PRELIMINARY DESIGN AND NUMERICAL MODELLING FOR COASTAL STRUCTURES IN NETANYA

Numerical Modelling Report

Prepared for

Mediterranean Coastal Cliffs Preservation Government Company Ltd (MCCP)

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Introduction

Netanya is located on the southern coast of Israel, approximately 15 miles north of Tel Aviv. The study area is approximately 3 km long as shown in Figure 1.1

Figure 1.1: Project Location

Two detached breakwaters were constructed to the North of Netanya in the 1970's to protect the beach and tombolos have formed in this area. However, south of the breakwaters the frontage has suffered severe coastal erosion and the sections of the cliffs at the rear of the beach are in danger of collapsing due to erosion at the toe of the cliffs.

CH2M have been commissioned by MCCP to undertake detailed numerical modelling studies to evaluate the proposed scheme at Netanya and to assess potential alternative designs and developing the preliminary design of a preferred layout.

This document provides a summary of the design approach taken and provides a preliminary design and cost estimate of the preferred option.

Project Approach

The aim of this project is to develop wave and sediment movement models to predict the performance of the beach line under differing wave exposure based on deployment of shore parallel breakwaters, and to produce the preliminary design of a preferred option for a coastal protection scheme to prevent the erosion of the beaches and cliffs along the Netanya coastline. The project has been split into the following three phases:

- Phase 1 – Data collation and review, numerical model calibration, and evaluation of Layout 0
- Phase 2 – Numerical modelling of alternative layouts
- Phase 3 - Preliminary design of preferred layout

This report addresses Phases 1 and 2 of the Scope.

2.1 Phase 1 – Model Setup and Calibration

Phase 1 of the study comprised the creation of a calibrated wave model for the Netanya coastline, and the development of a 2D shoreline morphology model which was used to simulate sediment transport over a five year operational period for each of the alternative breakwater and nourishment configurations considered in the study.

2.1.1 Data Collation and Review

The data collation and review stage provided an overview of the existing meteorological and oceanographic data available for the study area and highlighted any areas where there may be insufficient data at Netanya. In conclusion, it was recommended that additional wave monitoring close to shoreline in the surf zone in front of project coastline should be undertaken, so the wave model parameters could be calibrated using reliable local data than the default parameters. An ADCP recorder was deployed at Netanya and the results from this, together with data from Haifa, Ashdod and Hadera, used to calibrate the spectral wave model for the Israel coast generally and for Netanya specifically.

2.1.2 Model Calibration

2.1.2.1 Wave Model

A spectral wave transformation model was set up covering the full Mediterranean Sea. This incorporated a finer mesh in the vicinity of Netanya to derive the offshore wave climate to be used in the project sediment transport model.

The wave climate in the model was generated by hourly wind data derived from a Climate Forecast System Reanalysis (CFSR) dataset, with the data checked using SW-Med model calibration and through comparisons with measured data. This calibration was based on data at Netanya, Hadera and Haifa. The model was further validated using other data sets taken at Hadera and Haifa.

A 35-year wave data series, from an Ocean Weather Inc (OWI) datapoint offshore from Netanya was used to estimate the extreme wave conditions offshore the project site and was input to a LITDRIFT model to estimate the sediment budget at the project site.

2.1.2.2 Sediment Transport Model

The results from LITDRIFT showed that, at Netanya, the integrated net sediment transport is directed towards the north. However, while the transport is northwards in deeper water, there is a zone close to the water line, out to 100m offshore, where the local net transport is southerly. This has an impact on the performance of beaches in the lee of protective structures in shallow water.

A 2D hybrid-shoreline morphology model (Coupled FM Shoreline Morphology (SM)), which simulates the hydrodynamics and sediment transport over the bathymetry of the model area with a morphological scheme, was developed to simulate sediment transport and long-term shoreline morphologic changes of the proposed shoreline erosion mitigation option along Netanya coastline.

The model was calibrated using the initial historical shoreline position data of May 1997 to reproduce a modelled shoreline that matches the historical shoreline positions from the May 2002 aerial (a five year period that was replicated in the model). Calibration results show that the 2D sediment transport model generates similar order of magnitude alongshore sediment transport rates as in the 1D shoreline evolution model. The 2D model results are also in agreement with the rates from previous studies by others in open literature (Golik and Rosen 1999, Golik 2002). Based on the calibrated sediment transport model, preliminary annual alongshore net and gross sediment transport rates are estimated to be 160k m^3 per year and 500k m^3 per year for the existing shoreline, for beach material of between 180 and 220 micron median diameter.

Model sensitivity simulations were carried out to determine model response to different input parameters. The model's predictive capability to produce salient formation behind a nearshore detached breakwater starting with initial straight shoreline with offshore bathymetric contours parallel to initial shoreline alignment, then two nearshore detached breakwaters, each approximately 250 m long at 4.0 water depth, were added into the model. Morphological shoreline response revealed two salient features similar to the existing Sironit Beach after the 5 year simulation (so replicating the development of the salients following construction).

In addition, the effect of median sediment grain size on morphological evolution was investigated using a larger median sediment grain size, D_{50}, 0.28 mm than the native beach. A nearshore detached breakwater at the southern end of the project shoreline was also included to check salient development elsewhere in the model. As expected, the alongshore transport rate reduced slightly compared to the original case with median sediment grain size, D_{50}, 0.22 mm.

In summary, it is found that the sediment transport model is capable to produce salient formation starting from straight initial beach after 5 years of shoreline evolution. In addition, the model using coarser median grain size diameter than the native beach predicted slightly smaller net alongshore sediment transport rates which results in very small differences in shoreline responses.

2.1.3 Project Premise

The evaluation of the original CAMERI breakwater layout and assessment of the alternatives developed as a result were based on the following premise:

1) Sand nourishment should be ideally be limited to 570k m^3 to reflect the existing permitted volume.
2) The extent of the scheme should match that used by CAMERI
3) The positioning of larger structures (to form enhanced beaches) should correspond to the three primary hotels on the cliff top
4) The criteria for successful solution should be measured by the absence of beach erosion under the modelling process resulting in the retreat of the existing cliff toe.

2.1.4 Assessment of CAMERI Breakwater Configuration

After successful model calibration, Phase 1 of the project involved modelling the original CAMERI breakwater layout to determine the effectiveness of this scheme. Initial beach nourishment using approximately 680k m^3 sand, above that set as the target nourishment volume. It was concluded that this configuration did not provide sufficient nourishment of the beaches and the shoreline receded up to the toe of cliffs. The same (CAMERI) breakwater layout was then modelled with increased beach nourishment, approximately 1.5 M m^3 (Layout A0_2) and the model results indicated that this provided sufficient protection to prevent erosion of the cliffs, albeit with nearly three times the permitted nourishment volume.

2.1.5 Phase 2 – Assessment of Breakwater Alternatives

Phase 2 of the project involved modelling alternative options. Four alternative layout options with some further refinements were modelled considering different combinations of beach nourishment and detached breakwater layouts. The model simulations considered a 5 year time frame as most of the morphological changes occur within the first couple of years and shoreline morphology remained more or less unchanged after 3 years of simulations. The main objective of this report is to supplement the calibration model report and provide detailed descriptions of each layout options along with modelling results.

Phase 1: Layout A0_1

The A0_1 layout comprises an array of 11 detached breakwaters, parallel to the coast, located to the south of the existing twin breakwaters, positioned as per the CAMERI breakwater configuration. These breakwaters are designed to protect approximately 3 km of coastline. The array consists of 3 large breakwaters, each 200 m long, at a distance of 250-265 m from the shoreline, and 8 smaller breakwaters with lengths ranging from 100 to 140 m, at a distance of 200 m from the shoreline as shown in Figure 3.1. At the southern end of the site a 250 m long groyne structure is added to reduce alongshore sediment losses from the beach system.

An initial beach nourishment slightly higher (680k m^3) than permitted (570k m^3) which provided approximately 25 m initial beach width at +1.5 m CD elevation was considered in the morphology model simulations. Figure 3.2 shows initial beach with local bathymetry for A0_1. Shoreline evolution with the initial beach nourishment volume is shown in Figure 3.3. The shoreline retreated to the toe of cliff behind the small detached breakwaters at the central and southern part of the project coastline after 5 years. This is due to the initial beach fill volume being too small. A zoomed in view of initial vs. final shoreline position near the southern extremity of the project coastline is shown in Figure 3.4. It can be seen that there is an area between small detached breakwaters where the beach cuts back into the cliff after 5 years. The model results revealed that erosion of the cliff would not be prevented. A slight shoreline erosion also occurred up to 300 m distance at the updrift side of the terminal groyne after 5 yrs.

