## A.1 Introduction

Jacobs have developed a suite of numerical models of the study area to support the design process. These models provide the following inputs:

- Wave and water level parameters that are essential for the design of coastal protection structures.
- Information on the historical shoreline change and predicted future shoreline change if no additional coastal protection works are undertaken.
- Modelling of key options to understand their effectiveness of reducing wave and water level impacts at the railway and any changes to how sediment circulates within the study area.

### A.1.1 Phase 1 Baseline Modelling Overview

Baseline modelling was undertaken by Jacobs during Phase 1 of the project. This baseline modelling also included the effect of spatial and temporal changes in water level on waves and variable sediment transport rates.

A two-dimensional wave model of the East Coast of Ireland was set up to derive wave data at nearshore points along the study area. This model uses wind and wave data recorded in the Irish Sea by the Irish Marine Data Buoy Observation Network and the UK Met Office and bathymetry information from INFOMAR and C-MAP to predict the wave heights, periods and direction close to the shoreline.

The baseline modelling of the shoreline looked at locations of interest between Dublin Bay and Wicklow Harbour to estimate the quantity of beach sediment moving along the coast and to predict the future shoreline position in 2055 and 2100. The results of this modelling highlight the areas of the railway which are most at risk of erosion.

### A.1.2 Phase 2 Modelling Overview

Under Phase 2 of the project, a shoreline evolution model (LITLINE) was set up to generate future coastline positions and calculate future erosion rates. This model was run for the present day (2025) and with an allowance for 100 years of climate change impacts. The model was initially run for the period 1988-2021 using historical wave conditions and the results were compared to coastline erosion rates derived from historical analysis of cliff-edge positions in OSI mapping.

The LITLINE model was then used to predict future coastline positions in 2025, 2055 and 2100. Additionally, sections of railway line at risk from erosion have been identified. The model has also been used to investigate the performance of selected options (groynes and breakwaters) for mitigating shoreline erosion.

Two-dimensional modelling for CCA2/3 was not carried out due to the absence of complex shore features. The LITLINE model extents are shown in Figure A.1-1; these extend to Bray Head in the south (CCA5-A) to capture the full extent of Killiney Bay.


**Figure A.1-1. LITLINE model extents showing baseline, hard defences (dashed line), profile and nearshore wave points (red squares) for CCA2-3**

# A.2 Waves and Water Levels

## A.2.1 Waves

Figure A.2-2 provides an example output of the regional wave model for offshore waves approaching from the eastern sector (95°N).

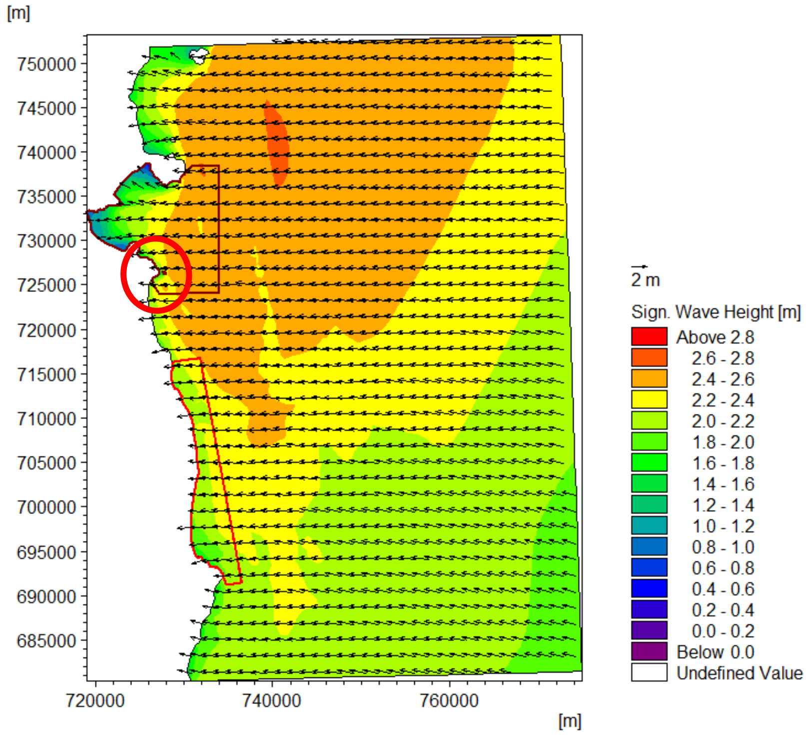


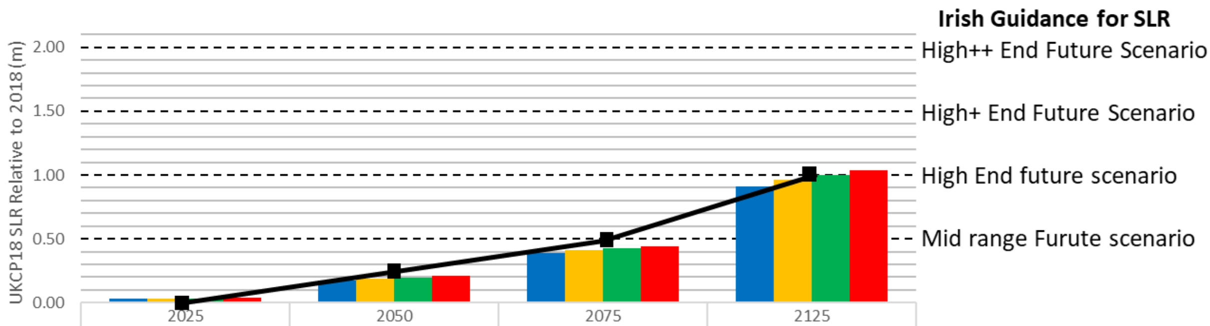

**Figure A.2-2. Representative wave heights (MWD 95°N); CCA2-3 location is circled in red**

## A.2.2 Water Levels

### A.2.2.1 Sea Level Rise

The following sea level rises have been adopted on consideration of Irish (OPW) and UKCP18 guidance. These are plotted against the guidance in Figure A.2-3.

- Present day (2025) = +0.00 m
- Year 2055(P + 30 yrs) = +0.30 m
- Year 2075 (P + 50 yrs) = +0.50 m
- Year 2125 (P +100 yrs) = +1.0 m




| | 2025 | 2050 | 2075 | 2125 |
|---|---|---|---|---|
| 53.94 -6.08 | 0.03 | 0.18 | 0.39 | 0.91 |
| 53.28 -4.75 | 0.03 | 0.19 | 0.41 | 0.96 |
| 52.72 -4.75 | 0.04 | 0.20 | 0.43 | 1.00 |
| 52.06 -5.25 | 0.04 | 0.21 | 0.44 | 1.03 |

**Figure A.2-3. Comparison of UKCP18 sea level rise projections and Irish Guidance. Proposed SLR curve shown with black line**

### A.2.2.2 Tidal Levels

Admiralty TotalTide (ATT, 2023) water levels have been extracted for the Irish Sea covering the extent of the modelled area (Figure A.2-4). The levels for Dublin North Wall are summarised in Table A.2-1. Tide levels for Dublin North Wall.

