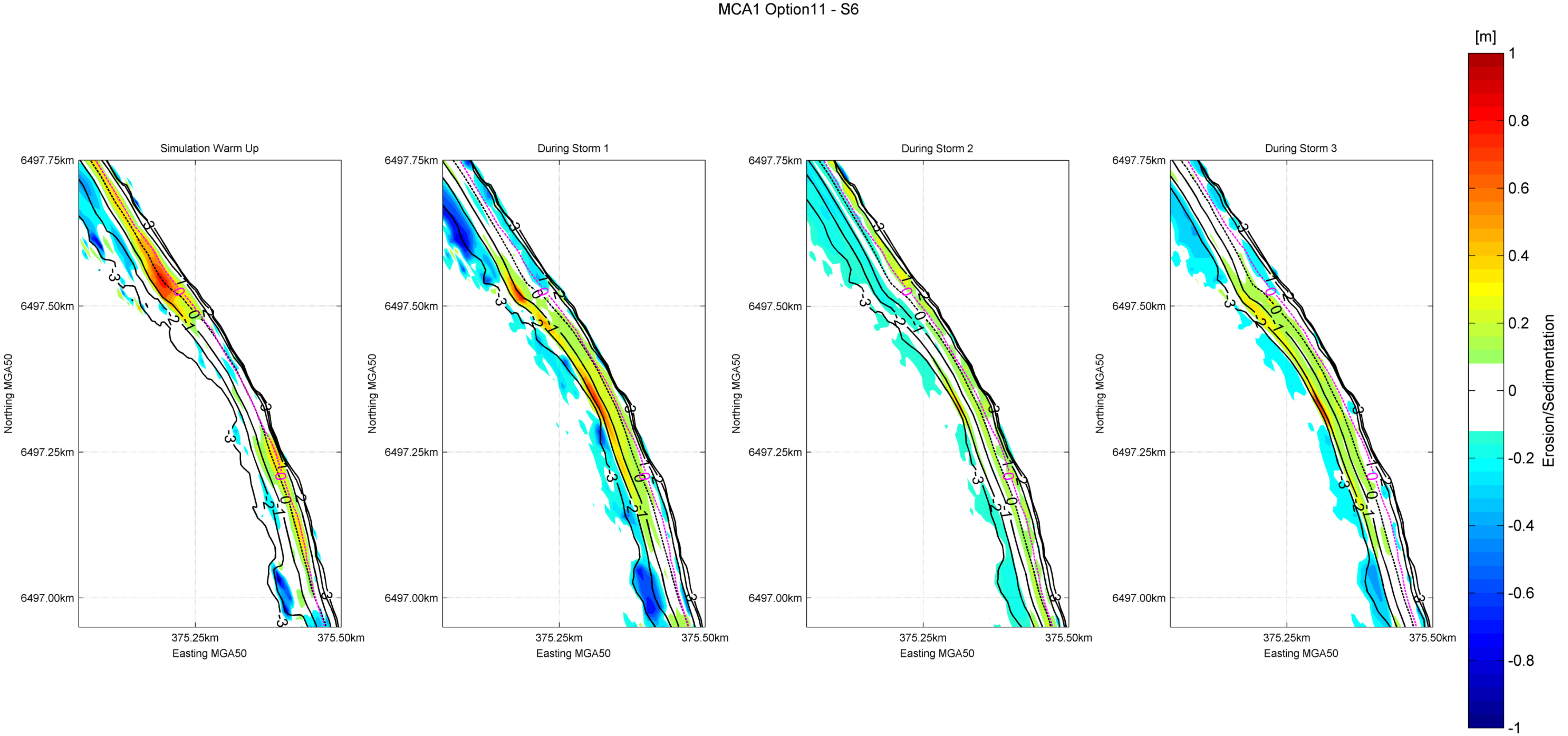


Figure D-12 XBEACH MCA1 Section 6: Sedimentation & Erosion

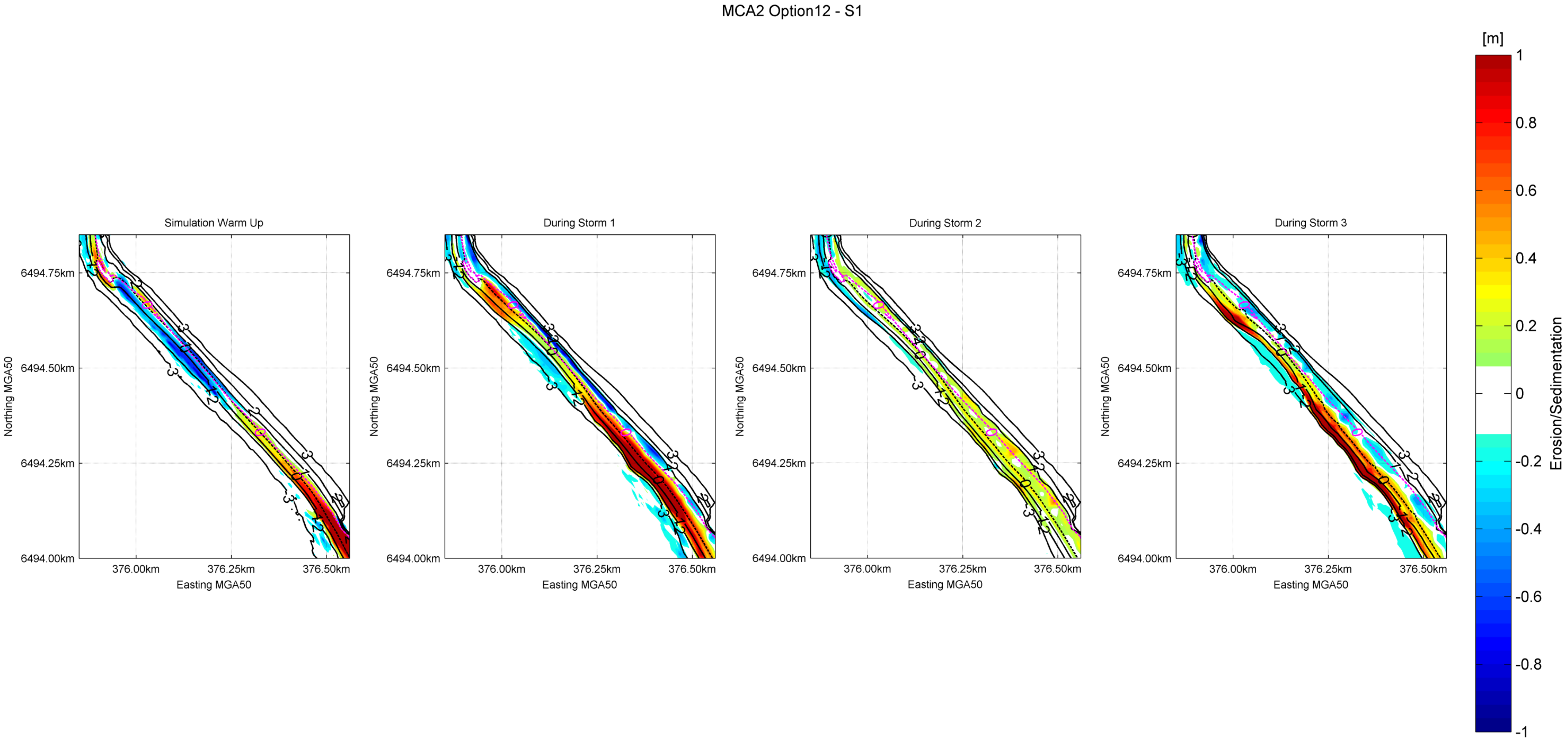


Figure D-13 XBEACH MCA2 Section 1: Sedimentation & Erosion

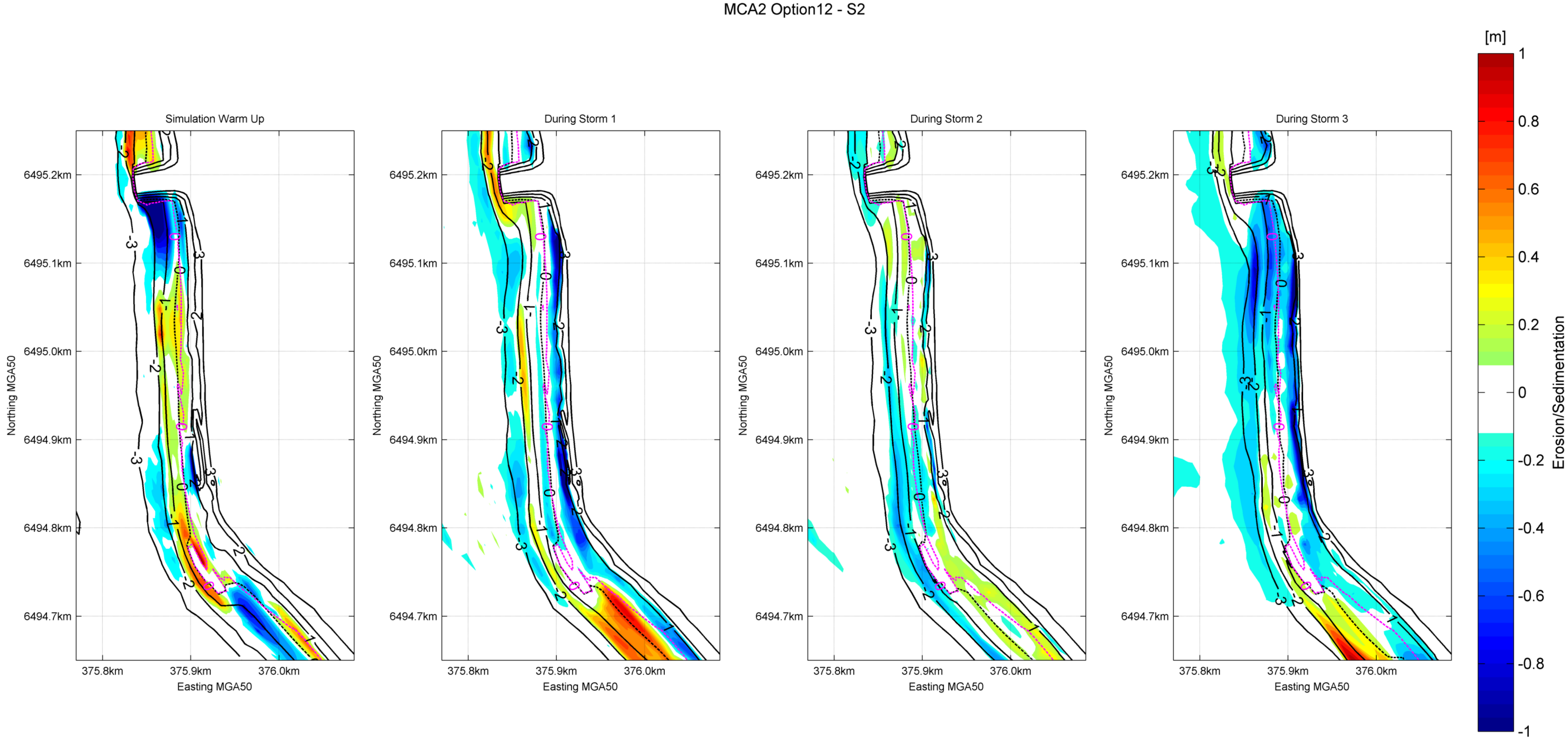


Figure D-14 XBEACH MCA2 Section 2: Sedimentation & Erosion

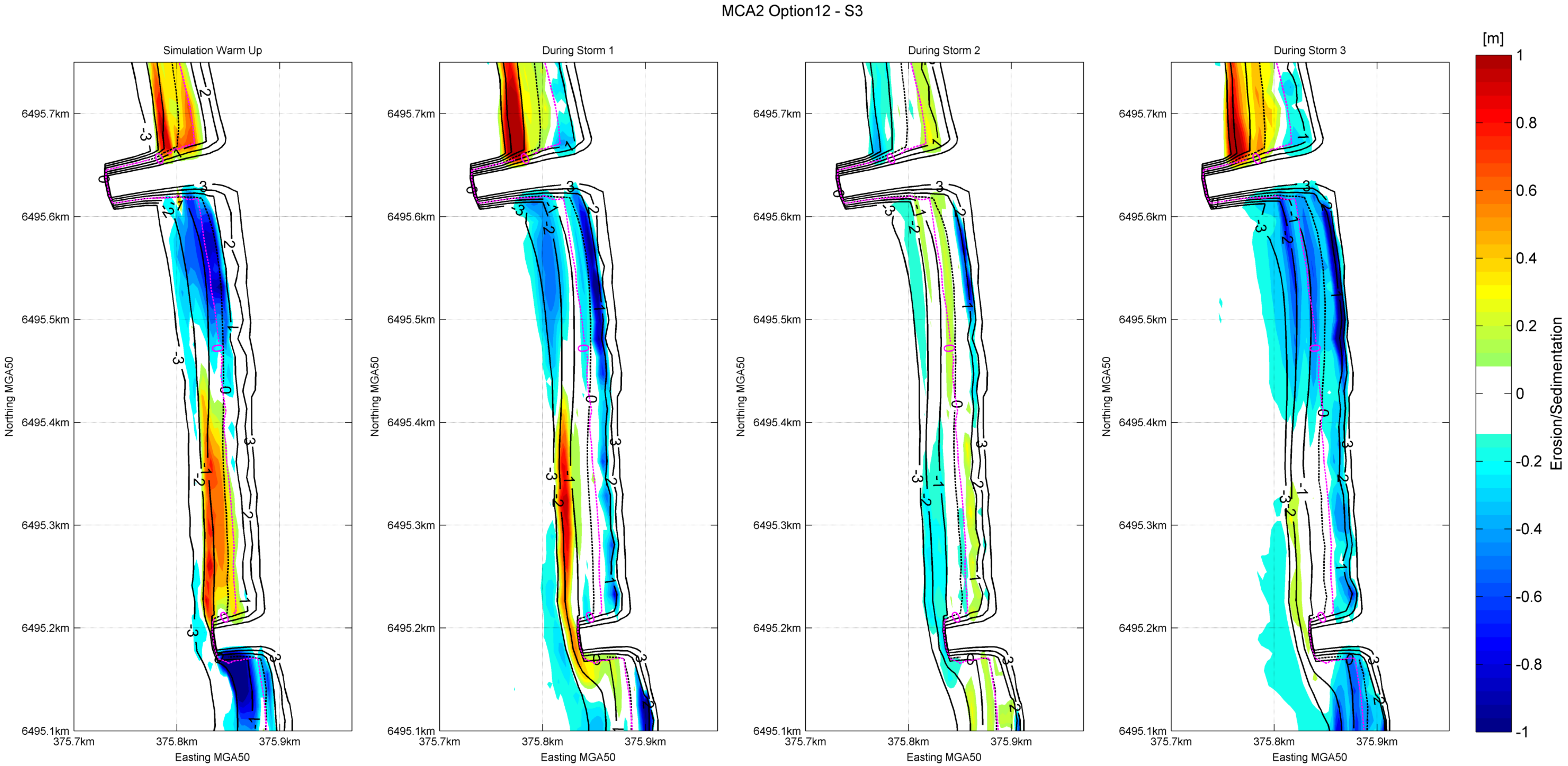


Figure D-15 XBEACH MCA2 Section 3: Sedimentation & Erosion

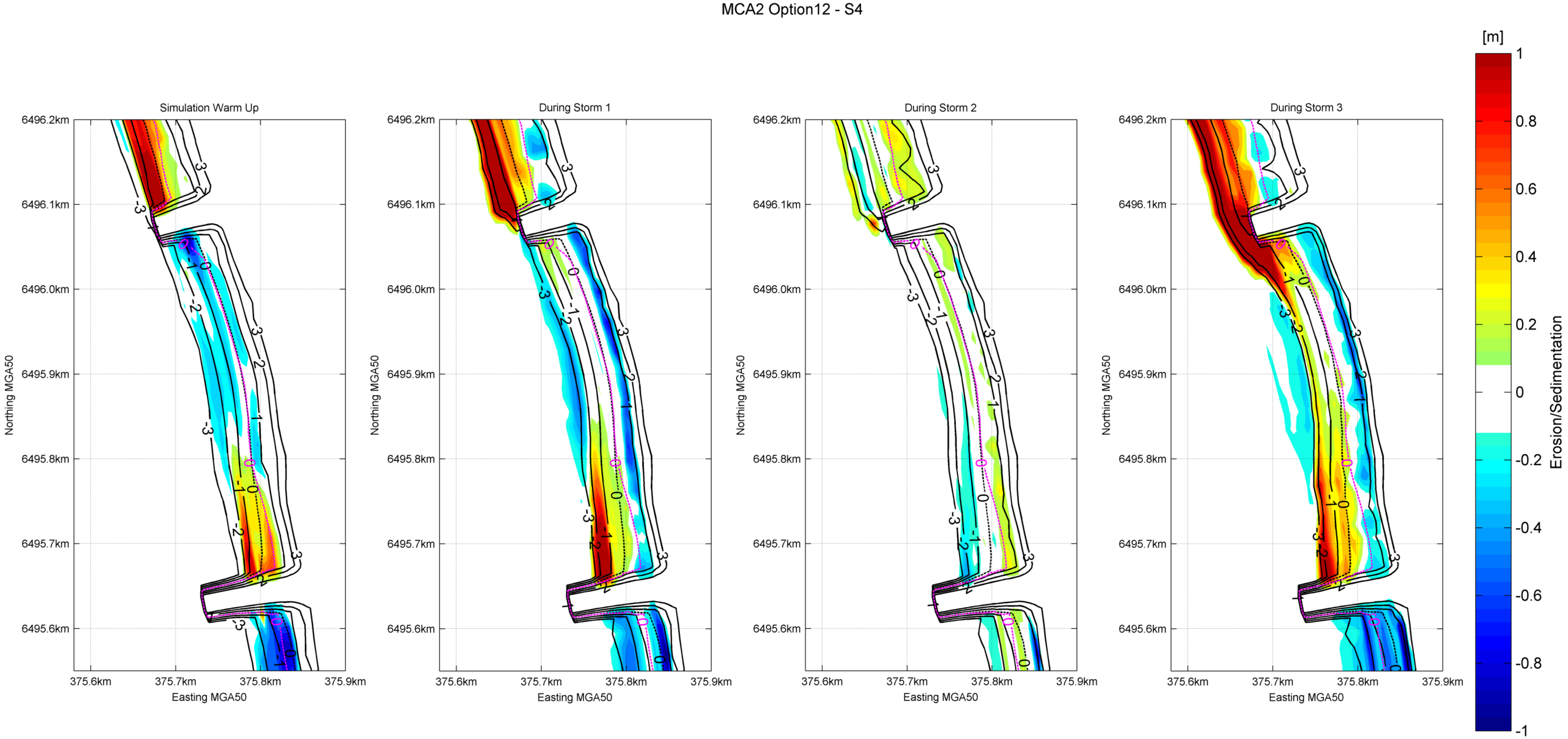


Figure D-16 XBEACH MCA2 Section 4: Sedimentation & Erosion

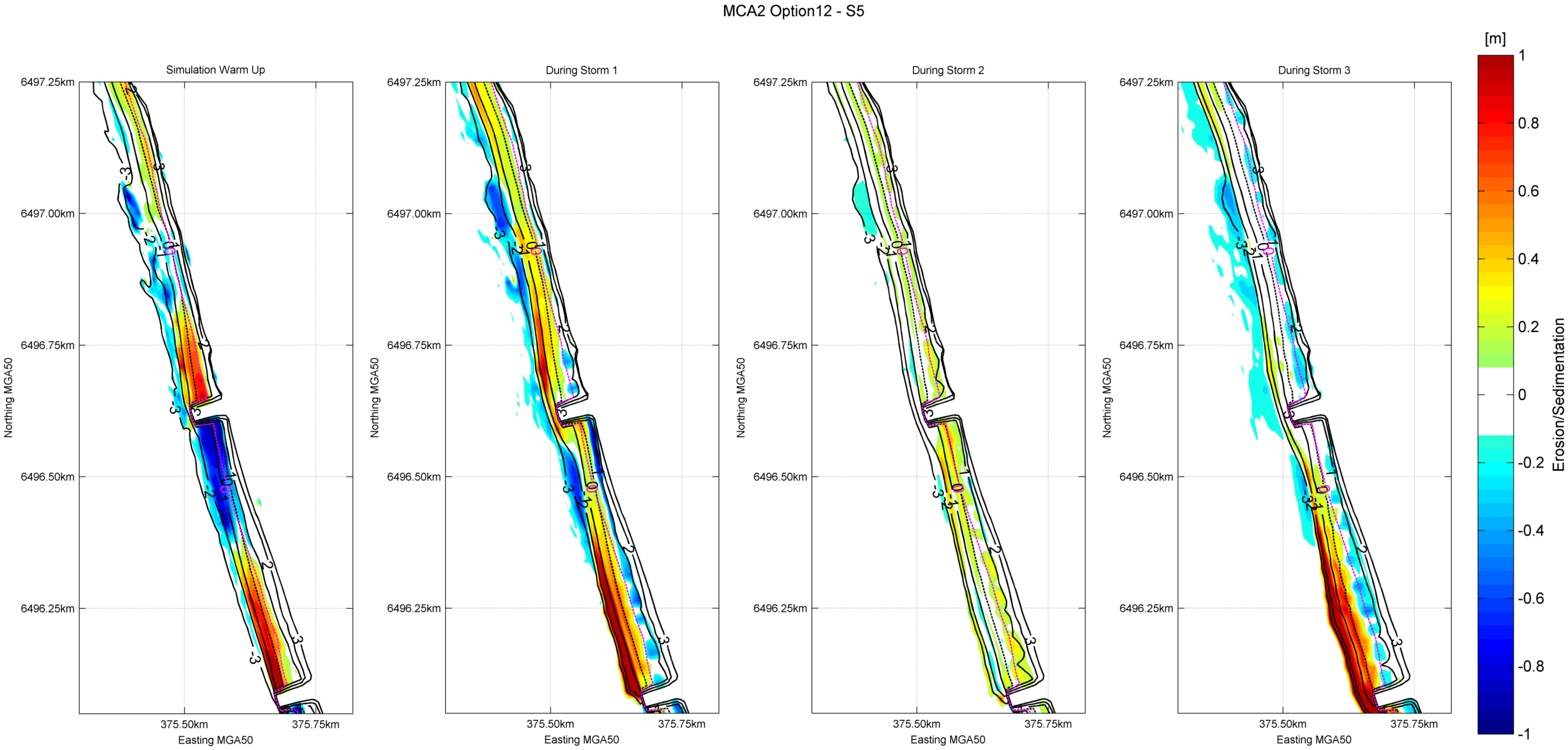


Figure D-17 XBEACH MCA2 Section 5: Sedimentation & Erosion

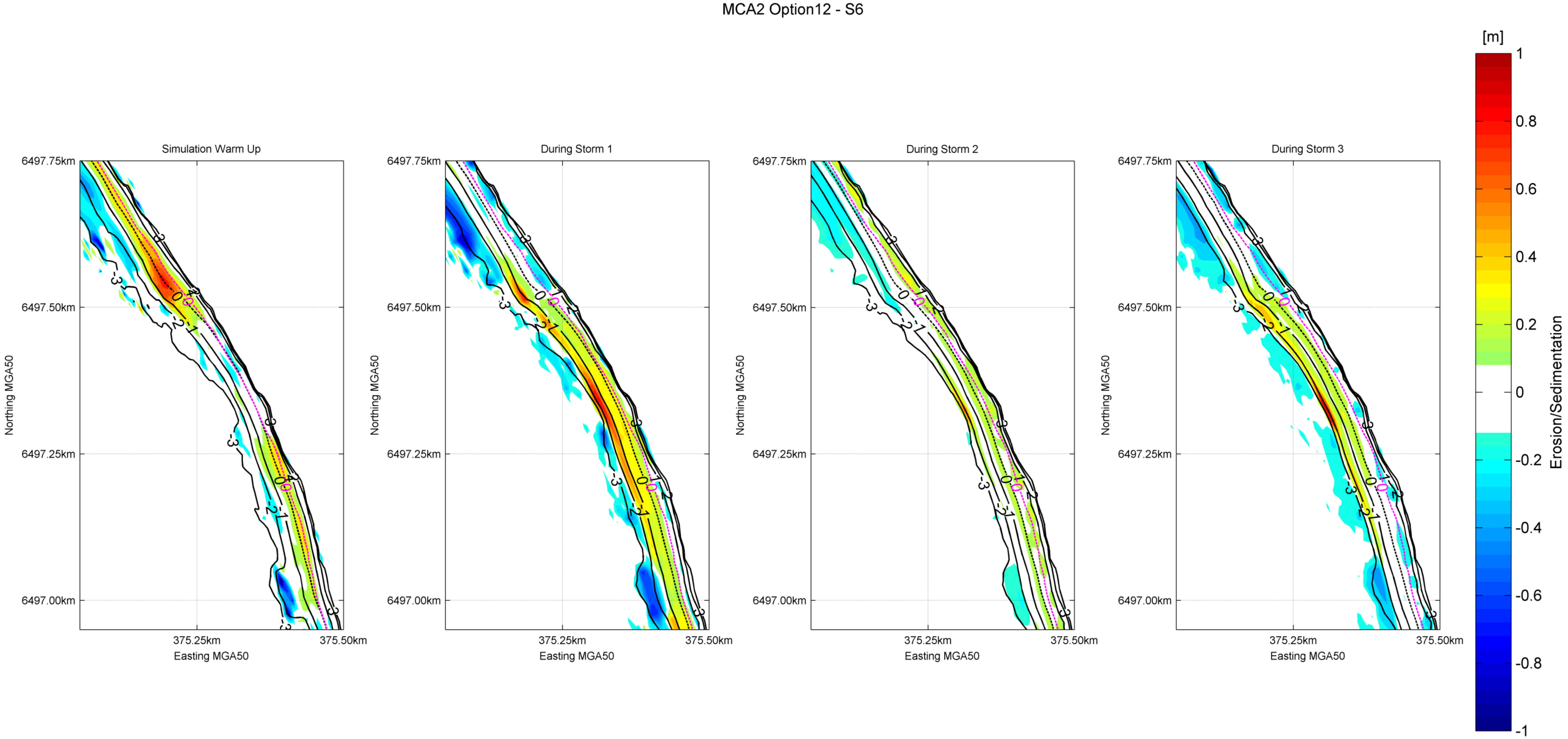


