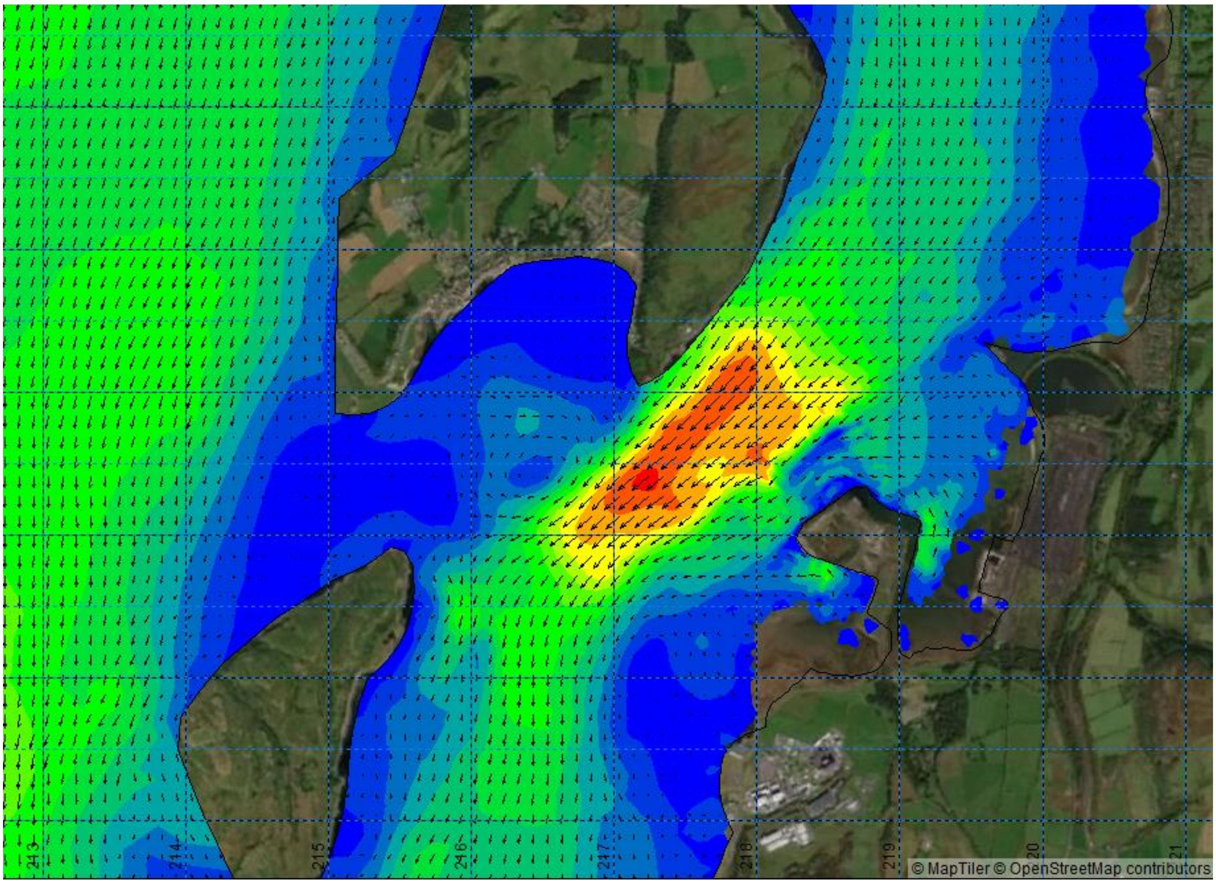
Hunterston Construction Yard
Technical Appendix 9.1: Coastal Modelling Study



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CONTROL SHEET

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1 INTRODUCTION

1.1 Terms of Reference

EnviroCentre Ltd has been appointed by Clydeport Operations Limited to undertake a Coastal Modelling Study in support of the Environmental Impact Assessment (EIA) of the proposed Hunterston Construction Yard development, Hunterston, Firth of Clyde. This report forms Technical Appendix 9.1 of the Environmental Impact Assessment Report (EIAR).

1.2 Scope of Report

This study aims to develop a coastal model of the Firth of Clyde, to include Hunterston Channel as well as approaches and surrounding coastal waters. The model will enable simulation and characterisation of tidal flow and wave climate under pre-development (baseline) and post-development conditions. This report will present details of the baseline coastal conditions at the development site, outline the Hydrodynamic (HD) and Spectral Wave (SW) model development, and describe the model simulations and results.

The study will also assess the potential dispersal of sediment plumes from the proposed capital dredging programme, as well as potential future maintenance dredge events. The dredge plume dispersal assessment will involve the use of coupled HD and sediment transport modelling techniques.

This report has been prepared for viewing in electronic format, with the resolution of the figures used intended to allow the reader to zoom in to view in greater detail, as required.

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2 HUNTERSTON CONSTRUCTION YARD

2.1 Site Location

The existing Peel Ports Hunterston Construction Yard (HCY) lies on the Firth of Clyde, north of the EDF Hunterston Power Station and west of the former Hunterston Coal Terminal as shown in Figure 2.1.

The site is reclaimed land that has historically been used for industrial purposes and currently comprises an access road, service infrastructure, a dry dock with an entrance bund in place and a hammerhead quay to the north-eastern extent.

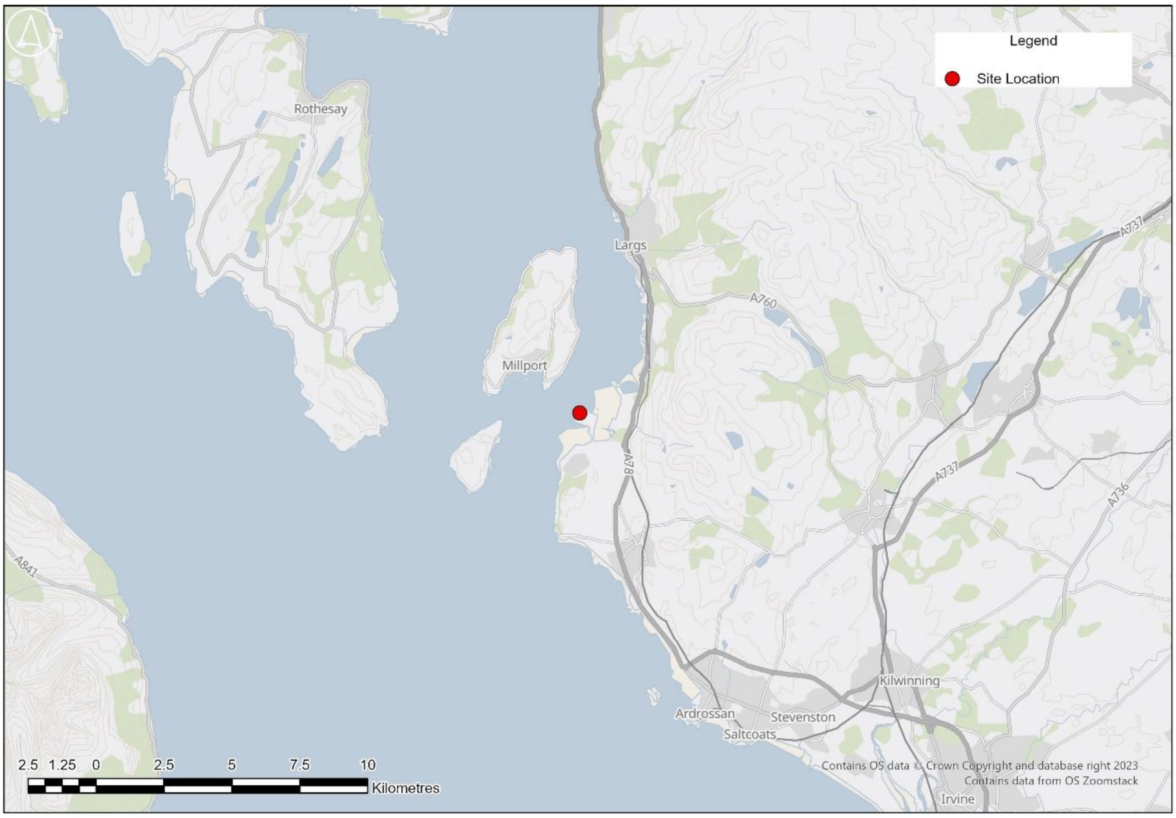

Figure 2.1: Site Location

2.2 Proposed Development

The proposed development is to upgrade the HCY into a harbour facility with a large working platform to support the needs of future tenants, with a focus on facilitating the construction and/or integration of offshore wind components.

On the marine side, it will comprise a quay wall for the safe mooring of vessels and the loading / offloading of cargoes and materials (e.g., offshore wind components), and a deepened seabed for the safe navigation and manoeuvring of vessels to and from the quay wall. The quay wall will comprise a piled structure topped with a concrete slab deck and finished with mooring bollards, fenders, ladders, utility provisions, and aids to navigation. The deepened seabed will comprise a dredged area where the bathymetry is lowered to approximately 12 m below Chart Datum (mCD) to provide sufficient water depth for navigation and berthing.

On the land side, the working platform will comprise approximately 40 hectares of compacted and levelled land situated behind the quay wall (including an area where the existing dry dock is infilled), utility provisions including a substation, and perimeter fencing, access, CCTV and lighting.

The following specific construction elements will be undertaken:

- Demolition of existing structures;
- Infilling of the dry dock to form a working platform;
- Formation of 570m quay wall 500mm back from MHWS i.e. in the terrestrial environment;
- Formation of a temporary working platform;
- Removal of the existing rock armour on the western boundary;
- Removal of the existing bund on the western boundary;
- Installation of sub-surface revetments for the new quay wall;
- Installation of fenders and other quay wall infrastructure i.e. drainage outfalls, mooring bollards and safety ladders and navigational aids ;
- Erection of port infrastructure including lighting columns, substations, drainage, security fencing, access gates, access road improvements (including resurfacing) and CCTV; and
- Erection of temporary site offices and staff welfare buildings to accommodate site workforce.
- Capital Dredging to a depth of -12m CD to enable access to the 570m quay wall;
- Disposal of dredging spoil to a licensed marine spoil disposal site;
- Construction of 3 mooring dolphins;
- Installation and removal of a temporary grounding pad to facilitate vessel birthing as required;
- Installation of navigational aids.

Further details of the proposed development are provided in Chapter 2, Volume 1 of the EIAR.

2.3 Background of Historic Industrial Development

The Hunterston Ore Terminal was constructed between 1974 and 1979, which separated Fairlie Sands to the north from Southannan and Hunterston Sands to the south. While the Hunterston Marine Construction Yard was developed to construct oil platforms between 1978 to 1983, which separated Southannan Sands to the north from Hunterston Sands to the south.

The shoreline of Southannan Sands is predominantly formed by an armour stone revetment, apart from the zone between the former coal yard and the Construction Yard, where there is a more natural boundary comprising of a thin strip of salt marsh and maritime grassland.

2.4 Southannan Sands Site of Special Scientific Interest (SSSI)

Southannan Sands SSSI is located adjacent to the development and comprises three separated coastal sections of inter-tidal sandflats habitats (designated feature) along the Clyde coastline, as shown in Figure 2.2. The sandflats extend for approximately 4 km, separated into three sections by the Hunterston Construction Yard. The three sections of the SSSI are named, Hunterston Sands (located south of the Construction Yard), Southannan Sands (located just north and east of the Construction Yard) and Fairlie Sands, (located approximately 500 m north of the Construction Yard). The inter-tidal sediment composition of the sandflats comprises primarily medium sheltered sands, with a small area of mud/silt present at Fairlie Sands. The SSSI is considered to be of importance for the presence of the nationally scarce dwarf eelgrass (Zostera noltei). Southannan Sands SSSI is considered to be of national (UK) importance.

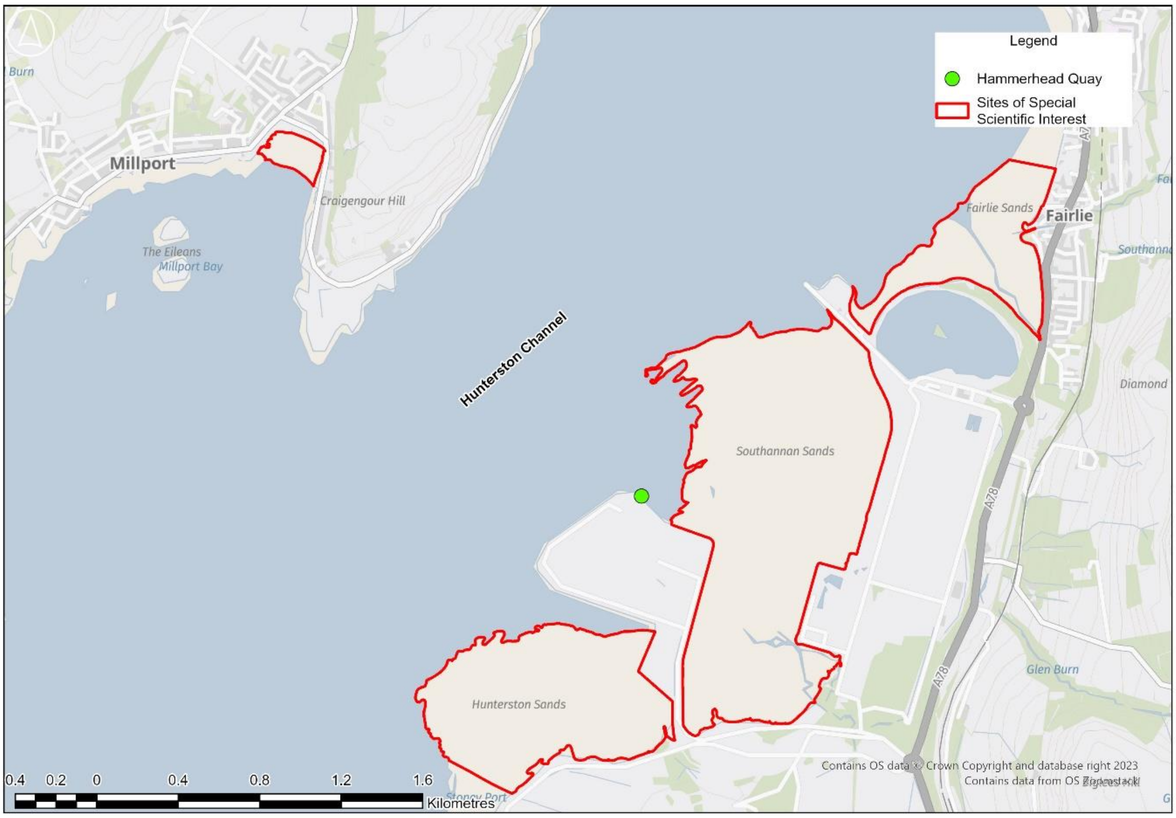

Figure 2.2: Site Context

3 BASELINE CONDITIONS

3.1 Overview

The baseline conditions at Southannan Sands have been characterised through a review of previous detailed studies undertaken in the area, interpretation of other available data sources and using a numerical coastal model to characterise the hydrodynamic and wave climate and inform the understanding of the sediment transport regime.

A comprehensive characterisation of the coastal processes at Southannan Sands was undertaken in support of the proposed Hunterston Multi-Fuel Power Station in 2010 (Environmental Statement, Chapter 13). The 2010 assessment led by EnviroCentre, included a detailed field study, thorough review of secondary data sources, and development of a MIKE coastal model to develop a robust conceptual model of coastal processes (referred to as the '2010 study' in this report). This has been used, in combination with the updated coastal modelling exercise described in this report, to inform the understanding of baseline coastal conditions in and around Southannan Sands.

3.2 Topography and Bathymetry

The most recent (July 2023) bathymetry survey of the local area is shown in Figure 3.1. Figure 3.2 shows the bathymetry of the wider surrounds, whilst the bathymetry of the site and Firth of Clyde is further described in Section 5.3.1.

Southannan Sands form an extensive area of shallow sublittoral and littoral waters to the north and east of the Construction Yard, which extend out westwards, before dropping steeply into Hunterston Channel down to between -40 to -30 mCD, with similar steep side slopes to the west at Great Cumbrae. Figure 3.2 shows two cross sections through the Hunterston Channel in towards Southannan Sands from north-south and west-east directions, clearly defining the character of the area.

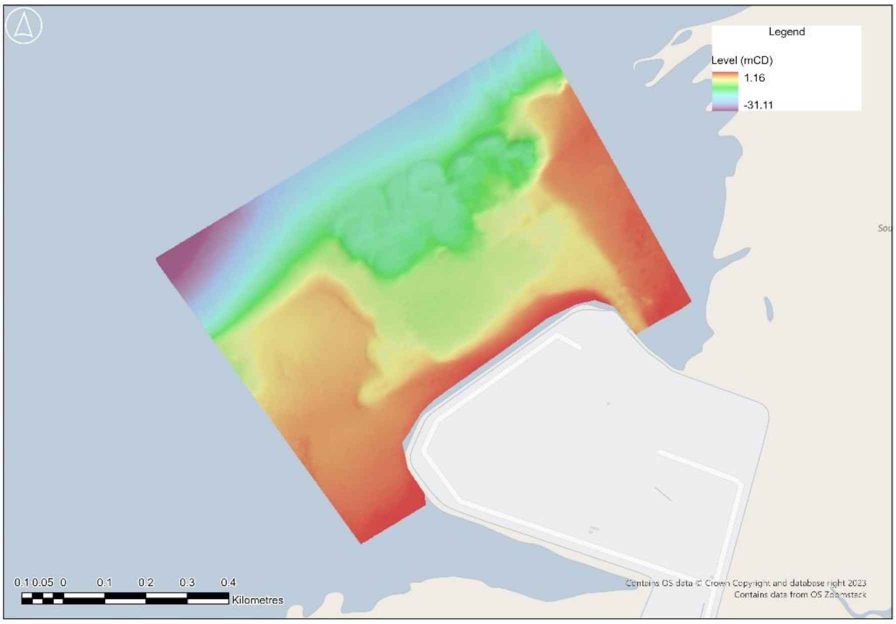

Figure 3.1: Hunterston Construction Yard Bathymetry Survey 2023

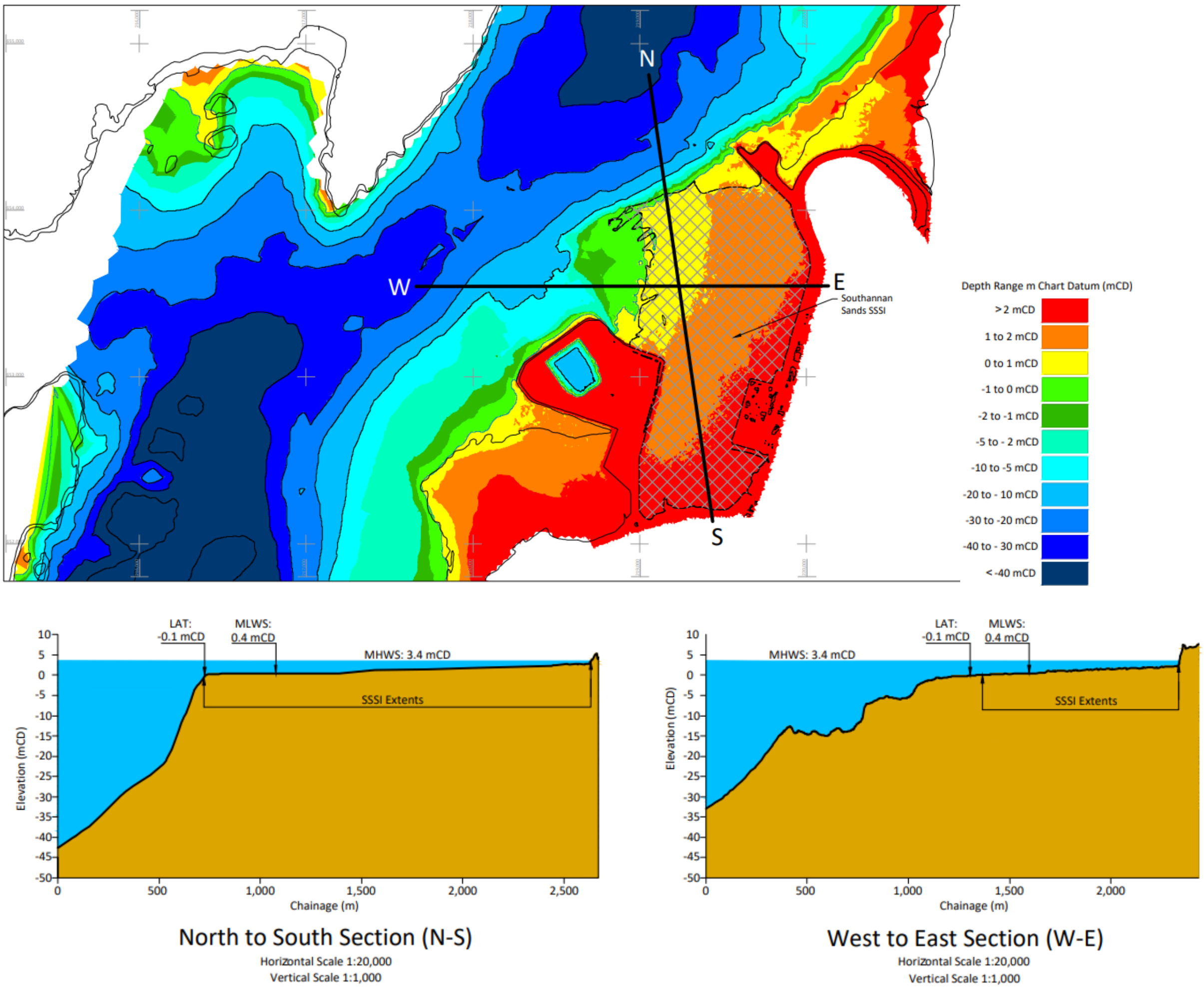

Figure 3.2: Surrounding Bathymetry and Cross-Sections

3.3 Recent History

The mapped change in the area around Southannan Sands over time is shown in Figure 3.3. Comparison of the mapped low water extents from the Firth of Clyde Admiralty Chart from 1852 through to the present-day Ordnance Survey mapping clearly identifies the changes to Southannan Sands brought about by industrial activity that created the Hunterston Terminal, Construction Yard and Nuclear Power Station, and a landward retreat of the low water extent.

Comparison of more recent mapping and the bathymetry data used to develop the coastal model (see Chapter 5), tends to also indicate a slight retreat in the low water mark, however it is recognised that accurately mapping the extent of mean low water over such an expansive area with shallow gradients is not straightforward.

The coastline at Southannan Sands is also included in the recent Dynamic Coast 2 update[1] (2021) to the National Coastal Change Assessment (NCCA), led by the Scottish Government. This confirms that there has been negligible change to the coastline of the mean high water spring tide level since the

[1] Dynamic Coast Webmaps (https://www.dynamiccoast.com/webmaps)

1970s, which is consistent with the shoreline armouring present along much of the infrastructure in the area. The assessment highlights the shoreline to the south of the construction yard, either side of the access road, as being at risk of erosion under a future climate high emissions scenario.

Figure 3.3: Review of Mapped Mean Low Water Springs (MLWS) Tidal Contour

3.4 Geology

The bedrock underlying Southannan Sands comprises of Devonian sandstone measures, with only one or two localised exposures of rock located close to the high water mark in the east-central sector of Southannan Sands.

At Southannan Sands, there is a large thickness of Pleistocene deposits overlying rock head, which are largely fluvio-glacial in origin. The 2010 investigation included shallow seismic profiling which did not reveal any extensive deposits of muds and sands in the wider area, with most seabed areas indicating the presence of gravelly deposits. The sand deposits that form the seabed over much of the area were interpreted as a thin veneer, a fraction of a metre thick in most places, covering Pleistocene gravel deposits into which the present submarine landscape is cut.

A geological review of available boreholes was previously undertaken as part of the 2010 study, which indicated that the clay content within the sands has contributed to the relative stability of Southannan Sands.

3.5 Seabed Sediments

Sand is the dominant seabed deposit in the area, with sediments in the north of Southannan Sands being medium sands with exposed cobbles and boulders, while finer sands and some muds are present in the shelter of the Construction Yard.

The 2010 study undertook a comprehensive investigation and assessment of the seabed sediments, which are summarised here within Table 3-1 and Figure 3.4. Sand is the dominant seabed deposit, with the particle size in the northern area of Southannan Sands being slightly coarser than the finer sands to the south of Southannan Sands, in the shelter of the Construction Yard. Gravel was encountered towards the northern extent of Southannan Sands as shell gravel, and also around the mussel beds to the west of the Construction Yard. Finer mud sized sediment was relatively sparse across Southannan Sands with the exception of around the mussel beds and in the areas of the slowest currents, within the dredged area of the Construction Yard quay and around the margins of the southern area of Southannan Sands.

Table 3-1: Summary of Seabed Sediment Type and Distribution from 2010 Study

Bed Sediment	Distribution and Description
Gravel	• In the deep water of the Hunterston Channel gravel is a minor component of the sediment (<1% - 5%) and is all shell dominated. • On the upper, northern slopes off Southannan Sands, there are small zones of mixed shell and lithological gravel, encompassing the exposures of coarse Pleistocene sediments. This gravel deposit is much more extensive on the slopes off Hunterston Sands. • On the outer (northern) Southannan sands there are extensive zones containing a thin layer of cockle/mussel shells over sand. Dense deposits of these shell gravels are found at up to 0.5 m below the bed surface. • On the inner Southannan shore the gravel concentration in the sediment is generally low (<1%). • At most sites sampled, dense gravel deposits were encountered at about 0.3 m or less below the sand bed surface.

Bed Sediment	Distribution and Description
Sand	• Sand is the dominant bed deposit in the area. • The sands generally are comprised of well sorted log-normally distributed grain size populations, indicative of the presence of active sand transport processes. These grain populations can be divided by their mean size as shown below (expressed at particle diameter and in phi scale): o Fine sand (<180 µm / 2.5 phi): Particles are easily dispersed into suspension once set in motion and can travel large distances in the water column. The presence of these particles on the seabed is normally indicative of a site conducive to the fallout of fine sand from suspension. o Medium-fine sand (180-220µm / 2.25-2.50 phi): Particles are most easily set in motion by flowing water and are sensitive to energy of the flow in regard to their mode of transport. Under the weak tidal flows of the Hunterston area, bedload transport probably predominates. o Medium sand (>220 µm / 2.25 phi): Particles tend to move near the bed once set in motion (by rolling and saltation), requiring constant high energy conditions to keep them in suspension. The bedload movement that results is much slower than movement in suspension. • Fallout sands are found in the deeper sectors of the Hunterston Channel floor, in the zone sheltered by the Construction Yard, in the dredged zone seaward of the Hunterston Terminal, and in a localised zone on the inner Hunterston Sands. Elsewhere bedload sand predominates. • Sand particles, inspected under the microscope, are seen to be primarily composed of angular and sub-rounded grains of quartz and rock fragments, consistent with local fluvio-glacial sands being the principle source of these deposits.
Mud and Organic Matter	• Mud (sediment <63µm) is generally present at low levels in this environment. • The three areas where muddy sediments are found are: o North east and south west sectors of the Hunterston Channel floor (up to 25% mud) o Mussel bed deposits (>50% mud) o Wave sheltered zone at the Construction Yard and south Southannan Sands (up to 25% mud) • Elsewhere mud forms <10% of the sediment, and in most areas <1%. • The mud comprises approximately 50% silt and 50% clay (range 40-60%). • Organic matter in the sediments is largely associated with the mud fraction. • The only area of elevated organic concentrations is in the over-deepened (dredged) channel off the north shore of the Construction Yard quay, which is floored with a mat of decomposing weed.