Table A.2-1. Tide levels for Dublin North Wall

| Tidal Level | Level (mODM) |
|---|---|
| **Highest Astronomical Tide** | +1.99 |
| **Mean High Water Springs** | +1.59 |
| **Mean High Water Neaps** | +0.89 |
| **Mean Sea Level** | -0.11 |
| **Mean Low Water Neaps** | -1.01 |
| **Mean Low Water Springs** | -1.81 |
| **Lowest Astronomical Tide** | -2.61 |

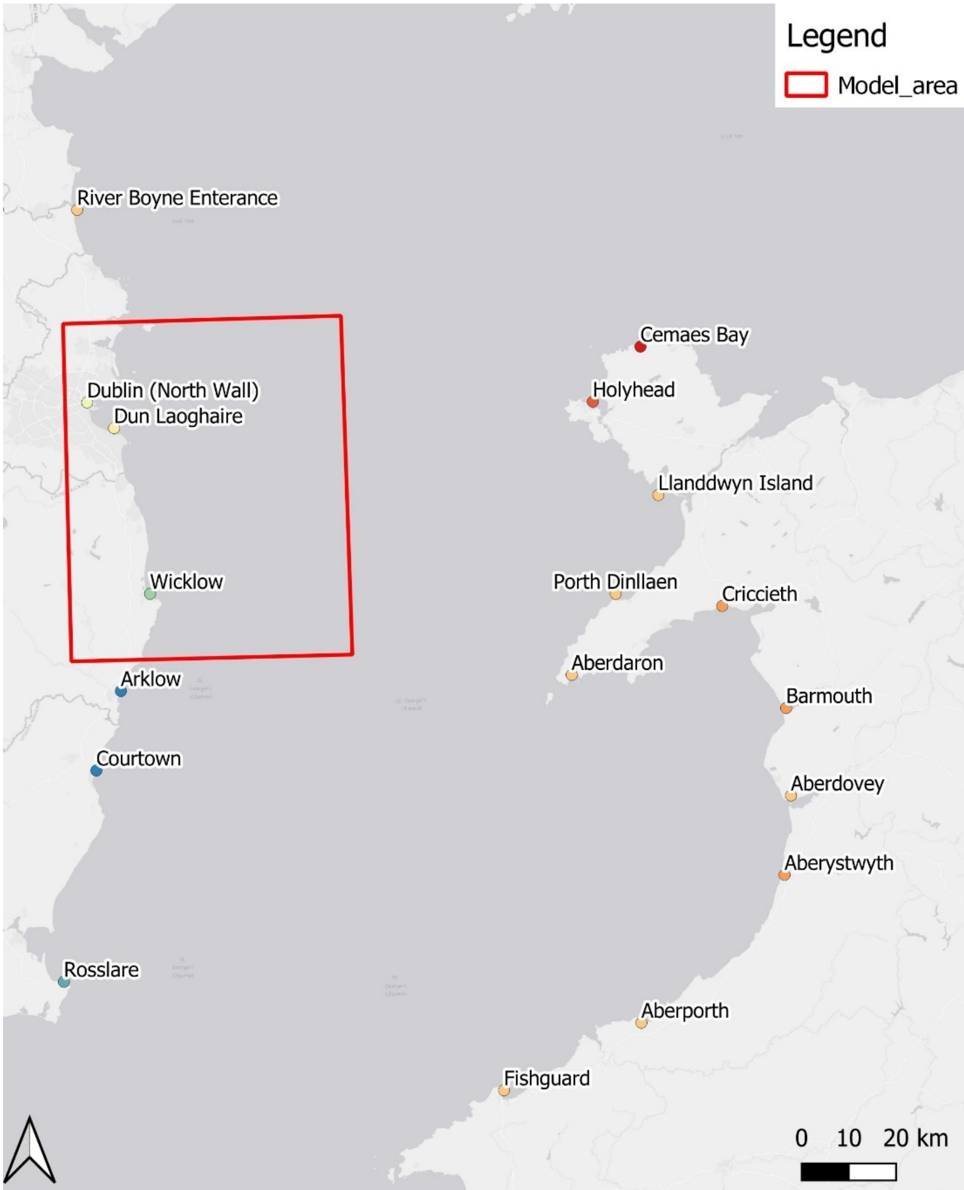



Figure A.2-4. Admiralty Total Tide data locations and model area

### A.2.2.3 Extreme Water Levels

Extreme water levels are available along the Irish coast from the Irish Coastal Wave and Water Level Modelling Study (ICWWS, 2018), and along the Welsh coast from the Coastal Flood Boundary (CFB, 2018) dataset. Both sets of data are used to provide boundary conditions to the general project model. Water levels at 39 locations from Dublin Bay to Wicklow Harbour have been extrapolated using these input data.

## A.2.3 Joint Probability of Waves and Water Levels

Joint probability analysis combines the likelihood of two different variables occurring at the same time. In the design of coastal structures, it is common to use joint probability pairs of wave heights and water levels; this provides the design team with several different inputs which have the same chance of occurrence to fine-tune the design against. Figure A.2-5 shows the joint probability results for the 1 in 2 and 1 in 200 year return period conditions in the present day, 2055, 2100 and 2125. The left hand panel contains the conditions at nearshore point 8 and the right hand panel contains the offshore conditions.

The wave climate is moderate with wave heights in the range of 3 to 5m expected at the nearshore wave points.

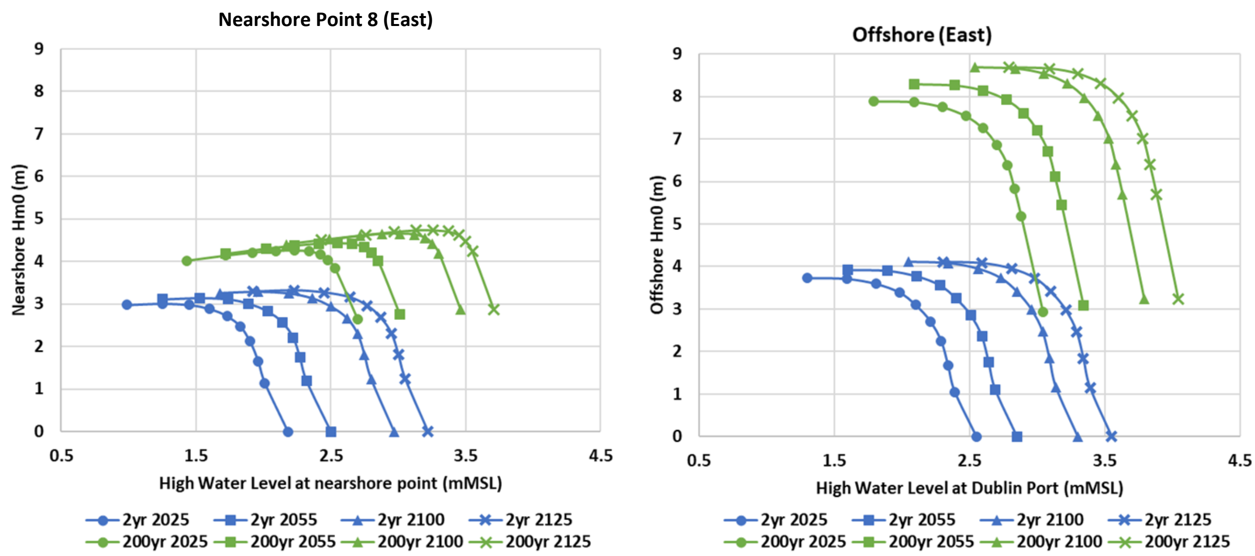



**Figure A.2-5. Joint probability plots of wave height (y-axis) and water level (x-axis) at nearshore point 8 and offshore for the 1 in 2 and 1 in 200 return period conditions in the present day and with sea level rise.**

# A.3 Shoreline Modelling

## A.3.1 Historical Shoreline Change

The initial shoreline used in the LITLINE shoreline change model is the high water mark; this was extracted from OSI mapping data. The OSI dataset was updated in May 2022 and therefore, is assumed to be representative of the 2022 shoreline position.

An additional assessment of historical rates of shoreline change in CCA2-3 has been carried out using georeferenced OS maps (1830, 1900, 1940) and aerial imagery (1995, 2000, 2005, 2012, 2017). The assessment was carried out by mapping the coastal cliff/slope or top edge and the analysis carried out using the DSAS tool. The results show low erosion rates along CCA2-3 between 1830 and 2017. The rate of change in cliff top position varies from stable (within +/- 0.05m/yr) in the northern section of the frontage to low erosion rates (-0.05 to -0.15m/yr) close to the Shanganagh Bray wastewater treatment plant.

The analysis carried out by mapping the cliff edge provides a useful indicator of the morphological state of the shoreline. However, it is expected that the erosion rate derived in this way may underestimate the rate of change of the MHWS shoreline position, since there may be a lag between the recession of the active profile and the steepening and eventual collapse of the cliff slope.