Figure D-18 XBEACH MCA2 Section 6: Sedimentation & Erosion

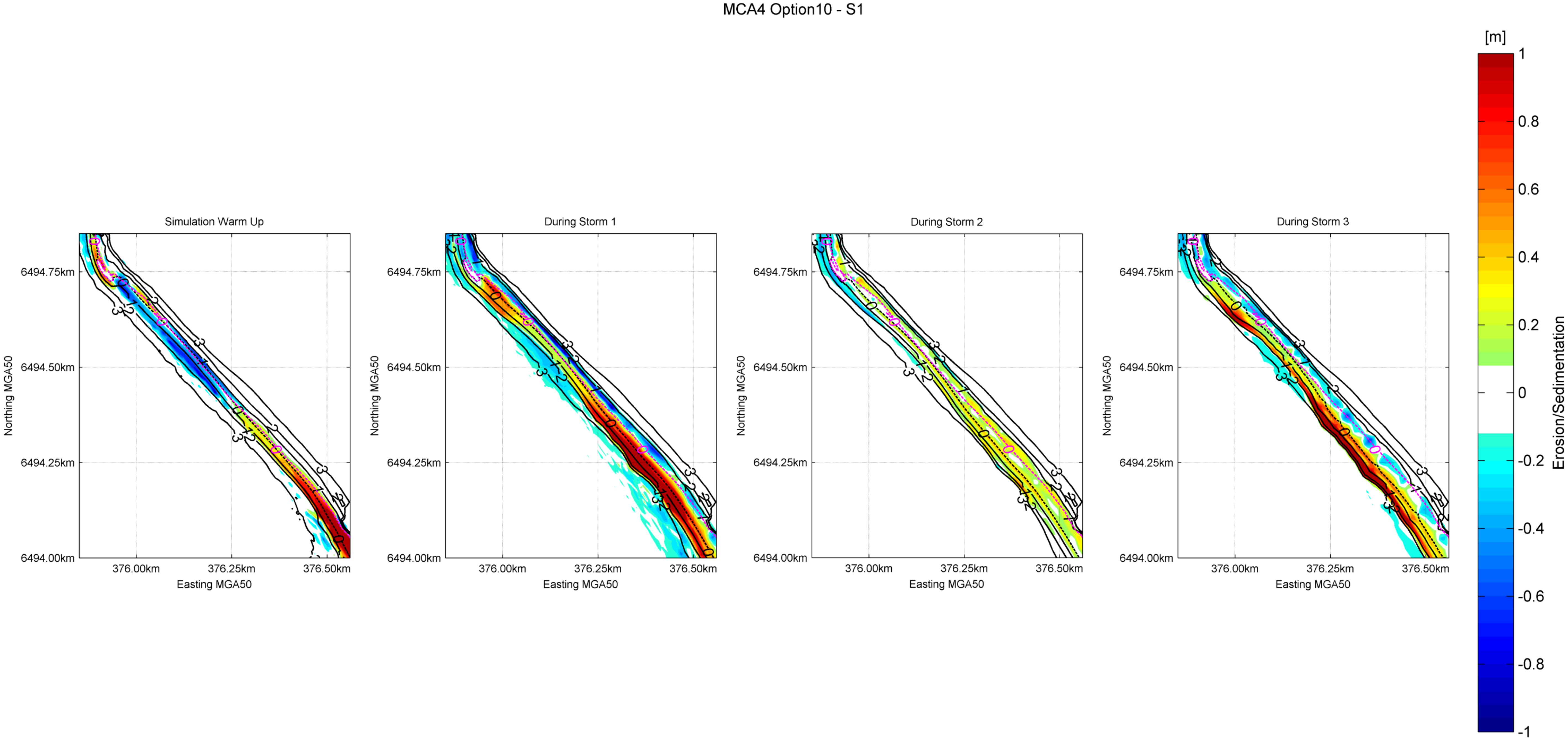


Figure D-19 XBEACH MCA4 Section 1: Sedimentation & Erosion

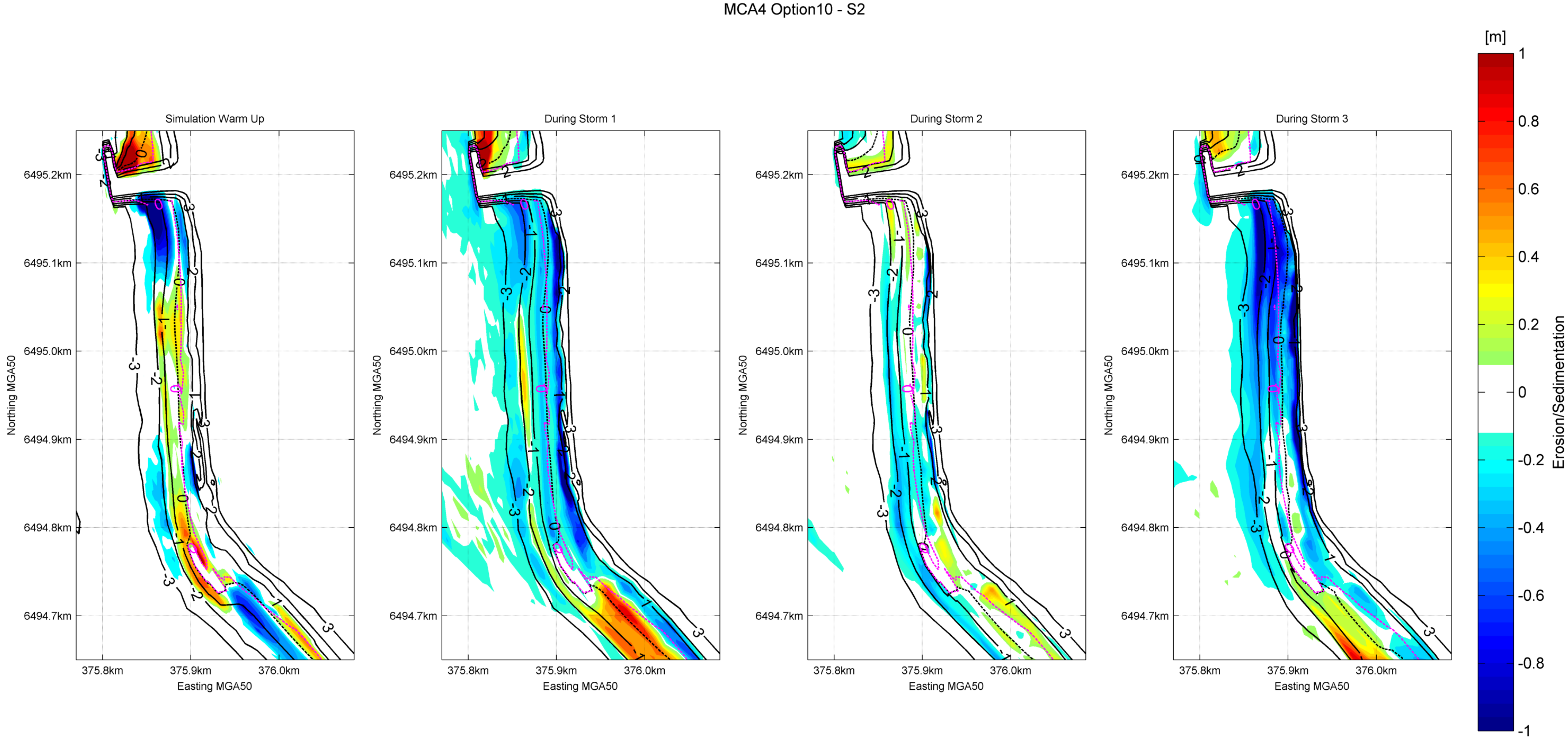


Figure D-20 XBEACH MCA4 Section 2: Sedimentation & Erosion

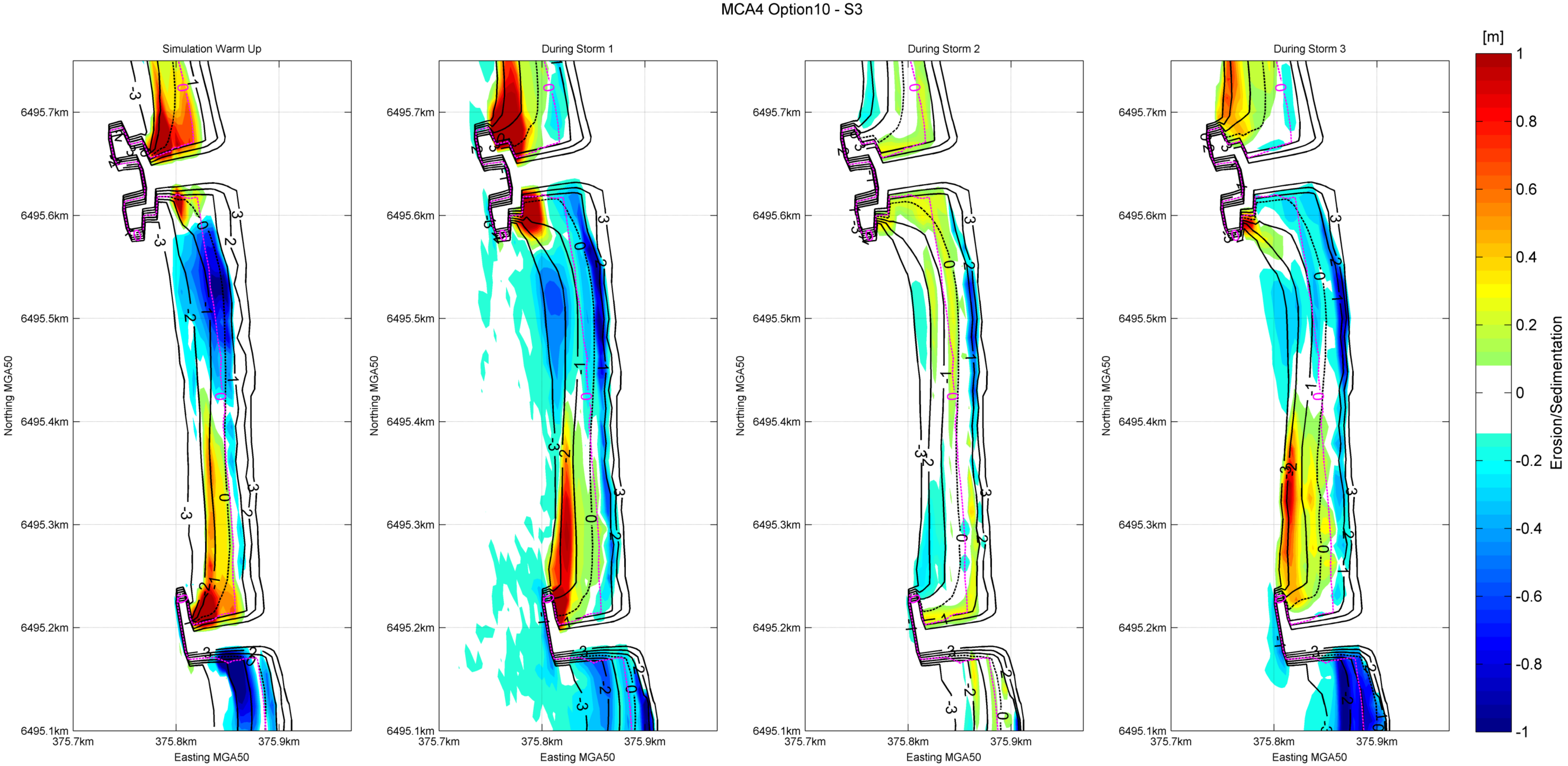


Figure D-21 XBEACH MCA4 Section 3: Sedimentation & Erosion

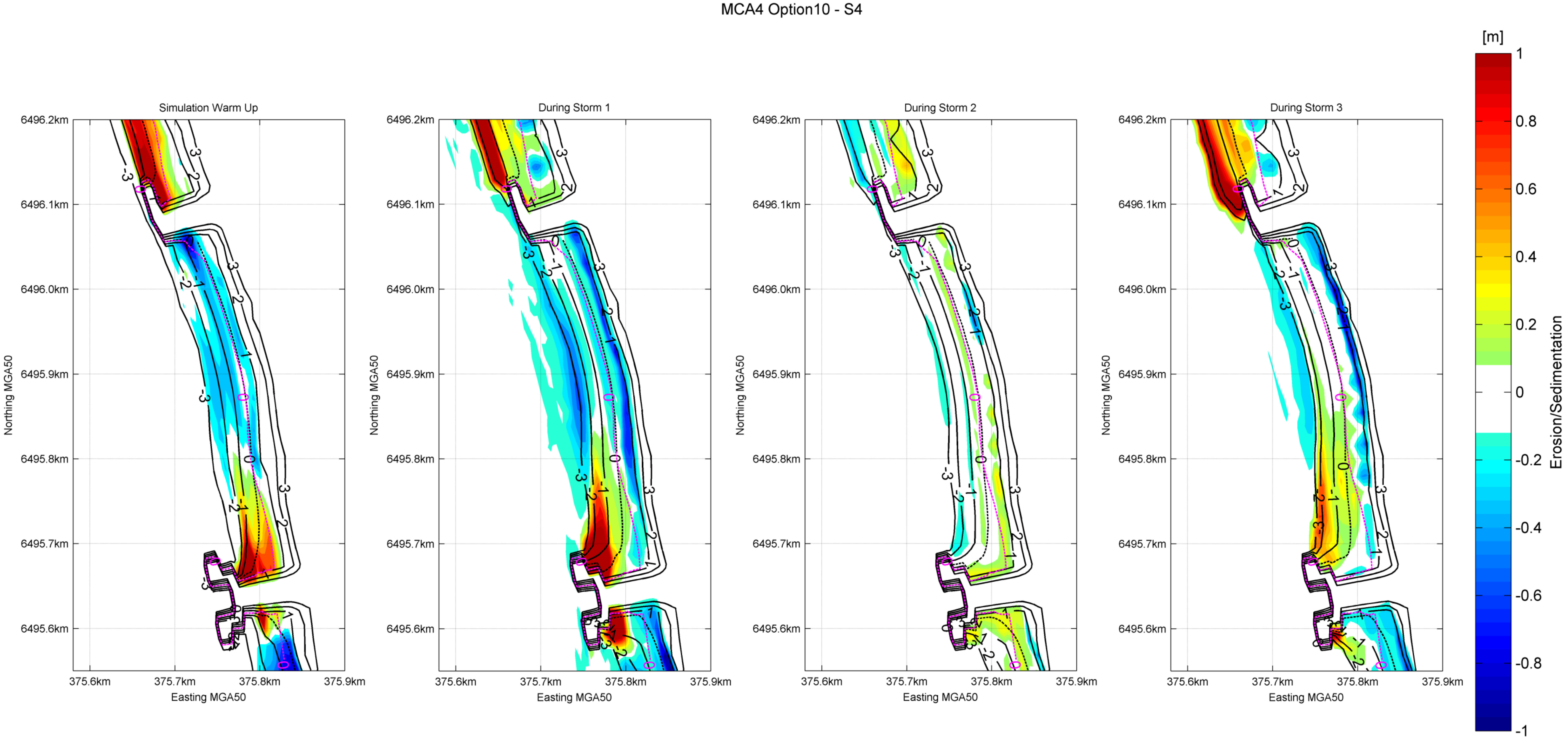


Figure D-22 XBEACH MCA4 Section 4: Sedimentation & Erosion

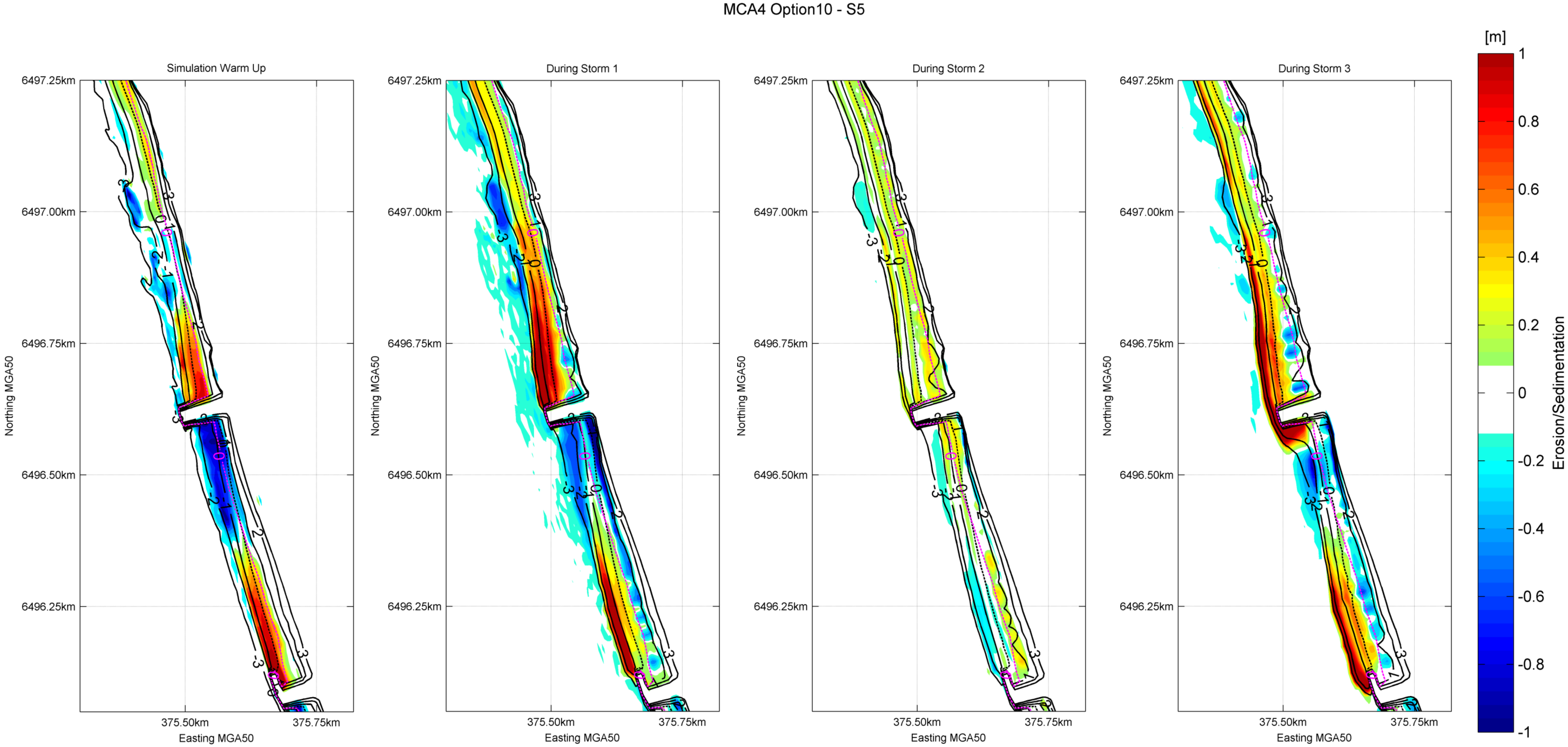


Figure D-23 XBEACH MCA4 Section 5: Sedimentation & Erosion

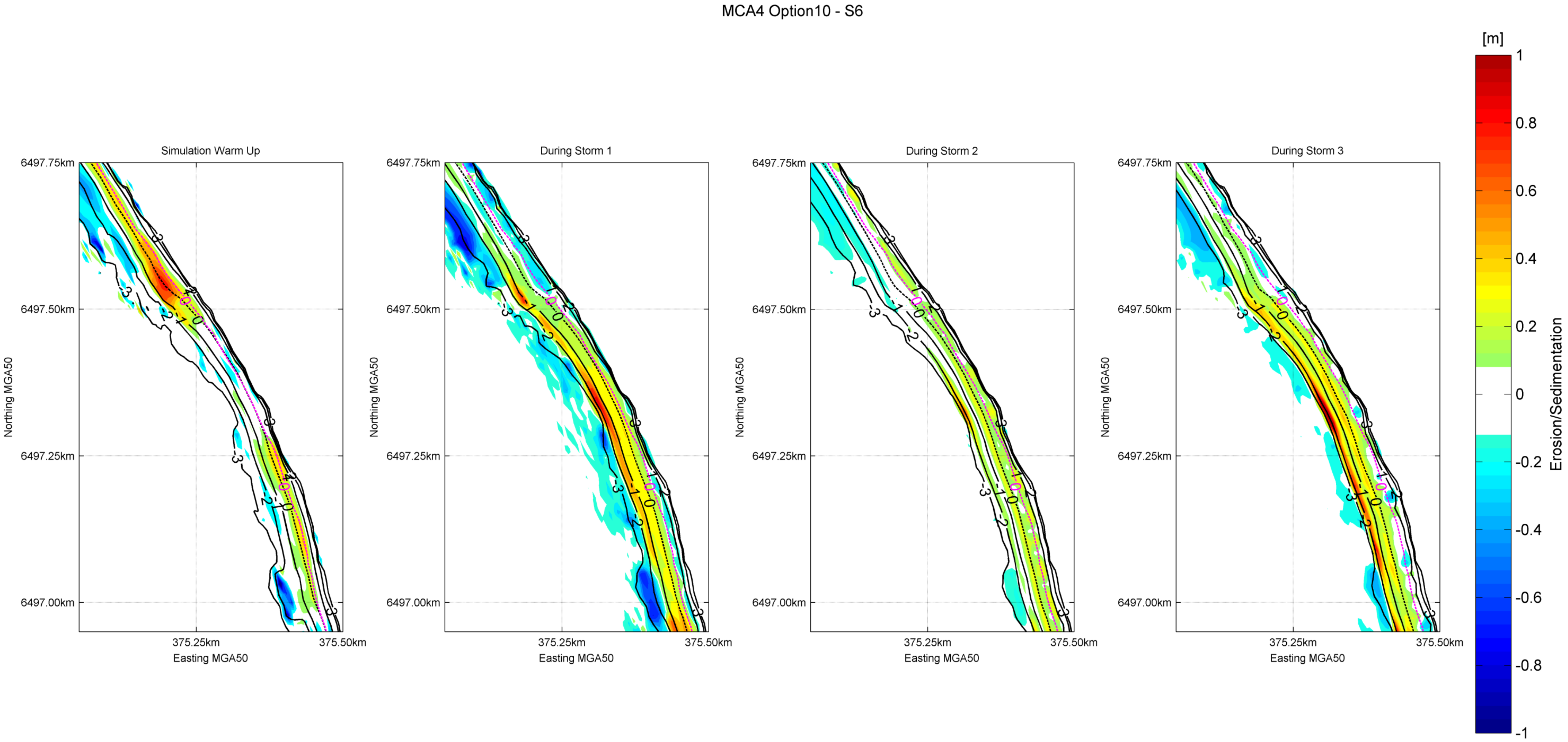