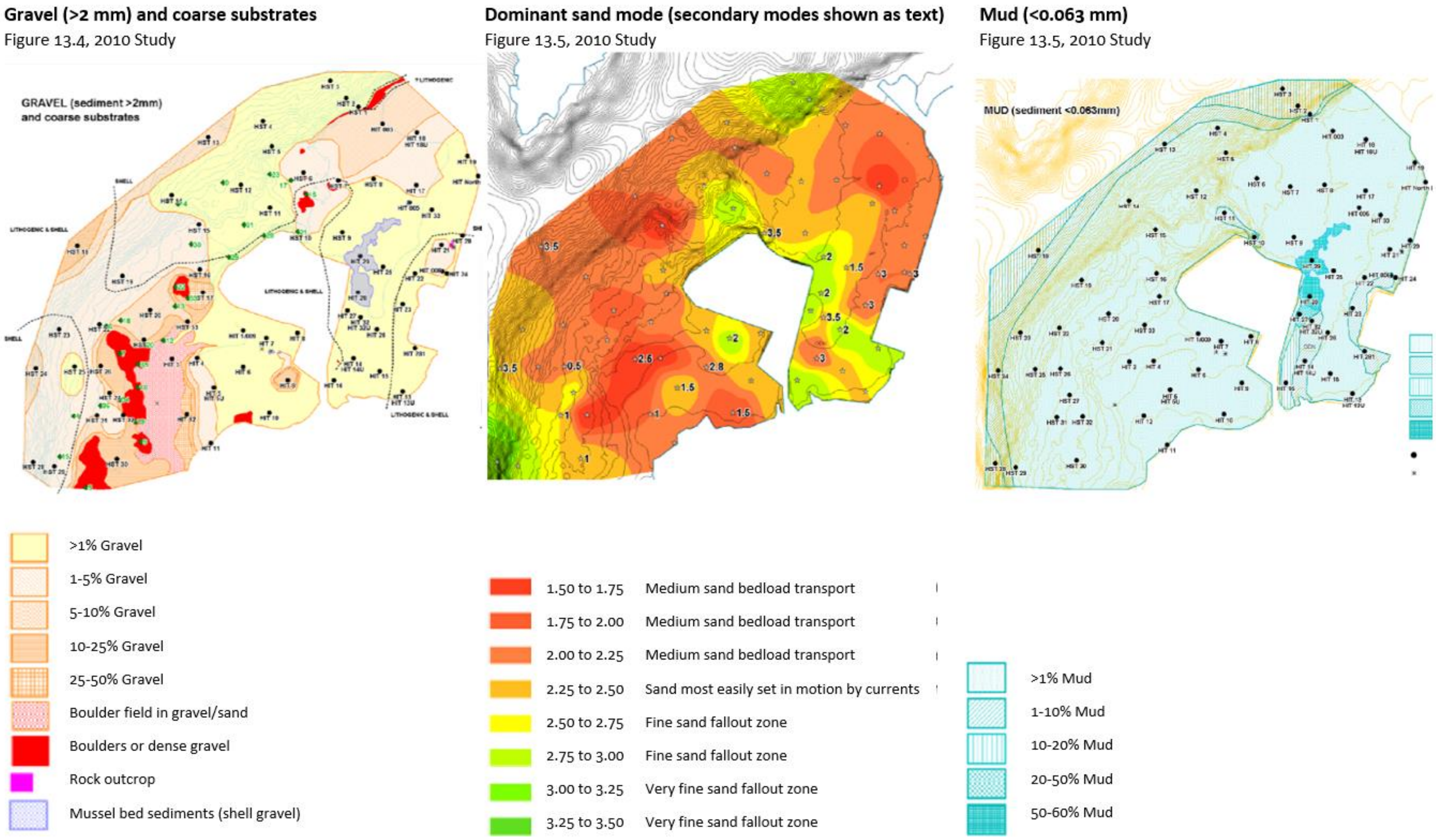

Figure 3.4: Bed Sediment Type and Distribution from 2010 Study

3.6 Tidal Regime

3.6.1 Tidal Levels

The closest tidal information to Southannan Sands is for Millport, Great Cumbrae, which is less than 3 km away. The astronomical tidal range for Millport from the Admiralty Tide Tables is shown in Table 3-2, where the highest astronomical tide is 3.9 mCD which is equivalent to 2.3 m above Ordnance Datum (AOD).

Table 3-2: Tidal Range at Millport

Tide Condition	Chart Datum (mCD)*	Ordnance Datum (mAOD)**
Highest astronomical tide	3.9	2.3
Mean high water spring	3.4	1.78
Mean high water neap	2.7	1.08
Mean level	1.99	-0.26
Mean low water neap	1.0	-0.62
Mean low water spring	0.4	-1.22
Chart Datum	0.0	-1.62

* Admiralty Tide Tables
** Chart Datum correction for Ordnance Datum is -1.62m (relative to Ordnance Datum at Newlyn)

3.6.2 Tidal Currents

Currents in the study area are primarily driven by the tidal rise and fall, modified to some extent by meteorological conditions (wind forcing, surges). The 2010 study included current monitoring at three locations in and around Southannan Sands, which confirmed that flow velocities in the area were generally low. The distribution of peak flows recorded general values in deep water areas (0.2-0.3 m/s), areas of slacker flows in the shallow bays (<0.2 m/s) and accelerated flow in the narrows between the Hunterston Terminal and the southeast point of Great Cumbrae Island (0.7 m/s). The hydrodynamic modelling study undertaken confirms these general flow conditions. Further details from the modelling of the baseline hydrodynamic conditions are contained in Chapter 5.

3.7 Wave Climate

The Firth of Clyde is relatively sheltered from the ingress of large swell waves, however there is a long fetch extending into the Irish Sea from the south-south-west direction. The shelter provided by the surrounding islands in the Firth will limit the wave fetch and reduce the wave energy. Wind waves will have a similar limited fetch, at Hunterston the direction of the largest fetch is from a south-westerly direction towards the Isle of Arran.

Waves reaching Southannan Sands will be subject to the processes of refraction and shoaling which will reduce their energy. The effect of these attenuating processes increases in a southerly direction along Southannan Sands.

A more detailed analysis of the baseline wind and wave climate has been undertaken and is provided in Chapter 4, with modelling of these conditions provided in Chapter 5.

3.8 Sediment Dynamics

The local sediment dynamics occurring around Southannan Sands were examined in detail during the 2010 study. The interpretation of the seabed sediment type and distribution provided in Table 3-1 and Figure 3.4 was undertaken along with consideration of recorded current meter readings in the vicinity, drogue tracking, side-scan sonar, aerial photography and hydrodynamic model runs. The summary output figure is presented as Figure 3.5, while the following paragraphs provide an abridged version of the findings.

3.8.1 Bedload Transport

Gravel transport requires high energy conditions, with fine gravel (2 mm) requiring a flow (1 m above bed) exceeding about 0.5 m/s for motion to be initiated. Tidal velocities of this magnitude are not attained within the study area. A wave-induced oscillatory current of about 0.5 m/s is similarly required to move fine gravel. This velocity is achieved under storm wave conditions in water off the outer margins of Southannan Sands.

The result of this intermittent wave action will be to scour emergent Pleistocene deposits and, under the landward residual that exists with flows under shoaling waves, push gravel landwards. This inshore dispersion of gravel is aided by seaweed rafting where seaweed attach to gravel particles and then under storm conditions the drag on the weed overcomes the weight of the stone which then moves landward.

Tidal sand transport as bedload occurs for the medium-fine sands that characterise this area when flow velocity 1 m above the bed exceeds about 0.25 m/s, which equates to a surface flow of 0.4 m/s (as derived from observed near-bed and surface current readings in 2010 study). This 0.4 m/s is considered indicative of conditions where bedload transport of sand might frequently occur and is generally within the Hunterston Channel. Tidal transport due to tide alone will only occur over spring tides and rapid sand transport rates would not be expected, as flows only just exceed the critical thresholds for motion.

The direction of sand transport under refracting/shoaling waves will tend to be at an angle to or normal to the depth contours, particularly in shallow water where refraction is complete, with a marked landward residual for medium-fine sand moving as bedload.

Combined tide/wave sand transport will occur for much of the time, particularly in shallow water. As tidal currents tend to run parallel to the depth contours, and (in shallow water) wave currents normal to them, the two motions will tend not to strongly reinforce or oppose each other. Net transport will be to diffuse sand both upstream and downstream of source areas, with a superimposed long-term landward (wave driven) residual. In deeper water, where refraction is not complete, motion induced by south west waves will tend to preferentially reinforce transport to the north east. Expected transport vectors (black for tide, blue for waves) are plotted in Figure 3.5.

The side-scan sonar survey of the area undertaken as part of the 2010 study identified various bedforms that indicated bedload sand transport. The features ranged from ridges to megaripples, most were quite weak (consistent with intermittent transport or conflicting wave/tide transport) and in a few areas quite strong (but small) forms were noticed. The areas containing these features are plotted in Figure 3.5, and are broadly coincident with the zones of predicted bedload sand transport based on wave and tide characteristics. Intertidally, the aerial photographs identify zones where sand is clearly moving as thin sheets/bars. These zones are plotted in Figure 3.5, and interpreted as resulting from frequently occurring sand transport as a result of the action of wave surge and small amplitude waves that penetrate these areas over the high-water period.

Evidence of sand erosion and deposition obtained by comparing the present bathymetry with that mapped in 1852 (Figure 3.1) shows that the low water mark has retreated exposing Pleistocene deposits where previously there was marine sand cover at Brigurd Spit and at the Perch (north of the Construction Yard). At the same time sand has built up along the outer southern shore of the Construction Yard. The changes around the Construction Yard are consistent with a natural south to north movement of sand on the outer intertidal, where the development of the Construction Yard and approach channel have cut off the supply of sand to the north, and are trapping sand to form a growing accumulation along the southern edge of the Construction Yard. If these changes have taken ~40 years, the indication is that sand bedload transport rates are relatively slow, consistent with the predictions based on wave and tide conditions.

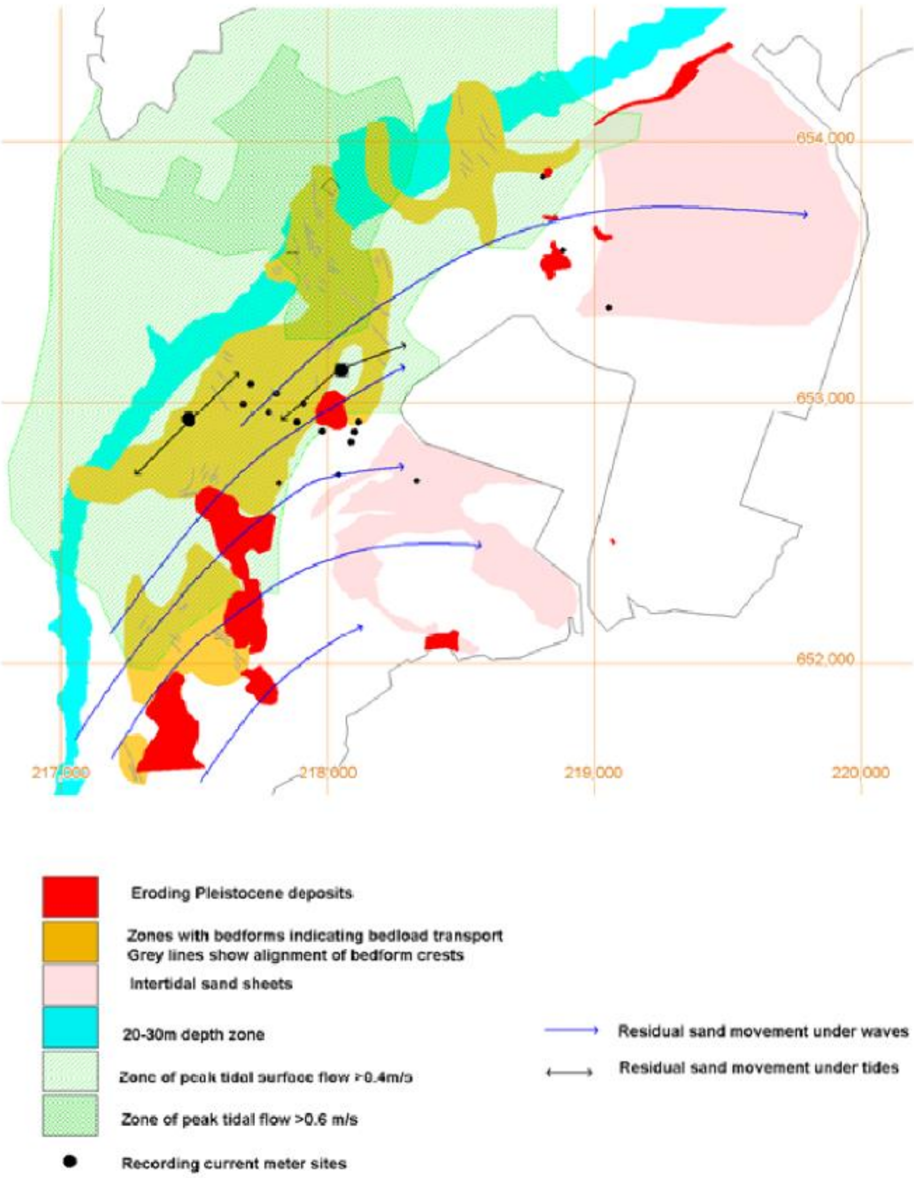

Figure 3.5: Indicators of Bedload Transport of Sand

3.8.2 Accumulation from Suspension

Fallout sand (fine and very fine sand <180μm) is generated at all sites of erosion and attrition within the area and is rapidly transported in suspension to accumulate in areas where, due to over-deepening or the presence of sheltered conditions, it may accumulate unhindered. These deposits occur naturally in the deeper waters of the Hunterston Channel, and they appear to be an active recent deposit within the intertidal area where they have infilled the former dredge zone at the entrance to the Construction Yard, accumulated in a deeper zone along the southern side of the Construction Yard (created by the construction of the Yard) and accumulated in the wave sheltered area of Southannan Sands, east of the Hunterston Construction Yard.

Approximately 0.2 to 0.3 m of this material (Figure 3.5) appears to have accumulated in the sheltered waters behind the Construction Yard over the ~40 years following construction, an accumulation rate of about 5 mm per year. The rate of movement and accumulation of this material in this area appears to equal or greater than that of coarser (bedload) sands.

Mud is not widely present in the bed sediments of the area which may reflect absence of local mud sources. As mud deposits occur in ‘quiet’ sites, such as wave-sheltered or deep water sites, it is likely that local wave energy is also responsible for the general absence of mud in the sediments. The development of the Construction Yard has modified the characteristics of the sediments accumulating on inner Southannan Sands, allowing a veneer of fine sand and mud to build up over the previously existing bed of coarser shelly gravelly sands and supporting an actively accumulating mussel mud.

Figure 3.6: Fine Sand and Mud Deposits (0.2 m) Over Previous Beach Surface of Shelly Sand

3.8.3 Comparison of Bathymetric Surveys

The original design drawings of the dredge zone of the Hammerhead Quay, located as shown in Figure 2.2, have been reviewed highlighting that the dredge zone extended down to -6 mAOD (-4.38 mCD) when constructed. Comparison with the 2018 bathymetric survey of this area highlights a difference in volume between design condition and the 2018 bed level of 9,800 m^3. The typical change in depth is between 0.0 – 0.6 m, with an average of 0.31 m across the area, with the largest changes observed along the quayside and at the eastern end of the dredge area, where tidal velocities will be lowest. Assuming the last dredge was sometime between construction (~1980) and last active use (~1995), this indicates an average accumulation rate of around 10 mm per year in this area.

A comparison has been undertaken between the latest bathymetry available for the proposed dredge pocket (2023), and the previous survey dataset for the same extent (2018). Figure 3.7 presents a plot of bathymetric change from 2018 to 2023, whilst Figure 3.8 presents a cross-sectional comparison between the two surveys at locations marked on Figure 3.7. Review of these figures highlights a spatially varying pattern of shallow deposition, deepest within the hammerhead berth to the east, but generally less than 0.25m and on average 0.12m, with minor areas of erosion present mainly towards the north-western margin of survey extent. The results of a volumetric cut fill analysis between the two datasets are presented in Table 3-3. This shows a total deposition volume over a 5-year period of 28,660m^3, approximating to an averaged per year depth of deposition of 25mm within the calculation area.

Figure 3.7: Bathymetric Change – 2023 Level Minus 2018 Level

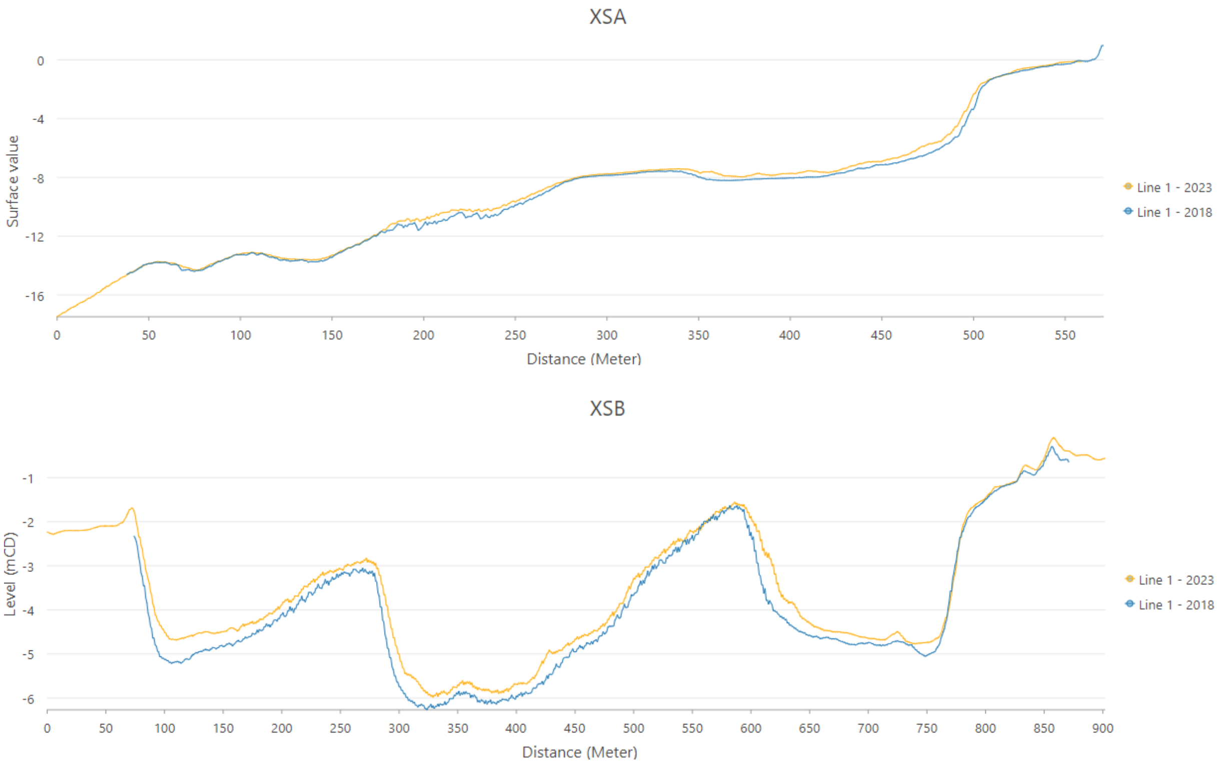

Figure 3.8: Bathymetry Cross-Sectional Comparison – 2023 (Orange) Versus 2018 (Blue)

Table 3-3: Bathymetric Cut-Fill Analysis 2018 to 2023

Bathymetric Cut-Fill Analysis	Value
Volume of deposition across pocket (2018 – 2023)	28,660 m^3
Volume of erosion across pocket (2018 – 2023)	2,926 m^3
Balance (net deposition) 2018 – 2023	25,734 m^3
Generalised depth of deposition	0.12 m
Per year averaged volume deposition	5,732 m^3
Per year averaged depth deposition	2.5 cm

3.9 Water Quality

The coastal waters adjacent to the site are classified under the Water Framework Directive (WFD) monitoring programme as Largs Channel (Fairlie Roads) a coastal waterbody (ID: 200026). The waterbody is classified as being of overall ‘Good’ status in 2012, with a hydromorphological and water quality status of ‘Good’. The only watercourse that discharges into the large Channel is Gogo Water located north-east in Largs, which is classified as being overall ‘Moderate’, with a water quality status of ‘Good’ and a hydromorphological status of ‘Moderate’.

Previous total suspended solids (TSS) measurements undertaken by EnviroCentre at the Construction Yard showed the water locally to be clear, with no suspended solids recorded (<5mg/l) during the summer months, whilst occasional short bursts of increased TSS concentrations appeared to be associated with small amplitude wave action. There are two designated Bathing Waters close to the site, Pencil Beach, Largs (~4.5km) and Millport, Great Cumbrae (~1.7km). SEPA has monitored the water quality in these areas since 2000 due to their general recreational use. In 2023 Pencil Beach was designated as ‘Good’ quality and Millport as ‘Excellent’ quality.

4 WAVE, WIND AND WATER LEVEL DATA

4.1 Overview

The coastal wave, wind and water level climate has been characterised through sourcing of various datasets, which have then been processed and analysed.

Offshore wave and wind data has been obtained from the DHI Metocean Data Portal (DHI, n.d.) for an offshore location in the outer Firth of Clyde (55°07'03.6"N 5°22'49.0"W), as shown in Figure 4.1 and Figure 4.2. The offshore location is approximately 75 km south-west of the Hunterston Construction Yard. The DHI Metocean Data Portal provides global hindcast wave and wind data, as well as various analytics of these datasets.

Additionally, hindcast tidal water level data has been obtained from the DHI Global Tide Model for the southern model boundary.

Further details on the wave, wind and water level data obtained are presented in the following sections.

4.2 Offshore Wave Data

Hindcast offshore wave data has been obtained from the DHI Metocean Data Portal for location 55°07'03.6"N 5°22'49.0"W, covering the period 27/02/1999 to 28/02/2019. The data is derived from the DHI North Europe MIKE 21 Spectral Wave Model, the extent of which is shown in Figure 4.1, with the data extraction location shown in more detail in Figure 4.2.

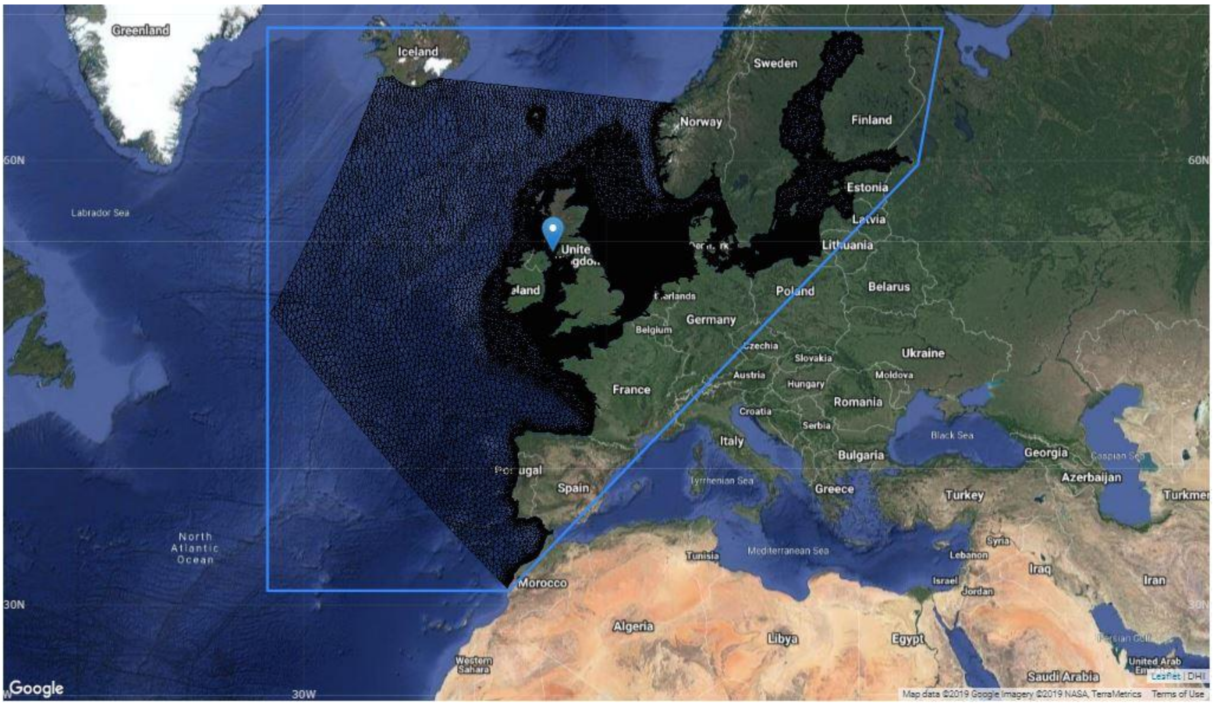

Figure 4.1: DHI North Europe MIKE 21 Spectral Wave Model Extent (Hindcast Location – Blue Pin)

Figure 4.2: DHI North Europe MIKE 21 Spectral Wave Model Mesh (Hindcast Location – Blue Pin)

The hindcast wave data includes the following components:

- Significant wave height (Hm0);
- Peak wave direction (PWD);
- Peak wave period (Tp);
- Mean wave period (T01);
- Zero-crossing wave period (T02);
- Mean wave direction (MWD); and
- Directional standard deviation (DSD).

The data is summarised in the form of maximum, median and minimum values of key components in Table 4-1. Figure 4.3 shows the directional frequency of significant wave height, highlighting the complete dominance of waves from the 180° and 300° sectors. Given the orientation of the Firth of Clyde, and the position of Hunterston to the north-east of the offshore wave location, the 180 degree sector is therefore considered the key wave sector. Figure 4.4 shows a comparison of DHI wave model values versus altimeter values.