Average annual littoral drift rates over the first 30 years of the modelled period from Jan/1988-Dec/2021 are presented in Figure A.3-6. Results show the following features for the present-day:

- The net littoral drift across CCA2-3 is mainly northwards (negative drift) although in CCA2-3-B, the net littoral drift is initially southwards, reverting to northward in the longer-term.
- To the south of CCA2-3-D, the net littoral drift is mainly southwards (positive drift) over the 30-year period. This is due to the beach along this section being more exposed to waves from the ENE and E compared to Killiney Bay beach further north which is partially sheltered by Dalkey Island. In addition, there is a change in coastline orientation leading to increased obliquity (and higher littoral drift) for waves from the ENE to E.
- Erosion is expected in CCA2-3-D (between chainage 1500m and 2100m in Figure A.3-6) due to the diverging transport along this section of the coast. Erosion is also expected in CCA2-3-A, due to the increasing northwards drift along this section of the coast.
- Net accretion is expected in CCA2-3-B and CCA2-3-C due to the reducing drift rates (between chainage 1500m and 700m on Figure A.3-6).

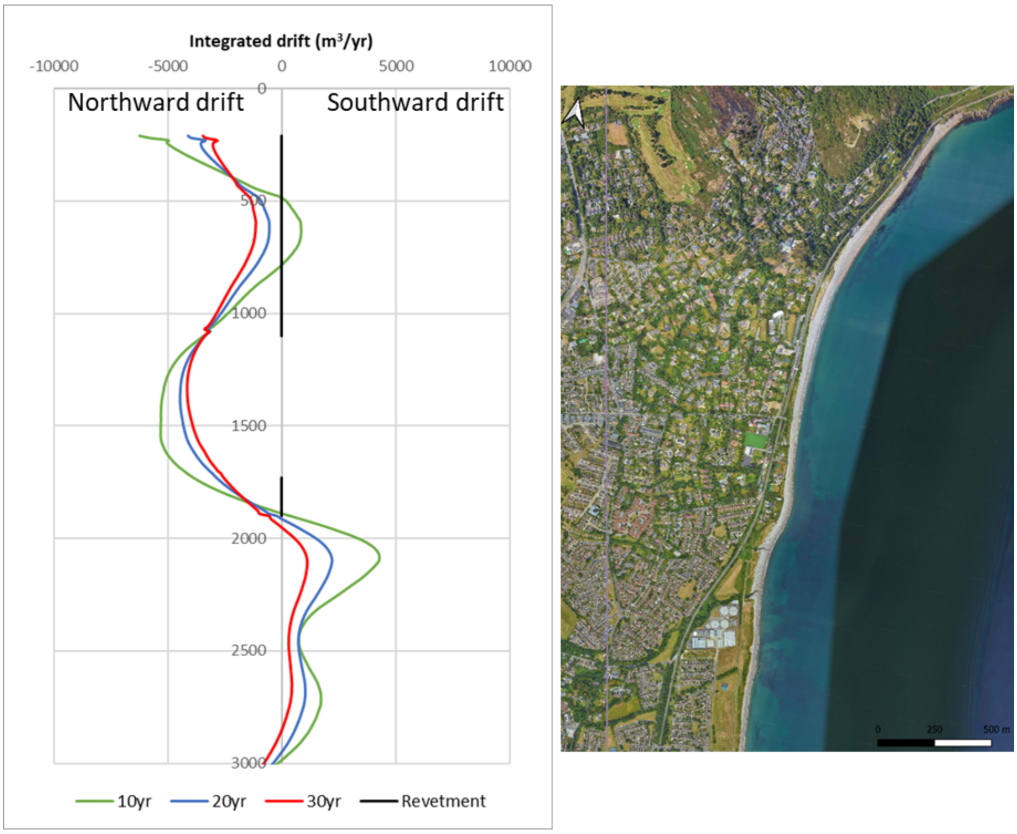



**Figure A.3-6. CCA2-3 annualised integrated drift rate over a 30-year period from Jan/1988-Dec/2017. Negative drift values indicate northwards transport and positive drift values indicate southwards transport**

The differences in the annual rate of coastline changes derived from historical shoreline analysis and the numerical model results may be due to:

- The historical analysis was based on mapping cliff edge, while the numerical model was based on simulating the movement of the MHWS shoreline. The erosion of the cliff edge will lag the erosion of the active beach profile seaward of the cliff. Furthermore, apparent changes to the cliff edge may not always be due to the effect of waves which is driving the changes to the active beach profile.
- Uncertainties in the nearshore profile and sediment characteristics. The nearshore profiles use an interpolated bed level in the gap between the LiDAR and the bathymetry survey available.
- Differences in the wave conditions during the modelled period and observational periods can also contribute to the discrepancy. The historical analysis is based on data from 1830-2021, while the shoreline evolution model is forced with wave data from 1988 to 2021, starting with a shoreline position from 2021 as the initial shoreline.
- Further, the beach in CCA2-3 is backed by cliffs up to 10 m in height which when eroded deposit material onto the beach. This cliff collapse acts to slow down coastal change and cannot be included in the LITLINE model. Hence, the coastal change rates may be exaggerated compared to observed rates.

Given the above uncertainties, it is considered best to use the model as is, to provide an estimate of future coastline changes.

### A.3.2 Future Shoreline Change

Using the LITLINE model the year end and minimum coastline position over time have been calculated for 2025, 2055 and 2100. The minimum coastline position is the most landward position of the coastline during the time period modelled and is not necessarily the final coastline position.

Figure A.3-7 shows the predicted coastline positions at the end of 2025, 2055 and 2100. Figure A.3-8 shows the distance between the edge of the railway line and the predicted coastline position at the end of 2025, 2055 and 2100 (chainage is along the LITLINE baseline). Results show:

- Towards the north of CCA2-3 (near Whiterock beach), the shoreline could be expected to erode by up to 45m by Year 2100, reducing the distance between the railway line and the coastline by Year 2100 to between 10 and 35m along this section. The presence of hard defences limits this erosion leading to beach level lowering in front of the defence, and an increased risk of undermining of the defence.
- Further south, in sub-cells CCA2-3-B and CCA2-3-C, the model generally predicts accretion of up to 10m by Year 2025, up to 2 m by Year 2055 and up to 25m by Year 2100.
- In sub-cell CCA2-3-D (from Killiney station to north of the wastewater treatment plant), the model predicts that the shoreline will erode by up to 45m by Year 2055 up to 55m by 2100. The minimum distance between the railway line and the predicted coastline reduces from approximately 45m in 2025to 30m by 2100.
- South of the wastewater treatment plant, the model predicts that the shoreline will accrete, but the accretion will gradually reduce with time.