Figure D-24 XBEACH MCA4 Section 6: Sedimentation & Erosion

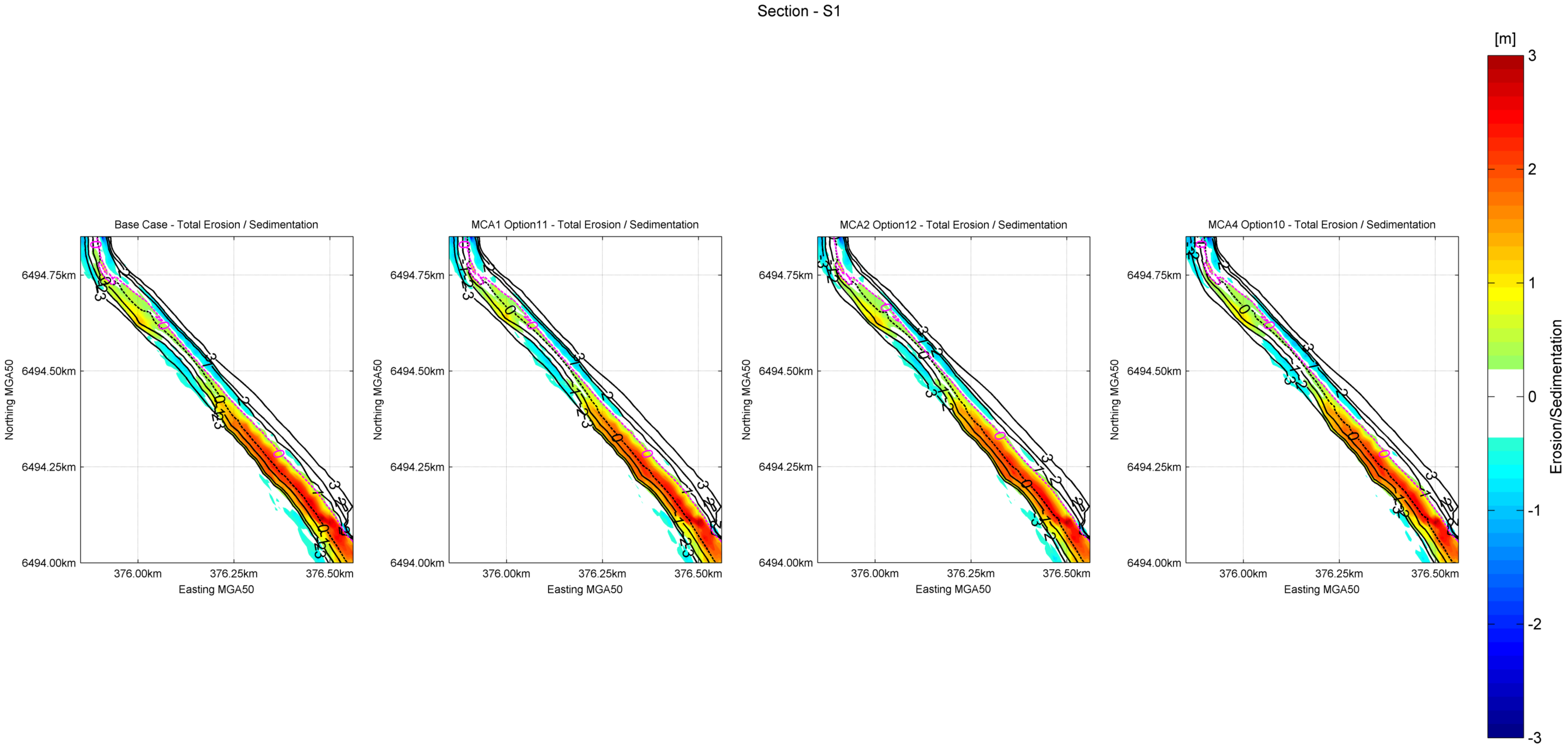


Figure D-25 XBEACH Section 1: Comparative Sedimentation & Erosion Summary

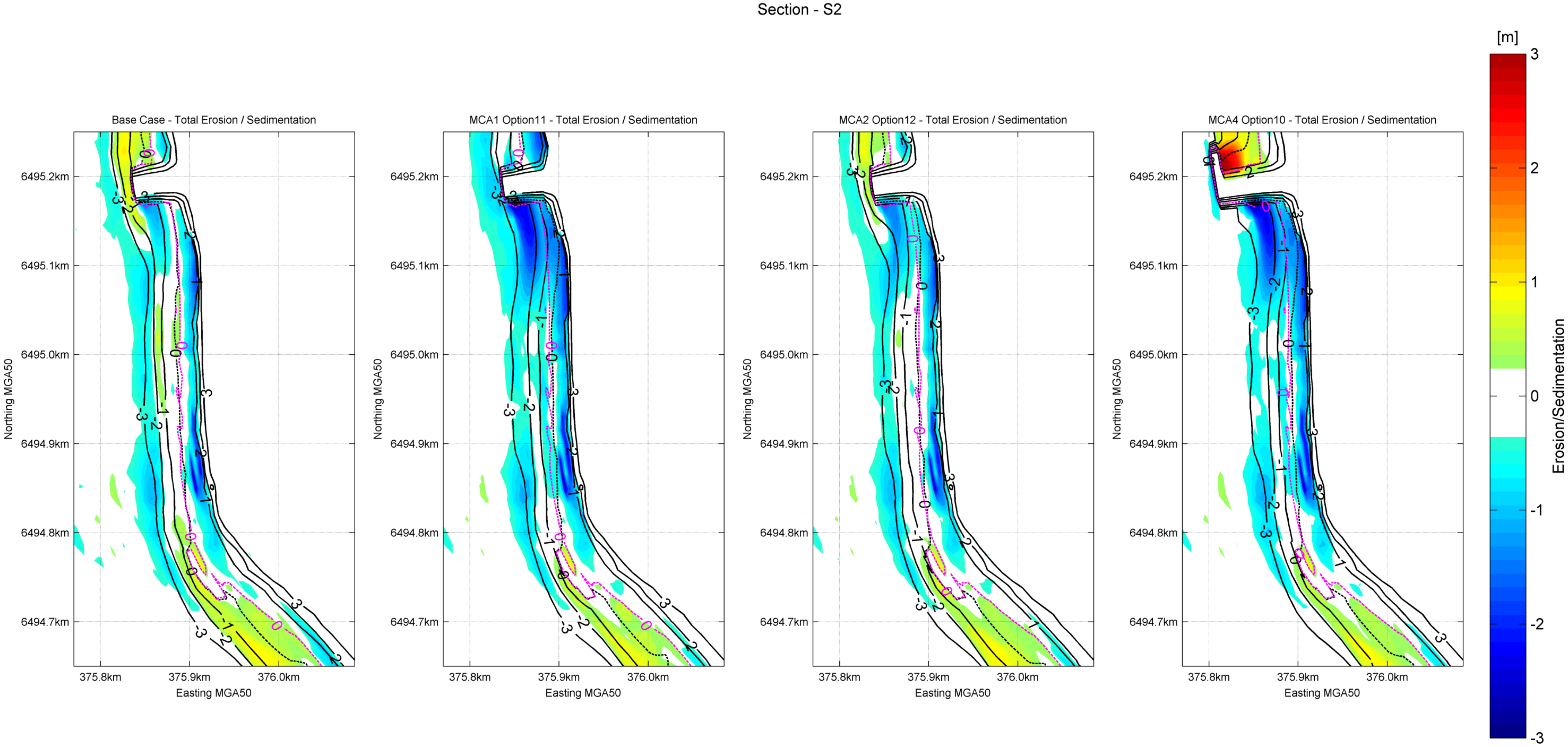


Figure D-26 XBEACH Section 2: Comparative Sedimentation & Erosion Summary

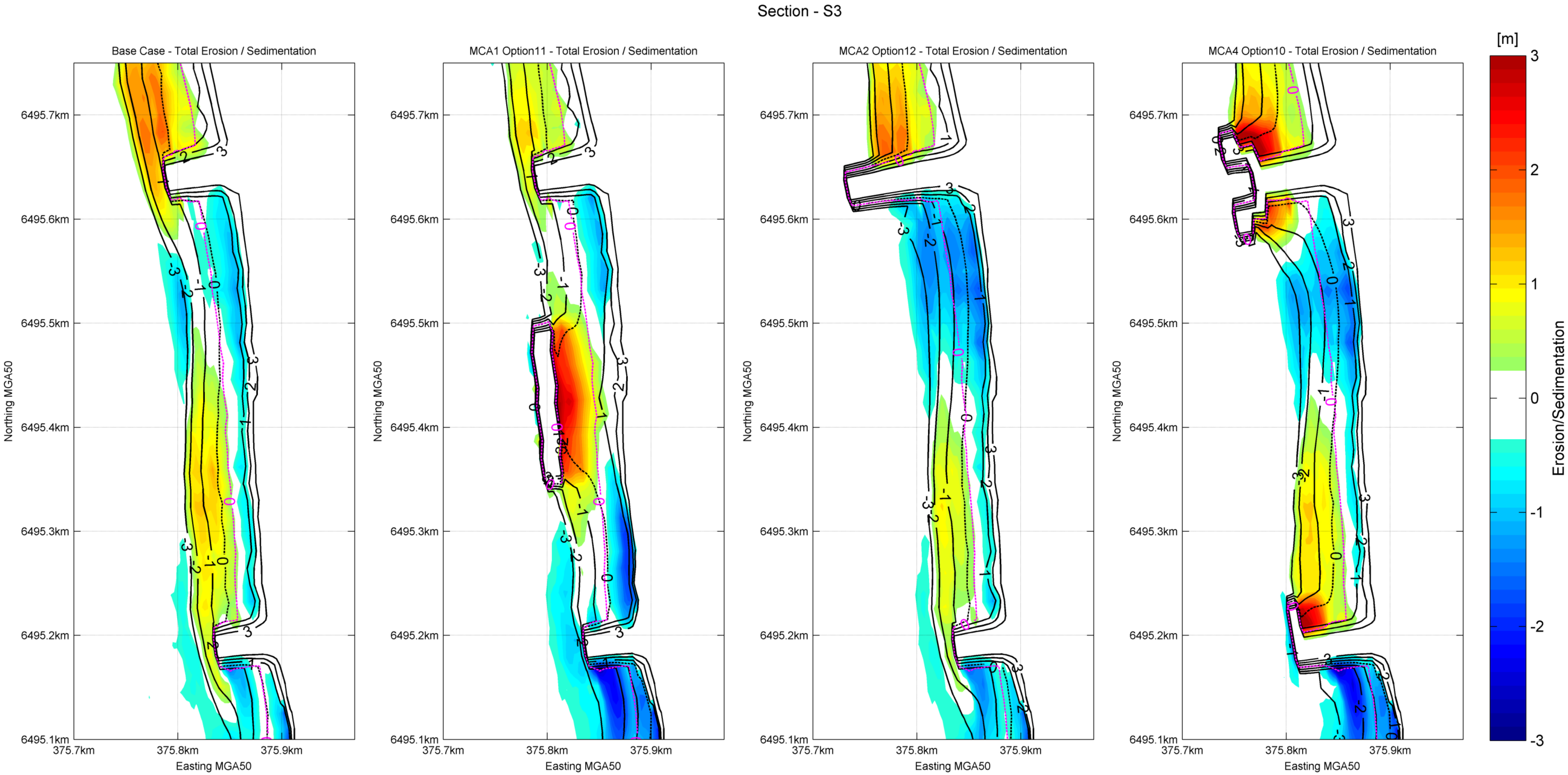


Figure D-27 XBEACH Section 3: Comparative Sedimentation & Erosion Summary

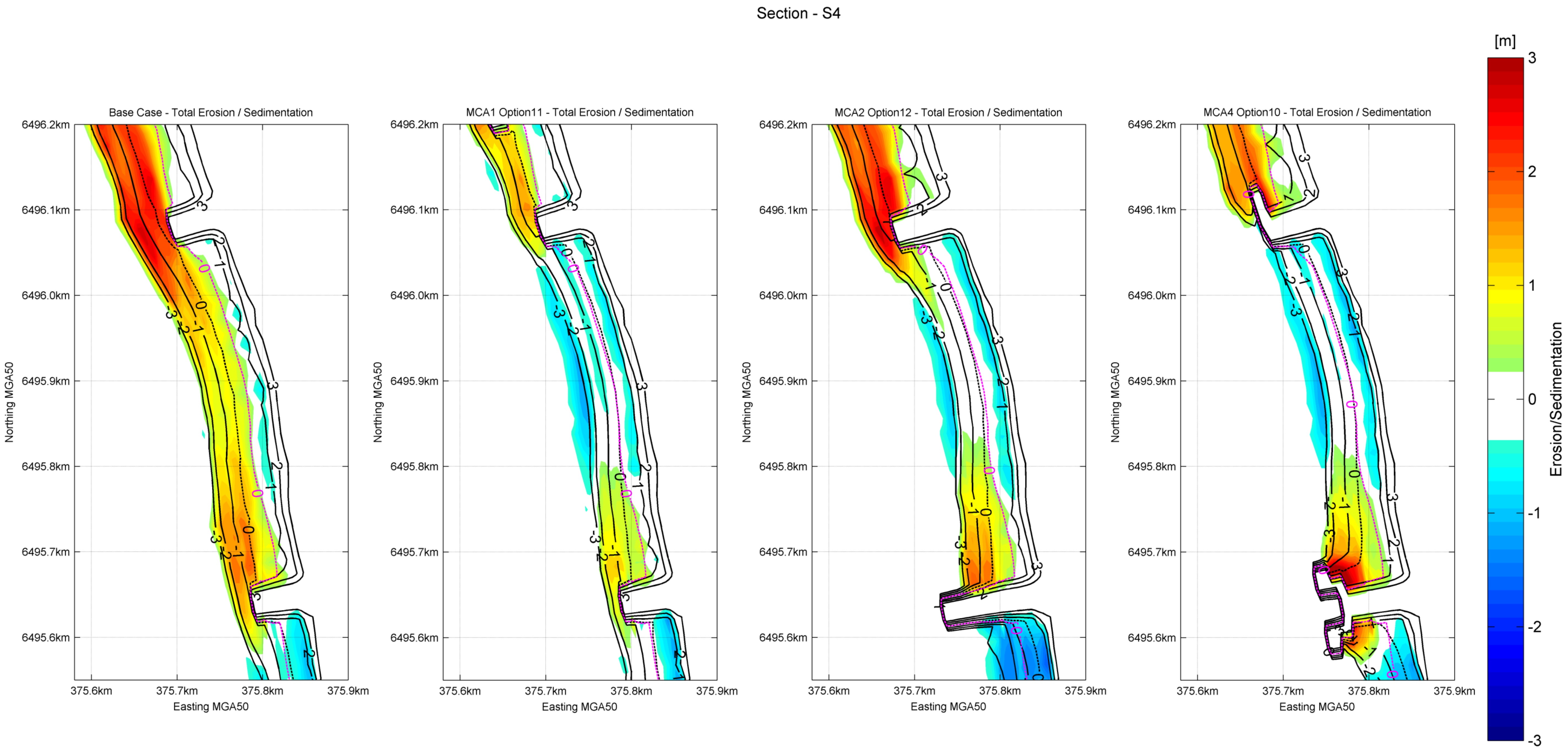


Figure D-28 XBEACH Section 4: Comparative Sedimentation & Erosion Summary

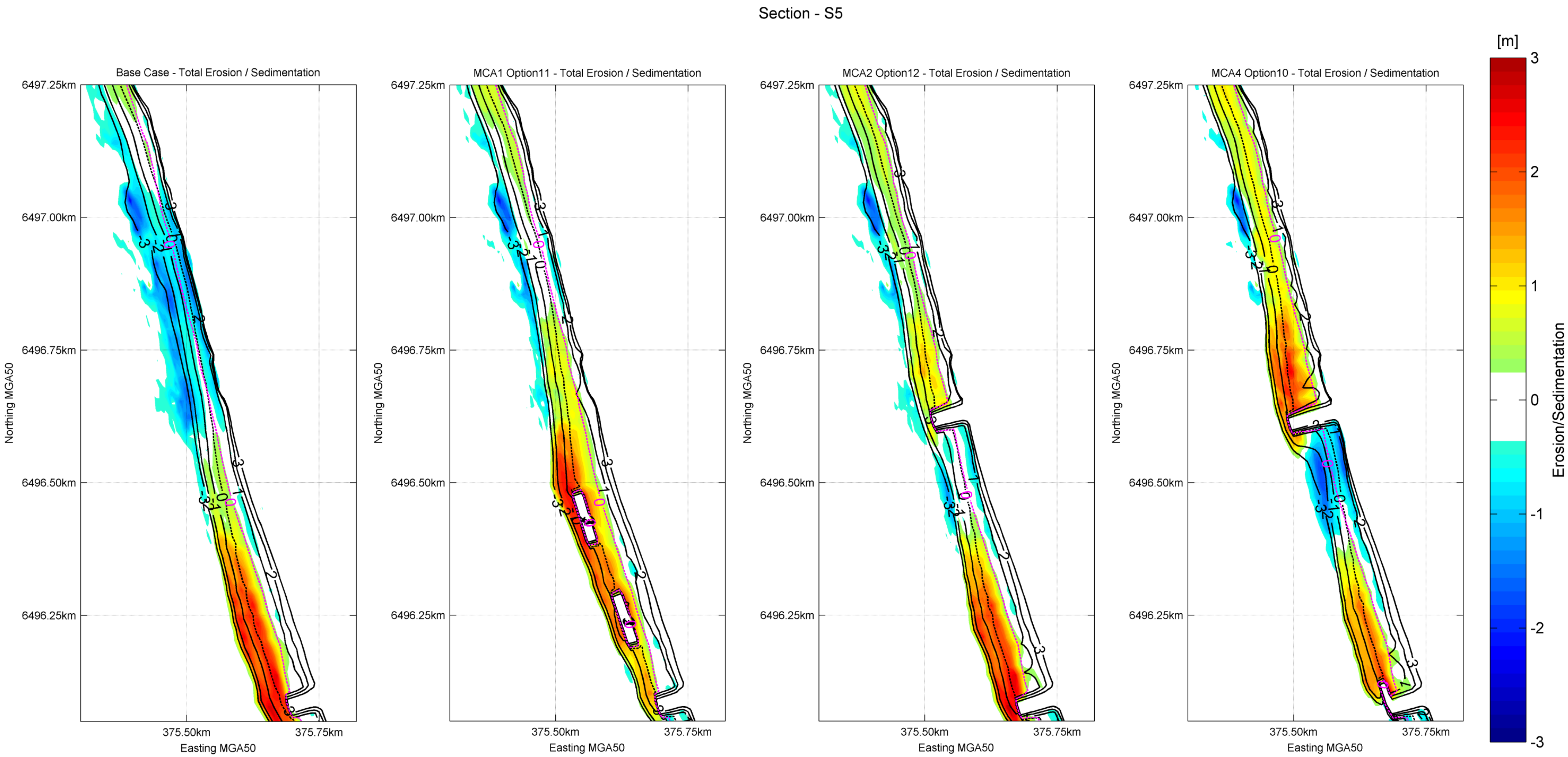


Figure D-29 XBEACH Section 5: Comparative Sedimentation & Erosion Summary

