

File Note

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Subject	Complementary note to Shoreline modelling - risk reduction assessment (ABPmer 2021)	

This technical note complements the Shoreline modelling – risk reduction assessment (ABPmer, 2021) report which is attached.

The purpose of the study was to assess the evolution of the coastline at Barmouth North Promenade following the placement of granular material to nourish the beach in front of the sea defences. This material will be used mainly to cover and protect the toe of the revetment, that consists of a set of sheetpiles. The main goals are:

- Minimise the required beach maintenance during the 50 years of design life.
- Maintain the toe of the structure under the beach levels.

By knowing approximately the amount of initial material needed to achieve the above goals, we can proceed to reduce the optimism bias in the cost estimate, as the final required volume is not expected to differ largely.

The purpose of Scheme 1 was to set up a baseline using the design proposed in the initial OBC study. Schemes 2 to 5 are used to check the sensitivity of the coastal processes to different parameters: material particle size, berm width, graded ends or contained by structures.

The following Table 1 offers a summary of the results based on the parameters assessed. All of the options offer adequate protection to the toe of the structure after 25 years modelling. Even though the 4.5mODN refers to the berm crest, the 2mODN line (see results in ABPmer report) showing in front of the defences frontage provides at least 0.5m cover from the top of the sheet piles. For the purpose of assessing the options, in Schemes 1 and 3 it is considered that the possibility of having less than 0,5m cover at the end of 25 years is high, therefore maintenance is going to be likely needed. That is not the case for the other scenarios.

Scheme 6 intends to measure how faster the material is moved beyond the first 25 years, due to climate change effects. This showed that slightly more material will be lost towards the end of the 50-year epoch, making the probability of a nourishment campaign very high. The approach taken is to assume that the beach is reinstated to the original design after 25 years.

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The option contained by groyne structures provides the greater confidence that no maintenance will be required in the first 25 years, however the cost, environmental and visual impacts are the highest.

Recommendations:

Based on the results of the study summarised in this note, the option represented in Scheme 2 offers enough confidence that the defence toe will be protected during the first 25 years and maybe beyond. The volume of material and site impact of this option is similar to the initial OBC option (with slightly bigger material size).

The shoreline modelling study has reduced uncertainties related to the whole life cost of maintaining a stable nourished beach that provides protection to the toe of the revetment. However, some residual uncertainty remains with the beach transport rate predictions. Refer to the main report for further details.

We recommend that appropriate long-term monitoring is carried out to better understand the performance of the nourished beach and inform future beach management.

It should be noted that the nourished beach will be modified by the incident wave and water level conditions. Under certain storm events, the shingle/cobble berm is likely to rise to levels above the primary defence crest level. Shingle/cobble is also likely to be moved over the defences on to the promenade and Marine Parade Road. The frequency and severity will increase as the sea level rises. We recommend that the design and maintenance strategy for the scheme considers this phenomenon.

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Scheme	Description	Nourishment sediment size	Extent	Cost (based on volume of material)	Impact on site	Uncertainty in modelling results	Impact on adjacent frontage incl. beach	Comment/ Conclusion	Expected maintenance campaigns in 50 years
1	OBC solution	40mm	560m	OBC solution	Medium	OBC solution	Potential for shingle/cobble to be transported to sandy beach off South Promenade	After 10 yrs berm at +5mODN partially lost but still more than enough protection to toe	2
2	Increased sediment size	70mm	560m	~ OBC solution	High (due to increase in sediment size)	OBC solution	Potential for shingle/cobble to be transported to sandy beach off South Promenade	Little difference compared to Baseline. After 25 yrs berm at +5mODN partially lost but still more than enough protection to toe	1-2
3	Reduced berm	70mm	560m	80-85% OBC solution	Medium (larger sediment but smaller berm)	OBC solution	Potential for shingle/cobble to be transported to sandy beach off South Promenade	After 25 yrs berm lost but still at +2mODN therefore provides protection to toe	2
4	Graded profile	70mm	700m	115-120% OBC solution	Very High (due to larger sediment size and extension)	OBC solution	Potential for shingle/cobble to be transported to sandy beach off South Promenade	Little difference compared to Baseline. After 25 yrs berm at +5mODN partially lost but still more than enough protection to toe	1-2
5	Groynes	70mm	560m	OBC solution + groynes	Very High (due to construction or hard structures)	Less than OBC solution due to containment	No	After 25 years beach nourishment still contained within the 2 groynes	0-1

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Scheme	Description	Nourishment sediment size	Extent	Cost (based on volume of material)	Impact on site	Uncertainty in modelling results	Impact on adjacent frontage incl. beach	Comment/ Conclusion	Expected maintenance campaigns in 50 years
6	Sea Level Rise	70mm	560m	Baseline	N/A	OBC solution	Potential for shingle/cobble to be transported to sandy beach off South Promenade	Transport rates after 10 years are increased by up to around 30% along part of the frontage, but the overall impact on the shoreline position is minimal. After 25 yrs berm lost but still at +2mODN therefore provides protection to toe	N/A

Table 1: Summary of results from the shoreline modelling scenarios

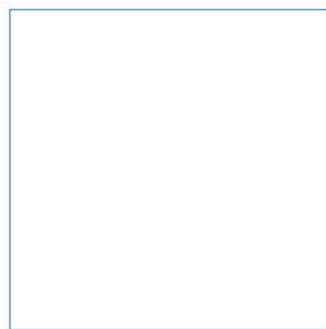
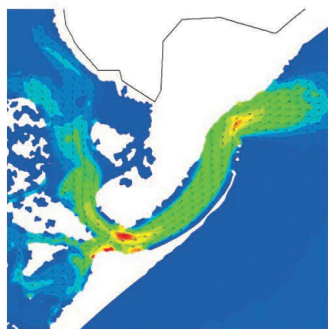
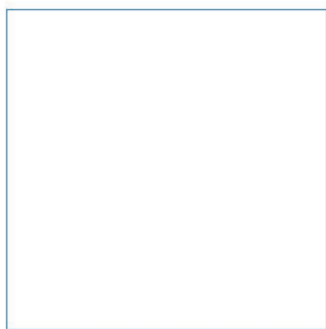
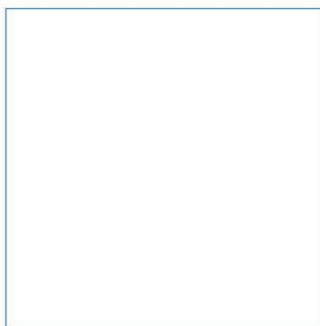
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Barmouth North Promenade

Shoreline modelling - risk reduction assessment

April 2021



Innovative Thinking - Sustainable Solutions

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Shoreline modelling - risk reduction assessment

April 2021



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1 Introduction

ABPmer is supporting Arup and Gwynedd Council in the development of the coastal defence scheme at Barmouth. The OBC recommended Pathway G which comprises of 'betterment of defences' for epoch 1 and 2 and managed realignment along North Promenade, Barmouth (Figure 1) in epoch 3.



Figure 1. Location of North Promenade study frontage. Shoreline Management Plan (SMP2) Policy units: Llanaber (11.16), Barmouth North (11.15) and Barmouth South (11.14) overlaid

The betterment of defences allows for an increase in the standard of protection over the period and comprises of:

- Raising defence height of existing structures;
- New rock revetment (300 m northern section); and
- Shingle beach profile to be built out to protect the primary sea wall and revetment. Extents to be defined during detailed design. Dependent upon stability of shingle material as a result of coastal processes (560 m)¹.

As a risk reduction measure Arup and Gwynedd Council are seeking to provide further understanding on the construction and whole life costs of the scheme. One of the uncertainties related to the whole life cost is the likely stability of the nourished shingle beach. Shoreline evolution modelling has been undertaken by ABPmer to examine this.

This report sets out the development of the sediment transport model and the results of the scenario modelling that has been undertaken. It is important to note that the shoreline evolution modelling predicts changes as a result of longshore sediment drift, changes as a result of onshore-offshore transport are not represented in the model. This approach is considered appropriate as the study is focused on coarse sediment that lies along the upper beach over a shallower slopping sandy foreshore which will be subject to longshore drift. Any cross-shore impacts will be temporal in nature.

¹ Barmouth North OBC Appendix J1 Preferred Option Drawings (002).

2 Shoreline Model Setup

2.1 Introduction

To examine the likely stability of the nourished shingle/cobble beach a shoreline evolution model has been developed for the wider Bournemouth frontage. The extent of the model runs from Llanaber to the north and includes the large sandy beach off Barmouth South. The model therefore incorporated the shingle/cobble beach directly to the north of the project site. The objective of the modelling study is to understand how the nourished shingle/cobble beach will evolve as sediment is transported along the coastline due to longshore drift.

The modelling has been undertaken using the Coastal Evolution module in the DHI Littoral Processes FM suite of models.

As there is very limited shingle/cobble on the project frontage a formal validation exercise has not been undertaken, however, the behaviour of the model over the wider study area has been examined for the 10-year period from 01/01/2007 to 31/12/2016 to help confirm that the model is performing appropriately. Having established this, the model was initially set up to simulate the behaviour of the proposed nourished beach over the same 10-year period. The results of this modelling were discussed with Arup and Gwynedd council and further 5 schemes were identified and tested.

2.2 Model configuration

The shoreline evolution baseline model was schematisation as shown in Figure 2, with further detail along North Promenade shown in Figure 3. Figure 2 and Figure 3, show the model baseline (red line), the location of the hard defence (blue line), and the shoreline which is defined by the representative 0 mODN contour (yellow line).

The definition and derivation of the representative contour is described below. Significant variations occur along the model frontage as follows:

- To the north of North Promenade, a significant shingle/cobble upper beach lies in front of the railway line;
- Along the northern end of North Promenade, there is no shingle present and the beach levels against the revetment are typically around 0.6 mODN (present day);
- Towards the southern end of North Promenade, the promenade is aligned seaward. Shingle/cobbles are present and the beach levels against the defence are higher, up to around +2 mODN. Groynes, in varying conditions, are present along the frontage, but it is believed that the shingle/cobble accumulation is due to presence of shallow harder shoal the foreshore as seen in Figure 3 and Figure 6 rather than the functioning of the groynes; and
- To the south of North Promenade, a large expansive sand beach is present backed with developing dunes. Along the main shoreline shingle/cobbles can also be observed along the upper beach. Particularly along the northern section of the Barmouth South frontage.

Whilst such variations exist, the frontage can generally be considered to have a shallow lower foreshore and a steeper upper beach. The presence and availability of the shingle/cobble upper beach is then affected by the location of the hard defence. For example, along the northern end of North Promenade there is no shingle/cobble upper beach and the sandy foreshore ties directly into the hard defence at lower bed level.

The frontage is therefore defined in the model, by assuming a single representative beach profile (See Section 2.3), with a shallow lower foreshore and steeper upper beach and the representative 0 mODN contour as shown in Figure 2 and Figure 3. Where the 0 mODN contour lies very close the defence the bed levels close to the defence will be only slightly above 0 mODN as seen at the northern end of North Promenade and there will be no shingle/cobble upper beach in the model.

The representative 0 mODN contour is based on the 0 mODN contour from the 2014 LiDAR DSM data, however slight adjustments have been made to address some of the variations observed along the frontage. Towards the southern end of North Promenade, the 0 mODN contour lies further seaward, due to the presence of a shallow shoal in this region. If this were used in the model the shingle/cobble beach at this location would be unrealistically large. Therefore, the representative 0 mODN contour at this location, lies slightly landward. In this way the location of the representative 0 mODN contour, together with the schematised beach profile, provides a more realistic representation of the quantity of mobile shingle/cobble material along the frontage.