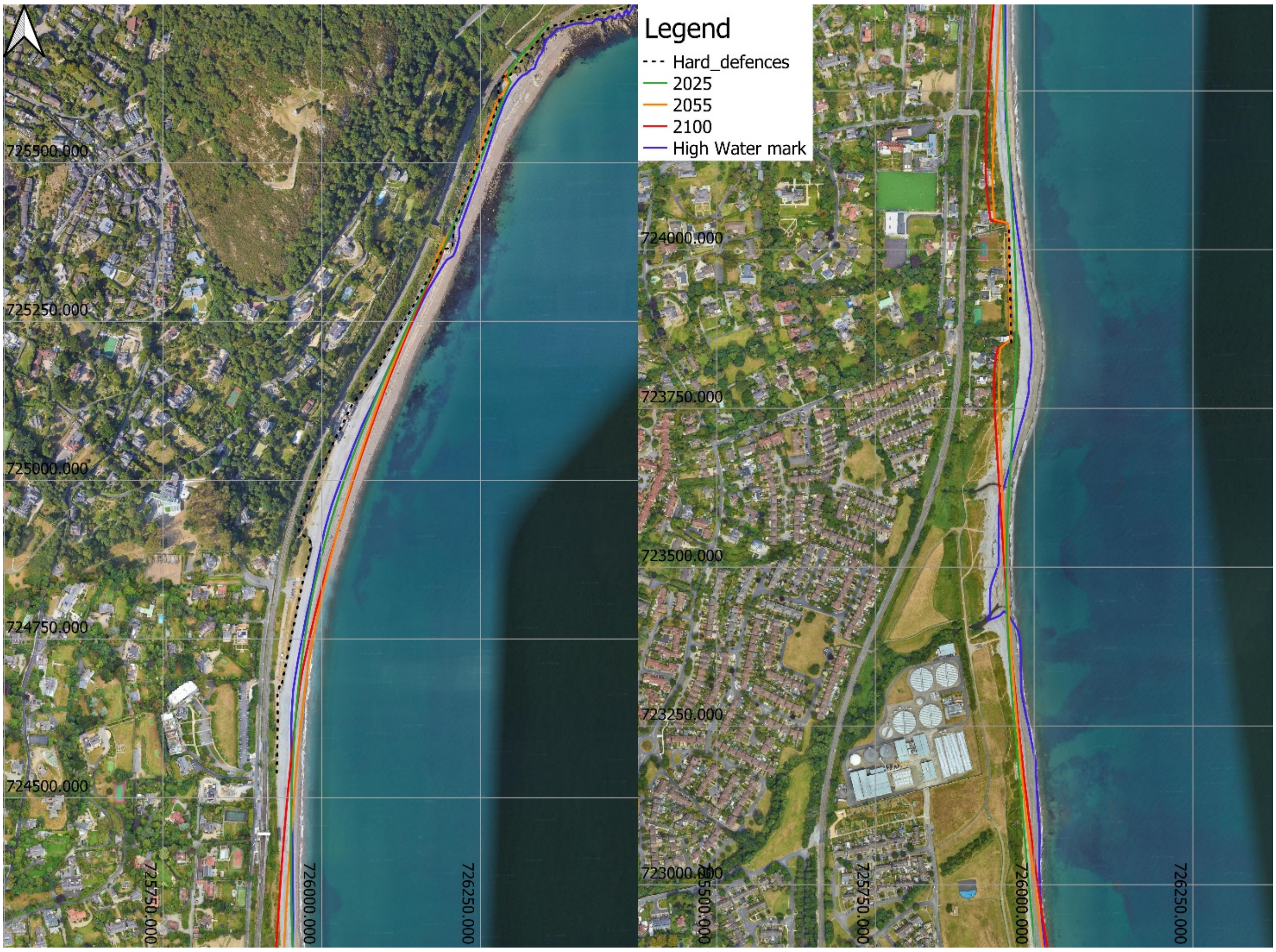



**Figure A.3-7. CCA2-3: Predicted shoreline positions at the end of 2025, 2055 and 2100**

The railway line in CCA2-3 is set back from the coast by more than 30 m and protected by hard defences. The coastline along CCA2-3 is predicted to be eroding in the northern section (near Whiterock beach) and south of Killiney station. These sections of CCA2-3 are protected by hard defences along some stretches, which limits the coastline erosion. However, the beach level in front of the hard defences may be lowered, with the possibility of toe undermining and collapse, especially during storm events. This is especially the case where the railway line is 30 m or less from the MHWS coastline.

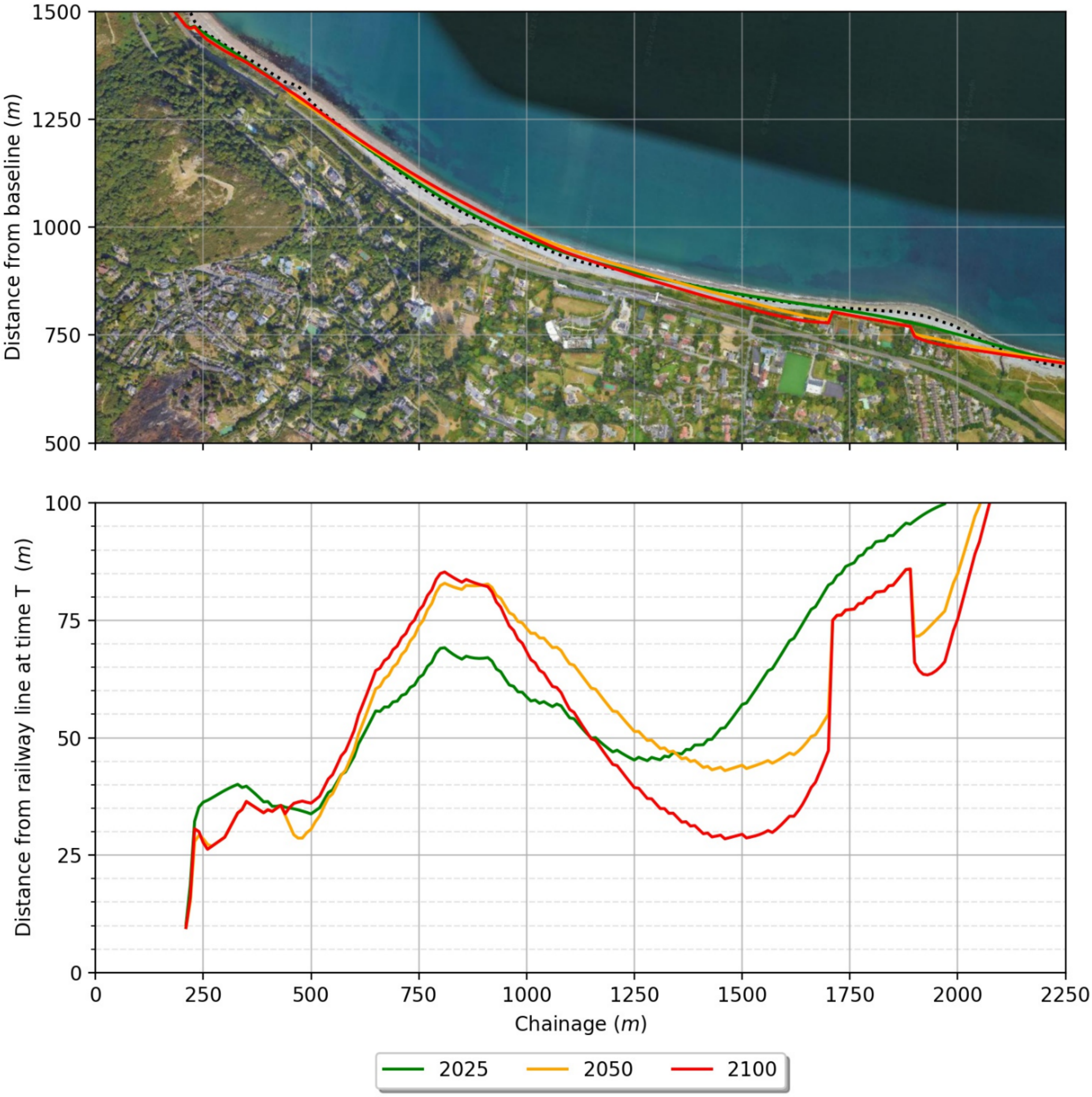



**Figure A.3-8. CCA2-3: Distance between the edge of the railway line and the predicted coastline position at the end of 2025, 2055 and 2100 (chainage is along the LITLINE baseline).**

## A.3.3 Shoreline Modelling of Options

### A.3.3.1 Description of Layouts

Options modelling in CCA2-3 was undertaken for three groyne layouts (Option B) and two breakwater layouts (Option C) to determine the best layout and orientation of the structures. The LITLINE model baseline was modified slightly to ensure it was approximately perpendicular to the modelled groynes (see baseline in Figure A.3-9). The model simulation was run for 10 years to allow a robust comparison between the different layouts.

The model layouts are shown in Figure A.3-10, Figure A.3-11 and Figure A.3-12 and are summarised in Table A.3-2. For all model runs, the back of the beach is represented as a hard structure to limit erosion.