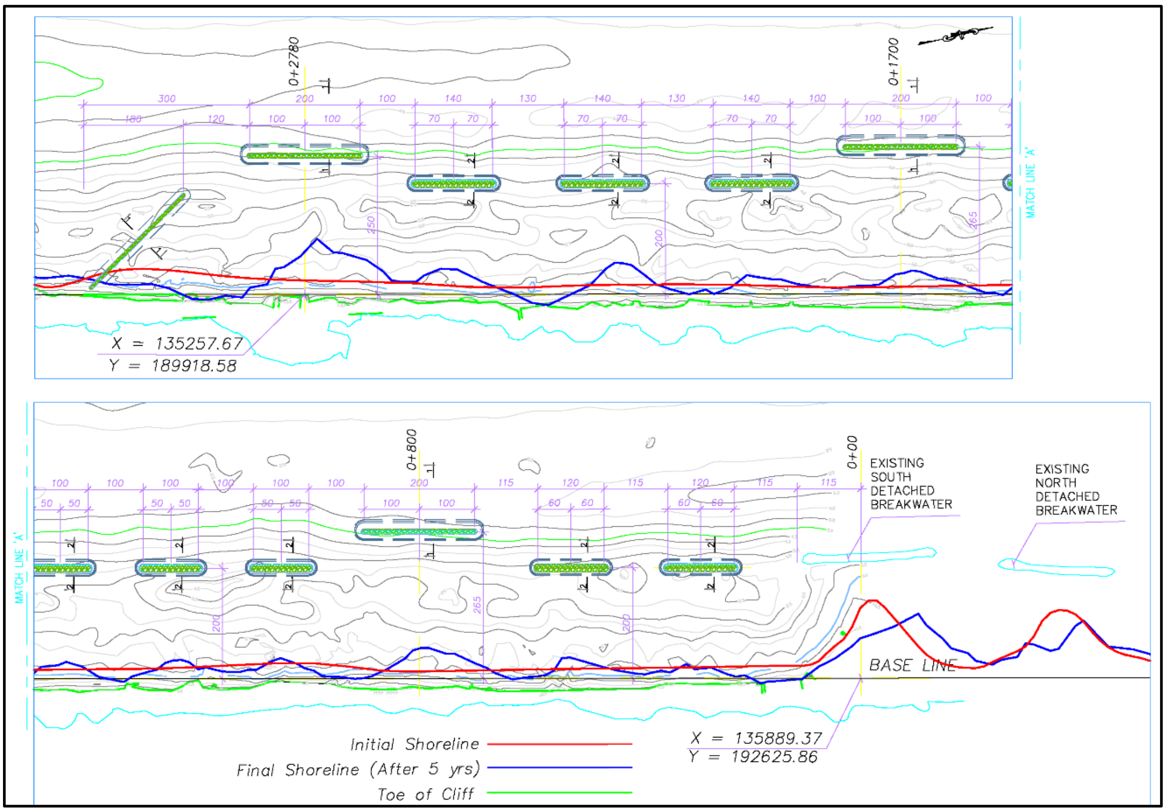

Figure 3.1 - Layout A0_1

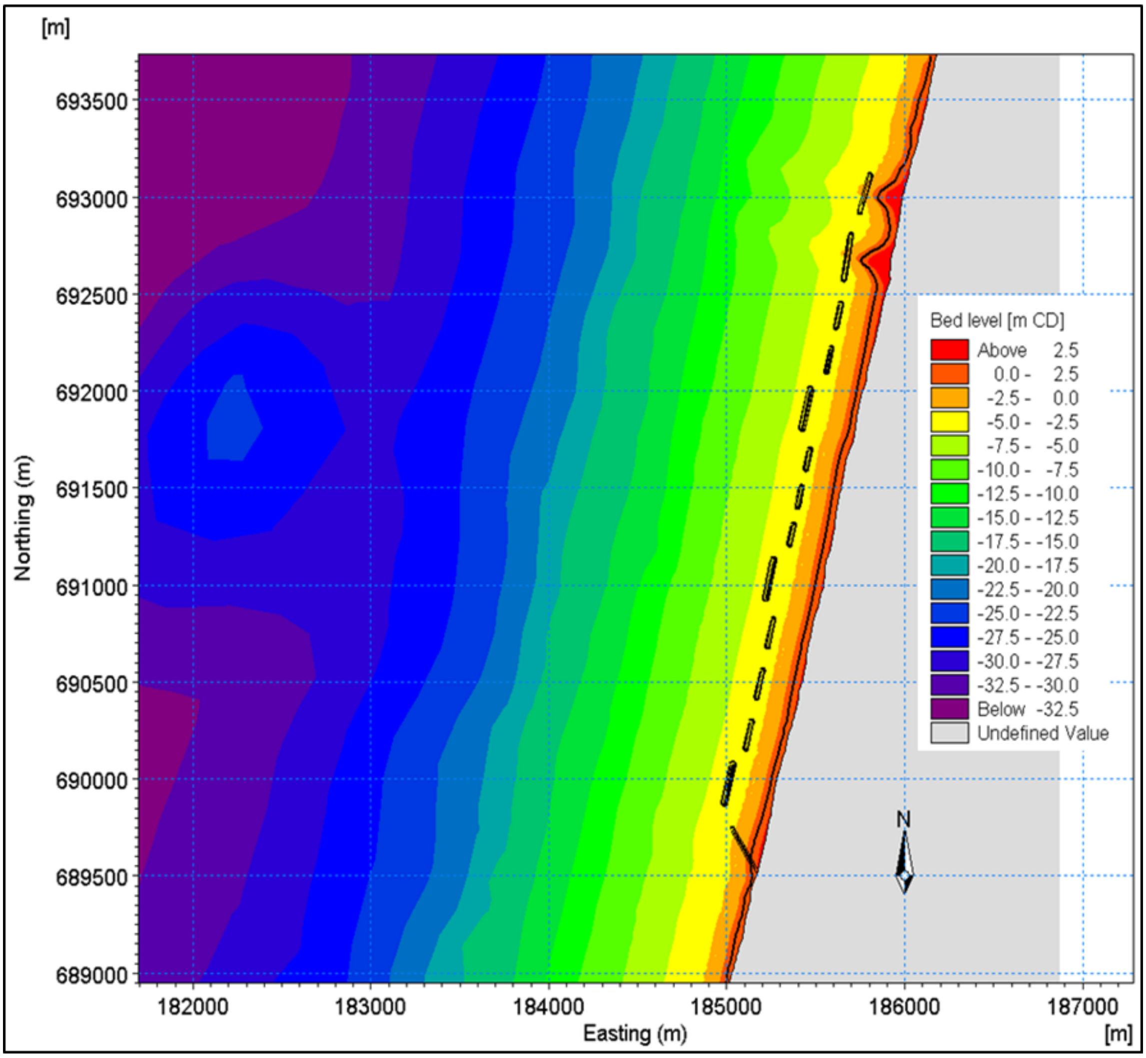

Figure 3.2 -Model bathymetry with Layout A0_1

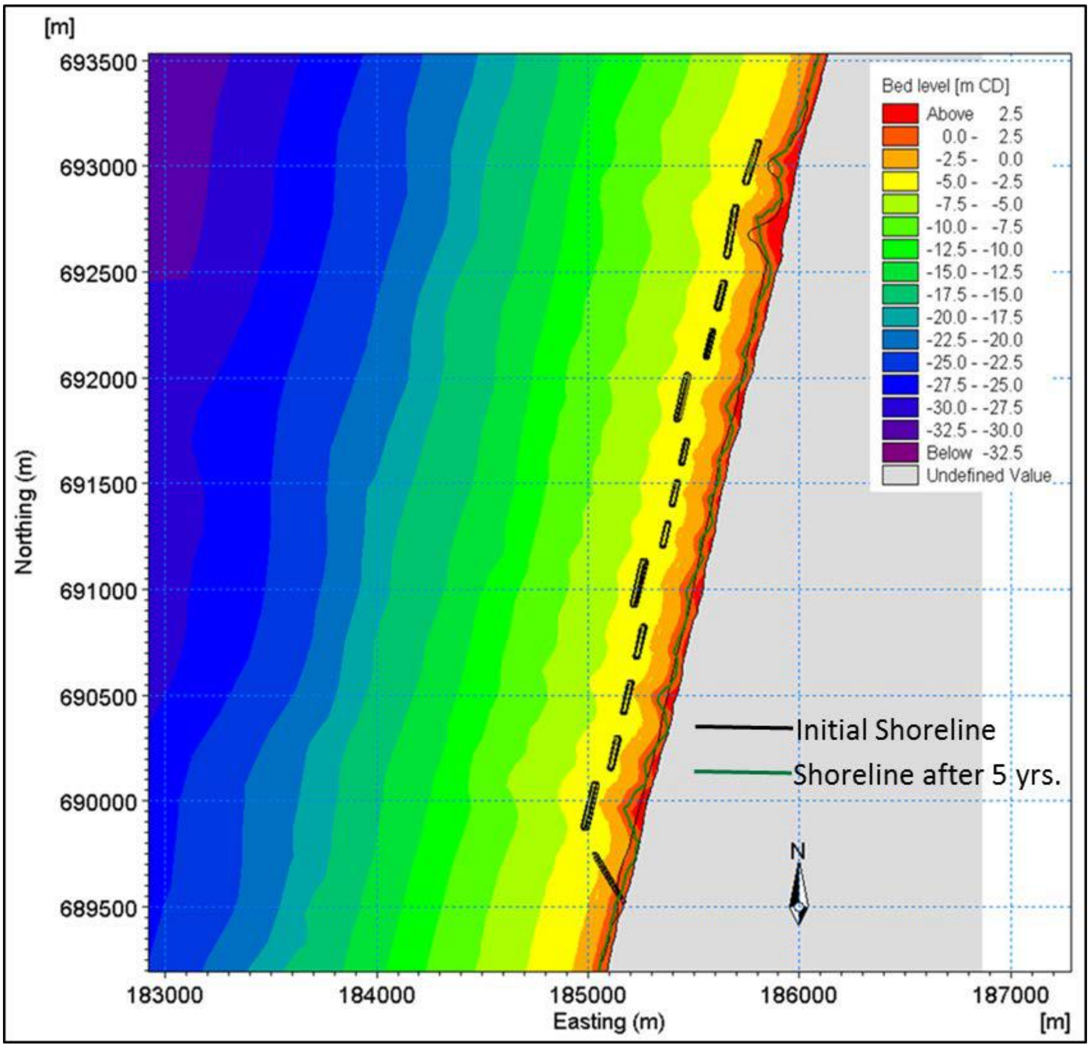

Figure 3.3: Equilibrium bathymetry for A0_1 Layout (after 5 yrs.)

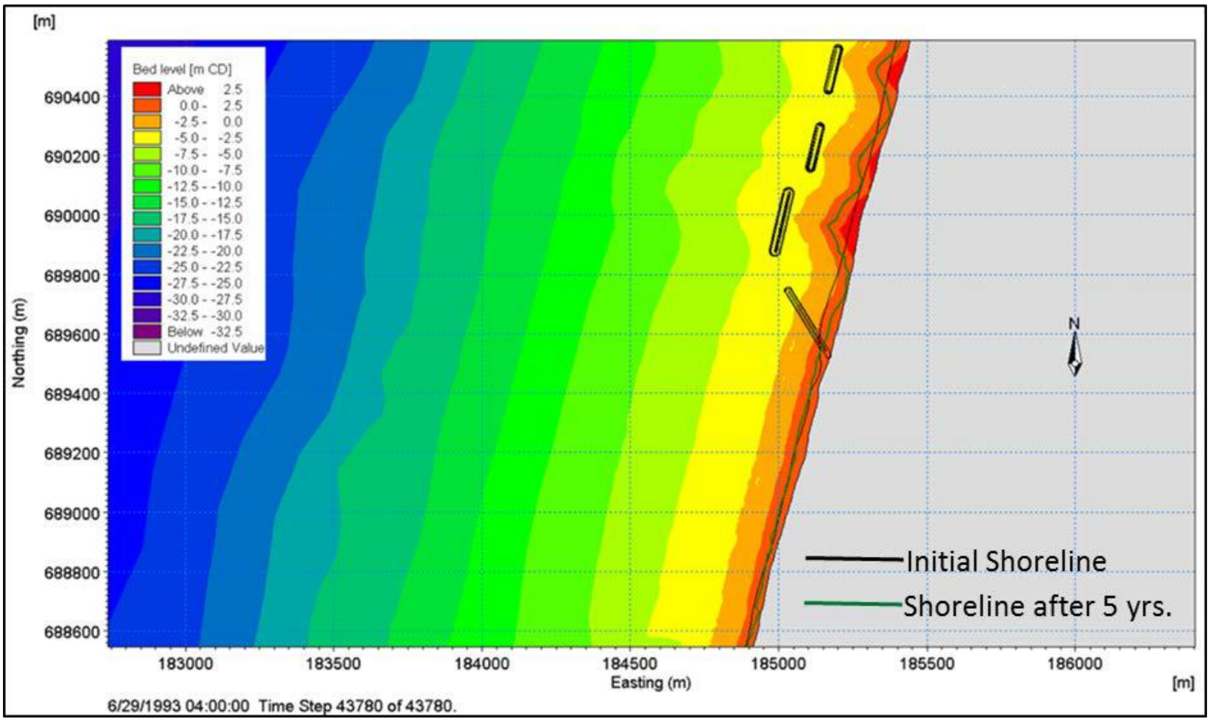

Figure 3.4: Zoom in view of equilibrium bathymetry for A0_1 Layout (after 5 yrs.)

3.1 Layout A0_2

Following the results of the A0_1 layout, the same breakwater layout was modelled with increased beach nourishment. It is assumed that beach will be pre-nourished with native sand giving a beach with a 75-m wide beach crest behind the large offshore breakwaters and 55 m wide beach behind the small detached breakwaters, (hereafter, A0_2). These dimensions match those indicated in the CAMERI design documentation. The initial beach fill volume was not clearly stated in the CAMERI report (CAMERI, 2012). Using the beach widths stated above, it was determined that a pre-nourishment volume of around 1.5 M m^3 along the 3.0 km long shoreline (see Figure 3.5) is required to form this initial beach profile. This exceeds the expected volumes set by MCCP.

Simulation results show that the project's protection scheme causes the shoreline to migrate seawards, and that the effects on the tombolo behind the existing twin breakwaters are minor. Assuming the 5-year simulated shoreline described the stable final situation, salient heights predicted are of the order of 75 m for the large breakwaters and 30 m for the small ones, with respect to the initial shoreline (see Figure 3.6). Although, the results show acceptable beach width after 5 years of evolution, the initial beach fill requirements of 1.5 M m^3 is excessively large from project feasibility point of view.

Results for selected representative winter waves, propagating roughly from west southwest, with respect to the present shoreline, is shown in Figure 3.7 Reduction in wave height and deflection of the waves behind the detached breakwaters are clearly visible. To reduce numerical model run time the model baseline was set up at the southern groyne. So, it wasn't possible to observe shoreline morphology at the south of the southern groyne for this case. It is anticipated that shoreline recession would be similar to A0_1 case as shown in Figure 3.3

Figure 3.8 depicts flow field for the same winter storm around detached breakwaters. The flow patterns obtained are quite complex. Eddy currents are formed in the area protected by the breakwaters. Therefore, similar patterns apply for the sediment transport fields too.

Some unusually high current speed occurs in the eddy circulations which forms in the lee of the southern breakwater. This is mainly due to the large opening (approximately, 200 m) between the tip of groyne and most southern large detached breakwater. The circulating flow speed, in the lee of the southern breakwater, reaches about 1.1 m/s (see Figure 3.8). In comparison, the largest average flow speed in the coastal area without breakwaters is, approximately, 0.6 m/s.

The flow field plots also show some strong flows entering the protected area, and some leaving it. This will ensure an appropriate water exchange within the area protected by the detached breakwaters.

Figure 3.9 shows distribution of annual net alongshore sediment transport rates along the project coastline. As anticipated, the transport rate is slightly larger in front of the southern groyne and varies between 100k m^3/yr. and 125k m^3/yr. at the detached breakwaters. The annual gross alongshore sediment transport rate fluctuates between 200k m^3/yr. and 250k m^3 /yr. for the same stretch of coastline (Figure 3.10).

