



**Ardersier Port Ltd.
Coastal Processes Assessment**



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Ardersier Port Ltd.

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1 INTRODUCTION

1.1 Terms of Reference

EnviroCentre have been commissioned by Ardersier Port Ltd. to undertake a coastal processes assessment at Whiteness Head for the proposed redevelopment works of Ardersier Port. This involves a review and update of the previous 2013 coastal processes assessment for the redevelopment of Ardersier Port, to inform the Environmental Impact Assessment Report (EIAR) for this project.

1.2 Scope of Report

This coastal processes assessment aims to update previous assessments to reflect present day conditions and address scoping opinions received from Highland Council and Marine Scotland in relation to coastal processes, and in particular, sediment transport connectivity.

The approach is to confirm the present day baseline conditions, review the conceptual model developed during earlier phases of study at the development site and update this conceptual model through review of baseline conditions, including successive topographic and bathymetry surveys, supported and informed by updated coastal modelling.

1.3 Report Usage

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2 CONTEXT AND METHODOLOGY

2.1 Development Proposals

The development proposals for the site are detailed in Chapter 3 of the Environmental Impact Assessment Report (EIAR).

2.2 Historic Development and Operation of the Site

The fabrication yard at Ardersier was developed to service the off-shore oil and gas industry in 1972 (see Figure 2.1). Initial construction of the yard area saw the formation of the channel with the dredged material being pumped ashore for land reclamation purposes to create the main yard area. With the construction phase completed, subsequent maintenance dredging operations were carried out with dredged material being placed at the spoil ground on Whiteness Sands. Maintenance dredging of the navigation channel was a regular occurrence, typically carried out every 18-24 months with a typical dredge quantity in the order of 100,000-150,000m³. The last dredge was undertaken in 2001 after which the yard ceased to operate.



Figure 2.1: Photograph of Operational McDermott Yard – Ardersier

The line of the navigation channel formed was fit for purpose taking into account of the type of vessels which would be using it, in the case of McDermott Ardersier, this was for ocean going barges laden with significant structures together with attendant ocean going tugs. The line of the channel was therefore kept as straight as possible given the limited ability of these vessels to manoeuvre in restricted waters. The frequency of use was also limited to finished jacket or module float out or to import of subcontracted elements of particular projects.

The channel width was nominally 100 m with the dredge depth taking account of the particular vessels using the channel but dredge depth was typically to -4 m Chart Datum (CD) – Admiralty Chart 1077 indicates a dredge depth to -4.7 mCD. Frequency of channel dredging was dependant on two factors: the float out draught requirements of the transportation barge with the completed structure; and the rate at which siltation in the channel had occurred.

Observations on the sedimentation of the channel were that it was very much dependant on the wind direction, with the channel general being fairly static except during easterly gales when more significant change occurred.

2.3 Overview of Previous Coastal Studies

A number of previous investigations have been undertaken into the coastal processes around Whiteness Head. Details of these studies are presented below:

- Whiteness Coastal Investigation and Flooding Update, April 2008. EnviroCentre Report No 3102 to Whiteness Property Company Ltd.
- Geological Conservation Review: Whiteness Head, J.D. Hansom © JNCC 1980–2007. Volume 28: Coastal Geomorphology of Great Britain, Chapter 6: Gravel and 'shingle' beaches – GCR site reports (GCR ID: 1442) (<http://www.jncc.gov.uk/page-2731>).
- Port of Ardersier: Whiteness Head Coastal Assessment, May 2013. EnviroCentre Report No 5474 to Port of Ardersier.

The coastline at Whiteness Head is also included in the recent National Coastal Change Assessment (NCCA) led by the Scottish Government (Hansom, Rennie & Fitton, 2017; The Scottish Government, 2017).

2.4 Consultation Process

Scoping opinions were received from the Highland Council and Marine Scotland in relation to the proposed development. In relation to coastal processes, responses were provided by Marine Scotland, Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH) and the Royal Society for the Protection of Birds (RSPB). These are detailed in Table 11.1 in Chapter 11: Water Environment of the EIAR.

SNH as the statutory body responsible for national and internationally designated environmental area required the previous assessment of coastal processes undertaken in 2013 be updated. In relation to coastal processes, three meetings were held with SNH through the development of this present assessment. These took place prior to the assessment commencing (12th June 2018, Inverness), following review of updated baseline information (31st July 2018, Glasgow) and following the outputs of the coastal modelling work (11th September 2018, Glasgow).

2.5 Methodology

The coastal processes assessment aims to update previous assessments and address comments on sediment transport connectivity raised by SNH in their consultation responses. The approach is to confirm the present

day baseline conditions, review the conceptual model developed during earlier phases of study at the development site and update this conceptual model through review of successive topographic and bathymetry surveys, the outputs from the recent NCCA, and further aided by a programme of coastal modelling.

1. Baseline Assessment

There are a number of previous investigations and studies that have been undertaken at the site. These are reviewed along with updated information from 2018, particularly in relation to bathymetry and topography. The coastal modelling undertaken in support of this assessment will be used to characterise baseline conditions in terms of hydrodynamics, wave climate and sediment transport.

2. Coastal Modelling

A previously developed coastal model will be updated and refined in resolution around the site, including the use of high resolution 2018 bathymetry. The model will simulate the main physical processes in the vicinity of the proposed development site, including tidal currents, wave action and sediment transport. One of the key aims of the modelling being to further examine sediment transport pathways and connectivity, and the associated evolution of Whiteness Head. Details of the model are contained in Appendix A.

3. Conceptual Model

The existing conceptual model of coastal processes will be revisited and refined technical review of expected processes, the baseline assessment and through review of successive topographic and bathymetric surveys, including the latest data captured in 2018, along with NCCA data. A focus of this revisit will be sediment connectivity across and around the spit. The outputs from the updated coastal modelling study will be used to assist in informing this conceptual understanding.

4. Impact Assessment

The impact of the proposed development on the coastal processes will be informed by the refined conceptual model of the present day conditions and supported by outputs from the coastal modelling.

3 BASELINE

3.1 Overview of Present Conditions

In the 17 years since the cessation of dredging works at the McDermott site, the Whiteness Head spit has continued to extend in a north-western direction. The former dredged channel has migrated west in response to movement of the head of the spit. Within the north-western portion of the harbour inlet significant sand deposition has occurred in recent years, whilst the south-eastern end of the harbour inlet remains relatively unchanged. Photographs from recent (April & August 2018) walkover surveys of the site are presented in Appendix C.

3.2 Topography and Bathymetry

A topographic and bathymetric survey covering the spit, immediate vicinity and Whiteness Sands, was undertaken by Aspect Surveys in May 2018. The survey was undertaken using varying methods and equipment dependent on physical and logistical constraints. The bathymetric survey component was undertaken by boat mounted multibeam sonar system, the spit and immediate surrounds were surveyed using an Unmanned Aerial Vehicle (UAV) aerial mapping system, whilst the intertidal area of Whiteness Sands was surveyed by means of a quadbike mounted Real Time Kinetic Global Positioning System (RTK GPS) system. Full details of the 2018 survey are presented in Technical Appendix 11.1 of the EIAR.

Previous bathymetric and topographic surveys have been undertaken over recent years in the vicinity of the development site. These previous surveys are detailed below:

- 2007 – Bathymetric and topographic survey of spit, harbour inlet and immediate surrounds (Clydeside Surveys);
- 2012 – Bathymetric and topographic survey of spit, harbour inlet and immediate surrounds (Clydeside Surveys); and
- 2016 – Bathymetric survey of harbour inlet and immediate surrounds (Aspect Surveys).

A review of the bathymetry of the Moray Firth in the wider local area (see Figure 3.1) highlights the presence of several important features to the local hydrodynamic regime. To the north of Whiteness Sands and the deeper channel (referred to as 'main channel' within this report), there is a large sand bank present. This feature is aligned with the main tidal stream, from south-west to north-east, and can also be observed to widen to the north-east. To the north of the sand bank a second deeper channel is present, although this does not reach the depths of the main channel to the south. To the east of Whiteness Head the constriction on flow associated with the deposits to the west decreases as the Moray Firth widens, and bathymetry is observed to deepen further east into the Outer Moray Firth.

To the west of Whiteness Sands the Moray Firth is constricted through the narrows between Fort George on the southern shores, and Chanonry Point on the northern shore. Bathymetry is significantly deeper in this location as a result of this constriction, which produces higher tidal current velocities.

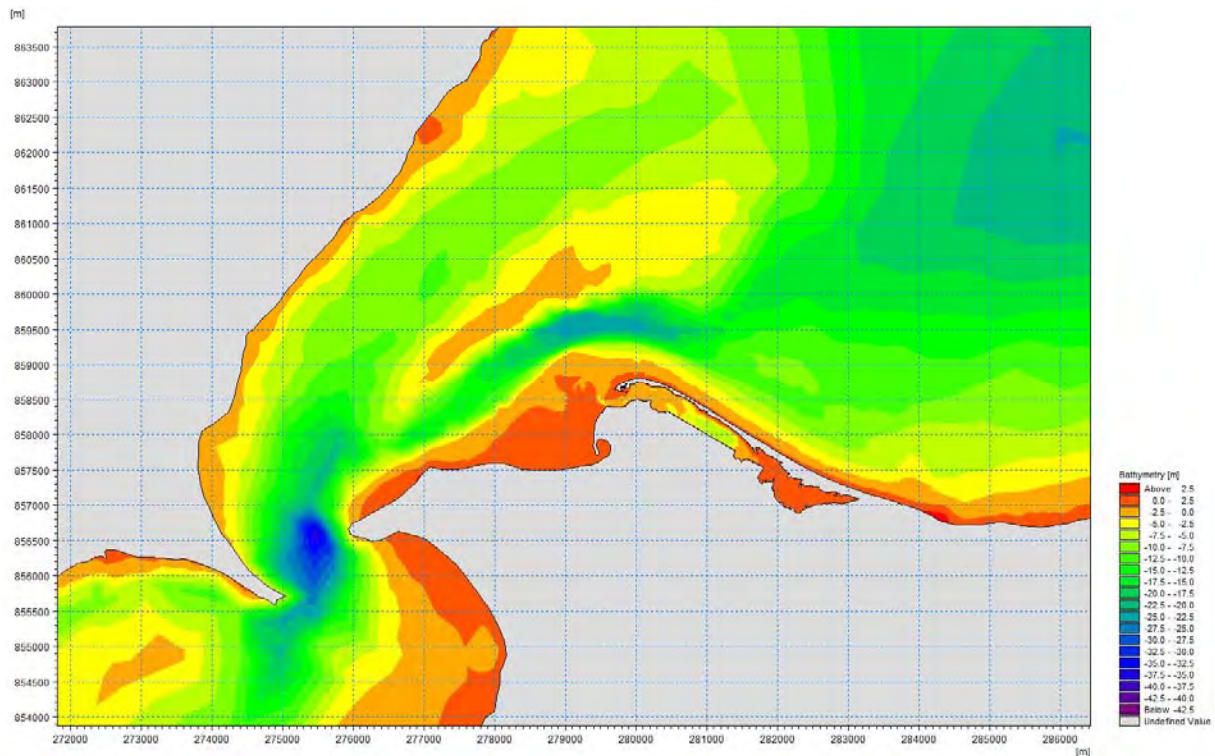


Figure 3.1: Wider Moray Firth Bathymetry in Vicinity of Whiteness Head

3.3 Historical Morphological Evolution

3.3.1 Review of Historical Mapping

Based on a review of historical map data for Whiteness Sands and the immediate vicinity the following observations can be made.

- Generally the intertidal area has stayed very stable over the period. Changes are observed in two zones, highlighted in red rectangles and labelled A and B (see Figure 3.2). The offshore shoal zones seem less stable, with significant changes in morphology seen between the two UKHO chart surveys (1845, 1975).
- In Area B (coastline at the root of the spit) significant erosion/retreat is seen between 1845 and 1890, coincident with the initial extensions of the spit (see below). It can be conjectured that a period of severe coastal erosion at this time, along the beach and nearshore area, provided a new source of shingle which fuelled the spit development. Continued slight erosion/change can be seen in this area through until 2001.
- Area A - spit extension to the northwest. The maps show the progressive extension of the shingle spit from hardly existing (1845). The position of the spit has not varied, just continually extended. The saltmarsh area that can develop on the lee of the spit has followed the extension.
- Area A – mean low water on Whiteness Sands eastwards from its furthest north extension. This line remained very similar through 1845 to 1960. This indicates that the growth of the spit through this area was a function of increased shingle supply rather than any modification of the sand system. However with the construction of the McDermott base in 1972 there was a marked change in the low water, outside of the dredged navigation channel area. The northern ‘point’ of the sands (west of the new navigation channel) extended some 100m further to the north, and the width of the sand intertidal area east of the channel (below the shingle spit) appears to have significantly widened. The

latter changes seem to have persisted to the present day, despite the natural infill of much of the dredged channel over the last decade.

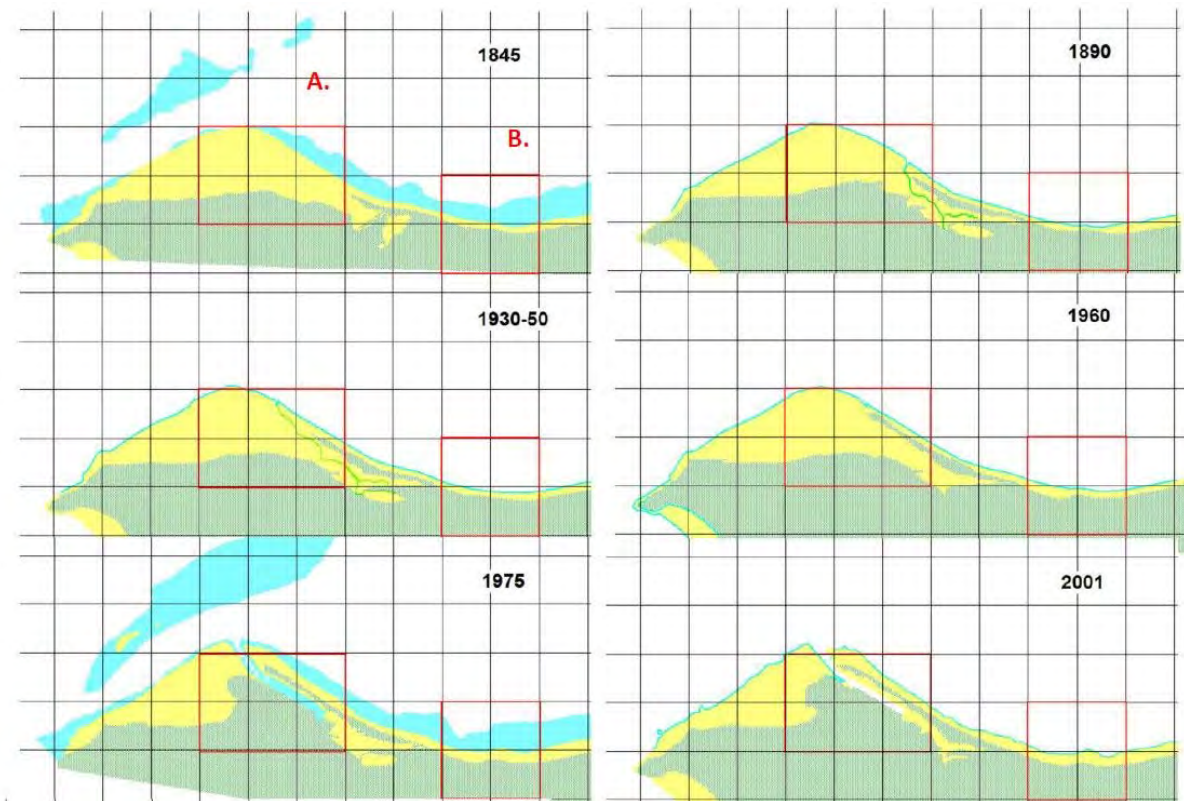


Figure 3.2: Analysis of Historical Mapping – Terrestrial (Green), Intertidal (Yellow) & Subtidal (Blue – White)

3.3.2 Comparison of Survey Data

Bathymetric and topographic survey data from 2018, 2016, 2012 and 2007 (see section 3.1) can be used to investigate the recent morphological evolution of the spit, harbour inlet and surrounds. The following findings have been observed through comparison of the datasets:

Eastern Shoreline of Spit

Away from the head, the eastern face of the spit around mean high water spring (MHWS) tide level appears to have experienced continuing retreat over recent years, with a general shallowing of seaward cross-sectional profile. A MHWS retreat of between 7 – 13 metres is observed between 2007 & 2012, and around 8 - 9 metres between 2012 and 2018, as shown in Figure 3.3 and Figure 3.10. Estimated rates of retreat are therefore between 1.4 to 2.6 metres per year, generally consistent with the findings of the recent NCCA report (Hansom et al., 2017; The Scottish Government, 2017).

Head of Spit

The head of the spit continues to accumulate in both a north-westerly and westerly direction. Comparison between the 2007 and 2012 surveys shows movement of MHWS between 80 – 120 metres (Figure 3.3). Movement between 2012 and 2018 is observed to be between 35 – 55 metres. Estimated rates of MHWS movement are therefore between 10 – 24 metres per year. Below MHWS significant accumulation within the intertidal and subtidal zone is also observed between 2012 and 2018 (Figure 3.4, Figure 3.5 and Figure 3.9).

Former Dredged Channel

The former dredged channel has migrated in response to ongoing sedimentation, moving west by around 130m from 2007 to 2012, and around a further 155m from 2012 to 2018 (Figure 3.4 and Figure 3.5). Additionally this channel is observed to have both narrowed and deepened during this period, with increased sinuosity having developed between 2016 and 2018 (Figure 3.8). The movement of the channel, and increase in sinuosity, has resulted in erosion to the eastern edge of Whiteness Sands in the immediate vicinity, as well as the development of some localised depositional features (Figure 3.4). The erosion of Whiteness Sands in this area has likely contributed to the infilling through deposition of the harbour inlet.

Harbour Inlet

Within the harbour inlet significant deposition (up to 4m depth) is observed along the north-western quay face, extending south into the former berth areas, and east towards the spit (Figure 3.10). This deposition has resulted in the migration of the former dredged channel east towards the spit, with localised scour observed on the bed, and some erosion to the intertidal spit face (Figure 3.4 to Figure 3.6).

Whiteness Sands

To the northwest of the tidal inlet and spit head, some localised erosion is shown to the north-eastern tip of Whiteness Sands around both MLWS level (Figure 3.4), and omCD (Figure 3.5), where up to 30m localised retreat is observed. A corresponding accumulation of subtidal levels is observed further to the north-west, with a north-western extension of the omCD contour between 2016 and 2018 of between 50 and 60m (Figure 3.5 and Figure 3.6).

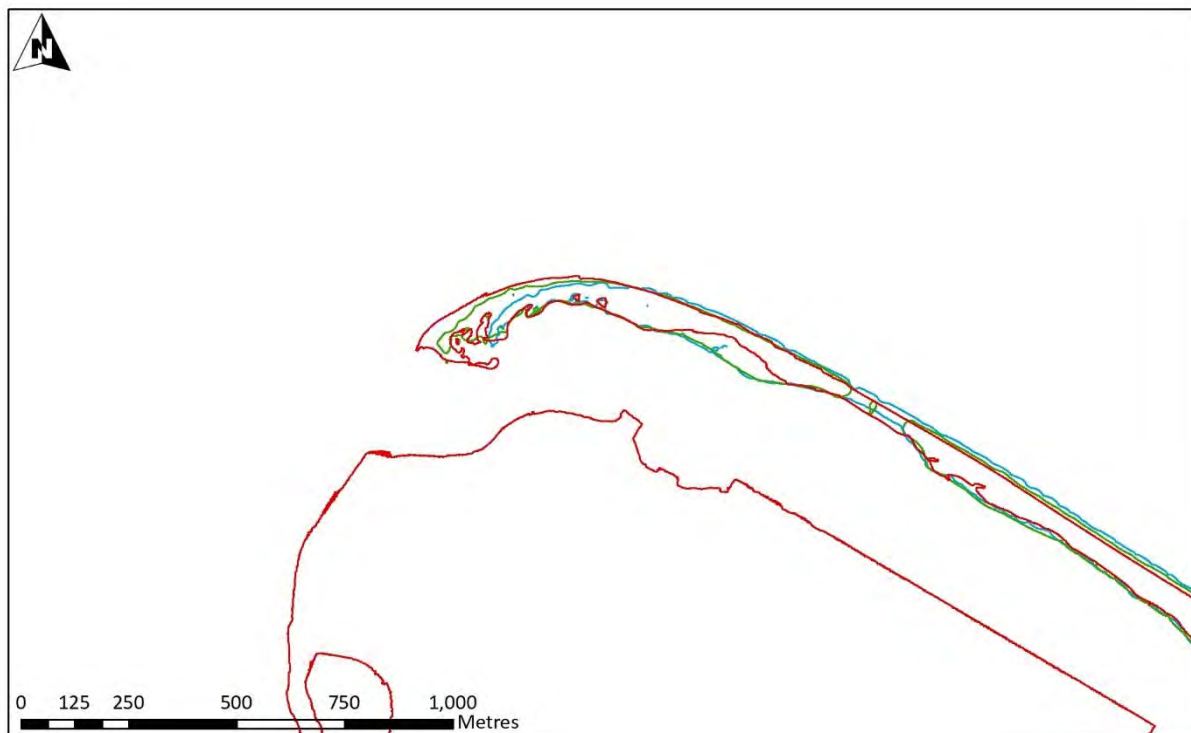


Figure 3.3: Surveyed MHWS Contours - 2007 (Blue), 2012 (Green) & 2018 (Red)

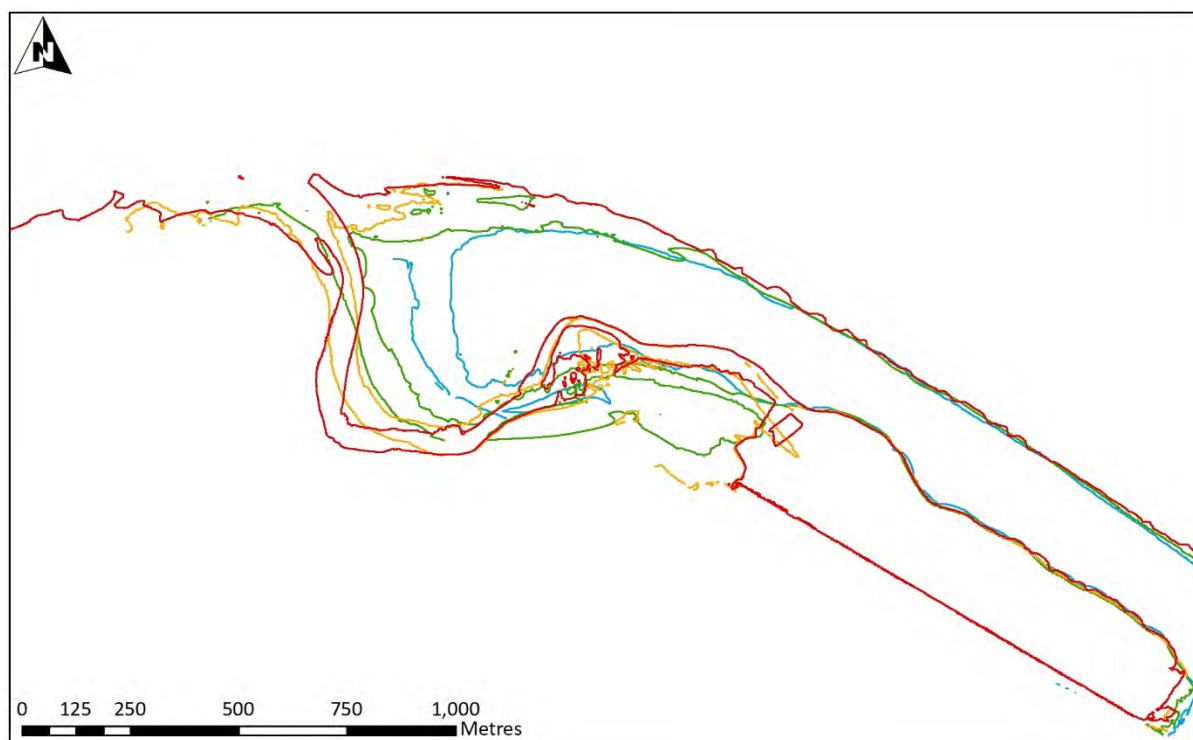


Figure 3.4: Surveyed MLWS Contours - 2007 (Blue), 2012 (Green), 2016 (Orange) & 2018 (Red)

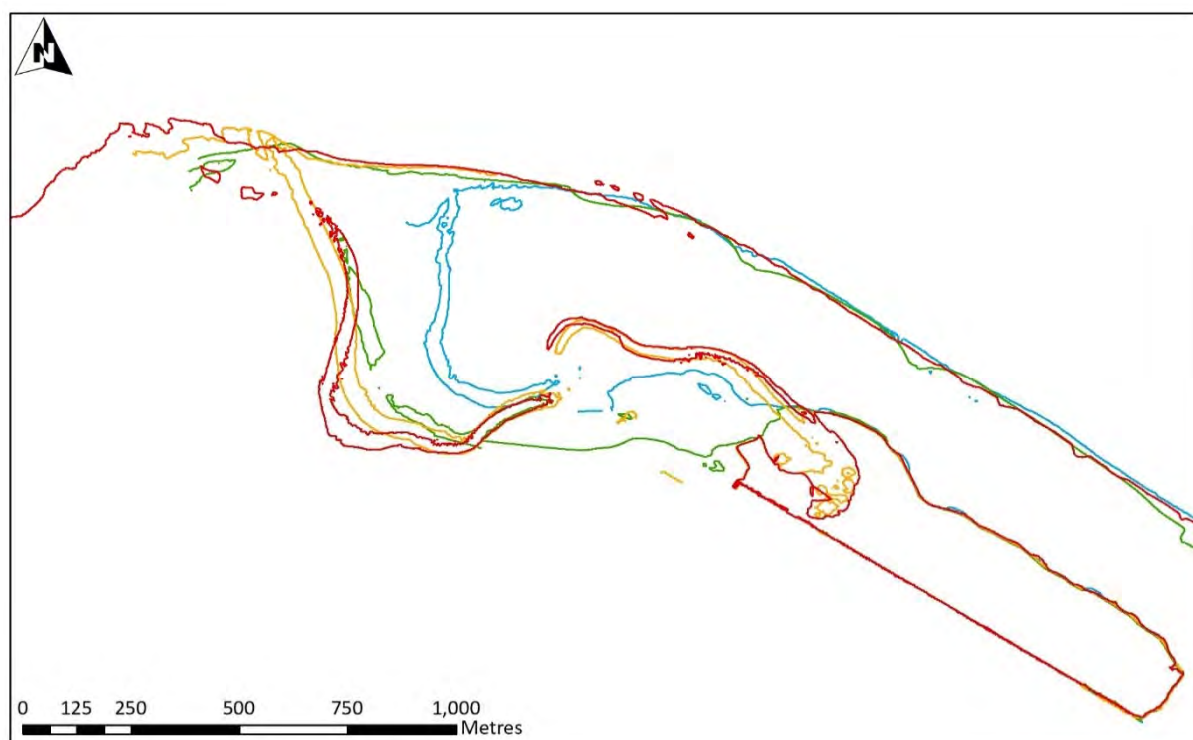


Figure 3.5: Surveyed omCD Contours - 2007 (Blue), 2012 (Green), 2016 (Orange) & 2018 (Red)