Figure A.3-9. Model baseline alignment for CCA2-3 options modelling

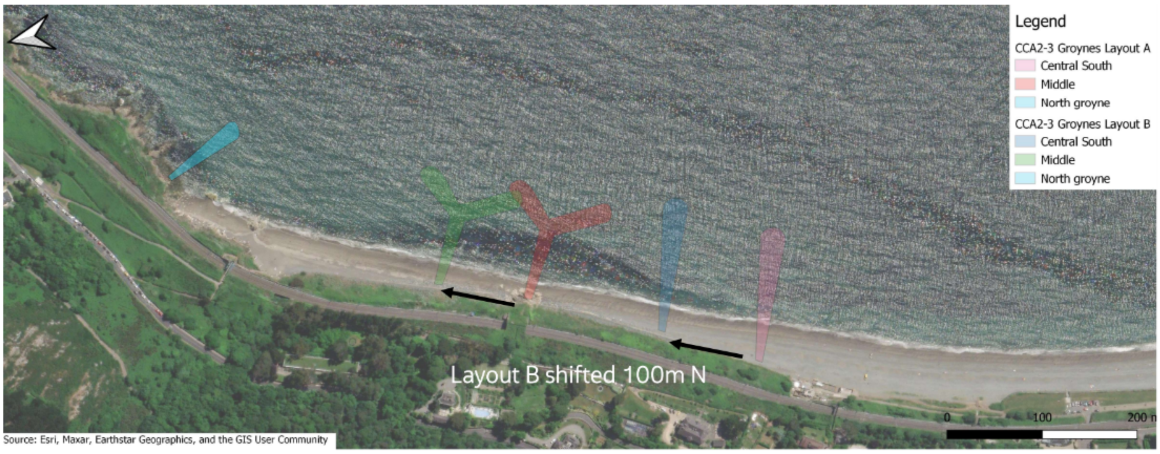



Figure A.3-10. Model layout for Groyne Layout A (in red/pink) and Layout B (in green/blue). The terminal groyne to the north is present in all layouts.

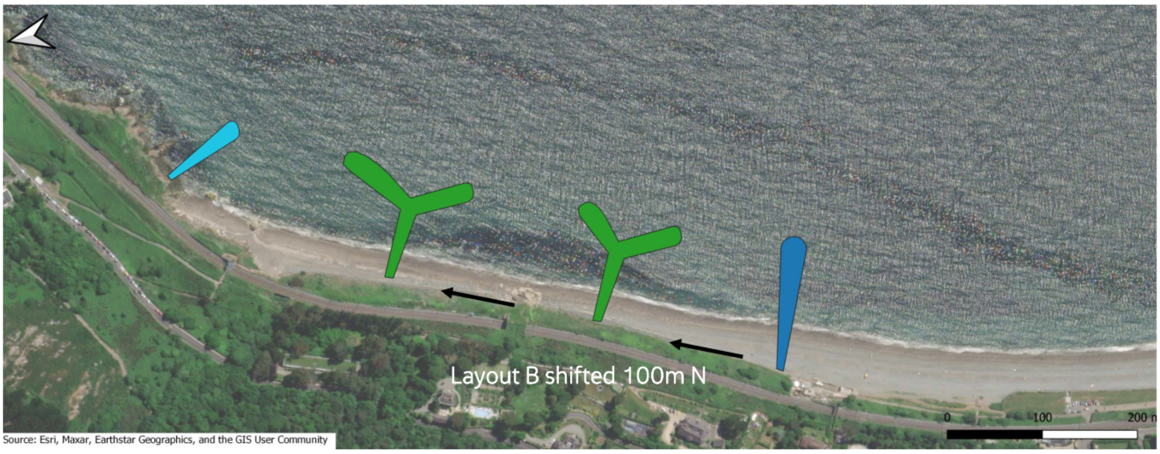
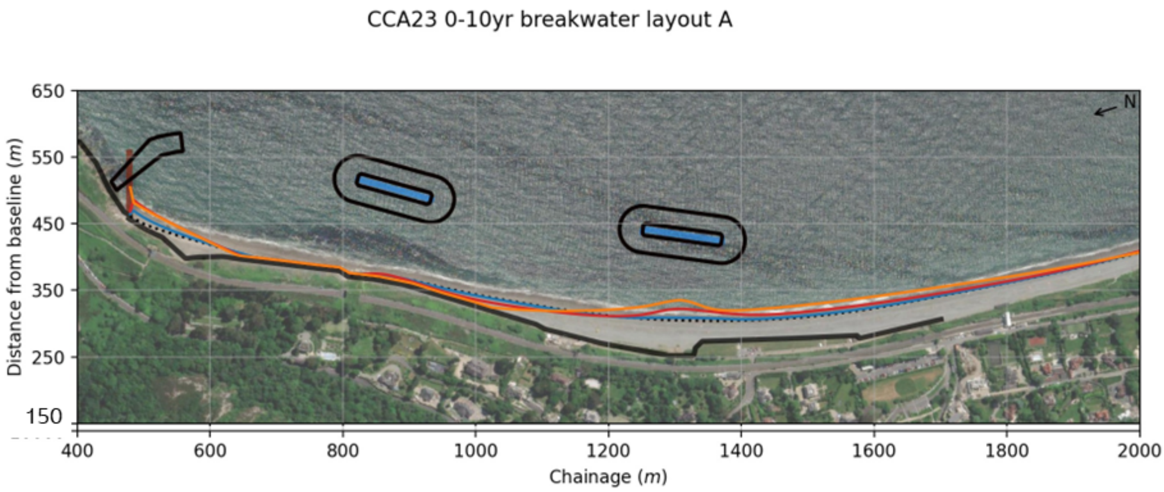



Figure A.3-11. Model layout for Groyne Layout C

Table A.3-2. Summary of modelling layouts

| Option | No. of structures | Beach recharge |
|---|---|---|
| **Groyne Layout A** | 3 groynes | No recharge; 20m recharge; 35m recharge |
| **Groyne Layout B** | 3 groynes | No recharge; 20m recharge; 35m recharge |
| **Groyne Layout C** | 4 groynes | No recharge; 20m recharge; 35m recharge |
| **Breakwater Layout A** | 1 groyne; 2 breakwaters | No recharge |
| **Breakwater Layout B** | 1 groyne; 3 breakwaters | No recharge |



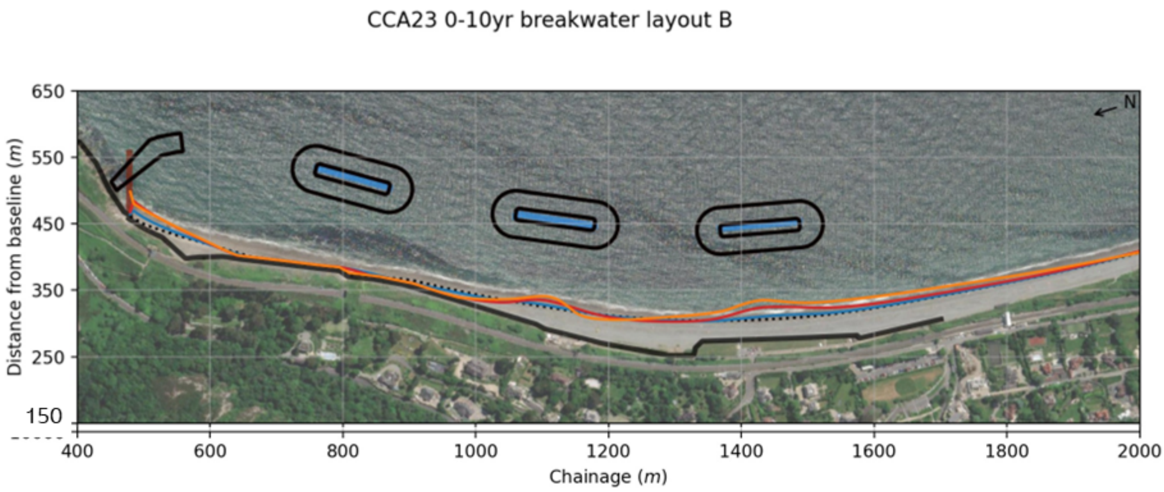




**Figure A.3-12. Breakwater layouts. Top: Layout A. Bottom: Layout B.**

### A.3.3.2 Results

All groyne layouts without recharge reach equilibrium beach orientation within 10 years; without the addition of beach recharge, this realignment will lead to areas of the beach receding to the hard structure at the back of the beach within 10 years. Figure A.3-13 shows sample modelling results for Groyne Layout A without recharge; the results for Groyne Layouts B and C are very similar.