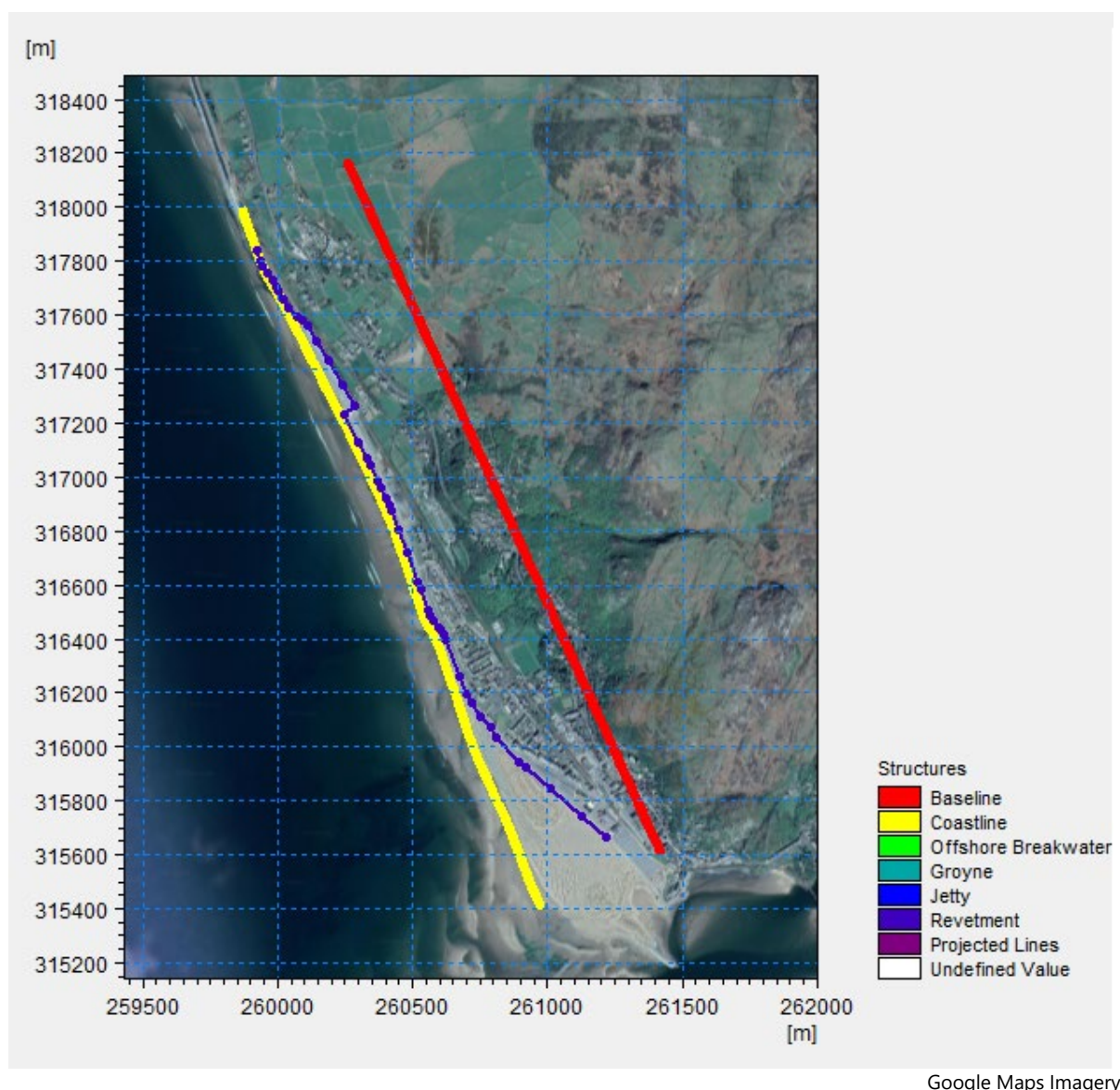


Figure 2. Shoreline evolution model baseline schematisation

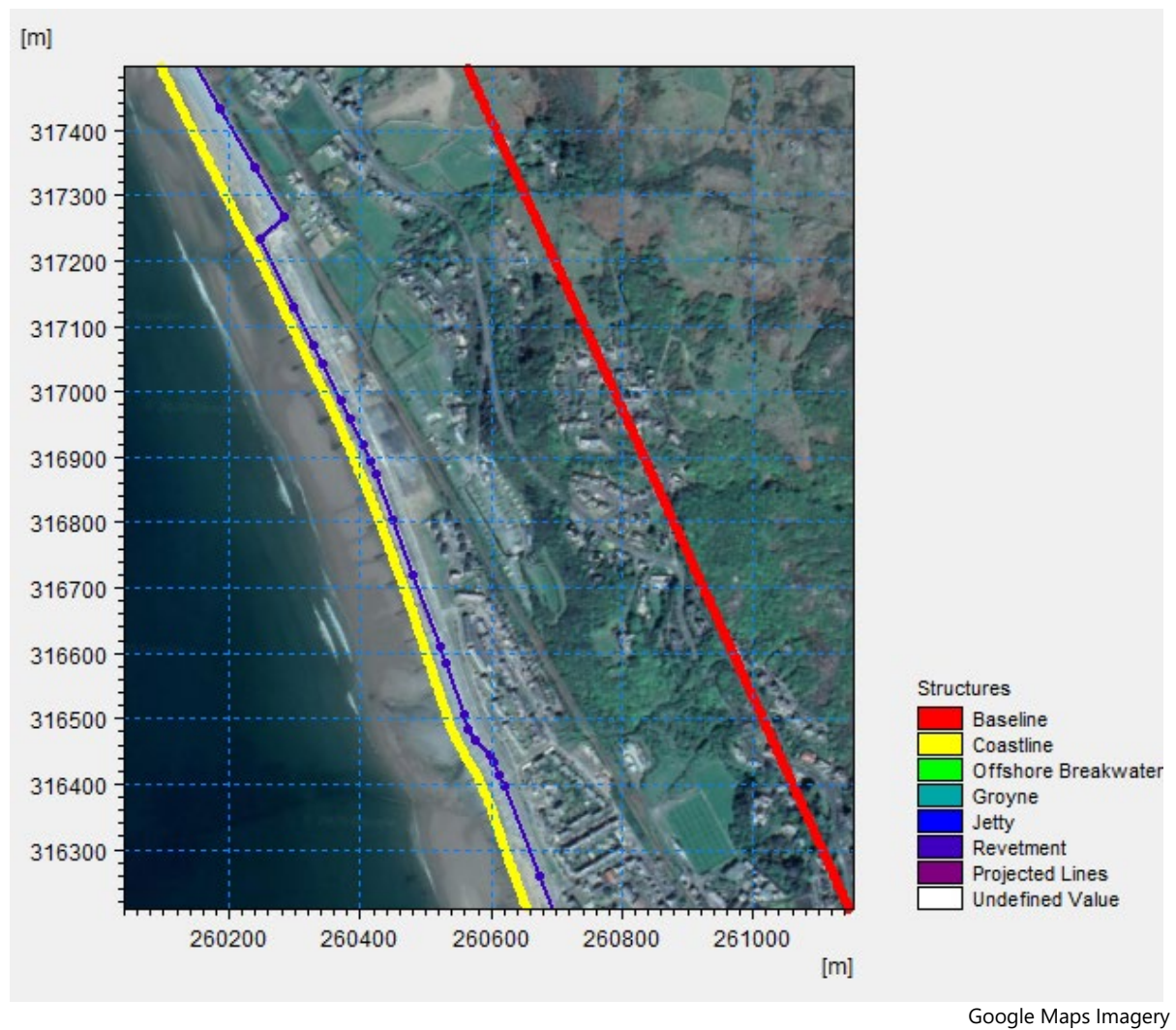


Figure 3. Shoreline evolution model baseline schematisation - detail North Promenade



Figure 4. Presence of shallow shoals across the foreshore, associated with seaward alignment of the shoreline - further possible shoals also seen offshore (darker areas)

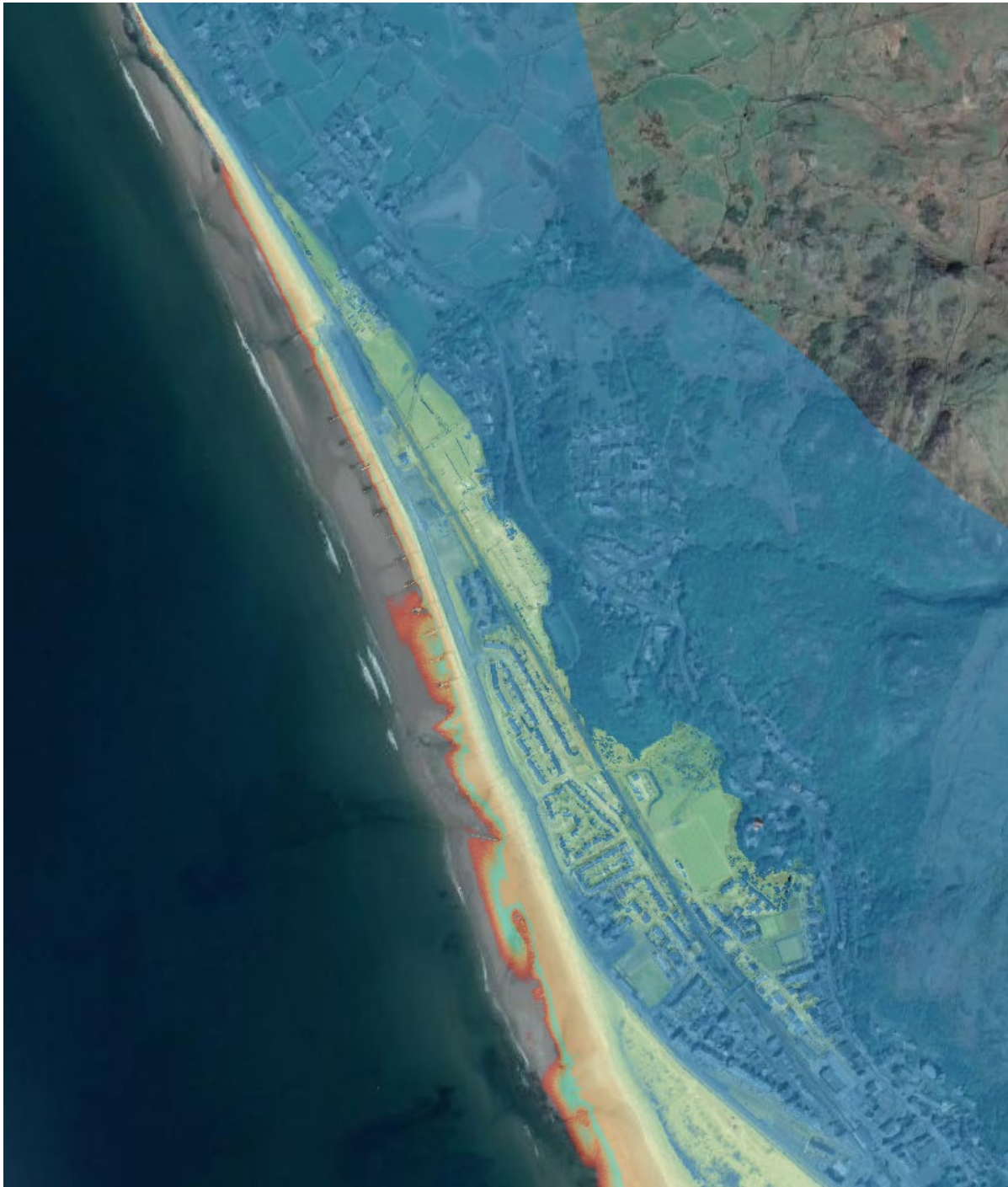


Figure 5. Presence of shallow shoals and 0 mODN contour (red values from 2014 LiDAR DSM)

2.3 Beach profile

In setting up the shoreline model a single beach profile has been defined. This schematised profile has been defined based on a review of the 2014 LiDAR DSM, together with a review of the proposed shingle nourishment profile Figure 6.

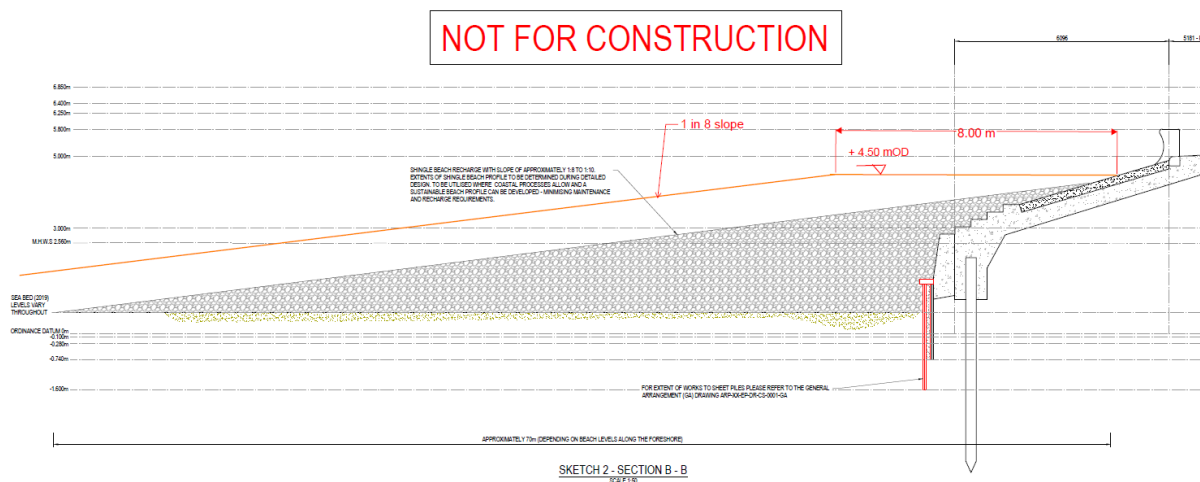


Figure 6. Proposed shingle nourishment profile (orange line) - From Arup drawing SK_Coastal Modelling - Rv01 .pdf

The profile extends offshore from the -7 mODN contour, with a relatively shallow slope up to a level of +0.5 mODN. Inshore of this, the upper shingle beach has a slope of 1:8 to a crest level of +5 mODN. The schematised profile is shown in Figure 7.