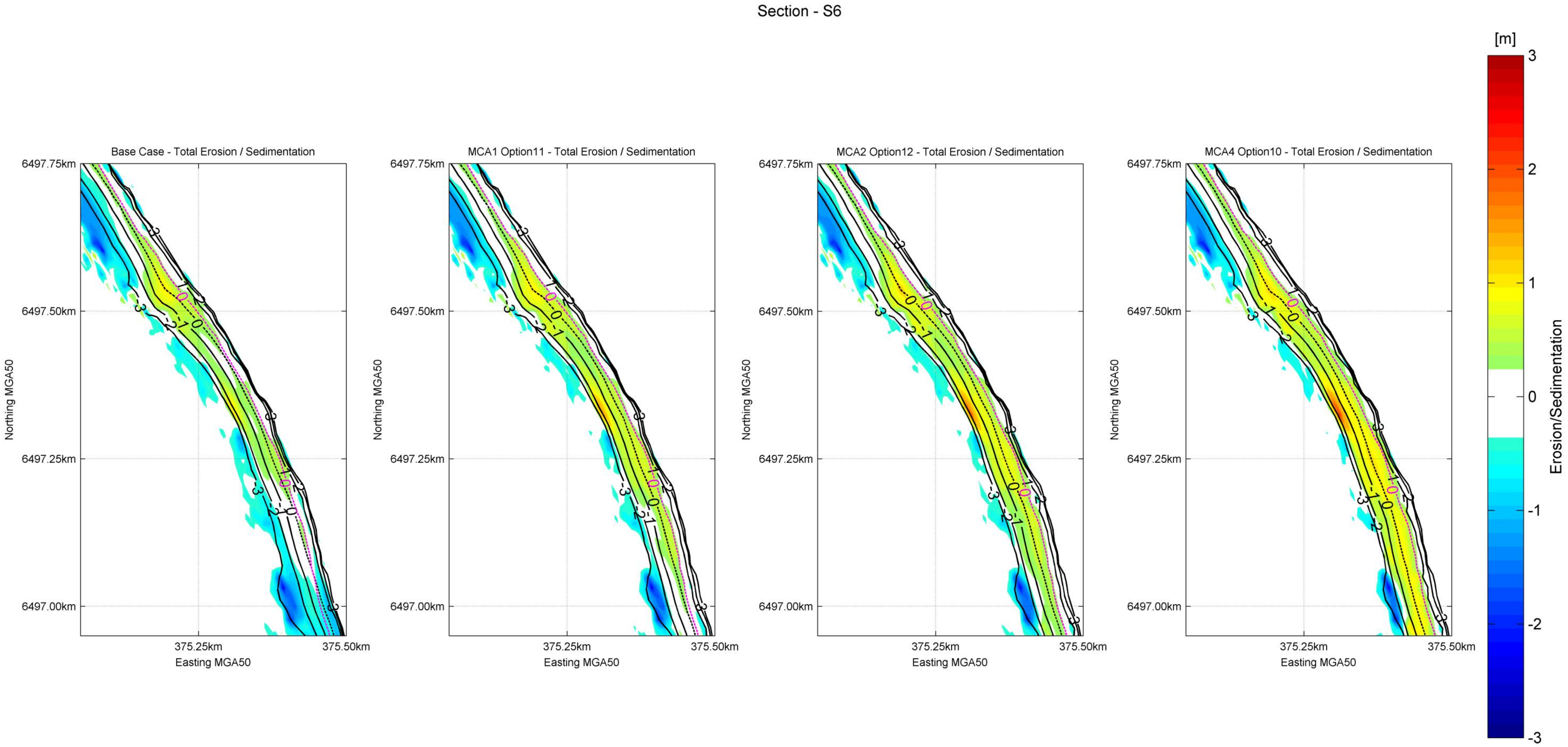


Figure D-30 XBEACH Section 6: Comparative Sedimentation & Erosion Summary

Figure D-31 XBEACH Profile Locations

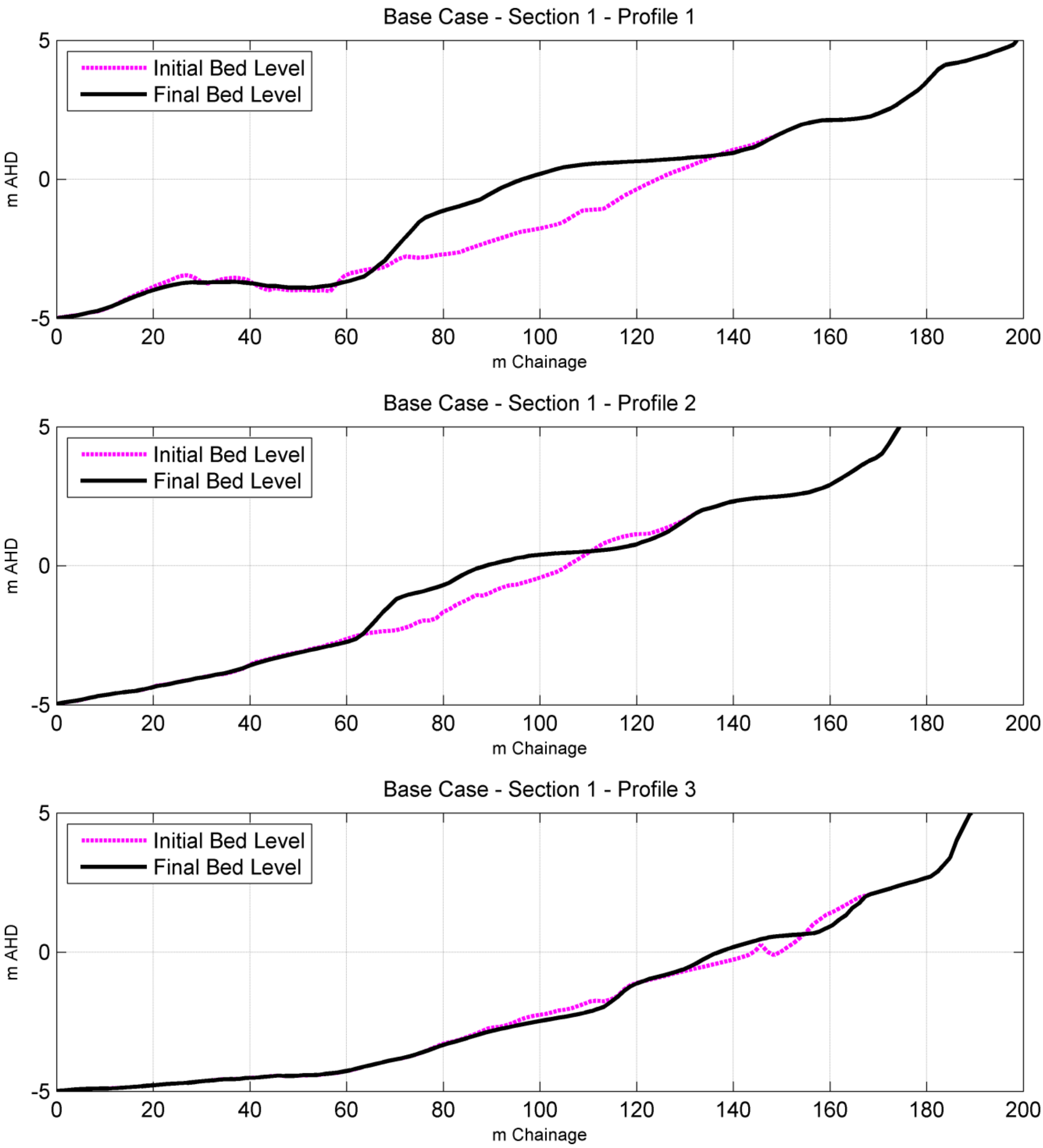


Figure D-32 XBEACH Base Case Section 1: Initial & Final Beach Profiles

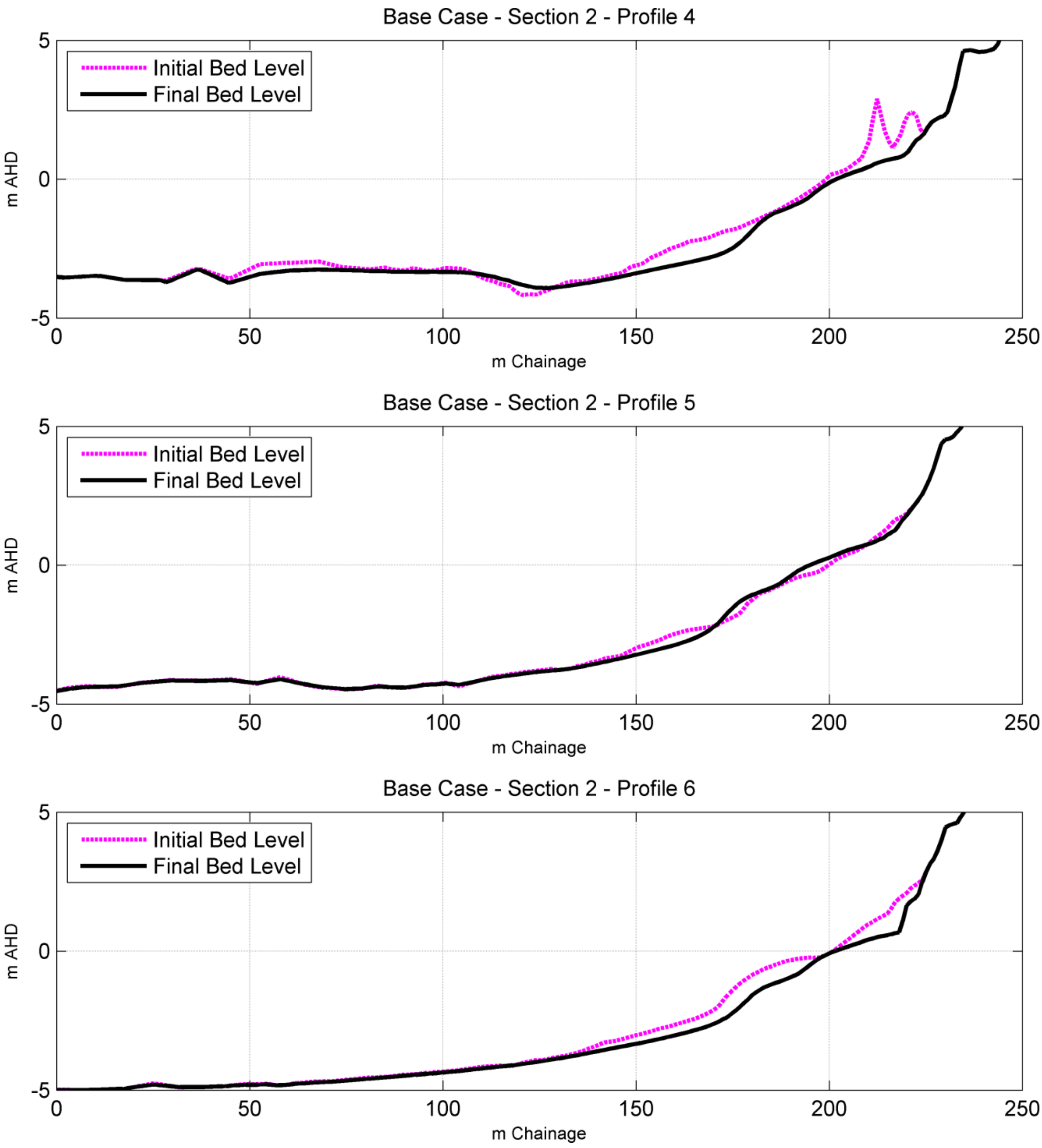


Figure D-33 XBEACH Base Case Section 2: Initial & Final Beach Profiles

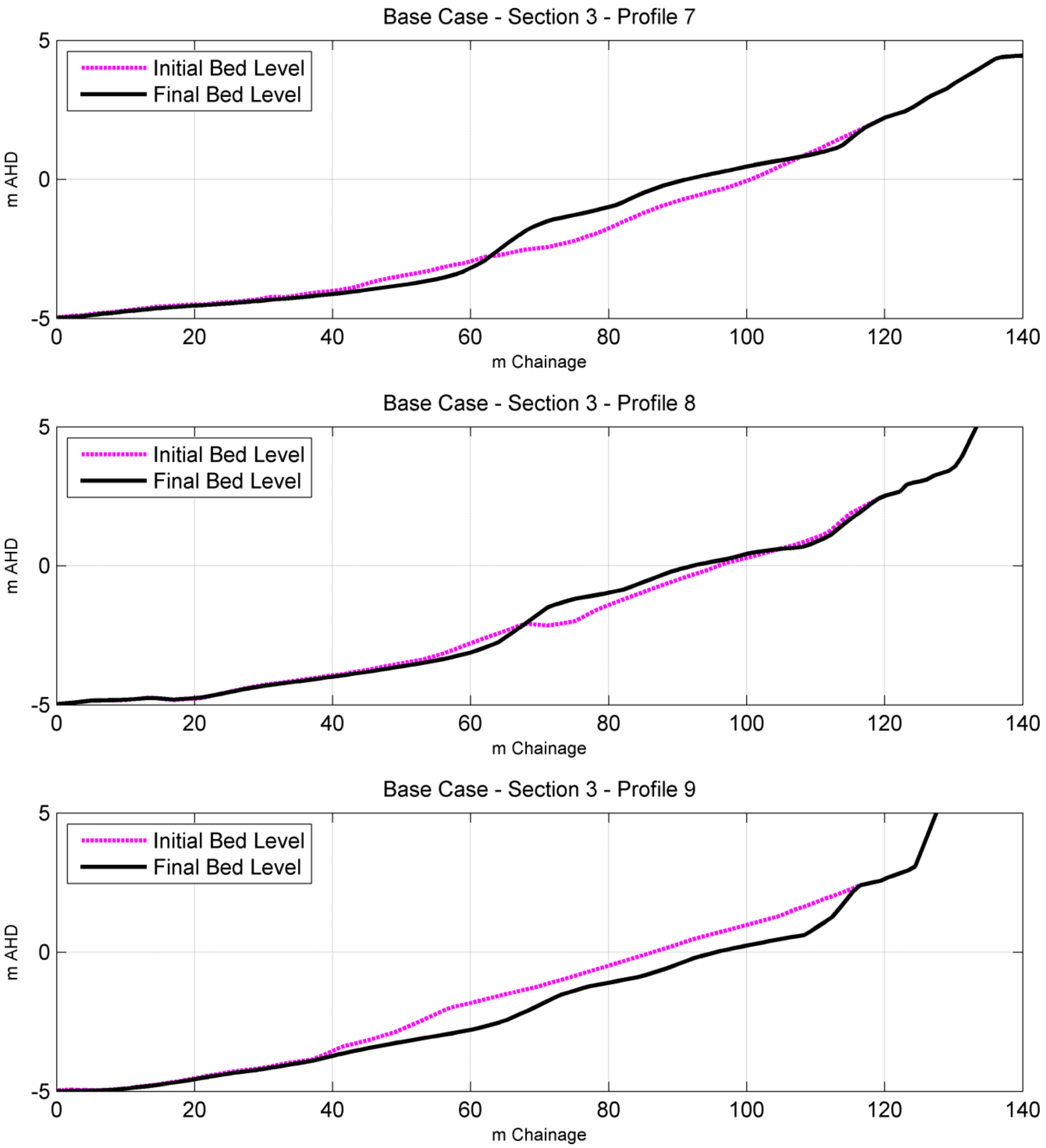


Figure D-34 XBEACH Base Case Section 3: Initial & Final Beach Profiles

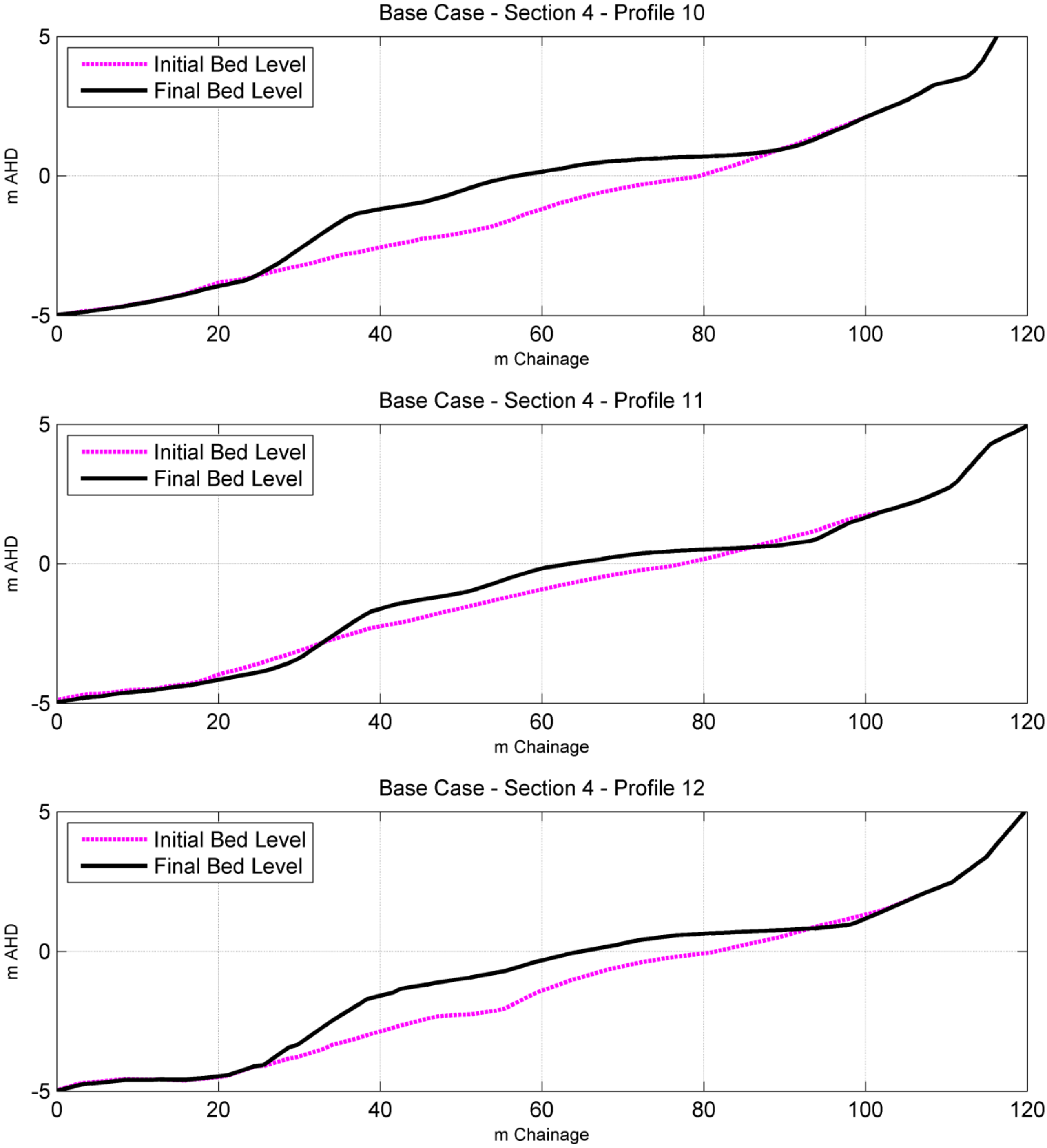


Figure D-35 XBEACH Base Case Section 4: Initial & Final Beach Profiles

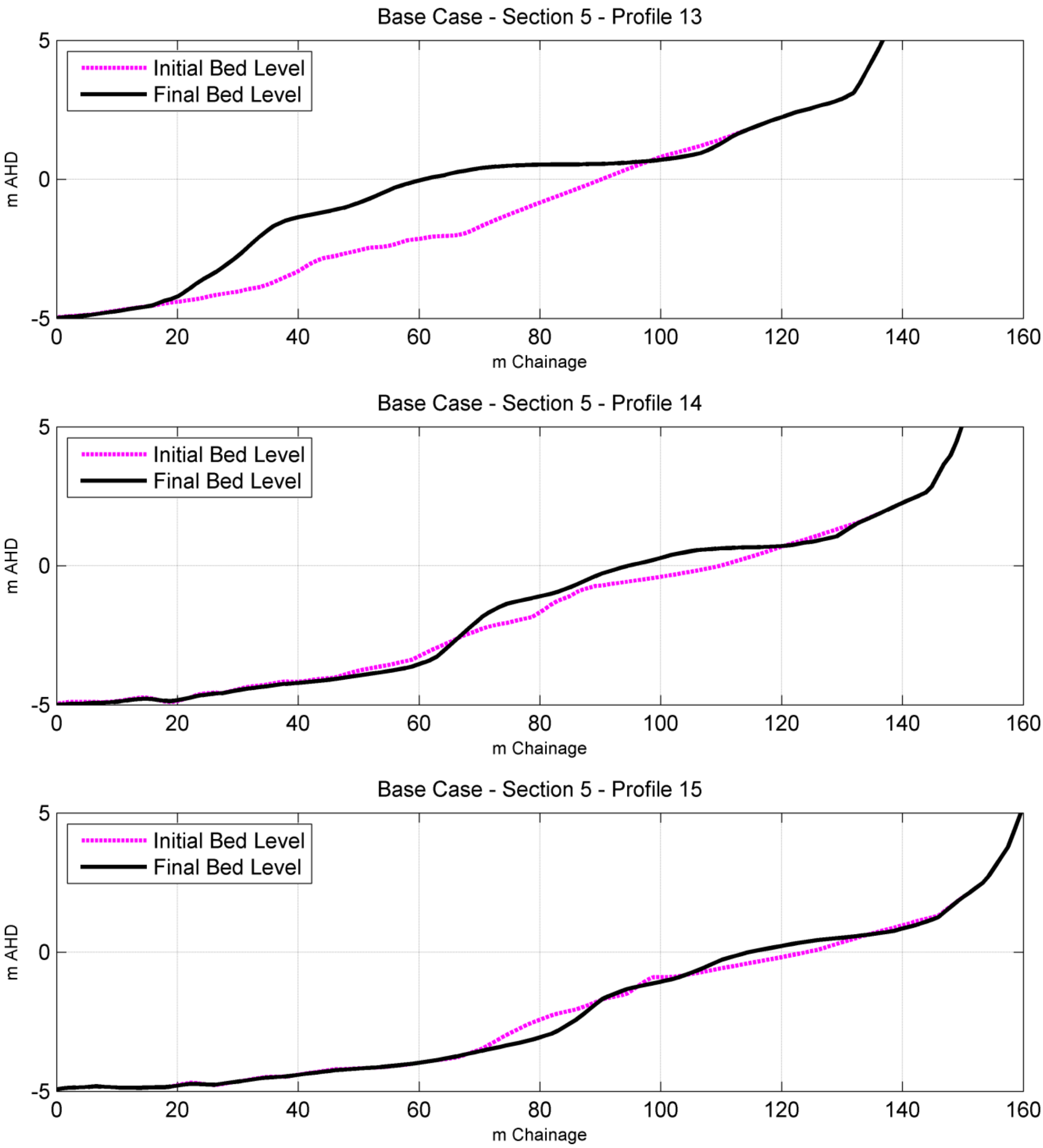