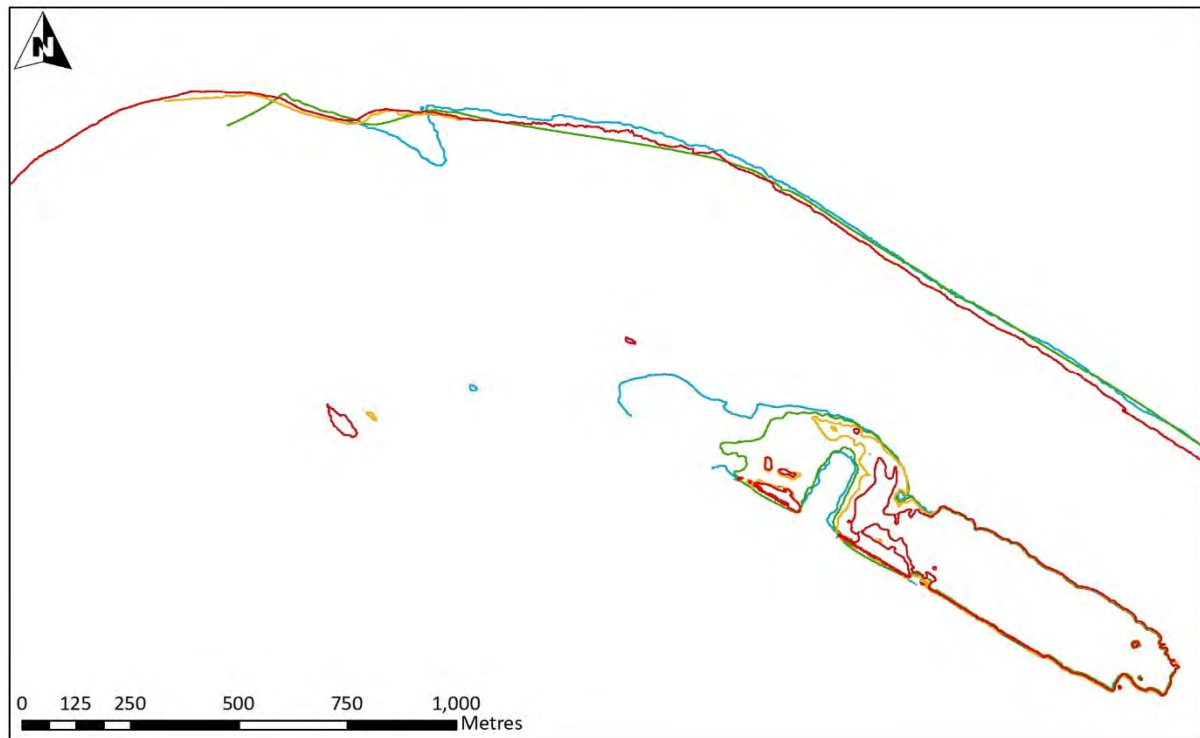


Figure 3.6: Surveyed -2.5mCD Contours - 2007 (Blue), 2012 (Green), 2016 (Orange) & 2018 (Red)

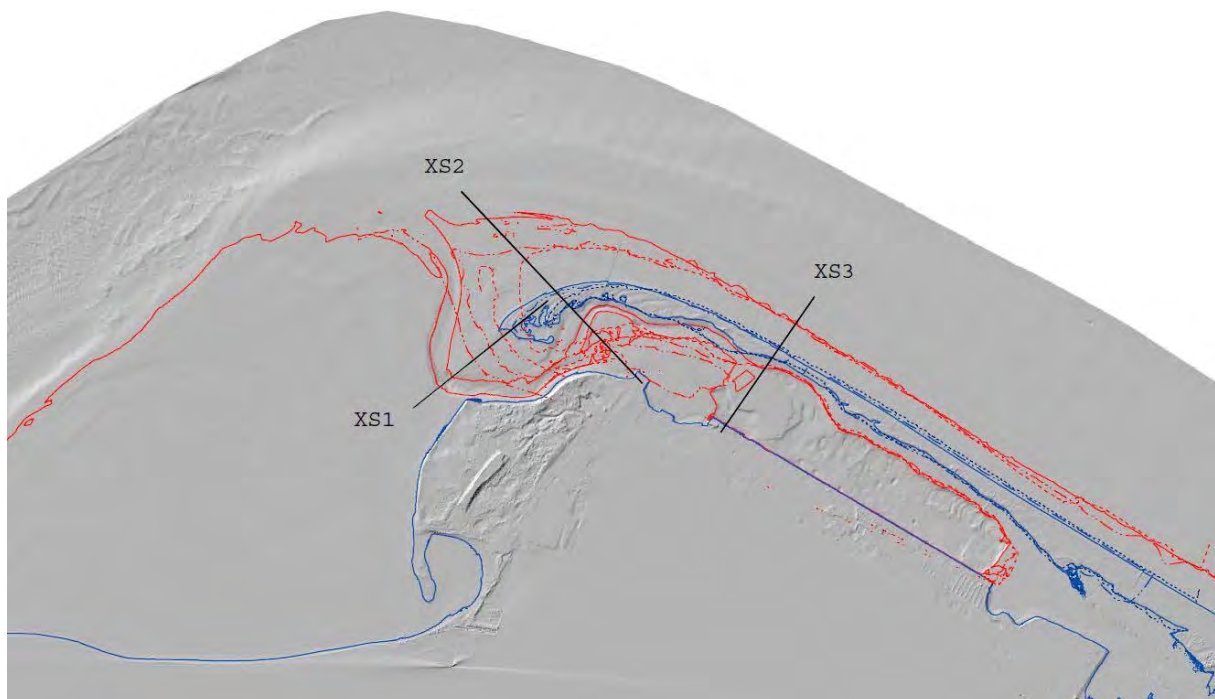


Figure 3.7: Survey Comparison Cross-Section Locations

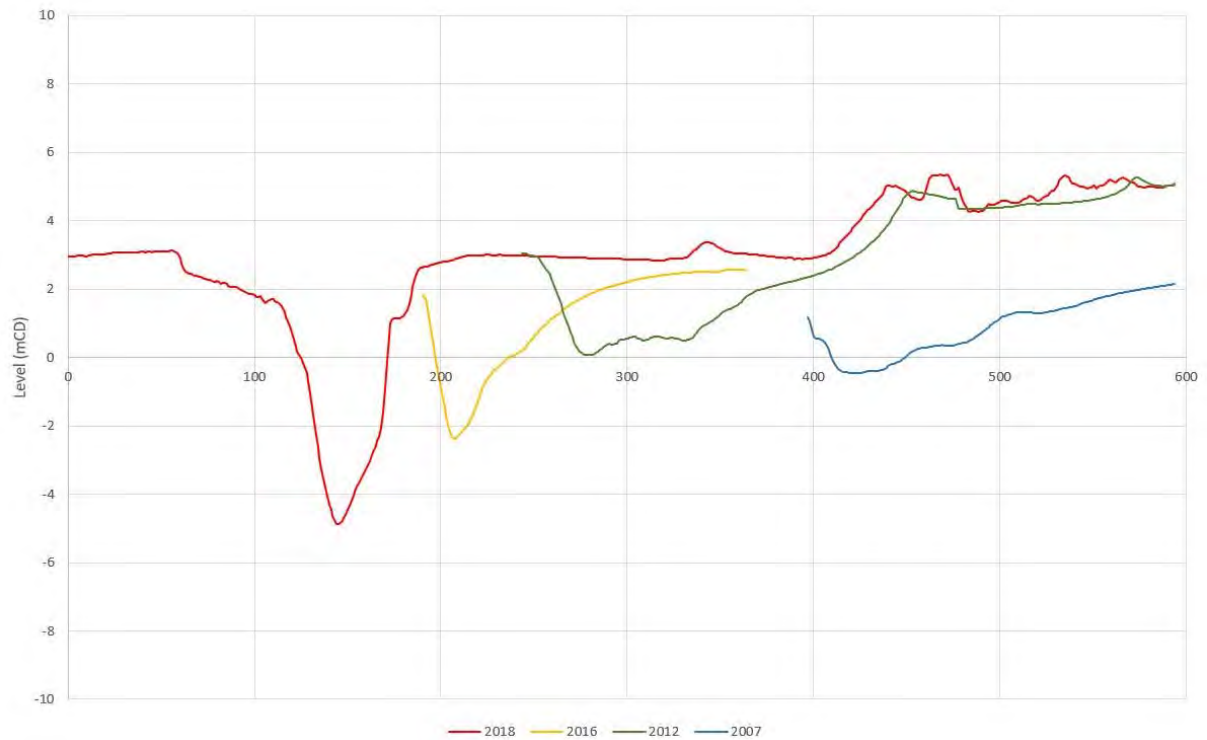


Figure 3.8: Survey Comparison Cross-Section 1 (Whiteness Sands to Spit Head)

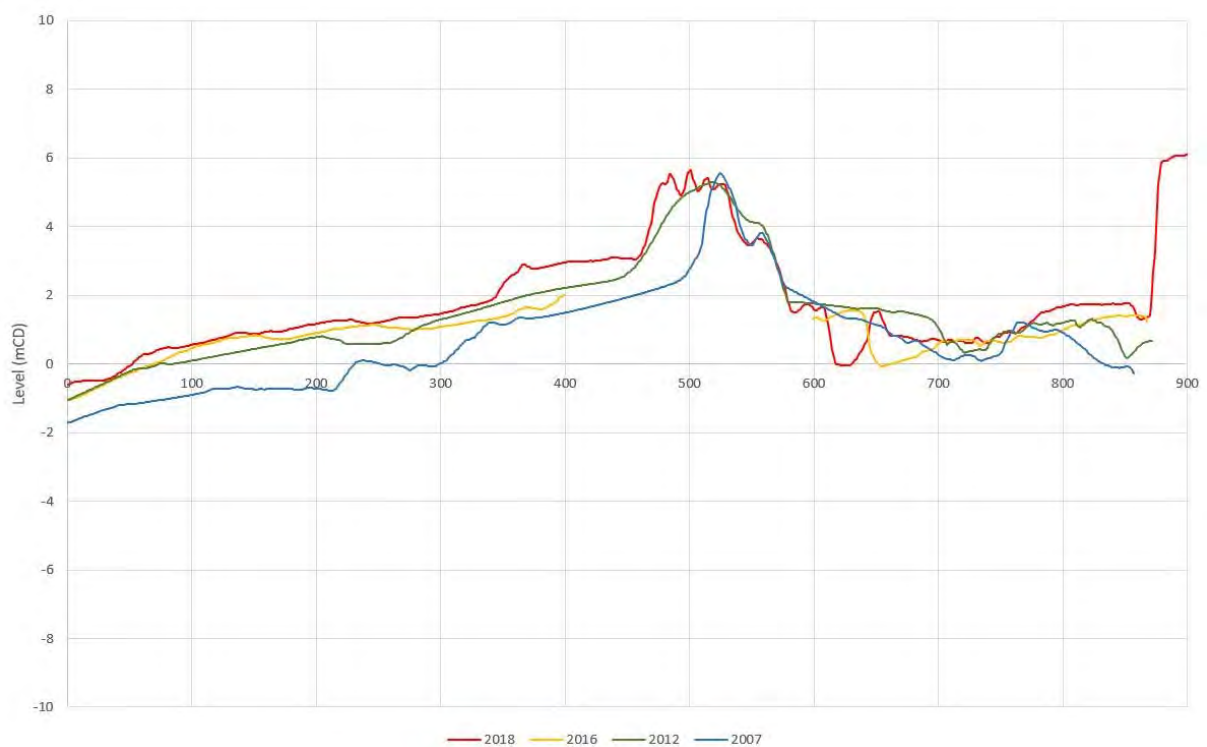


Figure 3.9: Survey Comparison Cross-Section 2 (North to South Across Spit Head)

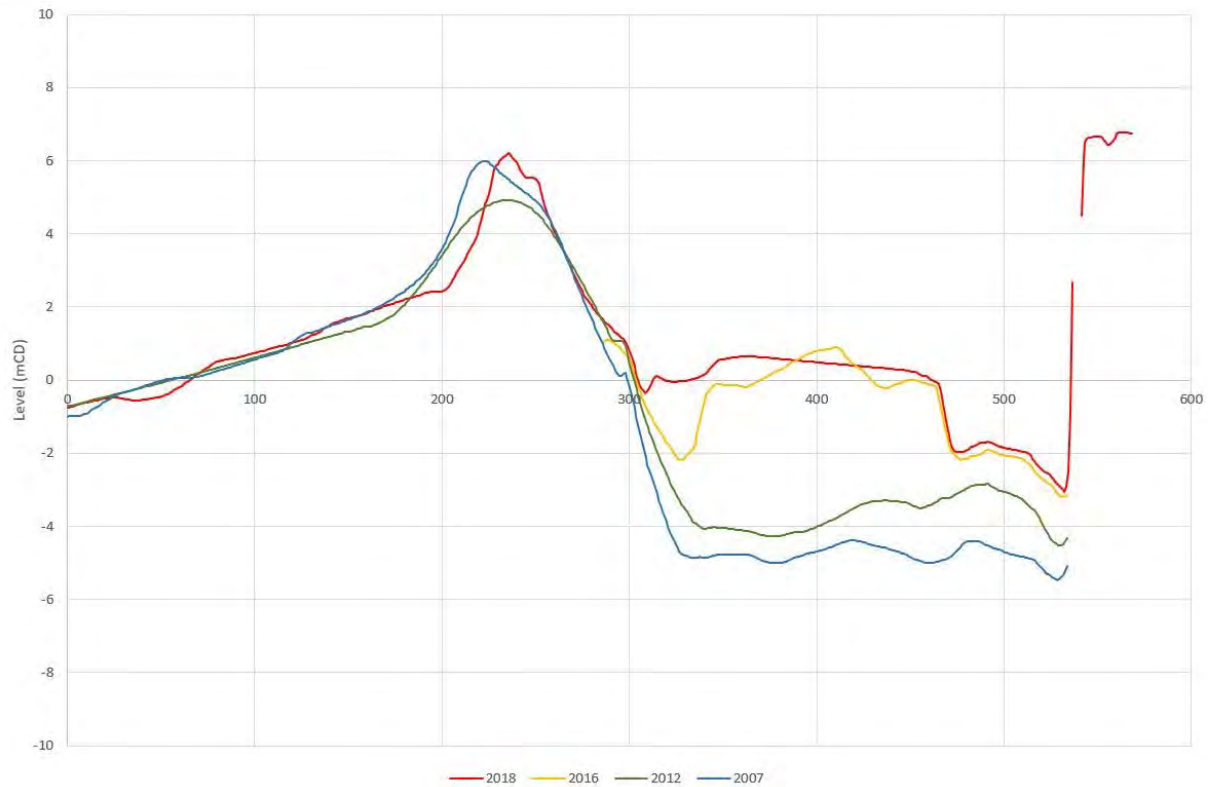


Figure 3.10: Survey Comparison Cross-Section 3 (East to West Across Spit and Inlet)

3.4 Sediment

Several phases of sediment sampling have been undertaken over recent years in the vicinity of the development site, these previous site investigations are detailed below, whilst the sample locations are shown in Figure 3.11:

- December 2012 – Offshore grab samples taken to the north of the spit (Clydeside Surveys);
- February 2013 – Boreholes (3) drilled through the tip of the spit (Blake Geotechnics), grab samples (22) and sea bed video in the vicinity of the spit, and the historic disposal ground on Whiteness Sands; and
- March 2013 – Boreholes (3) drilled through the existing quayside (Blake Geotechnics).

The site investigations to date have found that Whiteness Sands, spit and associated channel are essentially formed in mobile sand deposits. Four sand types can be identified based on lognormal particle size populations. The spatial distributions of the following sand fractions at the time of survey (2013) are shown in Figure 3.11:

- **Medium-coarse sand** – Mode 0.355mm. Normally present forming a secondary bimodal grain population with a dominant medium-fine sand. Indicative of bedload transport.
- **Medium sand** – Mode 0.250mm. Normally present forming a bimodal grain population with a dominant medium-fine sand. Indicative of bedload transport.
- **Medium-fine well-sorted sand** - Mode 0.180mm. Almost ubiquitous outside the zone immediately offshore from the spit. The sand population most easily set in motion by flowing water, typically moving as near-bed suspension.
- **Fine sand** – Mode 0.150 – 0.125mm. Dominates the seabed offshore from the spit, typically unimodal. Indicative of suspended load transport processes.

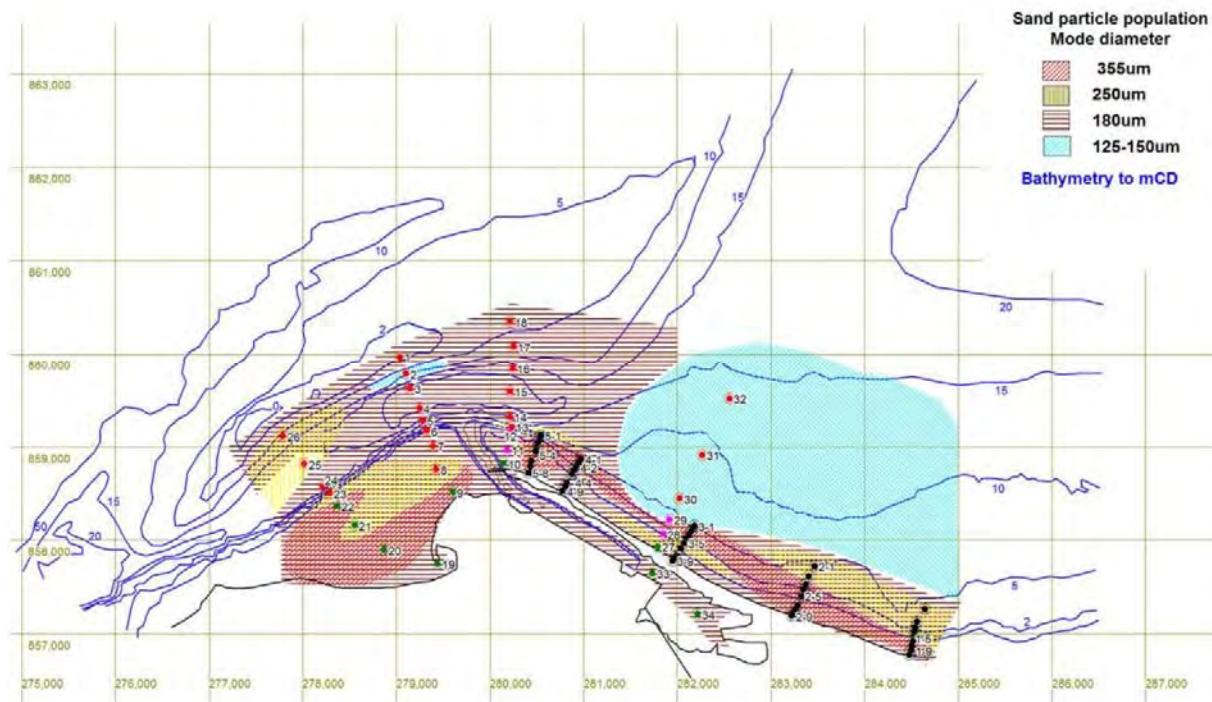


Figure 3.11: Distribution of Sand Particle Populations and Grab Sample Locations (2013)

Lithogenic gravel deposits are present to the surface of the spit, predominantly along and above the high water mark, as highlighted in the boreholes taken through the spit crest (see Figure 3.12). Gravels are present in lower quantities within the immediate vicinity of the spit, whilst to the north of Whiteness Sands the gravel component consists of shell debris as shown in Figure 3.13 and Figure 3.14. Sediment within the immediate vicinity of the development site is generally associated with present day processes, however, chart annotations of seabed conditions highlight adjacent areas of drift deposit exposure (see Figure 3.13). These annotations indicate there are two eroding Holocene or Pleistocene deposits in the area, the foreshore and offshore area to the east of the spit, and the Fort George narrows area. In these two zones recent deposits are probably thin or absent, with erosion providing an important source of gravel to be reworked by present day processes.

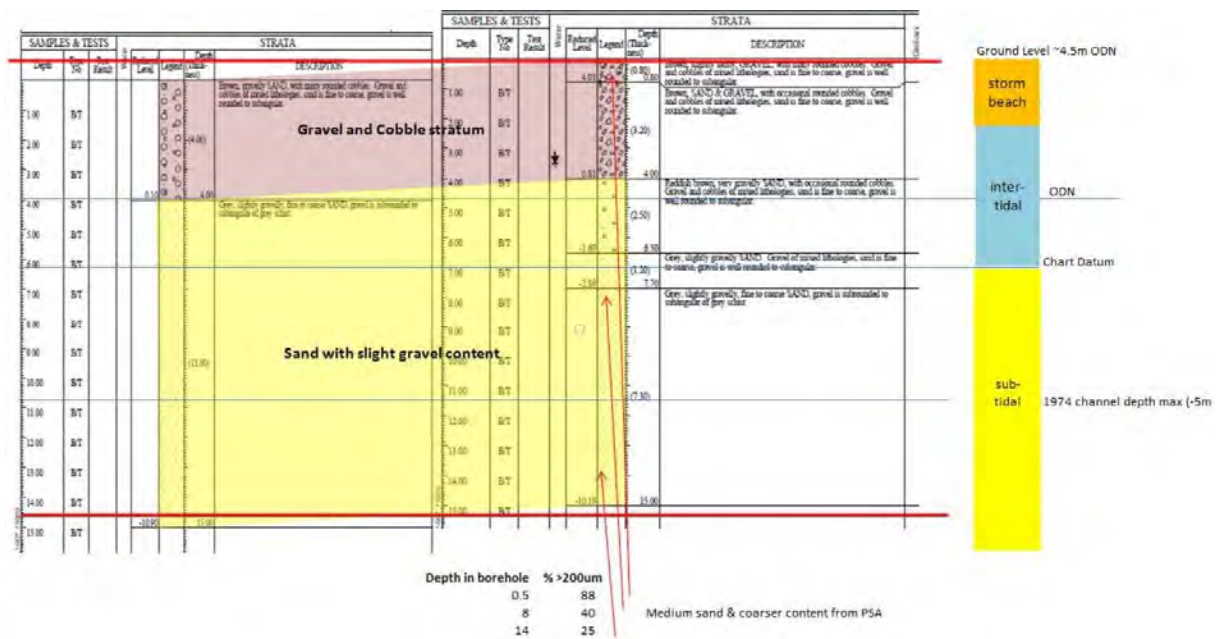


Figure 3.12: Borehole Sections – Spit Crest (2013)

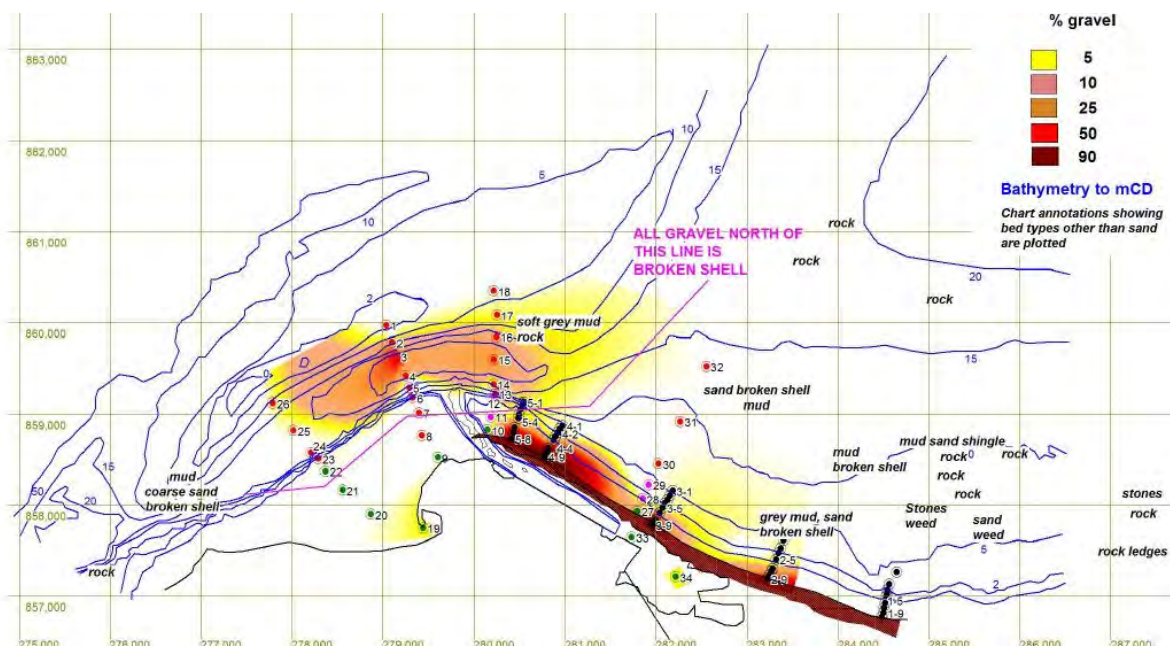


Figure 3.13: Chart Annotations and Gravel Content (2013)



Figure 3.14: Lithogenic Shoreface Gravels (Top Left), Channel Shell Gravel (Top Right), Actively Mobile Rippled Sands (Bottom)

3.5 Tidal Regime

3.5.1 Water Levels

Tidal levels at Ardersier Port (formerly McDermott Base) as presented within the Admiralty Tide Tables (UKHO, 2018) are shown in Table 3.1. The mean tidal range at Ardersier Port is 3.3m during spring tides and 1.6m during neap tides.

Table 3.1: Tidal Water Levels – Ardersier Port

Tide Condition	Chart Datum (mCD)*	Ordnance Datum (mOD)
Highest Astronomical Tide (HAT)	4.8	+2.66
Mean High Water Spring (MHWS)	4.2	+2.06
Mean High Water Neap (MHWN)	3.3	+1.16
Mean Sea Level (MSL)	2.5	+0.36
Mean Low Water Neap (MLWN)	1.7	-0.44
Mean Low Water Spring (MLWS)	0.9	-1.24
Lowest Astronomical Tide (LAT)	0.2	-1.94

*Chart Datum correction for Ordnance Datum is -2.14m (relative to OD at Newlyn)

Extreme sea levels have been predicted around the whole UK coastline and published by the Environmental Agency/Department for Environmental Food and Rural Affairs report (McMillan et al., 2011). These extreme levels include the effects of both tides and storm surge but not the effect of amplification within estuaries or sea lochs. In order to provide better estimates around the Scottish coastline, SEPA have updated the original estimates (SEPA, 2014). As presented in Table 3.2 the SEPA derived extreme sea levels, predicted at a point offshore from Ardersier Port, are 3.35m Above Ordnance Datum (AOD) for the 1 in 200 year return period event and 3.51mAOD for the 1 in 1,000 year return period event.