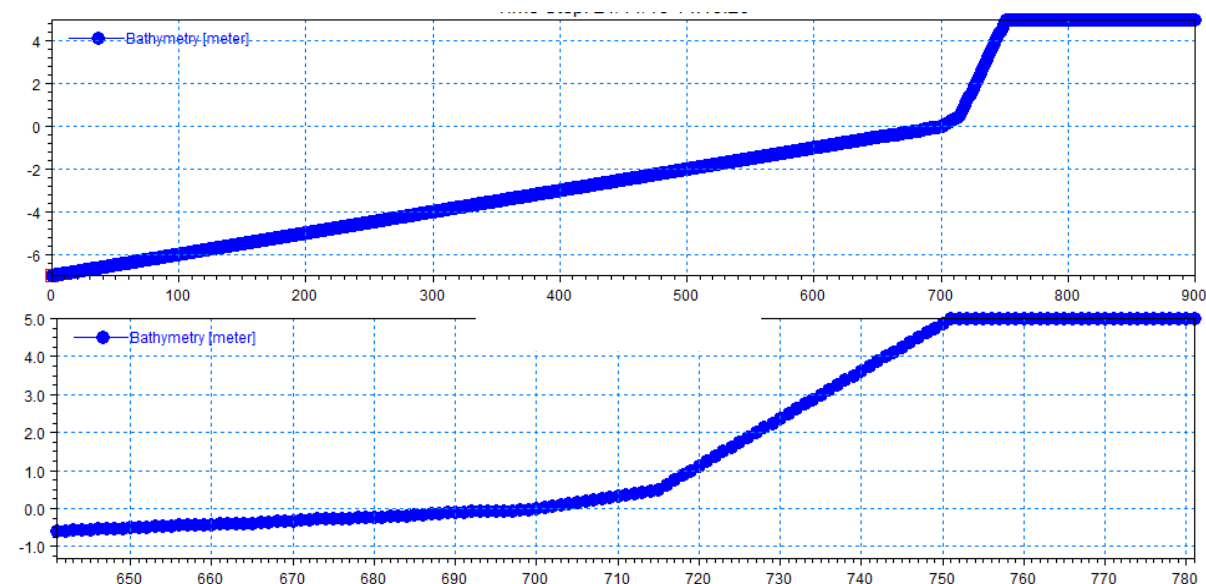


Figure 7. Shoreline evolution model schematised beach profile, Upper - full profile, Lower - upper beach detail (levels to mODN)

The +0.5 mODN transition level utilised in this profile coincides closely to the level on the foreshore at which the upper shingle/cobble beach is observed. Along much of the North Promenade no, or very limited shingle/cobble, is present and the beach level is close to +0.5 mODN. With the schematised profile and coastline as identified in Figure 2 and Figure 3, the baseline model includes limited mobile shingle/cobble along North Promenade.

The crest height of the schematised profile is set as +5 mODN not +4.5 mODN as per the proposed nourishment profile (Figure 6). This is because initial simulations showed that wave setup on top of the still water level would exceed 4.5 mODN for some of the events in the hindcast data set. It is further noted that to the north of North Promenade, the natural beach crest of the shingle/cobble beach reaches level of around 5.8 mODN under present day conditions. Therefore, after nourishment, where significant quantities of shingle/cobbles remain in front of the North Promenade defence, it can be expected that the beach berm would be pushed up to similar elevations under extreme wave conditions. The likelihood and consequence of this needs to be considered in the design process, but for the present assessment it was agreed with Arup to fix the crest berm at a lower level.

2.4 Structures

The structural defence/revetment (blue line in Figure 2 and Figure 3) was digitised from recent aerial imagery of the frontage and represents the hard defence beyond which the beach cannot retreat. In the model simulations, if the coastline encroaches on to the hard defence line, the revetment/hard defence line is shown as the shoreline position and the beach is effectively drawn down in front of the revetment until no part of the active beach profile remains in front of the defence.

The existing groynes have not been included within the model.

2.5 Wave and water level conditions

The model is driven from time-series wave conditions extracted from the long-term hindcast wave model dataset developed under the Barmouth OBC study (ABPmer, 2019b). The wave extraction location is located offshore with a bed level of -7 mODN (Figure 8). During model setup and initial testing hindcast wave data for the period 2007 to 2016 were used from the present day hindcast with the Mean Relative Sea Level (MRSL) at present day levels (see below).

The water level time-series used in the model were obtained from ABPmer's long-term Tide and Surge hindcast data sets for the site. This is the same water level time-series record that is utilised in the wave model hindcast for the Barmouth OBC study (ABPmer, 2019b). The water level variations are applied uniformly along the extent of the coastline evolution model.

During the initial model setup and testing small adjustments were made to wave directions as described in Section 0.

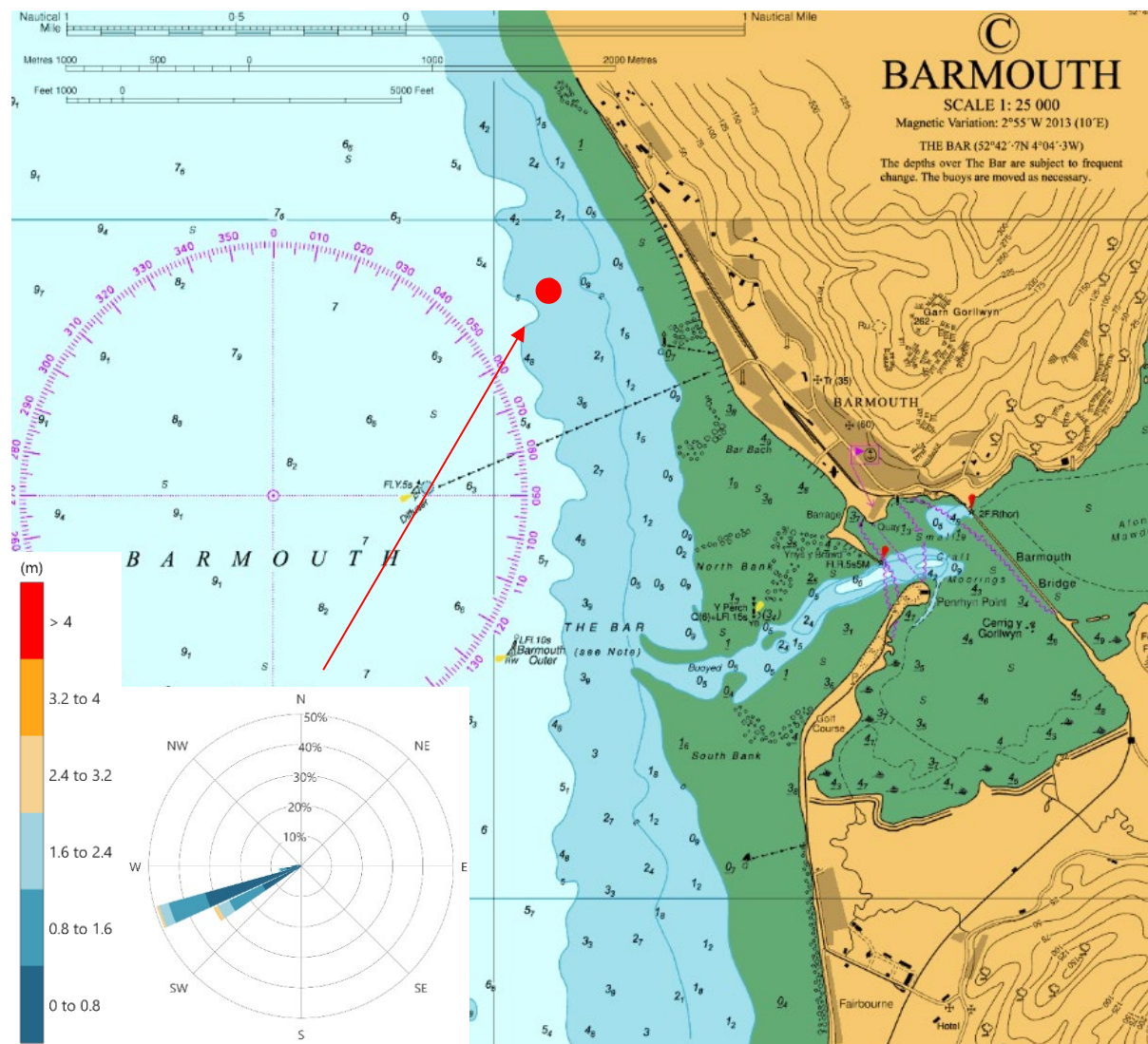


Figure 8. Wave extraction location (red circle) overlaid over admiralty chart [Insert 2019 hindcast wave rose for wave extraction location]

2.6 Sediment characteristics

From visual inspection the shingle/cobble on the upper foreshore appear to be quite mixed and relatively coarse (Figure 9). The grading of the material which will be used in the nourishment is also yet to be determined.

Beach sediment sampling data shows that the d50 of the coarse material along the railway line to the North of North Promenade (Profile 29) is typically around 30-40 mm, with a significant proportion (10-30%) of the material above 63 mm. This data was provided by Gwynedd Council from sampling undertaken in 1997, 2004 and 2011 (Gwynedd Council 2011, Pye 2011, Digital Mapping Services, 2004),

The model was therefore initially been setup with a grading size of 40 mm to represent the upper shingle/cobble beach above +0.5 mODN. Significant quantities of material of this size to appear to be present currently on the frontage, although it is noted much larger cobbles are also present.

Below 0.5 mODN, the shallower sloping foreshore is considered immobile in the model, as the model is focused on assessing the morphology of the upper shingle/cobble beach. In reality, sand transport on the lower foreshore will be expected to occur and some possible lowering is anticipated in the future. The previous coastal modelling assessment (ABPmer, 2019a), identified that bed levels along the existing North Promenade may reduce by around 0.2 by 2069. However, as the shingle/cobble upper beach is much steeper than the shallower sloping foreshore, the consequence of this when modelling the upper shingle/cobble beach is relatively minor.



(Asset Inspection Photos provided by Arup)

Figure 9. Shingle/cobble present on frontage from 2016 Asset Inspection Offshore contour

The model is driven by a single wave point (Figure 8) at -7 mODN. The offshore bed contours along the wider frontages are not parallel to the shore but vary significantly along the frontage as shown in Figure 8. Therefore, as waves approach from the south west (SW), the dominant offshore wave direction, they will be refracted more at the southern end of the frontage compared to the northern end.

Within the model the chart datum contour has therefore been digitised and included within the model as an 'offshore contour', this enables the model to take some account of local differences in refraction along the frontage.

During the initial model setup and testing, it was also identified that the shingle/cobble beach north of North Promenade had a dominate southerly drift. However, the shingle/cobble beach along this part of the frontage has been relatively stable in the past. The predicted dominant southerly transport is likely to be due to the differential levels of refraction afforded to the waves relative to the wave extraction location (aligned slightly further south). After a series of initial tests, a more realistic representation of the present-day situation was obtained by applying the offshore contour combined with a fixed -3.5 degree shift to the extracted hindcast wave directions.

In addition, toward the southern end of the frontage, including at the southern end of North Promenade the nearshore shoals (Figure 4) are observed to locally hold the coastline slightly seawards at specific locations. Therefore, small adjustments were made to the chart datum 'offshore contour' to replicate these shoal features. These adjustments prevent the model from rapidly straightening these observed perturbations in the natural coastline position.

The schematised shoreline (0 mODN contour) and chart datum 'offshore contour' are shown in Figure 10 for the existing baseline condition.

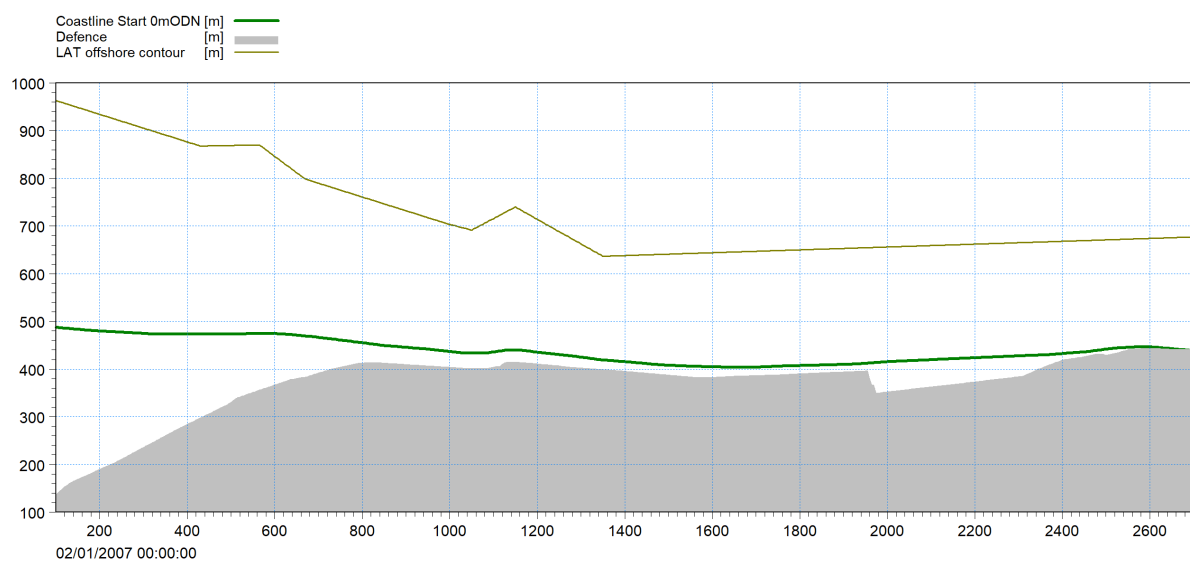


Figure 10. Baseline model schematisation showing offshore contour

3 Baseline Model Results

The baseline model has been run for a 10-year period, utilising the wave and water level conditions for the period January 2007 to December 2016 inclusive. The model was run for present day conditions with no increase in the still water level.