Figure A.3-14, Figure A.3-15 and Figure A.3-16 show the modelling results from Layouts A, B and C, respectively for 20m and 35m wide initial beach recharge. The following points are noted:

- The shoreline realignment does not reach the wall if initial recharge is included in the layout.
- The 35m initial recharge allows more space for the beach to develop between the groynes.
- Layout B performs better than Layout A due to the reduced gap between the northern and central groynes.
- Layout C performs best overall due to the addition of a fourth groyne, reducing the spacing between all groynes.

The results for the breakwater layout modelling are presented in Figure A.3-17 and Figure A.3-18. The following points are noted:

- Both layouts show clockwise rotation of the shoreline between the northern groyne and northern breakwater.
- Layout A predicts erosion of up to 10m over 10 years between the two breakwaters.
- Layout A predicts accretion of up to 30m over 10 years in the shadow of the southern breakwater.
- Layout B predicts erosion of up to 10m over 10 years between the northern and central breakwaters and erosion of up to 8m over 10 years between the central and southern breakwaters.

- Layout B predicts accretion of up to 16m in the shadow of the central breakwater and accretion of up to 30m in the shadow of the southern breakwater.
- Overall, both breakwaters improve on the baseline erosion (reducing from 13m to 10m maximum) but do not fully mitigate the erosion risk to the hard defence over 10 years. Beach nourishment would be required to achieve and maintain the required standard of protection.

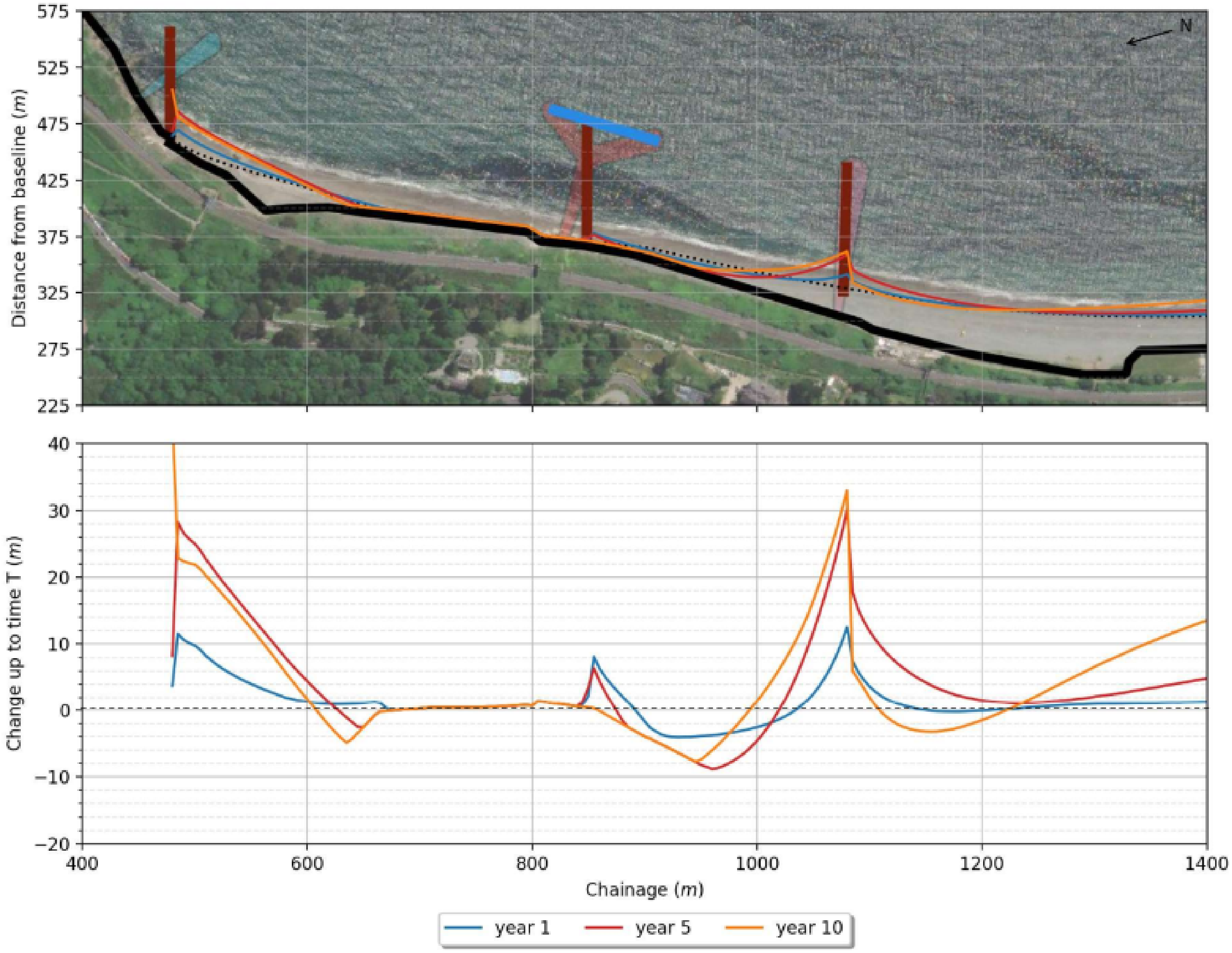



**Figure A.3-13. Groyne Layout A without recharge; bottom panel shows the linear change of the MHWS contour from the initial shoreline position**

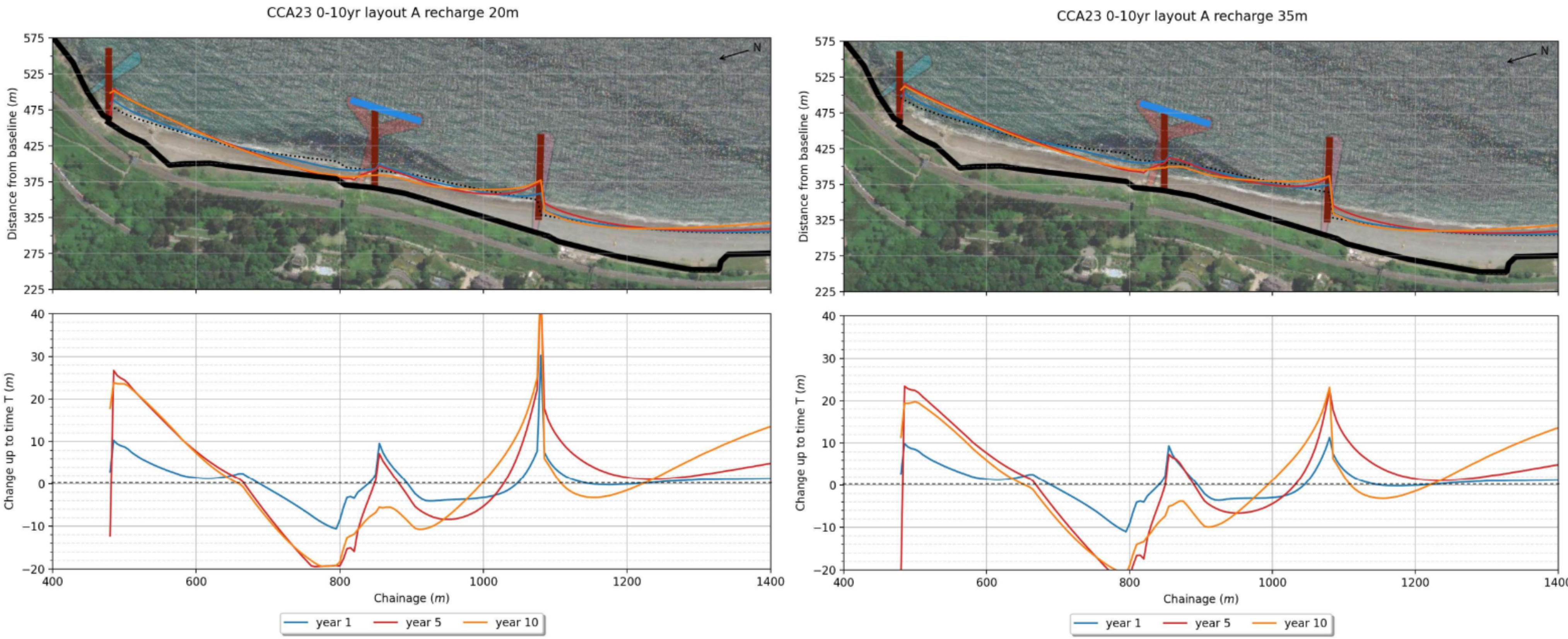



**Figure A.3-14. Groyne Layout A with 20m and 35m of initial recharge; bottom panel shows the linear change of the MHWS contour from the initial shoreline position**