Figure D-36 XBEACH Base Case Section 5: Initial & Final Beach Profiles

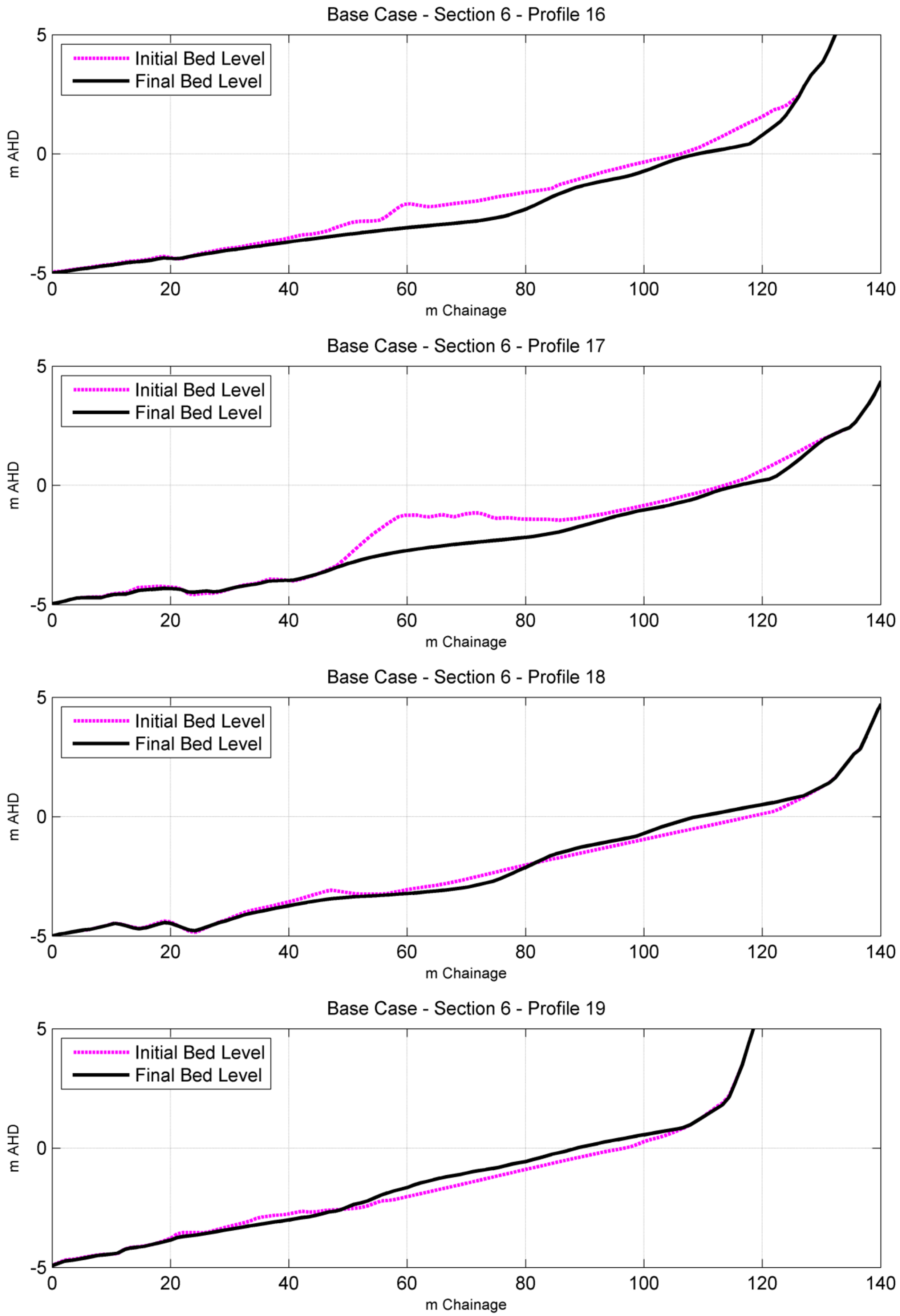


Figure D-37 XBEACH Base Case Section 6: Initial & Final Beach Profiles

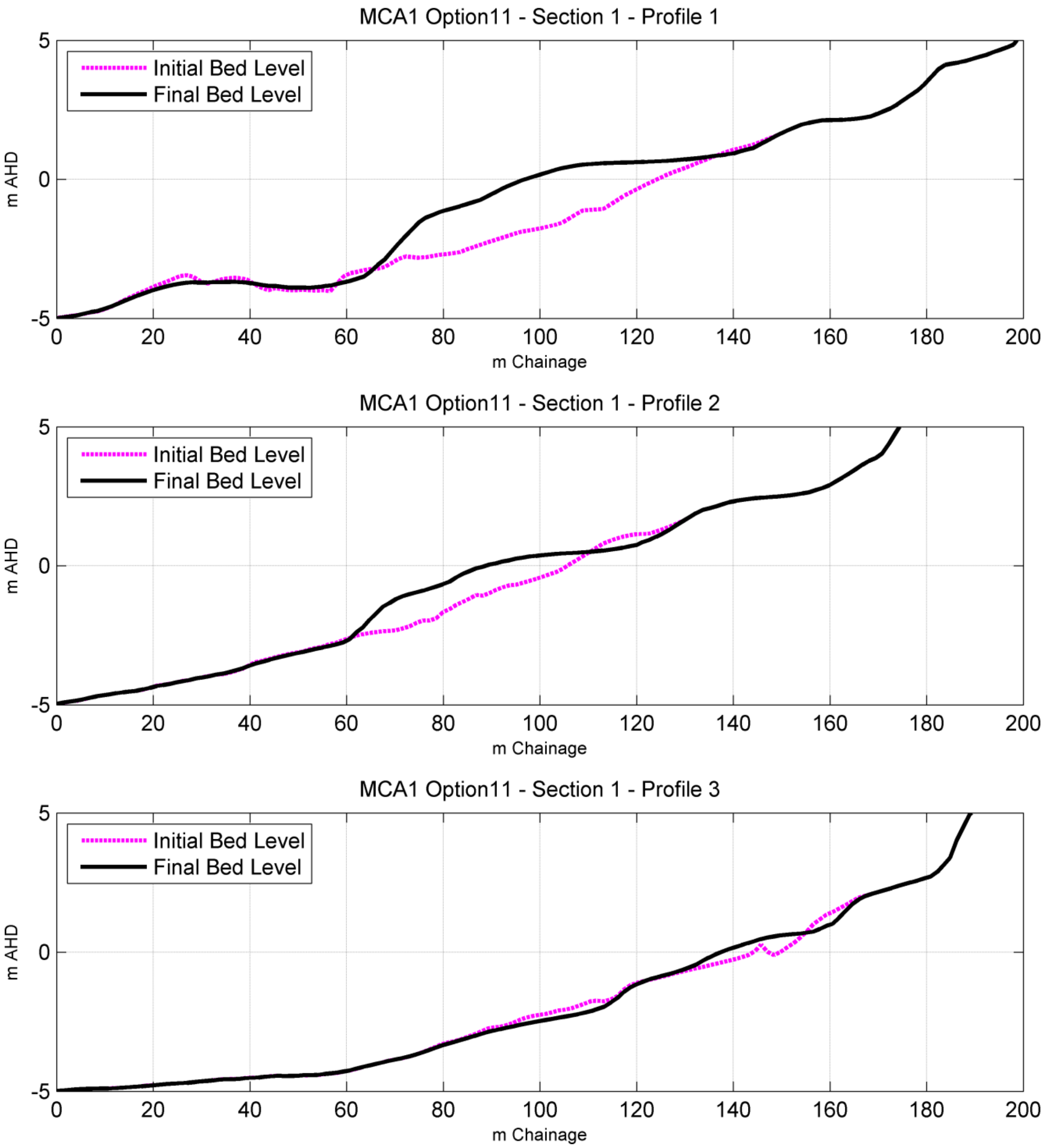


Figure D-38 XBEACH MCA1 Section 1: Initial & Final Beach Profiles

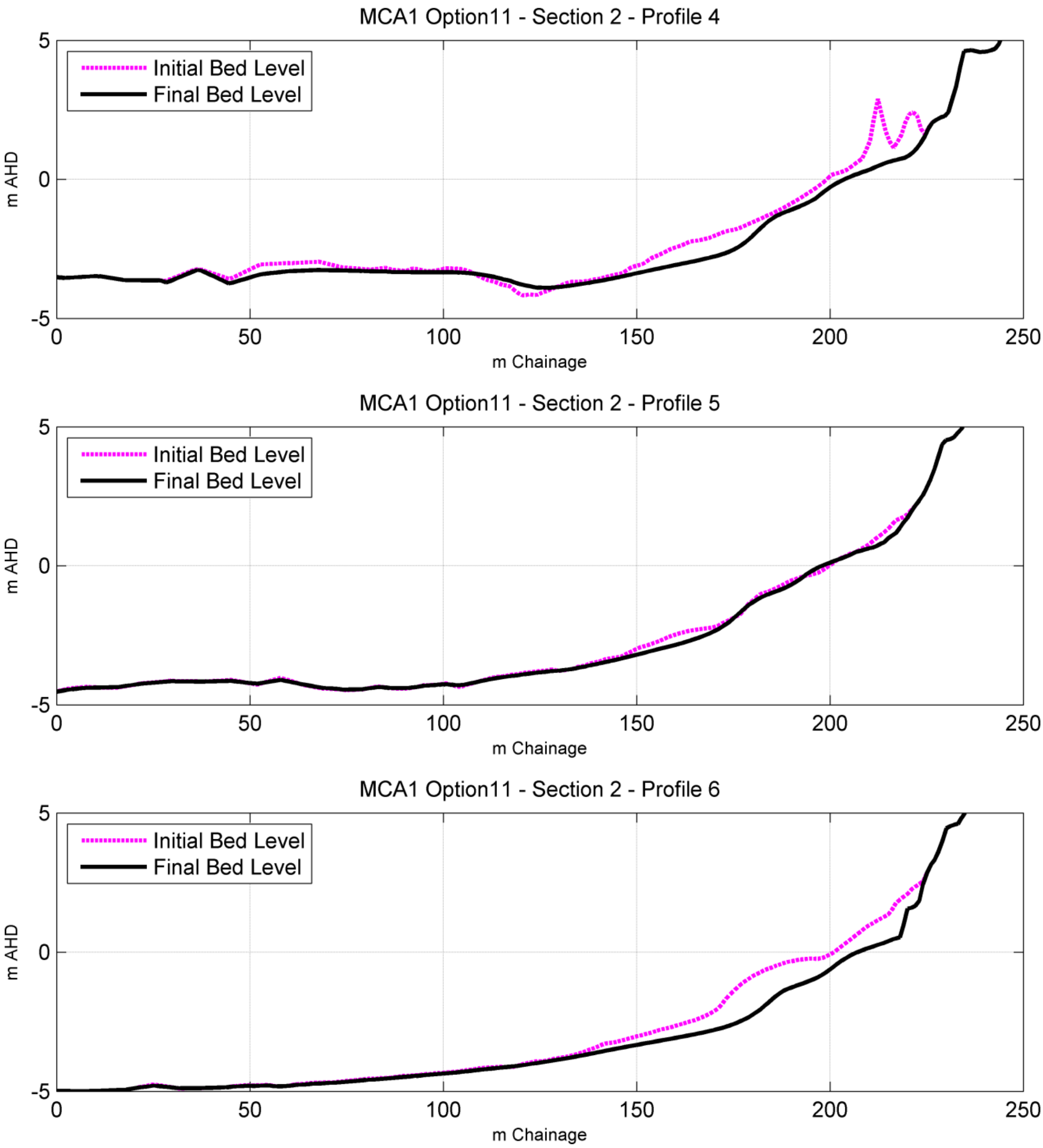


Figure D-39 XBEACH MCA1 Section 2: Initial & Final Beach Profiles

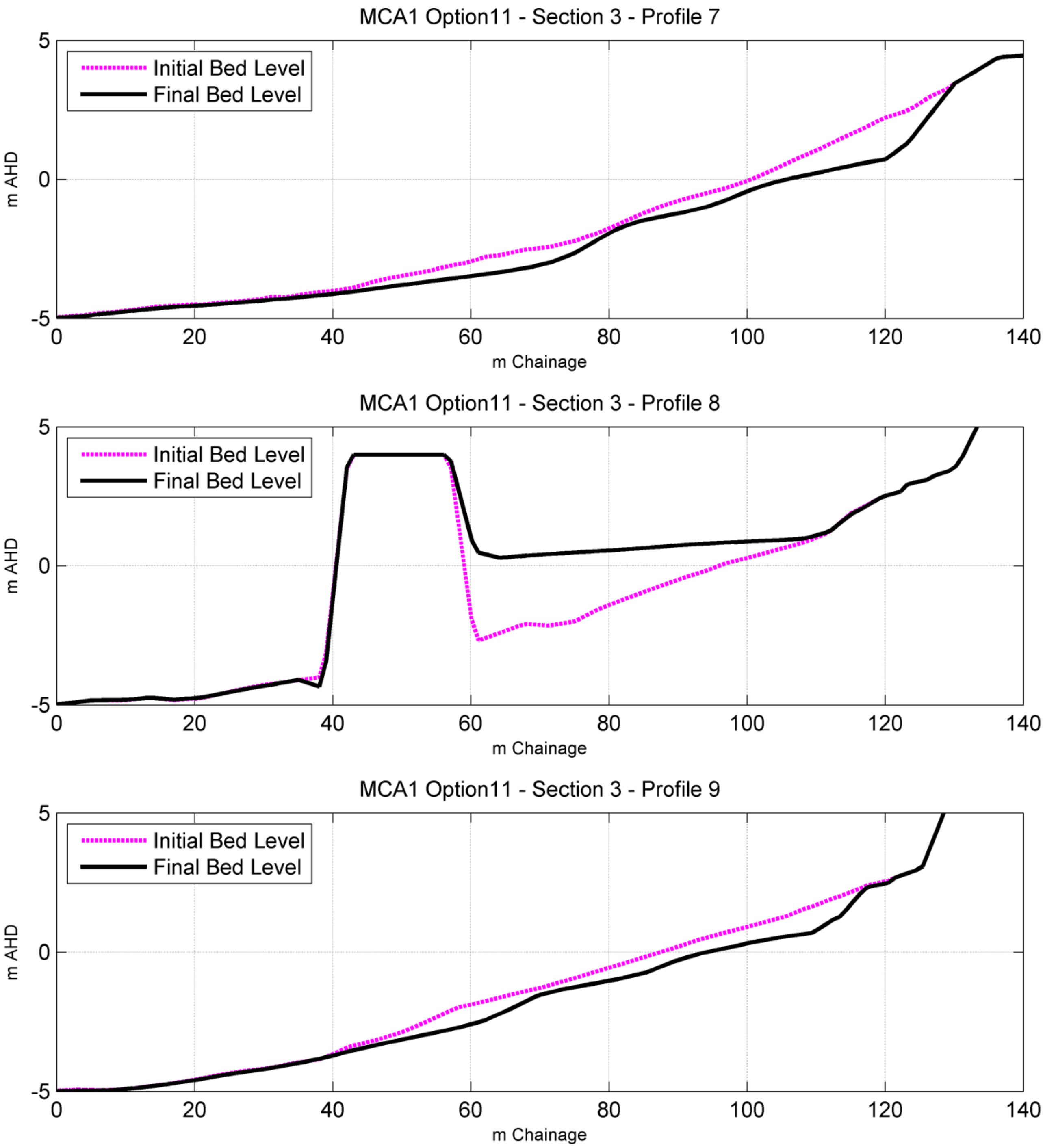


Figure D-40 XBEACH MCA1 Section 3: Initial & Final Beach Profiles

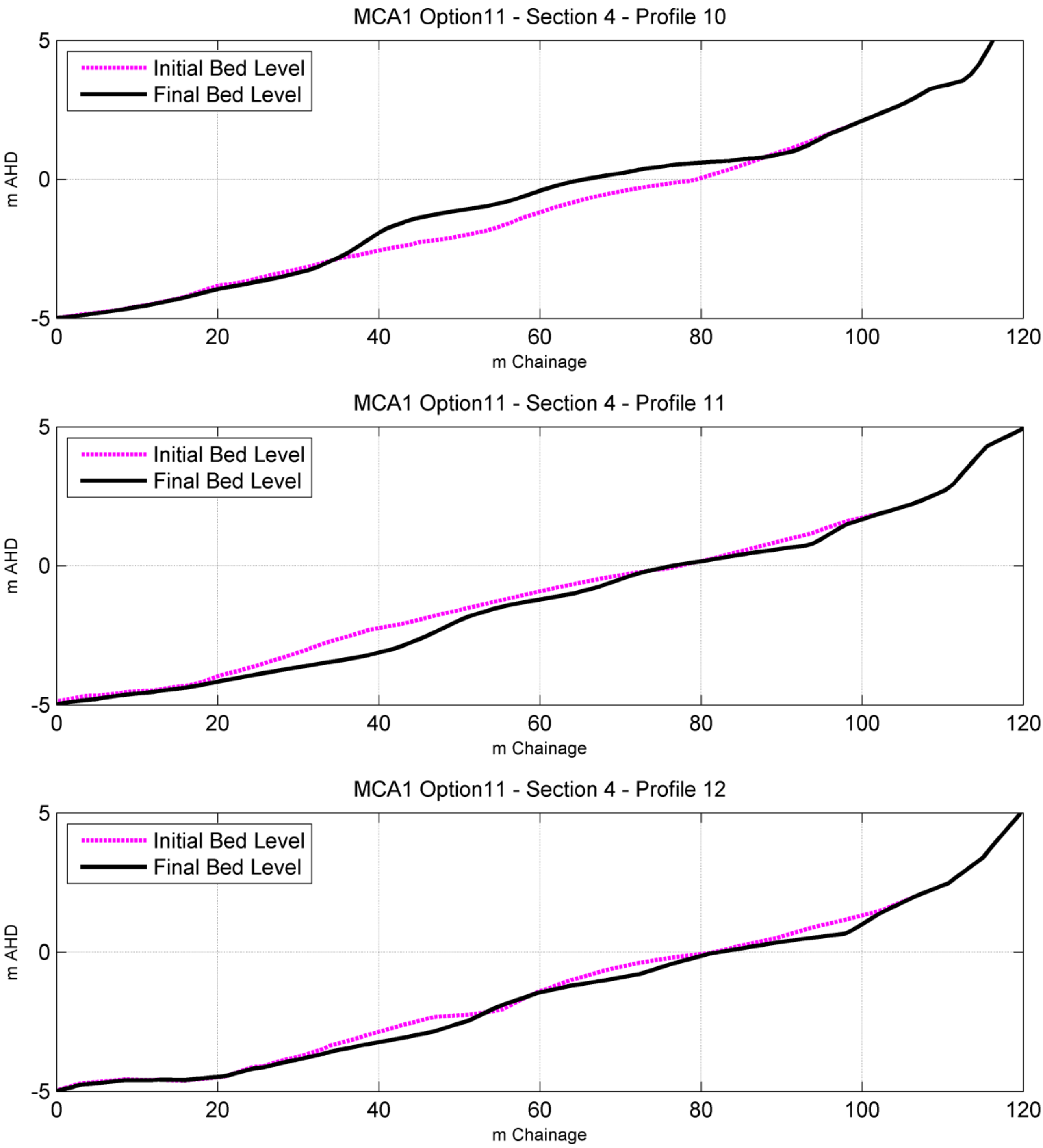


Figure D-41 XBEACH MCA1 Section 4: Initial & Final Beach Profiles

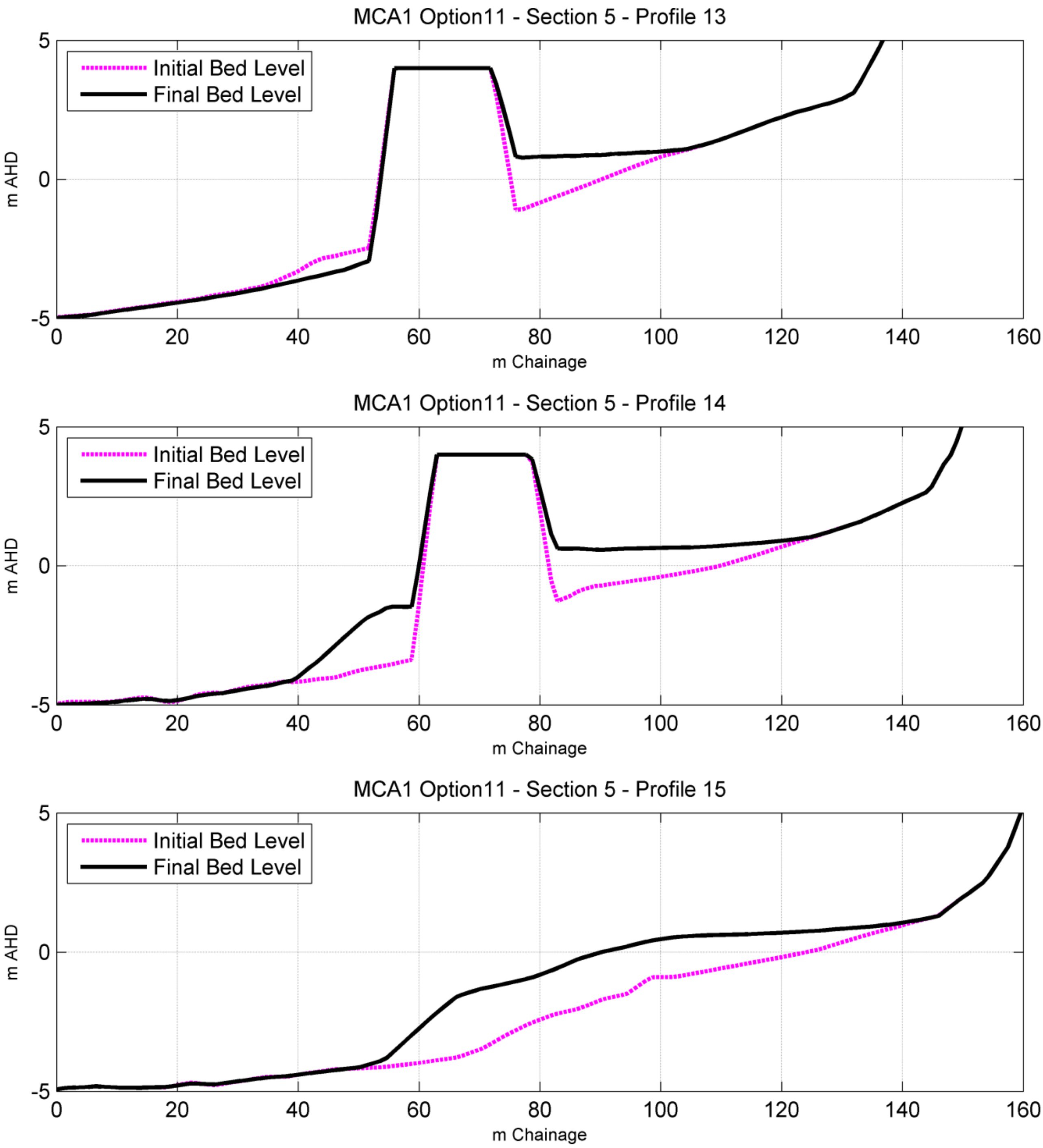