Figure 11 show, the predicted changes to the shoreline after 2, 5 and 10 years. Limited changes to the shoreline are predicted which is consistent with the relative stability observed in the upper shingle/cobble beach. Figure 12 shows the integrated sediment transport over the same simulation. The transport rates presented relate to the upper shingle/cobble beach as the foreshore has been made immobile within the model as discussed above.

The transport rates are relatively low with transport rates less than 500 m³/yr. Note: Figure 12 shows transport rates over a 10 yr period, not over a single year. Transport rates along the Llanaber headland (chainage 2400-2600) and at the northern end of North Promenade (chainage 1700-1950) are negligible as there is no effective upper shingle/cobble beach in these regions. North of North Promenade there is very slight net southerly transport along the shingle/cobble beach fronting the railway (Chainage 1950-2400). Along the southern end North Promenade and the northern section of Barmouth South frontage (Chainage 600-1600) the net transport rates is predicted to be northerly.

To examine the variability in transport rates over the longer period a separate simulation was undertaken using the 38-year hindcast without the shoreline being updated. The simulation utilised a fixed shoreline orientation (no morphological updating), therefore differences in the annual transport rates between years are directly related to the difference in the wave conditions during each year. From this simulation the integrated sediment transport over the full simulation is shown in Figure 13 and Table 1 summarises the annual variability in the net and gross drift rates at 6 key chainages along the frontage. The annual net drift rates for chainage 1250, is also presented for each individual year from the long-term hindcast.

Both the net and gross transport rates predicted are very low, in relation to transport rates that can occur along an open coast subject to similar wave heights. However, it is noted that the modelling is only considering the transport of the upper mobile shingle/cobble beach, and in many places along the frontage there is very limited shingle/cobble available to be mobilised. With the shingle/cobble restricted to the upper beach it is only mobilised and transported by waves during part of the tidal cycle. Furthermore, the wave climate at the -7 mODN wave extraction location, is already confined to a very narrow sector that is close to shore normal. As these waves are transformed further inshore, they will become aligned even closer to shore normal. Therefore, by the time they break on the upper shingle/cobble beach the wave will be almost perpendicular to the coast, thus littoral drift on the upper beach can be expected to be relatively low.

Nevertheless, it is noted that there remains some uncertainty as to the actual longshore transport rates of the upper shingle/cobble beach and this need to be considered when interpreting the results with the scheme included.

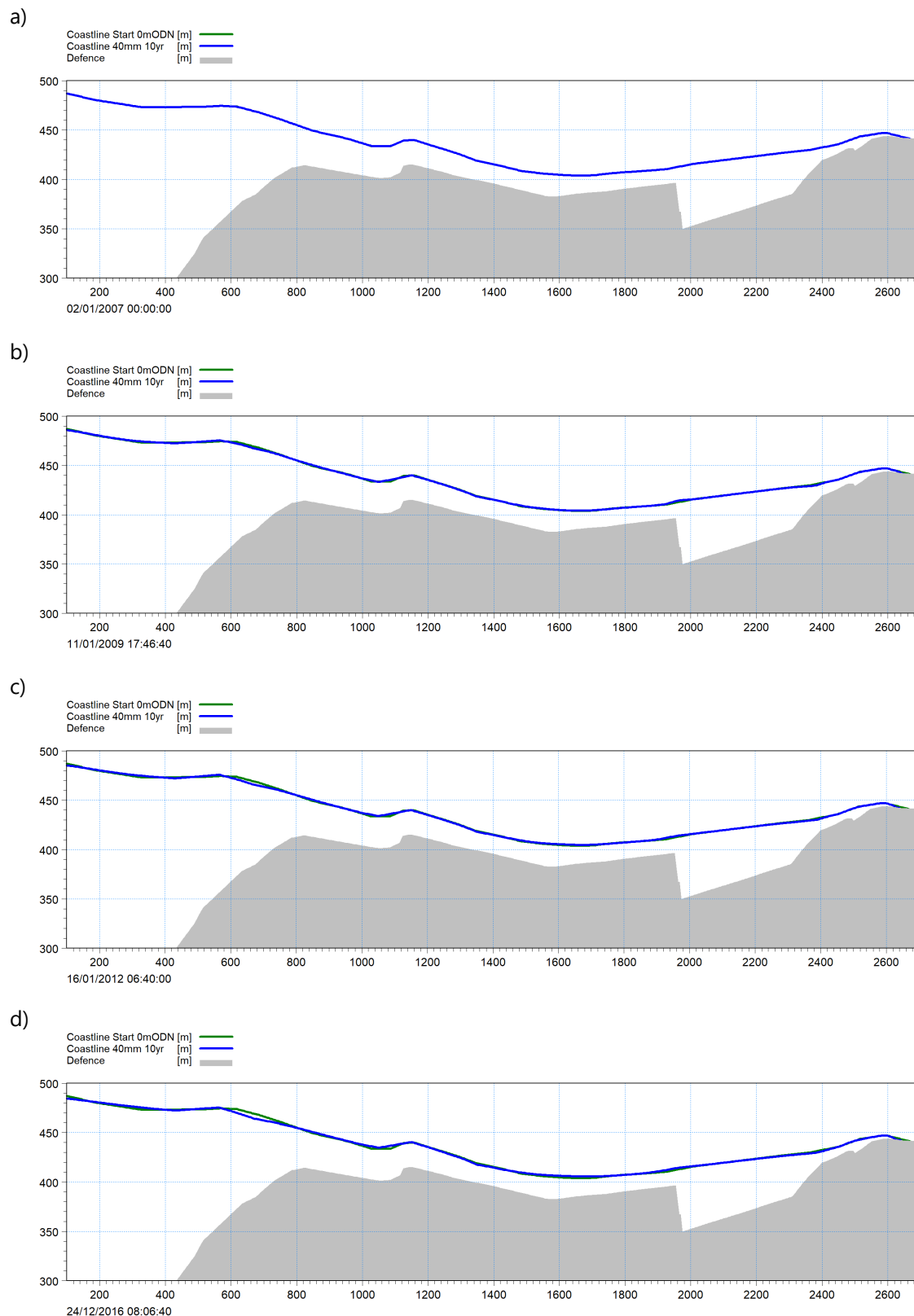


Figure 11. Shoreline development - Baseline 10-year simulation present day, shoreline represented by 0 mODN, at: (a) 2007 start; b) after 2 years; c) after 5 years; d) after 10 years

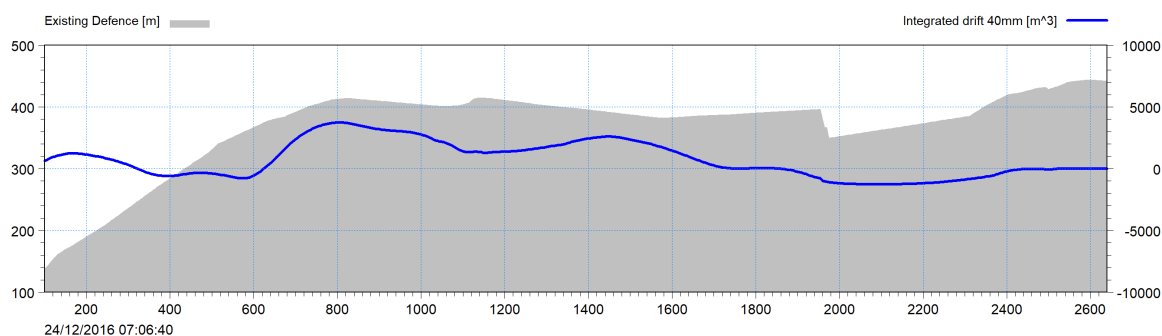


Figure 12. Integrated transport - Baseline 10-year simulation present day

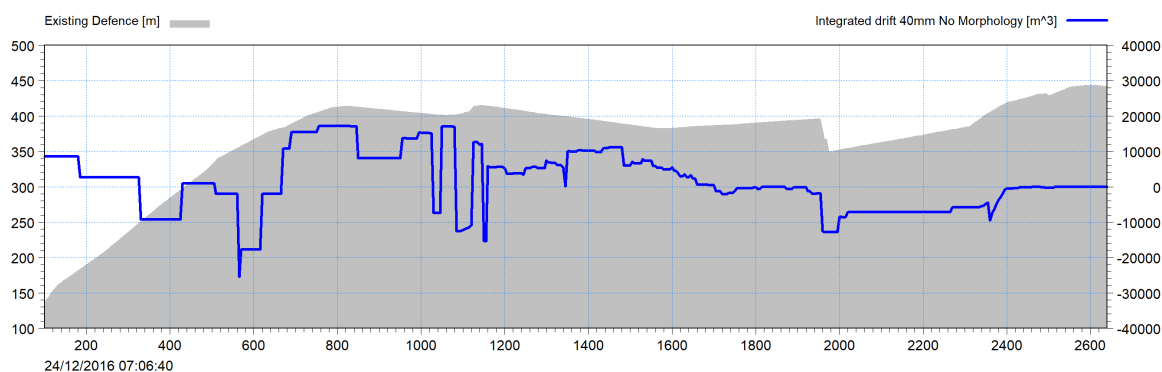


Figure 13. Integrated transport - Baseline 38-year simulation present day with no morphological updating (+ve indicated drift indicates net northerly transport; -ve indicates net southerly transport)

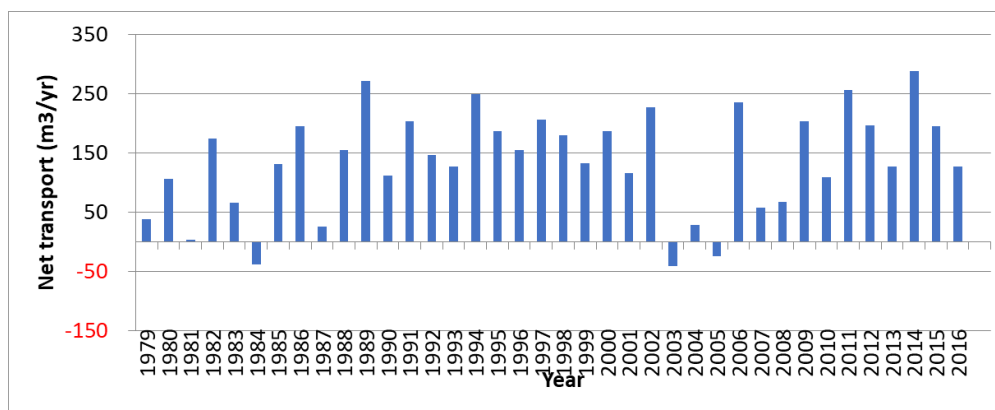


Figure 14. Variation in annual net transport rate at chainage 1250 - Baseline 38-year simulation present day with no morphological updating (+ve indicates net northerly transport; -ve indicates net southerly transport).

Table 1 Variability in annual net and gross transport rates

	Annual transport rates at given chainages along frontage (m ³ /yr)											
	Ch. 1000		Ch. 1250		Ch. 1500		Ch. 1750		Ch. 2000		Ch. 2250	
	net	gross	net	gross	net	gross	net	gross	net	gross	net	gross
Avg	403	640	136	342	155	293	-32	121	-226	454	-188	450
Max	724	972	289	535	306	455	27	214	3	788	40	774
Minimum	76	410	-41	206	10	181	-123	59	-528	248	-481	246
stdev	161	116	87	67	73	53	37	35	146	145	144	140

(+ve indicates net northerly transport; -ve indicates net southerly transport)

As identified in Section 2.3, the crest height in the model has been raised to +5 mODN as some of the most extreme events results in still water levels at the shoreline greater than 4.5 mODN (based on offshore still water level plus wave setup).

In Figure 6, the beach crest width is shown to be present over the lower (sloping part) of the hard defence, and therefore the actual effective width of the beach, i.e. width of beach with significant shingle/cobble for transport is around 4 m.

The initial scheme has therefore been schematised, based on the 0 mODN baseline conditions with the 0 mODN contour adjusted along the 560 m of the North Promenade, to be nourished. Along this section a beach crest width (representing width of material available for transport) of 4 m has been defined and the associated location of the 0 mODN contour derived based on the schematised beach profile. The schematised 0 mODN shoreline for the scheme is shown in Figure 16. On this figure, the location of the +2 mODN and +4.5 mODN are also shown. These are derived by applying offsets to the 0 mODN contour, based on the schematised profile.