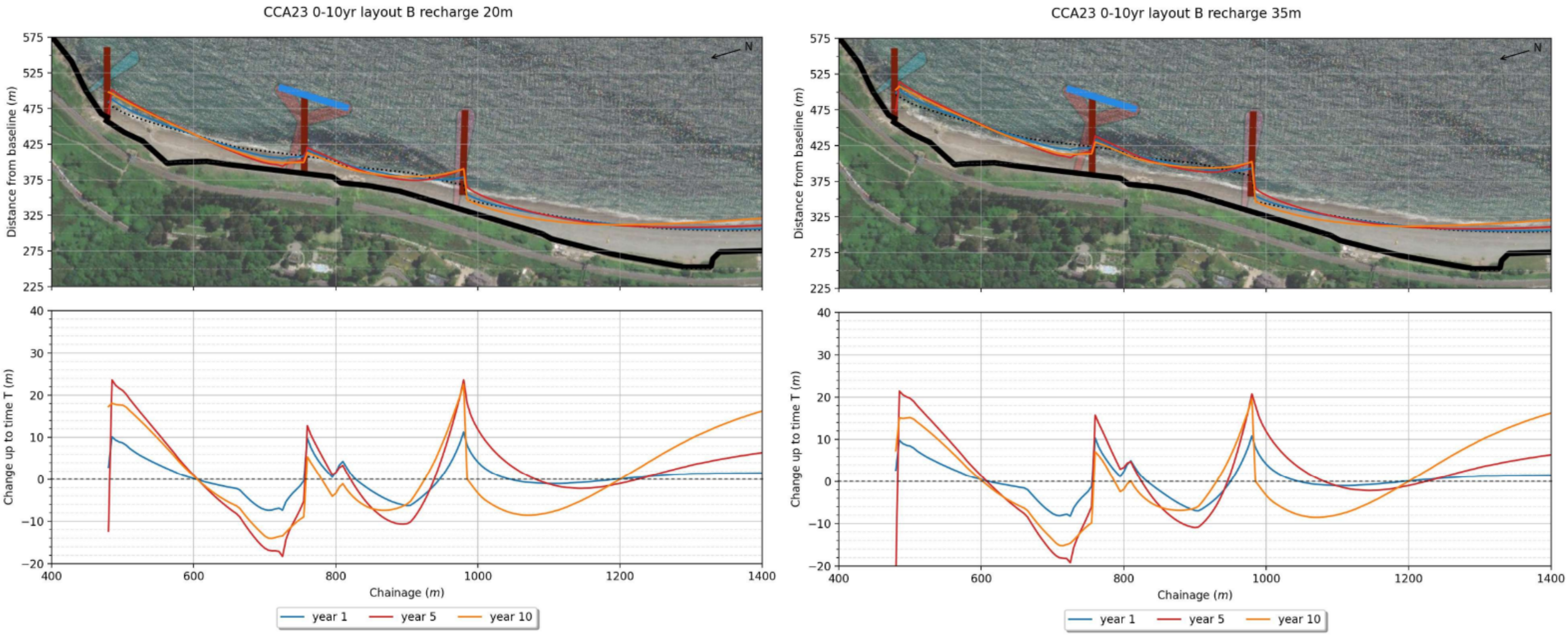



**Figure A.3-15. Groyne Layout B with 20m and 35m of initial recharge; bottom panel shows the linear change of the MHWS contour from the initial shoreline position**

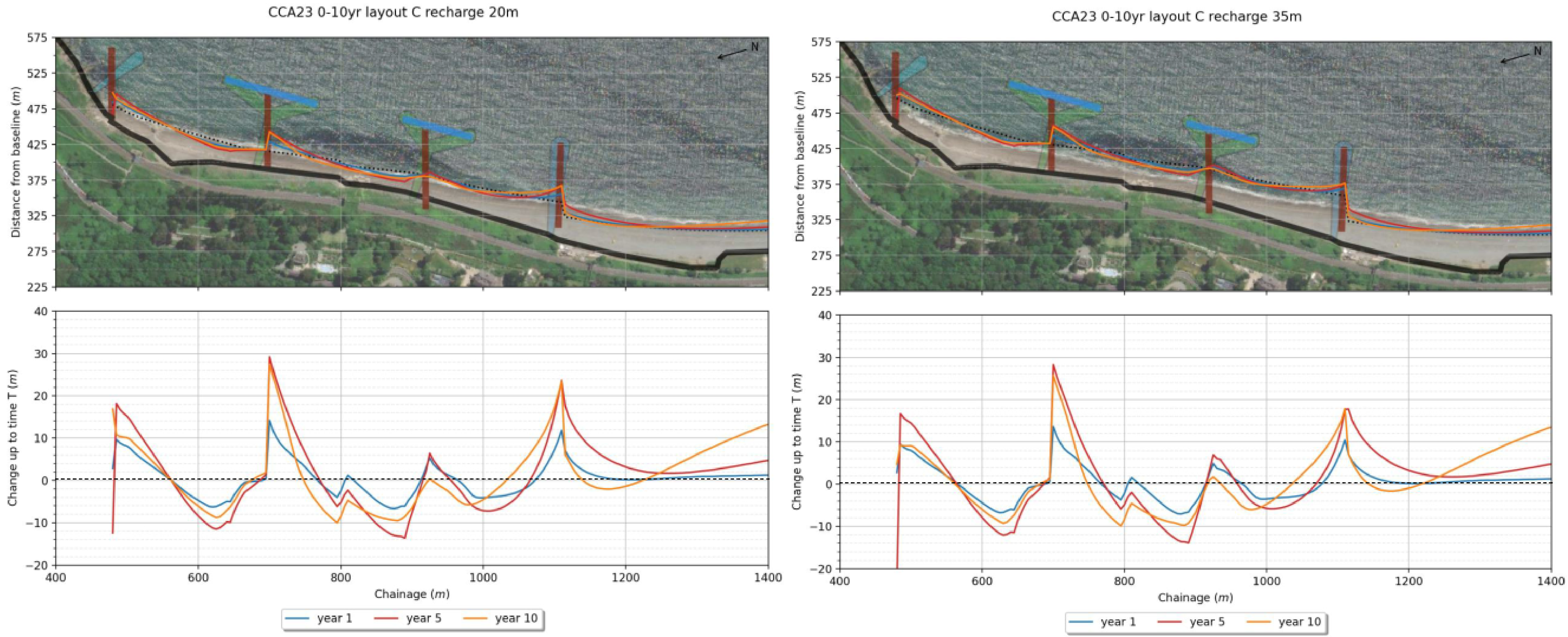



**Figure A.3-16. Groyne Layout C with 20m and 35m of initial recharge; bottom panel shows the linear change of the MHWS contour from the initial shoreline position**