Table 4-1: Summary of DHI Hindcast Wave Data by Directional Sector

Wave Component	180° Sector			300° Sector		
	Max. Value	Med. Value	Min. Value	Max. Value	Med. Value	Min. Value
Significant wave height (Hm0) - Metres	4.97	1.10	0.08	5.55	0.79	0.07
Peak wave period (Tp) - Seconds	19.96	6.68	1.80	19.84	9.50	1.84
Mean wave period (T01) - Seconds	8.51	4.52	1.65	11.62	5.20	1.80
Zero-crossing wave period (T02) - Seconds	7.92	3.95	1.41	10.37	4.17	1.45
Mean wave direction (MWD) - Degrees	195	177	165	315	297	285
Directional standard deviation (DSD) - Degrees	79.5	35.5	8.1	80.4	26.6	8.7

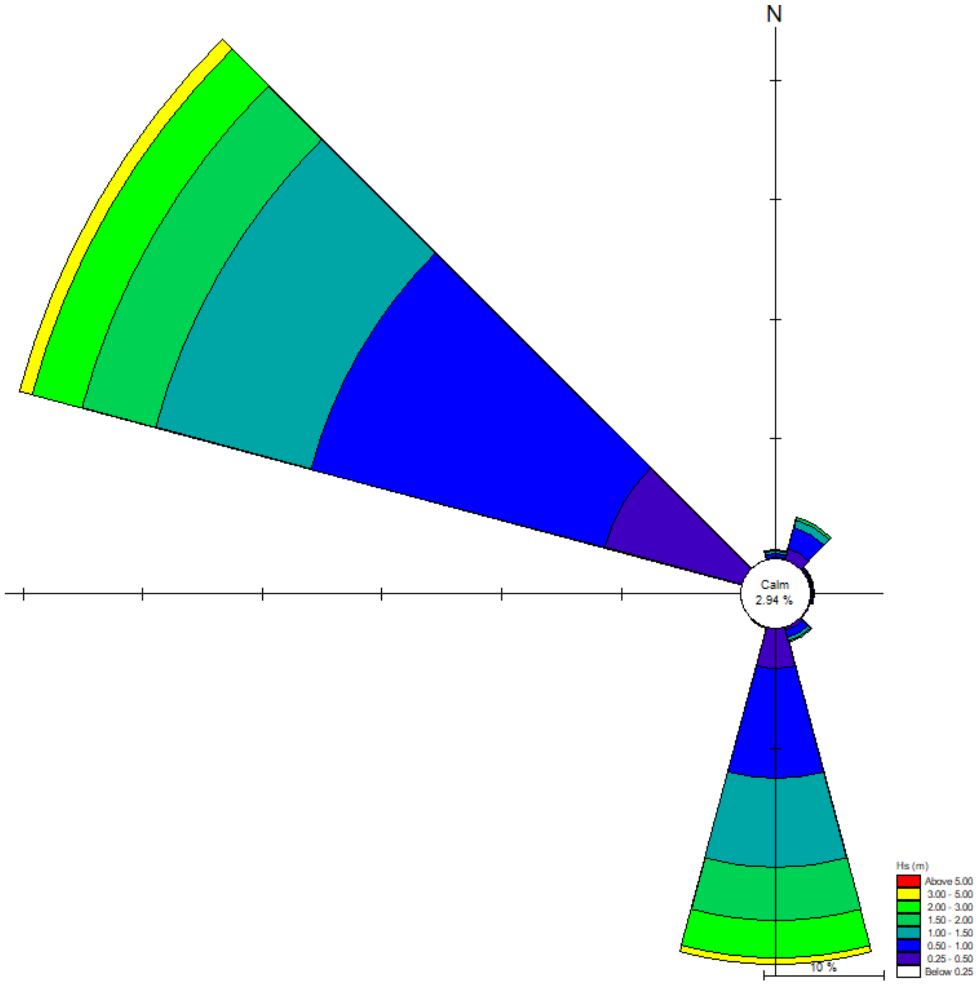

Figure 4.3: Wave Rose – Significant Wave Height by Directional Sector (1979 – 2019) Hindcast Location

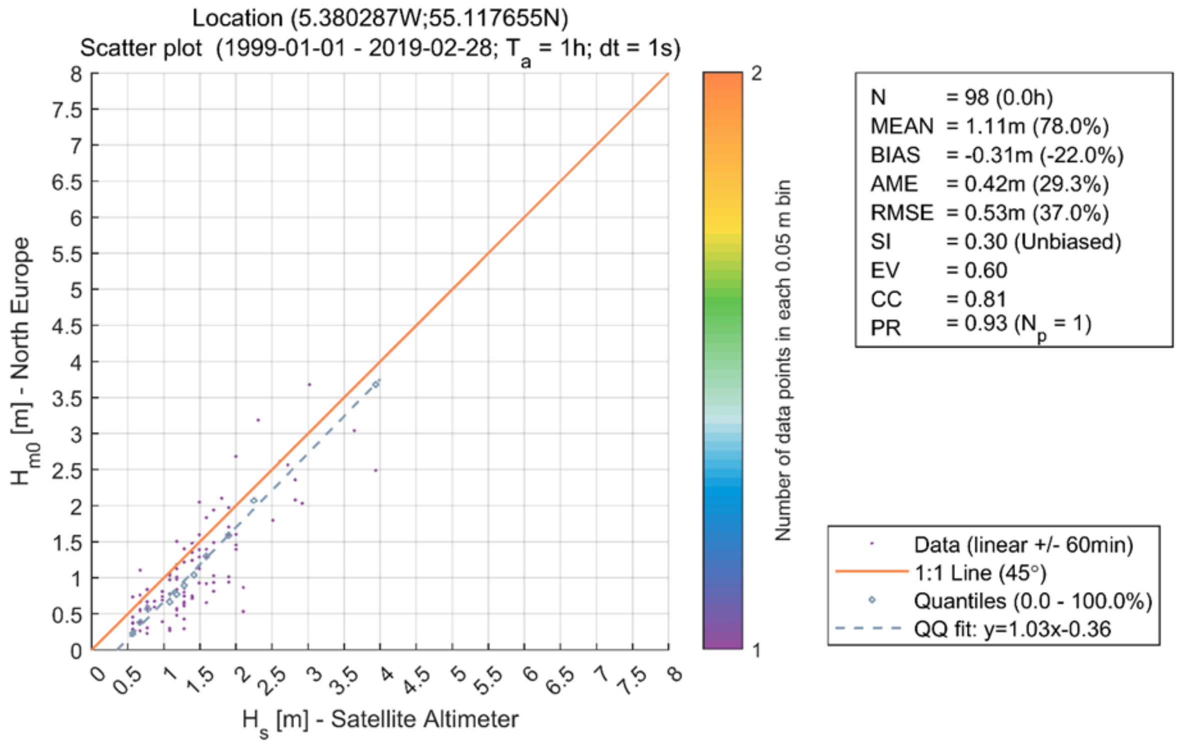

Figure 4.4: Comparison of DHI Wave Model with Satellite Altimeter Values

4.3 Wind Data

Hindcast wind data has also been obtained from the DHI Metocean Data Portal for both the offshore location 55°07'03.6"N 5°22'49.0"W, and for Hunterston Construction Yard, covering the period 01/01/1979 to 31/05/2019. The data is derived from the NCEP NOAA Climate Forecast System Reanalysis (CFSR) Global Wind Model. The hourly data includes the following components:

- Wind Speed at 10 m (WS10), [m/s]
- Wind Direction at 10 m (WD10), [Deg. N. (coming from)]
- Air Pressure at Mean Sea Level (Pair), [hPa]
- Air Temperature at 2 m (Tair2m), [°C]
- Clearness (Clearness), [%]
- Downward SW Radiation (DSWR), [W/m^2]
- Ice Concentration (icecon), [%]
- Sea Surface Temperature (SST), [°C]

A summary of the wind speed and direction data is presented in Table 4-2, whilst Figure 4.5 presents a wind rose diagram showing wind speed by directional sector for the offshore hindcast location (as shown in Figure 4.2). This analysis highlights the predominant wind direction for higher wind speeds is from 270°, whilst the 180° through to 330° sectors are also significant.

Table 4-2: Summary of Hindcast NCEP NOAA Wind Data

Wind Component	Offshore Location			Hunterston Construction Yard		
	Max. Value	Med. Value	Min. Value	Max. Value	Med. Value	Min. Value
Wind Speed at 10m (m/s)	28.6	6.1	0	33.1	6.3	0
Wind Direction at 10m (Degrees)	360	210	0	360	211	0

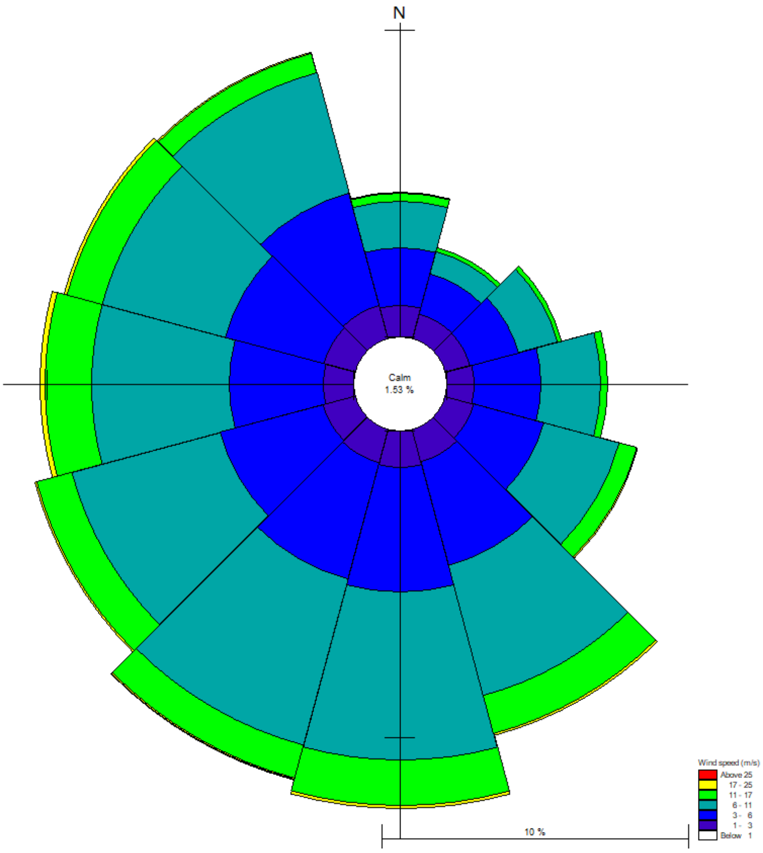

Figure 4.5: Wind Rose – Wind Speed by Directional Sector (1979 – 2019) Hindcast Location

4.4 Water Level Data

Hindcast tidal water level data has been obtained from the DHI global tide model, for the period 1st January 2023 to August 2023, providing 0.125 x 0.125 degree resolution, 15 minute interval, tidal level data. This data set covers a full tidal cycle of spring and neap tides, including large spring tides extending above MHWS and below MLWS.

4.5 Extreme Value Analysis

4.5.1 Tidal Water Level

Extreme sea levels have been predicted around the whole UK coastline and published by the Environment Agency as the Coastal Flood Boundary (CFB) conditions for the UK: Update 2018

(Environment Agency, 2019). These extreme levels include the effects of both tides and storm surge, and the effects of amplification within estuaries and sea lochs. The extreme sea levels, predicted at a point adjacent to Hunterston Sands, are 3.39 mAOD for the 1 in 50 year return period event and 3.65 mAOD for the 1 in 200 year return period event, as presented in Table 4-3.

Table 4-3: CFB Extreme Sea Levels Hunterston (CFB Location 2199)

Return Period (Years)	Water Level (mAOD)	Water Level (mCD)
1	2.67	4.29
2	2.79	4.41
5	2.96	4.58
10	3.09	4.71
25	3.26	4.88
50	3.39	5.01
100	3.52	5.14
200	3.65	5.27
1000	3.97	5.59

4.5.2 Offshore Wave Height

An extreme value analysis (EVA) has been undertaken utilising the in2extRemes[2] package for the R software environment. The in2extRemes R package is a specialised EVA software for weather and climate applications developed by the National Center for Atmospheric Research (NCAR), Boulder, Colorado.

The EVA process involves determining Annual Block Maxima values (by calendar year) for the dataset of interest, then fitting a Generalized Extreme Value (GEV) distribution function to the block maxima dataset. The GEV fit is analysed through review of diagnostic plots. From the GEV fit it is possible to obtain return level estimates for the parameter of interest, along with their normal approximation confidence intervals (95%).

The EVA has been undertaken using the block maxima method for the key 180 degree directional sector. Table 4-4 presents a summary of the return period significant wave heights for this sector. Figure 4.6 presents a summary of the EVA GEV fit diagnostics, including a plot of return period significant wave height.

Table 4-4: Significant Wave Height (Hm0) Extreme Value Analysis (180° Sector)

Estimate	Significant Wave Height (m) by Return Period (years)						
	1	2	5	10	25	50	200
Lower confidence	2.88	3.69	4.15	4.36	4.51	4.55	4.54
Central Estimate	3.22	3.95	4.41	4.62	4.83	4.95	5.12
Upper confidence	3.55	4.21	4.66	4.89	5.16	5.36	5.70

[2] Gilleland, E., & Katz, R. (2016). in2extRemes: Into the R Package extRemes - Extreme Value Analysis for Weather and Climate Applications. National Center for Atmospheric Research, NCAR/TN-523+STR, 102 pp. doi:10.5065/D65T3HP2

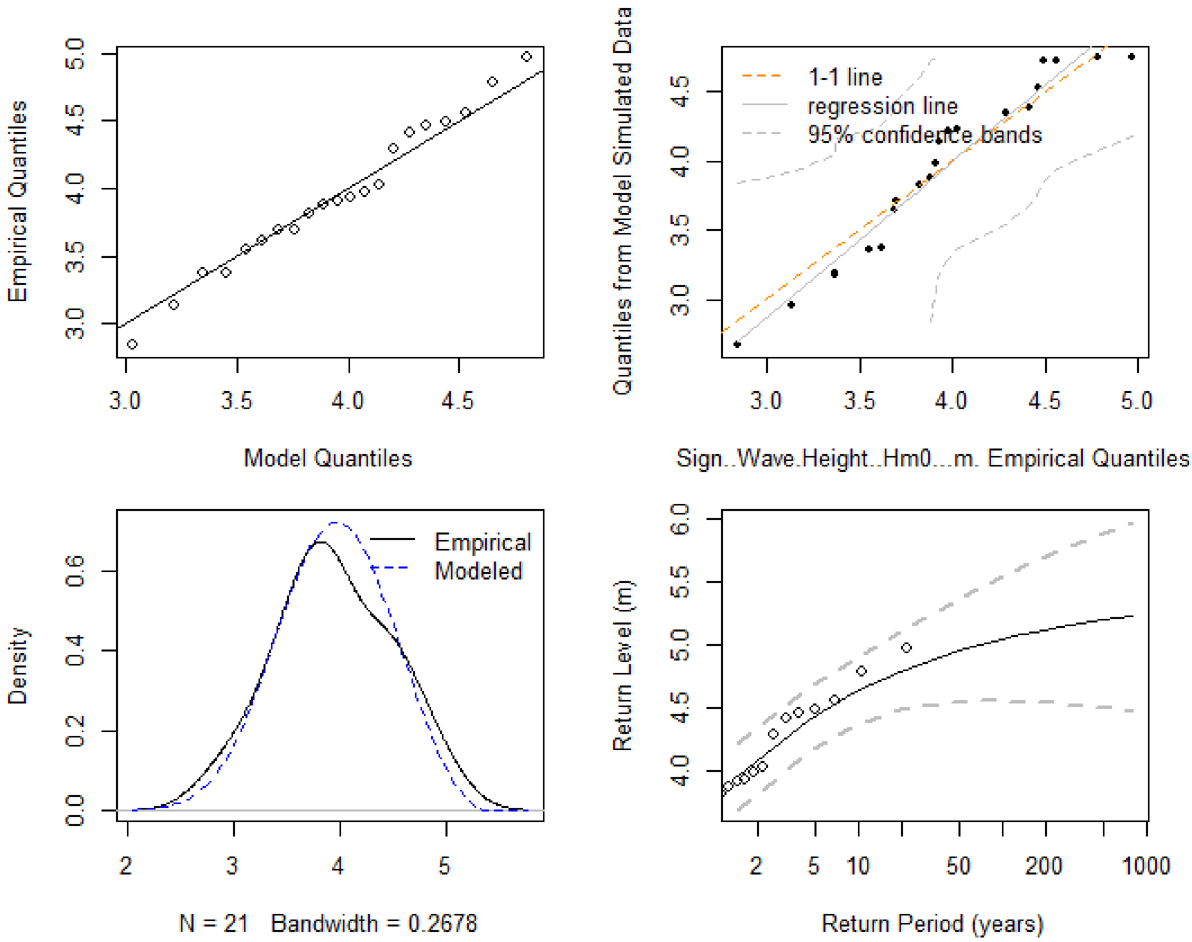

Figure 4.6: EVA Fit Diagnostics for 180° Significant Wave Height at DHI Hindcast Location

4.5.3 Wind Speed

An EVA has been undertaken on the whole spectrum NCEP NOAA wind dataset described in section 4.3, utilising the in2extRemes package for the R software environment[2].

The EVA process involves determining Annual Block Maxima values (by calendar year) for the dataset of interest, then fitting a Generalized Extreme Value (GEV) distribution function to the block maxima dataset. The GEV fit is analysed through review of diagnostic plots. From the GEV fit it is possible to obtain return level estimates for the parameter of interest, along with their normal approximation confidence intervals (95%). Table 4-5 presents a summary of the EVA by directional sector for key return periods, showing that the highest wind speeds occur from the 270° sector, whilst Figure 4.7 shows the associated fit diagnostics including confidence intervals for the 180° sector.

Table 4-5: Summary of EVA Return Period Directional Wind Speed at DHI Hindcast Location

Return Period (Years)	Wind Speed at Offshore Hindcast Location (m/s)					
	180°	210°	240°	270°	300°	330°
1	15.8	14.7	15.6	17.2	16.6	14.3
2	18.4	18.3	19.8	20.2	19.9	17.2
5	20.3	21.0	22.6	22.7	21.8	19.5
10	21.4	22.5	24.1	24.3	22.7	20.9
25	22.5	24.2	25.6	26.1	23.5	22.5
50	23.3	25.4	26.6	27.4	23.9	23.6
200	24.4	27.2	28.0	29.8	24.4	25.5

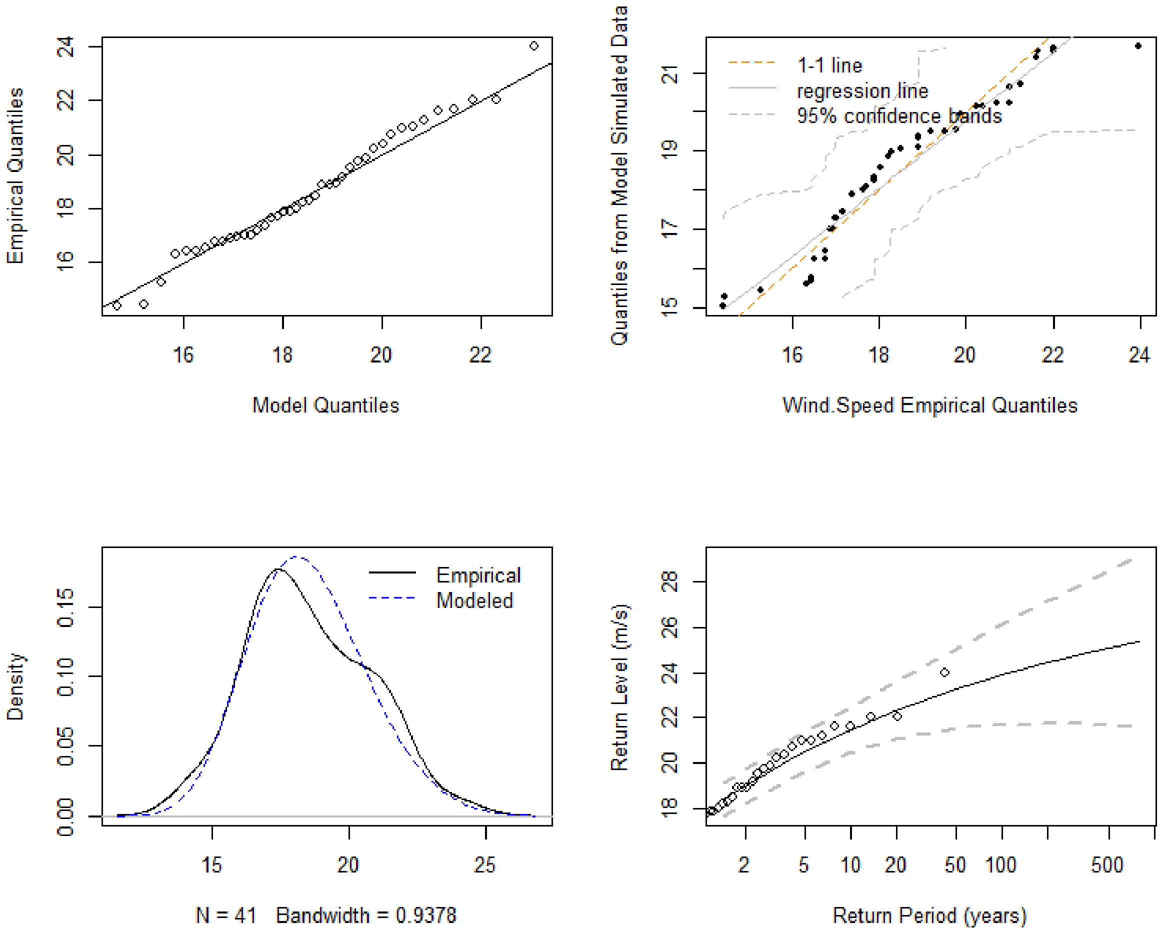

Figure 4.7: EVA GEV Fit Diagnostics for 180° Wind Speed at DHI Offshore Hindcast Location

4.6 Joint Probability of Extreme Values

4.6.1 Joint Probability Methodology

Joint probability analysis is used to predict the probability of occurrence of events in which two or more partially dependent variables have high or extreme values. The DEFRA Join-Sea joint probability methodology[3] has been used to define appropriate extreme conditions for this project. The desk study approach adopted relies on correlation parameters for combinations of variables including sea level and wave height.

The following steps are involved in the application of the methodology:

- Select the variables and any conditions attached to those variables;
- Decide how the variables will be represented;
- Obtain extreme values for each variable;
- Obtain the level of dependence between the variables;
- Apply the desk study approach; and
- Apply the results of the desk study approach.

4.6.2 Dependence of Variables

In order to apply the Join-Sea joint probability method it is necessary to evaluate the dependence between the parameters of interest. For sea level and wave height these dependencies have been computed within the DEFRA Join-Sea joint probability report around the mainland of the UK in the form of correlation parameters, as shown in Figure 4.8.

The Join-Sea guidance[4] highlights that where wave transformation modelling is being undertaken as part of the study, then an offshore joint probability analysis is preferable in the absence of detailed nearshore wave conditions. For offshore joint probability analysis the dependence is purely meteorological, and therefore representative of a larger area. Therefore, in the case of this study, in the absence of nearshore wave measurements, and with wave transformation modelling being undertaken, it is considered that offshore joint probability analysis is preferable.

As outlined in section 4.2, offshore hindcast data has been obtained. This offshore data location is positioned within an area where wave height and sea level are considered to be strongly correlated (Millport - Figure 4.8), and a correlation coefficient (ρ) of 0.55 is specified.

When generating wave transformation simulations the extreme value analysis undertaken on the offshore wind data will be used to provide the concurrent wind data i.e. co-incident occurrence of 5 year return period wave and wind. Model sensitivity to wind direction will be considered, with model runs undertaken to examine the impact of varying wind and wave directions.

[3] Hawkes, P. J. (2005a). Joint Probability: Dependence Mapping and Best Practice: Technical report on dependence mapping. R&D Technical Report FD2308/TR1. Defra
[4] Hawkes, P. J. (2005b). Use of Joint Probability Methods in Flood Management; A Guide to Best Practice (No. FD2308/TR2). London: Defra

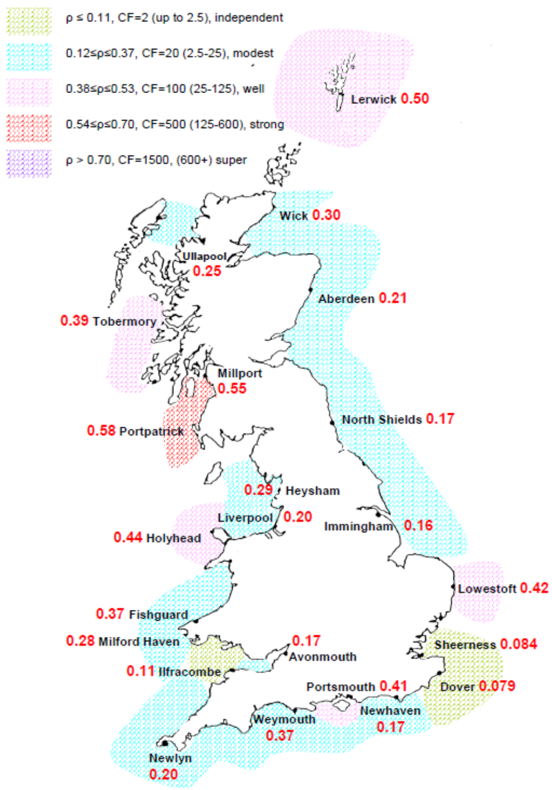

Figure 4.8: Join-Sea sea level and wave height correlation parameters

4.6.3 Combined Offshore Extreme Water Level and Waves

Joint probability calculations have been undertaken with use of the DEFRA spreadsheet model, with calculated extreme values of water level and significant wave height required as inputs. The output is a series of combinations of water level and wave height with the specified joint probability of exceedance, as shown in Table 4-6 and Table 4-7. It is assumed that directional wind speed with the return period of the waves will also occur at the same time as the joint wave and water level event. All return period values of less than 1 year have also been derived by extrapolation in the DEFRA Joint Probability Assessment (JPA) spreadsheet model.

Table 4-6: Extreme Sea Level and Waves Joint Exceedance Return Period – Marginal Return Periods

Marginal return period for present-day sea level (years)	Joint Return Period (Years)					
	2	5	10	25	50	200
	Marginal return period for offshore significant wave height (years)					
0.16	0.52	1.91	5.07	18.45	49.05	200.00
0.5	0.17	0.61	1.62	5.90	15.69	110.93
1	0.08	0.30	0.81	2.95	7.85	55.46
2	0.04	0.15	0.41	1.48	3.92	27.73
5		0.06	0.16	0.59	1.57	11.09
10			0.08	0.30	0.78	5.55
25				0.12	0.31	2.22
50					0.16	1.11
200						0.28

Table 4-7: Joint Exceedance Return Period Extreme Sea Levels and Waves

Present-day sea level (mAOD)	Joint Return Period (Years)					
	2	5	10	25	50	200
	Offshore Significant Wave Height (m)					
2.32	2.54	3.90	4.41	4.76	4.95	5.12
2.53	1.34	2.70	3.73	4.46	4.72	5.05
2.67	0.61	1.97	3.00	4.15	4.55	4.96
2.79	0.20	1.24	2.27	3.63	4.29	4.85
2.96		0.27	1.30	2.66	3.69	4.64
3.09			0.57	1.93	2.96	4.44
3.26				0.97	2.00	4.00
3.39					1.27	3.33
3.65						1.87

4.7 Future Climate

4.7.1 UK Climate Projections

The UK government has published a range of climate projection reports and data for use in the assessment of climate change risks to help plan adapting to a changing climate. The latest set of comprehensive reports produced by UK Climate Projections (UKCP18) was published in 2018 and provides future climate projections for land and marine regions as well as observed (past) climate data for the UK.