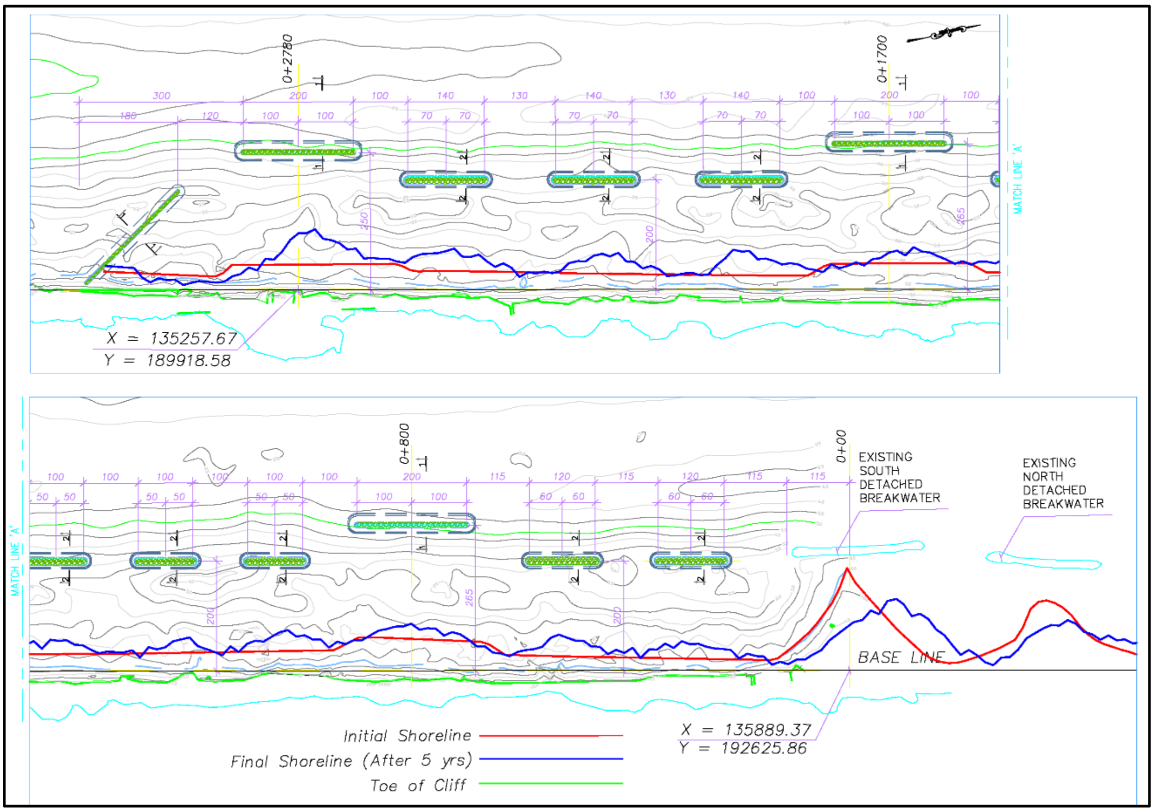

Figure 3.5: Layout A0_2

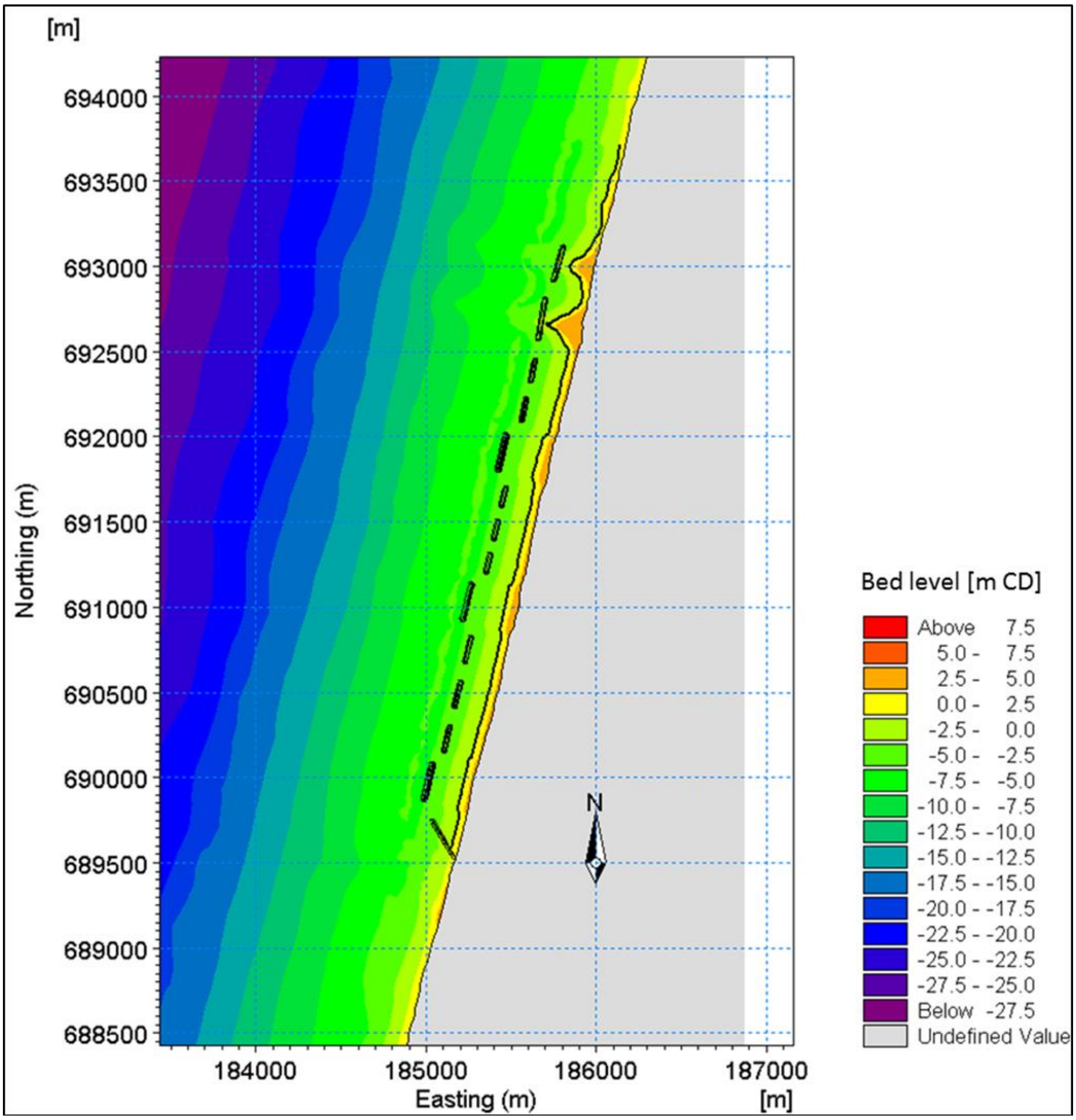

Figure 3.6: Model bathymetry with modified A0_2 Layout

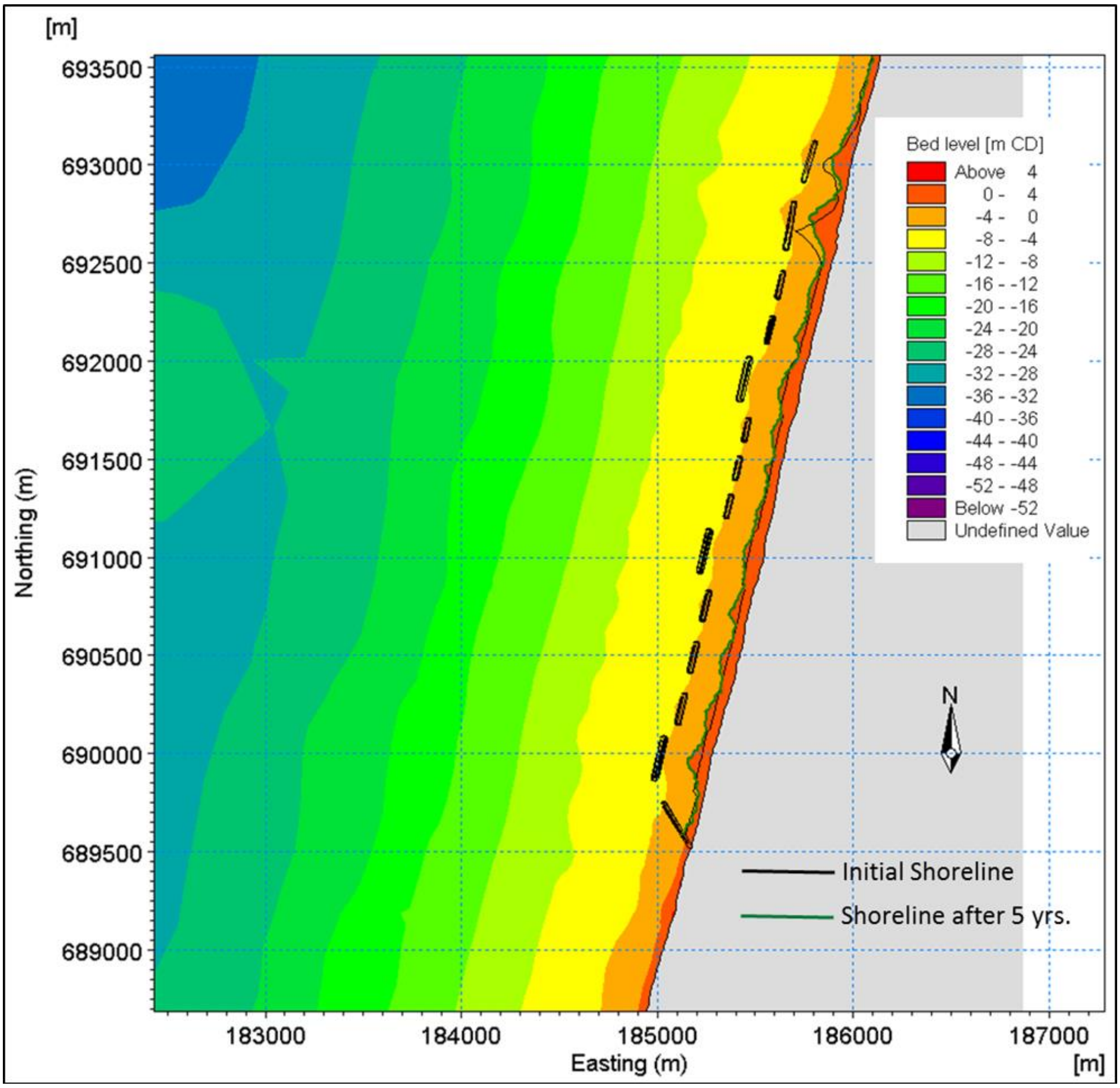

Figure 3.7: Equilibrium bathymetry obtained after 5 years of morphological evolution for modified A0_2 Layout

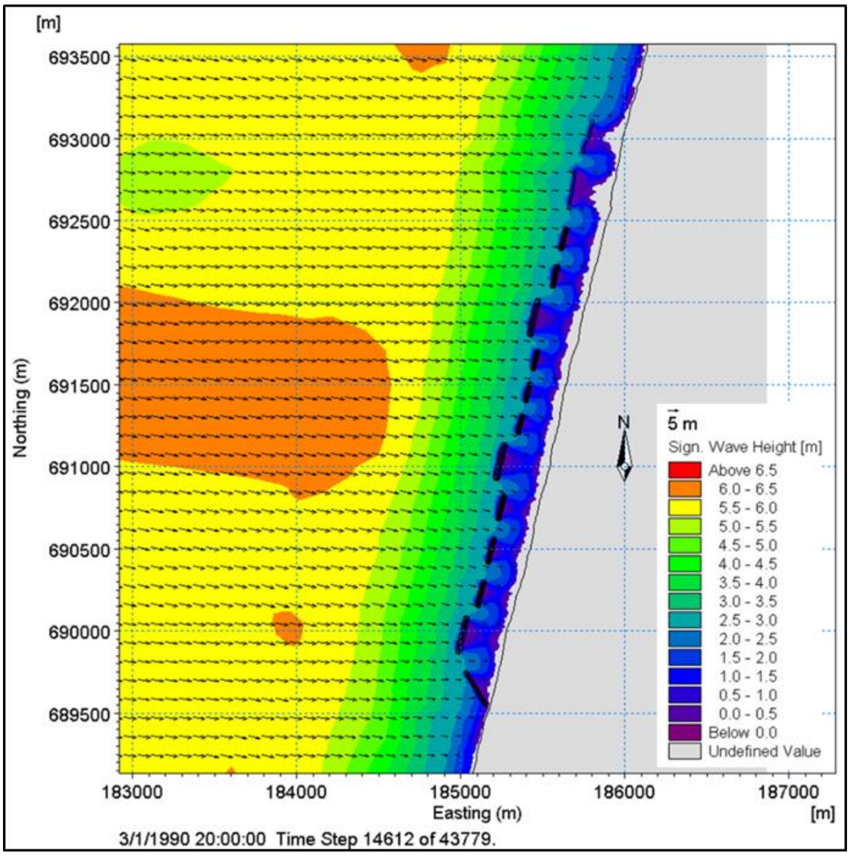

Figure 3.8: Wave field during a winter storm event for modified A0_2 Layout (Offshore Wave Climate- H_{m0} =6.2 m, T_p =12.9 s, MWD=272^{O}N)

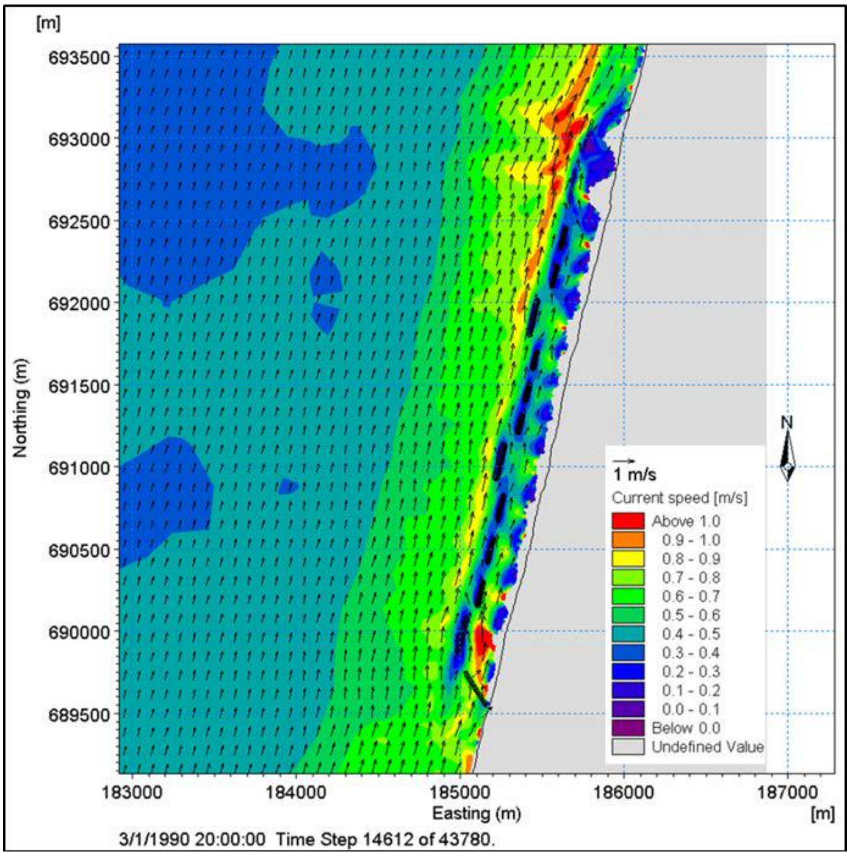

Figure 3.9: Flow field during a winter storm event for modified A0_2 Layout (Offshore Wave Climate - H_{m0}=6.2 m, T_p=12.9 s, MWD=272°N)

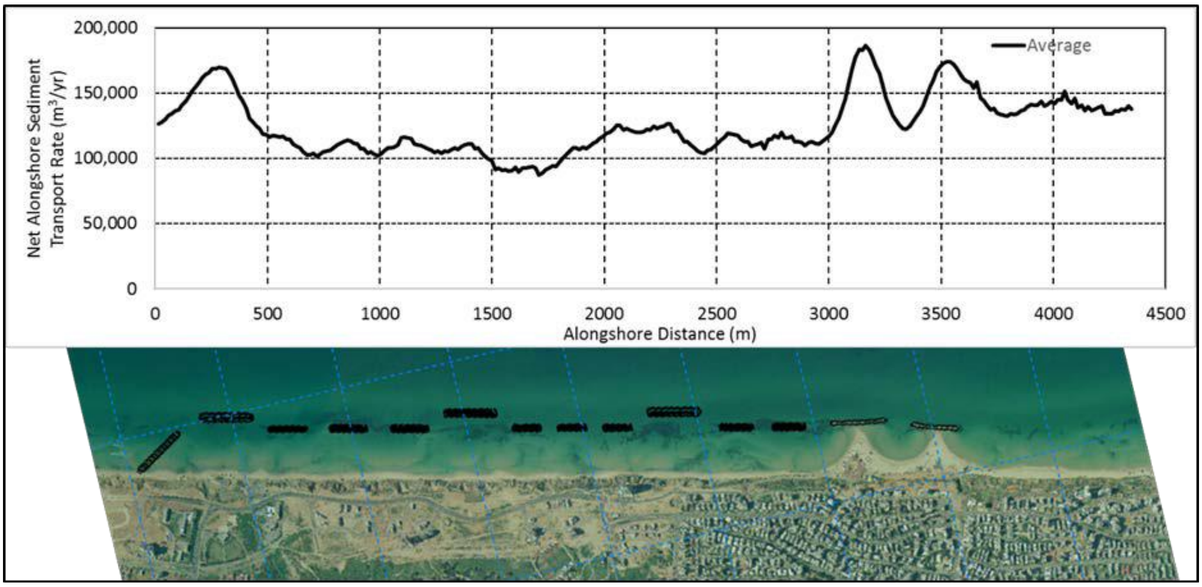

Figure 3.10: Annual net alongshore sediment for transport rate for modified A0_2 Layout

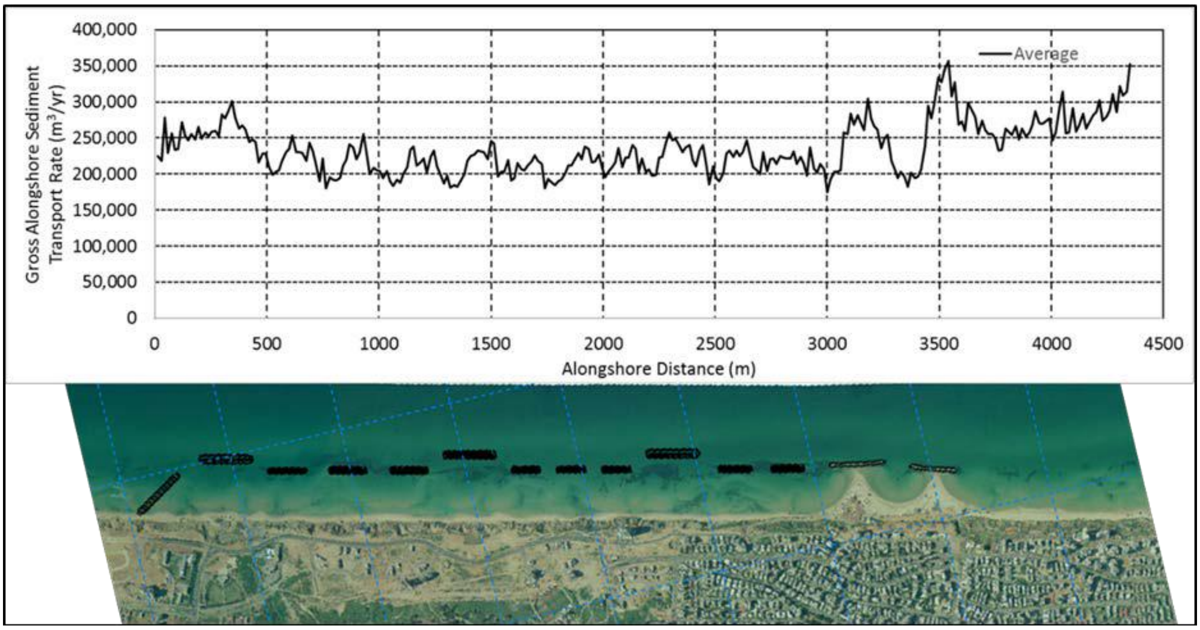

Figure 3.11: Annual gross alongshore sediment for transport rate for modified A0_2 Layout

Phase 2: Alternative Layouts

4.1 Alternative Layout 1 (A1)

The model results from Layout A0_1, which included original the CAMERI A0 breakwater layout, indicate that the original scheme with initial beach nourishment of 680k m^3, won't prevent erosion at the toe of cliffs. Therefore, a reduced detached breakwater scheme with the same volume of beach nourishment as in the Layout A0_2 is considered for optimization as A1 layout.