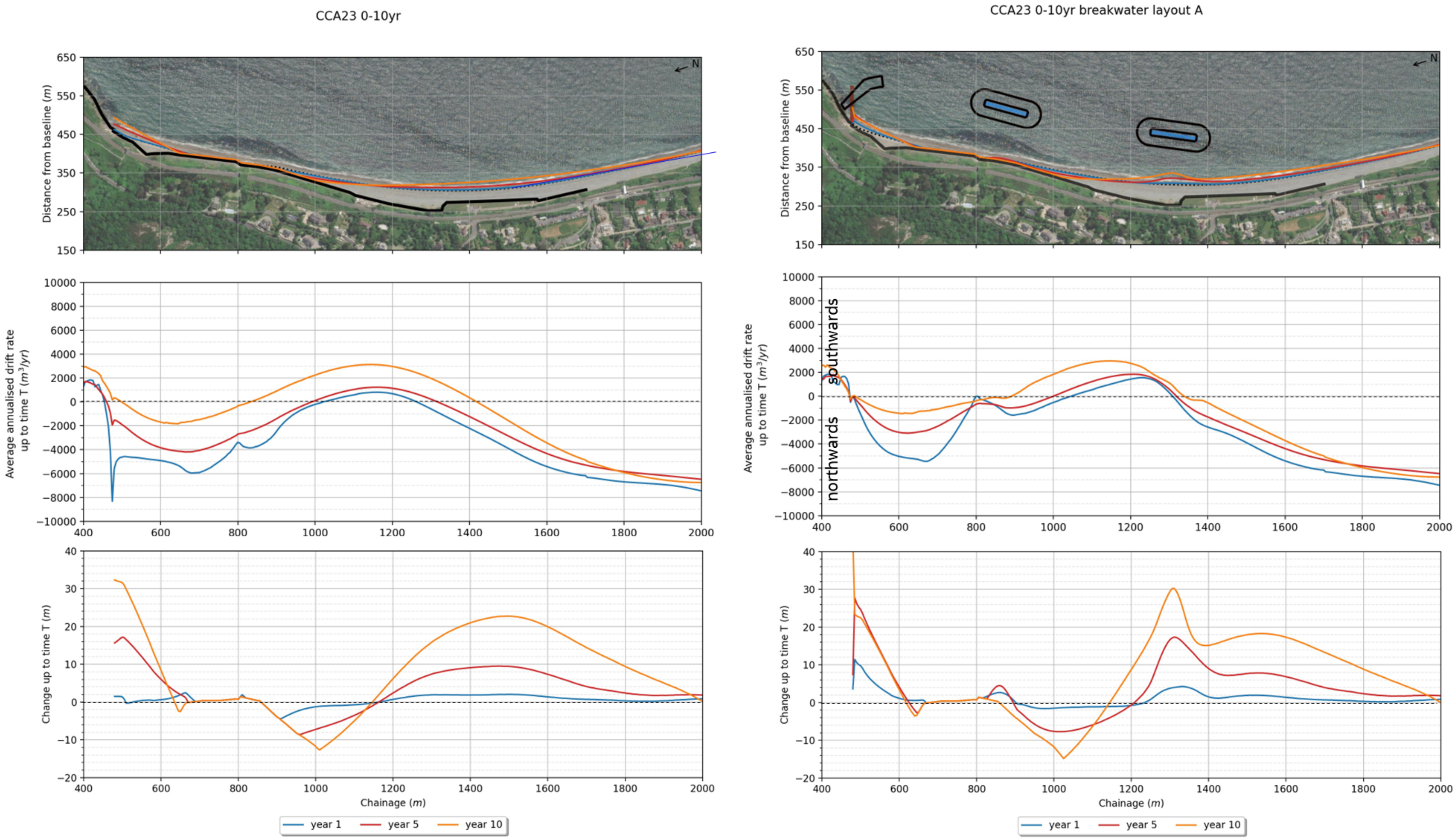



**Figure A.3-17. Comparison of Baseline with Breakwater Layout A. Top: Predicted shoreline positions. Middle: Net annual littoral drift rates. Bottom: Shoreline changes**

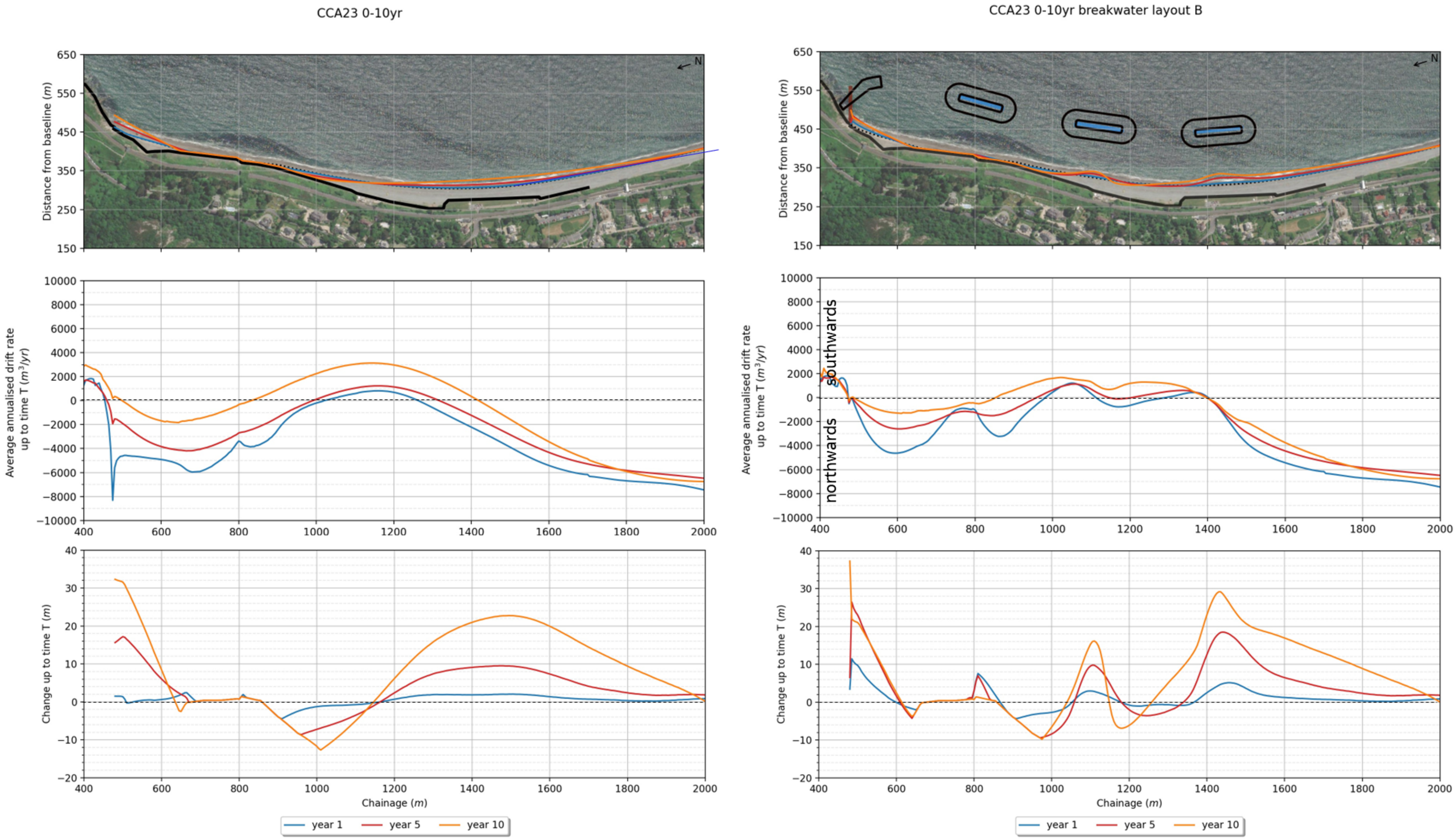



**Figure A.3-18. Comparison of Baseline with Breakwater Layout B. Top: Predicted shoreline positions. Middle: Net annual littoral drift rates. Bottom: Shoreline changes**

## A.4 Summary

Waves heights within CCA2-3 are moderate, with wave heights of 4 to 5m expected at the nearshore wave points. With climate change, small increases in wave height are predicted. Sea level rise of 1m over 100 years is expected; this will have a limited effect on the design of options as the railway is located well above the predicted water levels.

The railway line in CCA2-3 is set back from the coast by more than 30 m and protected by hard defences. The coastline along CCA2-3 is predicted to be eroding in the northern section (near Whiterock beach) and south of Killiney station. These sections of CCA2-3 are protected by hard defences along some stretches, which limits the coastline erosion. However, the beach level in front of the hard defences may be lowered, with the possibility of toe undermining and collapse, especially during storm events. This is especially the case where the railway line is 30 m or less from the MHWS coastline.

Modelling of the impact of a range of groyne and breakwater options on the shoreline has been undertaken for CCA2-3. The shoreline change modelling showed that groynes would only increase the resilience of the beach if a large amount of beach recharge was included (widening the beach by 35m) and that breakwaters alone could not stabilise the beach. In all cases, a hard defence at the back of the beach would still be needed to prevent undermining of the railway.