Table 3.2: Ardersier Port Extreme Sea Levels (SEPA Dataset)

Return Period (Years)	Water Level (mCD)	Water Level (mAOD)
2	0.77	2.91
5	0.86	3.00
10	0.93	3.07
50	1.08	3.22
100	1.15	3.29
200	1.21	3.35
1000	1.37	3.51

3.5.2 Currents

Hydrodynamic modelling undertaken for this assessment highlights the main tidal streams within the vicinity of the development site. During the flood phase the main tidal stream passes from east to west, aligned with the spit closer in to shore, flowing round the head of the spit into the harbour inlet, and spreading across Whiteness Sands from the north-east. Modelled maximum current velocities at mid-flood during a spring tide occur in the main channel off the northern edge of Whiteness Sands (1m/s), and within the former dredged channel adjacent to the spit head (0.85m/s). Figure 3.15 shows the modelled tidal current at mid-flood during a spring tide.

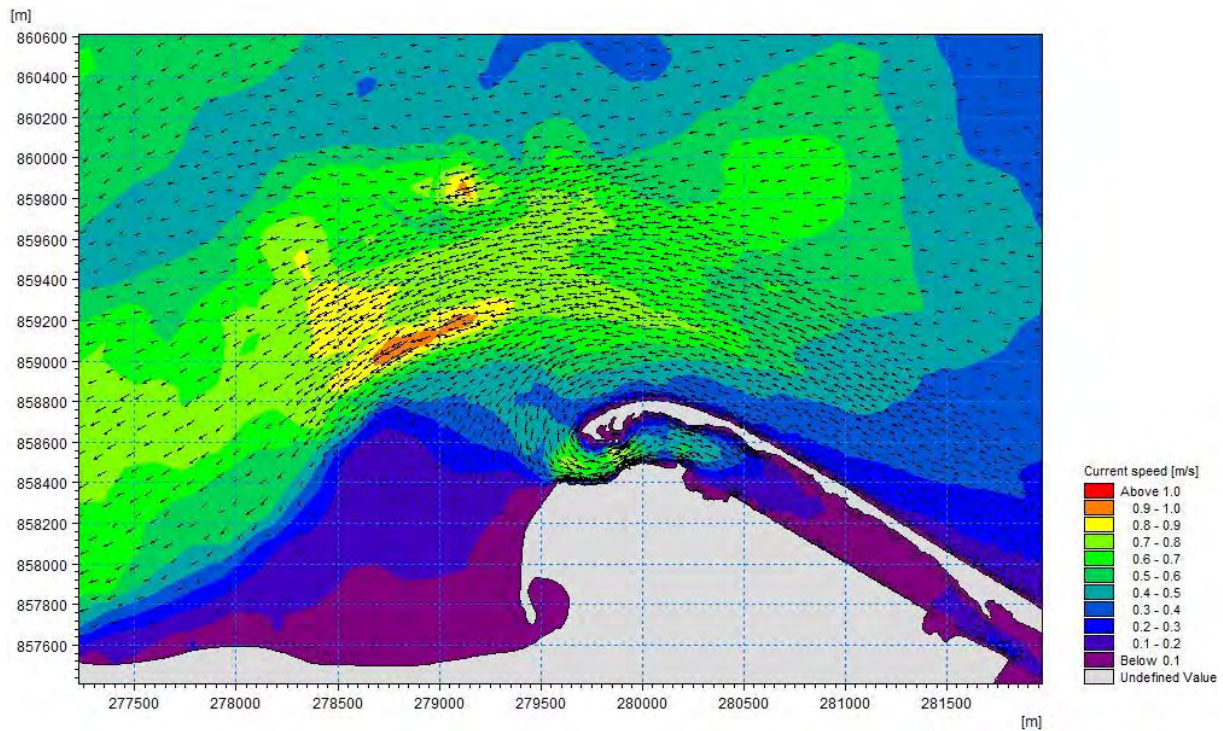


Figure 3.15: Modelled Mid-Flood Spring Tide – Current Speed and Direction (Vector Arrows)

During the ebb phase the main tidal stream reverses, passing generally from west to east, draining towards the north-eastern edge of Whiteness Sands, and flowing out of the harbour inlet round the head of the spit. Modelled maximum current velocities at mid-ebb during a spring tide again occur in the main channel off the northern edge of Whiteness Sands (1m/s), and within the former dredged channel adjacent to the spit head (0.70m/s). Figure 3.16 shows the modelled tidal current at mid-ebb during a spring tide.

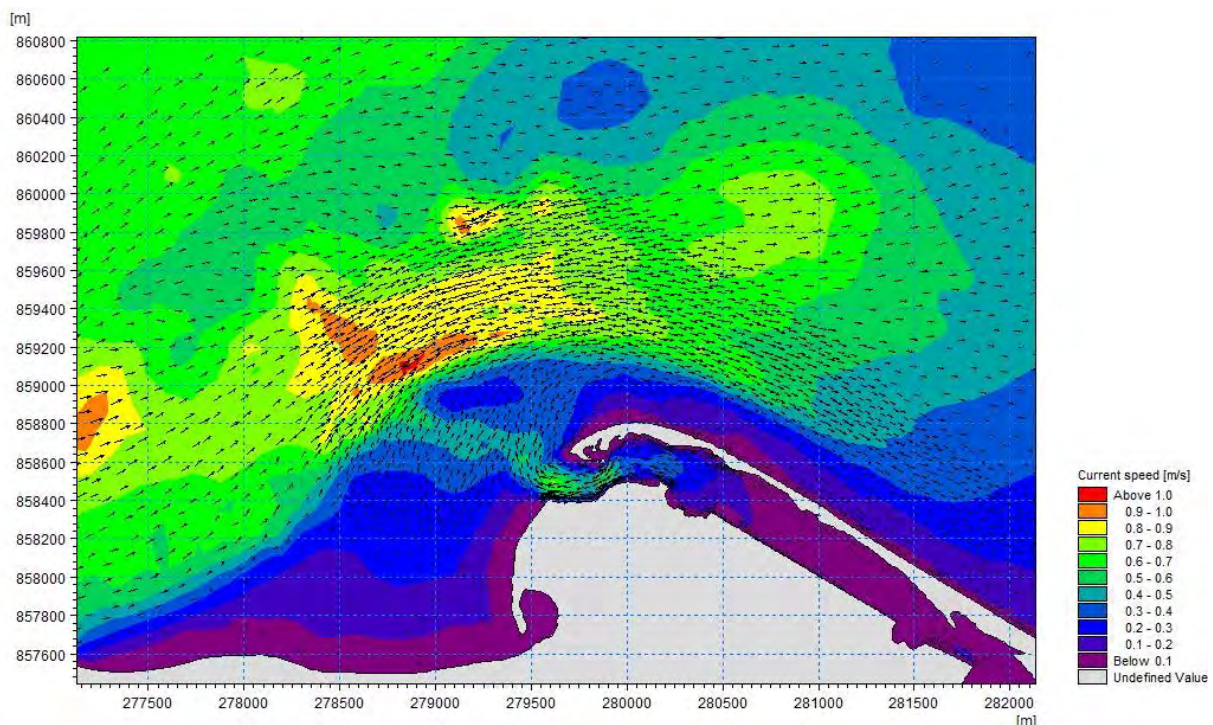


Figure 3.16: Modelled Mid-Ebb Spring Tide – Current Speed and Direction (Vector Arrows)

Either side of low water the tidal stream into and out of the harbour inlet aligns with the former dredged channel, meandering from east to west and then north to south on the ebb tide, reversing on the flood tide. Peak current velocities fall towards low and high water. A consistent pattern of tidal stream orientation is observed during neap tidal cycles, with velocities of a lower order during all phases of a neap tide. Figure 3.17 shows modelled tidal current for ebb near low water during a spring tide.

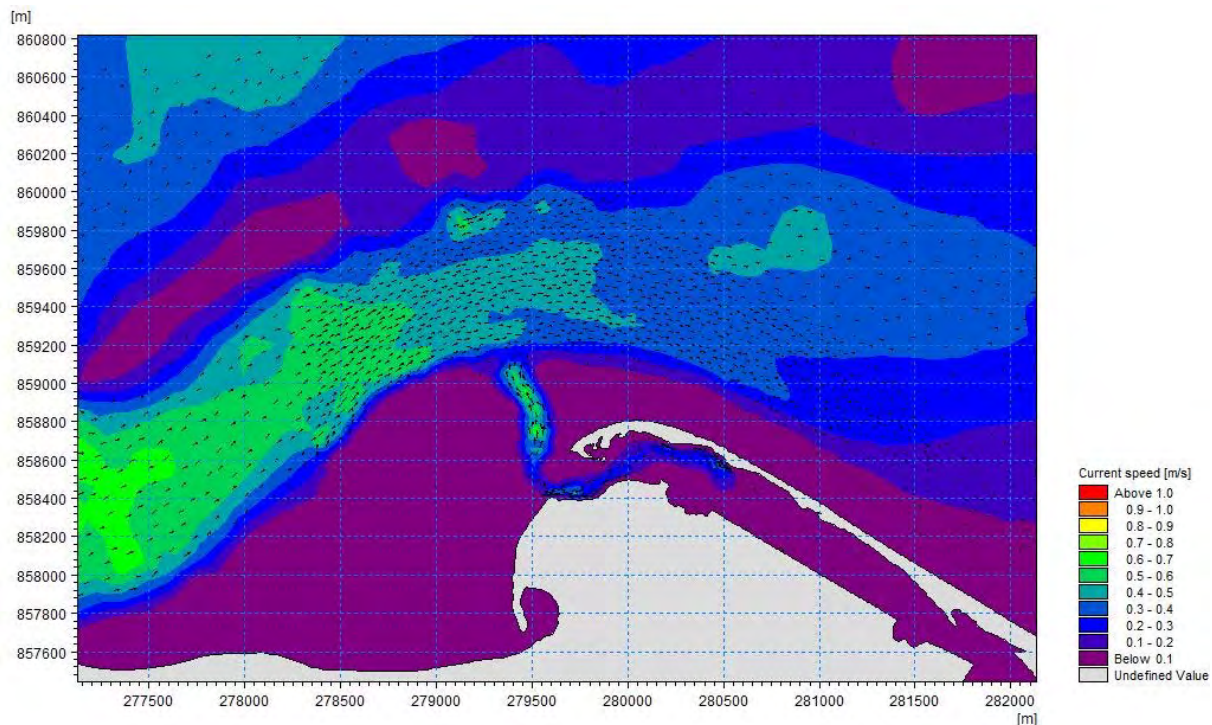


Figure 3.17: Modelled Near Low Water Ebb Spring Tide – Current Speed and Direction (Vector Arrows)

Comparison of modelled peak flood and ebb spring tidal currents has been undertaken to examine residual current patterns within the vicinity of the development site (see Figure 3.18). The results of this analysis highlight a dominant residual peak flood current extending from east to west around the head of the spit across the north-eastern tip of Whiteness Sands, and also south into the harbour inlet. Further offshore to the north-west of the spit head a dominant residual peak ebb current is observed within deeper waters. Localised residual ebb current dominance is observed along the northern edge of Whiteness Sands, and in central areas of the sands. Along the southern shoreline of Whiteness Sands a slight residual flood current is apparent. Elsewhere model results indicate negligible differential between the flood and ebb phase.

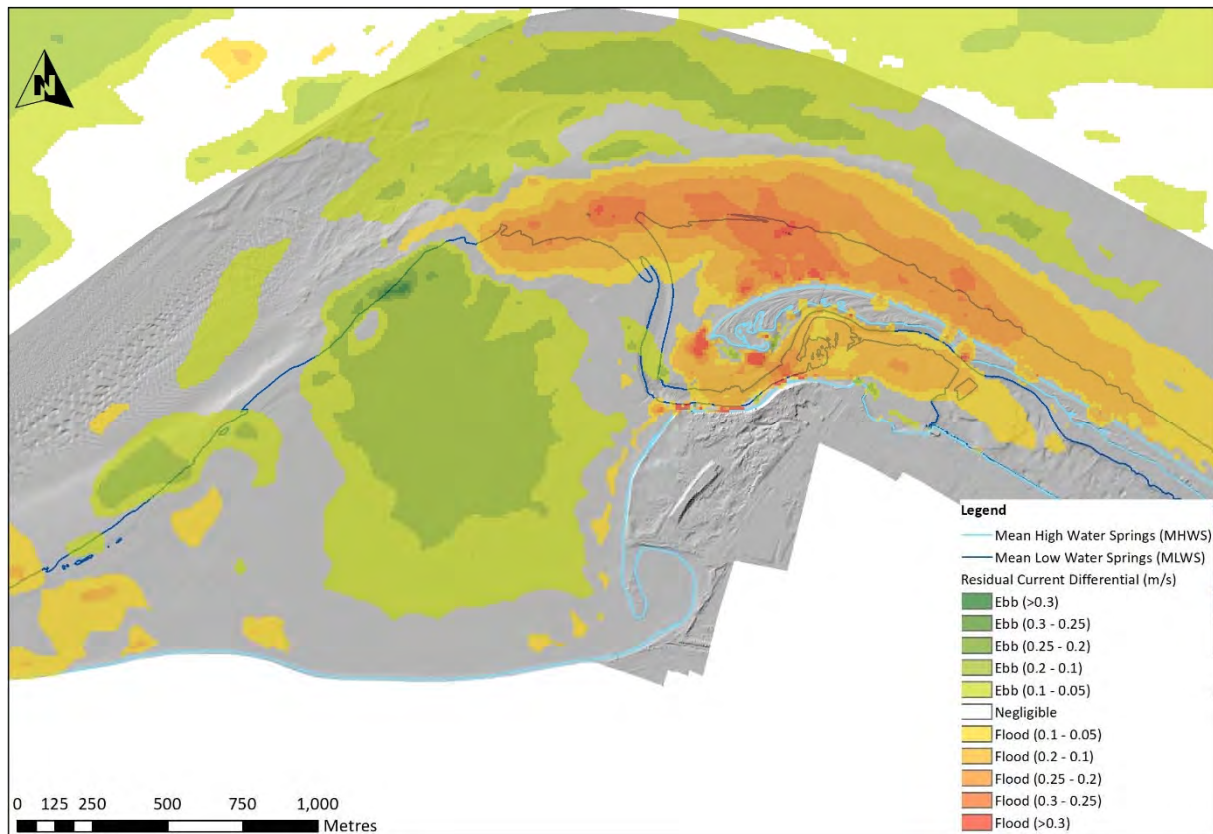


Figure 3.18: Residual Modelled Peak Spring Flood and Ebb Tidal Current Differential

3.6 Wave Climate

3.6.1 Offshore Wind and Wave Conditions

In the Moray Firth the prevailing wind direction is from the southwest, whilst the offshore wave direction is predominantly from the northeast. Offshore wind and wave data from the Met Office from the period March 2000 – March 2007, for an area situated over 20km offshore from the proposed development site in the Outer Moray Firth, has been analysed to inform the assessment. The prevailing wind directions are from the southwest, with wind speeds in excess of 10m/s occurring during winter months. The data shows the significant wave height (average height of the largest 1/3 of waves in a 15-20 minute dataset at 3 hour intervals) to be typically less than 2m and rarely in excess of 3m (0.06%). The significant wave height is generally used to characterise and model the wave climate, although it should be recognised that as this is an averaged dataset, and larger waves will occur.

Analysis of the Met Office offshore wind and wave data, shows the estimated 1 in 200 year return period offshore significant wave height is 5.18m, whilst the 1 in 2 year return period offshore significant wave height is 2.56m. Maximum wave heights are not included in the data, however, using a conservative approximation of maximum wave height being 2 times the significant wave height, the corresponding 1 in 200 and 1 in 2 year return period maximum wave heights would be in the order 10.4m and 5.1m respectively.

The offshore wind rose, wave rose and time series plots for the Met Office dataset are presented in Figure 3.19 and Figure 3.20.

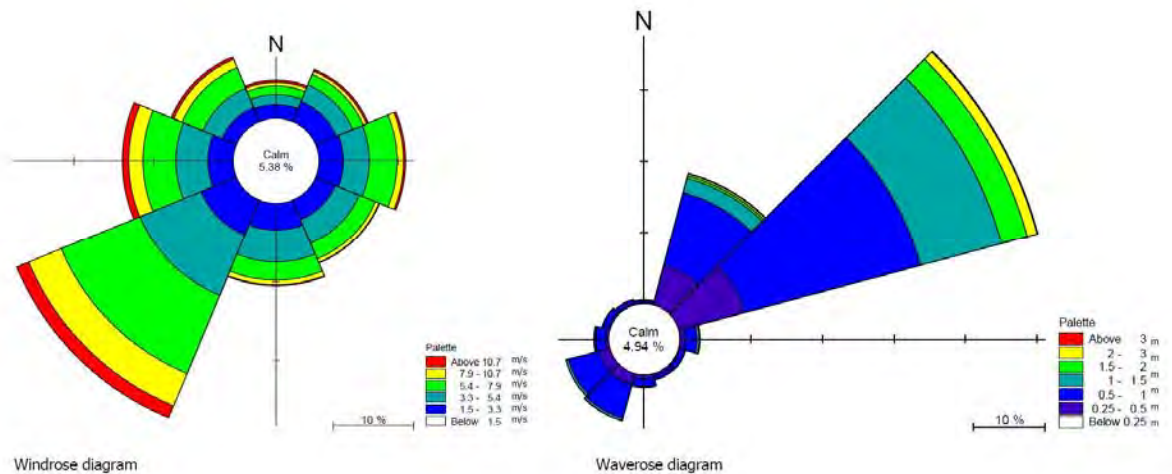


Figure 3.19: Offshore Wind Rose and Wave Rose (Met Office Data)

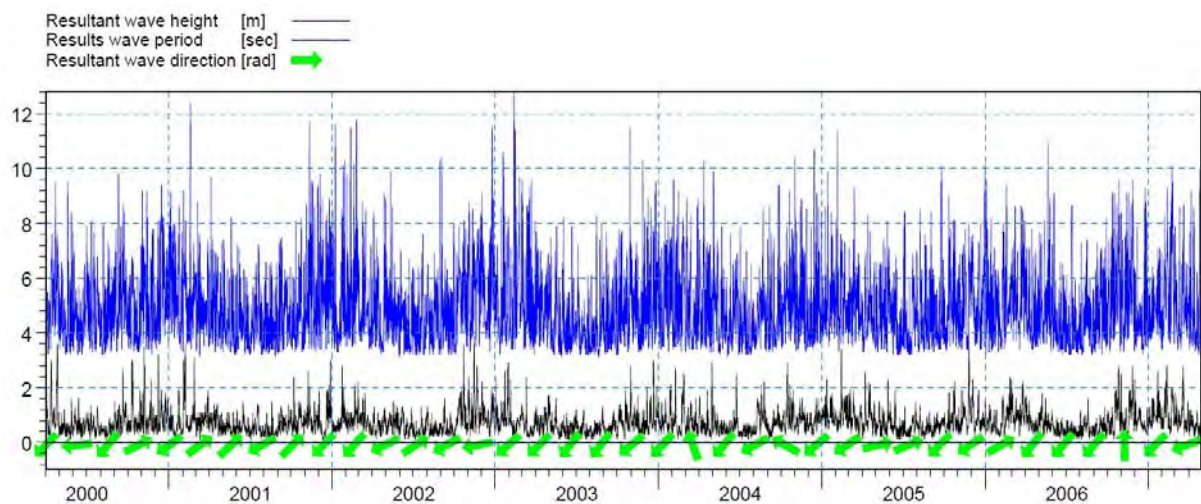


Figure 3.20: Offshore Wave and Wind Time Series Plot (Met Office Data)

3.6.2 Nearshore Wave Conditions

The nearshore wave climate in the vicinity of the development site has been examined by transformation of offshore wave conditions using Mike 21 FM SW (Flexible Mesh Spectral Wave Model) software as part of the coastal modelling study undertaken for this assessment (see Appendix A). The nearshore wave climate has been modelled for a 6 month period using offshore Met Office Data (January – June 2003), with results extracted from the model at 4 points immediately offshore of the spit eastern frontage at approximately 10m depth of water (see Figure 3.21). The results indicate that significant wave height is typically less than 2m in the nearshore environment, with modelled significant wave heights generally slightly greater than half the offshore wave height.

Nearshore wave rose plots for points 1 to 4 are presented in Figure 3.22. A spatial plot of significant wave height during a typical winter storm event is presented in Figure 3.23. The model results indicate that wave heights are greatest along the exposed eastern frontage of the spit, reducing around the head of the spit and into the more sheltered waters of Whiteness Sands.

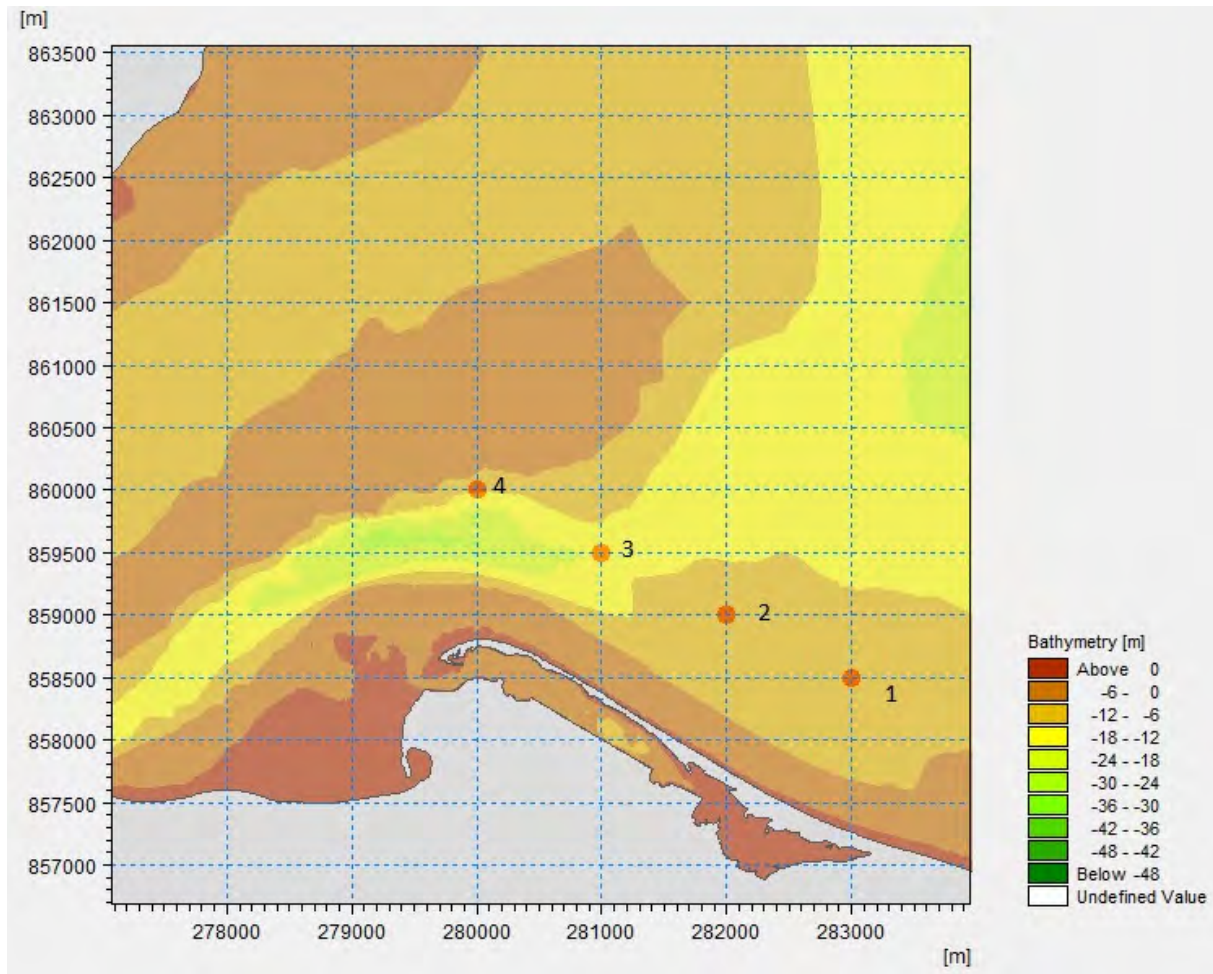


Figure 3.21: Nearshore Wave Climate Result Extraction Locations

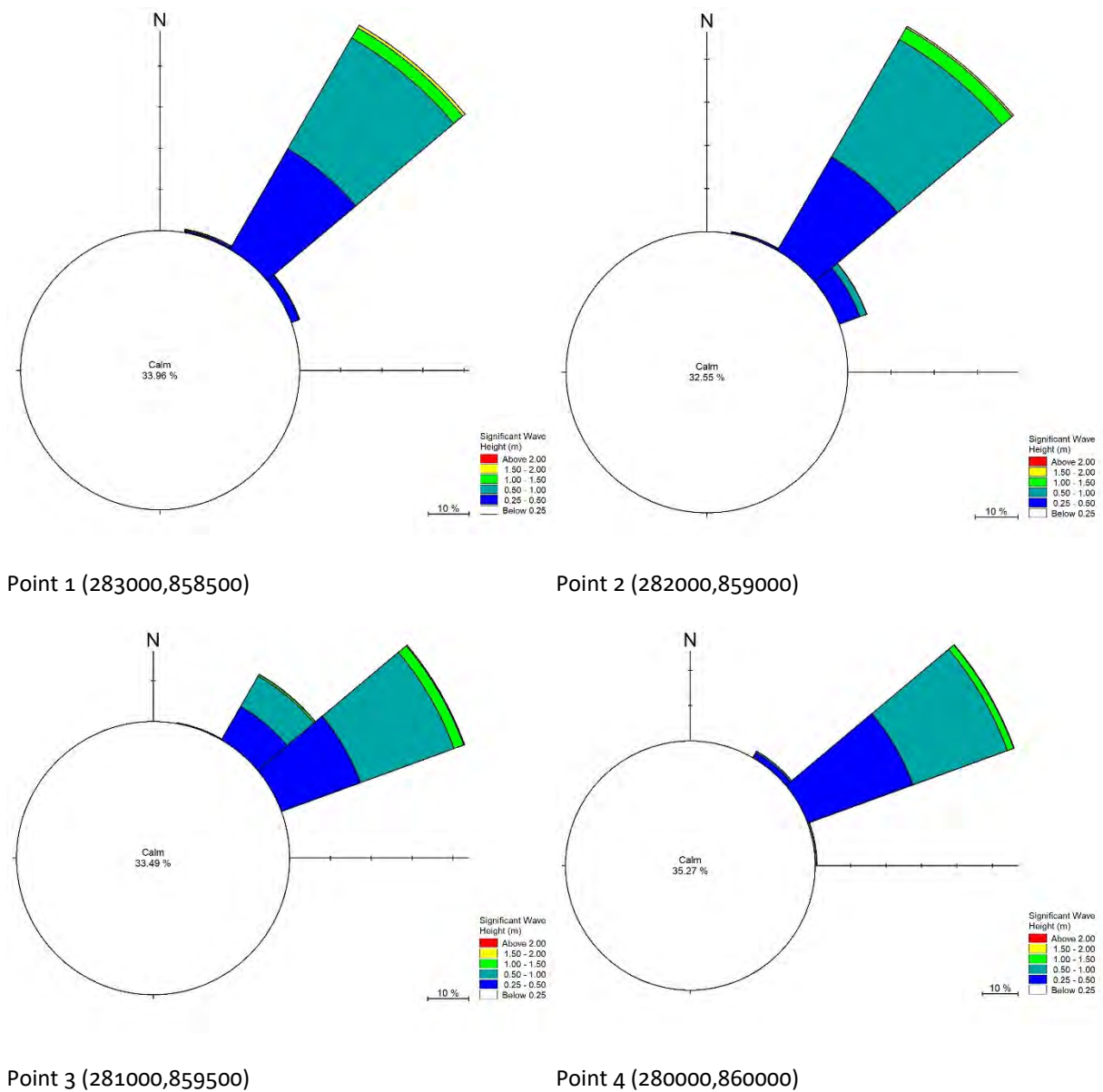


Figure 3.22: Wave Roses for Transformed Nearshore Waves with 2018 Bathymetry (Jan – June 2003, Points 1 – 4)