Figure D-42 XBEACH MCA1 Section 5: Initial & Final Beach Profiles

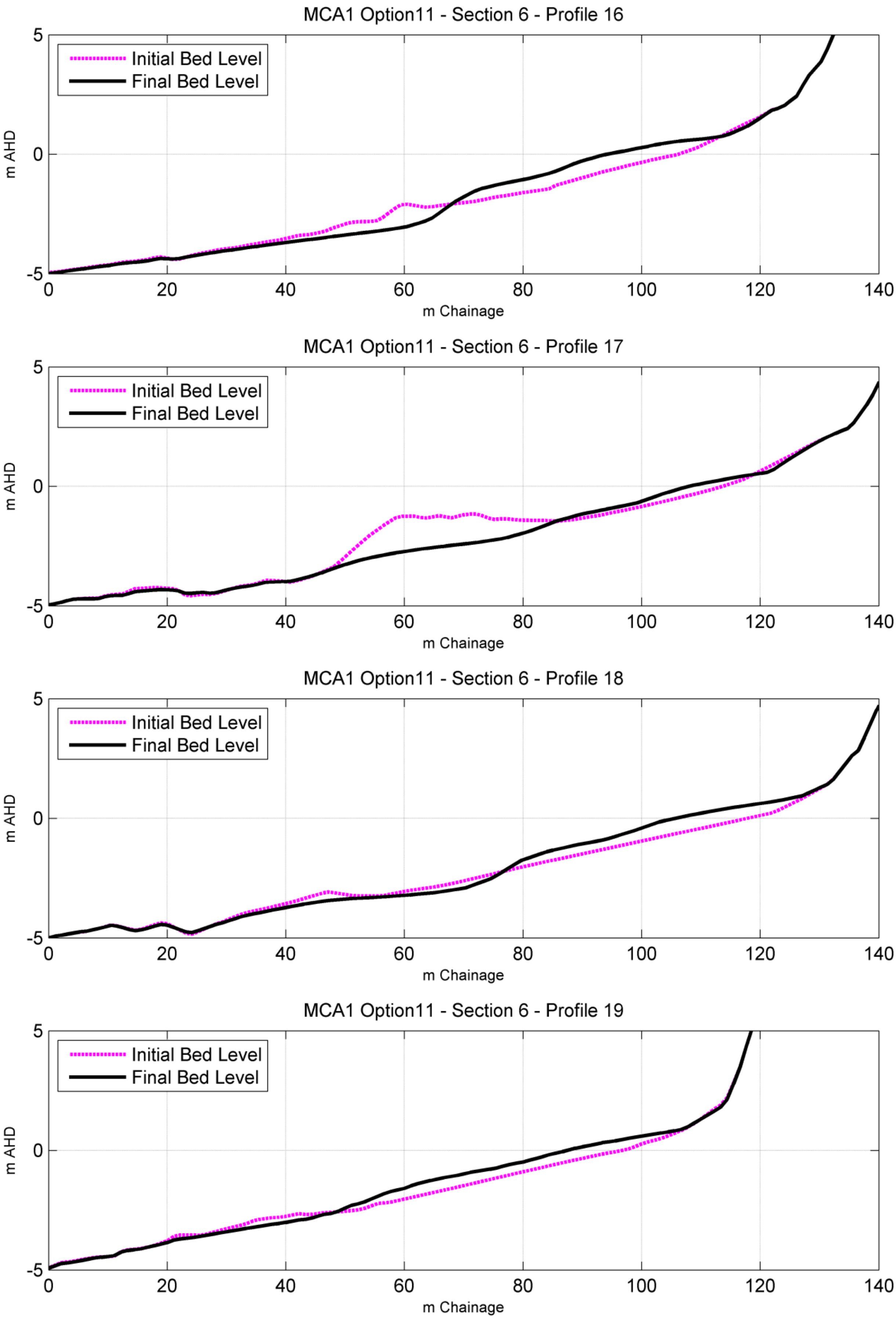


Figure D-43 XBEACH MCA1 Section 6: Initial & Final Beach Profiles

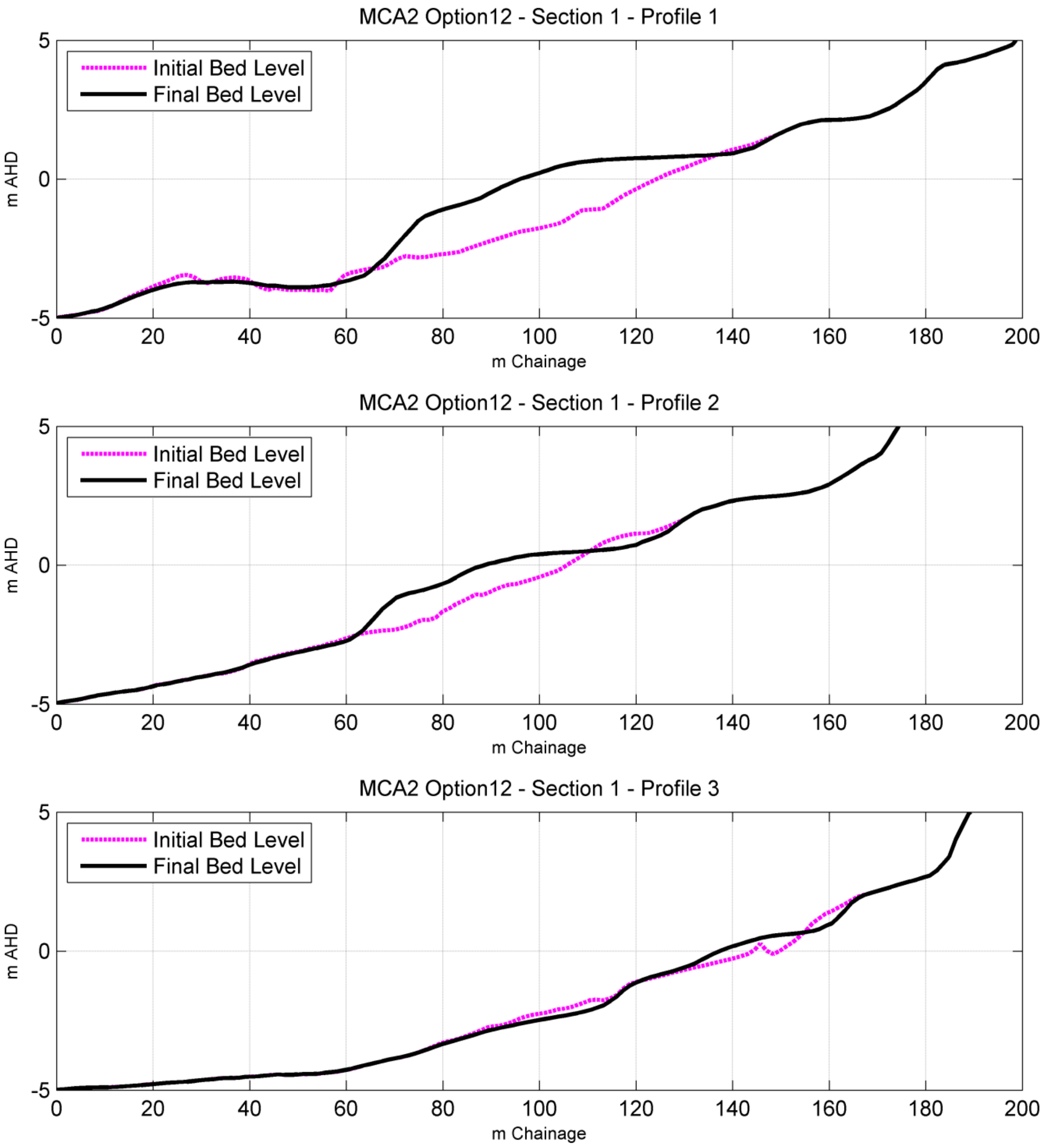


Figure D-44 XBEACH MCA2 Section 1: Initial & Final Beach Profiles

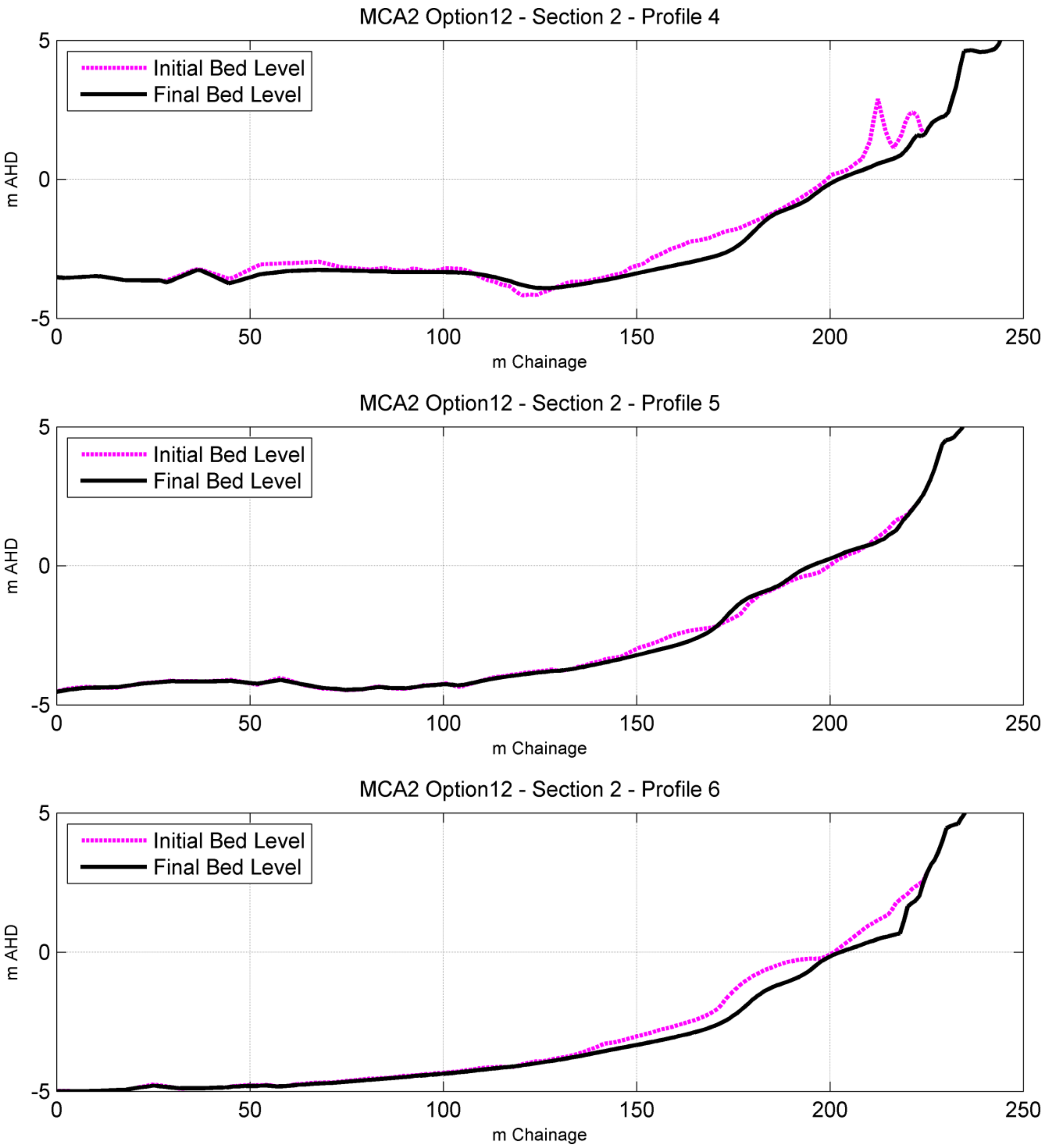


Figure D-45 XBEACH MCA2 Section 2: Initial & Final Beach Profiles

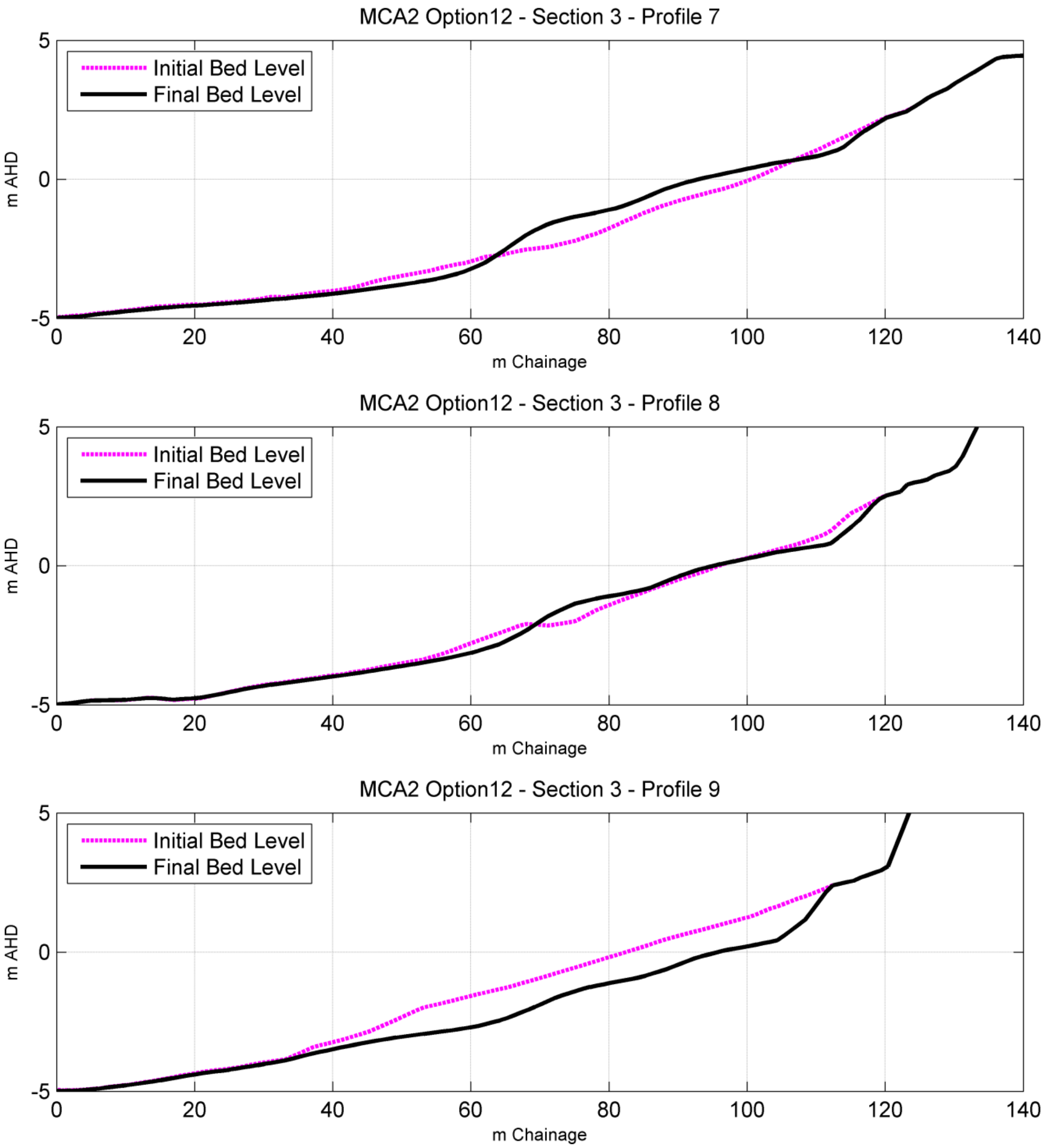


Figure D-46 XBEACH MCA2 Section 3: Initial & Final Beach Profiles

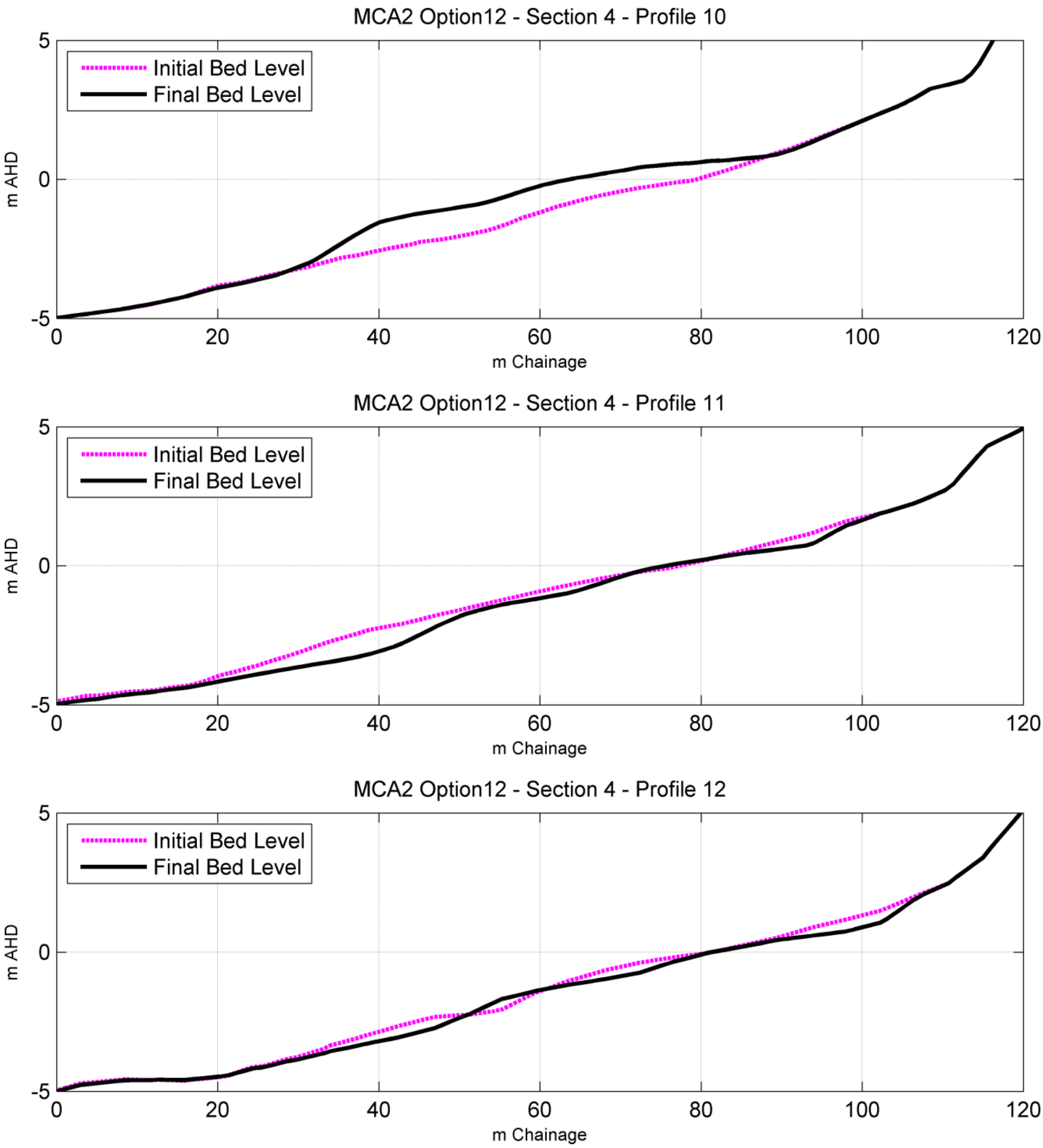
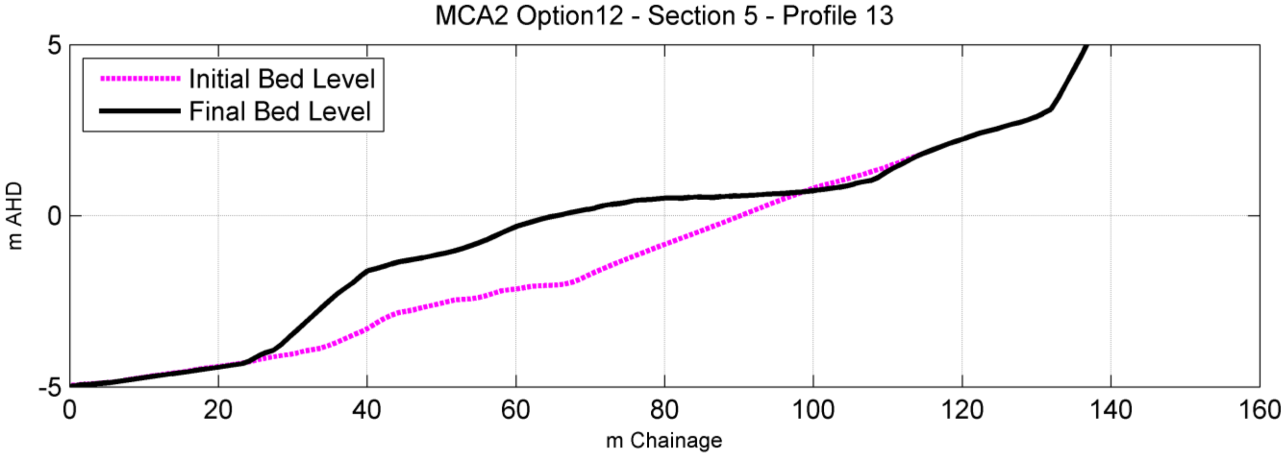
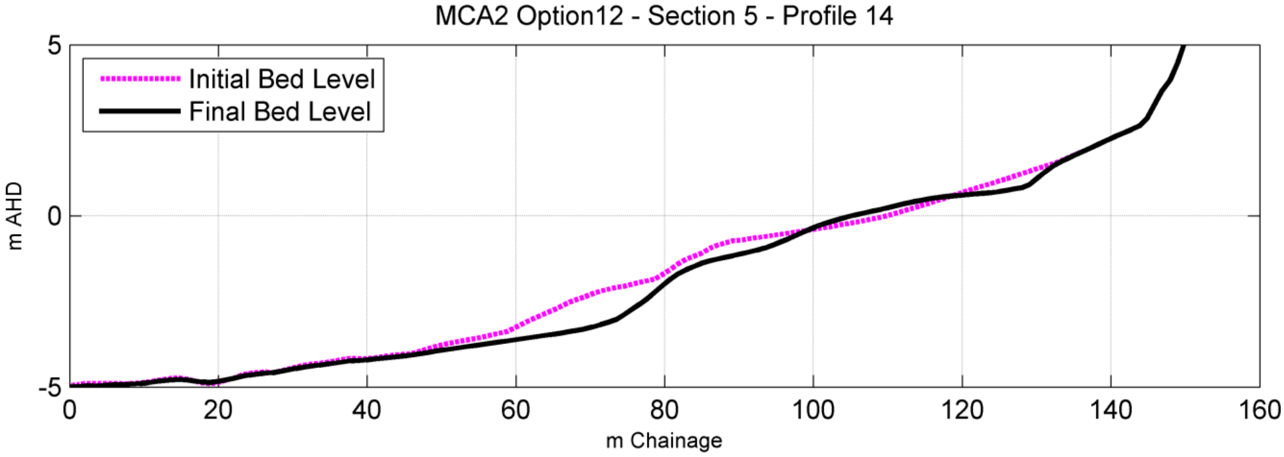