The A1 Layout comprises an array of 9 detached breakwaters, parallel to the coastline, located to the south of the existing twin breakwaters. These breakwaters are designed to protect approximately 3 km of shoreline. The array consists of 3 large breakwaters, each 200 m long, at a distance of 250-265 m from the coastline, and 6 smaller breakwaters of between 100 and 140 m long, at a distance of 200 m from the shoreline as shown in Figure 4.1. The gap between the small detached breakwaters are 200 m between the most southern large detached breakwaters decreasing to 115 m to the south of existing twin detached breakwaters. At the southern end of the site a 250 m long groyne structure is added to reduce alongshore sediment losses from the beach system.

It is assumed the beach will be pre-nourished with native sand giving a beach width a 75-m wide beach crest behind the large offshore breakwaters and 55-m wide beach behind the small detached breakwaters. Total sand nourishment quantity will be approximately 1.5 M m^3 along the 3 km long project shoreline (see Figure 4.2).

Figure 4.3 depicts the equilibrium shoreline morphology after 5 years overlaid with the initial shoreline. Results showed that performance of this layout is not satisfactory. While reasonably wide salient are formed behind the detached breakwaters, the beach receded further in the gaps between the structures up to the toe of cliff. These are especially evident between the most northern small detached breakwater and existing twin detached breakwaters as well as between the most southern large breakwater and southern groyne. Shoreline was also experienced slight erosion at the updrift side of the southern groyne after 5 yrs.

Figure 4.4 shows distribution of annual net alongshore sediment transport rates along the project coastline. As anticipated, the transport rate is slightly larger in front of southern groyne and varies between 70k m^3/yr. and 175k m^3/yr. at the detached breakwaters. The annual gross alongshore sediment transport rate fluctuates between 200k m^3/yr. and 350k m^3/yr. for the same stretch of coastline (see Figure 4.5).

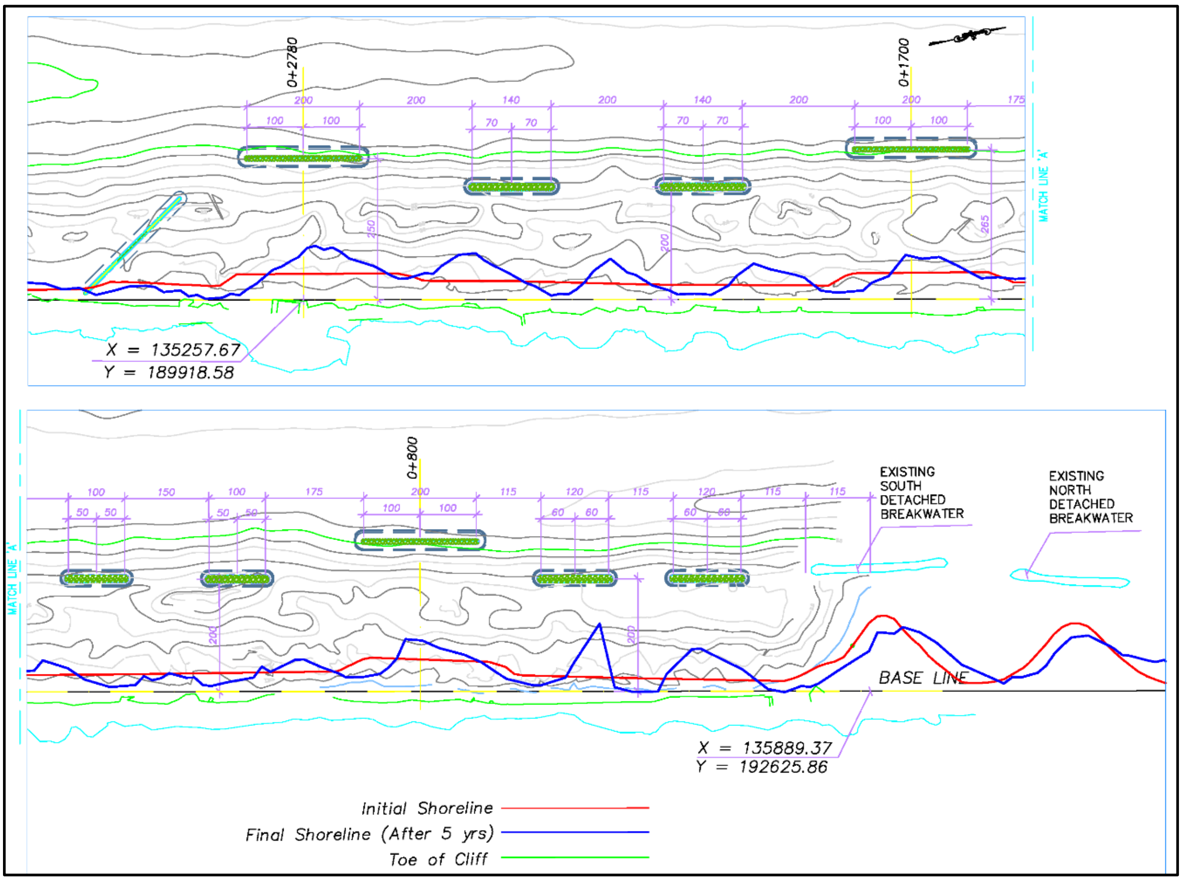

Figure 4.1: Alternative Layout 1

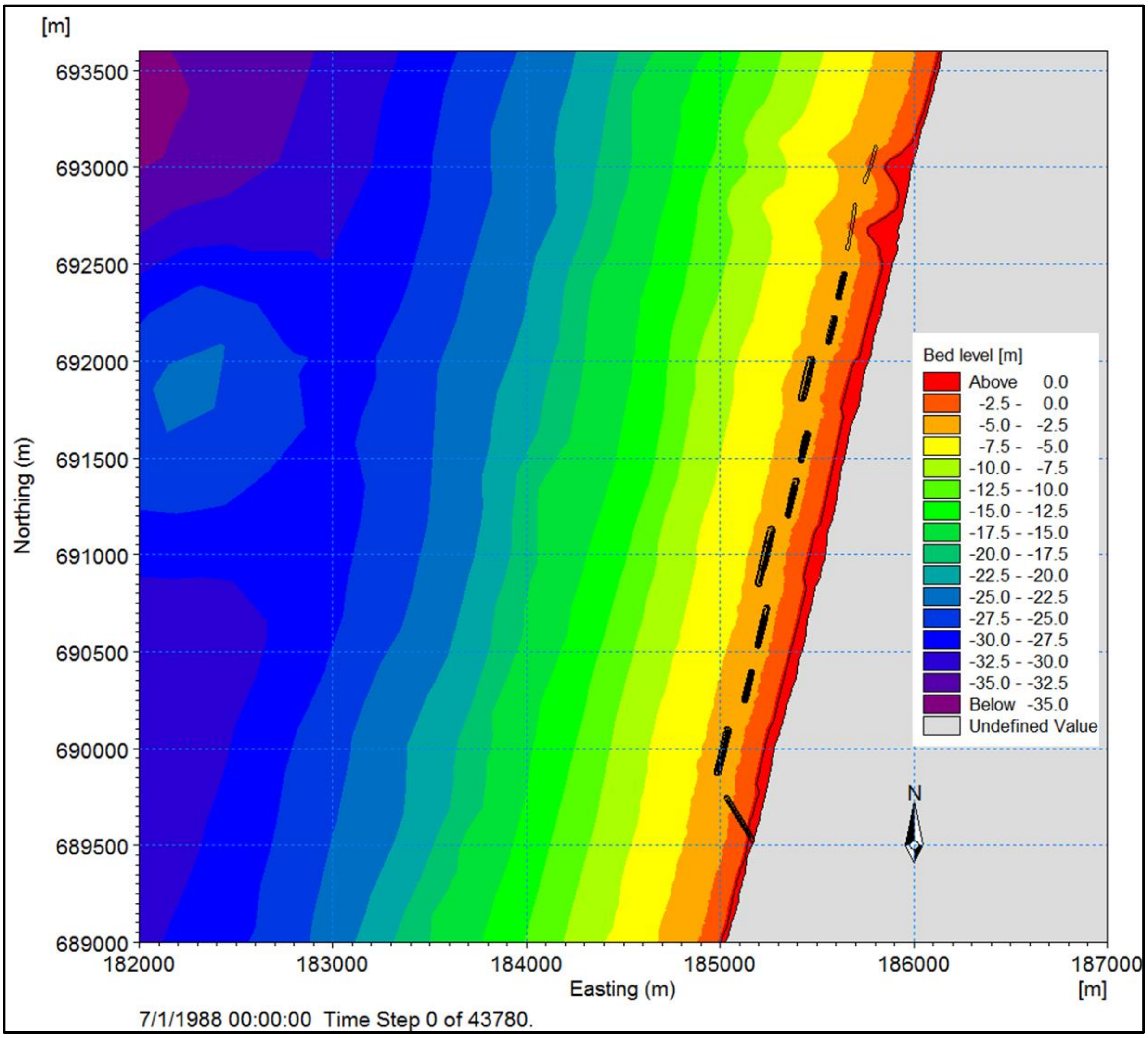

Figure 4.2: Model bathymetry Alternative Layout 1

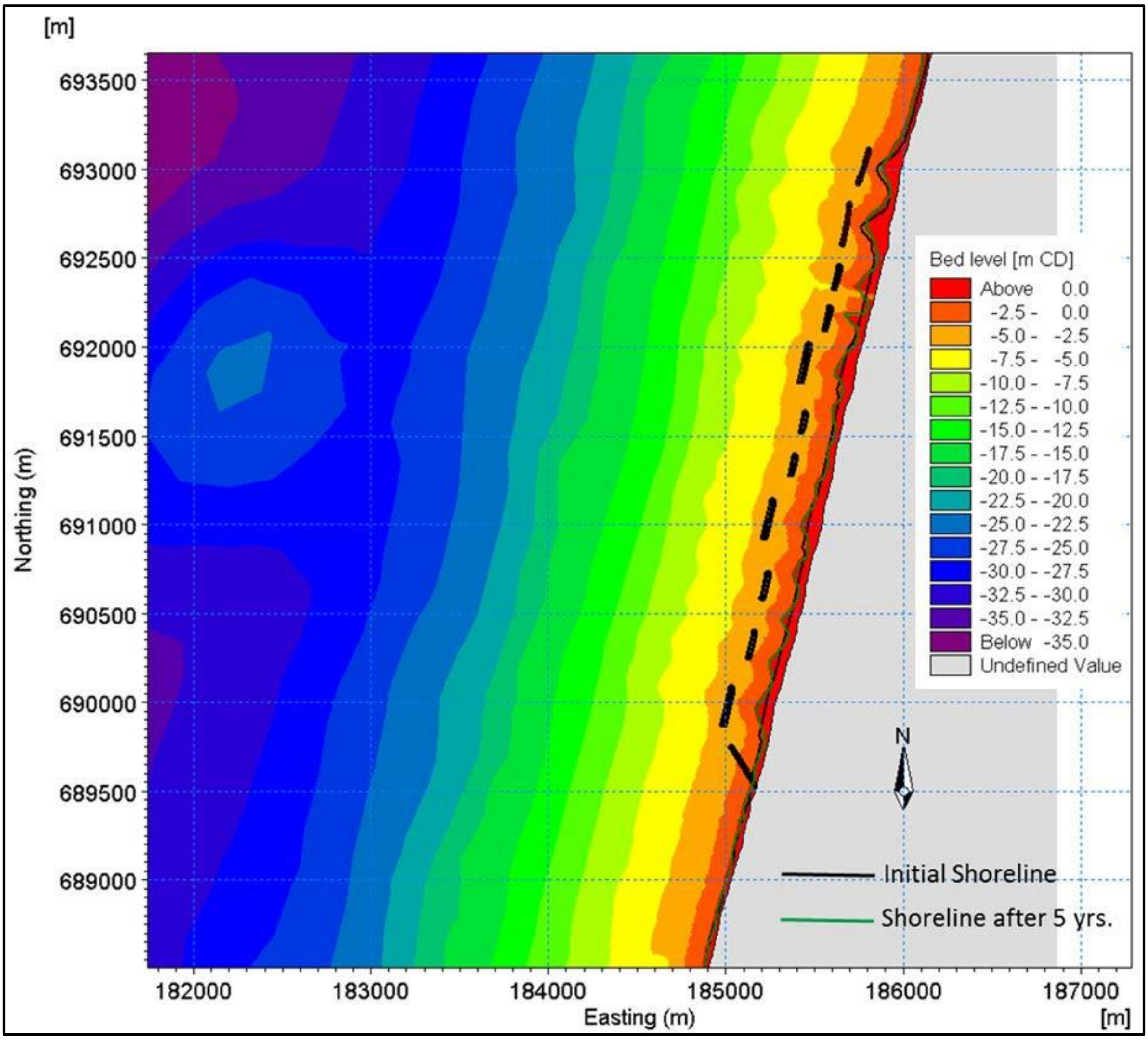

Figure 4.3: Equilibrium bathymetry for Alternative Layout 1 (after 5 yrs.)

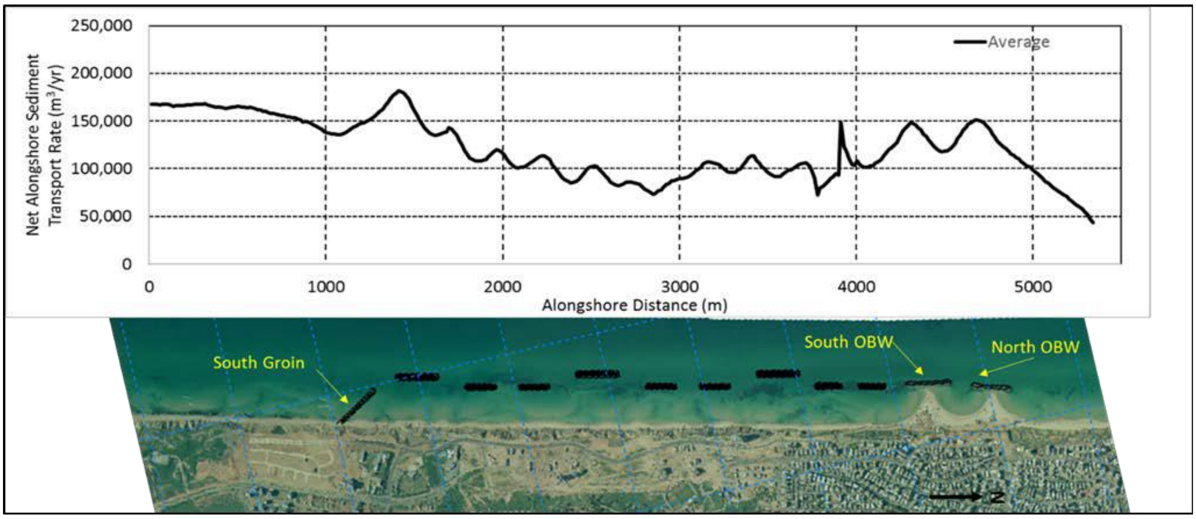

Figure 4.4: Annual net alongshore sediment for transport rate for Alternative Layout 1 (after 5 yrs.)