The climate projections are presented for a range of different scenarios or Representative Concentration Pathways (RCPs), which reflect different assumptions on future economic, social and physical changes to our environment that will influence climate change. The UKCP18 predictions for carbon dioxide concentrations, along with resulting changes in global mean surface temperatures for the three main RCP scenarios are shown in Figure 4.9.

Under the United Nations Climate Change Paris Agreement the UK is committed to attempt to hold the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit warming to 1.5°C. These targets are in line with those allowed for within RCP 2.6, or the lower end of RCP 4.5, in terms of median global temperature increase by 2100. In terms of Scottish guidance, the Scottish Environment Protection Agency (SEPA) advise that when considering flood risk, a precautionary approach should be adopted and the UKCP18 RCP 8.5 (95th percentile) scenario should be considered.

The RCP predictions for mean sea level change based on an average of UK ports, along with the spatial pattern of sea level change around the UK coastline at year 2100 is shown in Figure 4.10. Review of these predictions highlights that Hunterston is within a zone of lower sea level change in a UK context.

4.7.2 Tidal Water Levels

The UKCP18 future projections of relative sea-level rise were obtained for Millport for the period 2007 to 2100 for the RCP 8.5 scenario. The 95th percentile projections of sea level rise from 2007 to 2050 is

+0.28 m, which are considered to provide an appropriate time period for the proposed works at Hunterston. The effect of this at Southannan Sands in terms of low water extents, would be to shift the Lowest Astronomical Tide extent landwards by between 4 – 125 m, and shift the mean low water spring tide extent landward by between 10 – 185 m, as shown in Figure 4.11. In terms of wider projections beyond this timescale, the projected sea level rise from 2007 to 2080 for this scenario is +0.62 m.

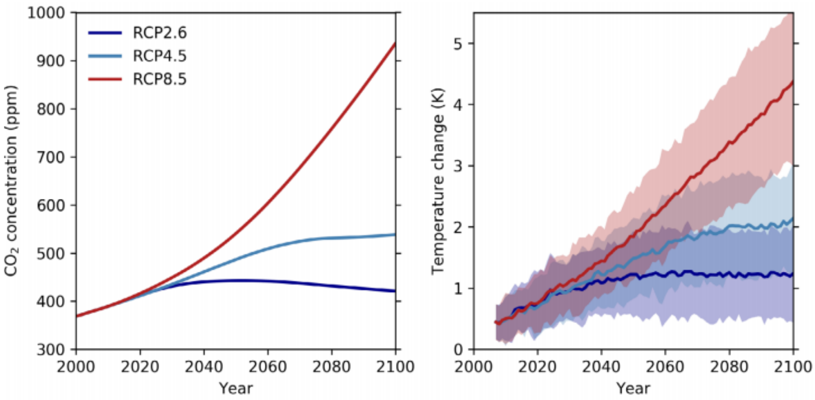

Figure 4.9: UKCP18 RCP predictions for CO2 (left) and global mean surface temperature change (right)

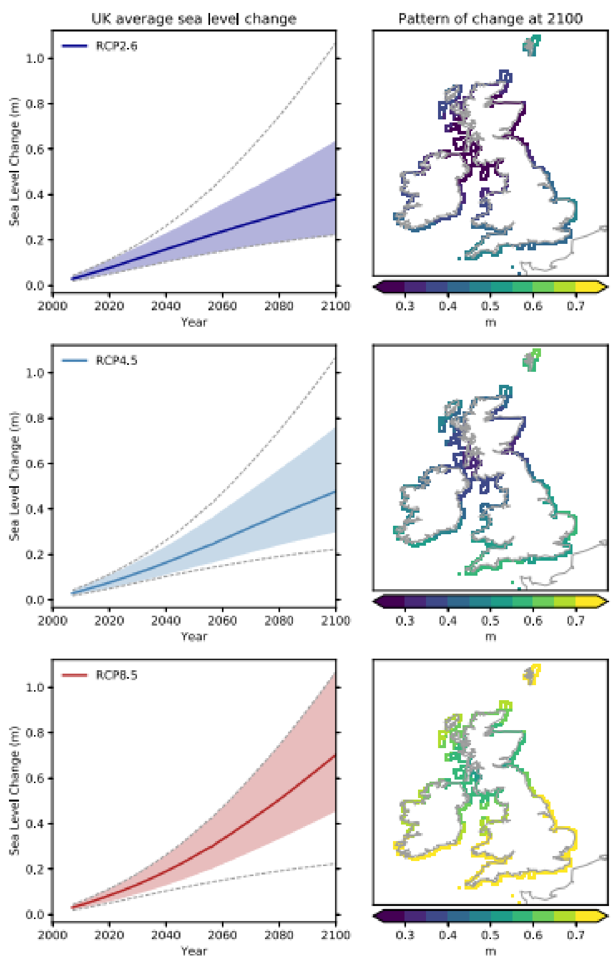

Figure 4.10: UKCP18 sea level change based on average of UK ports (left) and spatial change at 2100 (right)

Figure 4.11: Potential Change in Low Water Extents as a Result of a +0.28 m Sea Level Rise to 2050

4.7.3 Wind

The UKCP18 wind speed analysis concludes that there are no compelling trends in storminess, as determined by maximum gust speeds, from the UK wind network over the last four decades. The global projections over the UK show an increase wind speeds over the UK for the second half of the 21st century for the winter, associated with an increase in frequency of winter storms over the UK, while overall there is no trend in the wind speed over the UK.

The Marine Climate Change Impacts Partnership (MCCIP)[5] highlights the poleward shift in the storm track since the 1990s and an increase in number of storms, but notes that the mechanisms are poorly understood, and that natural variability will likely continue to dominate storm conditions for the next few decades.

[5] Marine Climate Change Impacts Partnership Website (https://www.mccip.org.uk/storms-and-waves)

4.7.4 Waves

The likely impact of climate change on wave height remains an area of significant uncertainty. The SEPA climate change guidance (SEPA, 2019) does not provide recommended allowances. It is noted that the size of waves at the coast is often limited by depth of water, and therefore sea level is likely to have a greater impact on wave overtopping. The guidance recommends that wave model sensitivity to offshore wave height is tested through an increase of 10 – 20% in offshore wave height to account for changes as a result of climate change.

MCCIP[5] notes that mean significant wave height has reduced in the north of the UK over the last 30 years, and that whilst the most severe waves could increase in height as a result of climate change, particularly under a high-emissions scenario, there could be an overall reduction in mean significant wave height in the North Atlantic.

5 COASTAL MODEL

5.1 MIKE 21 Platform

MIKE 21 FM is a modelling package based on a flexible mesh (FM) structure, developed by the Danish Hydraulic Institute (DHI). The modelling system has been developed for applications within oceanographic, coastal and estuarine environments. This study utilises the Hydrodynamic (HD) and Spectral Wave (SW) modules as further described below.

5.1.1 Hydrodynamic (HD) Module

The Hydrodynamic Module (HD) is the central computational component of the package, solving 2D shallow water equations. The module simulates unsteady flow taking account of bathymetry, sources and external forcing, it consists of continuity, momentum, temperature, salinity and density equations. The latest version of the software, MIKE 2024, has been used within this assessment.

5.1.2 Spectral Waves (SW) Module

Offshore to inshore wave transformation modelling has been undertaken using the MIKE 21 Spectral Waves (SW) module. MIKE 21 SW FM is a new generation spectral wind wave model based on unstructured meshes. The latest version of the software, MIKE 2024, has been used in this assessment. The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas.

5.1.3 Mud Transport (MT) Module

To simulate sediment plume dispersal from the proposed dredge campaign, the MIKE 21 Mud Transport (MT) module has been utilised. The mud transport module simulates the erosion and deposition of mud or sand/mud mixtures. It can be coupled with the MIKE 21 HD module, as described above, to assess the dispersion of spilled sediment from a dredger by tidal forcing.

Amongst the key features of the MIKE 21 MT module are:

- Multiple sediment fractions;
- Multiple bed layers;
- Flocculation;
- Hindered settling;
- Inclusion of non-cohesive sediments;
- Consolidation; and
- Capability to simulate morphological update of the seabed.

As MIKE 21 is a two-dimensional (depth-averaged) flow model, the simulation of the transport of material is averaged over depth.

5.2 Model Extent

The MIKE 21 coastal model extent is shown in Figure 5.1.

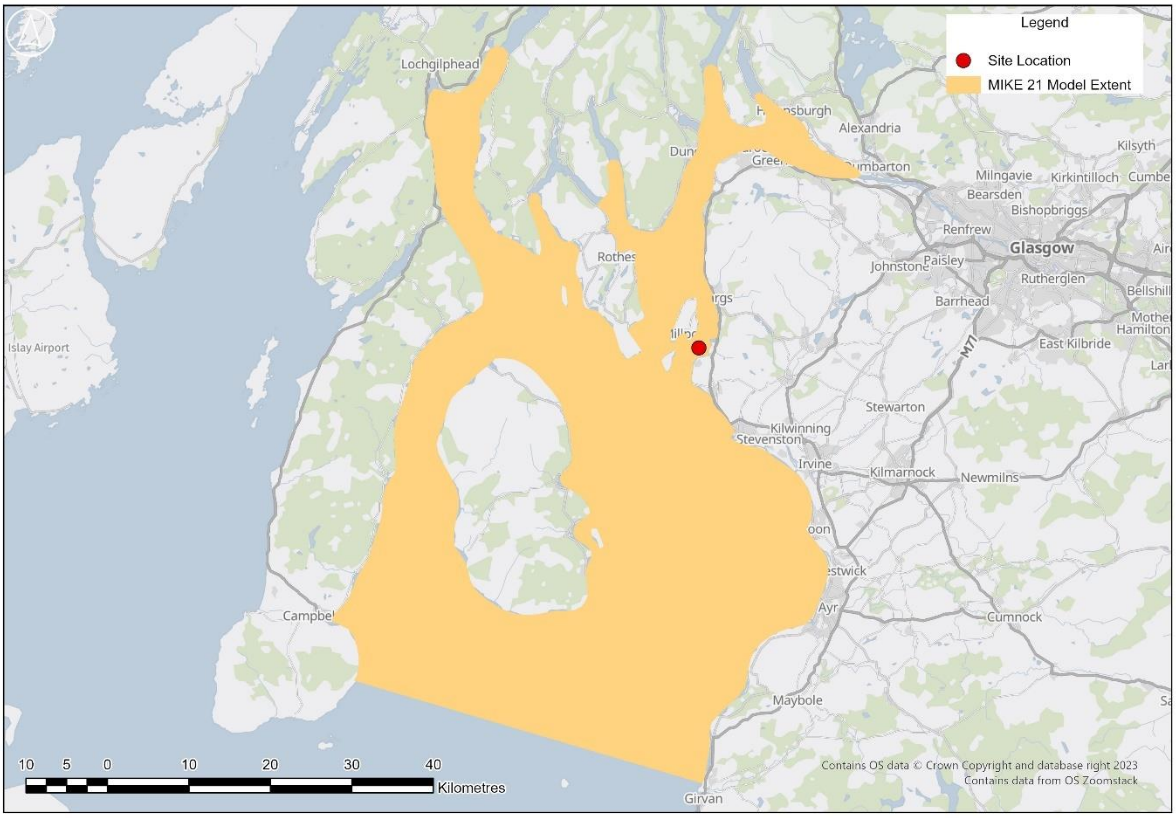

Figure 5.1: MIKE 21 Model Extent

5.3 Input Data

5.3.1 Bathymetry

The following bathymetric and topographic survey data has been used to develop the bathymetric model that underlies the model mesh used within the assessment:

- Aspect Surveys bathymetry survey - <1 metre resolution multibeam survey (2023);
- Aspect Surveys bathymetry survey - <1 metre resolution multibeam survey (2018);
- Ambios bathymetry survey data - <1 metre resolution (2009);
- MIKE C-Map Digital Bathymetry - Offshore Firth of Clyde;
- LiDAR Digital Terrain Model - 1 metre resolution (The Scottish Government, n.d.); and
- Aspect Surveys topographic survey of development area (2018).

The datasets have been used to create a combined Digital Terrain Model (DTM) for use within the hydrodynamic and wave modelling. A snapshot of the DTM with bathymetry displayed relative to Chart Datum is presented in Figure 5.2 for the whole model extent, and a zoom view of Hunterston Sands in Figure 5.3.

A post-development DTM has also been generated, encompassing all works including the new quay wall installation and dredge. Figure 5.4 presents a zoom view of the post-development DTM. The post-development DTM has identical input and setup to the baseline DTM in areas outside the development envelope.

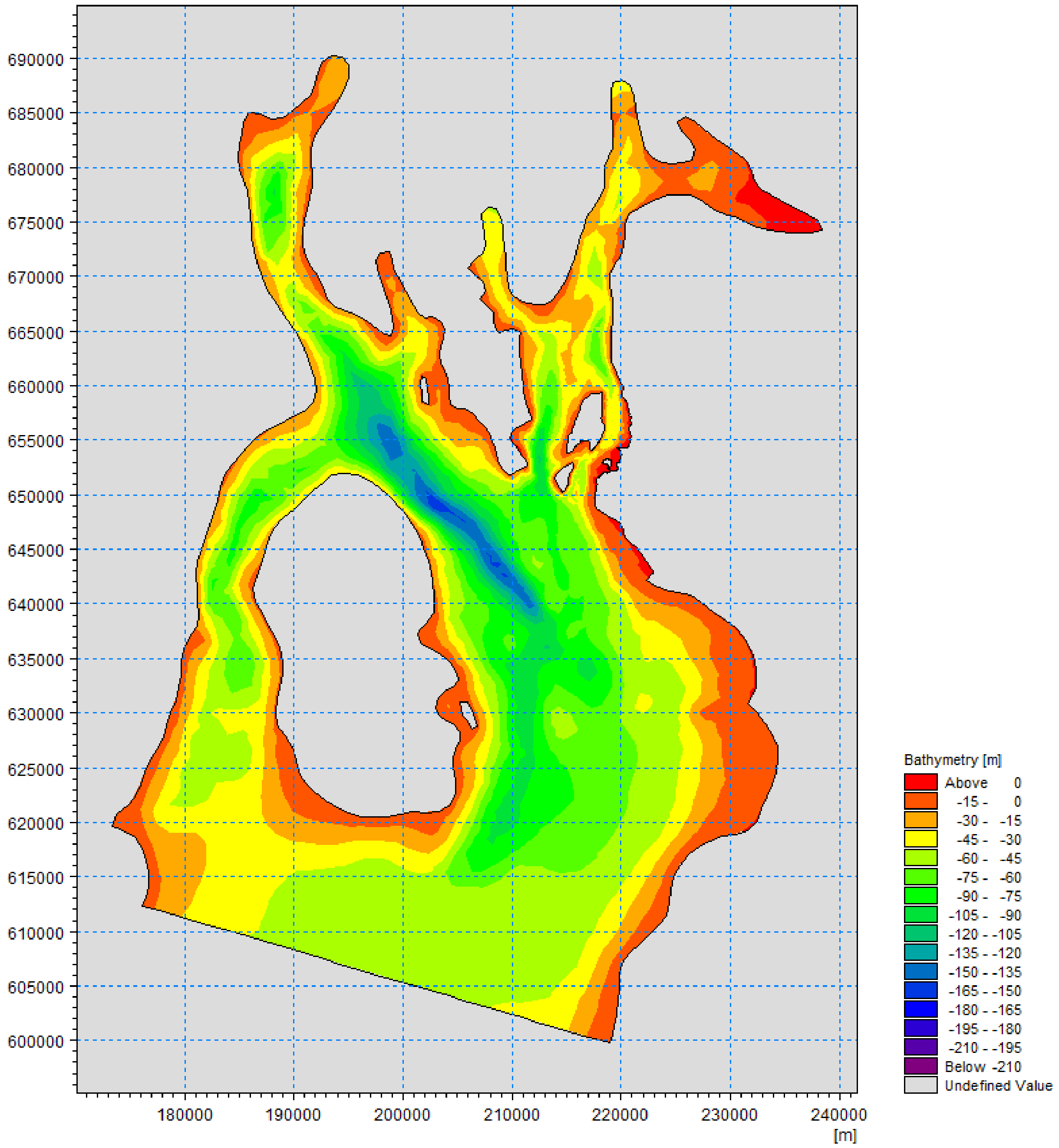

Figure 5.2: Baseline Bathymetry DTM – Full Model Extent

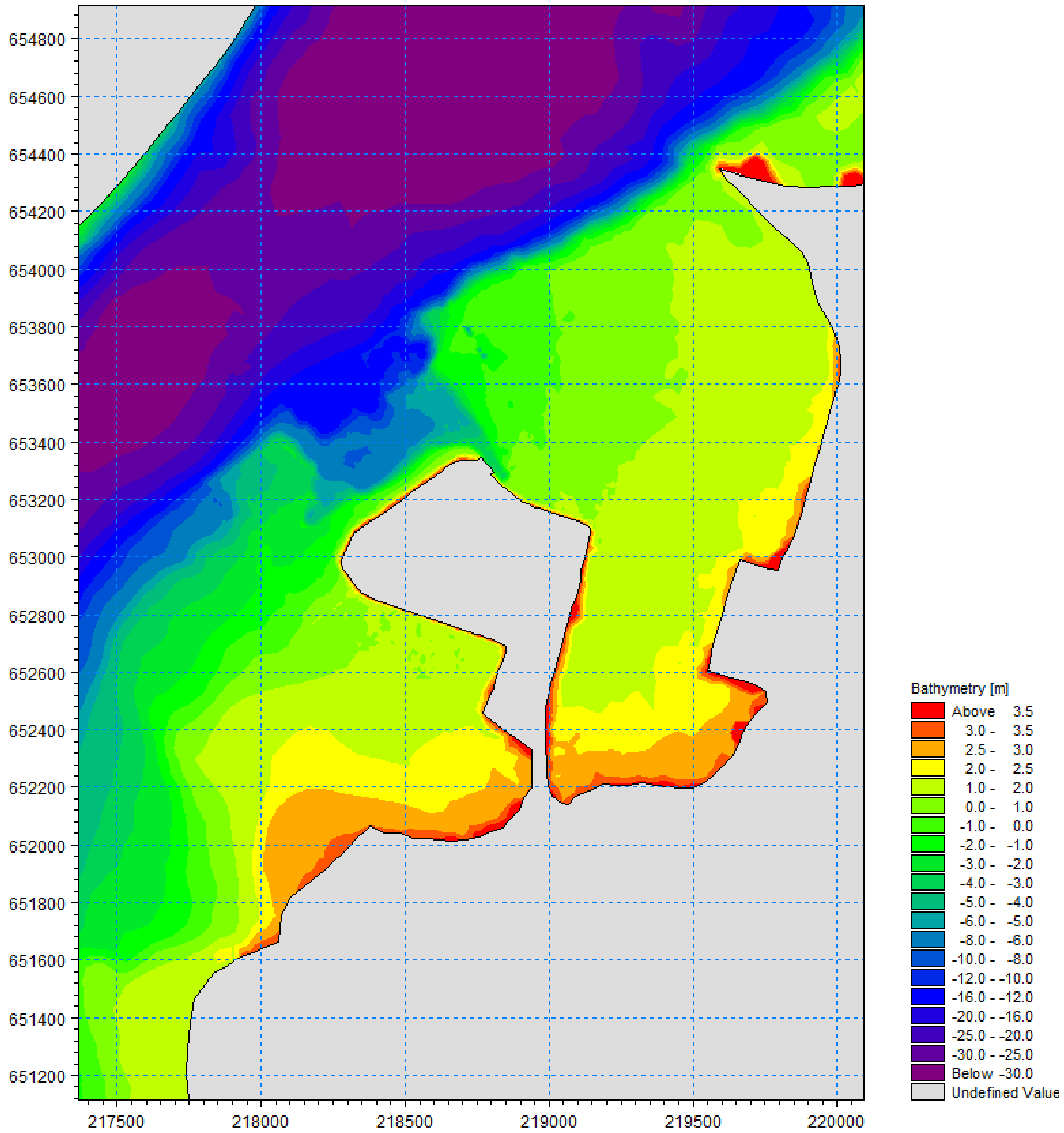

Figure 5.3: Baseline Bathymetry DTM – Site and Surrounds

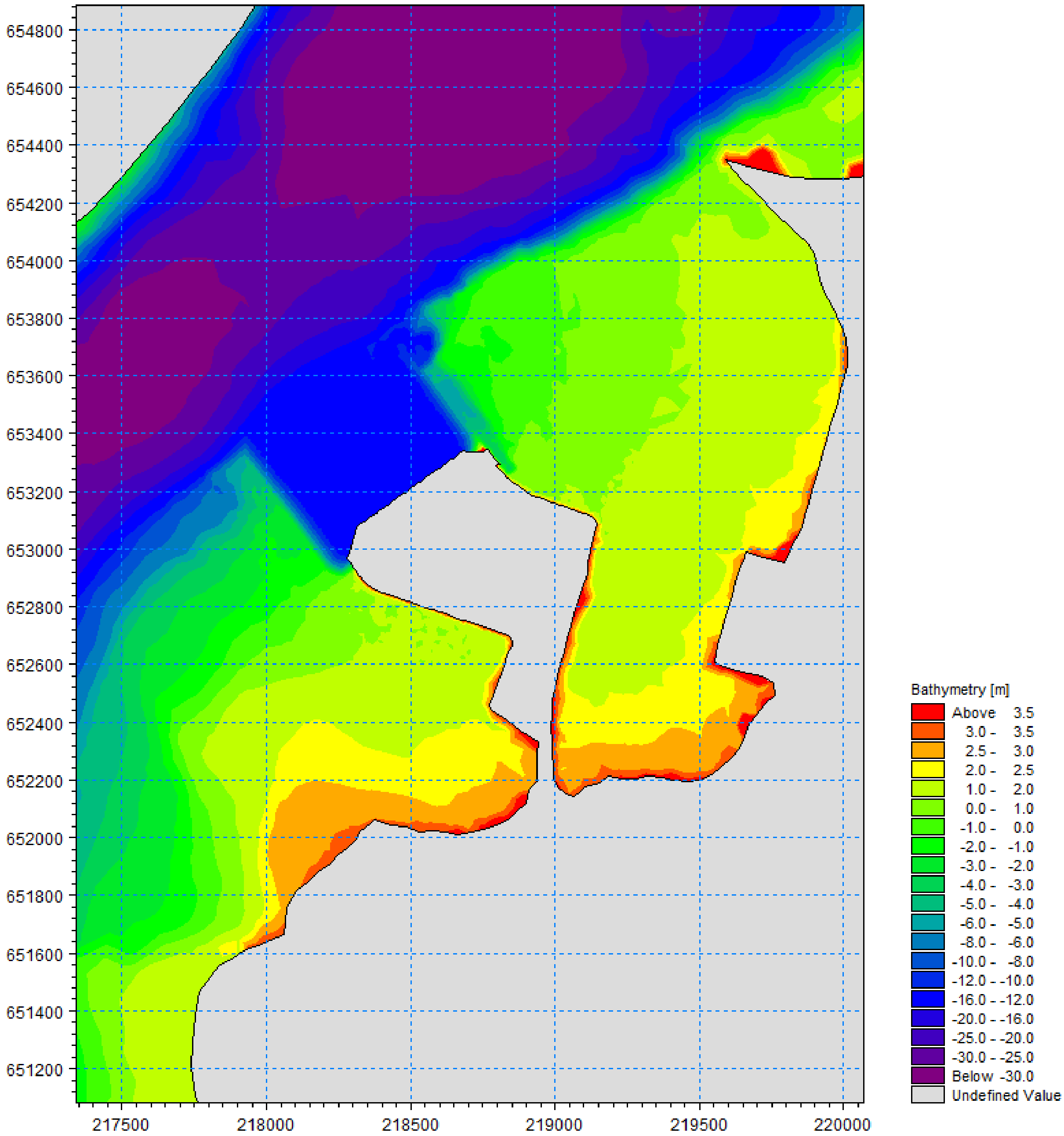

Figure 5.4: Post-Development Bathymetry DTM - Site and Surrounds

5.3.2 Tidal Boundary

There is one tidal boundary within the model extent, extending across the mouth of the Firth of Clyde, from Johnston's Point, Campbeltown in the west to Girvan in the east, as shown in Figure 5.1.

Tidal boundary conditions for the HD model have been extracted from the DHI MIKE 21 Global Tide Model. This provides 0.125 x 0.125 degree resolution, 15 minute interval, tidal level data along the open model boundaries.

5.3.3 Wind and Wave

The hindcast wave and wind data utilised in the modelling assessment is described in sections 4.2 and 4.3 respectively.

5.4 Model Mesh

The model utilises a flexible mesh to represent the offshore and coastal areas. The flexible mesh is composed of triangles of varying size and can therefore represent complex coastal alignments or bathymetry accurately.

The baseline model mesh extent and bathymetry are shown in Figure 5.5 below. The mesh has been generated using the bathymetric data described in section 5.3.1. The mesh has progressive refinement in resolution towards Hunterston, becoming finer in the area of interest, as shown in Figure 5.6. Finer mesh regions have also been used to represent areas in the immediate surrounds, where narrow channels and small islands influence tidal flows and wave propagation. A post-development version of the mesh is shown in Figure 5.7. Key characteristics of the model mesh are summarised in Table 5-1.