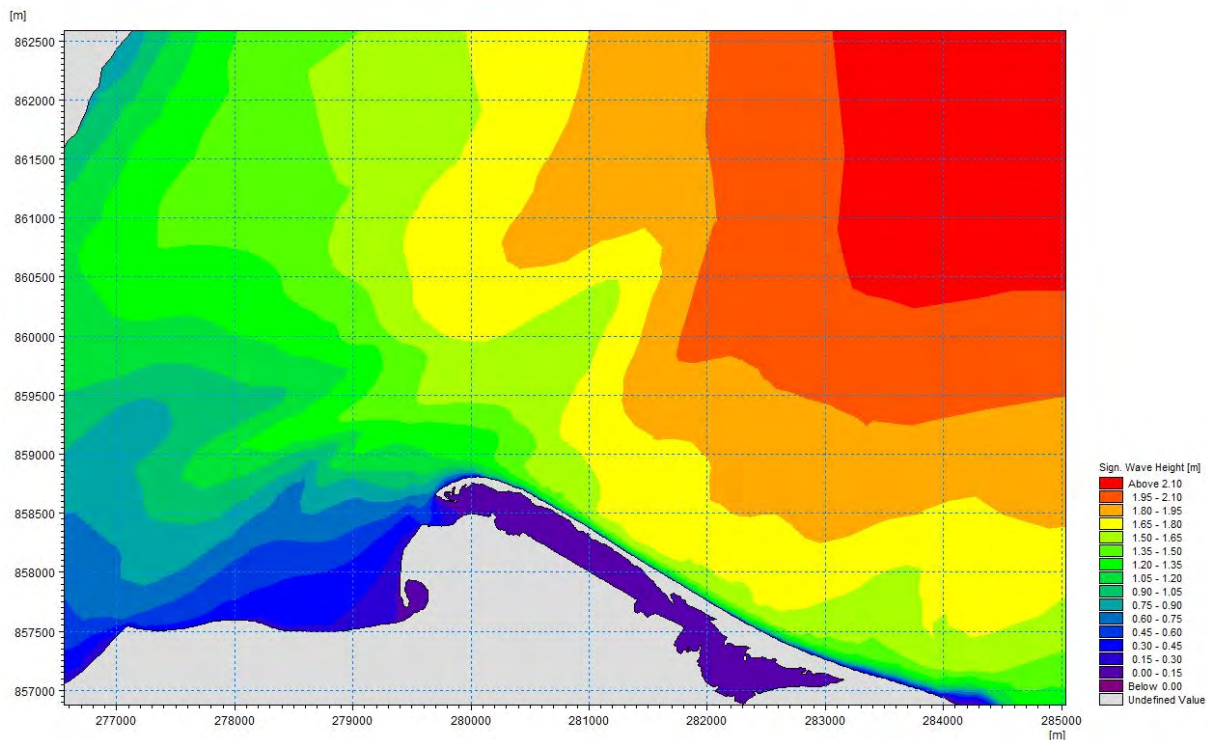


Figure 3.23: Modelled Nearshore Significant Wave Height - Winter Storm Event

Earlier phases of modelling informed peaks over threshold statistical analysis of wave heights in the nearshore environment of the spit. This analysis provides estimates of return period wave heights along the frontage of the spit, as presented in

Table 3.3: Estimated Nearshore Significant Wave Height Return Periods

Return Period (Years)	Nearshore Wave Height (m)			
	Point 1	Point 2	Point 3	Point 4
2	1.84	1.77	1.63	1.32
10	2.16	2.04	1.76	1.48
25	2.35	2.19	1.84	1.56
50	2.48	2.31	1.90	1.63
100	2.62	2.43	1.96	1.69
200	2.76	2.54	2.01	1.76

3.6.3 Wave Overtopping

Wave overtopping rates were assessed in the 2013 coastal assessment using the EUROTOP methodology. The characteristic spit crest levels and cross section coastal slopes have not significantly altered, so the previous findings are considered to remain appropriate.

These indicated that the spit and beach crest are likely to be overtopped during a 1 in 200 year joint probability return period of sea level and wave height event. The predicted rates of overtopping at the spit are relatively low and in the range of joint probability cases examined, would not be a hazard. Some combinations of high water and waves may generate overtopping rates that are hazardous to pedestrians, particularly when water levels are high.

4 CONCEPTUAL MODEL OF COASTAL PROCESSES

4.1 Morphological Review

The resolution of the recent 2018 bathymetric and topographic survey (see 3.2) allows a detailed examination of intertidal and subtidal features which was not possible with previous datasets. This information is considered a key component in developing a conceptual understanding of coastal processes in the vicinity of the proposed development site. A number of key features have been identified, a visual overview is provided in Appendix B, whilst the features are described within the following sub-sections.

4.1.1 Intertidal Spit

As highlighted in section 3.3.2 a north-western extension of the intertidal spit is observed through comparison recent survey datasets. Looking at the 2018 bathymetry in more detail there are several features of particular interest within this zone. A prominent intertidal recurve is observed immediately to the north of the present day terrestrial spit head with surface elevations between 2.5 and 3mCD. This recurve is shown in Appendix B (Inset D), and also in Figure 4.2. To the north and east of the intertidal recurve an elevated linear intertidal feature is observed, orientated in a north western direction in line with the longshore sediment feed. Surface elevations on this feature range between 1.6 and 2mCD, and it is shown in Appendix B (Inset D). Further to the north-west around MLWS level the intertidal spit extent forms a linear point feature, again orientated north-west, as shown in Appendix B (Inset B).

4.1.2 Subtidal Spit and Whiteness Sands

Below MLWS in the northern subtidal fringe of Whiteness Head spit and Whiteness Sands there are several features of note. Inset B, Appendix B, shows areas of subtidal deposition to the north-west of the spit, extending along the northern fringe of Whiteness Sands, as highlighted previously in section 3.3.2. These features have surface levels between 0 and 0.6mCD. Further to the south-west some linear bedforms are observed aligned with the intertidal fringe of Whiteness Sands, as shown in Appendix B (Inset E). Crest levels for these features are between -2.7 and -6mCD.

4.1.3 Main Channel

The 2018 bathymetry has revealed the presence of a number of bedforms on the floor of the deep channel to the north of Whiteness Sands. Inset A, Appendix B, highlights the presence of a bedform with two curved limbs extending from the base of the Whiteness Sands subtidal slope, proximal to the north-western subtidal extent of features associated with the Whiteness Head spit. Closer examination of the bathymetry in this area shows a fan shaped deposit at the base of the slope, just under 80m in width, 40m in length, and 1m in height, with some linear disturbance to the slope present above. The bedform is shown in Figure 4.5, and is also visible in 3D renders of the bathymetry (Figure 4.2 to Figure 4.4). It is considered that this bedform represents a feed of sediment from the spit to the south-east, which is then subject to re-distribution on both the flood and ebb tide.

Numerous other bedforms are visible on the main channel floor as shown in Appendix B (Inset E), and Figure 4.1 through to Figure 4.9. These features include dunes, megaripples, sand ribbons, possible landslip deposits and larger scale accumulation. Spatial variation is apparent across the channel floor, Appendix B (Inset E) shows dunes and transverse megaripples towards the western extent of the surveyed data, north-west of Whiteness Sands, with linear features such as ribbons more apparent further to the east. This spatial variation in bedforms

is considered consistent with the variation in current velocities observed in modelling results (see section 3.5.2). As presented in Figure 4.11, linear features are characteristic of higher velocity environments, whilst the presence of dunes further west is consistent with modelled velocities in that area.

Closer investigation of the dunes to the west (Figure 4.7) shows wavelengths of around 40m with heights up to and around 2m. The dune crests are rounded, with stoss slopes to the east and slipface to the west, indicative of westward transport in this location.

To the north of the spit head transverse megaripples are observed on the fringe of the subtidal slope (see Figure 4.8). Investigation of these features shows wavelengths between 15 to 20m, and heights in the order of 0.3m. The crests are sharp, whilst the slopes are more uniform than those observed further west, some show stoss slopes to the east and slipface to the west, indicative of westward transport, however it is considered there is also an eastward current influence on the geometry of these bedforms.

Figure 4.9 shows an extended long-section from west to east along the main channel floor. This reveals a large scale wave like feature with smaller scale dunes superimposed on top. It is considered that this is representative of sand deposits caught between a westward dominant flood current and the strong outgoing ebb current from the Fort George narrows further to the west. The presence of the large sand banks immediately to the north of this channel are considered further evidence for this larger scale process (Kenyon & Cooper, 2005).

Possible landslip deposits are observed to the northern extent of the bathymetry survey, these appear to contain boulder grade material, and slope south-east, extending from the sand bank to the north onto the main channel floor. Figure 4.10 shows a cross-section and long-section through one such deposit, which is around 2m deep, over 100m in length, and up to 80m wide.

4.1.4 Intertidal Whiteness Sands

The intertidal Whiteness Sands is for the most part relatively flat, with small scale ripples dominant, and a general absence of larger scale bedforms. Smaller scale variations in bathymetry are observed towards the northern margin of the sands, associated with ebb tide drainage paths, and around the former dredged channel to the east, associated with ongoing processes of deposition and erosion (see Appendix B). Along the southern coastline small scale depositional features, including a small spit, are present associated with sediment circulation and longshore transport.

4.1.5 Harbour Inlet

As outlined in section 3.3.2 significant recent infill within the harbour inlet has been observed through comparison of recent survey datasets. Inset C & D, Appendix B, highlight the spatial variation of this deposition, and associated migration of the former dredged channel. Deposition is within the north-western half of the harbour inlet, with evidence of dredge excavations (scoops) still apparent towards the south-eastern extent indicating limited recent deposition in this area.

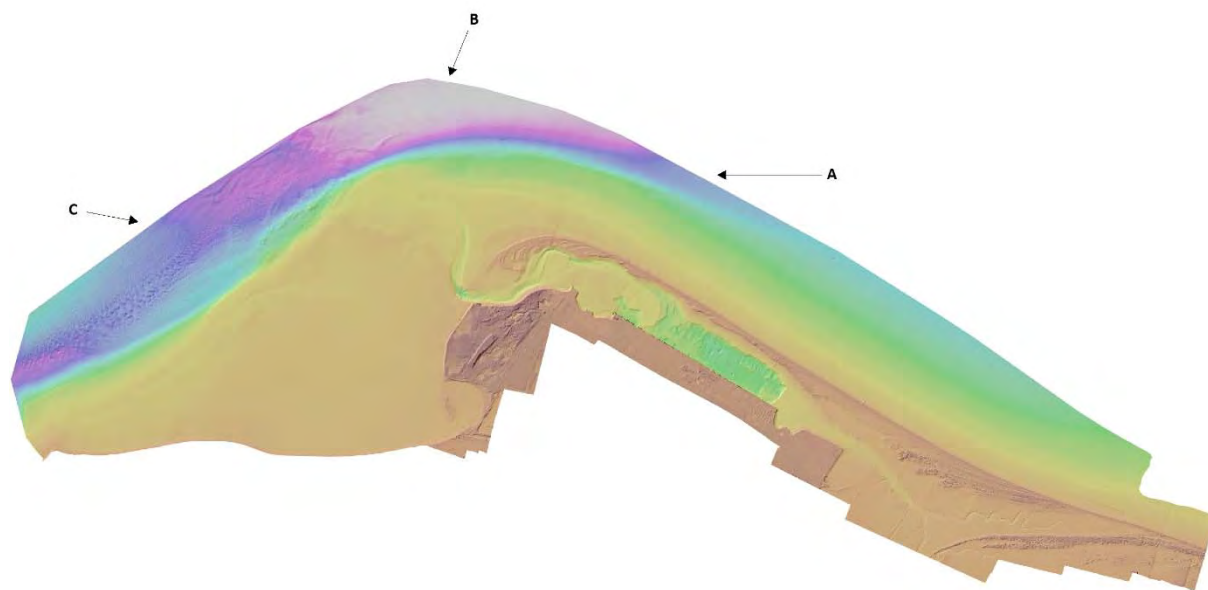


Figure 4.1: Location and Direction of 2018 Bathymetry 3D Render Views

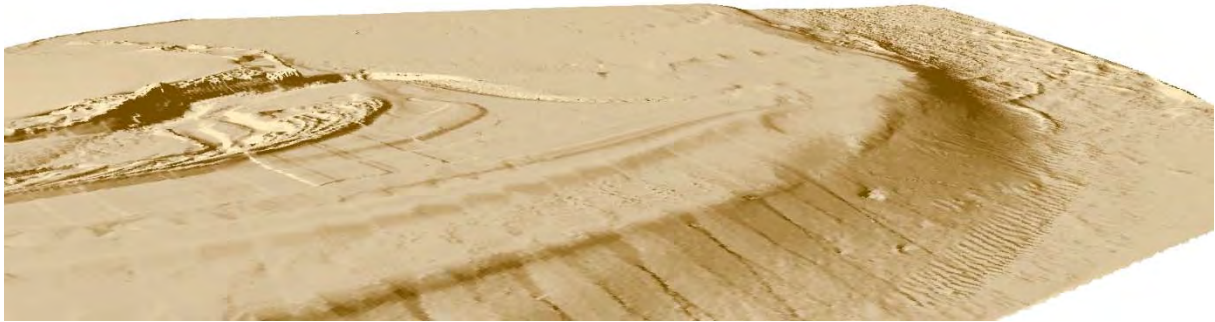


Figure 4.2: 3D Render A - 2018 Bathymetry Looking West Over Spit Head and Channel

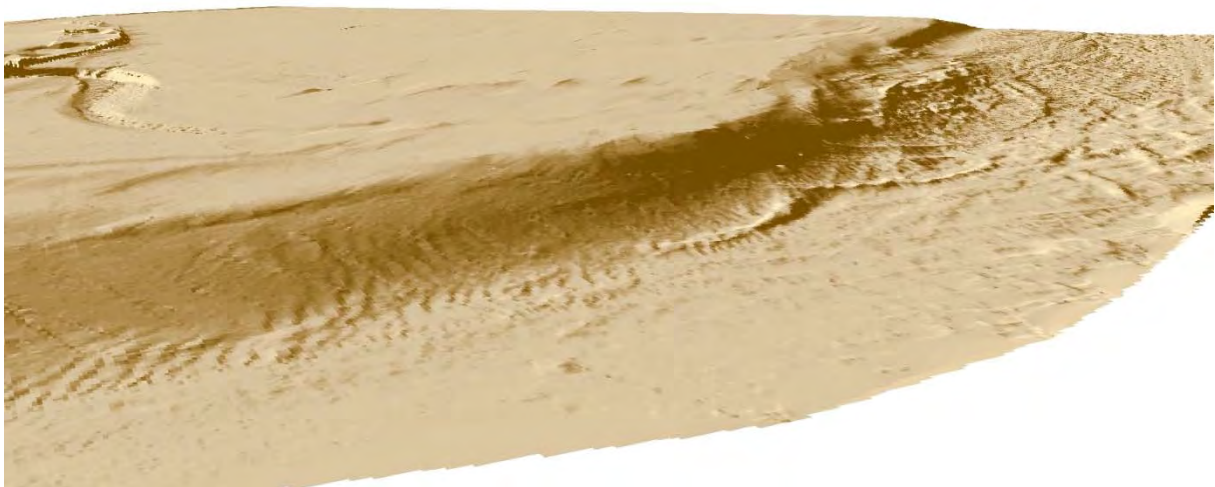


Figure 4.3: 3D Render B - 2018 Bathymetry Looking South-West From Main Channel Over Former dredged channel to Whiteness Sands

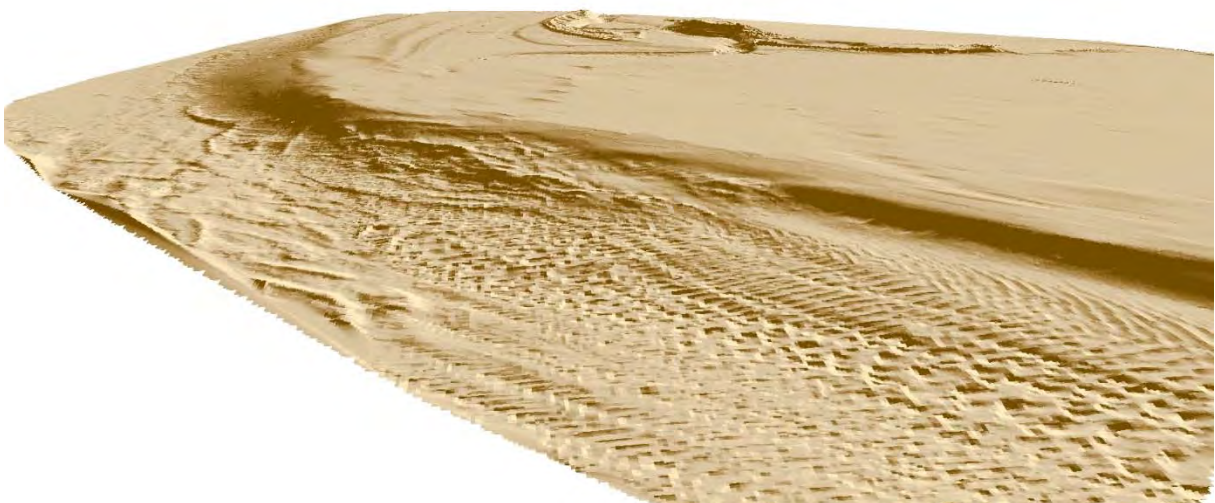


Figure 4.4: 3D Render C - 2018 Bathymetry Looking South-East Across Main Channel to Spit and Tidal Inlet