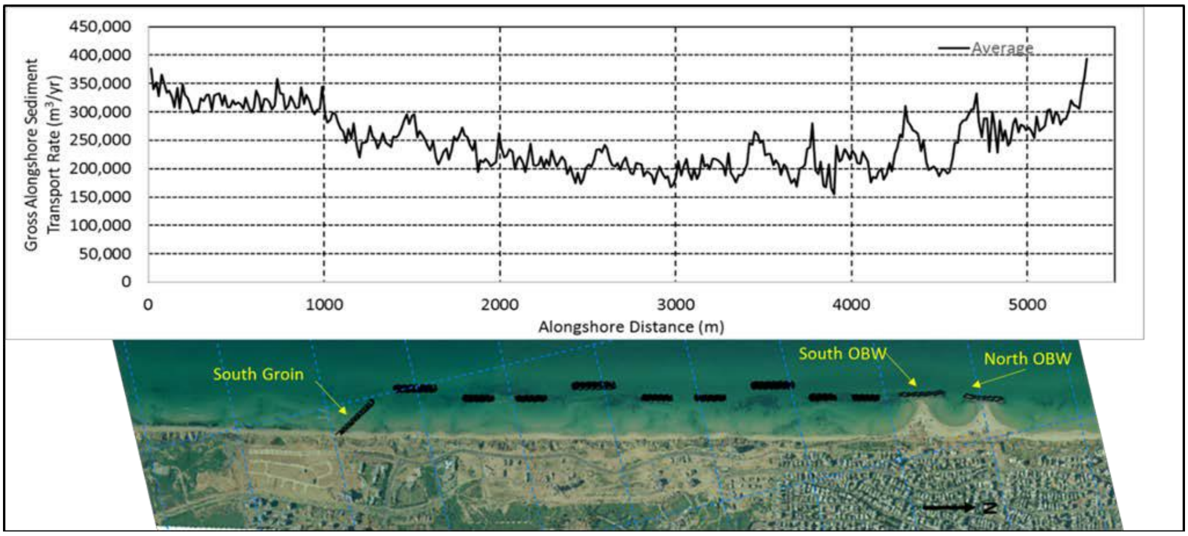

Figure 4.5: Annual gross alongshore sediment for transport rate for Alternative Layout 1 (after 5 yrs.)

4.2 Alternative Layout 2 (A2)

Although simulation results showed that the beach behind the large and small breakwaters somewhat acceptable beach width, the shoreline between the most southern large breakwater and groyne was close to cliff toe. In addition, excessive shoreline erosion occurred behind the small detached breakwaters at the south of the existing twin breakwaters. In short, the A1 layout with large pre-nourishment of 1.5M m^3 volume is not an option due to insufficient beach quality sand source for the project. Therefore, an alternative scheme with smaller gaps between the detached breakwaters with reduced initial beach nourishment was adopted for the next layout. The gap between the small detached breakwaters was set to 150 m at the southern and central section of project shoreline, the gap between northern small detached breakwaters was set to 115 m as shown in Figure 4.6. It is assumed that the beach will be pre-nourished with native sand giving a 40 m wide beach crest behind the detached breakwaters. Total sand nourishment quantity will be around 1.1 M m^3 along the 3-km long shoreline.

Figure 4.7 depicts the model bathymetry with initial beach nourishment for this A2 layout. The equilibrium shoreline after 5 years is shown in Figure 4.8. The size of the salient behind the large detached breakwaters are larger than that for A0_1 layout. However, the shoreline receded to the toe of the cliff between salient behind the small detached breakwater in the central and southern section of the coastline. This is also evident in the bed level change plot shown in Figure 4.9. Areas where the shoreline receded and the bed level eroded up to 1.5 m are highlighted in red rectangular and zoom in view is shown in Figure 4.10. Shoreline on the downdrift side of the groyne receded due to shielding by the structure and experienced slight accretion on the updrift side of it after 5 yrs. Figure 4.11 shows spatial distribution of wave height and current field for a representative summer extreme wave event. Westerly waves with a significant wave height of 2.0 m reached the shoreline only losing a fraction of initial energy whereas generating alongshore current speed up to 0.8 m/s.

Figure 4.12 shows distribution of annual net alongshore sediment transport rates along the project coastline. As anticipated, the transport rate is slightly larger in front of southern groyne and varies between 100k m^3/yr. and 125k m^3/yr. at the detached breakwaters. The annual gross alongshore sediment transport rate fluctuates between 200k m^3/yr. and 250k m^3 /yr. for same stretch of coastline (see Figure 4.13).