Figure D-47 XBEACH MCA2 Section 4: Initial & Final Beach Profiles





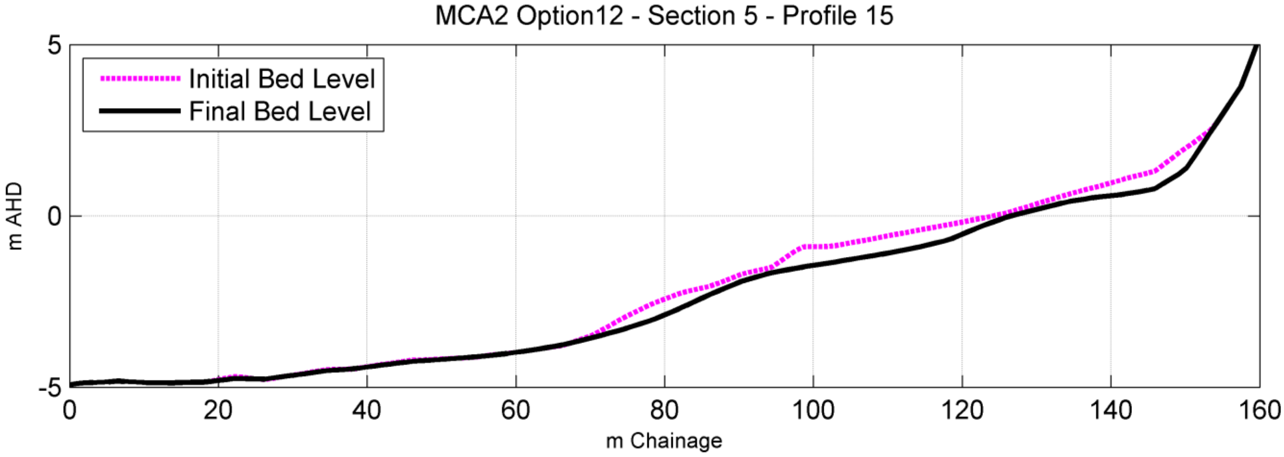


Figure D-48 XBEACH MCA2 Section 5: Initial & Final Beach Profiles

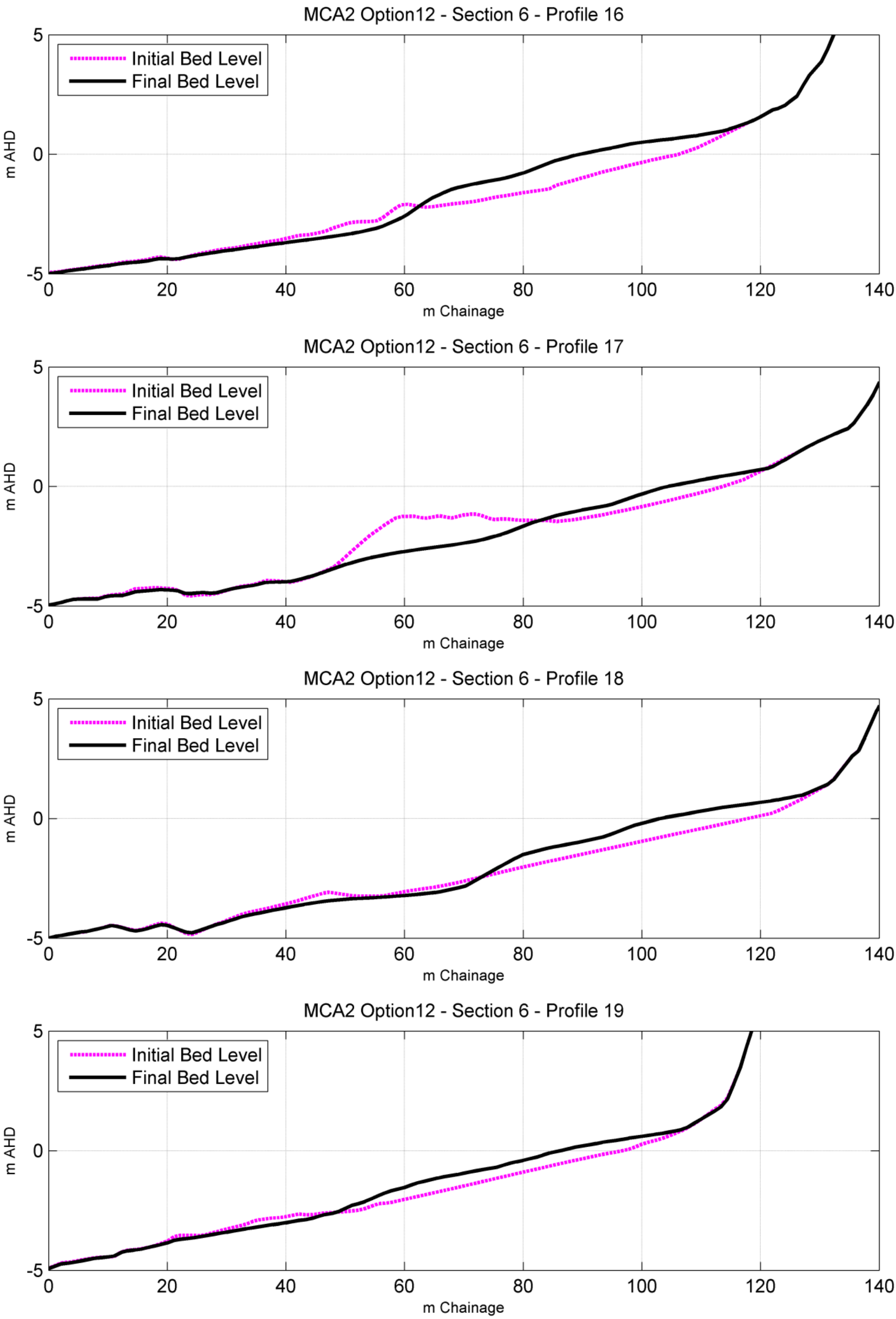


Figure D-49 XBEACH MCA2 Section 6: Initial & Final Beach Profiles

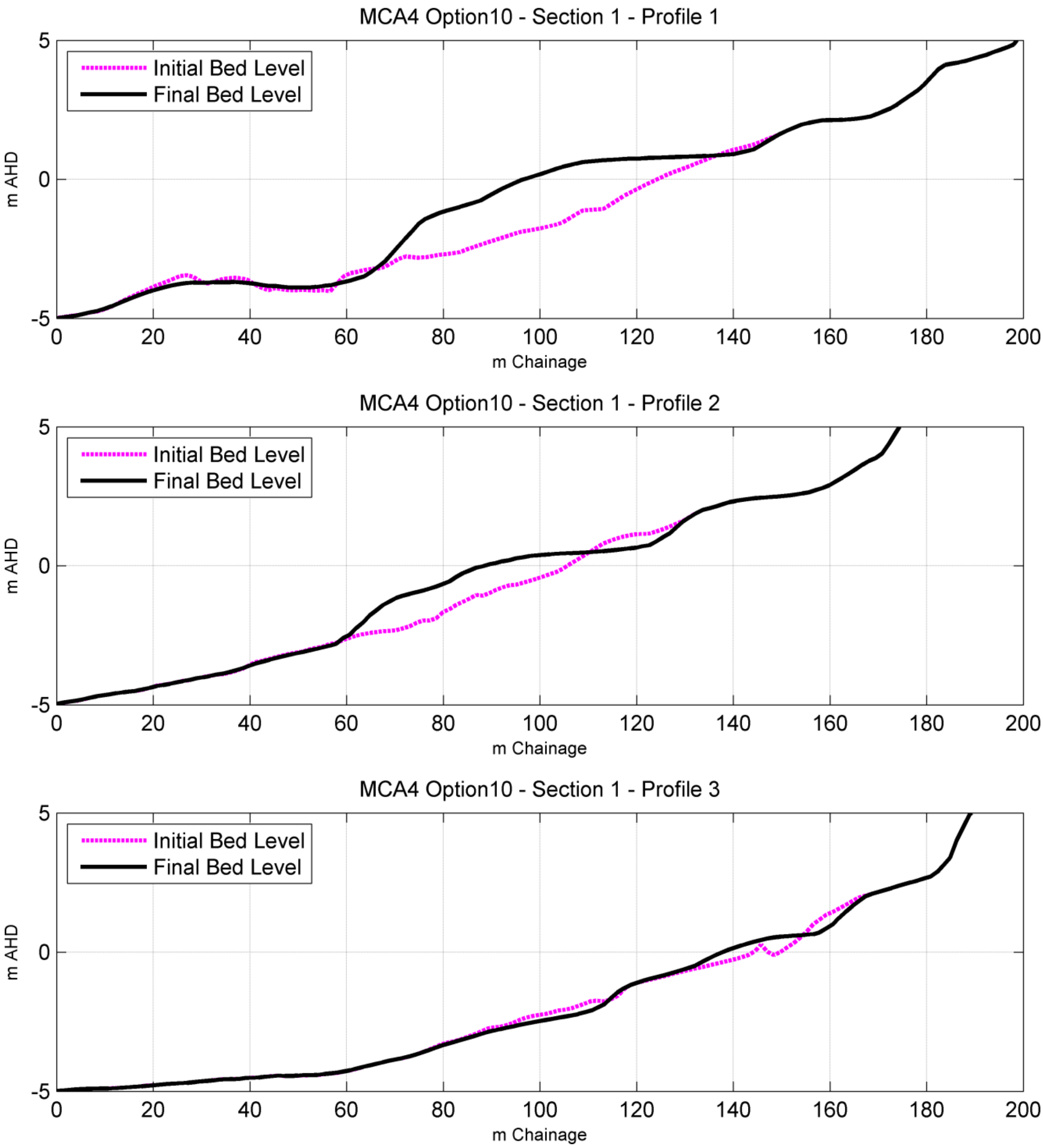


Figure D-50 XBEACH MCA4 Section 1: Initial & Final Beach Profiles

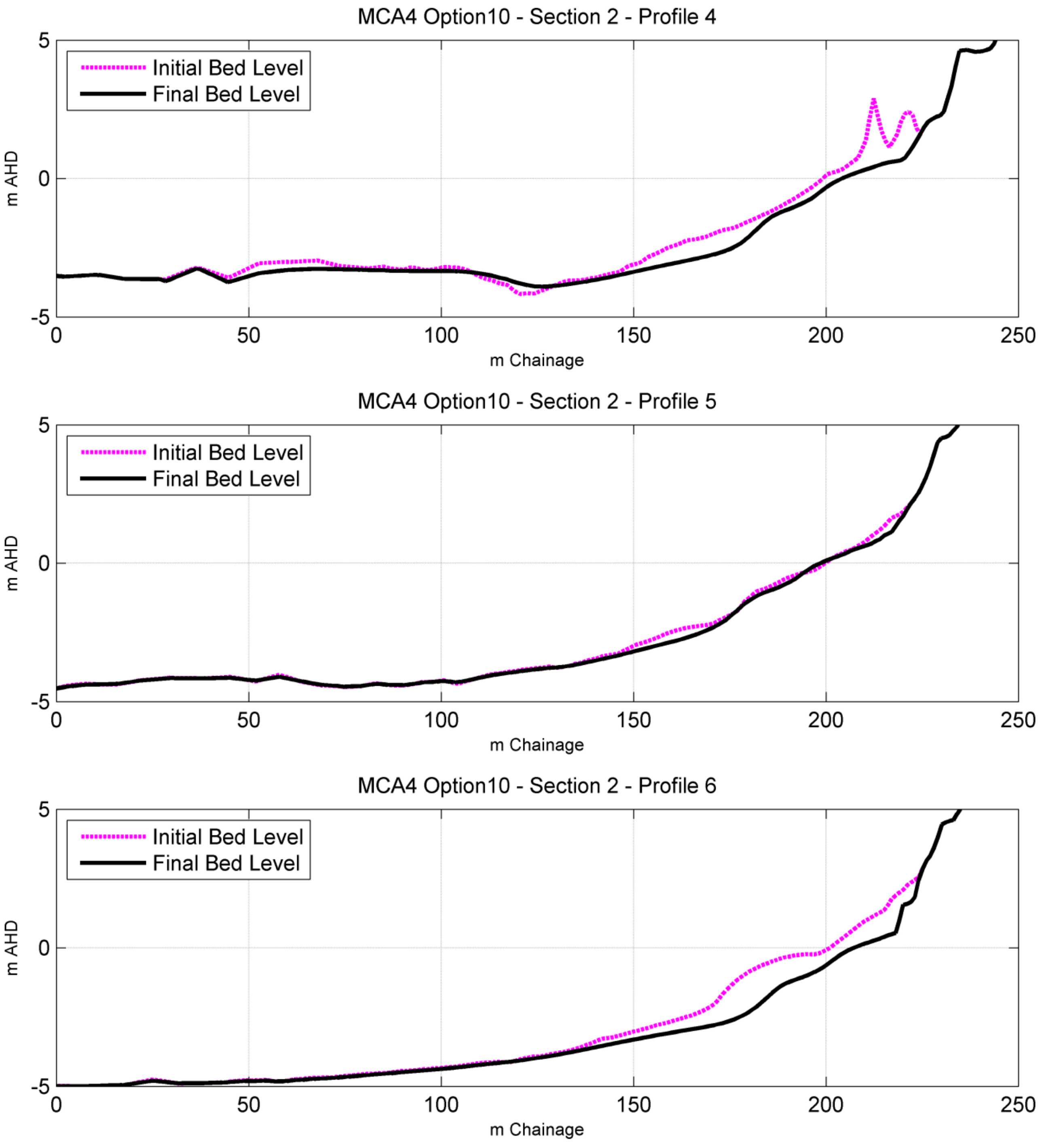


Figure D-51 XBEACH MCA4 Section 2: Initial & Final Beach Profiles

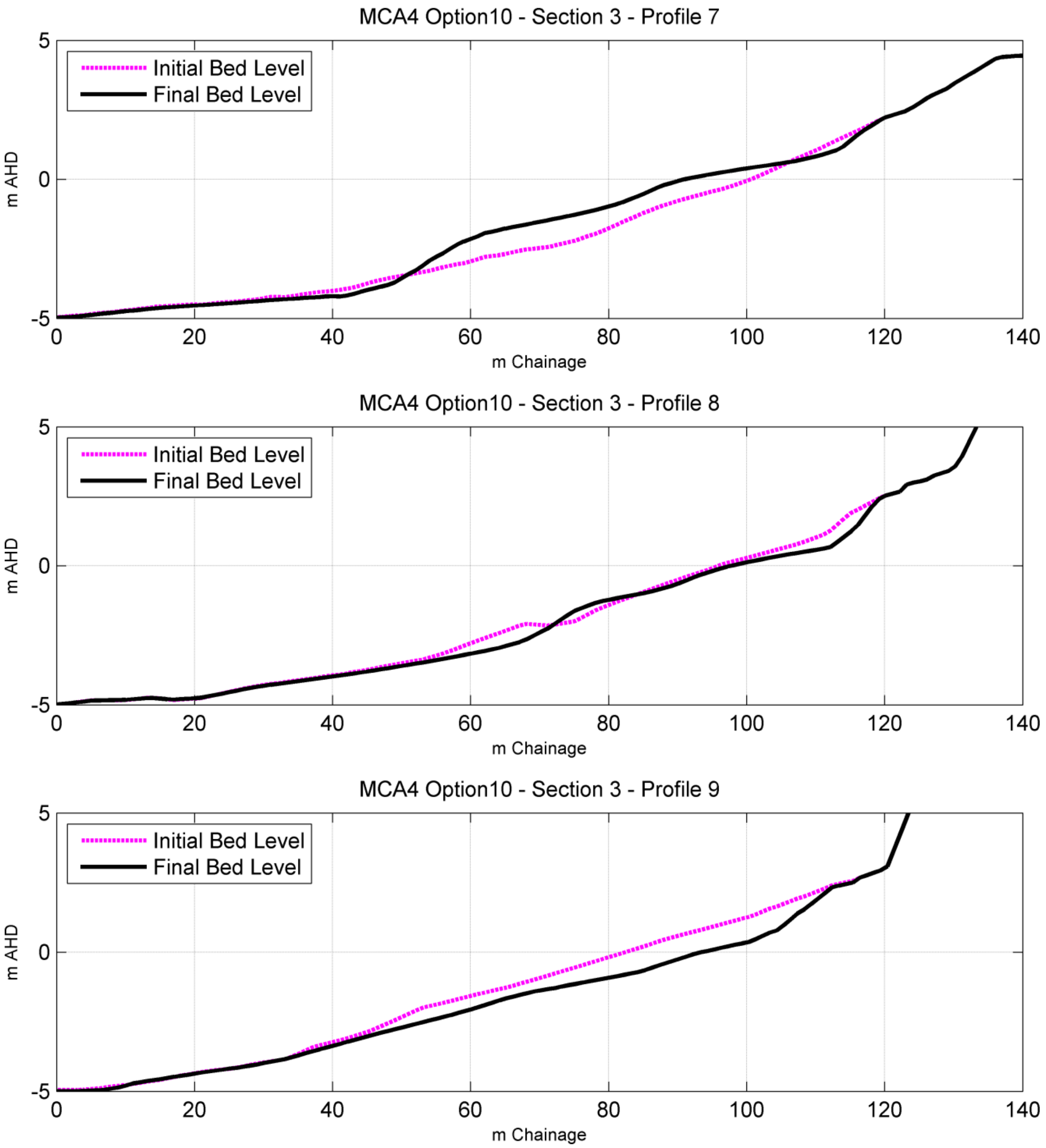


Figure D-52 XBEACH MCA4 Section 3: Initial & Final Beach Profiles

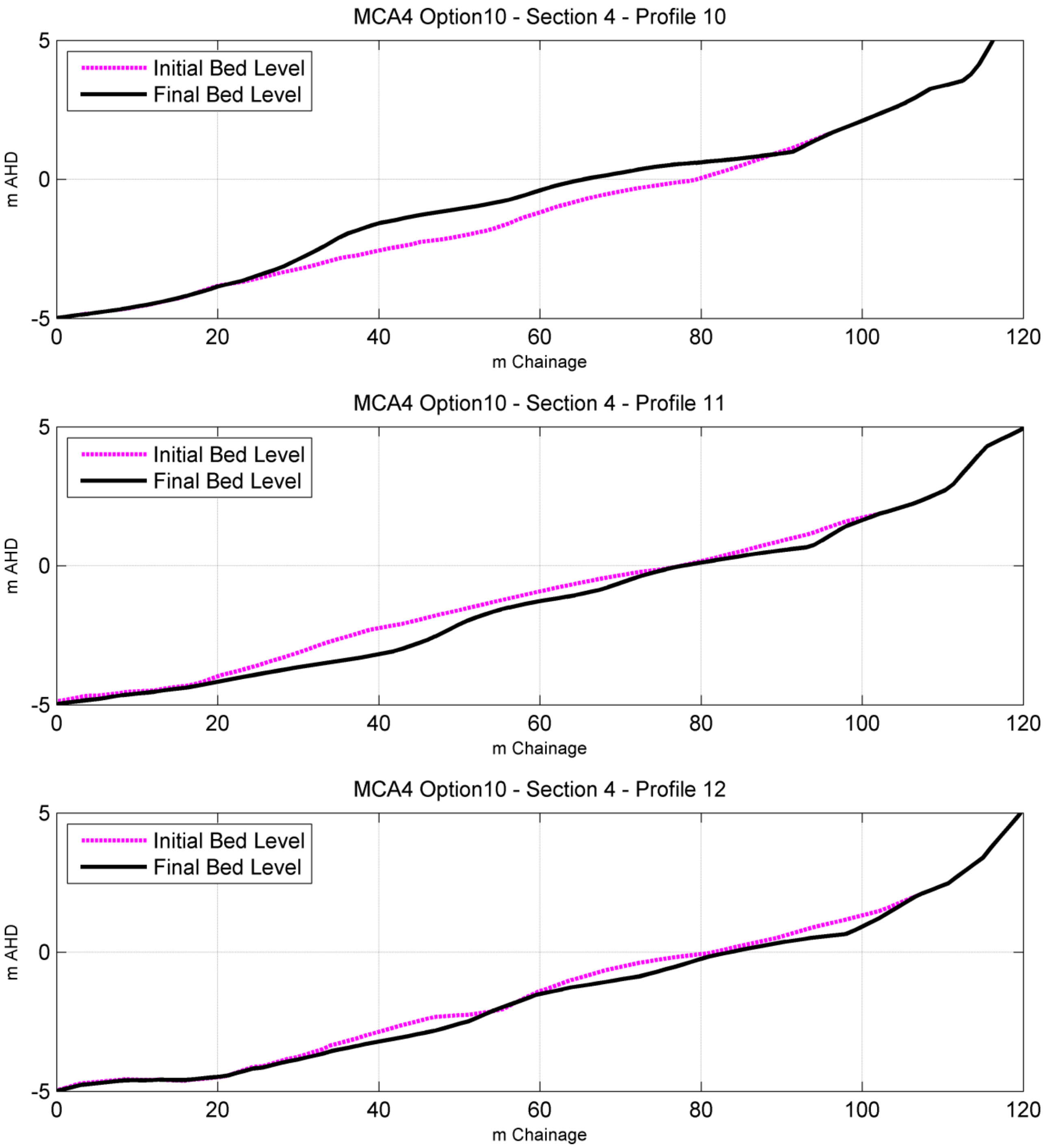


Figure D-53 XBEACH MCA4 Section 4: Initial & Final Beach Profiles

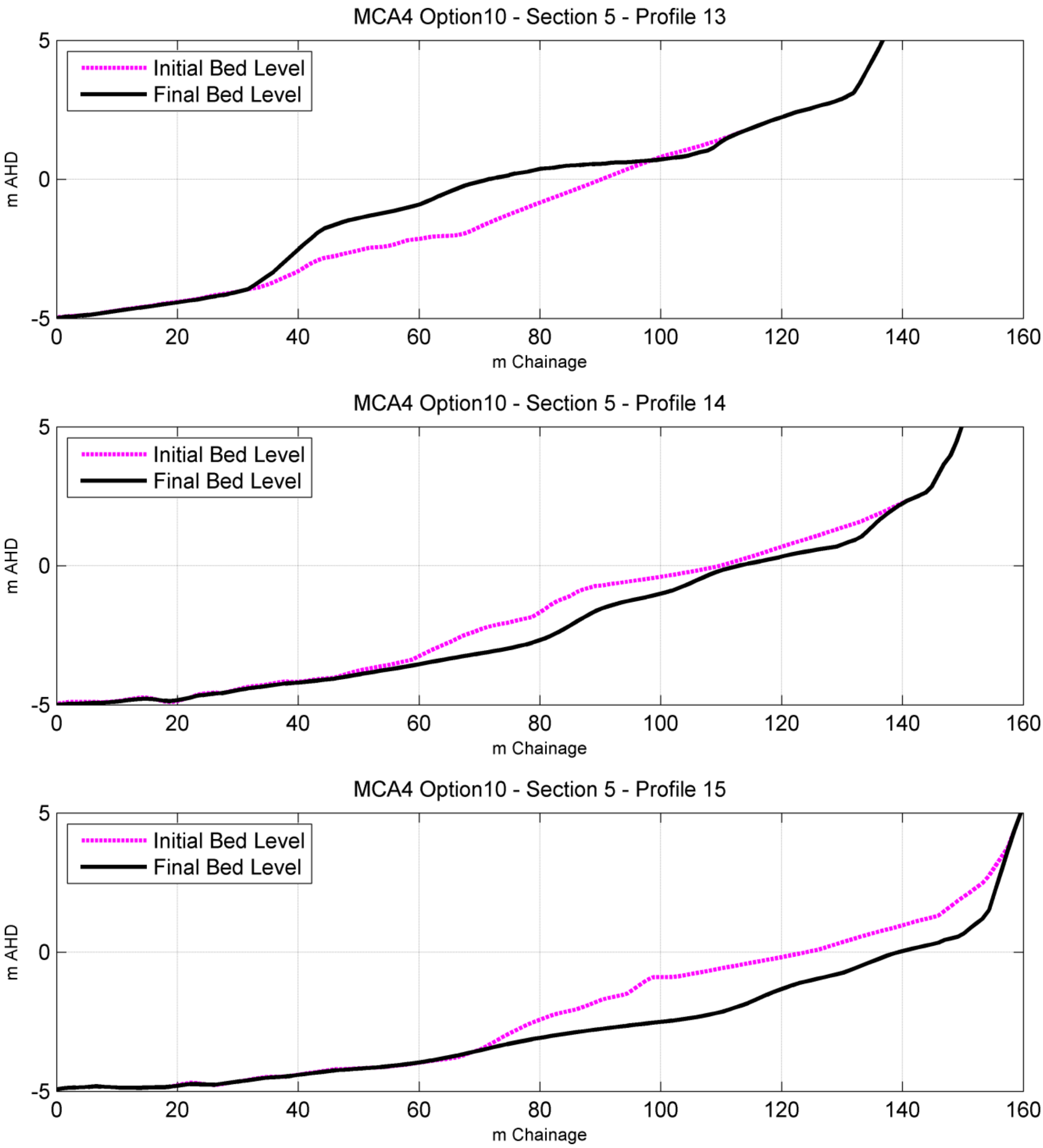


Figure D-54 XBEACH MCA4 Section 5: Initial & Final Beach Profiles

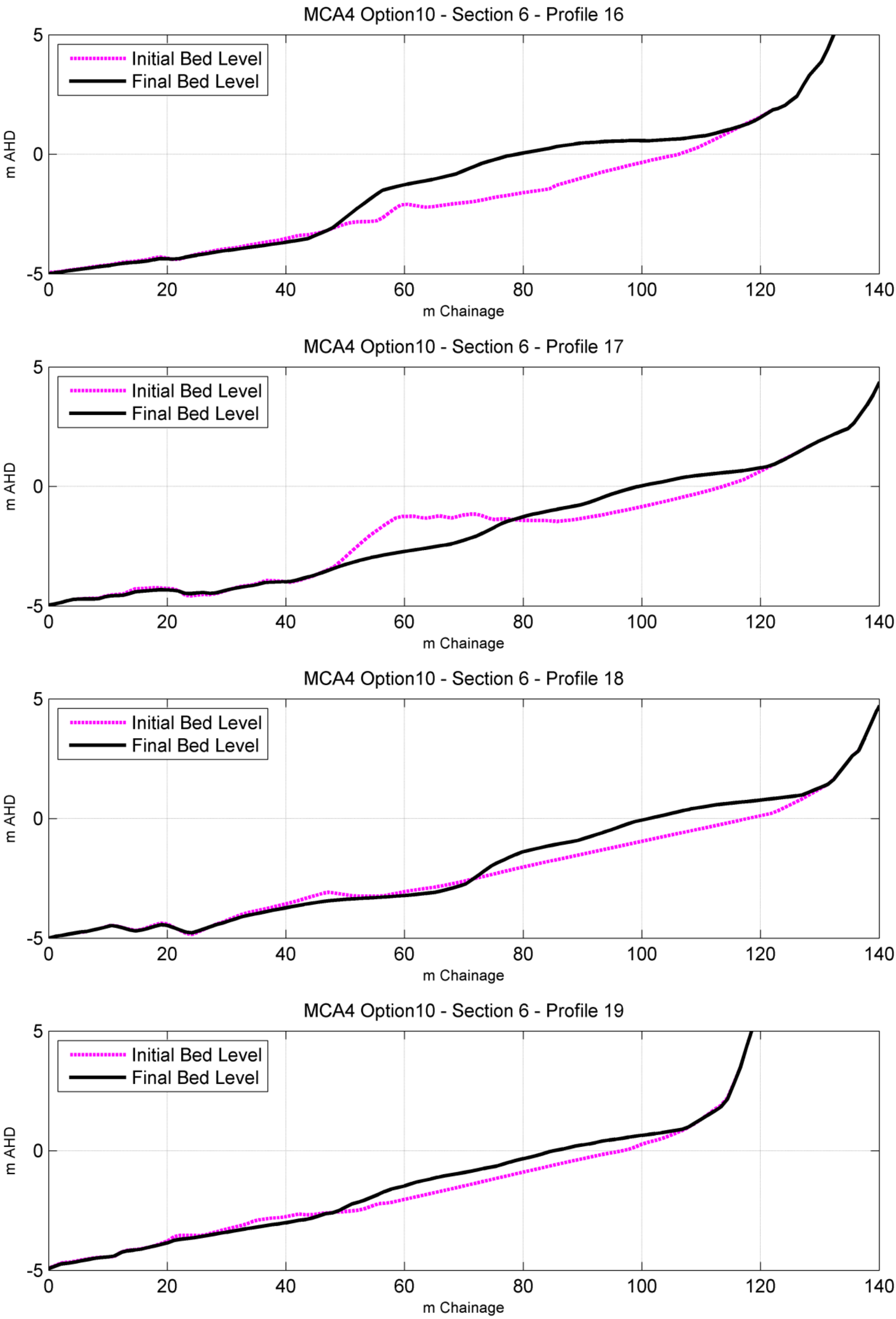


Figure D-55 XBEACH MCA4 Section 6: Initial & Final Beach Profiles

Conceptual Options Assessment

APPENDIX E

COST BREAKDOWNS

Cardno
Shaping the Future

Reference		Description	Qty	Units	Rate	Total
MCA1		Option 11	1	Item	4,135,387.98	4,135,387.98
A		*...Offshore B North*	*1*	*Item*	*1,193,104.02*	*1,193,104.02*
	1	......Preliminaries	1	Item	74,440.02	74,440.02
	2	......Core Material	2,200.00	m3	52.88	116,340.00
	3	......ElcoMax® 600R Geotextile	774	m2	9.49	7,344.00
	4	......Secondary Armour	2,240.00	TN	75	168,000.00
	5	......Primary Armour	10,820.00	TN	76.18	824,260.00
	6	......Clean up	1	Item	2,720.00	2,720.00
B		*...Offshore B Mid*	*1*	*Item*	*1,193,104.02*	*1,193,104.02*
	1	......Preliminaries	1	Item	74,440.02	74,440.02
	2	......Core Material	2,200.00	m3	52.88	116,340.00
	3	......ElcoMax® 600R Geotextile	774	m2	9.49	7,344.00
	4	......Secondary Armour	2,240.00	TN	75	168,000.00
	5	......Primary Armour	10,820.00	TN	76.18	824,260.00
	6	......Clean up	1	Item	2,720.00	2,720.00
C		*...Offshore B S3*	*1*	*Item*	*1,749,179.95*	*1,749,179.95*
	1	......Preliminaries	1	Item	108,685.02	108,685.02
	2	......Core Material	3,300.00	m3	52.88	174,510.00
	3	......ElcoMax® 600R Geotextile	1,174.00	m2	9.49	11,139.36
	4	......Secondary Armour	3,300.00	TN	73.04	241,017.87
	5	......Primary Armour	16,370.00	TN	73.98	1,211,107.71
	6	......Clean up	1	Item	2,720.00	2,720.00
		Contingency	10%		413,538.80	413,538.80
		Total			4,548,926.78	4,548,926.78

Quinns Beach Groynes - Cardno (OPTION MCA1)	Budget Estimate	Rev: 26th October 2015

Item	Item	Unit	Quantity	Rate	Total
A	**PRELIMINARIES**				
1	Site establishment, insurances and BCITF	Item	1	$90,154.05	$ 90,154.05
B	**OTHER INDIRECTS**				
1	Management and Supervision, Survey, Testing and Environmental Monitoring etc	Item	1	$362,906.25	$ 362,906.25
C	**ROCK SUPPLY AND DELIVER, LOAD AND HAUL AND INSTALLATION**				
1	SUPPLY & PLACING CORE	T	10,780	$42.62	$ 459,389.70
2	SUPPLY & PLACING SECONDARYARMOUR	T	7,787	$64.87	$ 505,111.55
3	SUPPLY & PLACING PRIMARY ARMOUR	T	38,010	$64.87	$ 2,465,629.24
4	TRIM CORE / INSTALL GEOTEXTILE 1200R (Using 3man Dive-Crew)	M2	2,722	$45.49	$ 123,829.22
5	INSTALL TEMPORARY BUNDS TO ACCESS OFF-SHORE GROYNES	T	6,599	$57.62	$ 380,250.88
6	LOAD & HAUL MATERIAL FROM STOCKPILE TO TIP HEAD	T	69,775	$13.07	$ 912,134.47
7	RECOVER & REMOVE TEMPORARY BUNDS OFF-SITE	T	6,599	$28.87	$ 190,496.63

D	**MOBILISATION/ DEMOBILISATION COSTS**		Unit	Rate	Total
1	MOBILISATION COSTS	EACH WAY	1	$ 127,050.00	$ 127,050.00
2	DEMOBILISATION COSTS	EACH WAY	1	$ 100,800.00	$ 100,800.00

E	**CONTINGENCY**	$ -
F	CONTRACT VALUE	$ 5,717,752.00

OK

Qualifications

Rev: 26th October 2015

W.A. LIMESTONE

1 Allowed surveyor full-time and 2No. GPS fitted to excavators.

2 No allowance for construction of access roads or temporary hardstand for incoming rock.

3 SCHEDULE OF RATES CONTRACT - based on quantities shown in above tables - revised rates to apply for any quantity variance more than "-15%"

4 Allowed Working hours Monday - Friday 7.00am to 5.00pm, and 7.00am - 1.00pm Saturday (5.5 days per week).

5 No Allowance for Weighbridge on site - Measurement of incoming materials by external weighbridges or Load-rite on site.

6 Above quantities have been based on imported Limestone Core and Armour to come from WA Limestone (Flynn Drive Quarry).

7 All rates and prices quoted are exclusive of GST.

8 Estimated Duration 16weeks

9 No allowance for roadsheeting material to groynes as no quants provided.

Reference	Description	Qty	Units	Rate	Total
MCA2:	Option MCA2: Option 12	1	Item	3,844,616.67	3,844,616.67
A	...Groyne 2 Extension	1	Item	1,965,461.65	1,965,461.65
1	......Preliminaries	1	Item	120,437.17	120,437.17
2	......Core Material	5,600.00	m3	53.3	298,467.62
3	......ElcoMax® 600R Geotextile	678	m2	9.56	6,483.73
4	......Secondary Armour	3,040.00	TN	75.59	229,793.49
5	......Primary Armour	17,030.00	TN	76.78	1,307,538.24
6	......Clean up	1	Item	2,741.40	2,741.40
B	...Groyne 3 Extension	1	Item	887,840.31	887,840.31
1	......Preliminaries	1	Item	89,757.74	89,757.74
2	......Core Material	1,600.00	m3	53.3	85,276.48
3	......ElcoMax® 600R Geotextile	242	m2	9.56	2,314.26
4	......Secondary Armour	4,000.00	TN	75.59	302,359.80
5	......Primary Armour	5,280.00	TN	76.78	405,390.64
6	......Clean up	1	Item	2,741.40	2,741.40
C	...Groyne 4	1	Item	991,314.71	991,314.71
1	......Preliminaries	1	Item	93,592.67	93,592.67
2	......Core Material	2,100.00	m3	53.3	111,925.36
3	......ElcoMax® 600R Geotextile	533	m2	9.56	5,097.09
4	......Secondary Armour	1,720.00	TN	73.61	126,609.57
5	......Primary Armour	8,710.00	TN	74.78	651,348.64
6	......Clean up	1	Item	2,741.40	2,741.40
	Contingency	10%		384,461.67	384,461.67
	Total			4,229,078.34	4,229,078.34

Quinns Beach Groynes - Cardno (OPTION MCA2)

Budget Estimate Rev: 26th October 2015

Item	Item	Unit	Quantity	Rate	Total
A	**PRELIMINARIES**				
1	Site establishment, insurances and BCITF	Item	1	$76,105.05	$ 76,105.05
B	**OTHER INDIRECTS**				
1	Management and Supervision, Survey, Testing and Environmental Monitoring etc	Item	1	$296,021.25	$ 296,021.25
C	**ROCK SUPPLY AND DELIVER, LOAD AND HAUL AND INSTALLATION**				
1	SUPPLY & PLACING CORE	T	13,020	$42.62	$ 554,847.30
2	SUPPLY & PLACING SECONDARYARMOUR	T	5,807	$64.87	$ 376,693.36
3	SUPPLY & PLACING PRIMARY ARMOUR	T	31,015	$64.87	$ 2,011,884.97
4	TRIM CORE / INSTALL GEOTEXTILE 1200R (Using 3man Dive-Crew)	M2	1,453	$45.49	$ 66,099.88
5	INSTALL TEMPORARY BUNDS TO ACCESS OFF-SHORE GROYNES	T	0	#DIV/0!	$ -
6	LOAD & HAUL MATERIAL FROM STOCKPILE TO TIP HEAD	T	49,842	$12.30	$ 613,237.68
7	RECOVER & REMOVE TEMPORARY BUNDS OFF-SITE	T	0	#DIV/0!	$ -

D	**MOBILISATION/ DEMOBILISATION COSTS**		Unit	Rate	Total
1	MOBILISATION COSTS	EACH WAY	1	$ 123,375.00	$ 123,375.00
2	DEMOBILISATION COSTS	EACH WAY	1	$ 97,125.00	$ 97,125.00

E	**CONTINGENCY**	$ -
F	CONTRACT VALUE	$ 4,215,389.49

OK

Qualifications

Rev: 26th October 2015

1 Allowed surveyor full-time and 2No. GPS fitted to excavators.

2 No allowance for construction of access roads or temporary hardstand for incoming rock.

3 SCHEDULE OF RATES CONTRACT - based on quantities shown in above tables - revised rates to apply for any quantity variance more than "-15%"

4 Allowed Working hours Monday - Friday 7.00am to 5.00pm, and 7.00am - 1.00pm Saturday (5.5 days per week).

5 No Allowance for Weighbridge on site - Measurement of incoming materials by external weighbridges or Load-rite on site.

6 Above quantities have been based on imported Limestone Core and Armour to come from WA Limestone (Flynn Drive Quarry).

7 All rates and prices quoted are exclusive of GST.

8 Estimated Duration 12 weeks

9 No allowance for roadsheeting material to groynes as no quants provided.

W.A. LIMESTONE

Reference		Description	Qty	Units	Rate	Total
A		Option MCA3: Removal of existing car park	1	Item	$ 240,573.37	$ 240,573.37
	1	...Preliminaries	1	Item	$ 58,630.02	$ 58,630.02
	2	...Removal of Car Park	1	Item	$ 80,160.00	$ 80,160.00
a		*......Remove and dispose of kerb*	*260*	*m*	*$ 9.00*	*$ 2,340.00*
b		*......Remove Drainage Structure (+backfill)*	*10*	*EA*	*$ 610.00*	*$ 6,100.00*