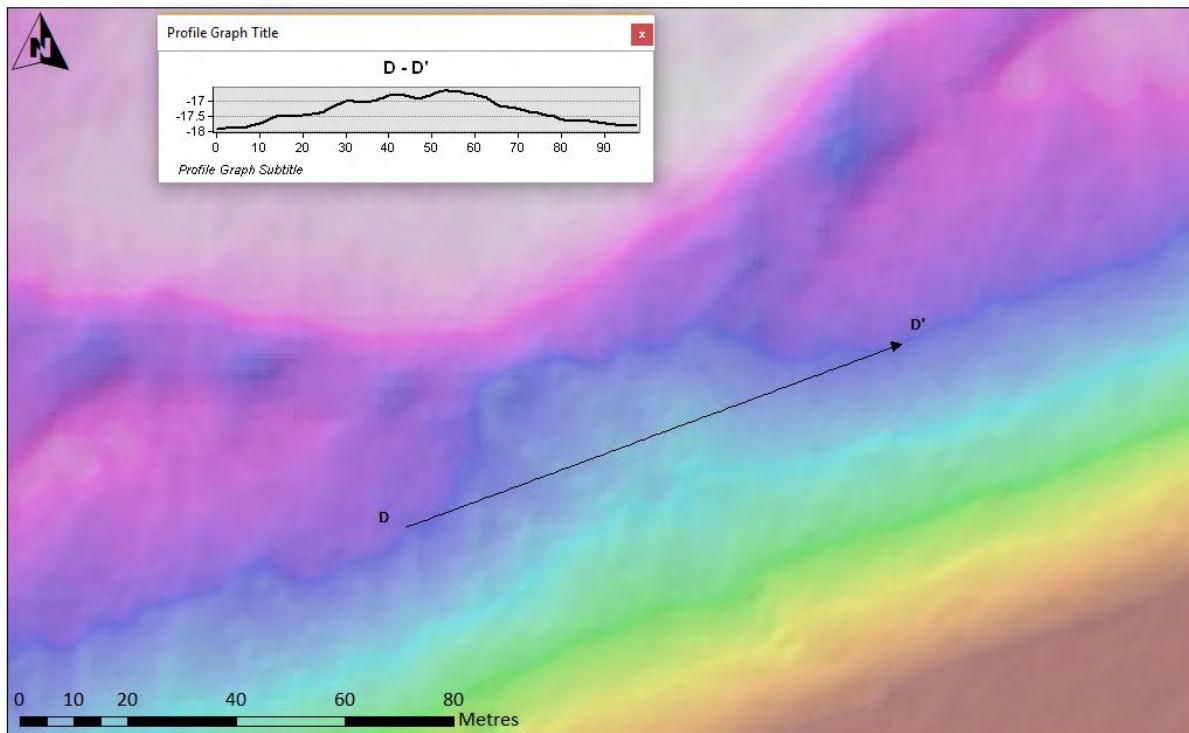


Figure 4.5: 2018 Bathymetry Slope Fan Bedform

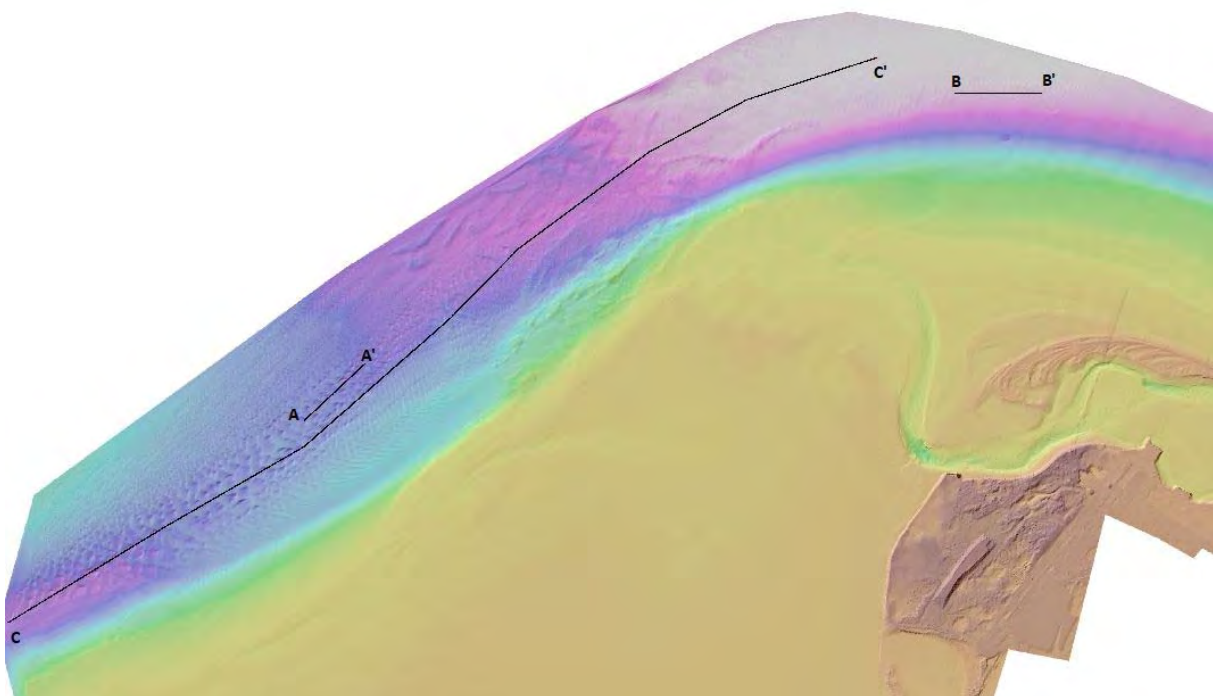


Figure 4.6: 2018 Bathymetry Bedform Long-Section Locations

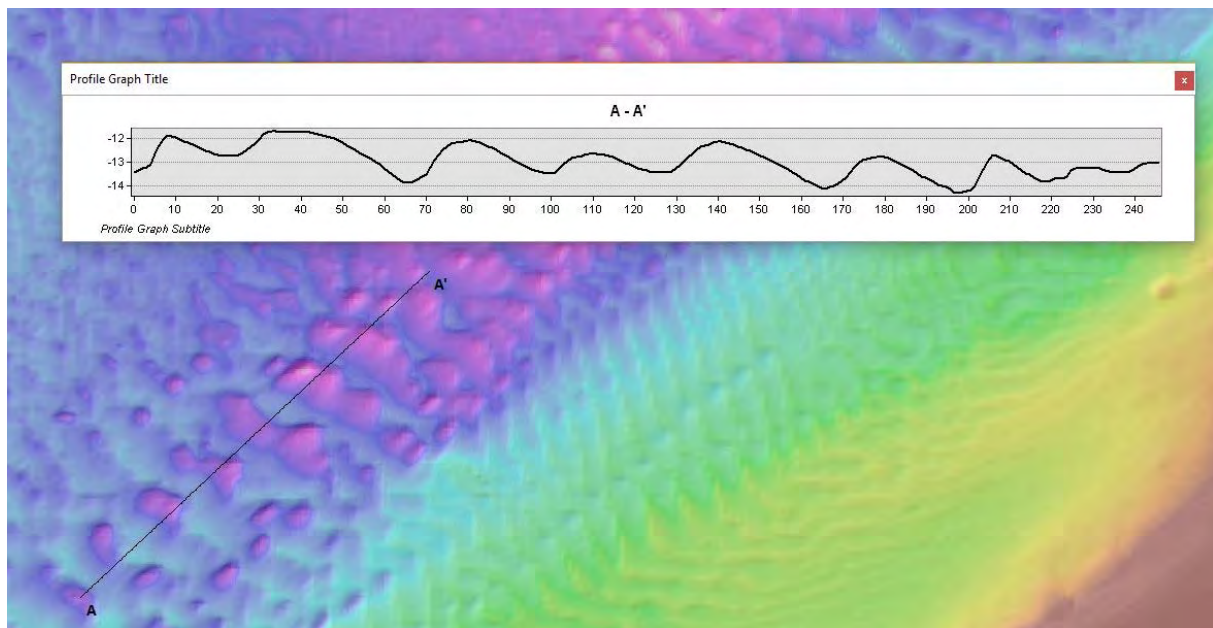


Figure 4.7: Long-Section A-A' of Transverse Dunes Within Main Channel

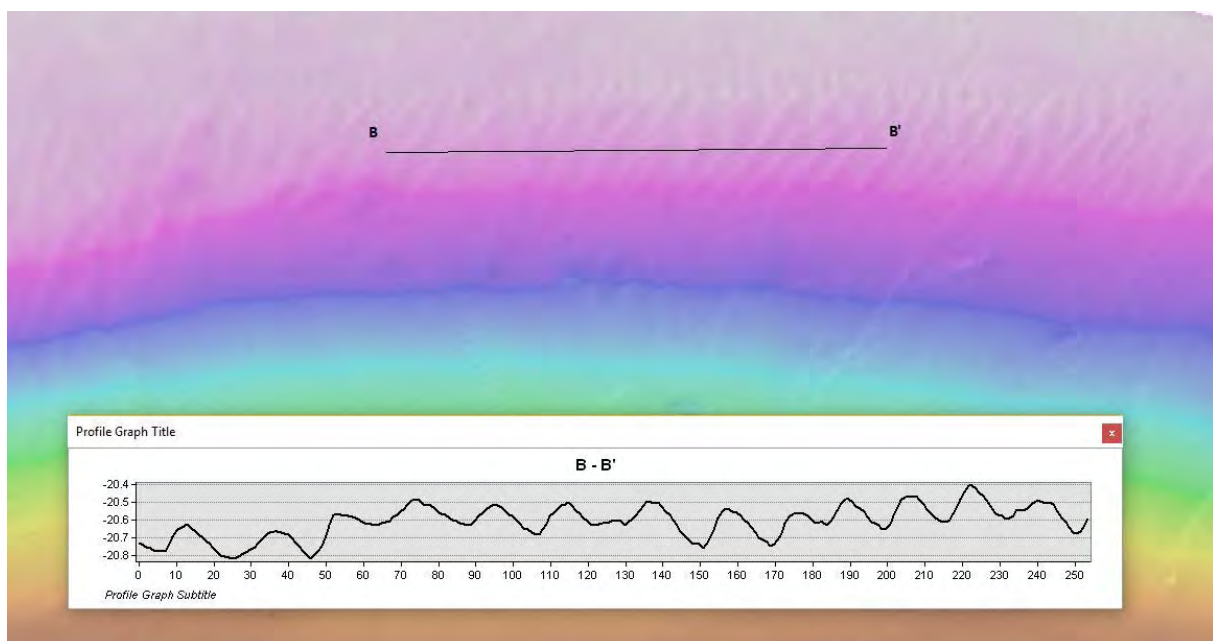


Figure 4.8: Long-Section B-B' of Transverse Megaripples to North of Spit Head

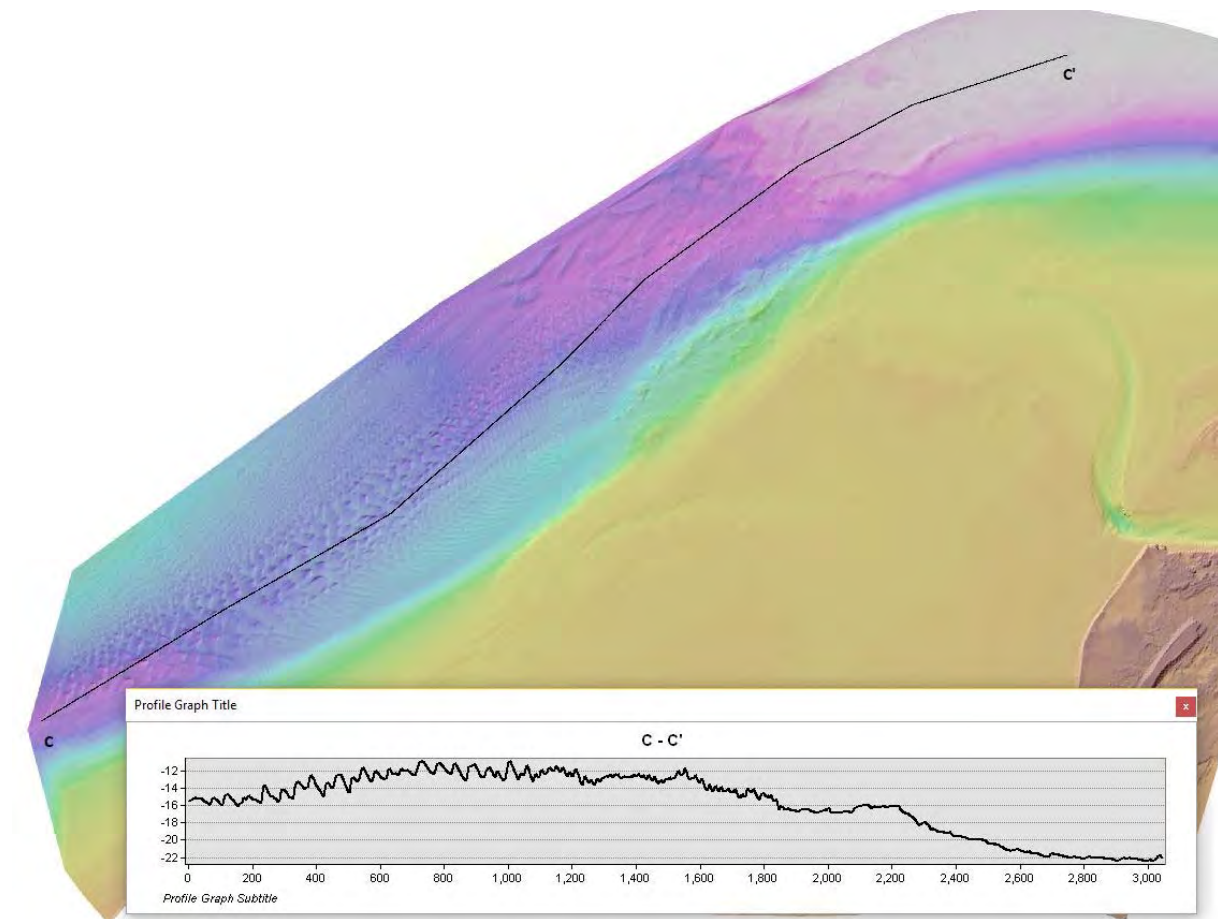


Figure 4.9: Long-Section C-C' Main Channel Large Scale Sand Wave

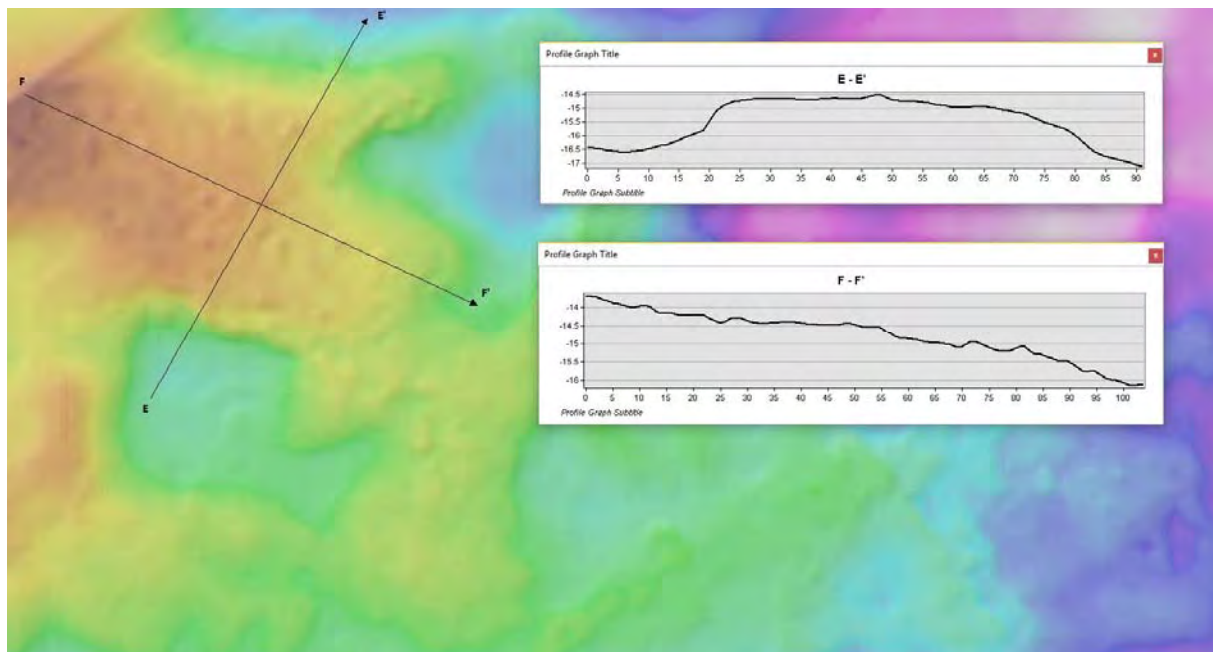
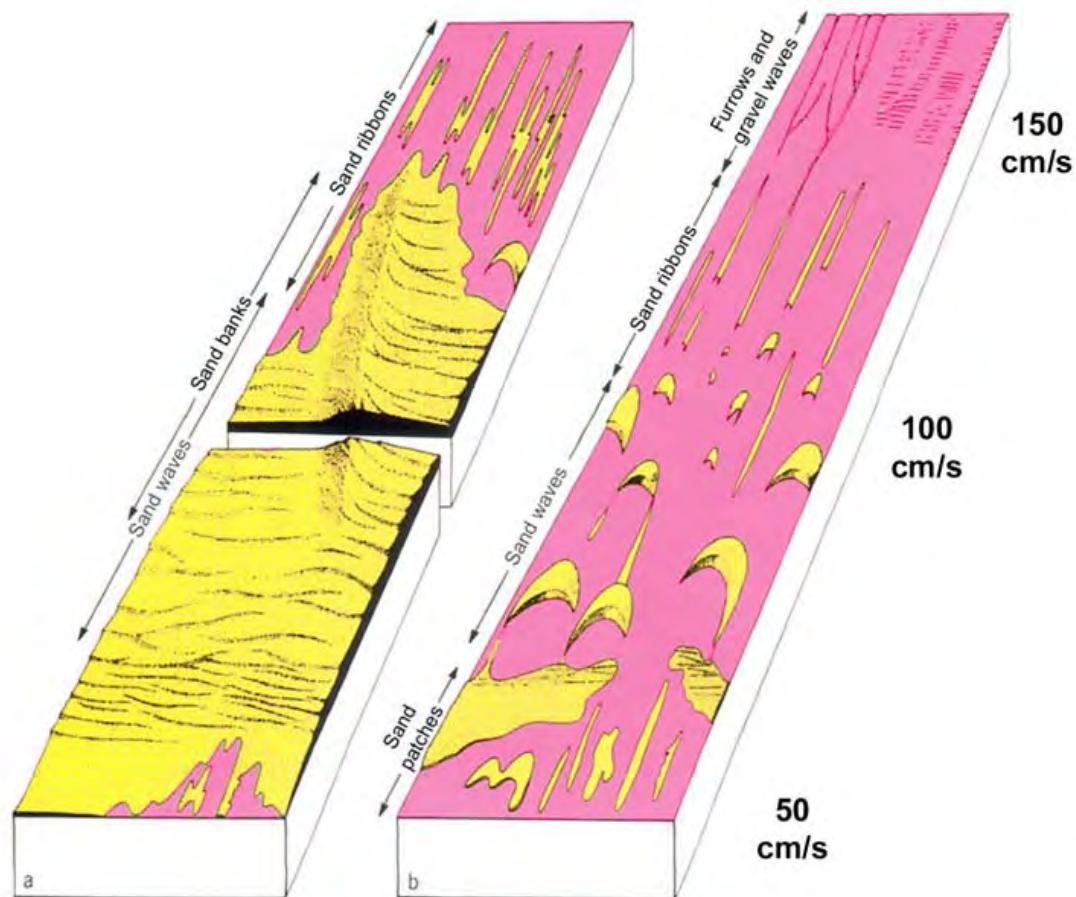


Figure 4.10: Landslip Deposits From Sand Bank to Northern Margin of Main Channel



Belderson et al. 1982

Figure 4.11: Scheme of Tidal Sea Bedform Zones With Sand Supply and Mean Spring Peak Surface Tidal Currents (Belderson, Johnson & Kenyon, 1982)

4.2 Gravel Transport

Gravel forms a key component of the spit. Eroding from ancient deposits exposed on the open coast beach and subtidal areas. Individual clasts move under wave action alone, only in the intertidal area. Residual motion is always westwards and always towards the shore. As a body, this deposit is extending westwards by forming a thin gravel layer over the pre-existing sand deposits that form the bulk of the spit. The steady westward growth over the last century seems to relate to increased release of gravel in areas of up-drift coastal retreat. At its westward (growing) tip, where the underlying sand spit falls away, wave refraction created a southward recurvature of the feature (sand with some shingle), which has moved over the former McDermott base navigation channel zone.

4.3 Sand Transport

To further examine existing sediment transport patterns and pathways, sand transport modelling has been undertaken. The model runs are based simulated hydrodynamic tidal conditions along with Met Office offshore wave data for a period covering January to June 2003. A speed up factor has been included in the sand transport modelling to extend the simulation to an effective 18 month period. This has been used with the present day (2018) bathymetry. The results shown are considered to provide an indication of expected

sediment transport patterns over an extended time period, rather than absolute values. Further details on the modelling approach are provided in Appendix A.

Scenarios have been modelled with sand transport active across the entire model extent (Figure 4.12). To examine sediment transport pathways in more detail around Whiteness Head, scenarios have also been modelled with initial sediment supply limited to around Whiteness Head spit to the east of the former dredge channel (Figure 4.13) and within Whiteness Sands to the west of the former dredge channel (Figure 4.14). The result plots (Figure 4.12 to Figure 4.14) show residual bed level change at the end of the 18 month run period. Further details of the model and run setups are presented in Appendix A.

The results highlight the north-western longshore transport of sand along the eastern face of the spit, driven by wave action and residual flood tidal currents, with the resultant subtidal build out of the spit head to the northwest (Figure 4.12). Examination of sand transport pathways highlights a north-western continuity of transport from the subtidal spit head to the northern subtidal fringe of Whiteness Sands, along with a feed of sand from the intertidal and subtidal spit head north into deeper offshore waters (Figure 4.13). A returning eastwards transport pathway from the northern edge of Whiteness Sands is highlighted further offshore, with an associated feed of material into the former dredged channel (Figure 4.14). An exchange of material between the intertidal and subtidal zones on the eastern face of the spit is observed. The model also shows the ongoing deposition of sand within the tidal inlet.

Towards the northern margin of Whiteness Sands the model runs indicate localised areas of erosion around the MLWS level, with material depositing immediately to the north in the subtidal zone. Across the vast majority of Whiteness Sands, particularly within central areas, the model runs indicate the sands are stable, with no significant movement of sediment observed. Along the southern shoreline of Whiteness Sands a clockwise transport of sand is highlighted, with deposition indicated to the southwestern corner (Figure 4.12 and Figure 4.14).

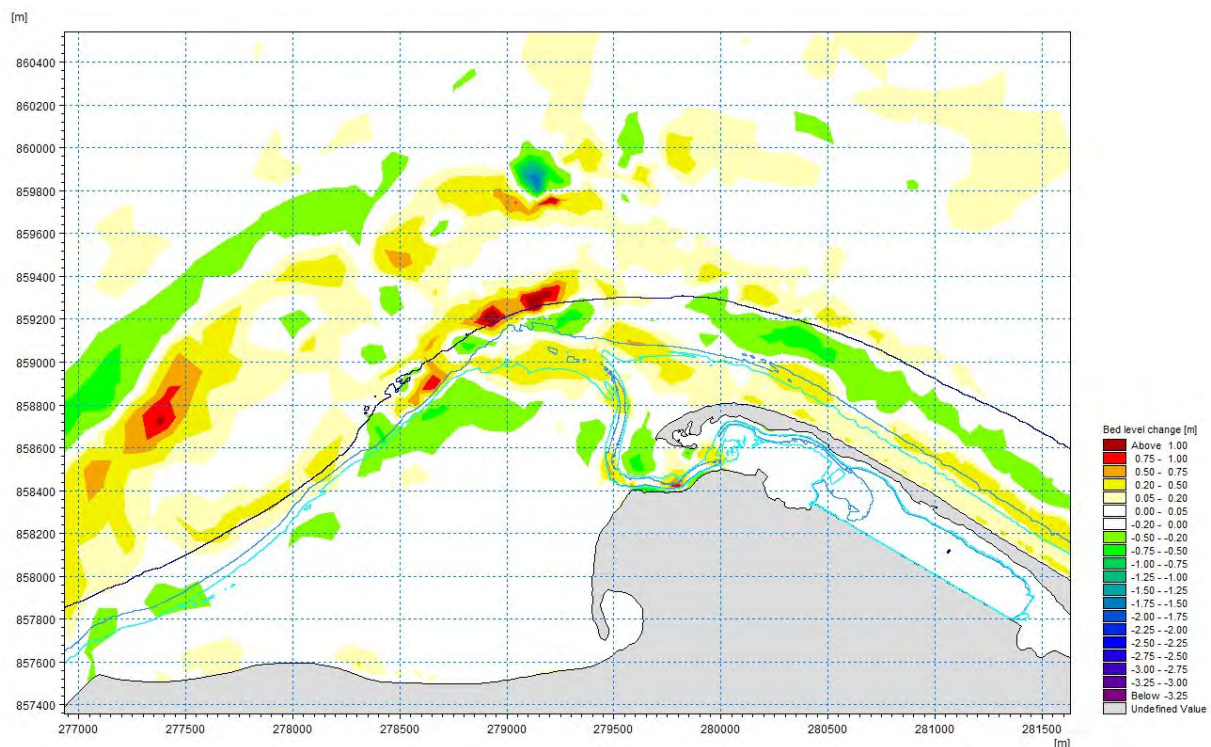


Figure 4.12: 2018 Bathymetry Sand Transport 18 Month Run – Residual Bed Level Change

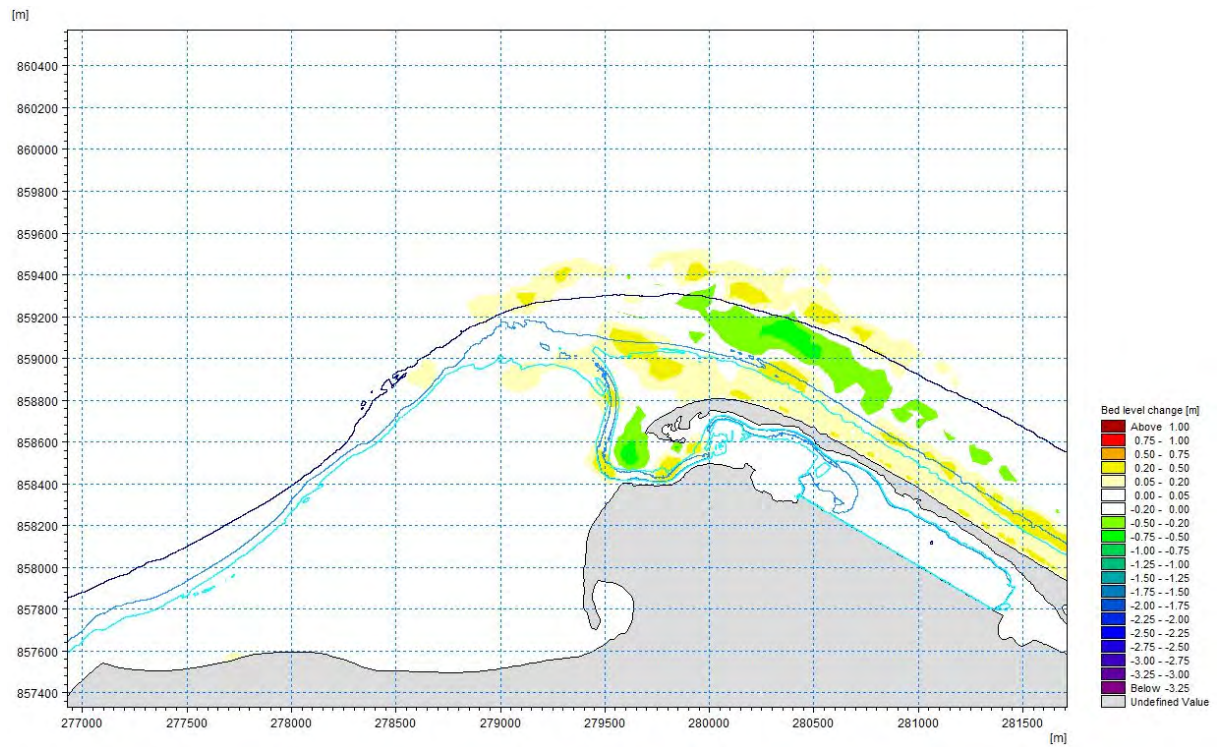


Figure 4.13: 2018 Bathymetry Sand Transport (Spit Only) 18 Month Run – Residual Bed Level Change

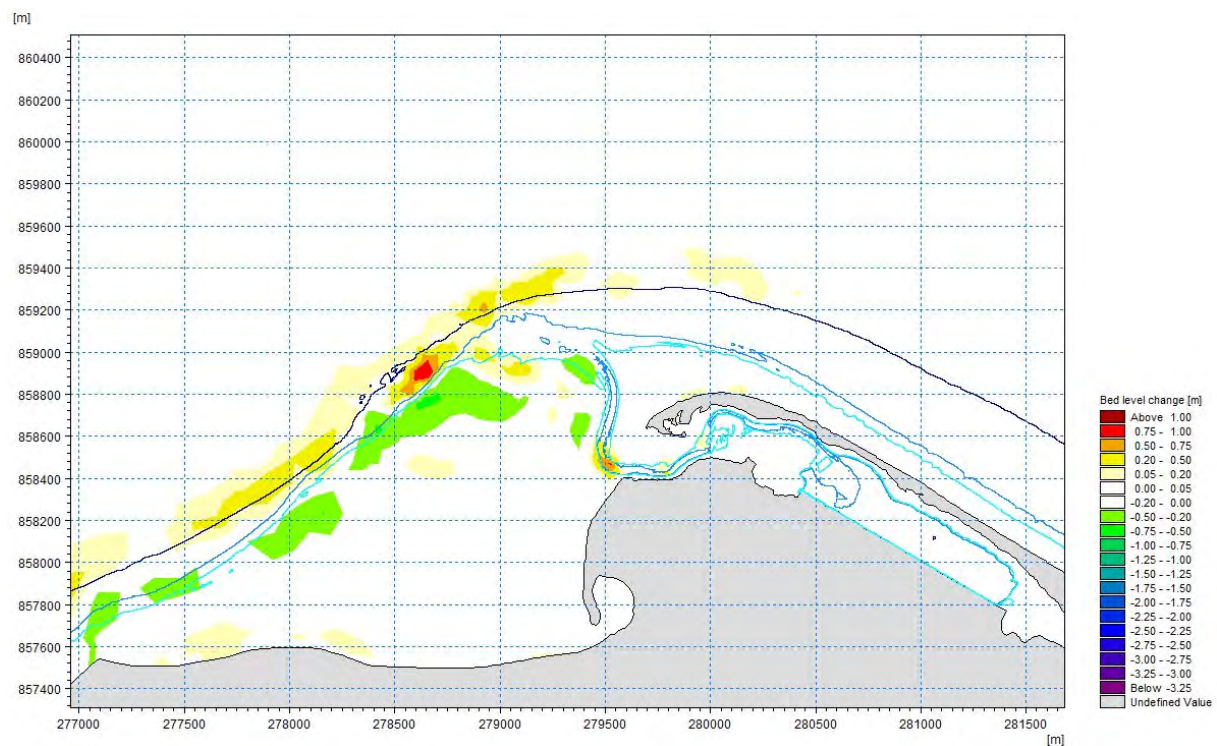


Figure 4.14: 2018 Bathymetry Sand Transport (Sands Only) 18 Month Run – Residual Bed Level Change

4.4 Conceptual Model

A conceptual understanding of sediment transport and coastal morphology within the local coastal system has been developed through review of observed and historic changes, supplemented by hydraulic modelling (Appendix A), and is visualised in Figure 4.15 below.

The conceptual model includes the longshore transport of sand and gravel along the eastern shore of Whiteness Head spit resulting in continued spit extension to the north-west, with recurves to the south-west. A continuity of this north-western transport pathway is highlighted, both offshore to the deeper waters of the main channel, and further west to the north-eastern intertidal and subtidal margin of Whiteness Sands.

The conceptual model includes the offshore movement of sand from the northern margin of Whiteness Sands, and a returning eastern transport pathway further offshore. This eastern pathway is considered to also contribute sediment to the tidal inlet, and the southern coastline of Whiteness Sands. Central areas of Whiteness Sands are considered to be generally stable within the local context of Whiteness Head.

This local coastal system has been subject to modification in the form of dredging for the McDermott Construction Yard from the early 1970's until around 2001. This site history remains an influence on present day processes, particularly on the extent and direction of spit head recurve, and on the volume of water exchanged within the tidal inlet. These have resultant localised impacts on currents and associated sediment transport processes, while the wider scale processes continue uninterrupted.

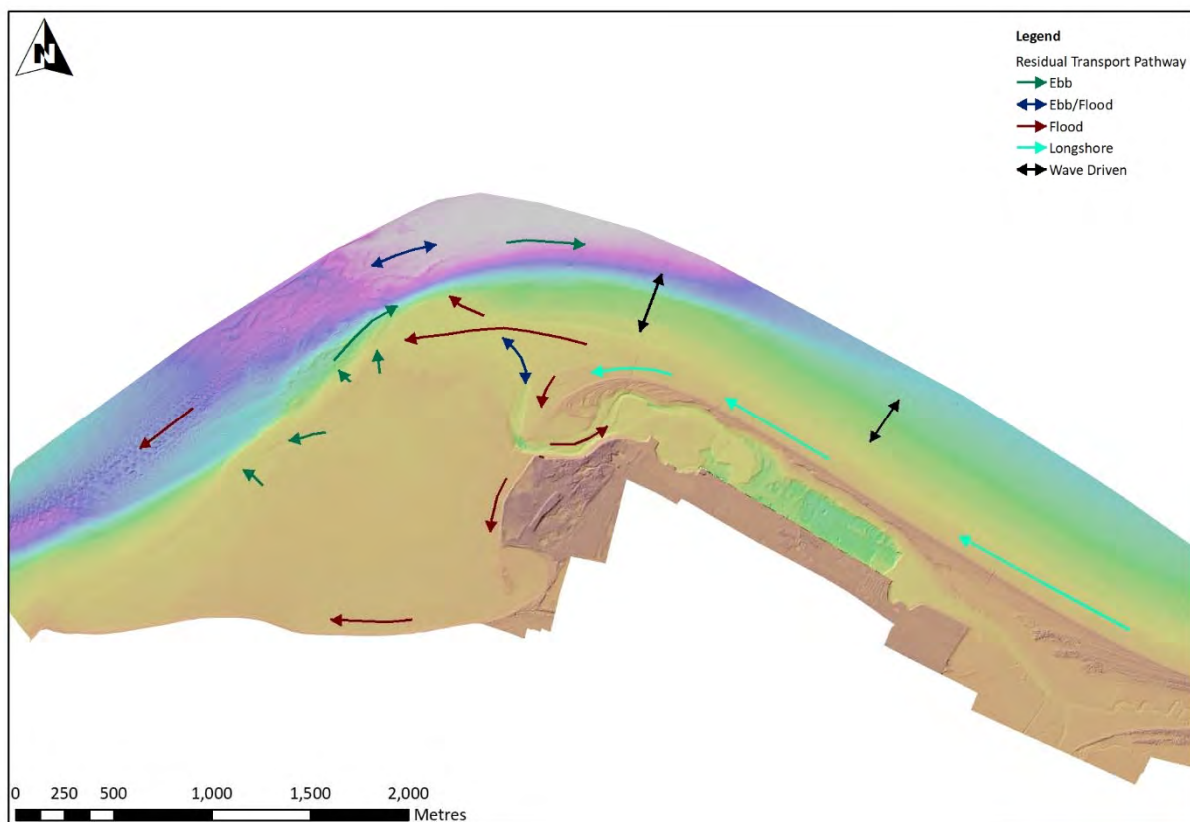


Figure 4.15: Conceptual Model of Sediment Transport Pathways

5 IMPACT ASSESSMENT

5.1 Impact on Coastal Processes

5.1.1 Tides

Details of tidal water levels within the Moray Firth in the vicinity of the site are presented in section 3.5.1. A comparison of the modelling results with and without the proposed development has been undertaken (see Figure 5.1, Figure 5.2 & Figure 5.3). This comparison highlights that there will be no significant impact on tidal levels, except to increase low water tidal range within the dredge zone. This is particularly evident where deposition has occurred, such as the location of comparison in Figure 5.1.