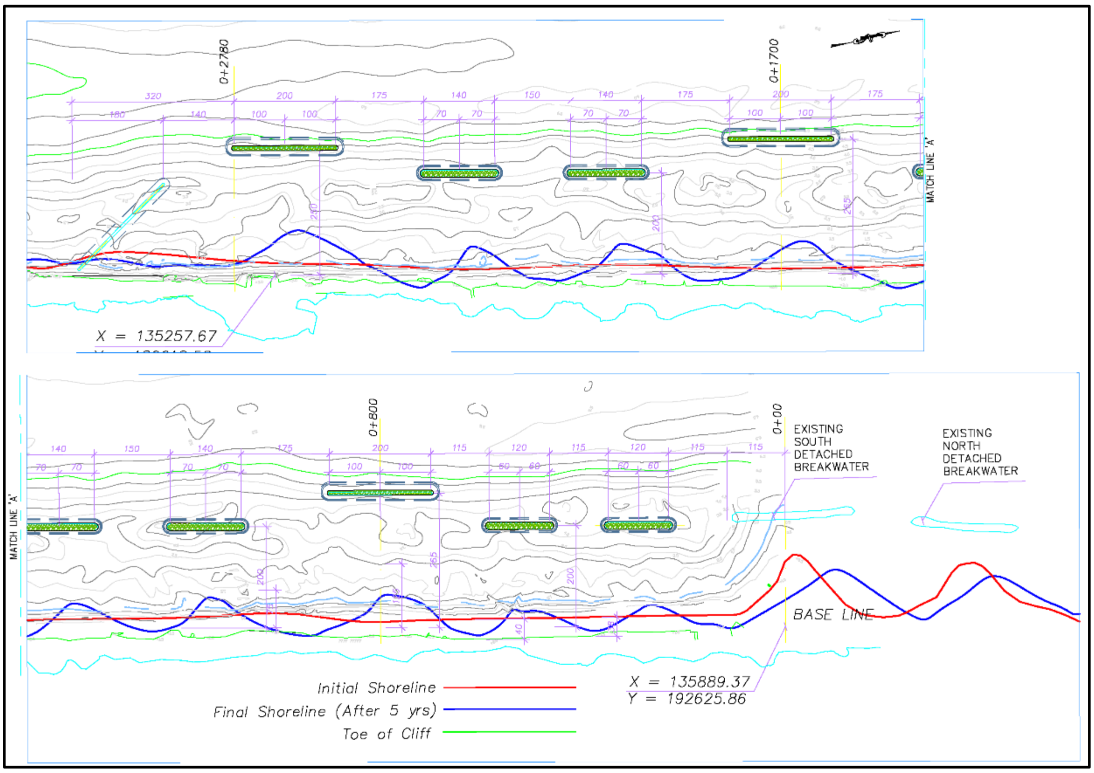

Figure 4.6: Alternative Layout 2

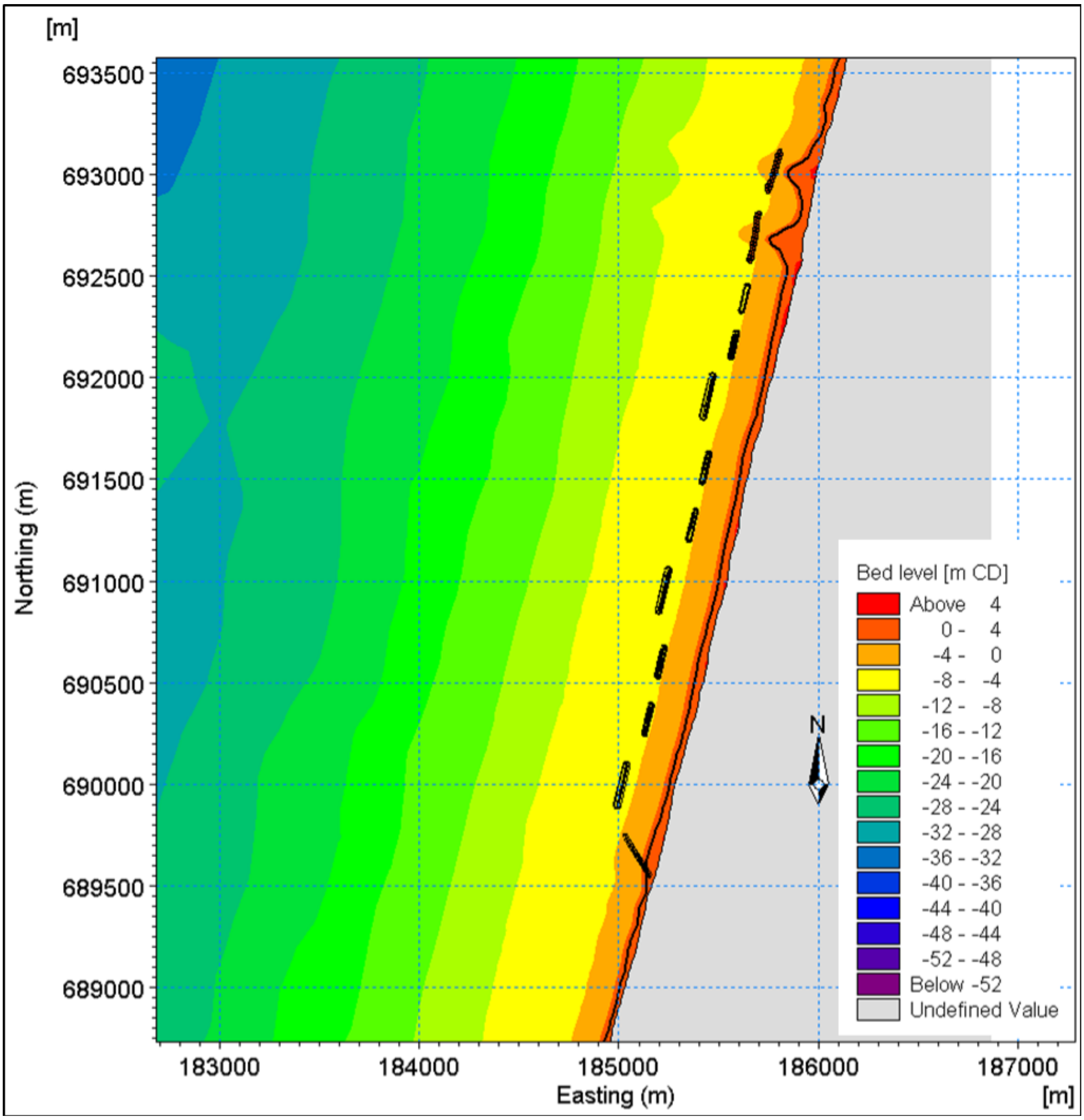

Figure 4.7: Model bathymetry for Alternative Layout 2

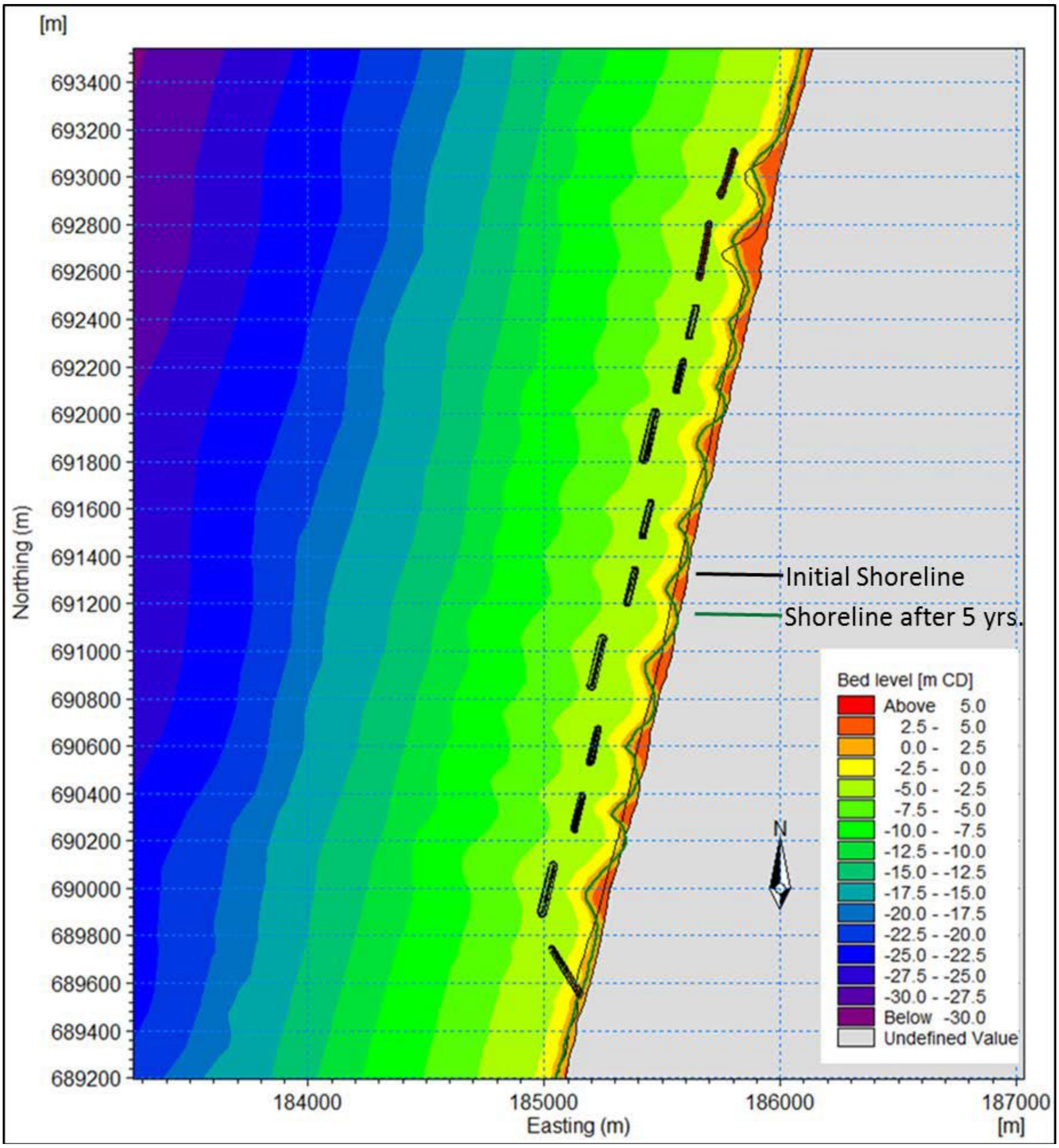

Figure 4.8: Equilibrium shoreline morphology for Alternative Layout 2

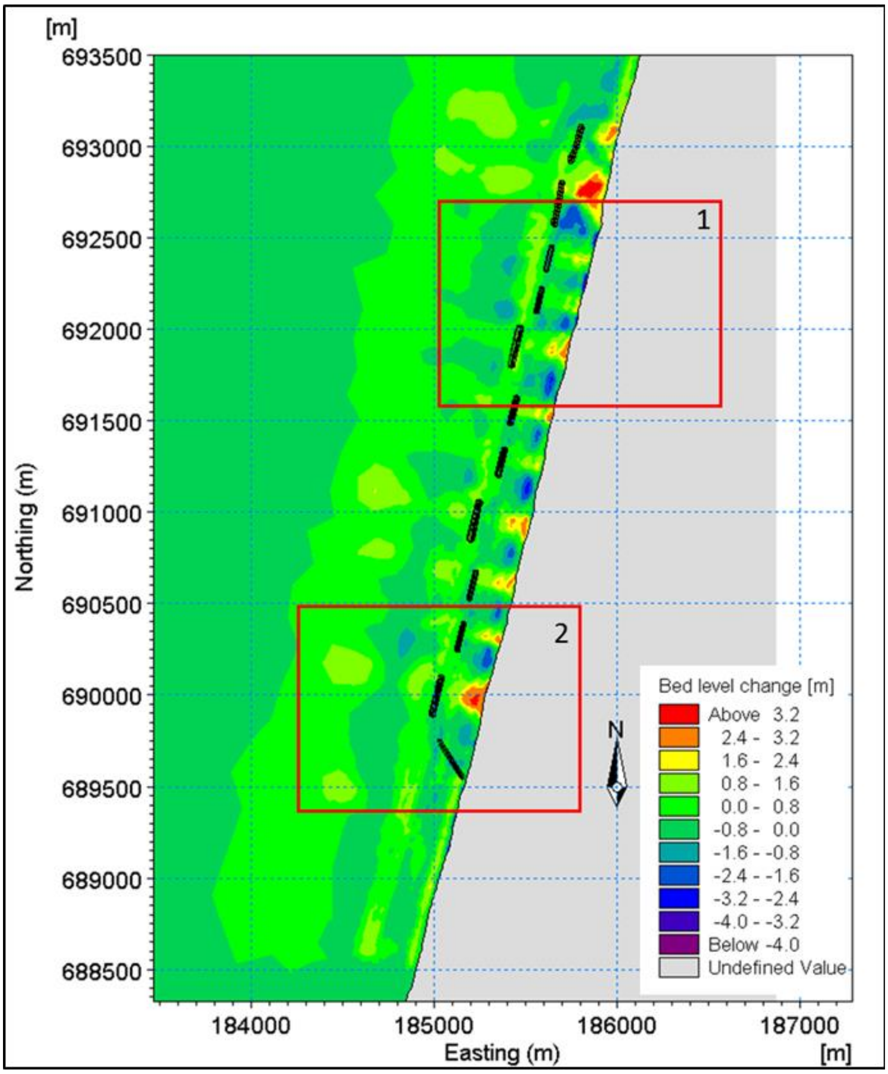

Figure 4.9: Equilibrium shoreline morphology for Alternative Layout 2

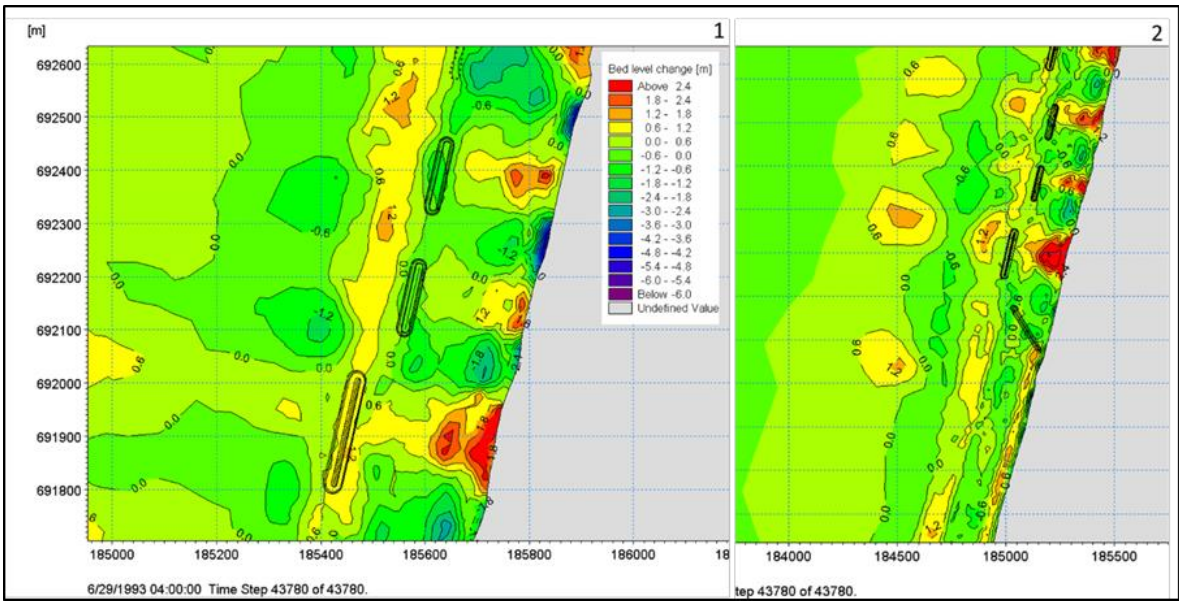

Figure 4.10: Zoom in view for bed level change for Alternative Layout 2

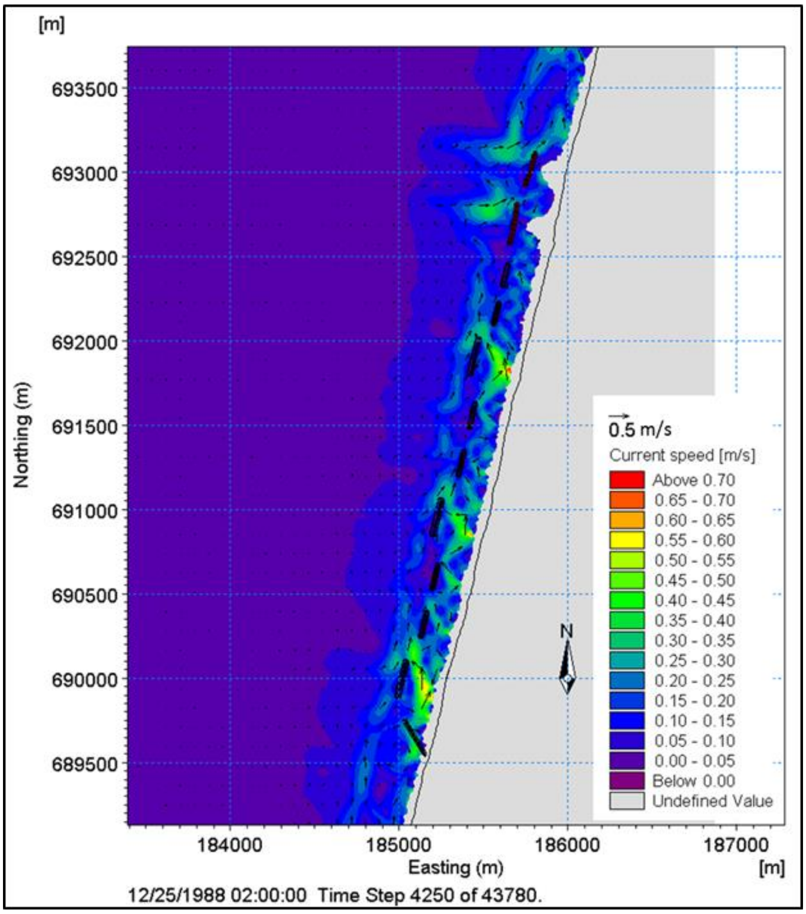

Figure 4.11: Equilibrium shoreline morphology for Alternative Layout 2

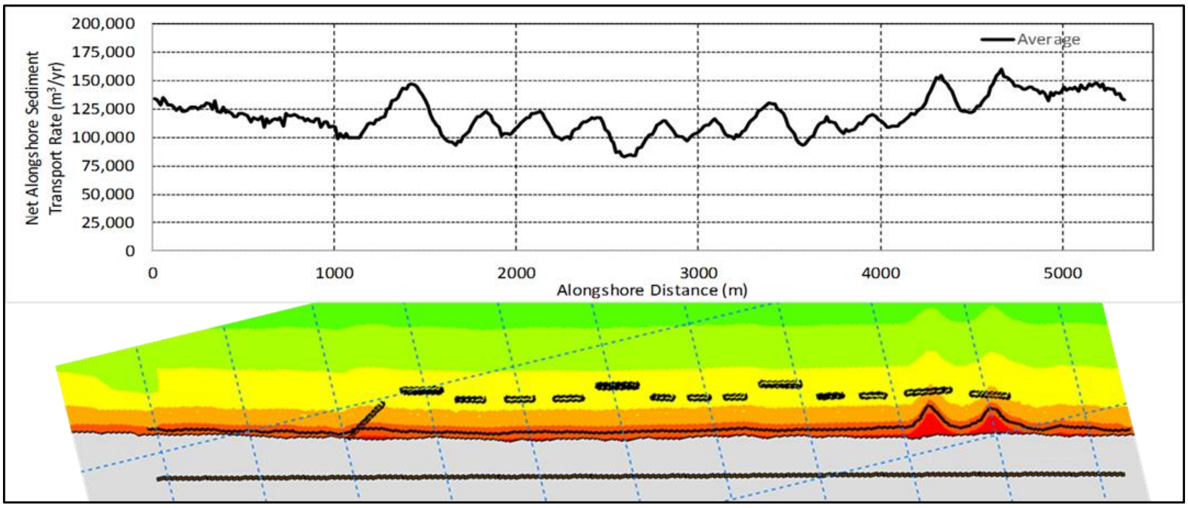

Figure 4.12: Annual net alongshore sediment transport rate for Alternative Layout 2

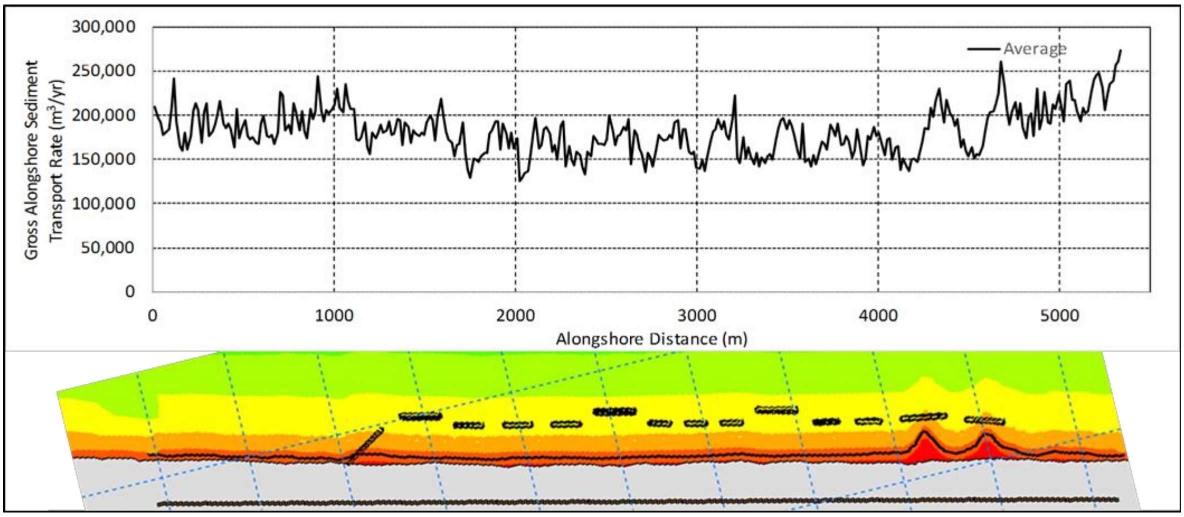

Figure 4.13: Annual gross alongshore sediment transport rate for Alternative Layout 2

4.3 Alternative Layout 3 (A3)

As further refinement on the Alternative Layout 2, **the southern groyne structure is removed since it is partly blocking net northerly directed alongshore sediment transport while holding some alongshore sediment transport directed southward in nearshore (Figure 4.14)**. Figure 4.15 depicts equilibrium bathymetry and shoreline after 5 years. It is noted that beach is wider at the south of most southern large detached breakwater compared to revised A1 layout. Like other cases shoreline experienced slight erosion at the updrift side of the southern groyne after 5 yrs. The size of salient behind the large and small detached breakwaters are **very similar with and without southern groyne in place**. Therefore, **it is decided that southern groyne is not needed.**