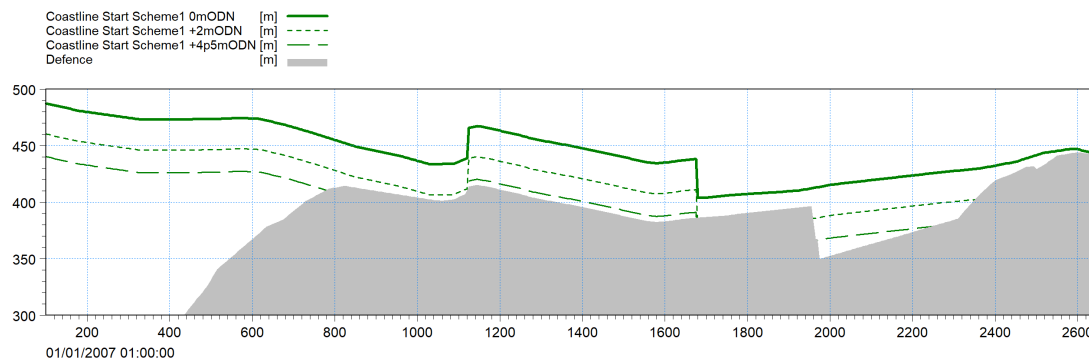


Figure 16. Initial Scheme model schematisation

4.1.2 Initial Scheme results

The initial scheme was simulated for the 10-year period 2007-2016 inclusive as examined for the baseline case. As per the baseline simulation the model was run for present day conditions with no increases in the still water level.

Figure 17 show, the predicted changes to the 0 mODN shoreline after 2 months, 2 years, 5 years and 10 years. The associated +2 mODN and +4.5 mODN contours are also shown together their initial starting positions. Whilst the beach crest is at +5 mODN, the +4.5 mODN contour is presented as this was initial level proposed for the nourished beach. The initial adjustments to the shoreline are very quick (Figure 17a), after this the rate of shoreline change decreases significantly.

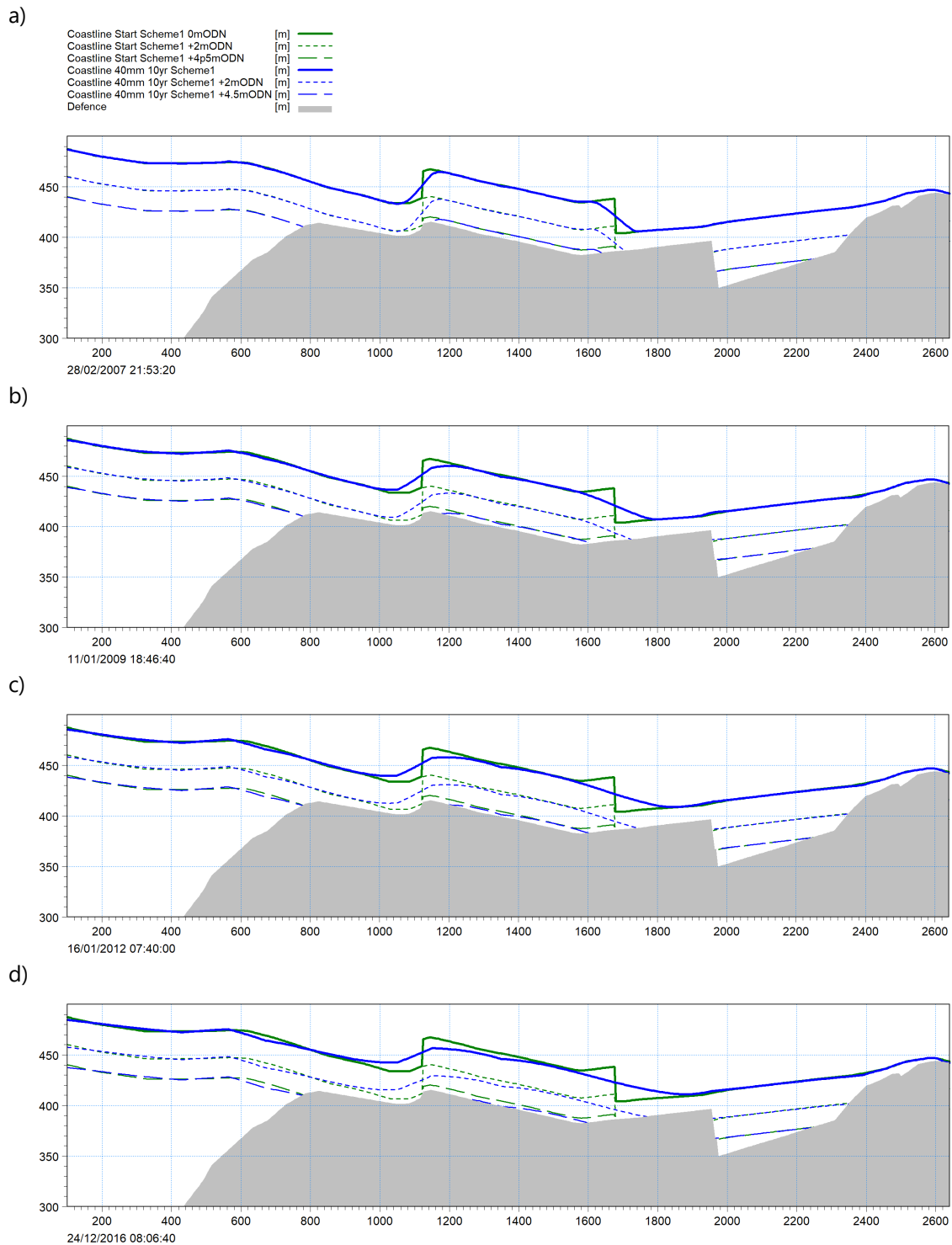


Figure 17. Shoreline development - Initial Scheme 10-year simulation present day, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours after: (a) 2 month; b) 2 years; c) 5 years and d) 10 years

Figure 18 shows the integrated transport over the simulation, with the integrated transport from the baseline simulations overlaid. The integrated transport rates show how the nourished beach is flattened out with significantly greater northerly transport at the northern end of the nourished beach and significantly greater southerly transport at the southern end of the nourished beach.

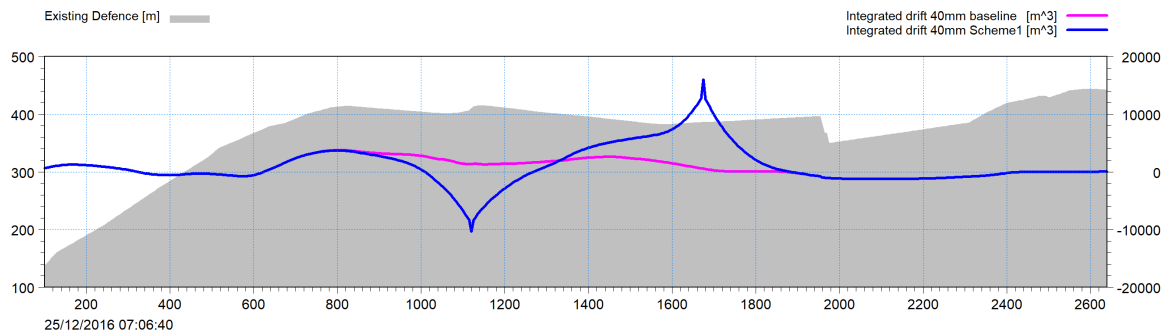


Figure 18. Integrated transport - Initial Scheme 10-year simulation (blue), with baseline integrated transport overlaid (pink)

4.2 Alternate scheme/model scenarios

Following provision and discussion of the Initial Scheme results the following alternate schemes were identified by Arup:

- Scheme 2 - Initial Scheme layout with coarser (70 mm) material;
- Scheme 3 - Initial Scheme layout with narrower 4 m berm width;
- Scheme 4 - Initial Scheme layout with nourishment graded in;
- Scheme 5 - Initial Scheme layout with terminal groynes included; and
- Scheme 6 - Initial Scheme layout with Sea Level Rise (SLR) allowance of 280 mm.

All the above schemes were run for an extended 25 years period. Scheme 3-6 were also undertaken with the coarser 70 mm material allowing the different schemes to be compared over this longer 25 year period.

4.2.1 Scheme schematisations

Details of the model schematisations are provided below.

Scheme 2 - Initial Scheme layout with coarser (70 mm) material

The Scheme 2 layout is identical to the Initial Scheme layout but utilises 70 mm nourishment material rather than 40 mm.

To run the scheme over the extended 25-year period, the wave and water level condition over the 10 years period 01/01/2007 to 31/12/2016, were repeated. This allows the results from the first 10 years of the simulation do be directly compared to the Initial Scheme layout results. From a visual inspection of Figure 14, the average net transport over this 10-year period is reasonably typical of the longer-term 38-year record. Therefore, this approach is considered appropriate.

Scheme 3 - Initial Scheme layout with narrower 4 m berm width

For Scheme 3, the initial berm width has been reduced from 8 m to 4 m. As the reduced berm width now lies entirely over the hard defence backing the beach (Figure 6) the model beach crest now lies directly along the line of the hard defence as depicted in Figure 19.

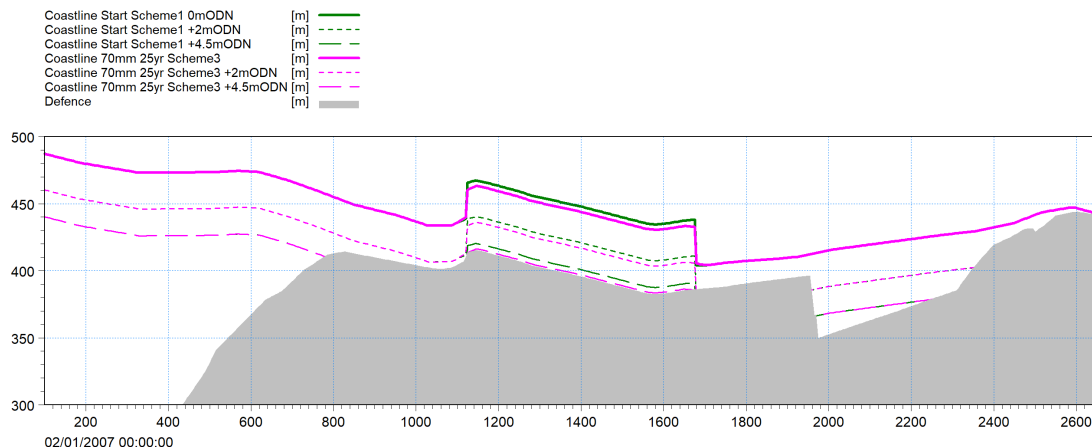


Figure 19. Scheme 3 model schematisation (pink) compared to Initial Scheme schematisation (green)

Scheme 4 - Initial Scheme layout with nourishment graded in

Scheme 4 includes additional beach material to merge the Initial Scheme nourishment into the existing defence. The scheme schematisation is shown in Figure 20 and Figure 21.

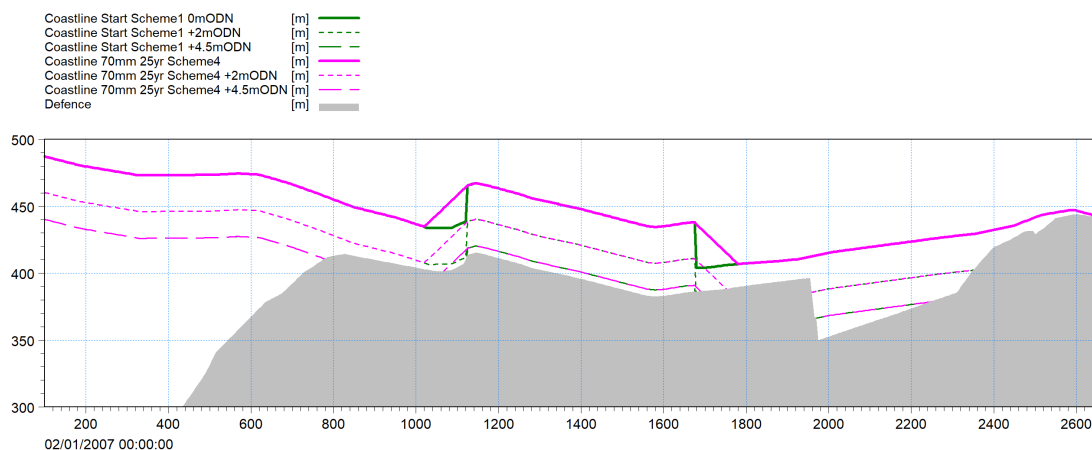
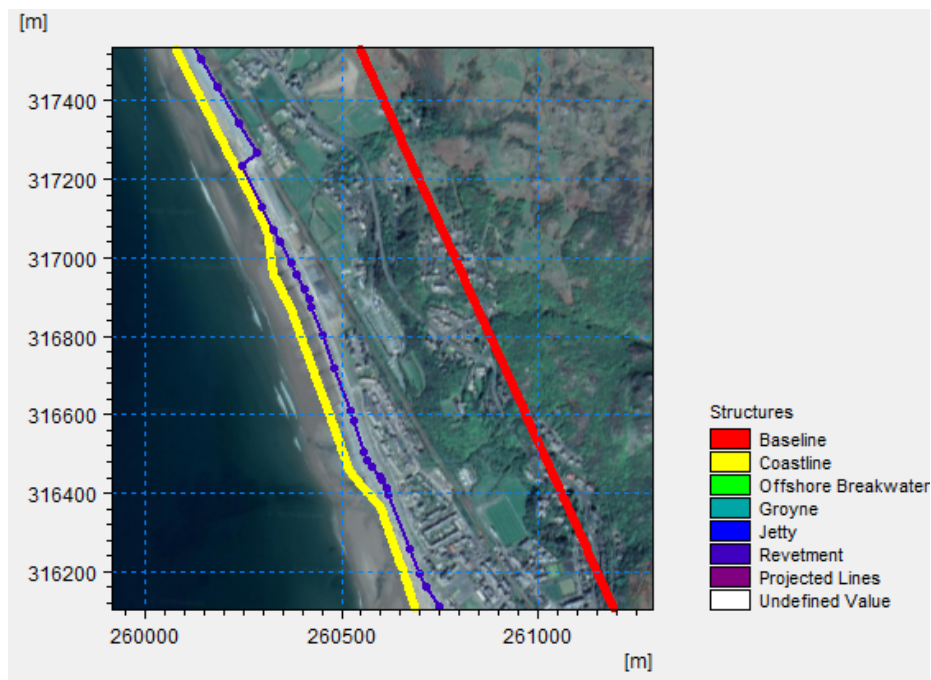