c		*......Remove Fence*	*250*	*m*	*$ 8.00*	*$ 2,000.00*
d		*......Remove unsuitable car park and dispose.*	*3,500.00*	*m2*	*$ 19.92*	*$ 69,720.00*
	3	...Reinstate Dune	1	Item	$ 101,783.35	$ 101,783.35
a		*......Bulk Cut to Fill 0-5000m3 (50m3/Hr) (no Haul)*	*1,750.00*	*m3*	*$ 9.00*	*$ 15,750.00*
b		*......Respread Topsoil*	*3,500.00*	*m2*	*$ 3.60*	*$ 12,600.00*
c		*......Supply and install Coir mesh*	*3,500.00*	*m2*	*$ 4.27*	*$ 14,945.00*
d		*......Plant tubestock*	*17,500.00*	*EA*	*$ 3.34*	*$ 58,450.00*
B		Option MCA3: Construction of new Car Park	1	Item	$ 267,184.02	$ 267,184.02
	1	...Preliminaries	1	Item	$ 54,225.02	$ 54,225.02
	2	...Clearing	2,100.00	m2	$ 9.00	$ 18,900.00
a		*......Clearing*	*2,100.00*	*m2*	*$ 5.17*	*$ 10,857.00*
b		*......Strip Topsoil 100mm (remove of site)*	*2,100.00*	*m2*	*$ 3.83*	*$ 8,043.00*
	3	...Car Park	2,100.00	m2	$ 44.79	$ 94,059.00
a		*......Bulk Cut to Fill 0-5000m3 (50m3/Hr) (no Haul)*	*1,050.00*	*m3*	*$ 8.40*	*$ 8,820.00*
b		*......Proofroll*	*2,100.00*	*m2*	*$ 0.33*	*$ 693.00*
c		*......Subgrade Prep Large Area*	*2,100.00*	*m2*	*$ 4.13*	*$ 8,673.00*
d		*......Limestone Sub base 1500m2 > 5000m2*	*2,100.00*	*m2*	*$ 12.06*	*$ 25,326.00*
e		*......Black Asphalt*	*2,100.00*	*m2*	*$ 20.00*	*$ 42,000.00*
f		*......SMK*	*150*	*m*	*$ 25.00*	*$ 3,750.00*
g		*......Linemarkig*	*1*	*Item*	*$ 2,000.00*	*$ 2,000.00*
h		*......Install signs*	*6*	*EA*	*$ 468.00*	*$ 2,808.00*
		Cardno addition				
	4	...Retaining Wall to Car Park	100.00	m	$ 1,000.00	$ 100,000.00
C		Construction of new toilet block			$ 80,000.00	$ 80,000.00
D		Path re-alignment and additional parking			$ 168,000.00	$ 168,000.00
a		*......Fill Material place and compact (from offsite)*	*1280*	*m3*	*$ 50.00*	*$ 64,000.00*
		......Path shift inc railings, signage, etc	*160*	*m*	*$ 100.00*	*$ 16,000.00*
		......Limestone retaining wall shift and raise	*160*	*m*	*$ 500.00*	*$ 80,000.00*
		......Black Asphalt	*400*	*m2*	*$ 20.00*	*$ 8,000.00*
		Contingency	10%		$ 67,575.74	$ 67,575.74
		Total			$ 823,333.13	$ 823,333.13

Reference	Description	Qty	Units	Rate	Total
MCA4:	Option MCA4: Option 10	1	Item	$ 8,351,329.47	$ 8,351,329.47
A	*...Groyne 1 Nib*	*1*	*Item*	*$ 1,238,791.67*	*$ 1,238,791.67*
1	......Preliminaries	1	Item	$ 170,882.65	$ 170,882.65
2	......Core Material	2,900.00	m3	$ 53.69	$ 155,686.69
3	......ElcoMax® 600R Geotextile	475	m2	$ 9.59	$ 4,557.59
4	......Secondary Armour	1,850.00	TN	$ 75.97	$ 140,543.49
5	......Primary Armour	9,900.00	TN	$ 77.21	$ 764,379.86
6	......Clean up	1	Item	$ 2,741.40	$ 2,741.40
B	*...Groyne 2 Y Extension*	*1*	*Item*	*$ 3,645,989.72*	*$ 3,645,989.72*
1	......Preliminaries	1	Item	$ 235,328.21	$ 235,328.21
2	......Core Material	10,600.00	m3	$ 52.94	$ 561,212.82
3	......ElcoMax® 600R Geotextile	1,234.00	m2	$ 9.50	$ 11,726.73
4	......Secondary Armour	5,680.00	TN	$ 75.42	$ 428,359.80
5	......Primary Armour	31,550.00	TN	$ 76.28	$ 2,406,620.77
6	......Clean up	1	Item	$ 2,741.40	$ 2,741.40
C	*...Groyne 3 Nib*	*1*	*Item*	*$ 1,951,301.02*	*$ 1,951,301.02*
1	......Preliminaries	1	Item	$ 195,164.54	$ 195,164.54
2	......Core Material	1,900.00	m3	$ 52.88	$ 100,475.48
3	......ElcoMax® 600R Geotextile	1,234.00	m2	$ 9.49	$ 11,708.66
4	......Secondary Armour	9,600.00	TN	$ 73.04	$ 701,142.87
5	......Primary Armour	12,670.00	TN	$ 74.20	$ 940,089.47
6	......Clean up	1	Item	$ 2,720.00	$ 2,720.00
D	*...Groyne 4*	*1*	*Item*	*$ 1,515,247.06*	*$ 1,515,247.06*
1	......Preliminaries	1	Item	$ 174,478.14	$ 174,478.14
2	......Core Material	3,100.00	m3	$ 53.16	$ 164,807.18
3	......ElcoMax® 600R Geotextile	477	m2	$ 9.57	$ 4,565.74
4	......Secondary Armour	2,640.00	TN	$ 73.41	$ 193,802.44
5	......Primary Armour	13,070.00	TN	$ 74.59	$ 974,852.17
6	......Clean up	1	Item	$ 2,741.40	$ 2,741.40
	Contingency	10%		835,132.95	835,132.95
	Total			9,186,462.42	9,186,462.42

Quinns Beach Groynes - Cardno (OPTION MCA4)

Budget Estimate Rev: 26th October 2015

Item	Item	Unit	Quantity	Rate	Total
A	**PRELIMINARIES**				
1	Site establishment, insurances and BCITF	Item	1	$109,436.25	$ 109,436.25
B	**OTHER INDIRECTS**				
1	Management and Supervision, Survey, Testing and Environmental Monitoring etc	Item	1	$448,691.25	$ 448,691.25
C	**ROCK SUPPLY AND DELIVER, LOAD AND HAUL AND INSTALLATION**				
1	SUPPLY & PLACING CORE	T	25,900	$42.62	$ 1,103,728.50
2	SUPPLY & PLACING SECONDARYARMOUR	T	11,350	$64.87	$ 736,264.29
3	SUPPLY & PLACING PRIMARY ARMOUR	T	67,178	$64.87	$ 4,357,657.24
4	TRIM CORE / INSTALL GEOTEXTILE 1200R (Using 3man Dive-Crew)	M2	2,652	$45.49	$ 120,644.78
5	INSTALL TEMPORARY BUNDS TO ACCESS OFF-SHORE GROYNES	T	0	#DIV/0!	$ -
6	LOAD & HAUL MATERIAL FROM STOCKPILE TO TIP HEAD	T	104,428	$11.62	$ 1,213,454.52
7	RECOVER & REMOVE TEMPORARY BUNDS OFF-SITE	T	0	#DIV/0!	$ -

D	**MOBILISATION/ DEMOBILISATION COSTS**		Unit	Rate	Total
1	MOBILISATION COSTS	EACH WAY	1	$ 127,050.00	$ 127,050.00
2	DEMOBILISATION COSTS	EACH WAY	1	$ 100,800.00	$ 100,800.00

E	**CONTINGENCY**	$ -
F	CONTRACT VALUE	$ 8,317,726.83

OK

Qualifications

Rev: 26th October 2015

W.A. LIMESTONE

1. Allowed surveyor full-time and 2No. GPS fitted to excavators.
2. No allowance for construction of access roads or temporary hardstand for incoming rock.
3. SCHEDULE OF RATES CONTRACT - based on quantities shown in above tables - revised rates to apply for any quantity variance more than "-15%"
4. Allowed Working hours Monday - Friday 7.00am to 5.00pm, and 7.00am - 1.00pm Saturday (5.5 days per week).
5. No Allowance for Weighbridge on site - Measurement of incoming materials by external weighbridges or Load-rite on site.
6. Above quantities have been based on imported Limestone Core and Armour to come from WA Limestone (Flynn Drive Quarry).
7. All rates and prices quoted are exclusive of GST.
8. Estimated Duration 21 weeks
9. No allowance for roadsheeting material to groynes as no quants provided.

Quinns Beach Groynes - Cardno (OPTION MCA5)

Budget Estimate Rev: 20th January 2016

Item	Item	Unit	Quantity	Rate	Total
A	PRELIMINARIES				
1	Site establishment, insurances and BCITF	Item	1	$56,869.05	$ 56,869.05
B	OTHER INDIRECTS				
1	Management and Supervision, Survey, Testing and Environmental Monitoring etc	Item	1	$253,464.75	$ 253,464.75
C	ROCK SUPPLY AND DELIVER, LOAD AND HAUL AND INSTALLATION				
1	SUPPLY & PLACING CORE	T	0	#DIV/0!	$ -
2	SUPPLY & PLACING SECONDARYARMOUR	T	2,000	$64.87	$ 129,745.18
3	SUPPLY & PLACING PRIMARY ARMOUR	T	10,000	$64.87	$ 648,683.08
4	TRIM CORE / INSTALL GEOTEXTILE 600R (Using 3man Dive-Crew)	M2	2,700	$38.95	$ 105,170.40
5	REMOVE CARPARK AND TRIM BATTER (SURPLUS SAND SPREAD TO BEACH)	T	2,250	$15.73	$ 35,388.75
6	LOAD & HAUL INCOMING MATERIAL FROM STOCKPILE TO TIP HEAD (Double-handling)	T	12,000	$11.62	$ 139,443.27

D	MOBILISATION/ DEMOBILISATION COSTS		Unit	Rate	Total
1	MOBILISATION COSTS		1	$ 95,865.00	$ 95,865.00
2	DEMOBILISATION COSTS		1	$ 74,865.00	$ 74,865.00

E	CONTINGENCY	$ 50,000.00
F	CONTRACT VALUE	$ 1,589,494.48

Qualifications

Rev: 20th January 2016

W.A. LIMESTONE

1. Allowed surveyor full-time and 2No. GPS fitted to excavators.
2. No allowance for construction of access roads or temporary hardstand for incoming rock.
3. SCHEDULE OF RATES CONTRACT - based on quantities shown in above tables - revised rates to apply for any quantity variance more than "-15%"
4. Allowed Working hours Monday - Friday 7.00am to 5.00pm, and 7.00am - 1.00pm Saturday (5.5 days per week).
5. No Allowance for Weighbridge on site - Measurement of incoming materials by external weighbridges or Load-rite on site.
6. Above quantities have been based on imported Armour to come from WA Limestone (Flynn Drive Quarry).
7. All rates and prices quoted are exclusive of GST.
8. Programme about 7 weeks from possession of site
9. Surplus sand material excavted from carpark batter to be spread on beach. Allowed 100T of material to go to landfill.

About Cardno

Cardno is an ASX200 professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

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