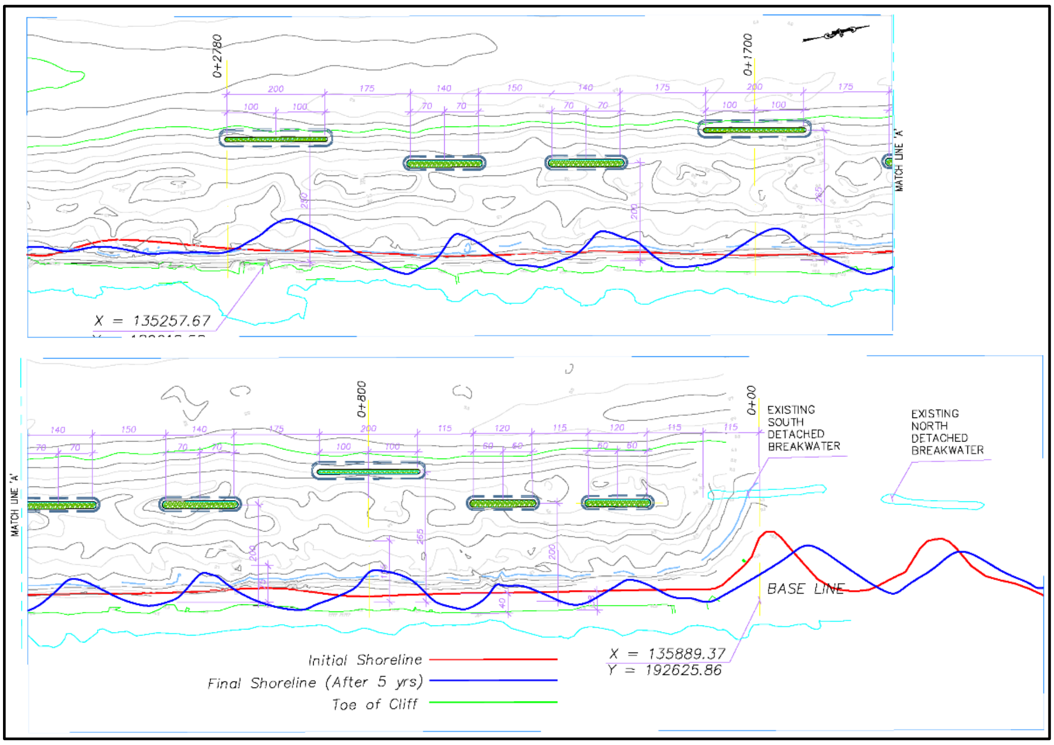

Figure 4.14: Alternative Layout 3

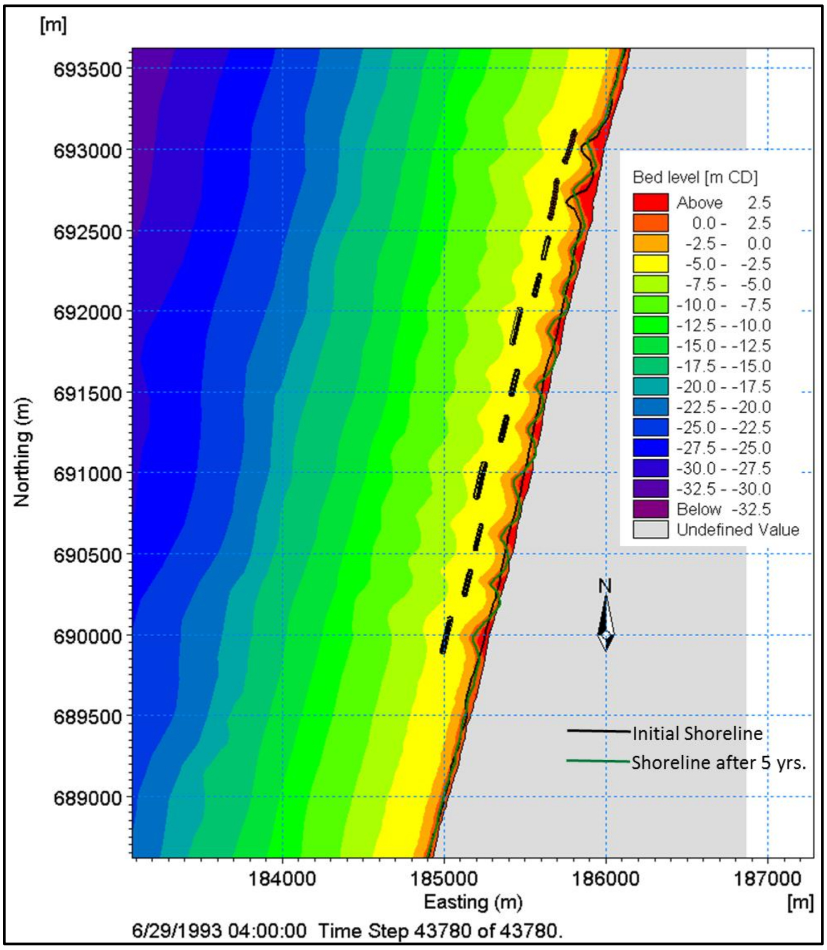

Figure 4.15: Equilibrium shoreline morphology for refined Alternative Layout 3

4.4 Alternative Layout 4

Based on experience gained in all previous alternative layouts, a more robust solution which meets the permitted initial sand nourishment volume of 570k m^3 using rock structures is considered to reach a functioning solution. The new layout, A4 Layout, comprises an array of 10 detached breakwaters, parallel to the coast, located to the south of the existing twin breakwaters. These breakwaters are designed to protect approximately 3 km of the project coastline. The array consists of 2 large breakwaters, each 200 m long, at a distance of 265 m from the shoreline, and 10 smaller breakwaters; three of them 120 m long and seven of them 100 m long and gap between them is set to 100 m at the southern and central section of project shoreline, the gap between northern small detached breakwaters was set to 115 m at the northern section of the project shoreline as shown in Figure 4.16.

It is assumed that beach will be pre-nourished with the native sand having beach a 21-m wide beach crest behind the detached breakwaters. The total sand nourishment quantity will be around 570k m^3 along the 3-km long project shoreline (see Figure 4.17).

Figure 4.18 shows equilibrium bathymetry and shoreline after 5 years. Salient behind the two large detached breakwaters reached 50 m at the apex of the salient with respect to initial shoreline position. Salient behind small detached breakwaters are relatively small compared to one behind the large detached breakwaters. The beach width varies between 17 m and 30 m at the apex of salient behind small detached breakwater after 5 years. It is found that the shoreline between salient receded close to the toe of the cliff but didn't encroach into cliff base anywhere along the project coastline after 5 years as shown in Figure 4.19 and Figure 4.20. This alternative showed better performance in terms of salient size behind the large detached breakwaters. Further refinement to the most southern small detached breakwaters will be done to find optimum gap between them during the detail design. In addition, buried revetment toe protection at the cliff base will be investigated with this alternative in the detail design.