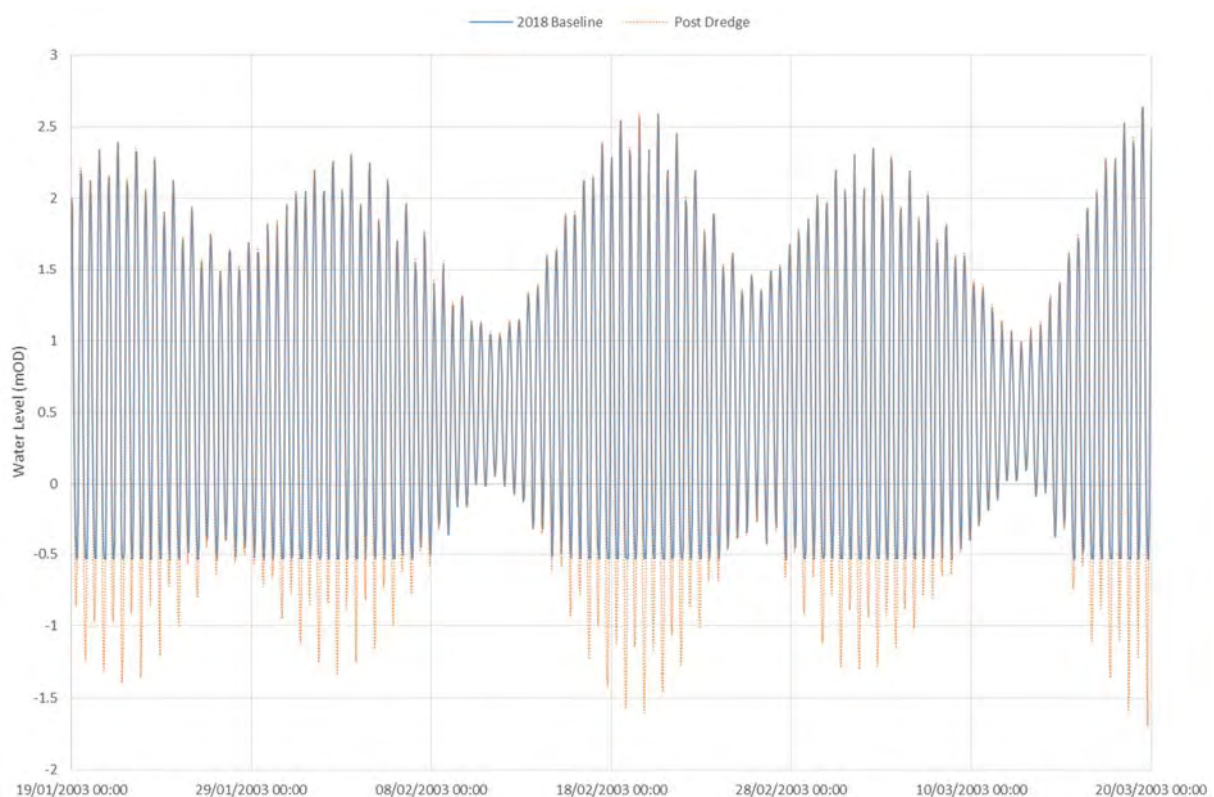


Figure 5.1: Plot Comparison (2 Month Excerpt) of Modelled Tidal Water Levels - Baseline 2018 (Blue) and Post Dredge Conditions (Orange Dash) at Location in Harbour Inlet

Hydrodynamic modelling results allow comparison of both flood and ebb tidal currents during a spring tidal cycle, with and without the proposed development. Comparison of the model results for the mid flood spring tidal currents (Figure 3.15 and Figure 5.4) indicates that there would be localised reductions in tidal velocity (up to 0.5 m/s) within the immediate vicinity of the proposed dredge channel, and within the former dredged channel (up to 0.8 m/s) which will remain in situ post dredge. Further outside the immediate vicinity of the proposed dredge zone, comparison of modelling results indicates there would be no significant impact on tidal velocities during the flood tide. Similarly, on the ebb tide comparison of modelling results (Figure 3.16 and Figure 5.5) indicates reductions in current velocity (up to 0.4 m/s) within, and immediately adjacent to, the dredged channel, and within the former dredged channel (up to 0.6 m/s). Again, outside the immediate vicinity of the proposed dredge zone comparison of modelling results indicates there would be no significant impact on

tidal velocities during the ebb tide. Whilst the modelling results presented above indicate that the proposed development will produce localised changes in current velocities. It is considered that these variations are insignificant in terms of the wider hydrodynamic regime of the Moray Firth, with post development velocities of a similar nature to those observed elsewhere.

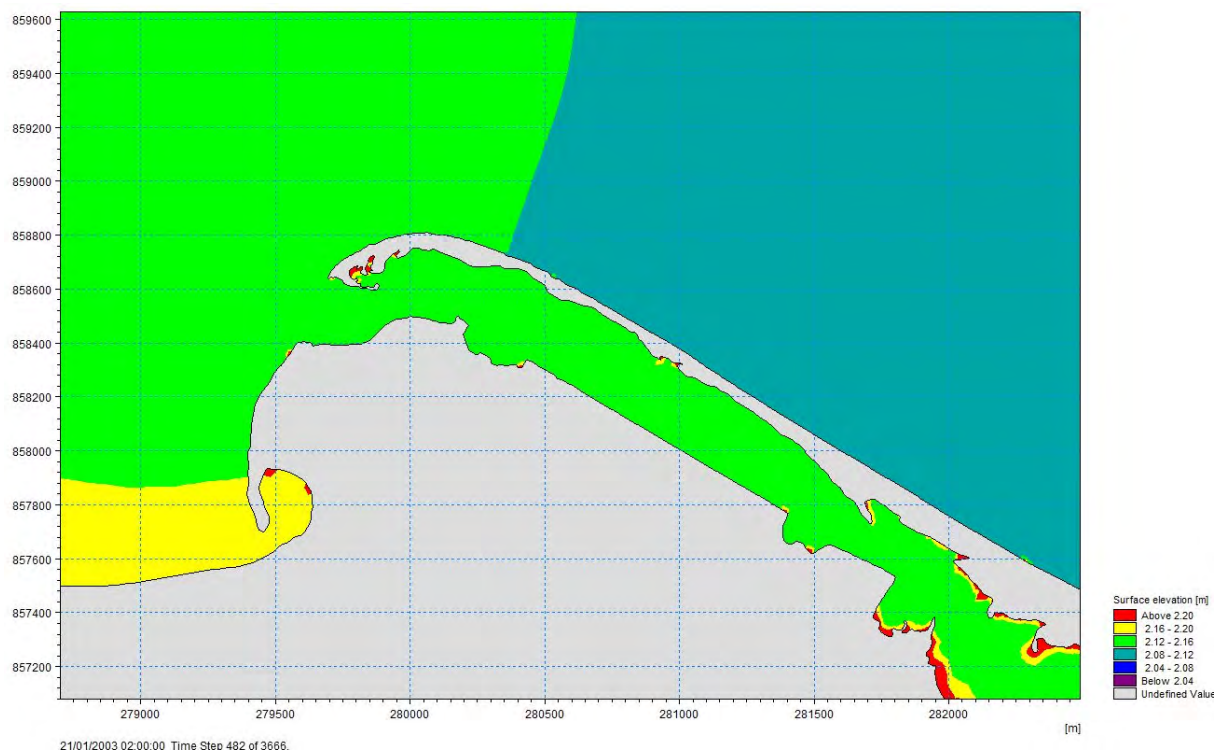


Figure 5.2: Water Level 2018 High Tide Example

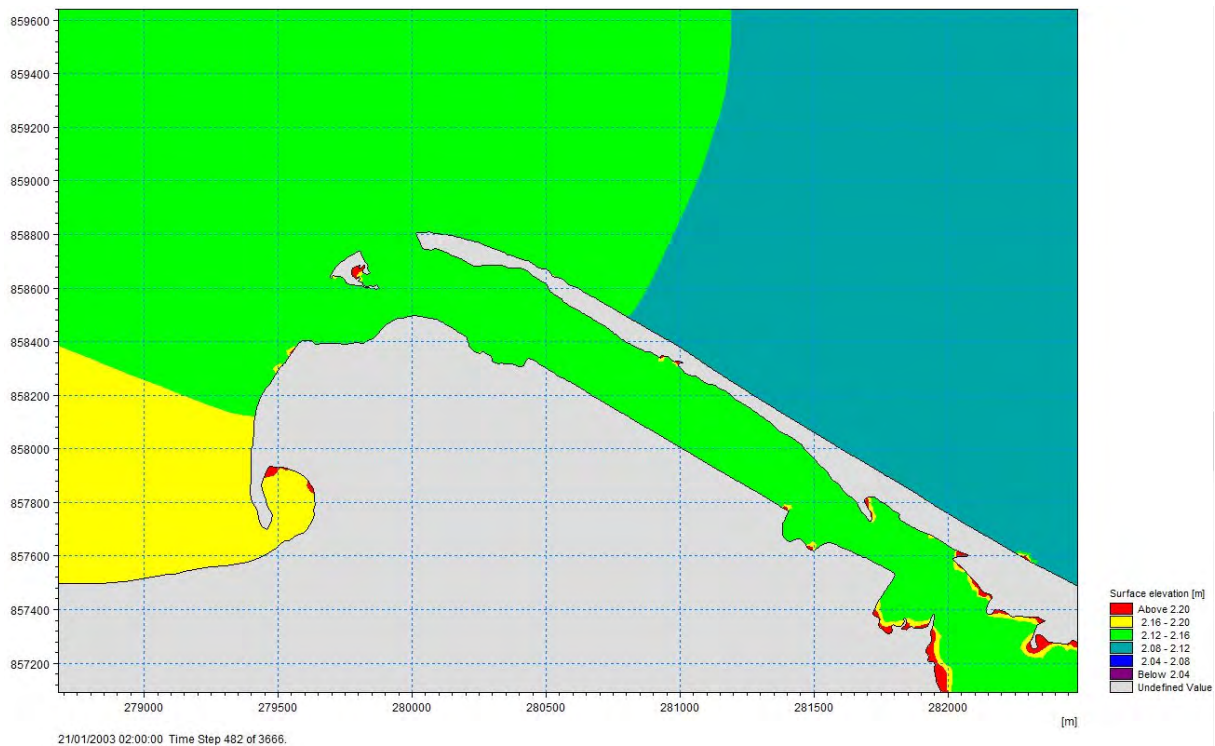


Figure 5.3: Water Level Dredge High Tide Example

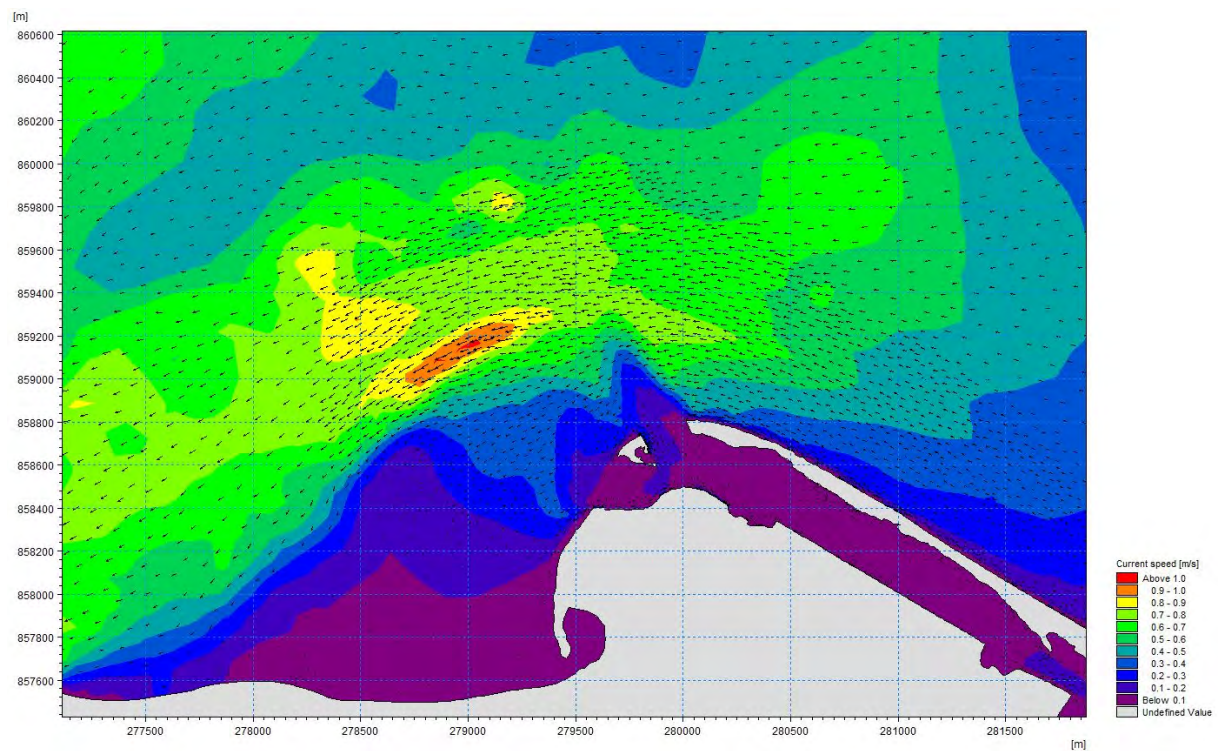


Figure 5.4: Dredge Mid Flood Spring

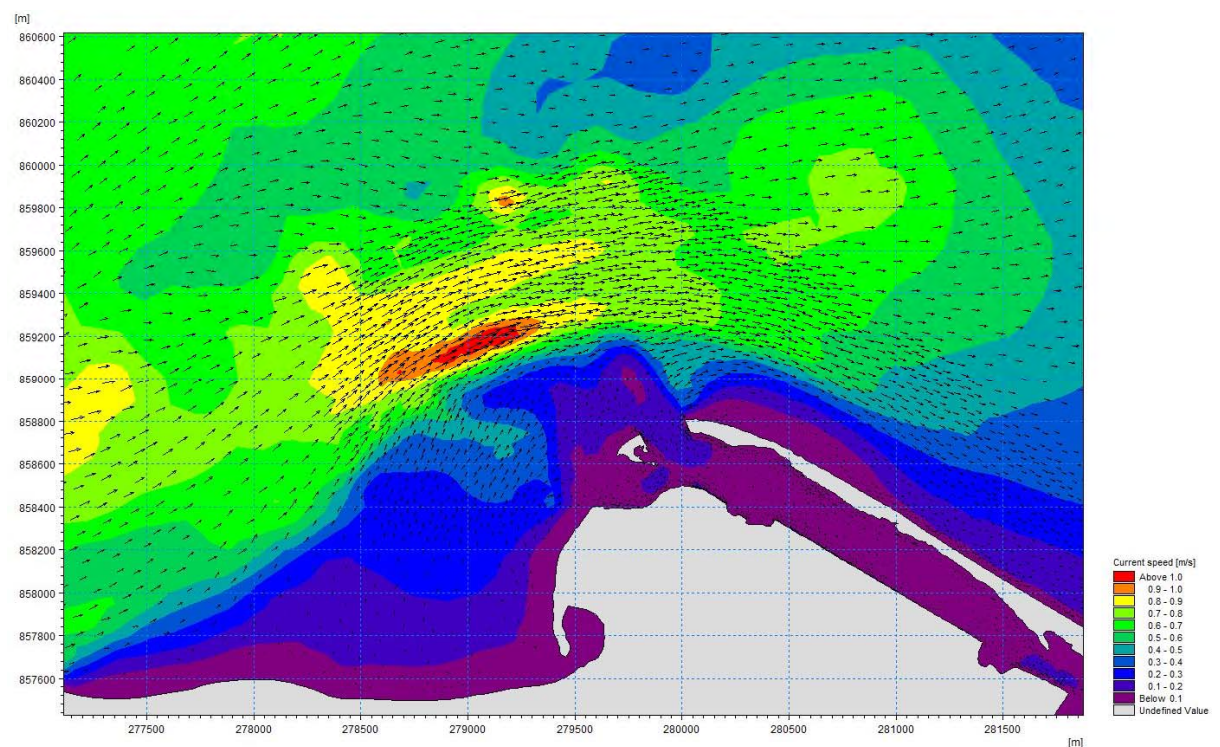


Figure 5.5: Dredge Mid Ebb Spring

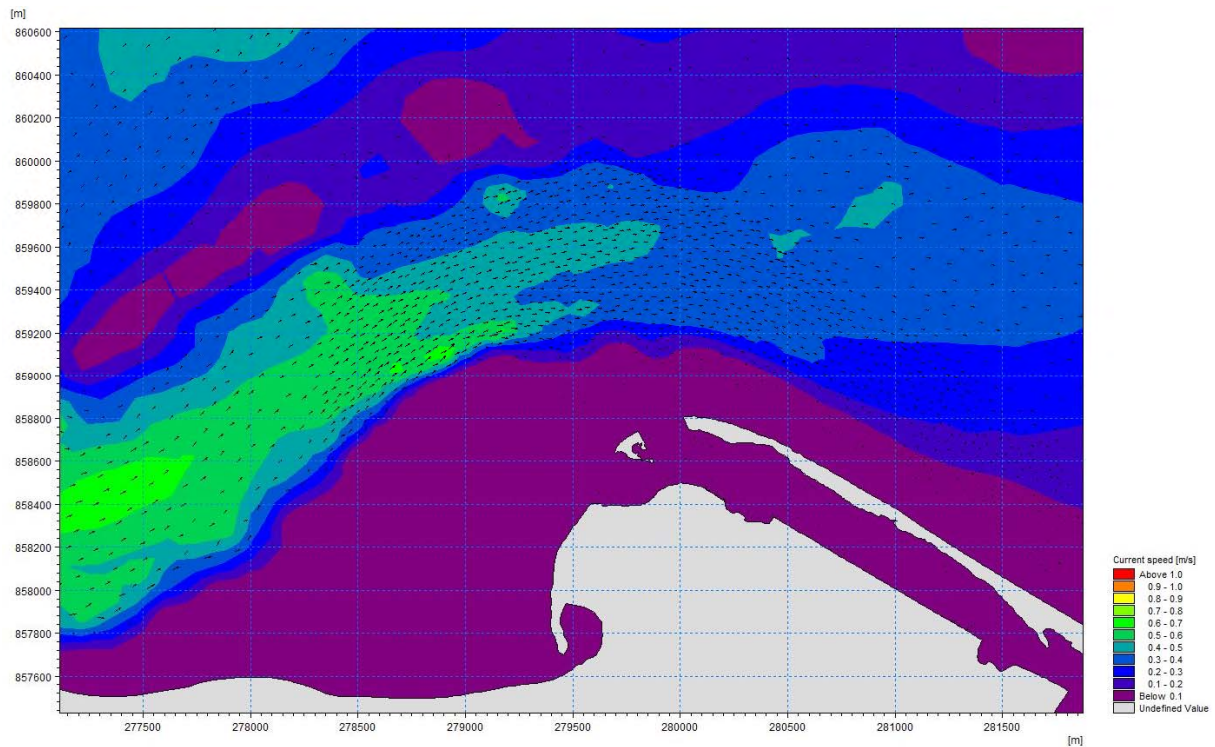


Figure 5.6: Dredge Low Ebb Spring

5.1.2 Waves

As outlined in section 3.6 the proposed development site is most exposed to waves originating from the Outer Moray Firth to the north-east. Modelling results show that during a typical winter period storm from the north-east the proposed development results in a slight increase in significant wave height within the dredge zone and immediate vicinity (Figure 3.23 and Figure 5.7). Following dredging waves would be able to penetrate into the harbour inlet via the navigation channel. Elsewhere, outside the immediate vicinity of the proposed dredge zone the modelling indicates that the proposed development will have no significant impact on wave climate.

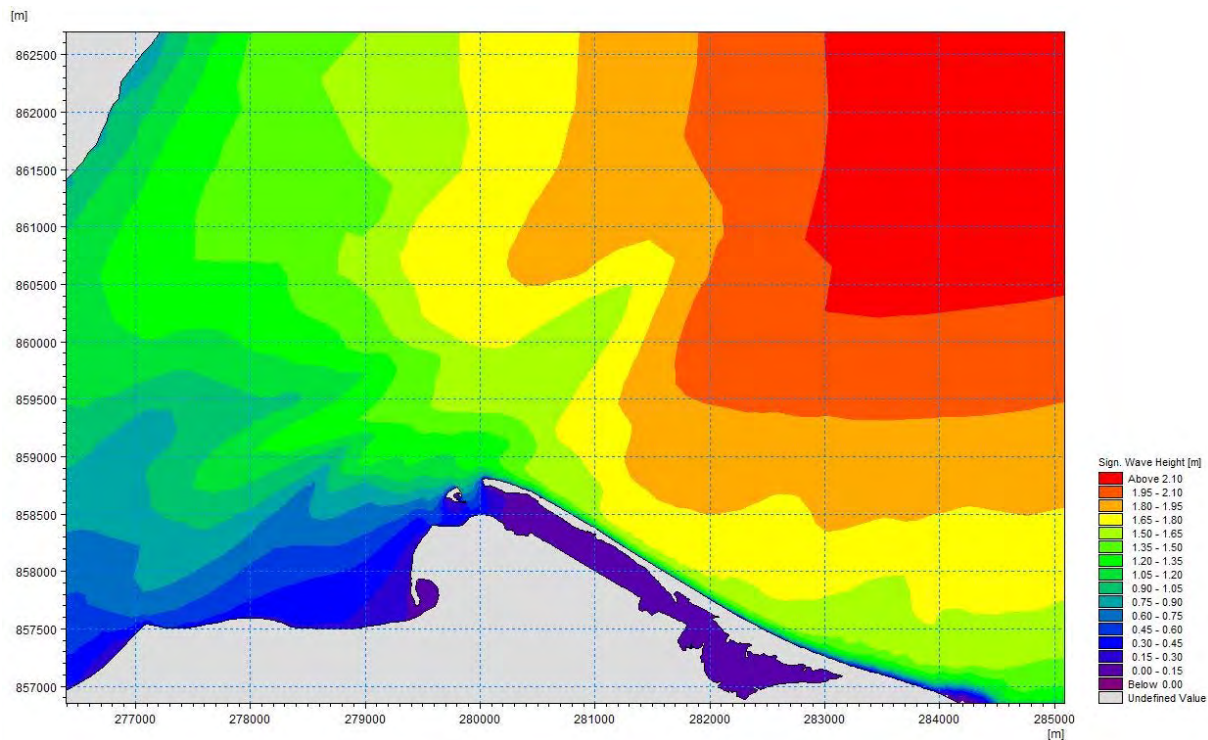


Figure 5.7: Dredge Winter Storm Event

5.1.3 Sand Transport (Coastal Morphology)

Additional model runs have been undertaken to simulate sand transport patterns and pathways following completion of dredging and construction works. Model runs simulating 18 months of sand transport under post-dredge conditions have been carried out, for the whole of the model extent (Figure 5.8), and also looking specifically at transport pathways from the east of the navigation channel (Figure 5.9) and from the west of the navigation channel (Figure 5.10). The result plots (Figure 5.8 to Figure 5.10) show residual bed level change at the end of the 18 month run period. Further details of the model and run setups are presented in Appendix A.

The results of these model runs indicate that the longshore transport of sand along the eastern face of the spit will continue unaffected by the proposed development. The modelling highlights that whilst the north-western intertidal and subtidal build out of the spit will continue to the east of the dredged navigation channel, the channel will act as a trap to the further westward transport of sediment.

To the west of the new channel the model runs indicate that the remaining intertidal and subtidal head of the spit will be subject to ongoing erosion, with sand predominantly being transported further west into the former dredged channel, and across the north-eastern fringe of Whiteness Sands, in line with present day processes. A smaller amount of sand is shown to move east into the new navigation channel immediately to the north of the remaining terrestrial spit head, which will remain as an island post dredging. Further south within the former dredged channel, the post-development lower energy conditions (see section 5.1.1) are predicted to result in increased deposition, particularly to the south-western lee of the remaining terrestrial spit head.

Further west across central parts of Whiteness Sands the model runs show limited movement, consistent with observed data and the conceptual understanding of transport in this area. The model runs indicate that present day processes will continue relatively unaffected by the development across Whiteness Sands. The model highlights the continued easterly subtidal transport pathway from the northern margin of Whiteness Sands, and a circulation of material into the remaining former dredged channel.

Due to the large volume of sediment currently available within the local coastal system, it is considered that the removal of the proposed dredge budget to land will not be significant in terms of the wider system. Observed trends, model results and the conceptual understanding of local sediment transport processes all indicate that potential impacts to sediment transport and coastal morphology will be localised in extent. It is considered that the longshore feed of sediment along the spit will continue, with change limited to the footprint and immediate vicinity of the dredge channel, and the north-eastern fringe of Whiteness Sands.