Figure 20. Scheme 4 model schematisation (pink) compared to Initial Scheme schematisation (green)

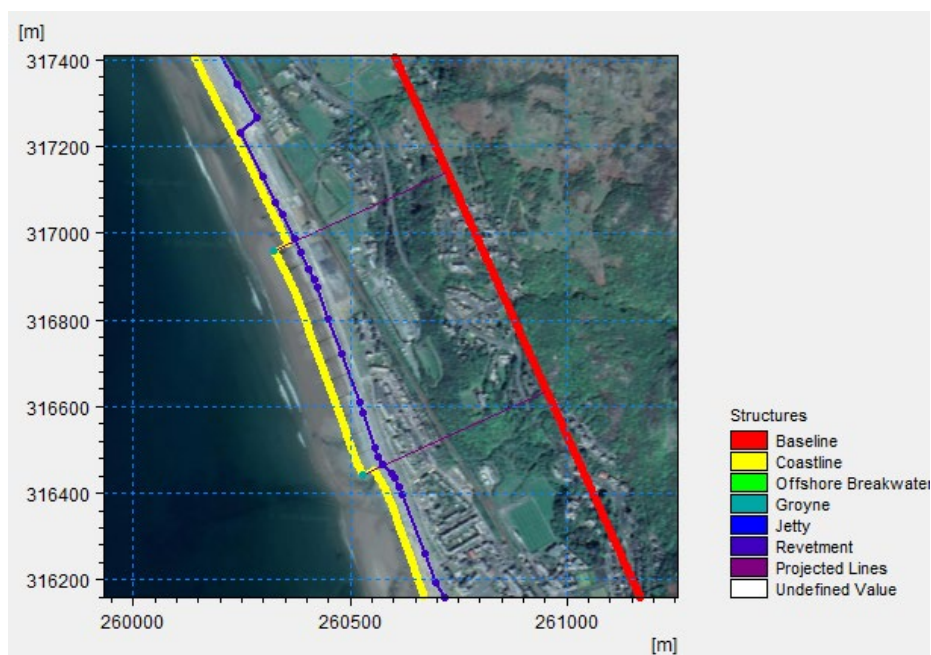


Google Maps Imagery

Figure 21. Scheme 4 model schematisation showing 0 mODN contour overlaid on aerial imagery

Scheme 5 - Initial Scheme layout with terminal groynes included

Scheme 5 includes terminal groynes at the southern and northern ends of the proposed nourishment. The groynes have been included so they extend down to the 0 mODN contour, thus they extend slightly further offshore of the nourished placed beach. The groynes have been included so that there would be very limited losses from the nourished beach. The location and extent of the groynes is shown in Figure 22.



Google Maps Imagery

Figure 22. Scheme 5 model schematisation showing 0 mODN contour and groyne locations overlaid on aerial imagery

Scheme 6 - Initial Scheme layout with Sea Level Rise (SLR) allowance of 280 mm

Scheme 6 is a repeat of Scheme 2 (Initial Scheme with 70 mm material), with an allowance of 280 mm SLR. Therefore, the mobile upper beach is exposed to waves for a greater period of time.

Sea level rise was estimated by Arup from Welsh Government guidance (NRW, 2017):: <https://gov.wales/sites/default/files/publications/2019-06/adapting-to-climate-change-guidance-for-flood-and-coastal-erosion-risk-management-authorities-in-wales.pdf>

From 2020 to 2070, sea level rise is approximately 430 mm. However, testing 25 years of sediment transport right at the end of the design life is considered overly conservative, therefore the 25 year assessment represents the period from 2045-2070 and sea level rise at the midpoint (2057) is approximately 280 mm.

As the natural crest height of the shingle/cobble beach will also increase in line with SLR, the berm crest height of the design profile was also increased by a similar factor. However, to enable more direct comparison with the present-day case (Scheme 2), the location of the re-nourished beach (0 mODN contour) was not modified between Scheme 6 and Scheme 7. Hence, the starting berm crest width will be slightly less. No modification was made to the wave climate at the -7 mODN contour.

4.2.2 Scheme results

Details of the scheme results are provided below.

Scheme 2 - Initial Scheme layout with coarser (70 mm) material

Scheme 2 results utilising the 70 mm material are present in Figure 23, with the position of the 0 mODN, +2 mODN and +4.5 mODN contours being shown after 2 months, 2 years, 5 years and 25 years. The shoreline position and integrated transport rate after 10 years are also compared to the Initial Scheme simulation with 40 mm in Figure 24 and Figure 25 respectively.

As per the Initial Scheme results there is rapid initial adjustment of the shoreline as the southern and northern end of the nourishment, and over time the rate of changes decreased with the material being spread out wider across the frontage. At the end of the 25 years, shingle/cobble is predicted to lie up against the hard defence to be protected with the crest level lying between +2 mODN and +4.5 mODN.

From Figure 24 and Figure 25 there appears to be very limited difference between the results with 70 mm and 40 mm material.

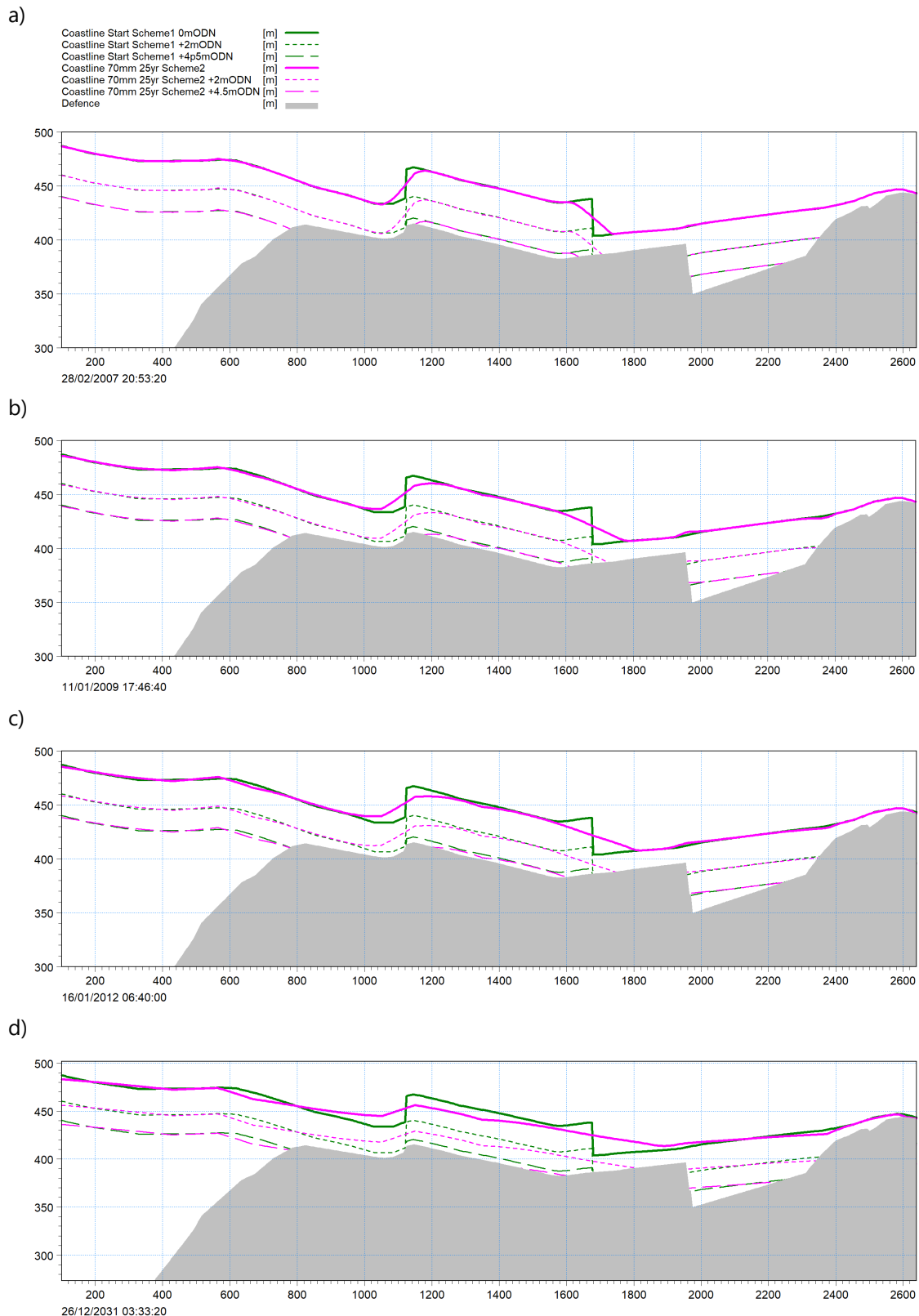


Figure 23. Shoreline development - Scheme 2, Initial layout with 70 mm material, 25 year simulation present day, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours after: (a) 2 month; b) 2 years; c) 5 years and d) 25 years

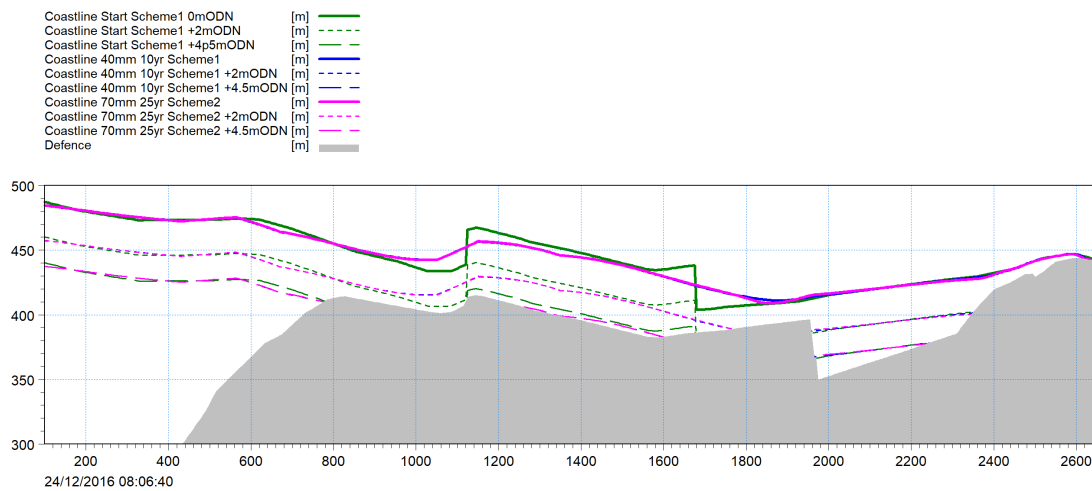


Figure 24. Shoreline development - Scheme 2, Initial layout with 70 mm material (pink), compared to results from Initial layout with 40 mm material, results provided after 10 years, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours

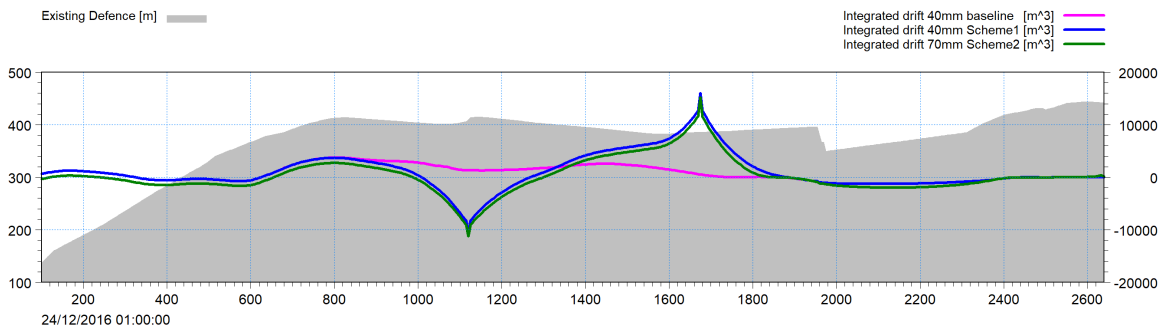


Figure 25. Integrated transport - Scheme 2, Initial layout with 70 mm material (magenta), with results from initial scheme with 40 mm material (blue) and baseline (pink) overlaid. Results shown at end of 10 years

Scheme 3 - Initial Scheme layout with narrower 4 m berm width

The results from Scheme 3, with the reduced berm are shown in Figure 26. In this figure the starting position shown relates to the Initial Scheme, with the wider initial berm crest, to make it easier to compare the results to the other scheme options.