Table 5-1: Model Mesh Characteristics

Mesh Characteristic	Value
Number of elements	35,761
Number of nodes	18,462
Min. Z level (mCD)	-157.6
Max. Z level (mCD)	11.3
Max triangular area at Hunterston	50m^2 (approx. 7m resolution)

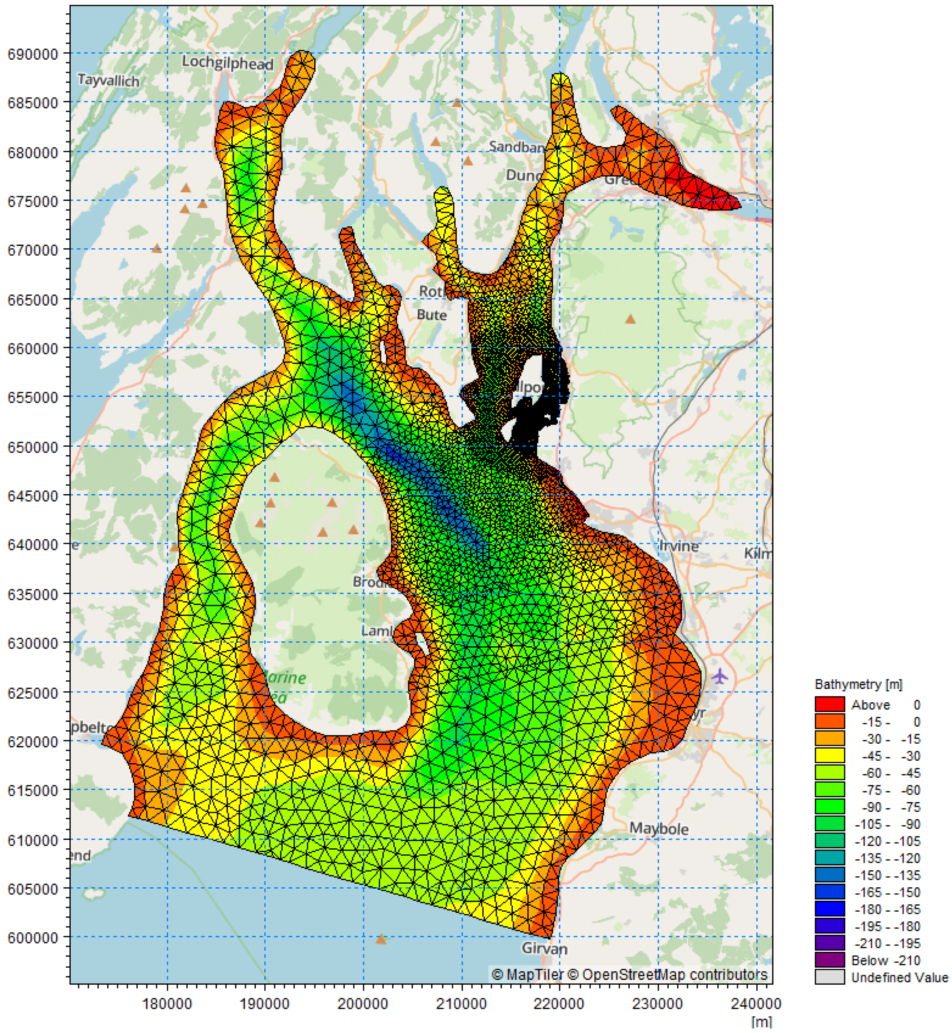

Figure 5.5: Overview of Model Mesh

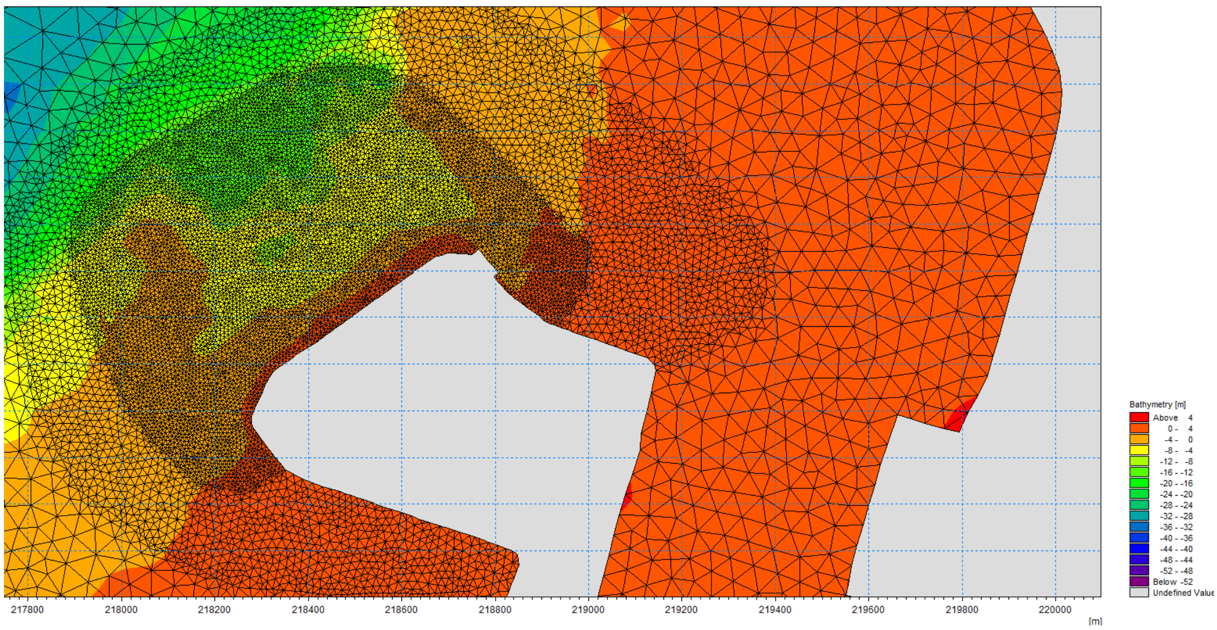

Figure 5.6: Baseline Model Mesh at Hunterston

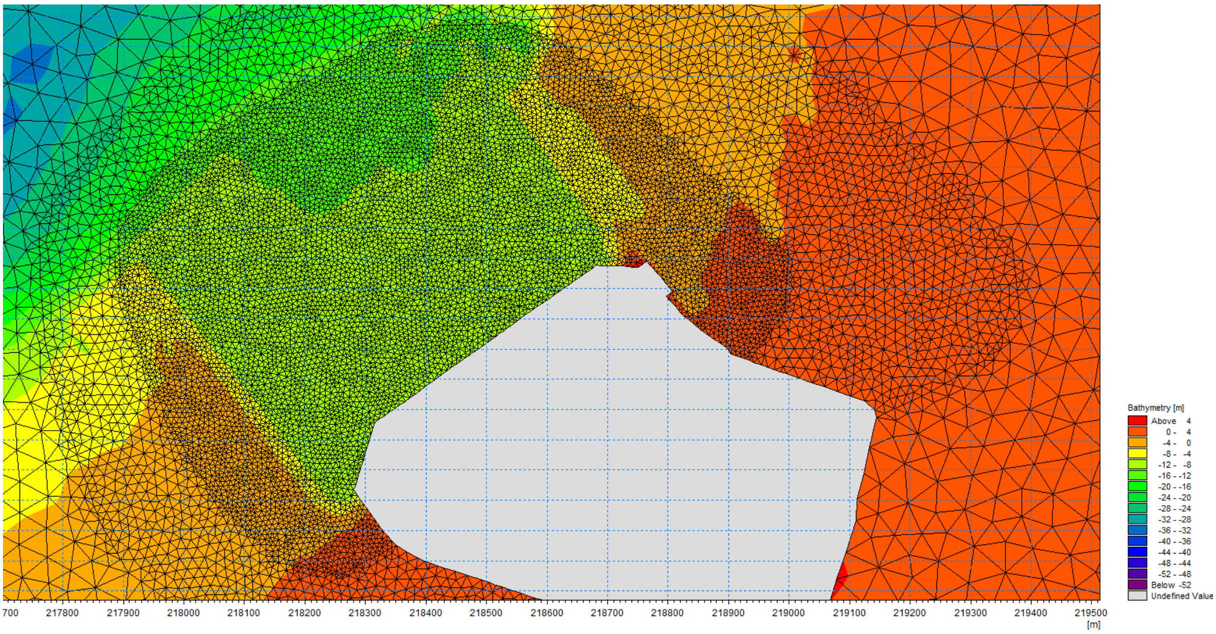

Figure 5.7: Post-Development Model Mesh at Hunterston

5.5 Computing Specification

The modelling has been undertaken with the following computing specification:

- Dell Precision 7960 Tower:
    - 255GB RAM;
    - Utilising 28 Cores – Intel Xeon CPU (2.5GHz);
    - Windows 11 Pro 64-bit operating system.

5.6 Model Setup

5.6.1 HD Model Setup

Further details of the MIKE 21 FM HD model setup are provided below:

- For each model simulation the modelled extent includes the entire mesh as described in section 5.4;
- Open boundary time-varying tidal water level conditions have been derived from the DHI global tide model as described in section 5.3.2;
- Further model parameters are detailed below:
    - Simulation time-step interval: 300 s
    - Model solution technique: Higher order shallow water equations
    - Model solution time-step: Minimum (0.01 s) Maximum (30 s)
    - Drying depth: 0.005 m
    - Wetting depth: 0.1 m
    - Bed resistance: 32 $m^{(1/3)}$/s

5.6.2 SW Model Setup

Further details of the MIKE 21 SW model setup are presented below:

- For each model simulation the modelled extent includes the entire mesh as described in section 5.4;
- Model input data is described in section 5.3.3;
- The model applies the fully spectral and quasi stationary (time) formulations;
- Wave breaking, white capping and bed friction are included; and
- The model time step interval is 1,800 seconds.

5.6.3 MT Model Setup

A summary of the proposed configuration of the general settings within the MT module for the dredge dispersal simulations is presented in Table 1 below. The assumed parameters of the dredge applied within the MT simulations are outlined in Table 5-2 and Table 5-3.

Table 5-2: General Settings Applied to MIKE 21 MT Module

Setting	Description/Value	
Number of fractions	3 fractions: 1. Clay and silt 2. Sand 3. Gravel	
Number of bed layers	1	
Hydrodynamic conditions	2-dimensional flow from HD model (no wind forcing)	
Solution technique	Higher order	
Simulation period	132 days	
Output time interval	15 minutes	
Settling velocity	Fraction 1: Clay and silt	0.0007 m/s
	Fraction 2: Sand	0.0395 m/s
	Fraction 3: Gravel	0.0933 m/s
Critical shear stress	Fraction 1: Clay and silt	0.136 N/m^2
	Fraction 2: Sand	0.211 N/m^2
	Fraction 3: Gravel	0.360 N/m^2
Flocculation	Calculations included	
Wave forcing	Not included	
Dispersion	Scaled eddy viscosity formulation - constant	
Initial conditions	Layer 1: No bed thickness	
Dredging	Dredger spill included as per Table 2	
Other sources	None	
Morphological update	Not included	
Bathymetry	Baseline (pre-dredge)	

Table 5-3: Assumed Parameters of Dredge Applied to MIKE 21 MT Module

Variable	Quantity	Comments
Total dredge volume	1,546,660 m^3	Maximum Dredge Area
Dredger type	Trailing Suction Hopper	
Dredge campaign duration	130 days	24 hours operation
Dredge rate	11,897 m^3/day	Assumed constant

Variable	Quantity	Comments
Dredge sediment composition (based on 2019 SI results)	Fraction 1 – 25.6%	Clay and silt
	Fraction 2 – 68.9%	Sand
	Fraction 3 – 5.5%	Gravel
Density of material	1,800 kg/m^3	Assumed constant
Spill rate	5% of total material	The proportion of dredged material lost to water column
Dredger path	-	As per Figure 1

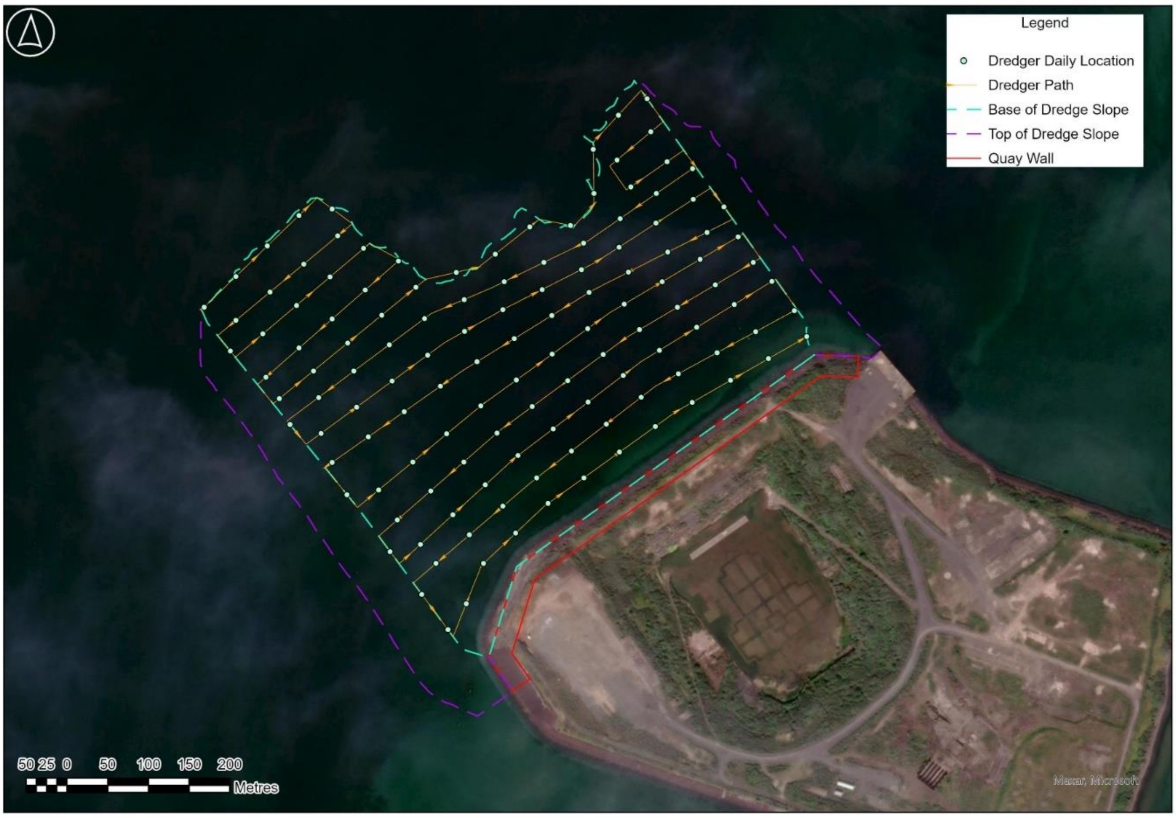

Figure 5.8: Indicative Dredger Path – Capital Dredge Scenario

5.7 Model Outputs

The MIKE 21 FM HD model simulations have been setup to produce results as both point and area outputs. The outputs include the following key parameters:

- Water surface elevation;
- Current speed;
- Current direction; and
- Bed shear stress.

The MIKE 21 SW model simulations have also been setup to produce results as both point and area outputs. The outputs include the following key parameters:

- Significant wave height;

- Maximum wave height;
- Peak wave period; and
- Mean wave direction.

For both models the area outputs are generated for the whole model extent, whilst point outputs have been generated at a number of identified locations within the model extent. Point output locations are described in Table 5-4 and shown in Figure 5.9.

Table 5-4: Model Point Output Locations

Location	Description	X	Y
Point 1	Dredge pocket south-west	218200	653200
Point 2	Dredge pocket centre	218400	653300
Point 3	Dredge pocket north-east	218600	653400
Point 4	Dredge pocket north-west	218300	653500
Point 5	Hunterston Sands north edge	218200	652800
Point 6	Southannan Sands south-west edge	219000	653500
Point 7	Main channel centre	218000	653900
Point 8	Millport Bay outer	216500	654200
Point 9	Southannan Sands south	219400	652800
Point 10	Hunterston Sands south	218400	652300
Point 11	Main channel north	219000	655000
Point 12	Main channel south	216500	652800
Point 13	Southannan Sands north	219600	653800
Point 14	Mussel bed – Southannan Sands	219203	652997
Point 15	Seagrass – Southannan Sands	219647	653200
Point 16	Oyster Farm – Fairlie Sands	219888	654385
Point 17	Seagrass – Fairlie Sands	220560	654464
Point 18	Seagrass – Hunterston Sands	218075	652292
Point 19	Bathing waters – Millport	216573	654891
Point 20	Cooling water intake – Hunterston B	217526	650684

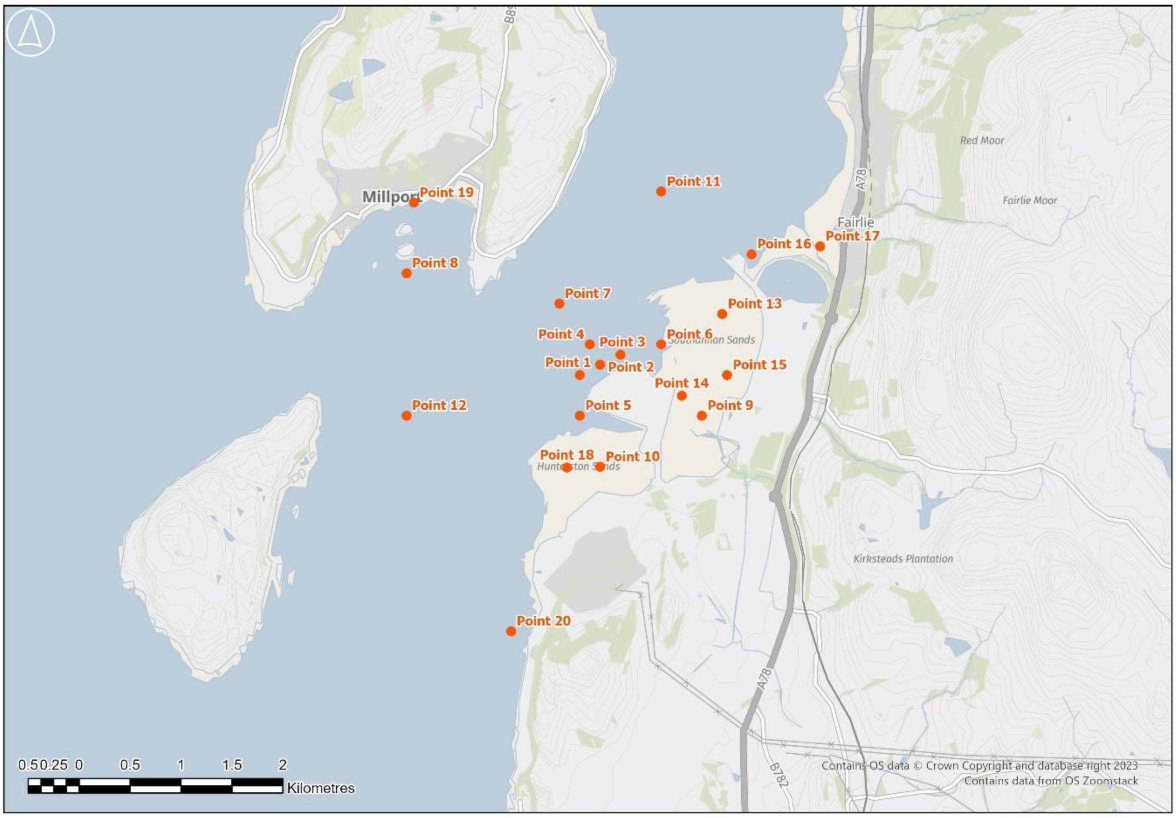

Figure 5.9: Model Point Output Locations

5.8 Model Validation

Validation of the model has been undertaken through comparison of baseline modelled tidal levels with Admiralty tide predictions[6] for the same tide, at Millport, as shown in Figure 5.10. This comparison highlights that the model predicts levels generally within 0.05m of the Admiralty predicted levels, with good correlation of phasing. Additionally, model results have been compared to gauged levels from the tidal gauge at Millport, again generally good correlation is seen between modelled and gauged levels and tidal phasing, noting that gauged levels will be subject to atmospheric forcing and other local factors.

Additionally, tidal current speeds predicted by the baseline model have been compared to annotated tidal stream speeds on UKHO hydrographic charts for Millport and surrounds, with model peak current speed predictions lying within the published range of current speed for the main tidal path through Hunterston Channel.

Given the results of the above validation exercise the model is therefore considered to perform well and is suitable for use within this assessment.

6 Admiralty Tide Tables – Volume 1B. UKHO, 2023.

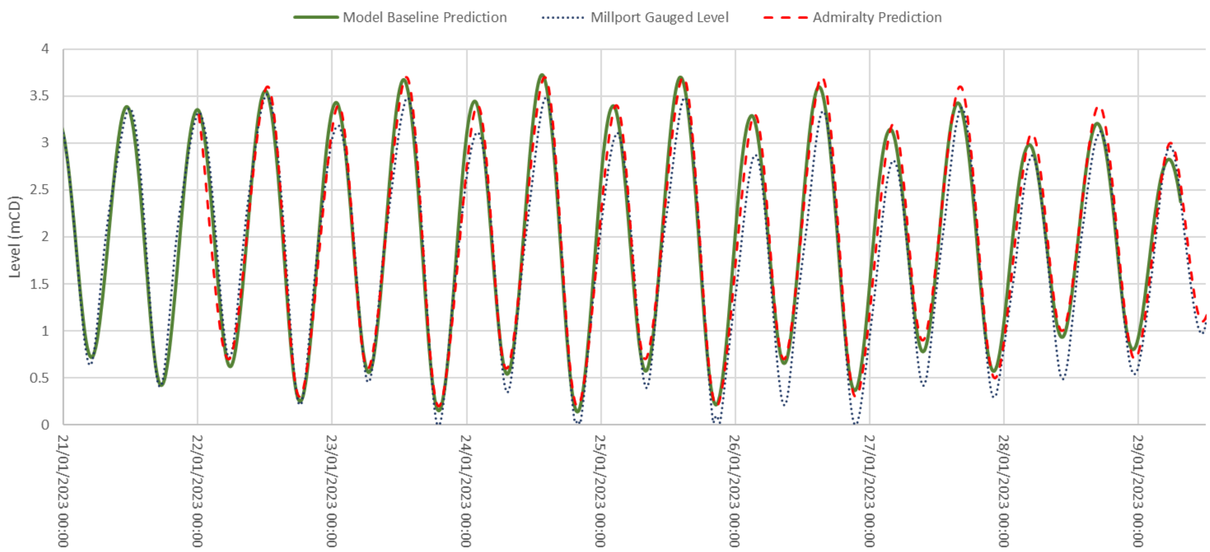

Figure 5.10: Comparison of Modelled (Green), Gauged (Blue Dot) and Admiralty Predicted (Red Dash) Water Levels at Millport

6 MODEL SIMULATIONS AND RESULTS

6.1 Model Simulations

The key model simulations undertaken using the MIKE 21 software platform are presented in Table 6-1.

Table 6-1: Model Simulations

Model Simulation	Description
HD1 (Baseline)	HD model simulating astronomical tidal cycle from January 2023 under existing (baseline) conditions. No wind or wave forcing.
HD2 (Post-development)	HD model simulating astronomical tidal cycle from January 2023 under proposed (post-development) conditions (max dredge envelope). No wind or wave forcing.
HD3 (Baseline plus wind)	HD model simulating astronomical tidal cycle from January 2023 under existing (baseline) conditions with wind forcing.
SW1 (Baseline 5yr RP wave)	Baseline SW model simulating 5 year Return Period wave and 5 year Return Period wind, both at 180 degrees from North, with constant Joint Probability (JP) water level (HAT).
SW2 (Baseline 5yr RP wave)	Baseline SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 210 degrees from North, with constant JP water level (HAT).
SW3 (Baseline 5yr RP wave)	Baseline SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 240 degrees from North, with constant JP water level (HAT).
SW4 (Baseline 5yr RP wave)	Baseline SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 270 degrees from North, with constant JP water level (HAT).
SW5 (Baseline 5yr RP wave)	Baseline SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 300 degrees from North, with constant JP water level (HAT).
SW6 (Baseline 5yr RP wave)	Baseline SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 330 degrees from North, with constant JP water level (HAT).
SW7 (Post-development 5yr RP wave)	Post-development SW model simulating 5 year Return Period wave and 5 year Return Period wind, both at 180 degrees from North, with constant JP water level (HAT).
SW8 (Post-development 5yr RP wave)	Post-development SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 210 degrees from North, with constant JP water level (HAT).
SW9 (Post-development 5yr RP wave)	Post-development SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 240 degrees from North, with constant JP water level (HAT).
SW10 (Post-development 5yr RP wave)	Post-development SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 270 degrees from North, with constant JP water level (HAT).
SW11 (Post-development 5yr RP wave)	Post-development SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 300 degrees from North, with constant JP water level (HAT).

Model Simulation	Description
SW12 (Post-development 5yr RP wave)	Post-development SW model simulating 5 year Return Period wave at 180 degrees from North, and 5 year Return Period wind at 330 degrees from North, with constant JP water level (HAT).
SW13 (Baseline early January 2023 hindcast)	Baseline SW model simulating 1 week of hindcast wind and wave data from early January 2023, with varying water level for the same period.
SW14 (Post-development early January 2023 hindcast)	Post-development SW model simulating 1 week of hindcast wind and wave data from early January 2023, with varying water level for the same period.
SW15 (Post-development 200yr RP wave)	Post-development SW model simulating 200 year Return Period wave at 180 degrees from North, and 200 year Return Period wind at 240 degrees from North, with constant JP water level.
SW16 (Post-development 200yr + CC RP wave)	Post-development SW model simulating future climate (2100) 200 year Return Period wave at 180 degrees from North, and future climate (2100) 200 year Return Period wind at 240 degrees from North, with constant future climate (2100) JP water level.
MT1 (Capital Dredge)	HD and MT model simulating the full capital dredge campaign with input parameters as per Table 5-2 and Table 5-3. Simulation extends for the period 2nd January 2023 to 14th May 2023.
MT2 (Capital Dredge – Wind/Wave Sensitivity)	HD and MT model sensitivity scenario simulating the initial days of the capital dredge campaign with wind and wave forcing derived from hindcast conditions as per SW13. All other input parameters as per Table 5-2 and Table 5-3.
MT3 (Maintenance Dredge)	HD and MT model simulating a maintenance dredge scenario extending just over 7 days, with an assumed dredge budget of approximately 86,000m^3. Other settings as per MT1, Table 5-2 and Table 5-3.

6.2 HD Model Results

6.2.1 Baseline (HD1)

Figure 6.1 presents a time-series plot of tidal water surface elevation at point output location 1, along with the corresponding current speed prediction at locations 1 (Dredge Pocket), 7 (Hunterston Channel) and 9 (Southannan Sands). Figure 6.2 presents an area plot of current speed at a model time-step mid spring ebb tide, whilst Figure 6.3 presents a corresponding plot mid spring flood tide. Review of these baseline HD model results shows that current speeds vary locally from above 0.5 m/s in the main tidal stream within the deeper water of Hunterston Channel, to less than 0.05 m/s in the shallow margins of Southannan Sands. Maximum current speeds in the proposed dredge area are just under 0.3 m/s. Highest current speeds are observed around mid-ebb and mid-flood during spring tides. The position of peak current speed in the main tidal stream varies between the flood and ebb tide. Neap tides bring reduced current speeds, whilst slack water dominates towards high and low water.