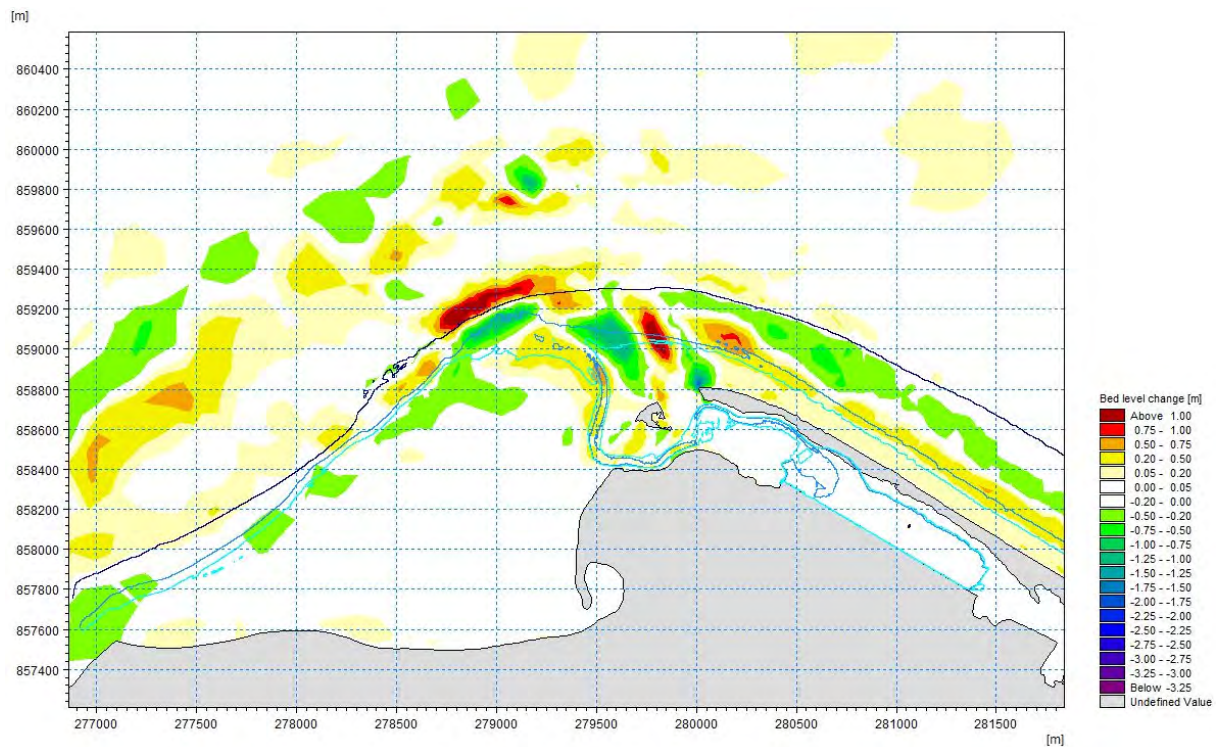


Figure 5.8: Post Dredge Bathymetry Sand Transport 18 Month Run – Residual Bed Level Change

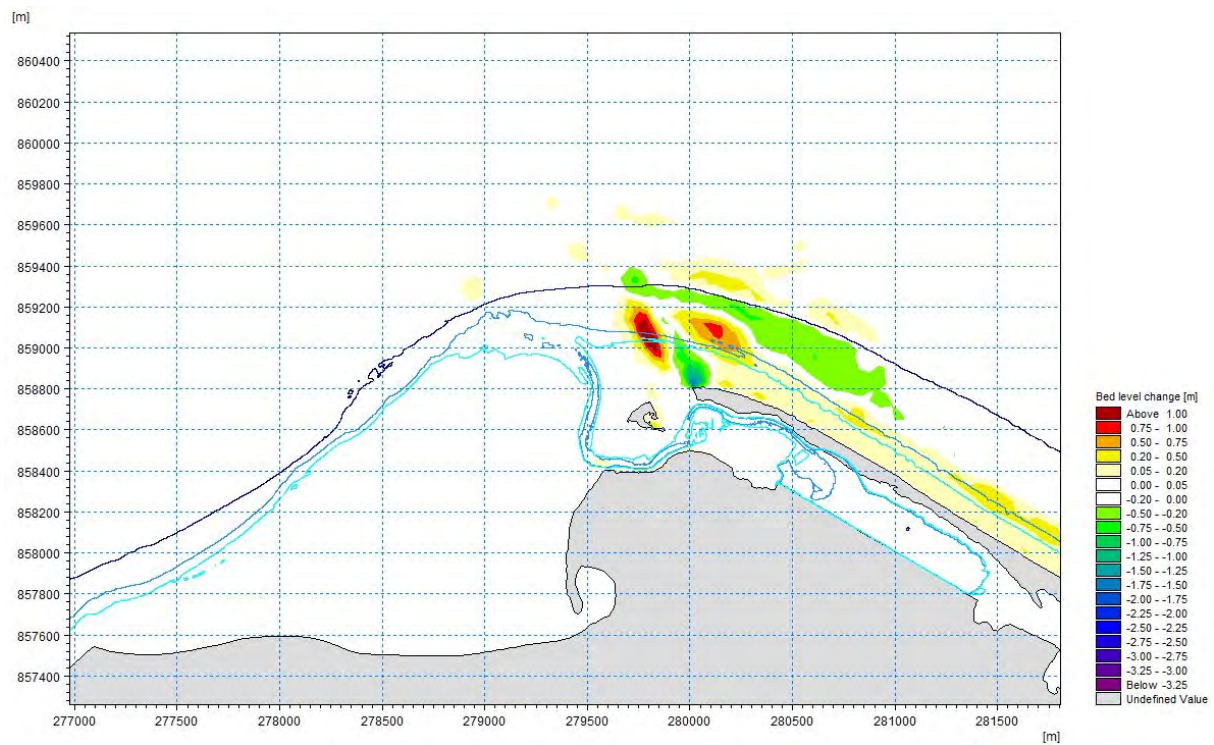


Figure 5.9: Post Dredge Bathymetry Sand Transport (East of Navigation Channel) 18 Month Run – Residual Bed Level Change

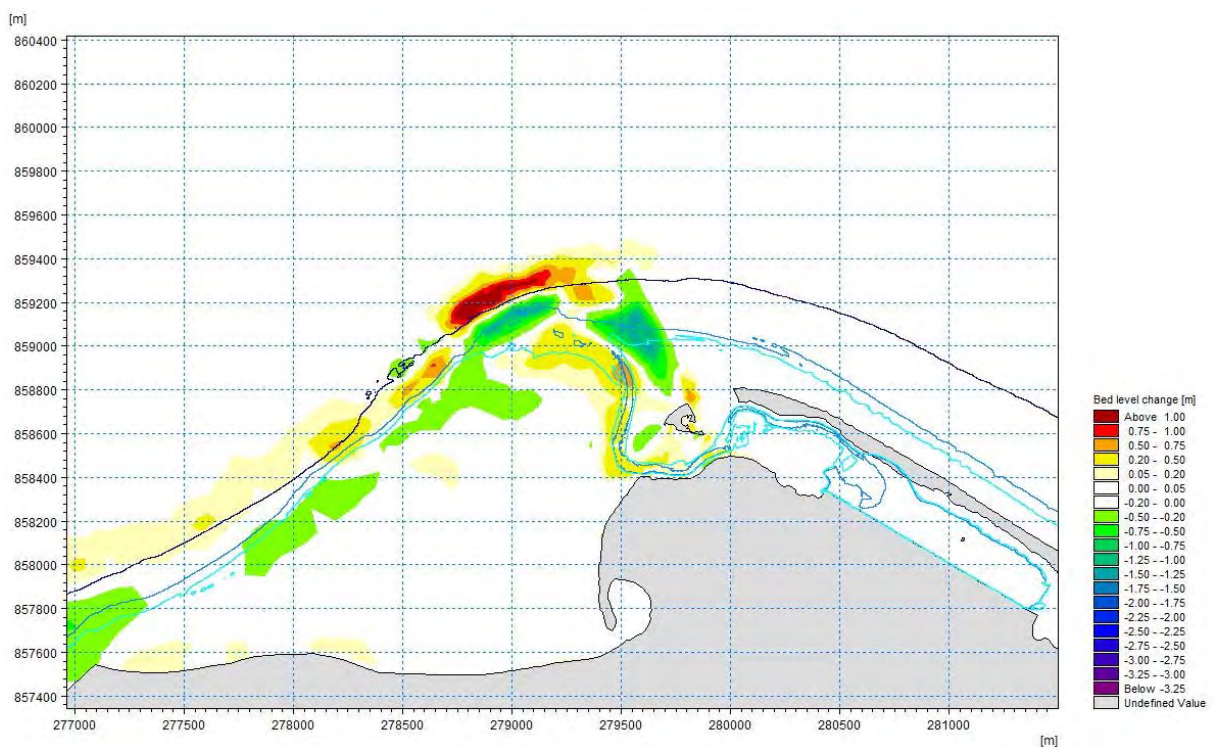


Figure 5.10: Post Dredge Bathymetry Sand Transport (West of Navigation Channel) 18 Month Run – Residual Bed Level Change

5.2 Impact on Designations

The predicted zone of impact to coastal processes from the proposed development in relation to designated sites is identified in Figure 5.11. These impacts relate primarily to the dredging activities to reinstate the navigation channel and harbour. The extents shown are based on the conceptual understanding (section 4) and supported by hydraulic modelling undertaken (Appendix A). Comments in relation to the extent of the impact on the designated sites, and relative proportions of designation impacted, are provided in Table 5.1. The areas of the designated sites potentially impacted are small.

The findings of this assessment are consistent with those of the NCCA report, Cell 3 – Cairnbulg Point to Duncansby Head, for Whiteness Head (Site 34) as presented below.

‘Currently the site has planning permissions for both a new town development (postponed after 2006) and a renewables fabrication yard, which has yet to advance due to the Port of Ardersier going into administration. The past, recent and anticipated changes do not present a risk or threat to the nature conservation designation interest of the site.’ (Hansom et al., 2017)

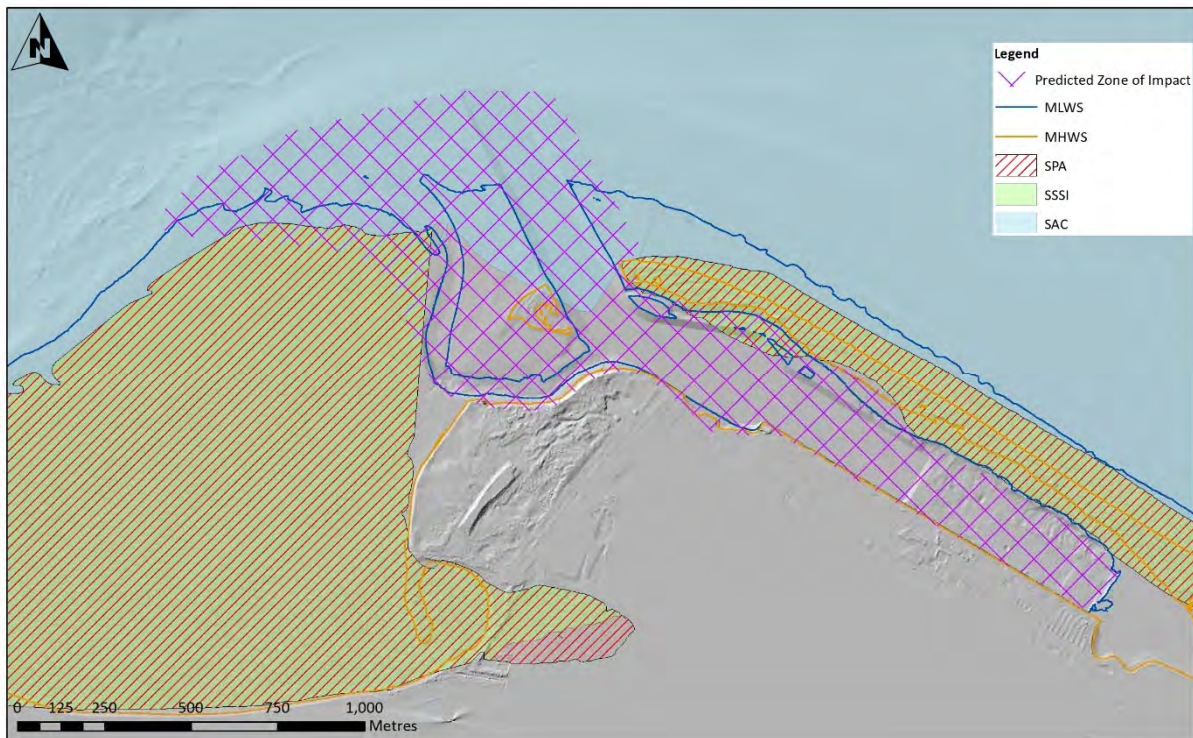


Figure 5.11: Predicted Zone of Impact in Relation to Designated Sites

Table 5.1: Zone of Impact Extents in Relation to Designated Sites

Designated Site	Comment	Area of Site Impacted
Whiteness Head SSSI	Spit: Predominantly outside designated boundary, but includes present spit head and future development area. Sands: Small area limited to north-eastern extent of intertidal sands.	<3%
Inner Moray Firth SPA	Impact zone limited to Whiteness Head and Whiteness Sands. Comments as per SSSI above.	0.1%
Moray Firth SAC	Intertidal and subtidal zone around dredge channel and immediately to the west.	<0.1%

6 MONITORING AND OPERATION

The previous planning consent for the site which is being renewed required that a Sediment Transport Monitoring Plan (STMP) be adopted. This was produced in 2017 in support of a Construction Environmental Management Document for a proposed capital dredge that did not commence. This STMP has been updated and is included as Technical Appendix 11.3 of the EIAR.

This STMP will be adopted to provide relevant information on sediment transport, erosion and deposition within the area of Whiteness Spit, Whiteness Sands and Ardersier Port, to inform future maintenance dredge works. The objectives of this plan are to:

- Define the scope of the type and frequency of monitoring that will be undertaken;
- Define areas that will be monitored to assess sediment transport;
- Collect data to compare with modelling predictions for dredged material deposited at the spoil ground;
- Provide data for analysis or modelling to design future maintenance dredge operations; and
- Inform the Natural Heritage Management Plan (EIAR Technical Appendix 7.7).

Monitoring of the coastal processes is important in an area with a dynamic coastline and it is important to ensure that this monitoring informs decision making in the event that baseline conditions change from those previously assessed. Local conditions can be affected over relatively short timescales due to storm events, weather patterns, dredging and disposal of dredge arisings. This monitoring is fundamental in relation to informing future maintenance dredge operations and monitoring the condition of designated habitats.

The coastal model has been used on a high level basis at this stage to examine the potential fate of possible future maintenance dredge disposal options at sea. This has looked at possible disposal at the licenced spoil ground on Whiteness Sands below the -5mCD contour and offshore towards the landward end of the spit. The findings indicate that the spoil ground at Whiteness Sands would result in material remaining within the deeper channel with some being reworked back towards the spit, and potential for a residual feed to the southern margin of Whiteness Sands (Figure 6.1), while material deposited to the east of the navigation channel would move westwards back towards the channel. This type of assessment would be examined in greater detail along with updated information from the STMP prior to any future maintenance dredge activities to ensure the most appropriate disposal route is adopted.

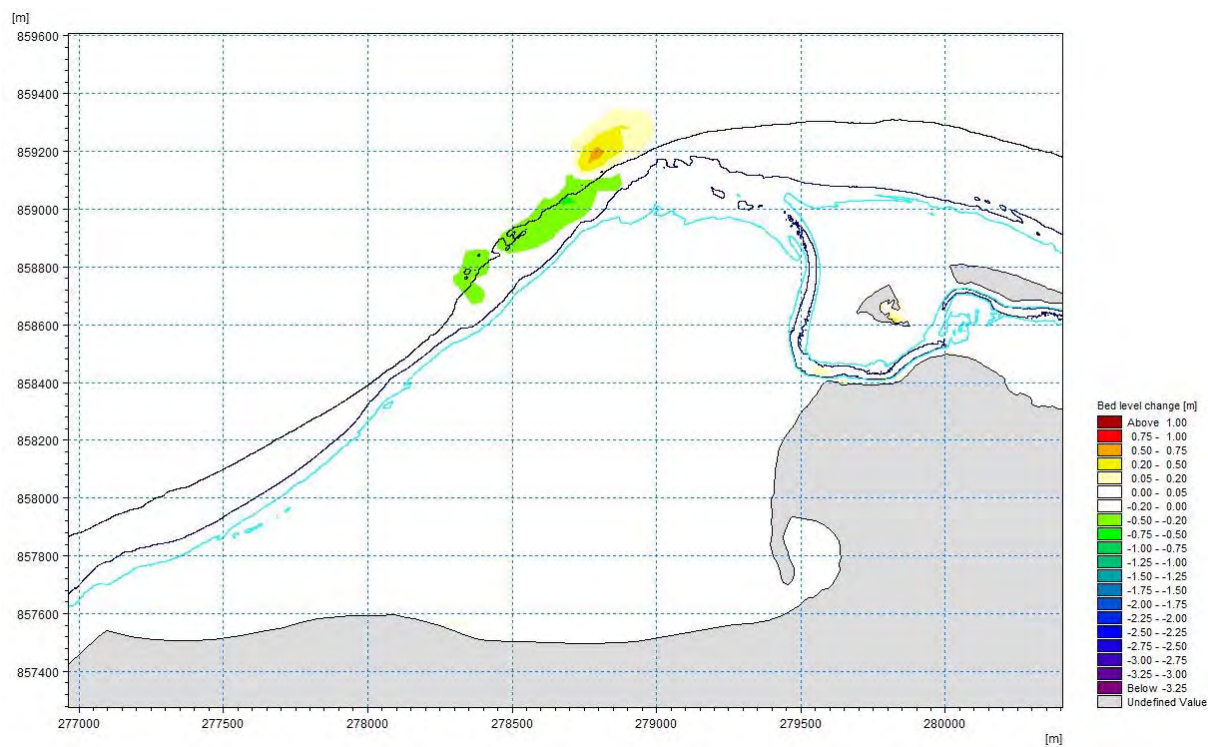


Figure 6.1: Modelled Dispersal of Indicative Maintenance Dredge Spoil From Below -5mCD Disposal Ground (18 Months)

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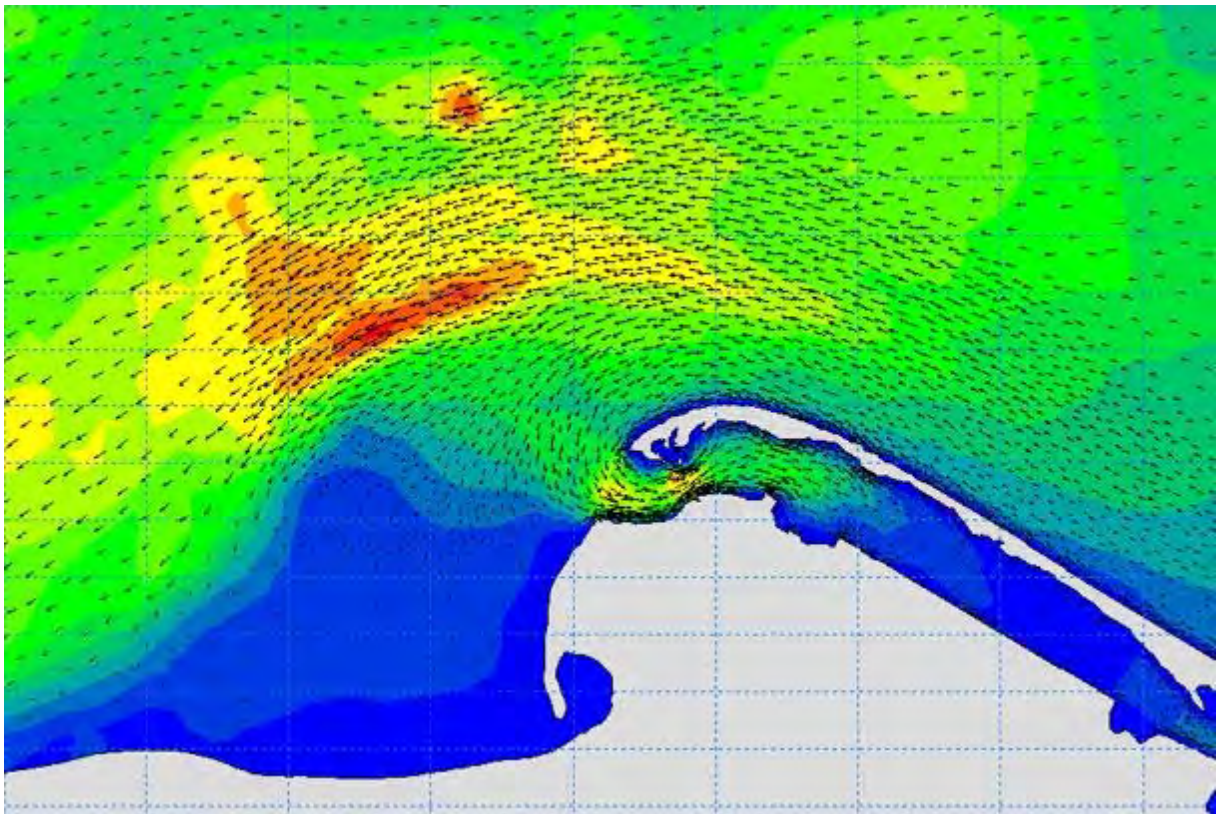
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APPENDICES

A COASTAL MODELLING REPORT



**Ardersier Port Ltd.
Coastal Modelling Report**



September 2018

Ardersier Port Ltd.

Coastal Modelling Report

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1 INTRODUCTION

1.1 Terms of Reference

Ardersier Port Ltd. have appointed EnviroCentre to undertake computational modelling of the hydraulic regime, wave climate and sediment transport processes within the vicinity of the proposed harbour redevelopment at Whiteness Head, Ardersier.

1.2 Scope of Report

A previously developed coastal model will be updated and refined in resolution around the site, including the use of high resolution 2018 bathymetry. The model will simulate the main physical processes in the vicinity of the proposed development site, including tidal currents, wave action and sediment transport. One of the key aims of the modelling being to further examine sediment transport pathways and connectivity, and the associated evolution of Whiteness Head.

1.3 Previous Modelling Studies

A coastal model for the site at Whiteness Head was originally developed in 2008 and this was subsequently revisited in 2013. Details of the development and use of this model at these times are contained within the studies below:

- Whiteness Coastal Investigation and Flooding Update, April 2008. EnviroCentre Report No 3102 to Whiteness Property Company Ltd.
- Port of Ardersier: Whiteness Head Coastal Assessment, May 2013. EnviroCentre Report No 5474 to Port of Ardersier.

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2 COASTAL MODEL SETUP

2.1 Software & Computing

The industry standard MIKE 21 coastal process modelling package (MIKE 21 Flow Model FM), developed by the Danish Hydraulic Institute (DHI), has been used to create a coastal model of the Moray Firth. The Flexible Mesh function incorporated within Mike21 allows maximum flexibility for tailoring grid resolution within the model. The model uses the following modules from within the MIKE 21 Flow Model FM package:

- Hydrodynamic Module (HD) – The HD module simulates water levels and flows in response to a variety of forcing functions;
- Spectral Wave (SW) – The SW module is a 3rd generation spectral wind-wave model based on an unstructured mesh. The model simulates the growth, decay and transformation of wind generated waves and swell in offshore and coastal areas;
- Sand Transport (ST) – The ST module simulates erosion, transport and deposition of sand under the action of currents and waves or pure current.

Further information on the MIKE 21 software package, and the individual modules described above, is available from DHI (mikepoweredbydhi.com).

The modelling described within this report has been undertaken with the following computing specification:

- Dell Precision 5820 Tower:
 - 64GB RAM;
 - 14 Cores - Intel Xeon CPU (2.5GHz).
- Windows 10 Pro 64-bit operating system.

2.2 Input Data

2.2.1 Bathymetric Survey

The following bathymetric survey data has been used within the model setup:

- Bathymetric survey covering the spit, immediate vicinity and Whiteness Sands, undertaken by Aspect Surveys in May 2018. The survey was undertaken using varying methods and equipment dependent on physical and logistical constraints. The bathymetric survey component was undertaken by boat mounted multibeam sonar system, the spit and immediate surrounds were surveyed using an Unmanned Aerial Vehicle (UAV) aerial mapping system, whilst the intertidal area of Whiteness Sands was surveyed by means of a quadbike mounted Real Time Kinetic Global Positioning System (RTK GPS) system. Full details of the 2018 survey are presented in Technical Appendix 11.1 of the EIAR;
- Bathymetric survey covering the spit and former dredge channel, undertaken by Clydeside Surveys in 2012; and
- Electronic bathymetry data supplied by C-Map and DHI to cover the remainder of the Moray Firth.

2.2.2 Water Levels

The coastal model has been setup using the following water level data sources:

- Daily 15-minutes interval observed tidal records for the McDermott fabrication yard (NH 8043 5834) from the British Oceanographic Data Centre (BODC) from 1994 – 2004 (within present site boundary); and
- UK Admiralty Tide Tables (UKHO, 2018).

2.2.3 Met Office Data

UK Meteorological Office wind and wave data for the Moray Firth at 57.7°N, 3.75°W at a 12 km grid from their 2nd Generation UK Waters Wave Model for the period March 2000 to March 2007 forms an input to the coastal model. The Met Office model data is provided at 3 hour intervals, with the wave data containing the significant wave height (average height of the largest 1/3 of waves from an averaging period of 15-20 minutes every 3 hours), and the wind data from an averaging period of 10 minutes. The primary references published regarding the model are provided in (Golding, 1983), (Holt, 1994), and (Stratton, Holt & Kelsall, 1995), and these should be referred to for further information.

2.3 Model Extent

The coastal model extent covers a large portion of the Inner Moray Firth, extending from the Beaully Firth in the west, to Balintore & Findhorn in the east, including the Cromarty Firth as shown in Figure 2.1. This extent is similar to previous phases of modelling undertaken in relation to Whiteness Head, however the coastline detail, bathymetry and model mesh has been considerably refined for this latest phase of modelling.

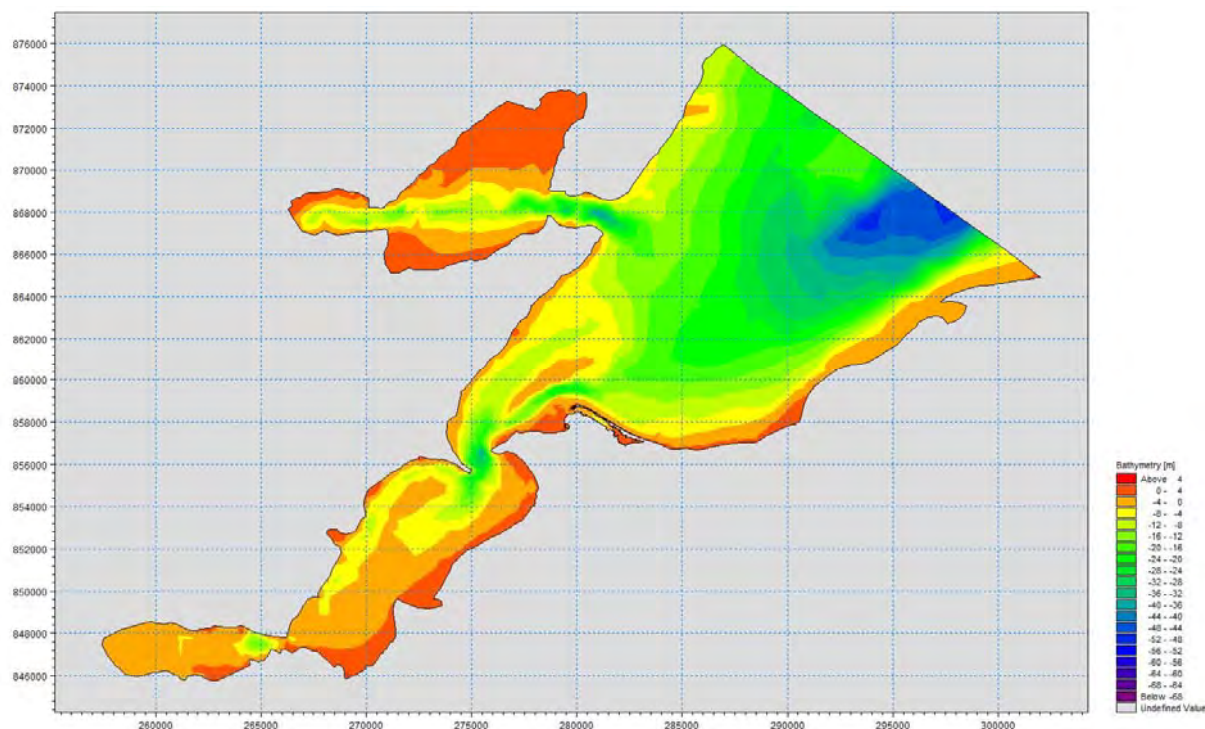


Figure 2.1: Model Extent and Bathymetry (2018)

2.4 Model Mesh

The model mesh has been refined to add more detail in the vicinity of Whiteness Head, particularly around the spit, former dredged channel, adjacent areas of Whiteness Sands, and the harbour inlet. The full mesh is shown within Figure 2.2, whilst the finer mesh around Whiteness Head is shown in more detail within Figure 2.3. The

refined mesh contains a total of 12,263 elements, this represents a substantial increase in resolution versus earlier phases of modelling, with over 9,000 more elements.