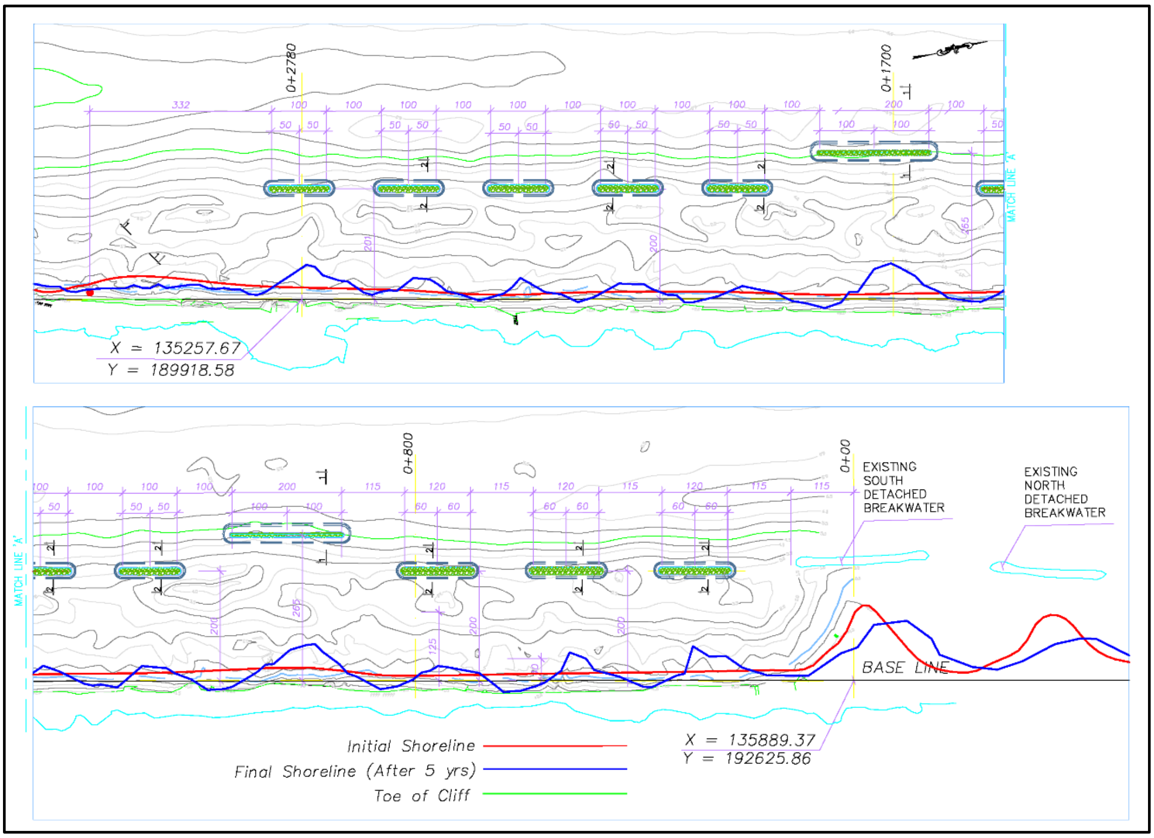

Figure 4.16: Alternative Layout 4

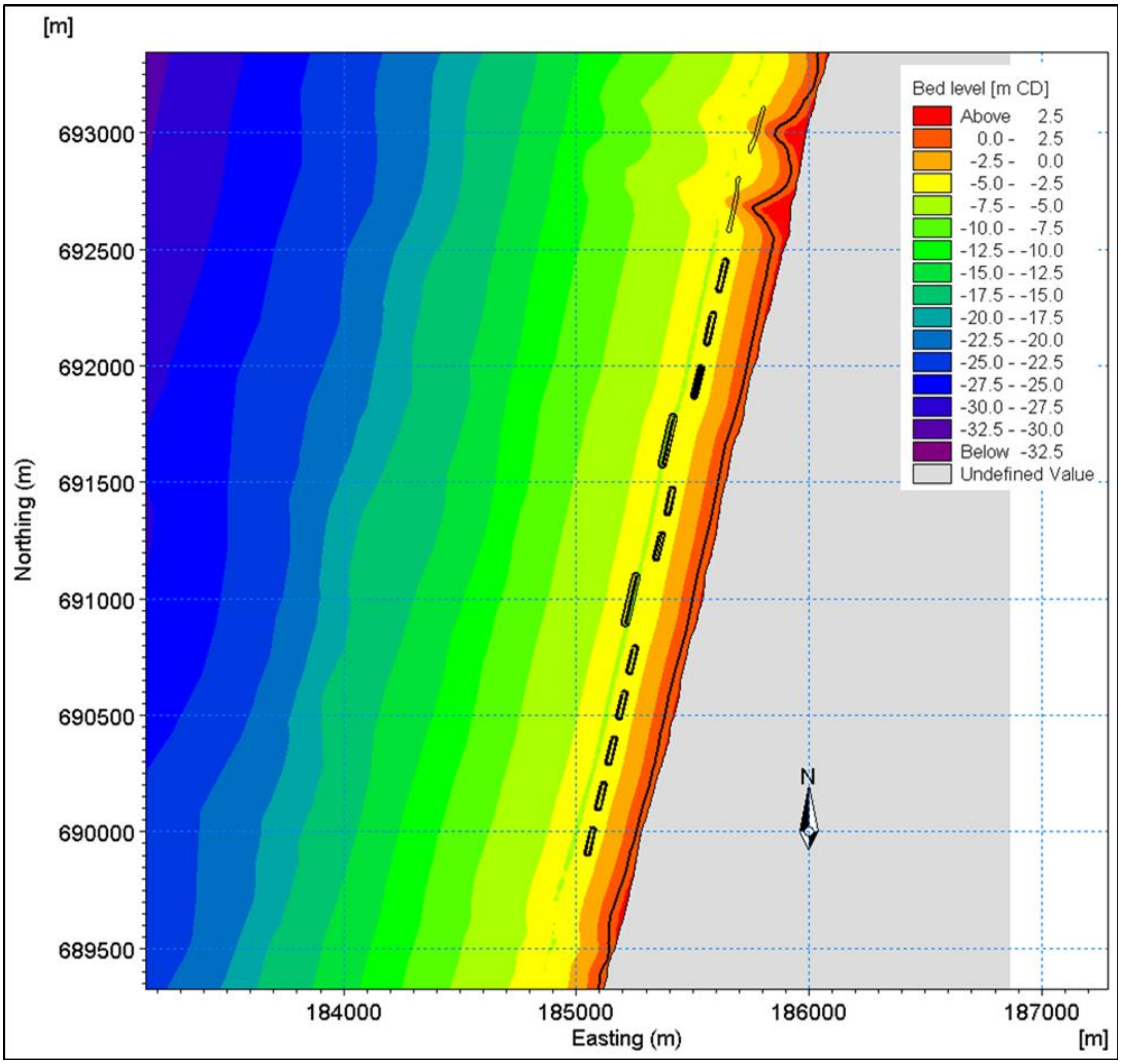

Figure 4.17: Model bathymetry for Alternative Layout 4

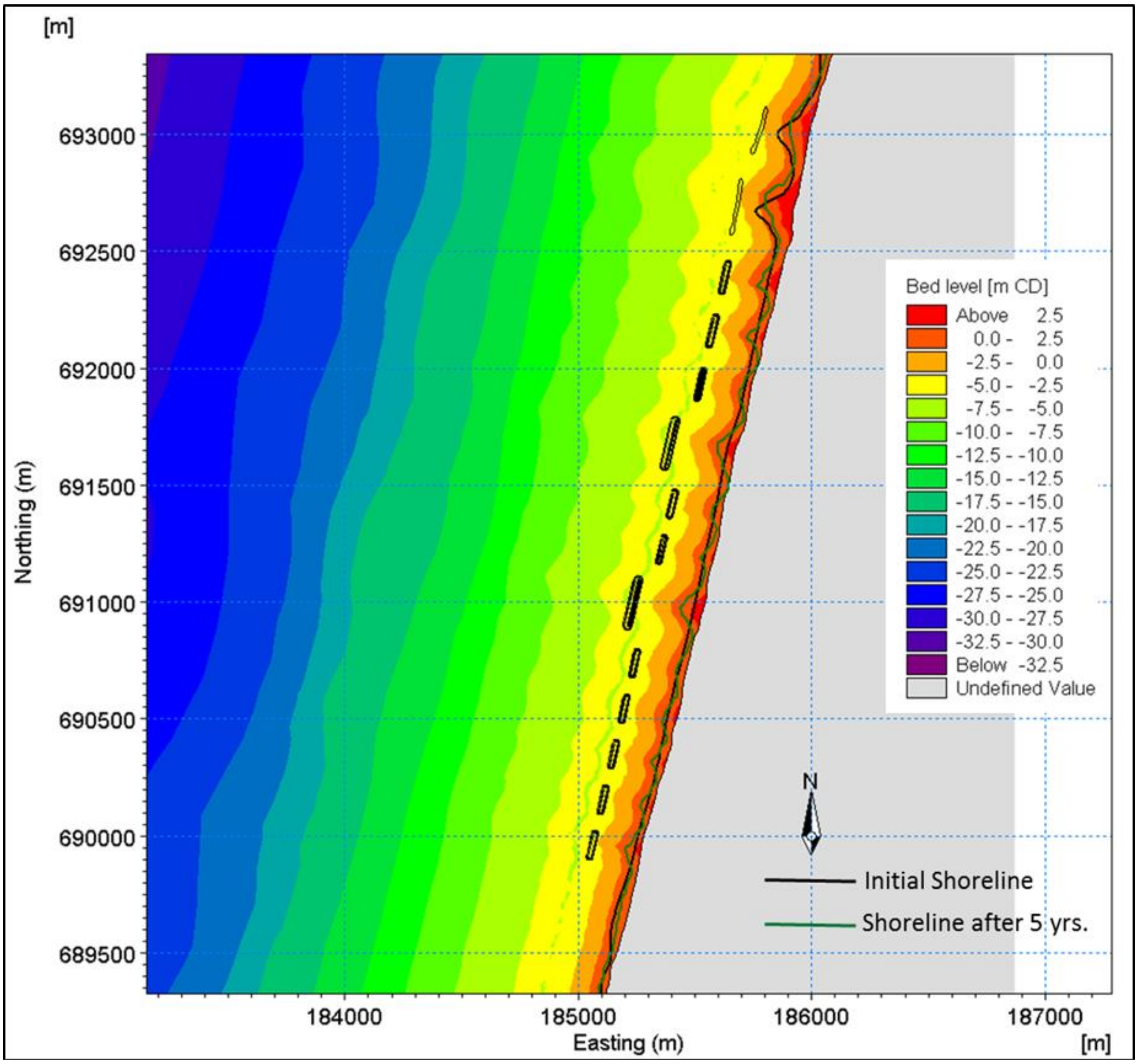

Figure 4.18: Equilibrium shoreline morphology for Alternative Layout 4

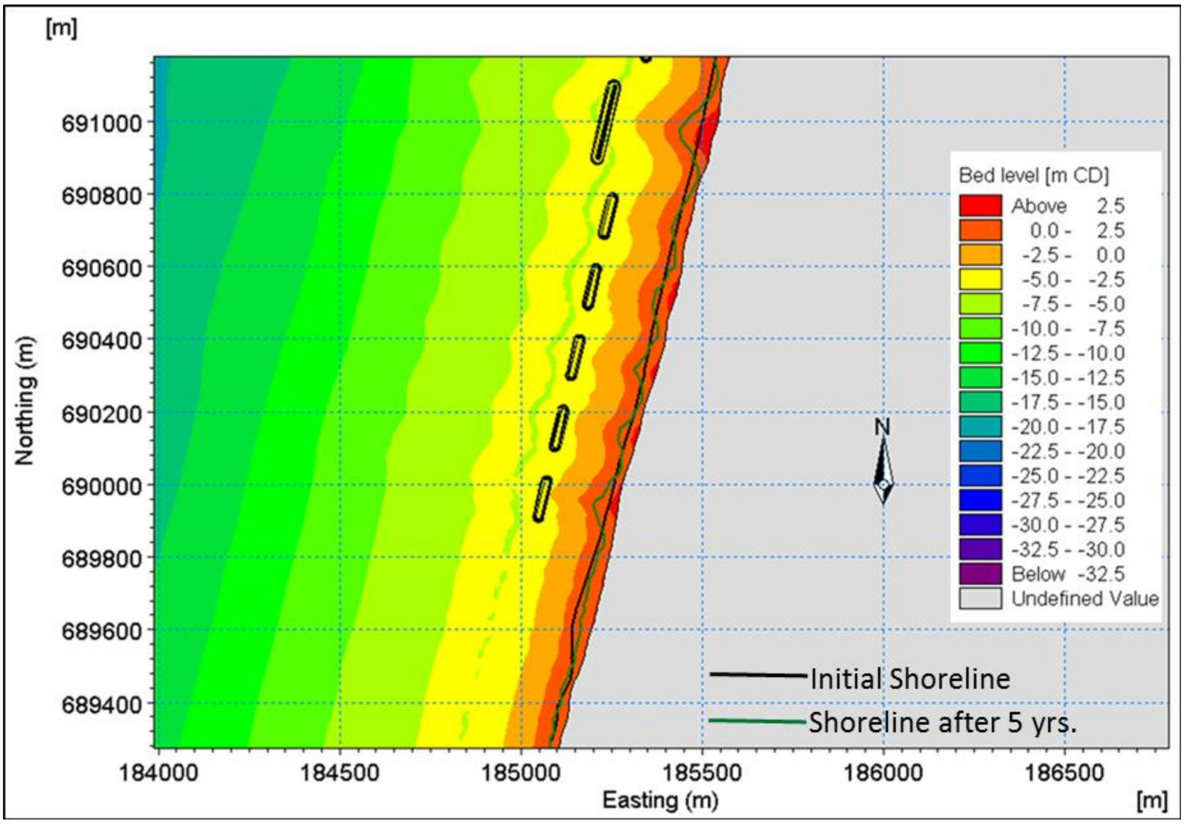

Figure 4.19: A zoom in view of equilibrium shoreline morphology for Alternative Layout 4 (southern end)

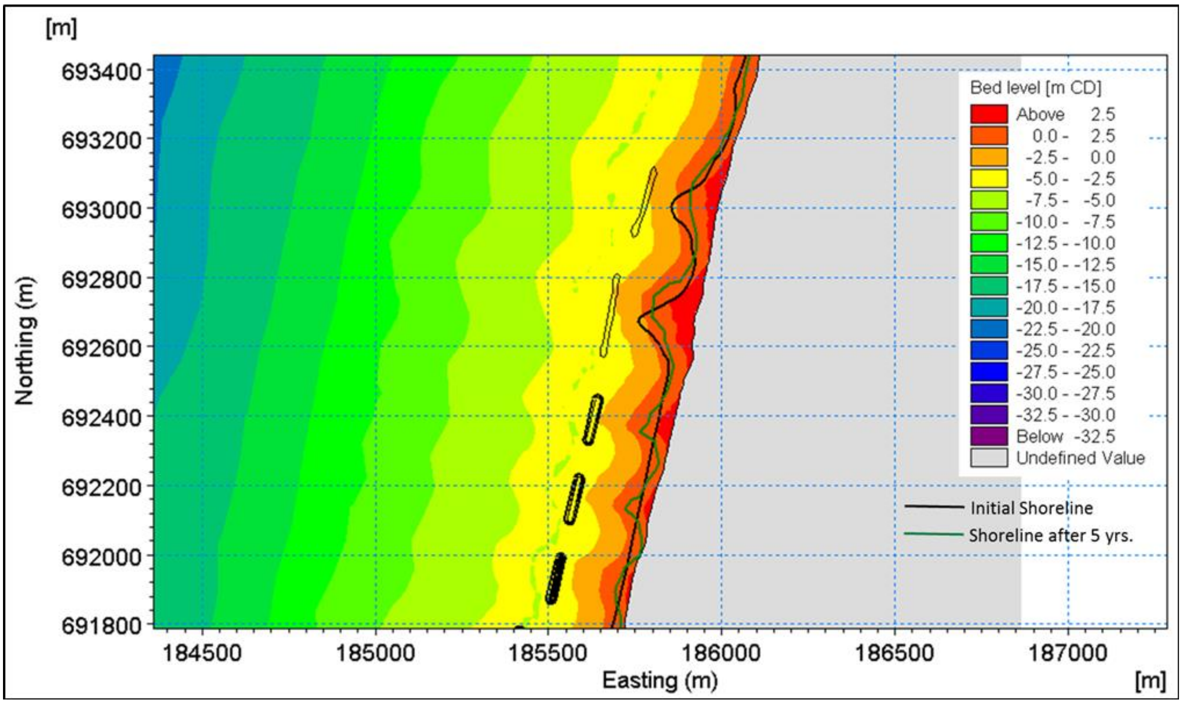

Figure 4.20: A zoom in view of equilibrium shoreline morphology for Alternative Layout 4 (northern end)

4.5 Alternative Layout 4a

As a further modification on the Alternative A4 layout, all small detached breakwaters were positioned along the large detached breakwater at approximately 5.5 m water depth as shown in Figure 4.21. Figure 4.22 depicts equilibrium bathymetry and shoreline after 5 years. As anticipated, shifting the small detached breakwaters resulted in smaller sand salient development because the large waves can easily be transmitted over them and reach the shoreline while losing some part of their energy. It is also found that shoreline between salient receded close to the toe of the cliff at two locations at the northern end of the project shoreline after 5 years as shown in Figure 4.21. Therefore, it is concluded that offsetting nearshore detached breakwater further offshore do not provide better protection than the original Alternative A4 layout.

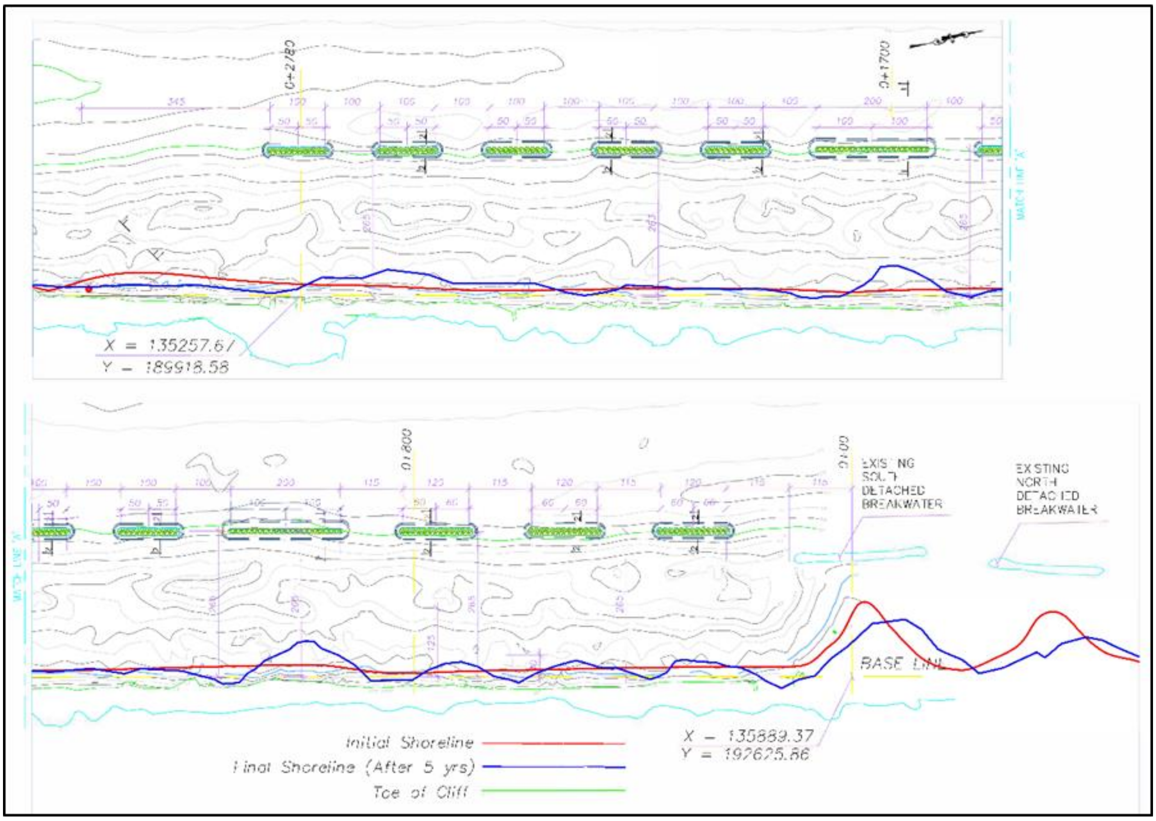

Figure 4.21: Modified Alternative Layout 4a

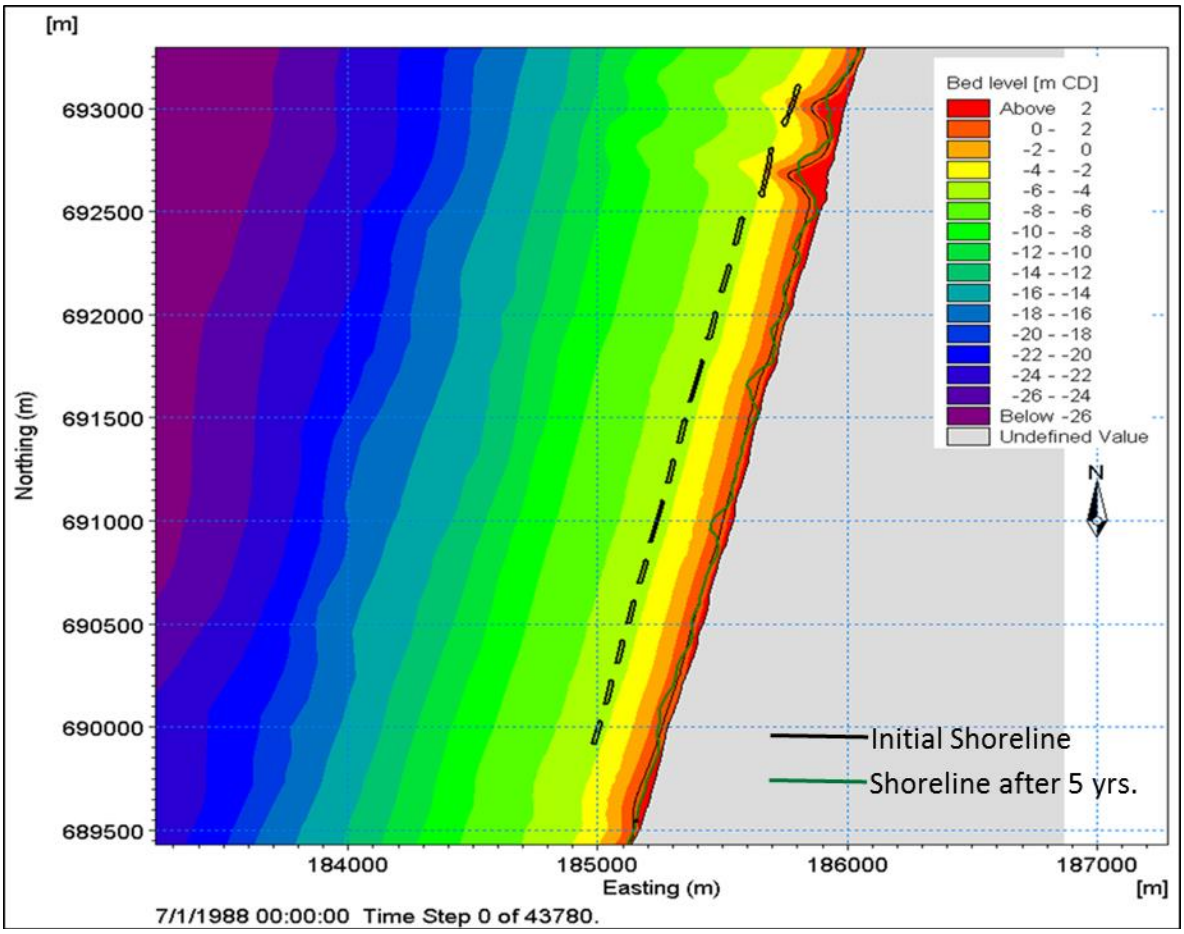

Figure 4.22: Equilibrium shoreline morphology for the modified Alternative Layout 4a

Results and Conclusions

A 2D hybrid-shoreline morphology model (Coupled FM Shoreline Morphology (SM)), which simulates the hydrodynamics and sediment transport over the bathymetry of the model area with a morphological scheme, was developed to simulate sediment transport and long-term shoreline morphologic changes of the proposed nearshore detached breakwater shoreline mitigation options at Netanya Beach.

The model was calibrated using the initial historical shoreline position data of May 1997 to reproduce a modeled shoreline that matches the historical shoreline positions from the May 2002 aerial. Calibration results show that the 2D sediment transport model generates similar order of magnitude alongshore sediment transport rates as in the 1D shoreline evolution model. The 2D model results are also in agreement with the rates from previous studies by others in open literature. Based on the calibrated sediment transport model, preliminary annual alongshore sediment transport rate is estimated to be 160k m^3 per year for the existing shoreline.

The 2D model is applied to predict the impact of the proposed nearshore detached breakwater options on the project shoreline. The Alternative A4 layout resulted in a salient formation behind the detached breakwater larger than the other tested layouts and the shoreline did not reach toe of cliff after 5 years of evolution, whereas small areas of erosion are found in the gaps between small detached breakwaters. This alternative is suggested as the preferred option to CAMERI A0 layout. However, due to the localized erosion observed in this layout, it is recommended that either shoreline positions shall be monitored on regular basis and additional sand fill to be placed in areas where cliff may be exposed or a hard shoreline protection structure (i.e. submerged revetment/wall) is to be constructed at the toe of cliff in areas that may exposed prior to initial project sand nourishment. Shoreline response for submerged revetment at the cliff toe will be investigated in detail during the detail design.

The results presented in this report have assumed that the re-nourishment material has a D_{50} of 0.22mm. In the event that the proposed source of material has a grain size that differs from this amount the modelling work should be re-evaluated. In particular, if the material is significantly smaller (e.g. $D_{50} < 0.18$mm) it is likely that more re-nourishment material would be required to protect the cliffs due to the increased longshore and cross-shore drift rates as well as the likely flattening of the beach profile. All of these effects will lead to higher erosion of the beach. An order of magnitude estimate suggests that if the D_{50} was less than 0.18mm the required beach nourishment would increase by approximately 50% (approximately, 250km^3). Further modelling work would be required to provide an accurate estimate.

References

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