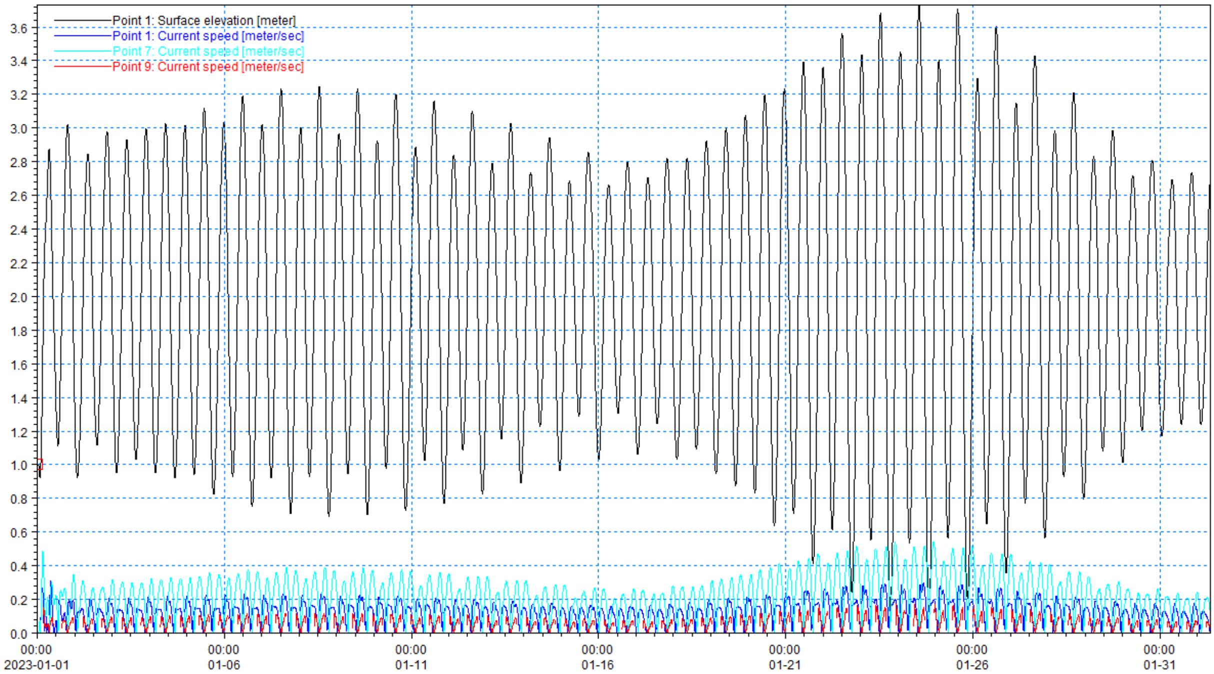

Figure 6.1: Baseline (HD1) Modelled Water Level and Current Speed at Selected Locations

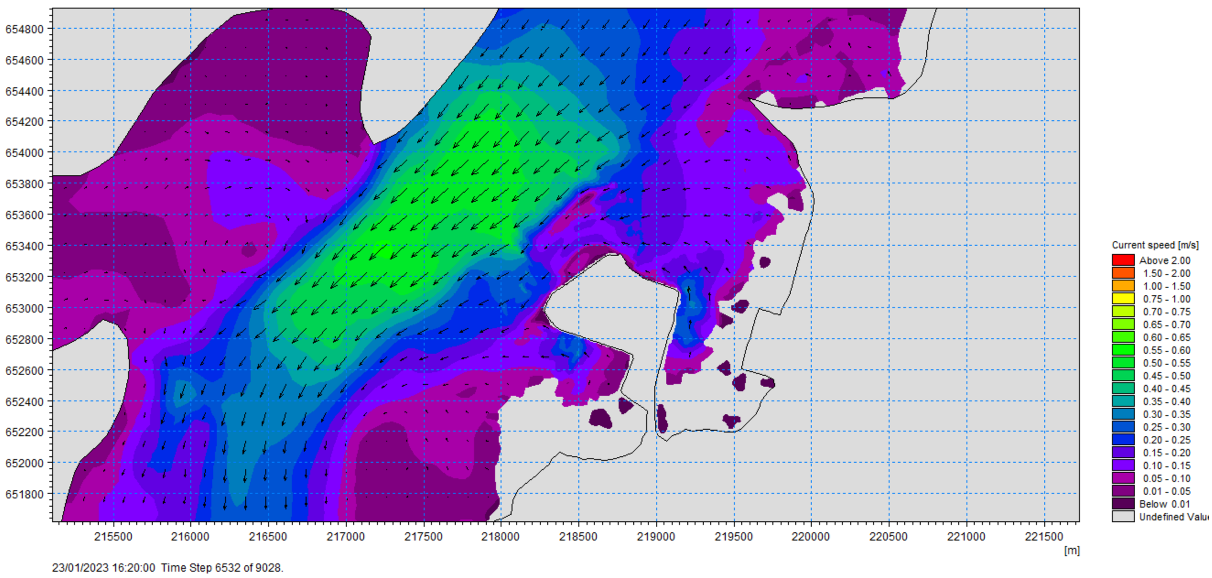

Figure 6.2: Baseline (HD1) Current Speed – Spring Tide Peak Ebb

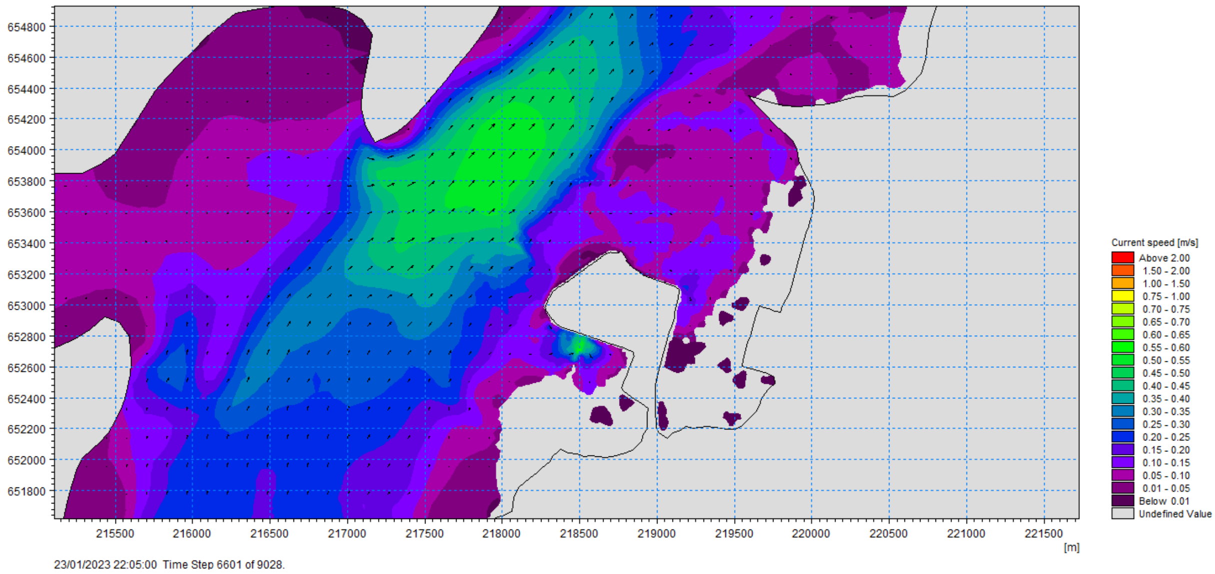

Figure 6.3: Baseline (HD1) Current Speed – Spring Tide Peak Flood

6.2.2 Post-Development (HD2)

Figure 6.4 presents a time-series plot of tidal water surface elevation at point output location 1, along with the corresponding current speed prediction at locations 1 (Dredge Pocket), 7 (Hunterston Channel) and 9 (Southannan Sands). Figure 6.5 presents an area plot of current speed at a model time-step mid spring ebb tide, whilst Figure 6.6 presents a corresponding plot mid spring flood tide. Review of these post-development HD model results shows that, as per the baseline results described in section 6.2.1, current speeds vary locally from above 0.5 m/s in the main tidal stream within the deeper water of Hunterston Channel, to less than 0.05 m/s in the shallow margins of Southannan Sands. Maximum current speeds in the proposed dredge area are just under 0.3 m/s. Highest current speeds are observed around mid-ebb and mid-flood during spring tides. The position of peak current speed in the main tidal stream varies between the flood and ebb tide. Neap tides bring reduced current speeds, whilst slack water dominates towards high and low water.

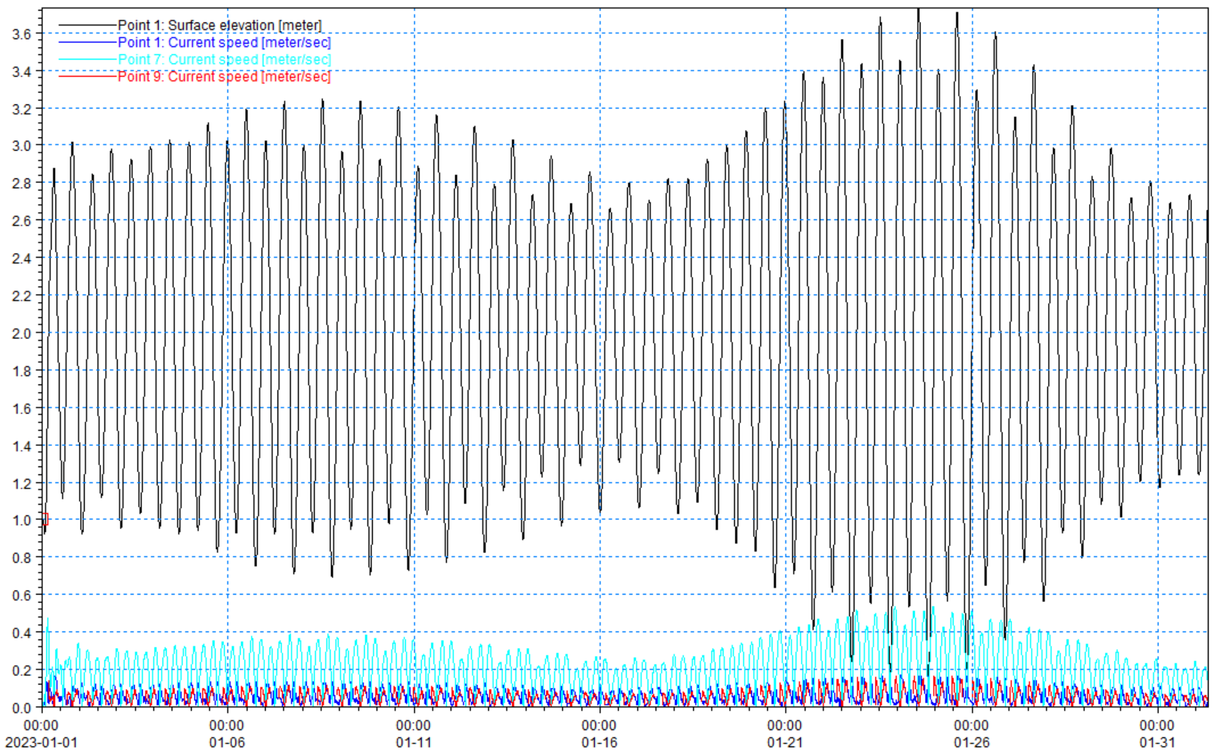

Figure 6.4: Post-Development (HD2) Modelled Water Level and Current Speed at Selected Locations

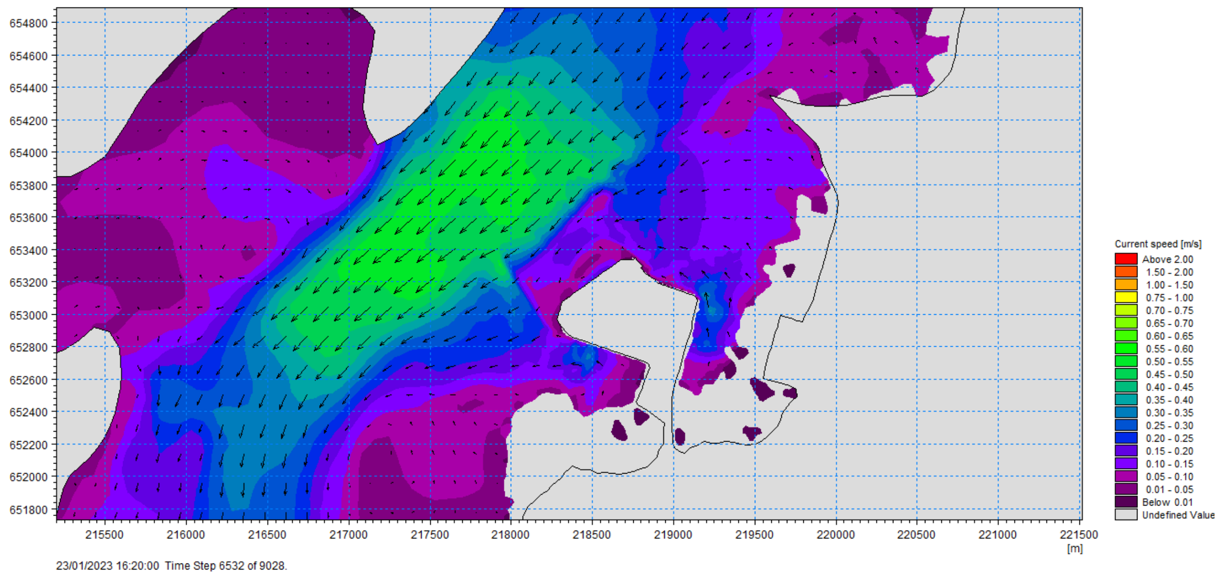

Figure 6.5: Post-Development (HD2) Current Speed – Spring Tide Peak Ebb

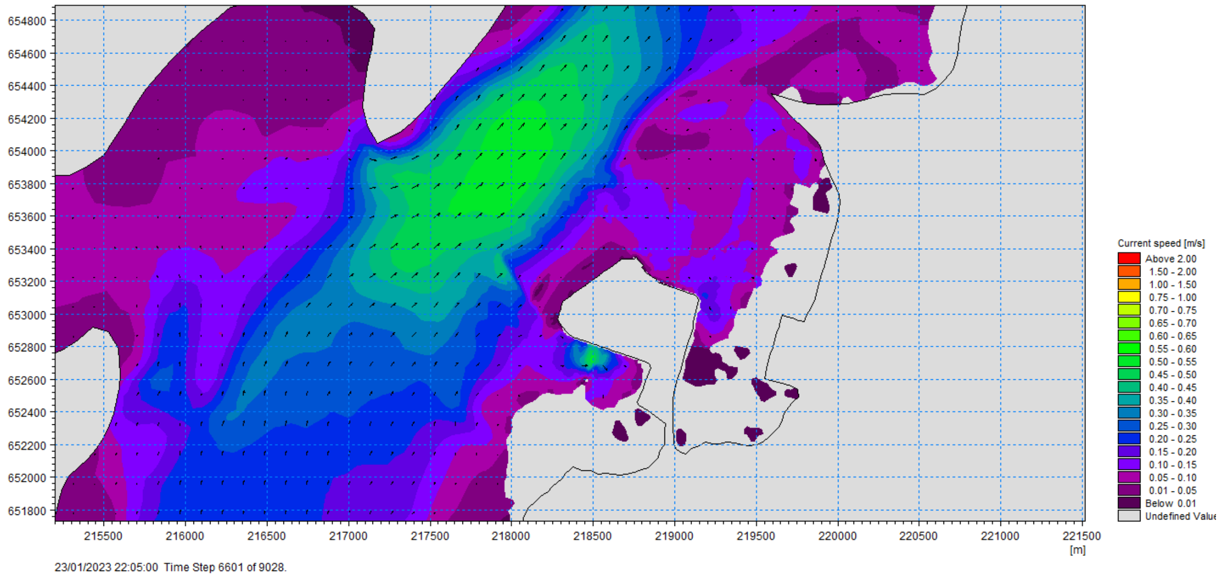

Figure 6.6: Post-Development (HD2) Current Speed – Spring Tide Peak Flood

6.2.3 Baseline Wind Sensitivity (HD3)

Figure 6.7 presents a time-series plot of tidal water surface elevation at point output location 1, along with the corresponding current speed prediction at locations 1 (Dredge Pocket), 7 (Hunterston Channel) and 9 (Southannan Sands). Figure 6.8 presents an area plot of current speed at a model time-step mid spring ebb tide, whilst Figure 6.9 presents a corresponding plot mid spring flood tide. Review of these wind sensitivity scenario results highlights similar patterns in current speed as observed with HD1 and HD2, but with some localised variations and fluctuations present, as further described in section 6.2.4.

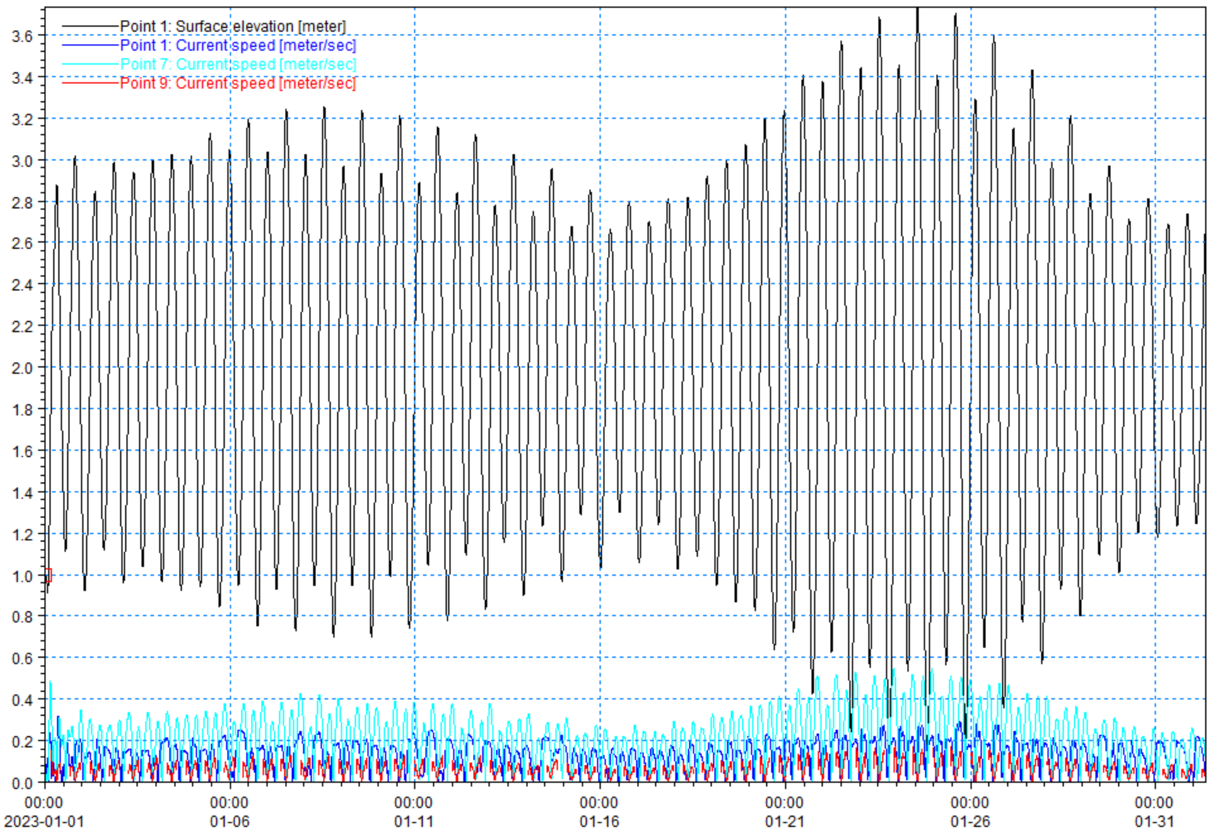

Figure 6.7: Baseline Inc. Wind (HD3) Modelled Water Level and Current Speed at Selected Locations

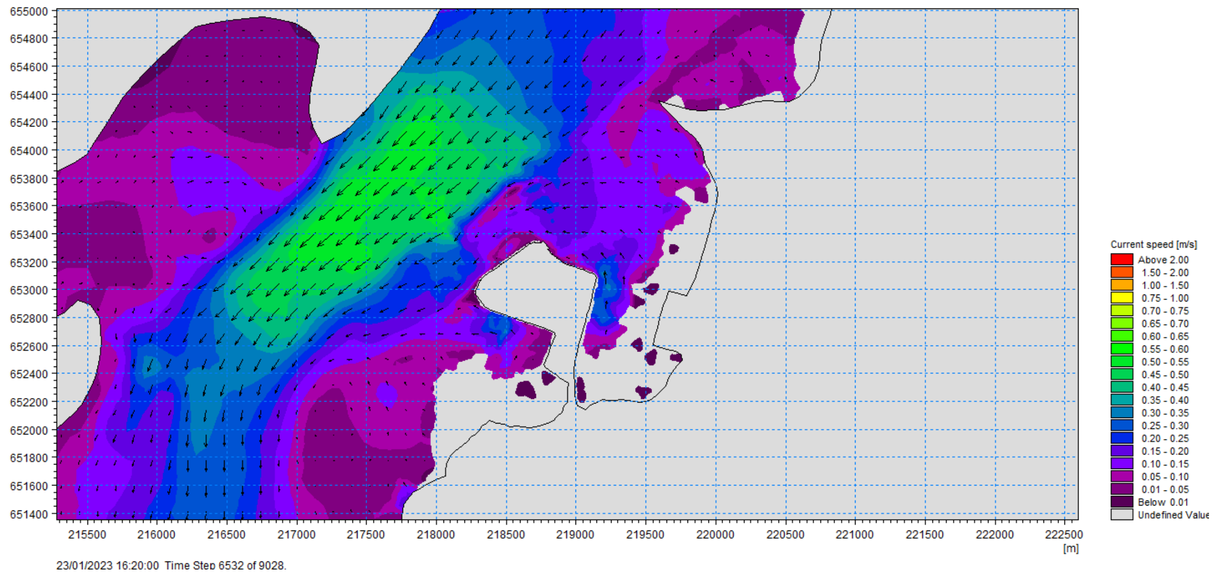

Figure 6.8: Baseline Inc. Wind (HD3) Current Speed – Spring Tide Peak Ebb

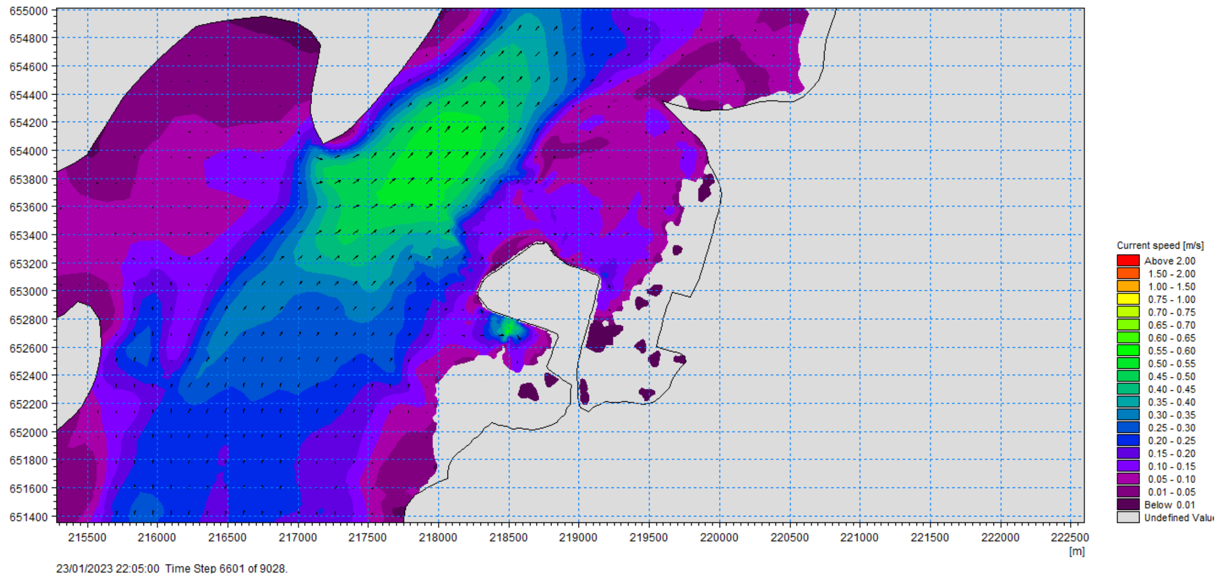

Figure 6.9: Baseline Incl. Wind (HD3) Current Speed – Spring Tide Peak Flood

6.2.4 HD Results Analysis

Figure 6.10 presents a current speed differential plot comparing post-development predictions (HD2) with baseline results (HD1) for a model timestep during a spring ebb tide. Figure 6.11 presents the corresponding plot for a model timestep during a spring flood tide. Figure 6.12 presents a time-series comparison of current speed at location 1, for the baseline (HD1) and post-development (HD2) scenarios. Review of these figures highlights that the predicted impact to current speed resulting from the proposed development is limited to the extent and immediate surrounds of the dredge pocket. Predicted impact is slightly greater during the ebb tide, versus the flood tide, however this is limited to a small, localised decrease in current speed (<0.2 m/s) around the south-western extent of the dredge pocket, and limited localised increases in current speed (<0.2 m/s) to the south-western corners of the dredge pocket, and along the quay wall. The predicted differential is lower during the flood tide, towards high and low water, and also during smaller neap tides. No significant impact to current speed is predicted within the adjacent SSSI, or further afield. No impact to tidal water level is predicted as a result of the proposed development.