As per the Initial Scheme there is rapid initial adjustment of the shoreline as the southern and northern end of the nourishment, and over time the rate of change decreases with the material being spread out wider across the frontage. The beach levels and quantity of shingle/cobble that lies in front of the section to be protected (the initial nourishment extent) after 5 years (Figure 26c) is relatively similar to that predicted under Scheme 2 after 25 years (Figure 23d). At the end of the 25 years shingle/cobble is predicted to lie up against the hard defence to be protected with a crest level lying over +2 mODN. From Figure 6, the crest of the proposed sheet-pile toe appears to be around 1.5 mODN. The predicted results, therefore, suggest the that the sheet-pile toe would be covered by at least 500 mm at the end of the 25-year period.

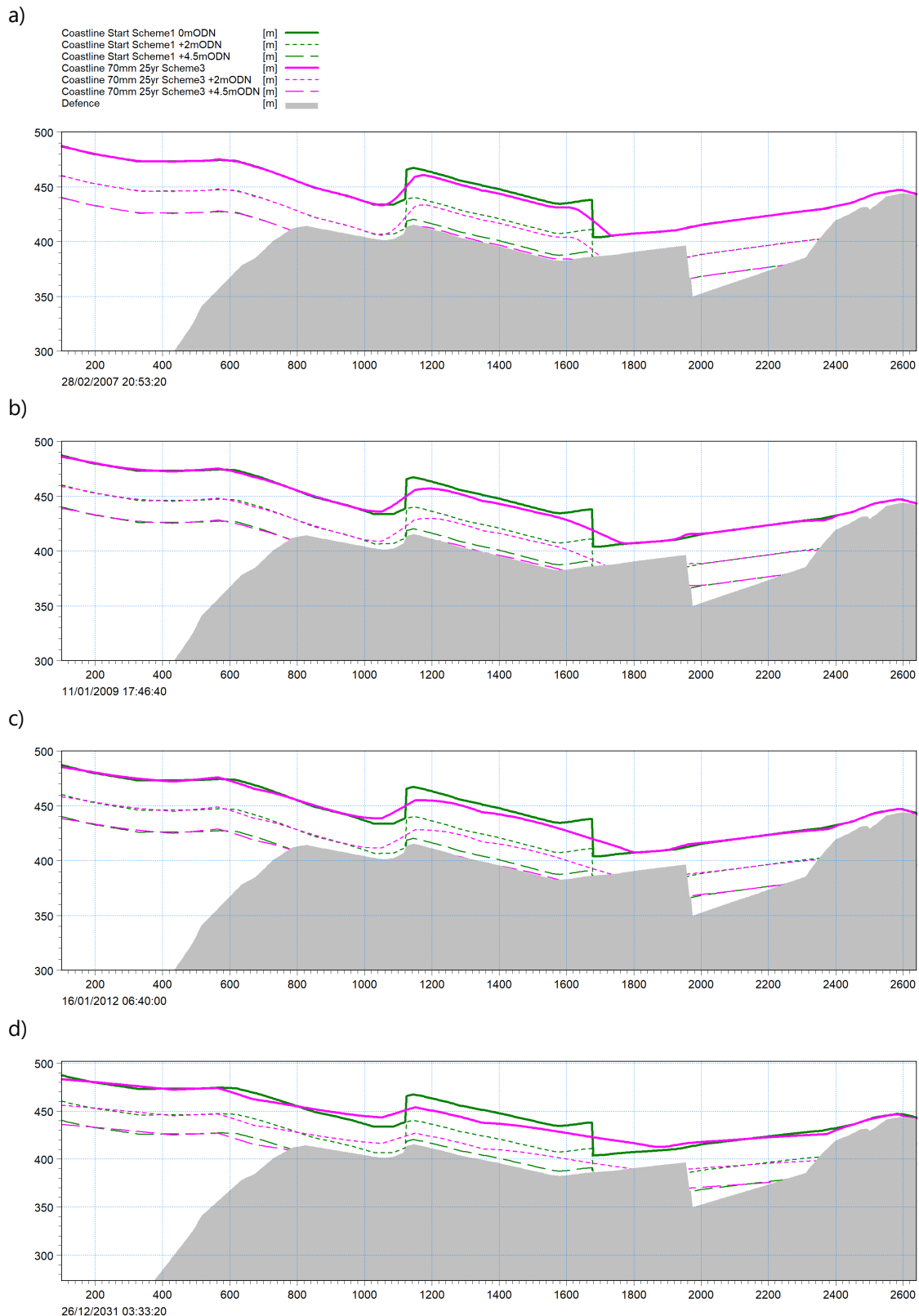
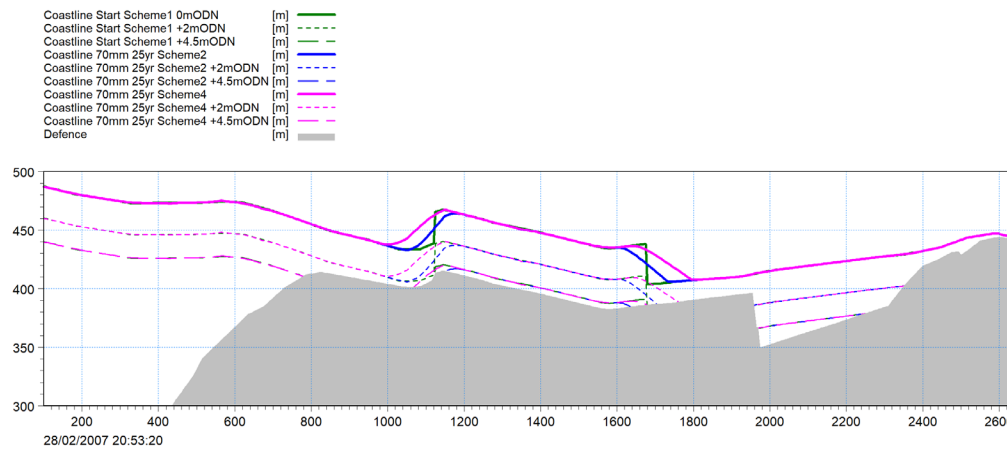


Figure 26. Shoreline development - Scheme 3, Initial layout with berm reduced to 4 m and 70 mm material and 4 m, 25 year simulation present day, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours after: (a) 2 month; b) 2 years; c) 5 years and d) 25 years

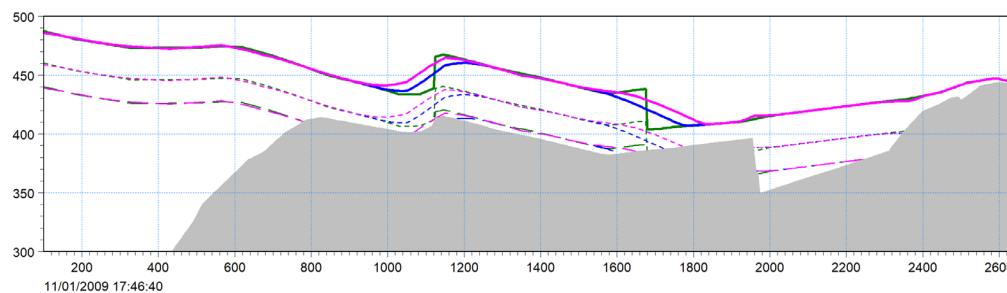
Scheme 4 - Initial Scheme layout with nourishment graded in

The results from Scheme 4 with the nourishment material graded in at the end of the main nourishment is shown in Figure 27.

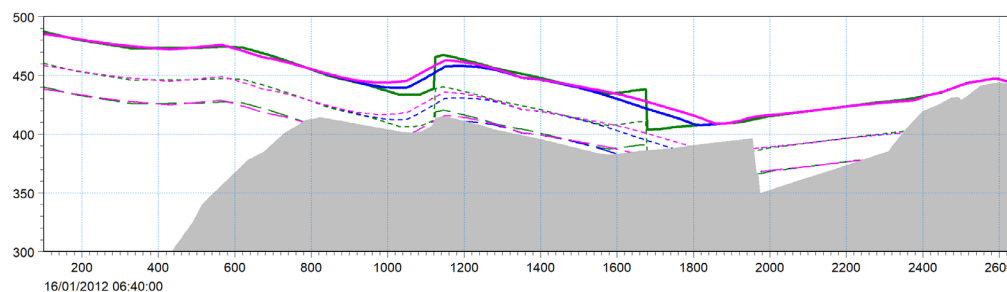
a)



b)



c)



d)

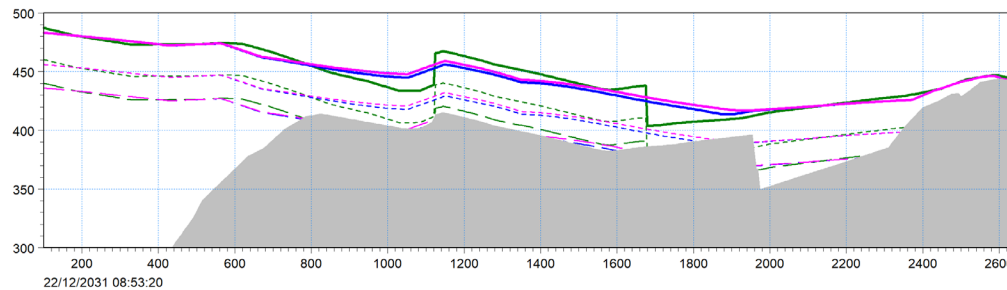


Figure 27. Shoreline development - Scheme 4, Initial layout with initial nourishment graded in compared to Scheme 2, without nourishment graded in, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours after: (a) 2 month; b) 2 years; c) 5 years and d) 25 years

On Figure 27 the model results are also compared to Scheme 2, without the material being graded in. In the figures the starting position shown relates to the Initial Scheme. without the additional graded in material, to make it easier to compare the results to the other scheme options.

With the material graded in at the southern and northern end of the main nourishment area, the initial change is much less significant, and the shoreline position and beach levels along the main section to be protected are maintained for longer than without the inclusion of the graded in material. This is highlighted in Figure 27, which shows that after 2 years it is only along short sections (approximately 30 m) at either end of the main nourishment where bed levels have reduced. Whilst for Scheme 2, without the additional graded in material, beach levels have reduced along section lengths of approximately 80 m at either end of the initial nourishment.

Scheme 5 - Initial Scheme layout with terminal groynes included

Scheme 5 results are presented in Figure 28, with the location of the two groynes overlaid.

With the inclusion of the two terminal groyne the beach has been maintained within the groyne bay with no significant loss off material and some small realignment of the beach over the full 25-year simulation period.

During the simulation there is very limited variability of the beach alignment within the groyne bay from one wave event to another. Typically, shingle/cobble would be expected to oscillate within a groyne bay as waves approach from more oblique angles.

However, at the site the waves approaching the mobile shingle/cobble upper beach are predicted to arrive from an extremely narrow shore normal direction. Whilst this may explain the lack of mobility observed, it is also noted that there remain some uncertainties related to the accuracy of the actual transport rates predicted by the model (Section 3), and this could also affect the variability predicted by the model.

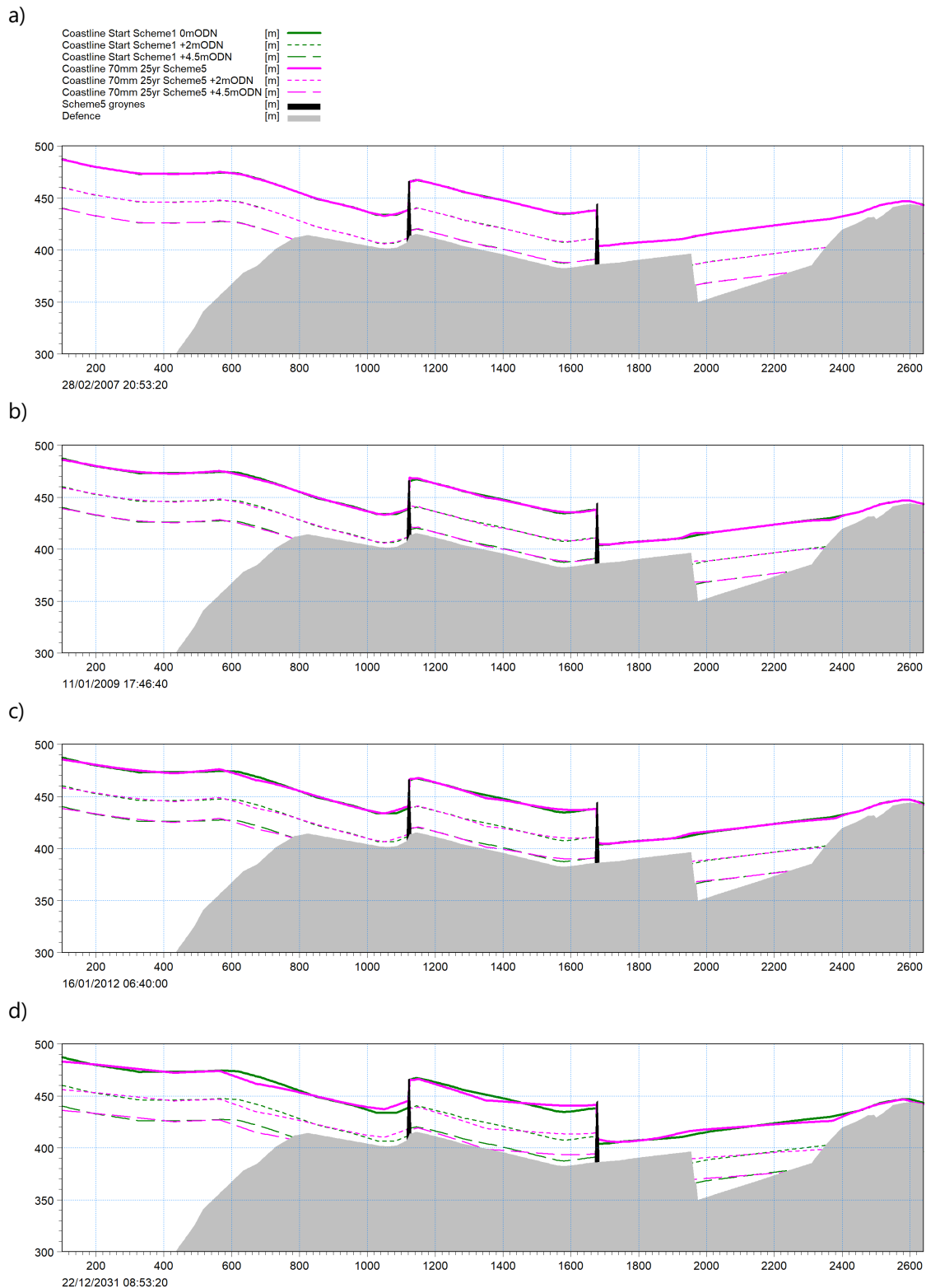


Figure 28. Shoreline development - Scheme 5, Initial layout with initial terminal groyne and 70 mm material, 25 year simulation present day, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours after: (a) 2 month; (b) 2 years; (c) 5 years and (d) 25 years