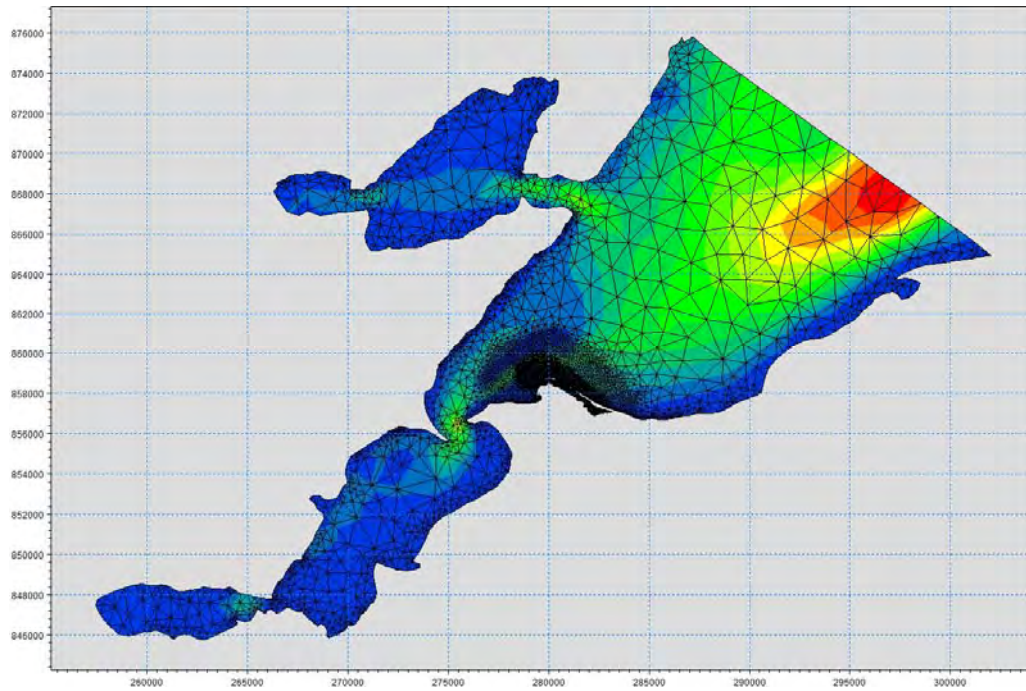


Figure 2.2: Full Model Extent Showing Model Mesh

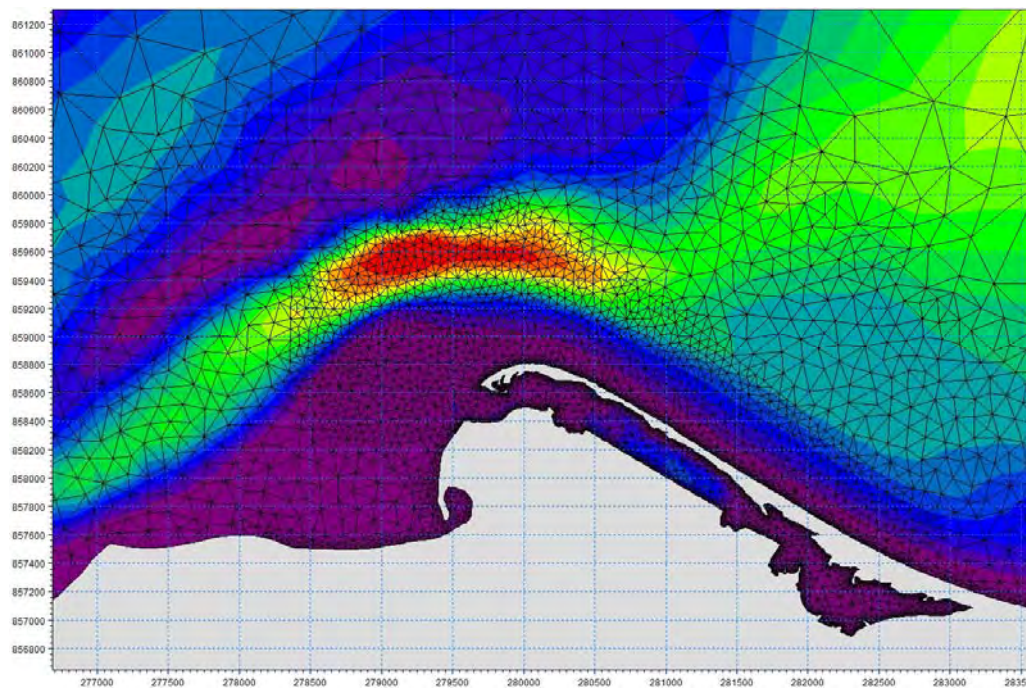


Figure 2.3: Refined Model Mesh in Vicinity of Whiteness Head

3 COASTAL MODEL DEVELOPMENT AND OUTPUTS

3.1 Model Calibration

The coastal model has been calibrated with respect to tidal water levels. The water levels at the eastern model boundary across the Moray Firth were derived using Admiralty Tide Tables for the period of the simulation. These levels vary across the boundary reflecting the progression of the tidal wave through the Moray Firth.

The simulated water levels from the initial boundary conditions were calibrated against gauged tidal levels at the McDermott site, within the harbour inlet (Ardersier Port). Subsequent adjustment and refinement of the boundary conditions has been undertaken and Figure 3.1 below shows the resulting simulated and gauged tidal water levels over a 2 month period in early 2003. This comparison demonstrates that the tidal phasing and elevations of the model are in good agreement with the observed data.

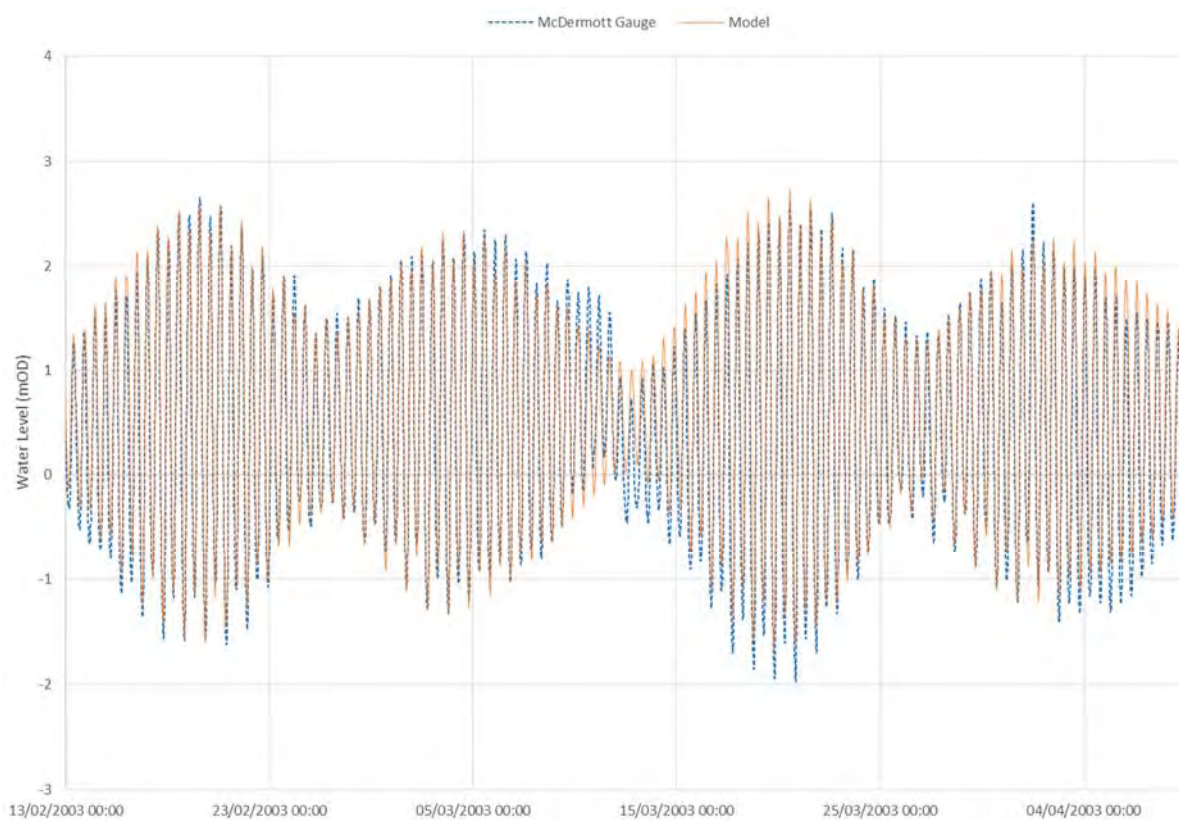


Figure 3.1: Comparison of Simulated and Gauged Tidal Water Levels – Ardersier Port

3.2 Model Validation

The sand transport model has been validated through both comparison to successive bathymetric surveys, and hindcast modelling utilising earlier (2012) bathymetry. The duration of the sand transport model runs are shorter than the duration between successive bathymetric surveys, so the validation approach has been to compare simulated zones of sediment deposition and erosion with observed changes and the conceptual understanding of the coastal processes. It is considered that the model provides a reasonable representation of the patterns of sand erosion, transport and deposition observed and is therefore deemed suitable for use in assessing coastal processes.

Due to lack of observed wave or current data in the vicinity of Whiteness Head it is not possible to validate the model outputs with respect to either waves or currents. However, simulated results for both current velocity and wave heights are closely aligned with those of previous modelling exercises, and it is considered that the simulated values are as expected for the physical setting.

3.3 Model Runs

Around 80 model runs have been undertaken during the setup, calibration, validation and application of the coastal model. Model runs have included HD only, SW only, combined HD/SW and combined HD/ST with DW forcing. The key model runs are summarised in Table 3.1.

The key outputs from the model simulations undertaken are provided in the Coastal Processes Assessment (2018 Environmental Impact Assessment Report: Technical Appendix 11.2).

Table 3.1: Summary of Key Model Runs

Module	Bathymetry	Description	Run Time (Hrs)
HD	2018	Run 15 – 6 Months Hydrodynamic (Jan – June 2003)	12.5
	Post- Dredge	Run 4 – 6 Months Hydrodynamic (Jan – June 2003)	16.5
SW	2018	Run 3 – 6 Months Spectral Waves (Jan – June 2003)	2.5
	Post- Dredge	Run 3 – 6 Months Spectral Waves (Jan – June 2003)	2.5
ST	2018	Run 8 – 6 Months HD SW (Jan – June 2003) with ST morphological speed-up factor (x3) [Model Extent]	12.5
	2018	Run 3 – 6 Months HD SW (Jan – June 2003) with ST morphological speed-up factor (x3) [Spit Pathway Trace]	14.0
	2018	Run 4 – 6 Months HD SW (Jan – June 2003) with ST morphological speed-up factor (x3) [Sands Pathway Trace]	12.5
	Post- Dredge	Run 4 – 6 Months HD SW (Jan – June 2003) with ST morphological speed-up factor (x3) [Model Extent]	18.5
	Post- Dredge	Run 3 – 6 Months HD SW (Jan – June 2003) with ST morphological speed-up factor (x3) [Spit Pathway Trace]	18.5
	Post- Dredge	Run 3 – 6 Months HD SW (Jan – June 2003) with ST morphological speed-up factor (x3) [Sands Pathway Trace]	18.5
	Post- Dredge	Run 1 – 6 Months HD SW (Jan – June 2003) with ST with ST morphological speed-up factor (x3) [Disposal Pathway Trace]	15.5

3.4 Influence of Model Setup on Simulation Results

The key factors influencing the simulation of coastal processes within the model are identified in Table 3.2 along with a discussion on how they are represented in the model, how effective this representation is and implications for how this may affect the results.

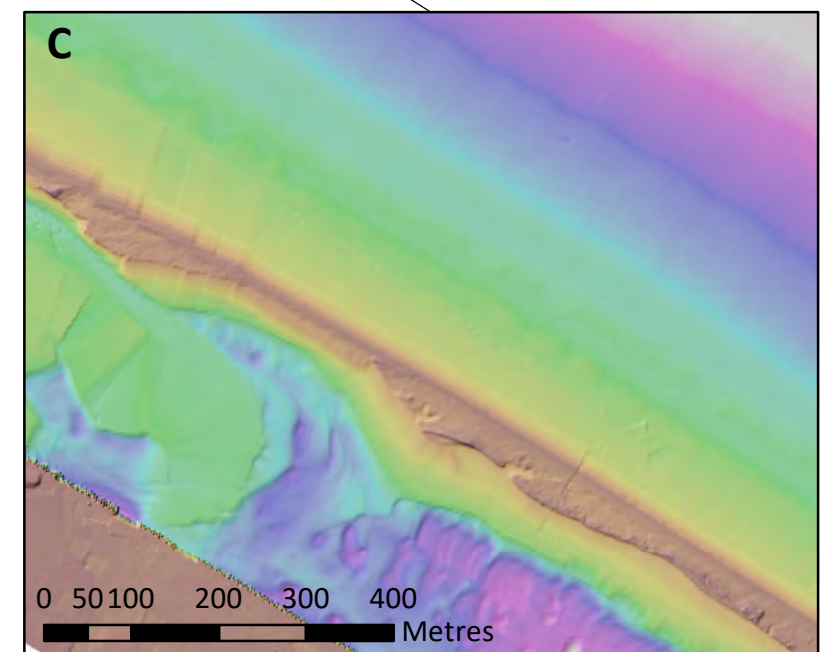
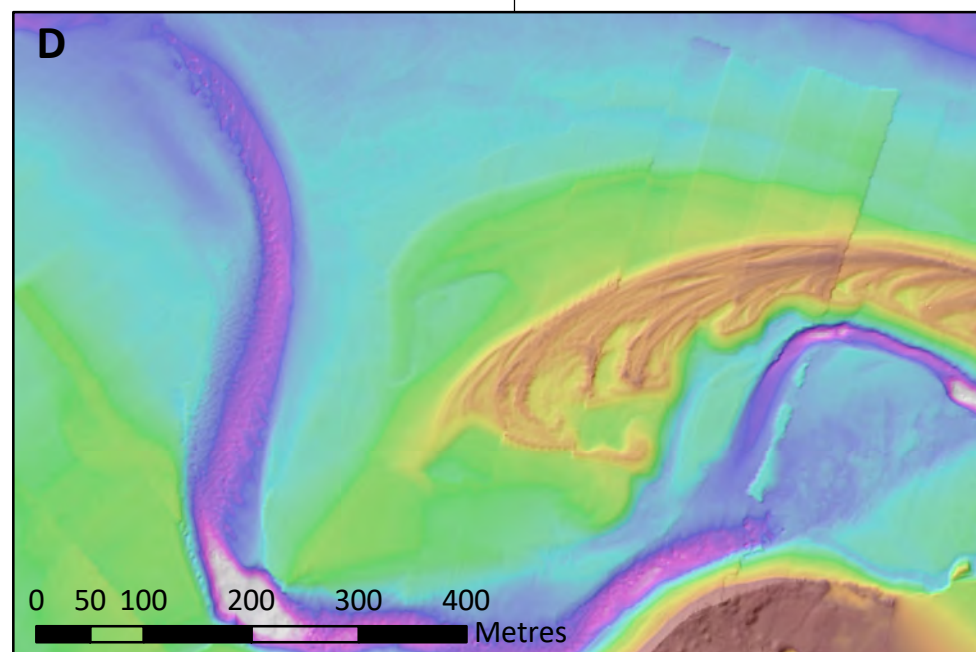
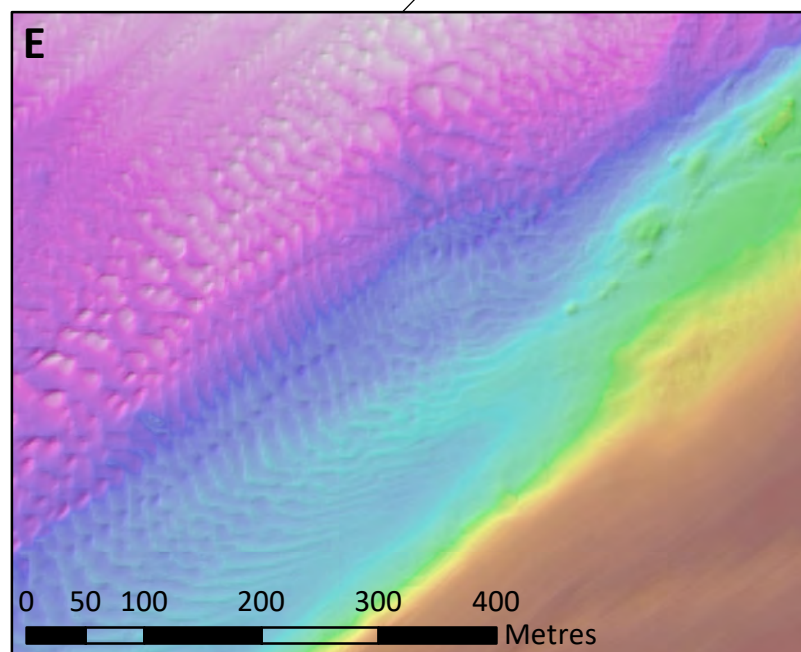
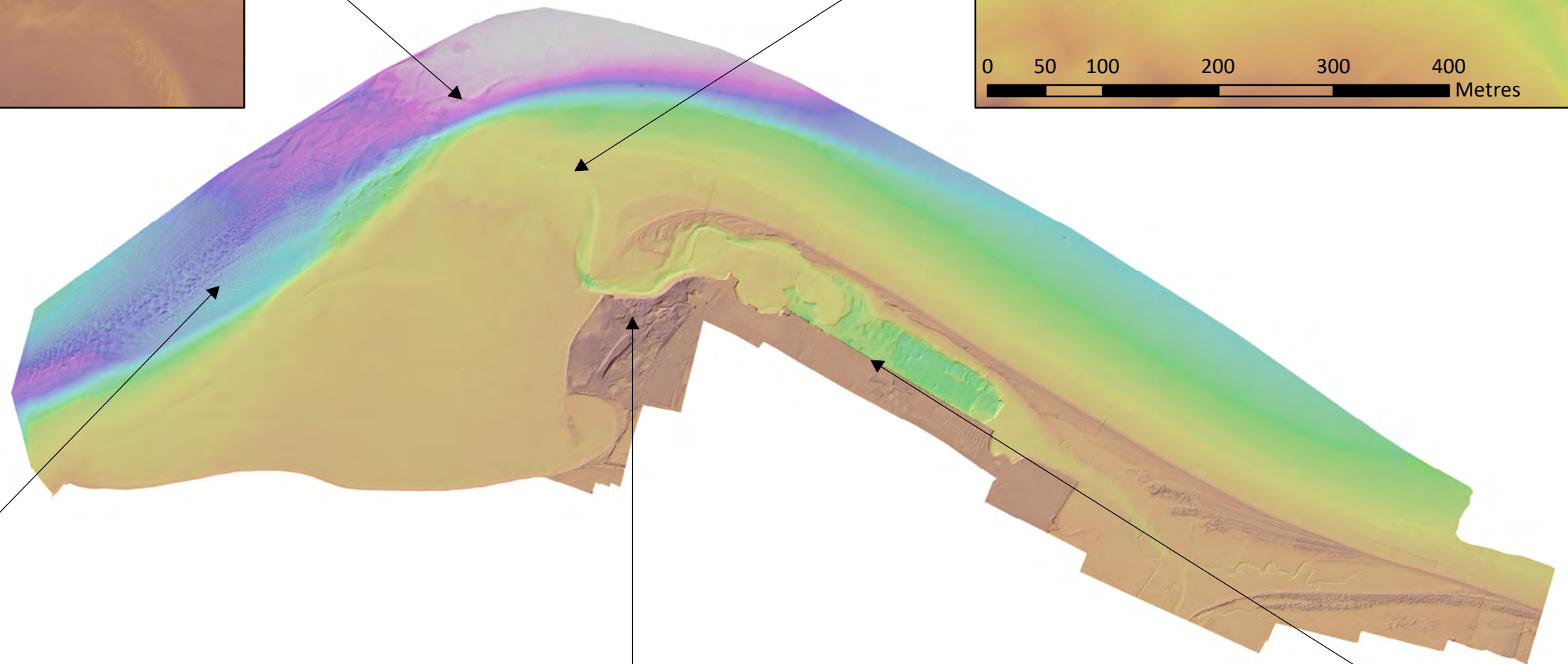
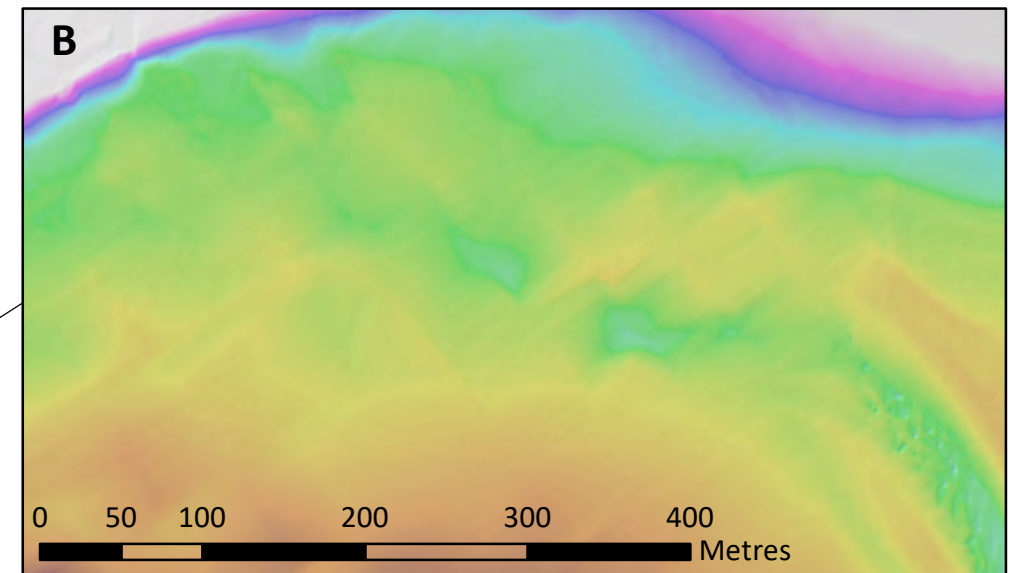
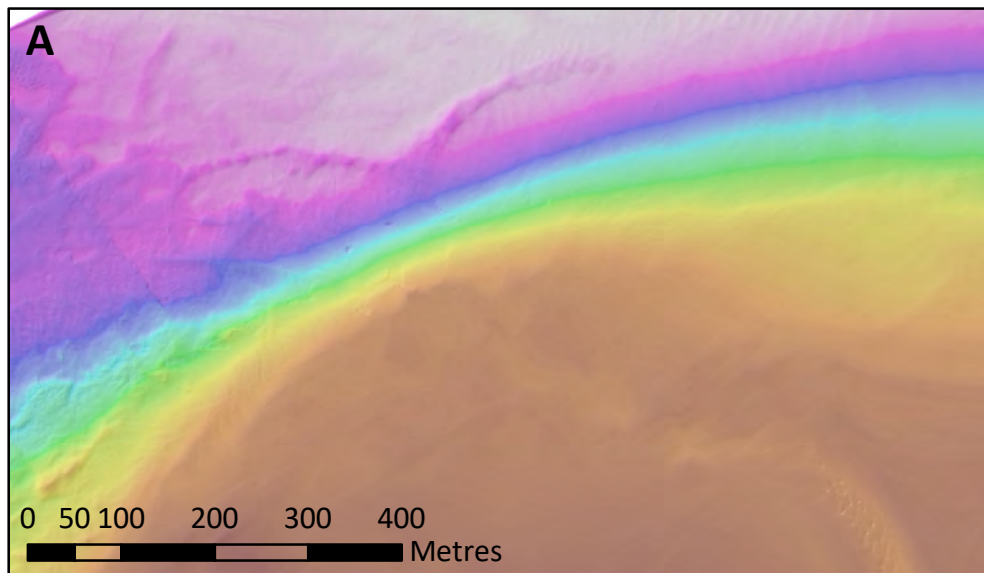
Table 3.2: Model Representation of Key Factors Influencing Coastal Processes

Factor	Influence on Coastal Processes	Representation in Model	Comment
Bathymetry	Key factor in all coastal processes	<ul style="list-style-type: none"> High resolution bathymetry within the vicinity of the site (2018). Lower resolution further away from the site. 	<ul style="list-style-type: none"> Good representation in key area of interest.
Boundary conditions	Water levels and tidal currents	<ul style="list-style-type: none"> Simulated water levels in good agreement with observed data. 	<ul style="list-style-type: none"> Good representation in key area of interest.
Coastline	Defines the model extent	<ul style="list-style-type: none"> High resolution within immediate area of site (2018). Lower resolution further way from site (updated in 2018). Coastline represents a fixed boundary within the model. 	<ul style="list-style-type: none"> Good representation of existing coastline in key area of interest. Locally in this dynamic environment, the fixed coastline cannot adjust to represent morphological evolution of terrestrial areas such as the progression of the spit. This influences the accuracy of the results immediately associated with this process.
Model mesh	Resolution of results	<ul style="list-style-type: none"> High resolution within immediate area of site (2018). Lower resolution further way from site (updated in 2018). 	<ul style="list-style-type: none"> Good representation in key area of interest. Despite relatively high resolution, small scale processes are not represented in detail.
Sediment characterisation	Mobility of sediment movement	<ul style="list-style-type: none"> Presence of sand substrate is assumed throughout the model extent (except where isolated for sediment tracking scenarios). Sand grading is based on sediment sampling from 2013. Analysis of sampling indicated that there was limited variation in sand grading within the local area. Outwith grading, sand is assumed to have consistent character throughout the model. 	<ul style="list-style-type: none"> Good representation of distribution and grading of sand. Model does not represent any other variations in sand character that may affect mobility. Sediment transport module does not simulate transport of fractions coarser than sand. The gravel present is typically within the inter-tidal / storm beach zone and is important in evolution of terrestrial areas.

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B BATHYMETRIC SURVEY BEDFORM OVERVIEW



C PHOTOGRAPHS



Photo		Description
1		View north-west along eastern face of spit, with gravel to left of photo and intertidal sand to right.
2		Looking north-west along spit crest, with vegetation colonising gravel deposits.
3		View south-west over sandy tip of spit recurve towards Whiteness Sands.

Photo		Description
4		Looking south-east into tidal inlet with some gravel present on surface of spit recurve in foreground
5		View west across tidal inlet from spit, with deposition of sand apparent.
6		Looking south-east on western face of spit with tidal inlet to right of photo.
7		View north-west down tidal inlet towards the spit head.






Photo		Description
8		Looking north from quay infrastructure over tidal inlet intertidal deposits towards spit.
9		View east over tidal inlet towards spit.
10		Looking north over former dredged channel towards the sandy head of the spit.

Photo		Description
11		View east across former dredged channel with spit in distance.
12		Looking west along former dredged channel towards Whiteness Sands.