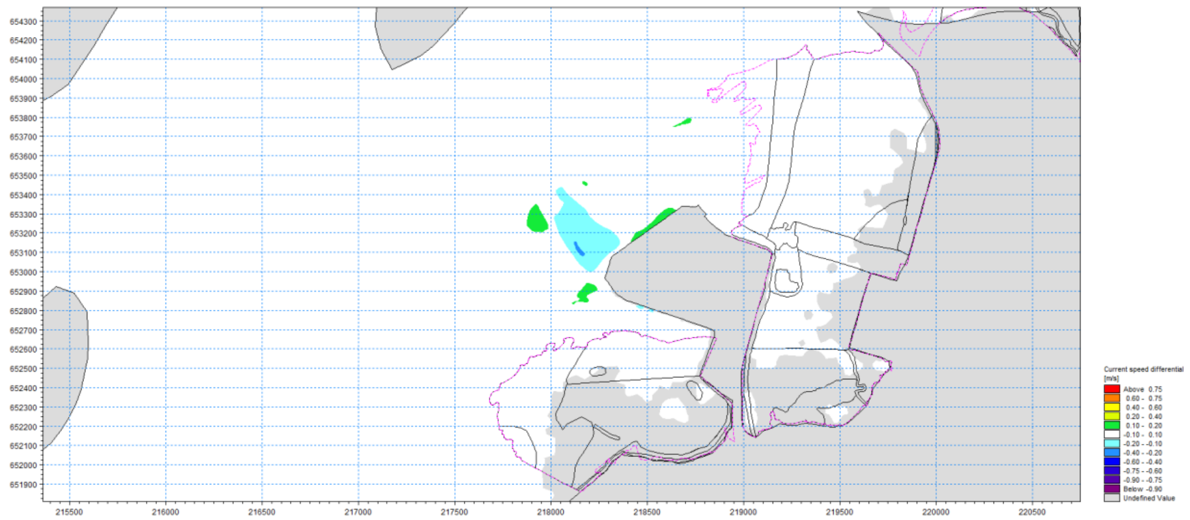

Figure 6.10: Current Speed Differential – Post-Development (HD2) Minus Baseline (HD1) Spring Tide Peak Ebb

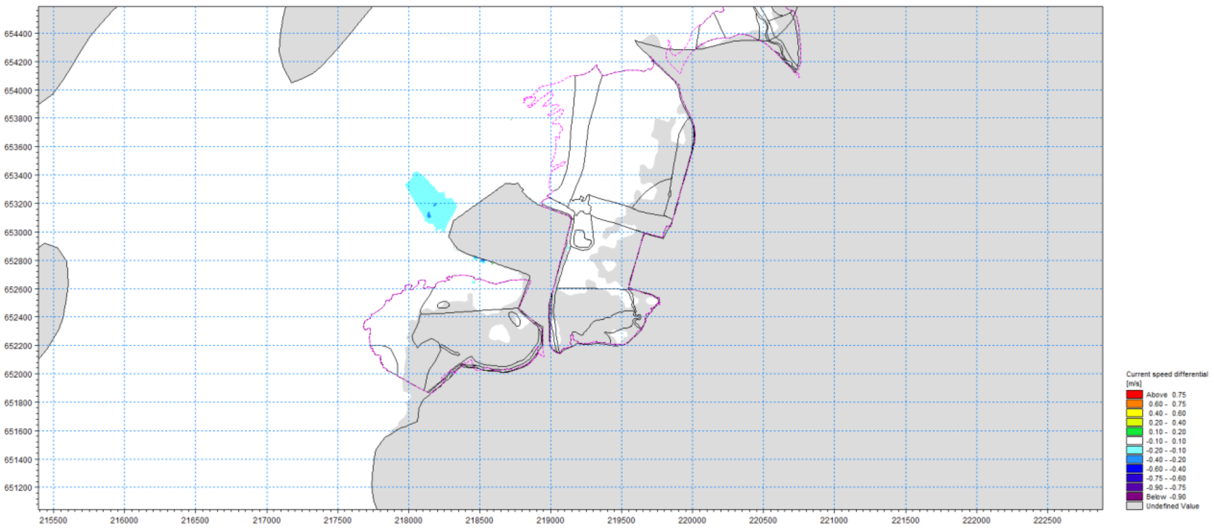

Figure 6.11: Current Speed Differential – Post-Development (HD2) Minus Baseline (HD1) Spring Tide Peak Flood

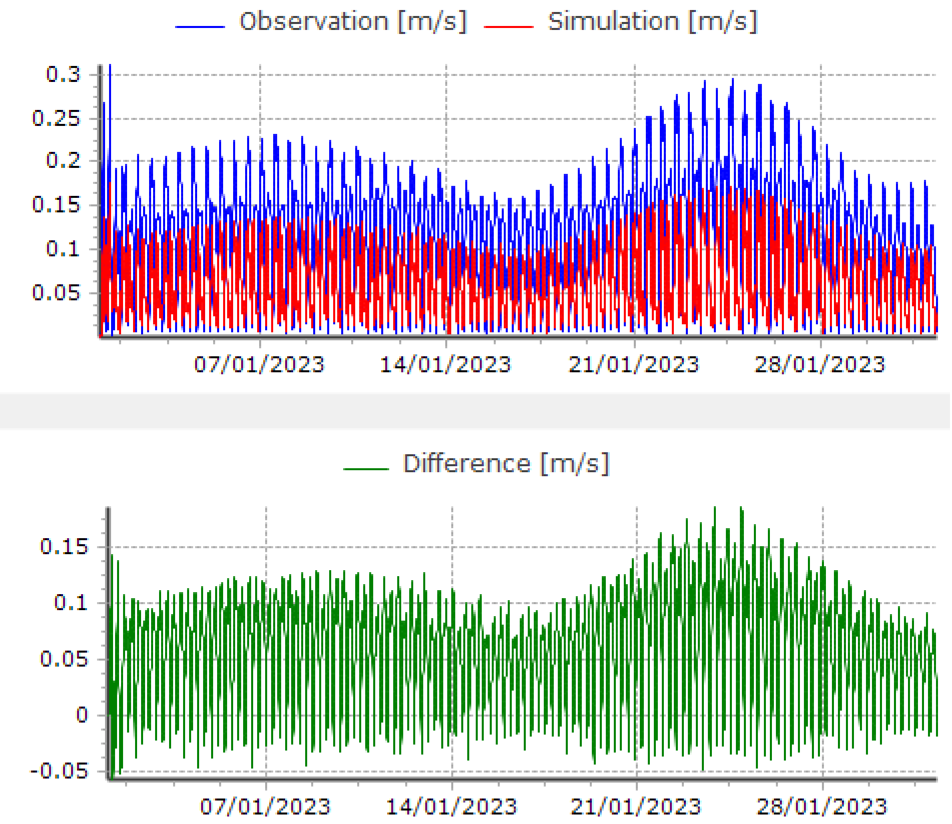

Figure 6.12: Time-Series Current Speed Comparison at Location 1 – Baseline HD1 (Blue) and Post-Development HD2 (Red) with Differential Plot in Green

Figure 6.13 presents a current speed differential plot comparing wind sensitivity baseline results (HD3) with baseline (HD1) results for a spring ebb tide timestep, with Figure 6.14 presenting the equivalent plot for a spring flood tide timestep. Figure 6.15 presents a time-series comparison of current speed between the two model scenarios at location 1, whilst Figure 6.16 is a time-series plot of the input forcing wind speed and direction to simulation HD3. Review of these figures highlights that wind forcing can act to influence current speeds locally, with the strength of the wind and the wind direction determining the extent of impact. However, the scale of influence predicted during the modelled period is limited to <0.05 m/s.

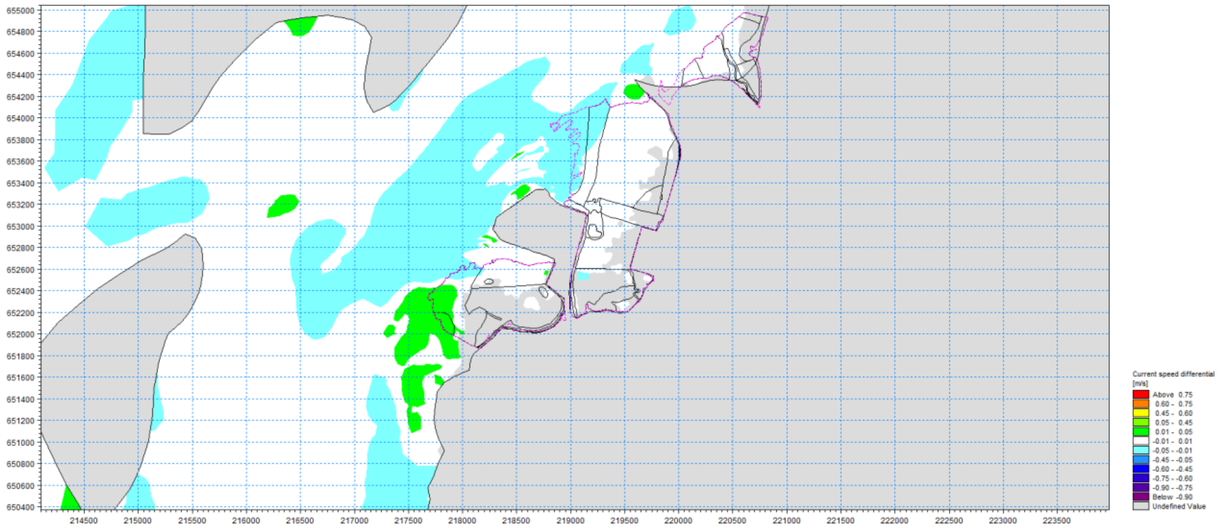

Figure 6.13: Current Speed Differential – Baseline Wind Sensitivity (HD3) Minus Baseline (HD1) Spring Tide Peak Ebb

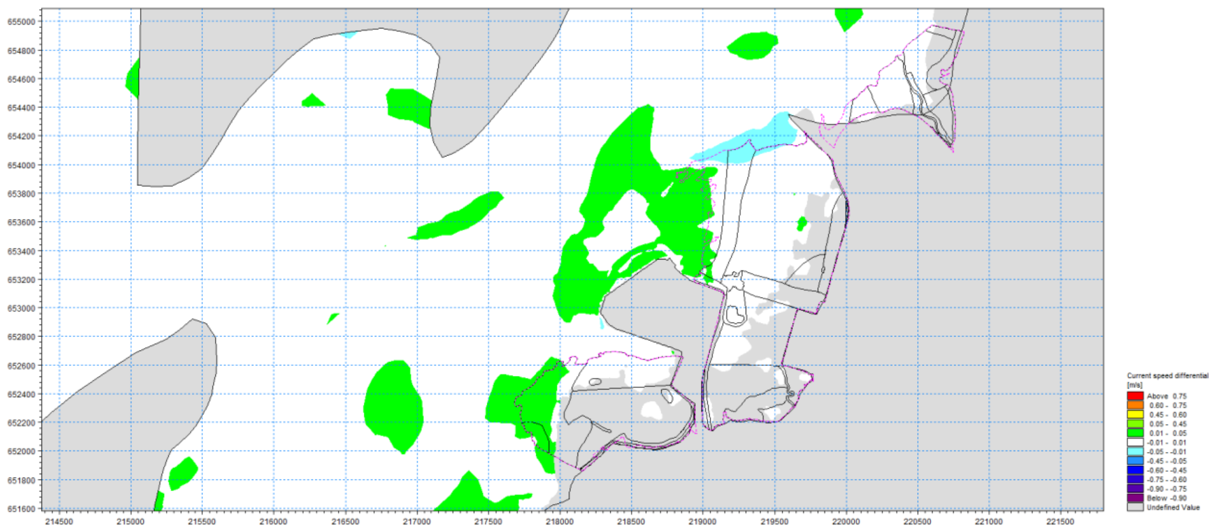

Figure 6.14: Current Speed Differential – Baseline Wind Sensitivity (HD3) Minus Baseline (HD1) Spring Tide Peak Flood

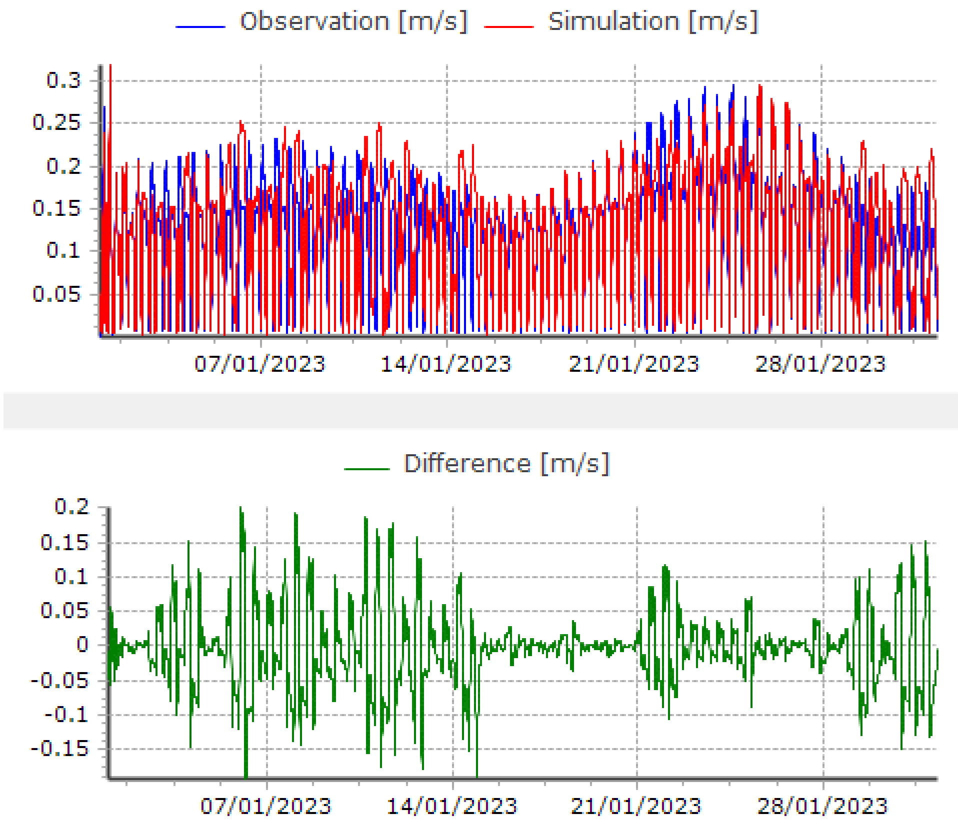

Figure 6.15: Time-Series Current Speed Comparison at Location 1 – Baseline HD1 (Blue) and Baseline Wind Sensitivity HD3 (Red) with Differential Plot in Green

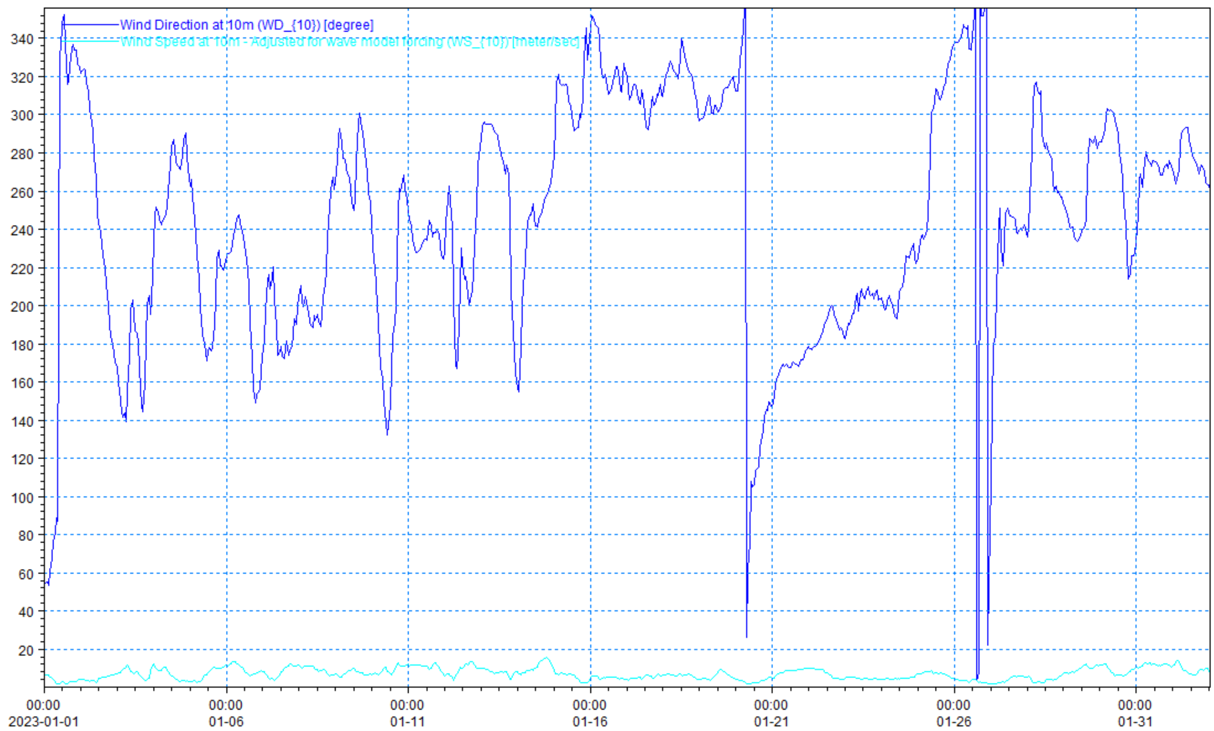

Figure 6.16: HD3 Wind Speed and Direction - Model Duration

6.3 SW Model Results

6.3.1 Baseline SW

Figure 6.17 presents a summary of baseline significant wave height predictions for 5 year return period waves entering the Firth of Clyde from the 180° sector, under wind forcing from the 180° sector (SW1) through to the 330° sector (SW6).

Review of these model results highlights that under baseline conditions offshore of the construction yard, towards the Hunterston channel, the highest significant wave heights can be expected to occur during wind from the 240° sector, with wind from the 270° sector also producing similar wave heights. In this area modelled 5-year return period (RP) significant wave heights range between 2.0 m and 2.5 m under wind forcing from the 240° sector.

Modelled wave heights reduce shoreward into the SSSI for all wind forcing sectors, with the 300° sector and 330° sector producing the largest waves on Southannan Sands for the modelled 5-year return period (RP) event, with predicted significant wave heights of 1.25 m towards MLWS, reducing southwards towards 0.1 m.

Figure 6.18 presents a time-series of input wind speed and direction to SW model simulation SW13, whilst Figure 6.19 shows the input wave boundary conditions for the same simulation. Figure 6.20 presents the predicted resultant significant wave height at point output locations 1 and 9. Review of the results highlights the importance of offshore wave height, as well as wind speed and direction, to the wave climate around Hunterston Construction Yard.

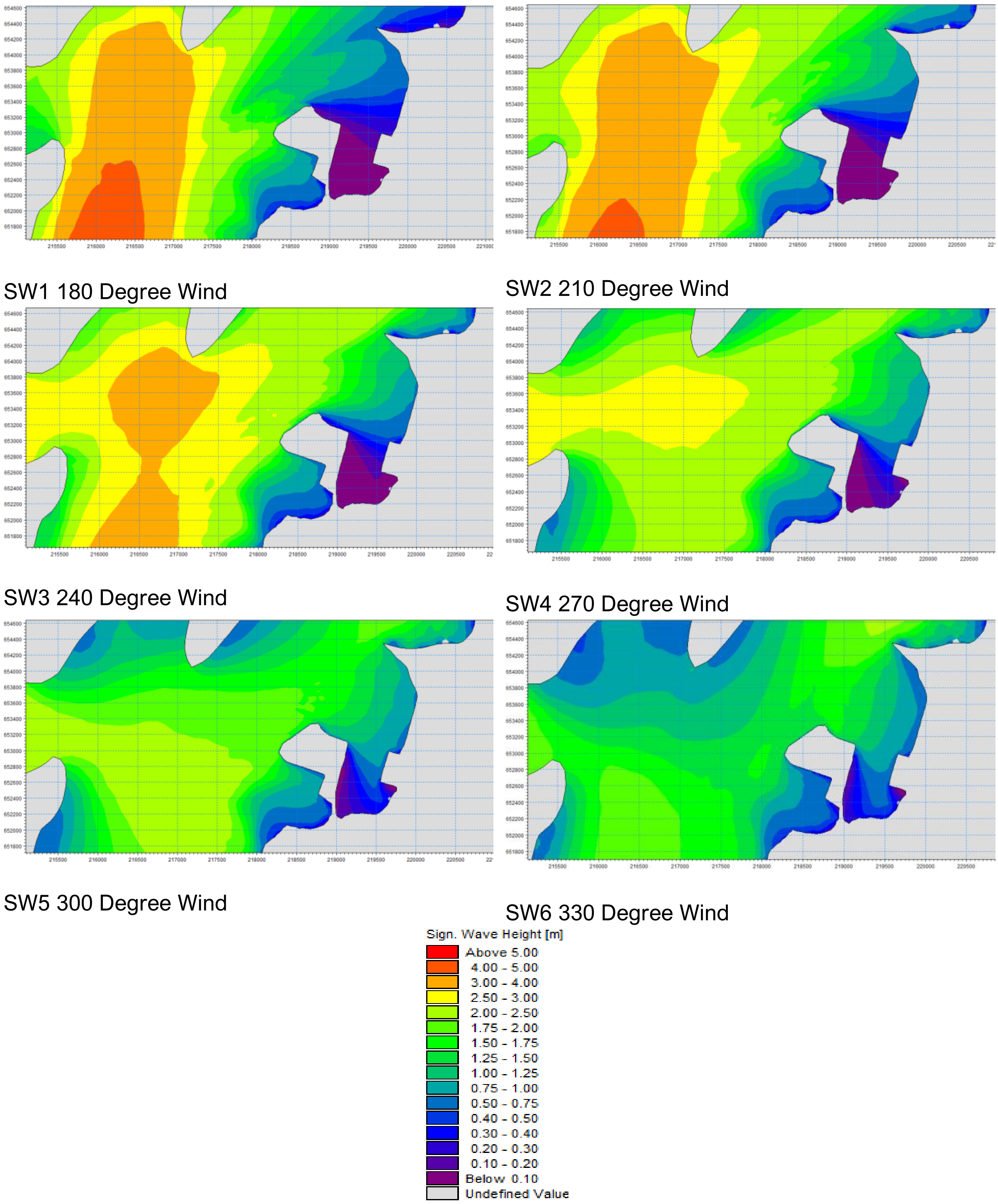

Figure 6.17: Summary of Baseline Wind Direction Sensitivity Analysis (SW1 – 6)

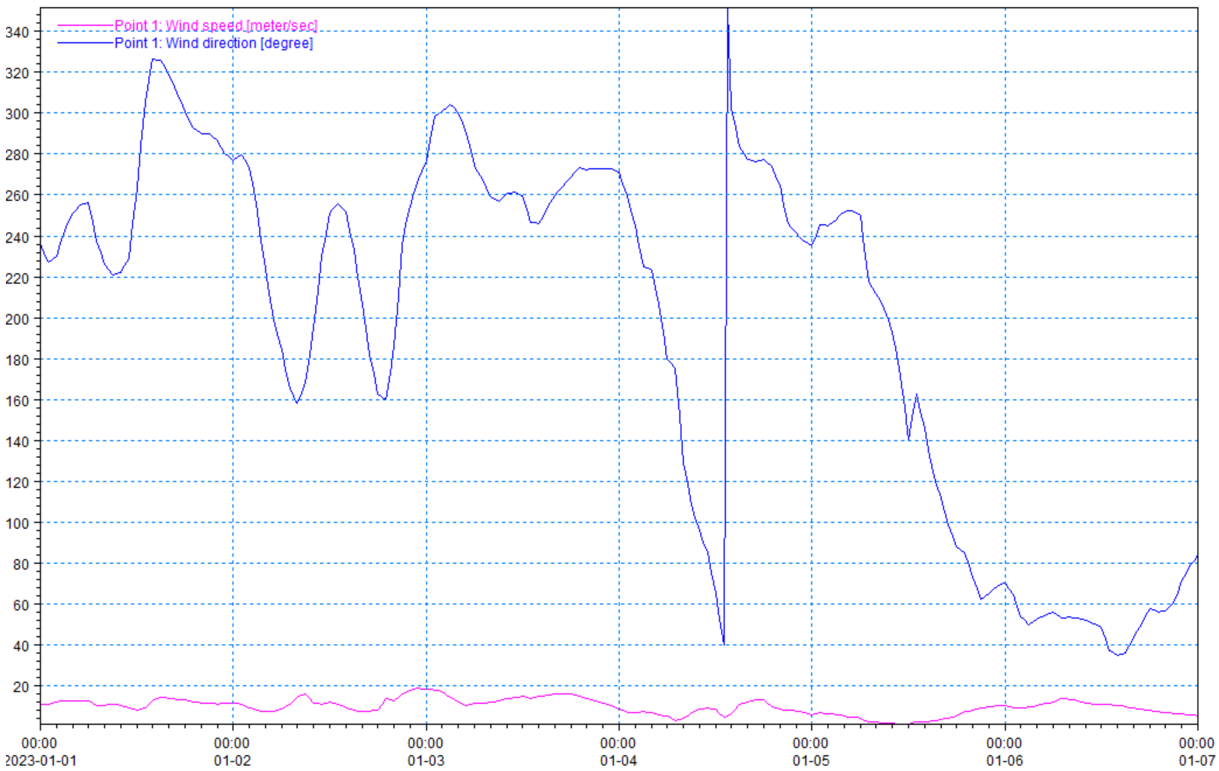

Figure 6.18: SW13 Hindcast Input Wind Speed and Direction

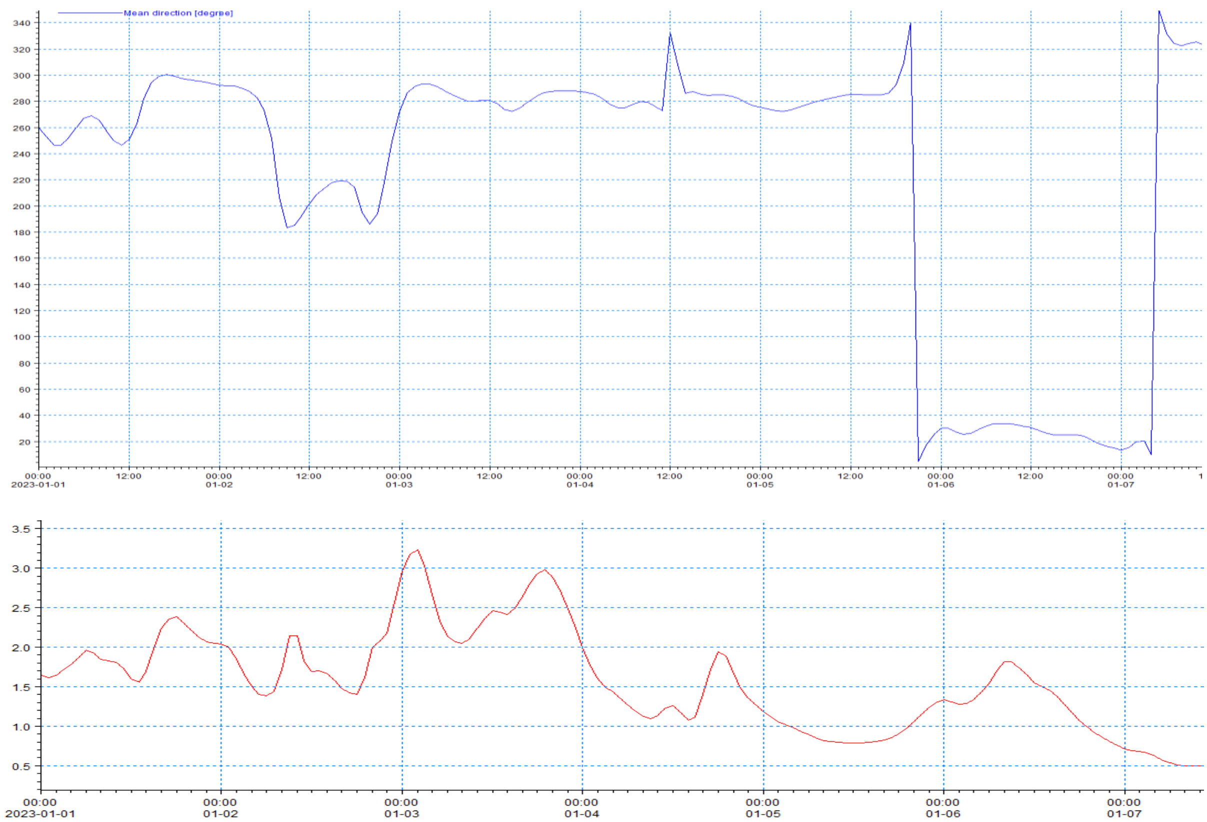

Figure 6.19: SW13 Hindcast Input Significant Wave Height and Mean Direction

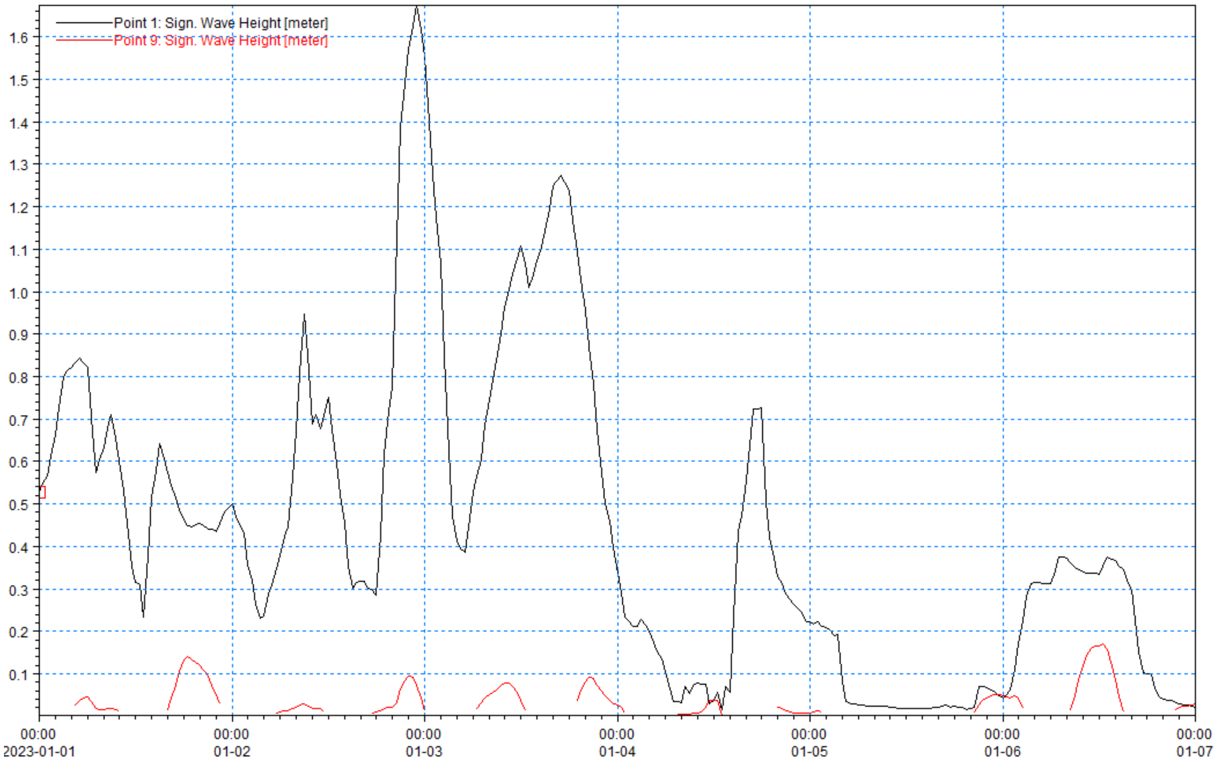

Figure 6.20: SW13 Baseline - Significant Wave Height Time-Series at Locations 1 and 9

6.3.2 Post-Development SW

Figure 6.21 presents a summary of post-development significant wave height predictions for 5 year return period waves entering the Firth of Clyde from the 180° sector, under wind forcing from the 180° sector (SW1) through to the 330° sector (SW6).