Scheme 6 - Initial Scheme layout with Sea Level Rise (SLR) allowance of 280 mm

The results from Scheme 6 with the inclusion of a 280 mm SLR allowance are provided in Figure 29.

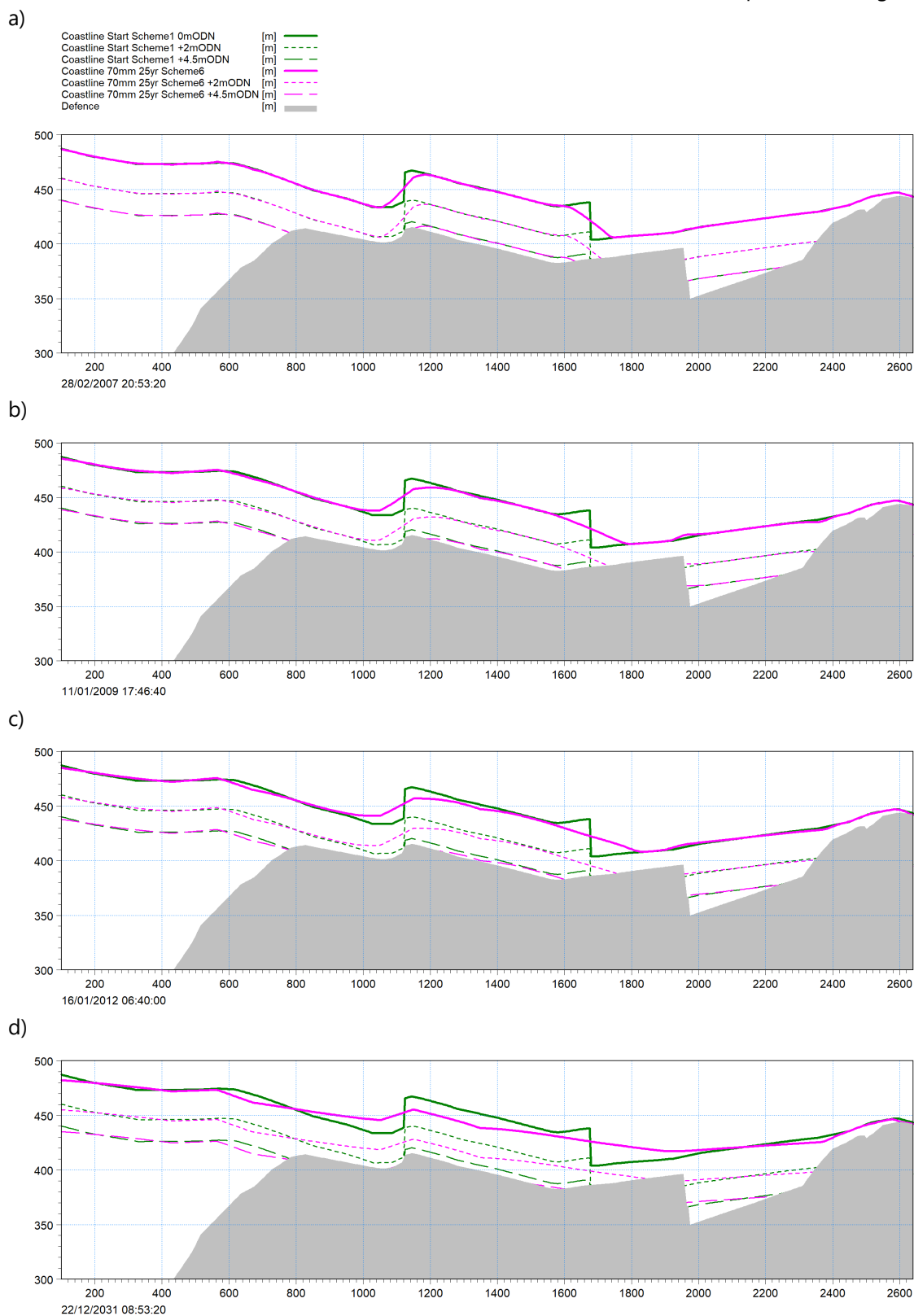


Figure 29. Shoreline development - Scheme 6, Initial layout with SLR allowance of 280 mm and 70 mm material, 25 year simulation, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours after: (a) 2 month; b) 2 years; c) 5 years and d) 25 years

The shoreline position and integrated transport rate after 10 years are also compared to the Scheme 2, Initial layout under present day conditions with 70 mm material in Figure 30 and Figure 31 respectively.

With the SLR allowance the net integrated transport rates after 10 years are increased by up to around 30% along part of the frontage, but the overall impact on the shoreline position is minimal.

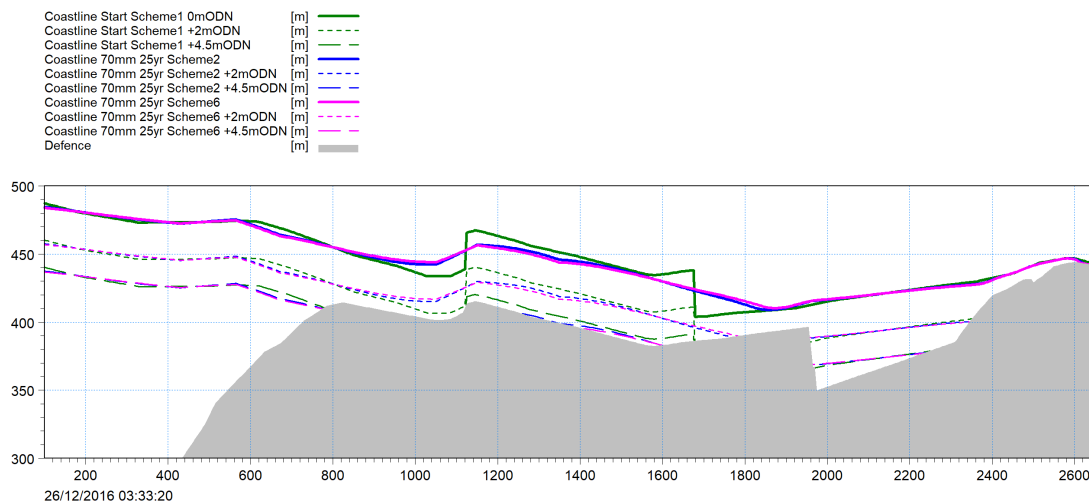


Figure 30. Shoreline development - Initial layout with 70 mm material, present day (blue) and with SLR allowance of 280 mm (pink), results after 10 years, shoreline represented by 0 mODN, +2 mODN and +4.5 mODN contours

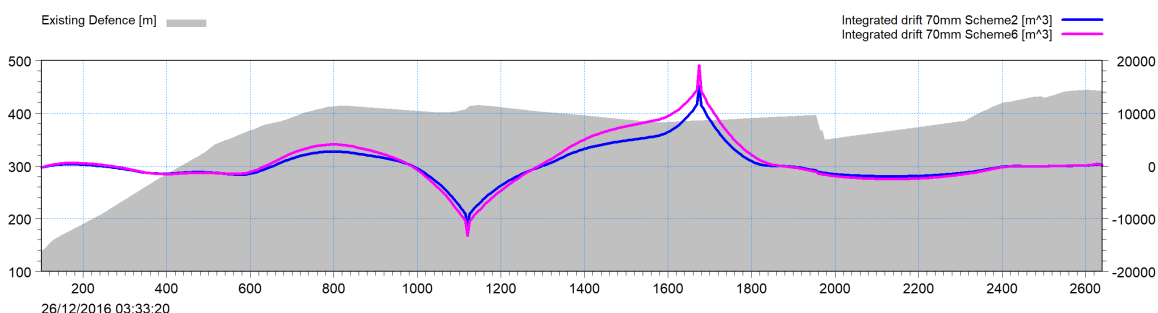


Figure 31. Integrated transport - Initial layout with 70 mm material, present day (blue) and with SLR allowance of 280 mm (pink), results after 10 years

5 Summary and Conclusions

The shoreline model developed to support the assessment was initial setup and used to examine the existing baseline condition along the frontage, in which there is very limited shingle/cobble along the main study frontage. The model was also extended to the north to incorporate the significant shingle/cobble beach that exist to the north of North Promenade.

From the available data examined there has been relatively little change to the volume and general locations of the shingle/cobble present on the North Promenade frontage in the past, and the baseline model has reproduced this situation. This is partly due to the very low sediment transport rates that are predicted by the model.

Due to the very narrow shore normal sector from which waves approach the coast and given that the upper shingle/cobble material is only mobilised during part of the tide, it is expected that the transport rate along the frontage would be relatively low. However, it has not been possible to validate actual transport rates in the model.

The consequence of this is that whilst a stable baseline shoreline with limited net transport has been predicted in the model, it is not possible to ascertain how accurately the gross transport rates are predicted by the model. This need to be considered when reviewing the scheme results.

Six different schemes have been simulated with shingle/cobble nourishment to protect the toe of the defence along the southern section of North Promenade. The schemes modelled have been used to examine the implication of:

- Material grading;
- Initial berm widths;
- Grading in of the initial nourishment material;
- Inclusion of terminal groynes, and
- Sea Level Rise

The results can be generally summarised as below:

If the initial nourishment is not graded in or groynes are included to hold the nourished material, there will be rapid adjustment to the placed beach at the southern and northern end of the frontage, with material moving both southward and northward. The rate of change is observed to then decrease as the nourished material spreads out across the wider frontage (other than when the terminal groynes are included). The grading in of the material results in less immediate change and the quantity of shingle/cobble remaining in front of the defence remains greater over time than without the graded in material.

The model predicts the longer-term spread of the material to be relatively slow with significant shingle/cobble remaining along the southern section of North Promenade to be protected, although the beach crest will have been lost. Due to the uncertainties identified regarding sediment transport rates it should, however, be noted that the actual rate that material is spread over the frontage could be different to that predicted.

The inclusion of the terminal groynes at either of the nourished material, provides a very different response to the other scenarios with the material remaining within the groyne bay.

This solution would therefore provide greater confidence in the performance of the scheme and the requirements for on-going maintenance, but at a greater initial capital cost. With this option the volume of material in front of the defence also remains greater for longer, which will help to limit waves reaching the hard defence.

A further consequence of including the nourishment without terminal groynes is that shingle/cobble will be transport to the south on to the predominantly sandy beach off South Promenade, which may be a disbenefit in respect to aesthetics and beach usage, Although it is noted some shingle/cobble does already exist along the upper active beach in this location.

It is important to recognise that the nourished shingle/cobble profile will be modified by the incident wave and water level conditions, and that under large events that shingle/cobble berm is likely to rise to levels above the primary defence crest level. Shingle/cobble is also likely to be thrown back over the hard defence. This situation will occur more frequently and be of greater significance as sea levels rise. The consequence of this need to be considered in the design and maintenance of the frontage.

Whichever solution is adopted, it is important that appropriate long-term monitoring is undertaken to better understand the performance of the scheme and to support future management of the frontage.

6 References

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7 Abbreviations/Acronyms

-ve	Negative
+ve	Positive
DHI	Danish Hydraulic Institute
DSM	Digital Surface Model
FM	Flow Model
LiDAR	Light Detection and Ranging
MRSL	Mean Relative Sea Level
OBC	Outline Business Case
ODN	Ordnance Datum Newlyn
SLR	Sea Level Rise
SMP2	Shoreline Management Plan 2

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

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