Review of these model results highlights that as per baseline conditions, offshore of the construction yard, towards the Hunterston channel, post-development the highest significant wave heights can be expected to occur during wind from the 240° sector, with wind from the 270° sector also producing similar wave heights. In this area modelled 5-year return period (RP) significant wave heights range between 2.0 m and 2.5 m under wind forcing from the 240° sector.

As per the baseline conditions, modelled wave heights reduce shoreward into the SSSI for all wind forcing sectors, with the 300° sector and 330° sector producing the largest waves on Southannan Sands for the modelled 5-year return period (RP) event, with predicted significant wave heights of 1.25m towards MLWS, reducing southwards towards 0.1m.

Figure 6.22 presents a time-series of the predicted significant wave height at point output locations 1 and 9 for SW model simulation SW14, whilst the input wind and wave boundary conditions remain the same as for SW13.

Figure 6.23 and Figure 6.24 present predicted post-development 1 in 200 year RP significant wave heights under present and future climate (2100) conditions respectively. Review of these figures highlights that significant wave heights in the order of 3 m are predicted adjacent to the new quay wall under present climate, with future climate conditions producing larger waves (>3 m) at the quay, as well as increased wave heights on Southannan Sands.

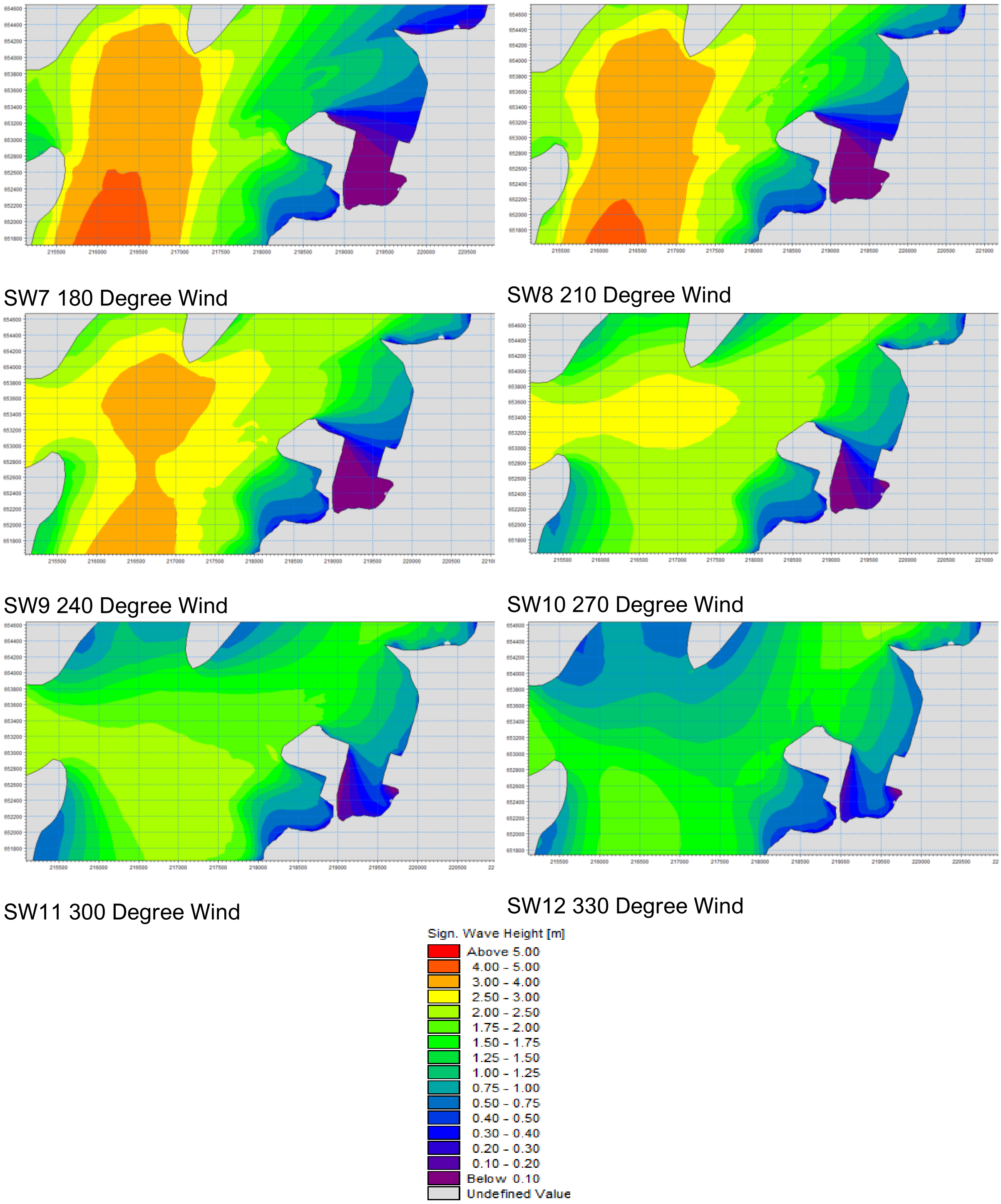

Figure 6.21: Summary of Post-Development Wind Direction Sensitivity Analysis (SW7 – 12)

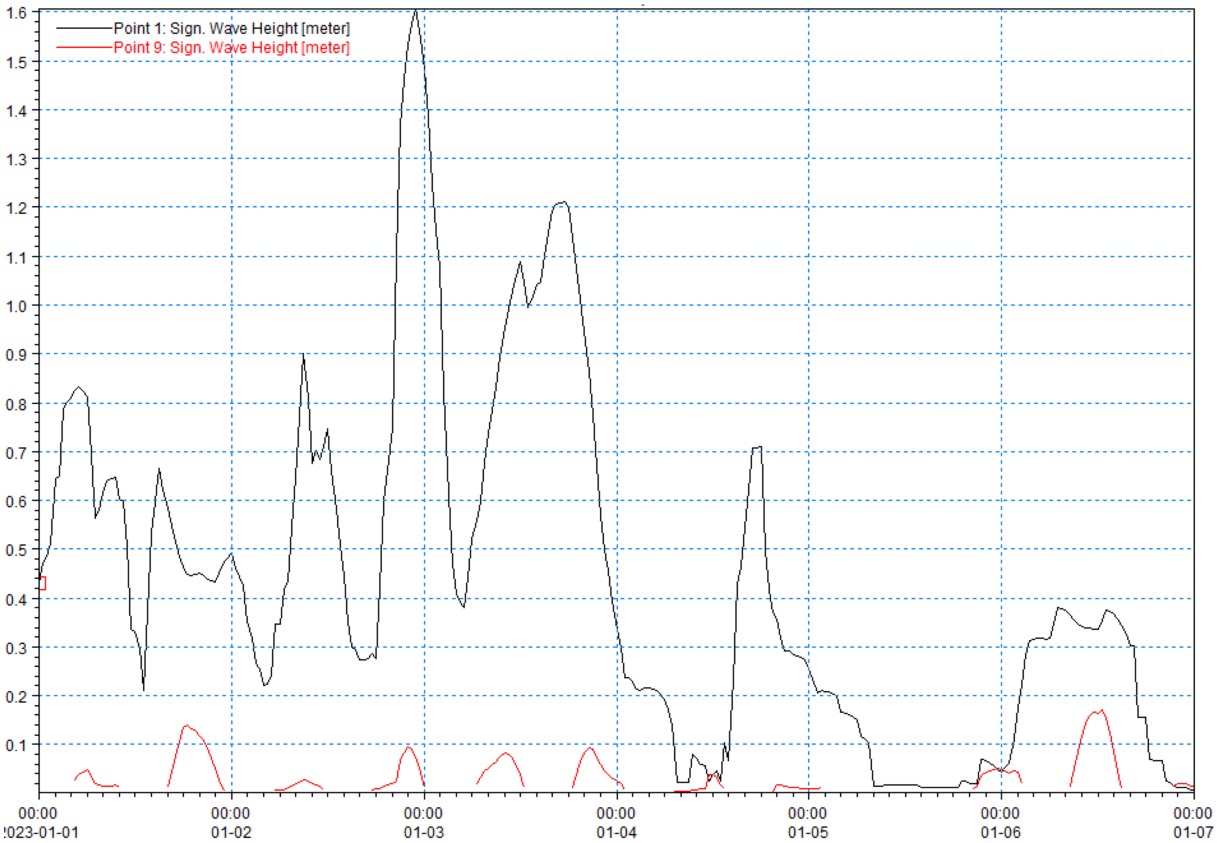

Figure 6.22: SW14 Post-Development - Significant Wave Height Time-Series at Locations 1 and 9

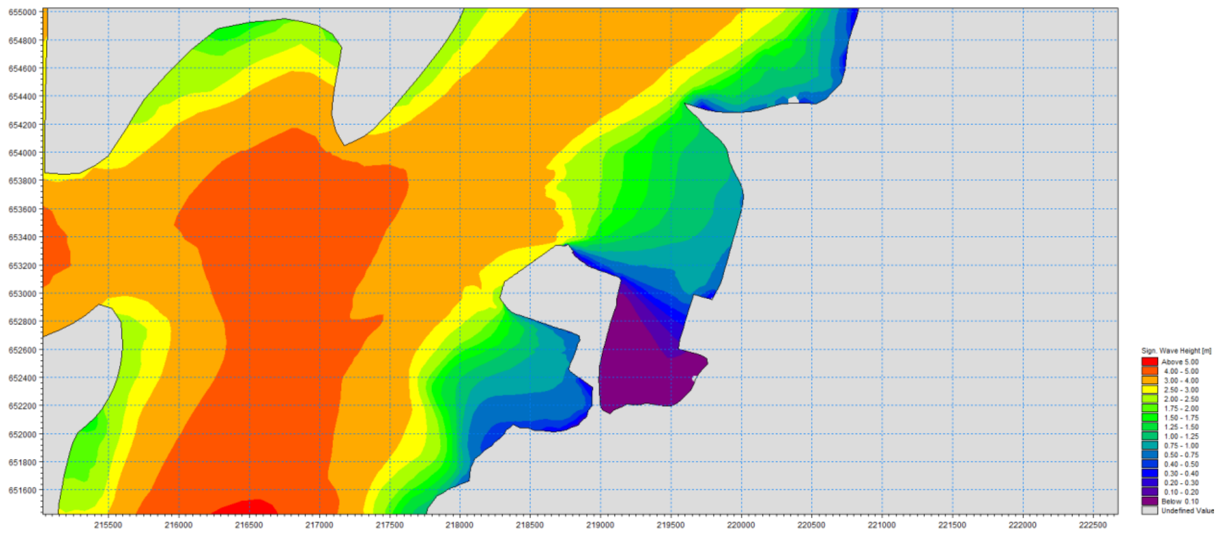

Figure 6.23: SW15 Post-Development – 1 in 200 Year RP Significant Wave Height (240 Degree Wind)

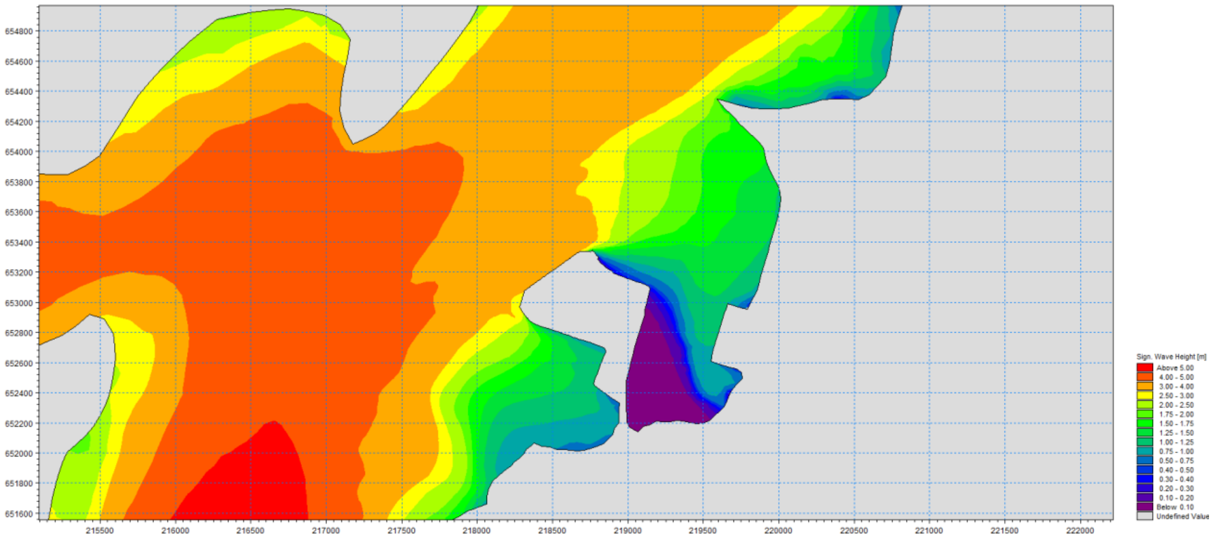

Figure 6.24: SW16 Post-Development – 1 in 200 Year RP Climate Change 2100 Significant Wave Height (240 Degree Wind)

6.3.3 SW Results Analysis

Figure 6.25, Figure 6.26 and Figure 6.27, present significant wave height differential plots (post-development minus baseline) for 5 year return period waves under wind forcing from the 180, 240 and 330 degree sectors respectively.

Review of these figures highlights that the proposed development would result in minor changes to significant wave heights (Hs) in the immediate vicinity of the dredge pocket. For waves approaching from the south, with wind from the 180 degree sector, during a 1 in 5 year return period event, increases in significant wave height of <0.5 m are predicted in the immediate vicinity of the dredge pocket. A limited area of wave height increase (<0.2 m) is predicted to extend north-east towards the edge of the Southannan Sands. For waves approaching from the south, with wind from the 240 degree sector, during a 1 in 5 year return period event, increases in significant wave height of <1.0 m are predicted in the immediate vicinity of the dredge pocket, with a limited area of wave height increase (<0.5 m) extending around the corner into the hammerhead quay area. For wave scenarios with wind from north-western and northern sectors predicted increases in significant wave height are limited to the immediate vicinity of the quay wall.

No impact to wave climate is predicted in the wider area as a result of the proposed development. Predicted changes to significant wave heights in the immediate vicinity of the proposed development are not considered to result in wave heights significantly different to those occurring under baseline conditions.

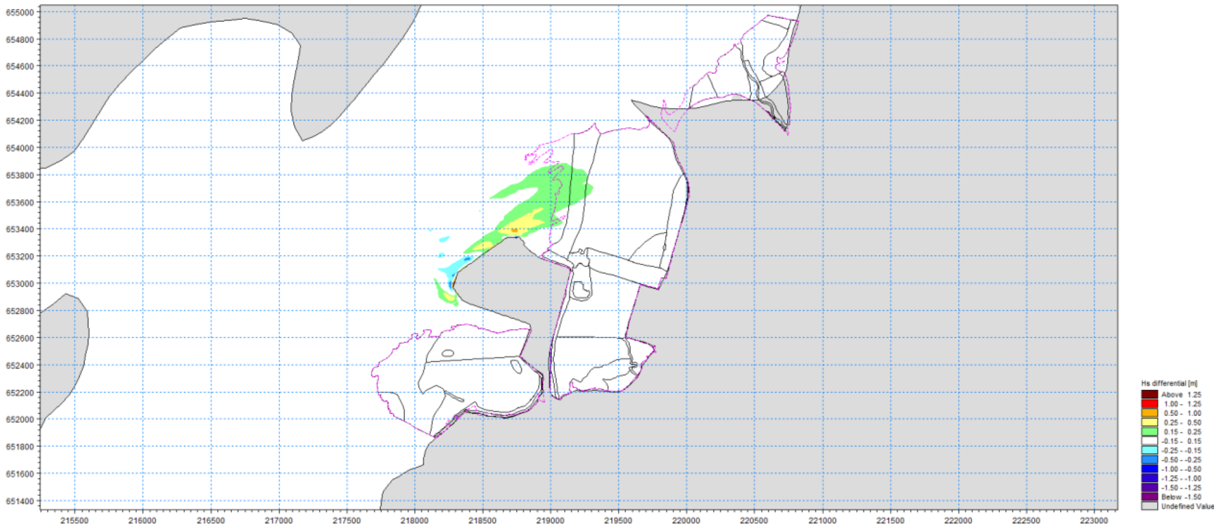

Figure 6.25: Significant Wave Height Differential 180 Degree Wind Sector – SW7 (Post-Development) Minus SW1 (Baseline)

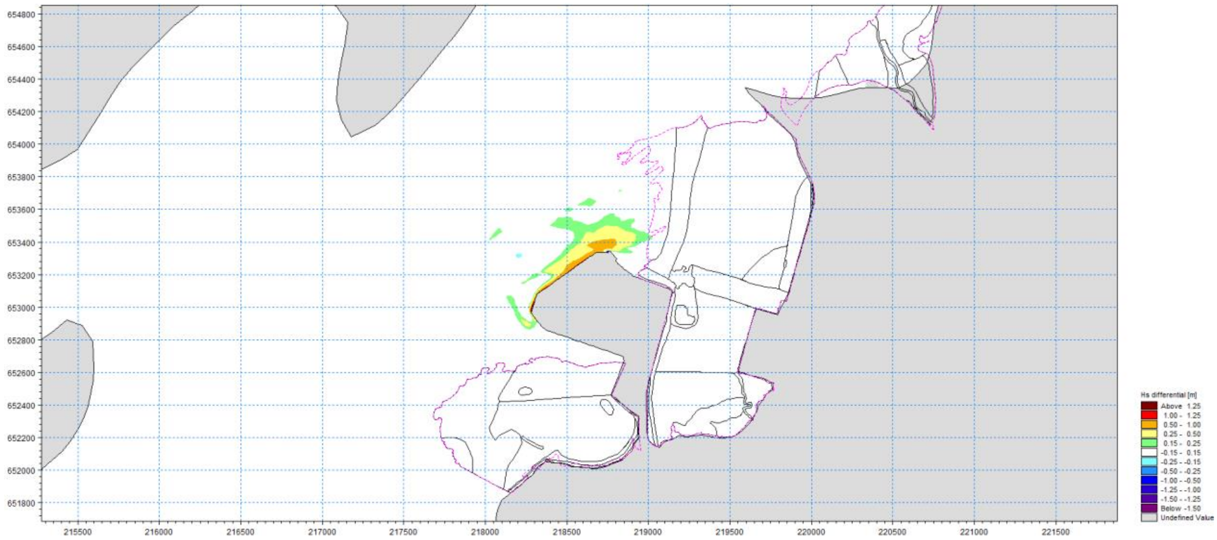

Figure 6.26: Significant Wave Height Differential 240 Degree Wind Sector – SW9 (Post-Development) Minus SW3 (Baseline)

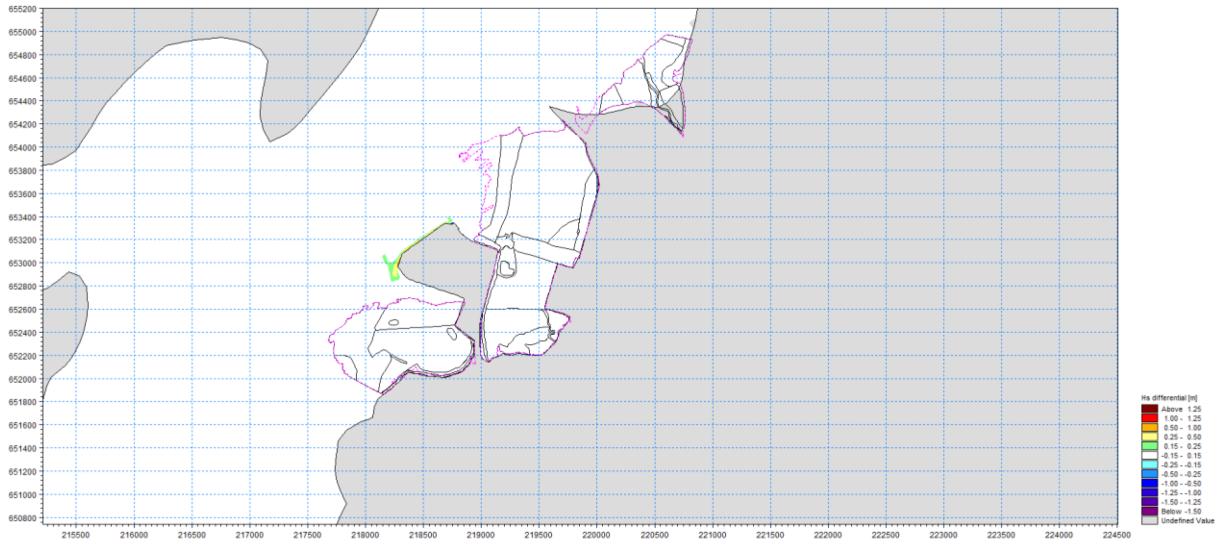

Figure 6.27: Significant Wave Height Differential 330 Degree Wind Sector – SW12 (Post-Development) Minus SW6 (Baseline)

6.4 MT Model Results

6.4.1 Capital Dredge (MT1)

Figure 6.28 presents time-series plots of total suspended solids (TSS) concentrations at key point output locations (14 – 20) for the full capital dredge simulation duration (MT1). Figure 6.29 presents a closer view of the previous figure, focussed on the final days of the simulation.

Figure 6.30, Figure 6.31 and Figure 6.32 present area plots of TSS during a flood tide, at high water, and on an ebb tide respectively, with the dredger positioned in proximity to the proposed quay wall and eastern extent of the dredge pocket. These model timesteps coincide with predictions of peak TSS values at the key point output locations on Southannan Sands (14 & 15), as shown in Figure 6.28.

Figure 6.33 presents an area plot of TSS at the end of the capital dredge simulation, 3 days following the cessation of dredging.

Figure 6.34 presents an area plot of statistical maximum TSS values for the full capital dredge campaign, whilst Figure 6.35 presents a similar plot for statistical mean TSS values.

Figure 6.36 presents an area plot of deposition thickness at a timestep towards the end of the capital dredge simulation, whilst Figure 6.37 presents an area plot of total net deposition accumulation at the same model timestep.

On review of the above model results, the following points summarise the key findings of the capital dredge simulation:

- The position of the dredge plume moves in response to the circulation of the tidal currents around Hunterston Construction Yard, with highest concentrations of TSS found within the dredge extent and immediate surrounds;
- Whilst the dredger is working in the outer (western) areas of the dredge pocket the dredge plume remains generally within the immediate surrounds and adjacent Hunterston Channel;

- As the dredger works closer to the quay wall and north eastern extent of the dredge pocket the plume increasingly moves on to the southern areas of Southannan Sands during the flood tide to high water, and back out again on the ebb tide;
- TSS values in excess of 0.01 kg/m^3 (10 mg/l) are restricted to the immediate surrounds of Hunterston Construction Yard, including the adjacent Hunterston Channel;
- TSS values remain below 0.02 kg/m^3 (20 mg/l) at most sensitive receptor locations (key output locations 16 – 20) for the duration of the capital dredge campaign, with the exception of locations 14 and 15, where TSS levels increase beyond this threshold towards the latter stages of the dredge campaign, in response to the working position of the dredger;
- TSS values remain below 0.1 kg/m^3 (100 mg/l) at locations 14 and 15 for most of the capital dredge campaign;
- Periods of elevated TSS values in excess of 0.1 kg/m^3 at sensitive receptors are for relatively short durations, with no occurrence of such levels continuously for periods of one month or more, at any of the sensitive receptors (key locations 14 – 20);
- Statistical mean TSS values over the duration of the capital dredge campaign are below 0.03 kg/m^3 (30 mg/l) at all sensitive receptors (key locations 14 – 20);
- On completion of the dredge campaign elevated TSS levels are observed to steadily reduce over a period of days;
- Sediment deposition depth outwith the immediate dredge zone, and at all sensitive receptors, is less than 0.001 m (1 mm);
- Total net deposition accumulation is less than 5 g/m^2 at most sensitive receptors, and less than 10 g/m^2 at all sensitive receptors (locations 14 – 20).

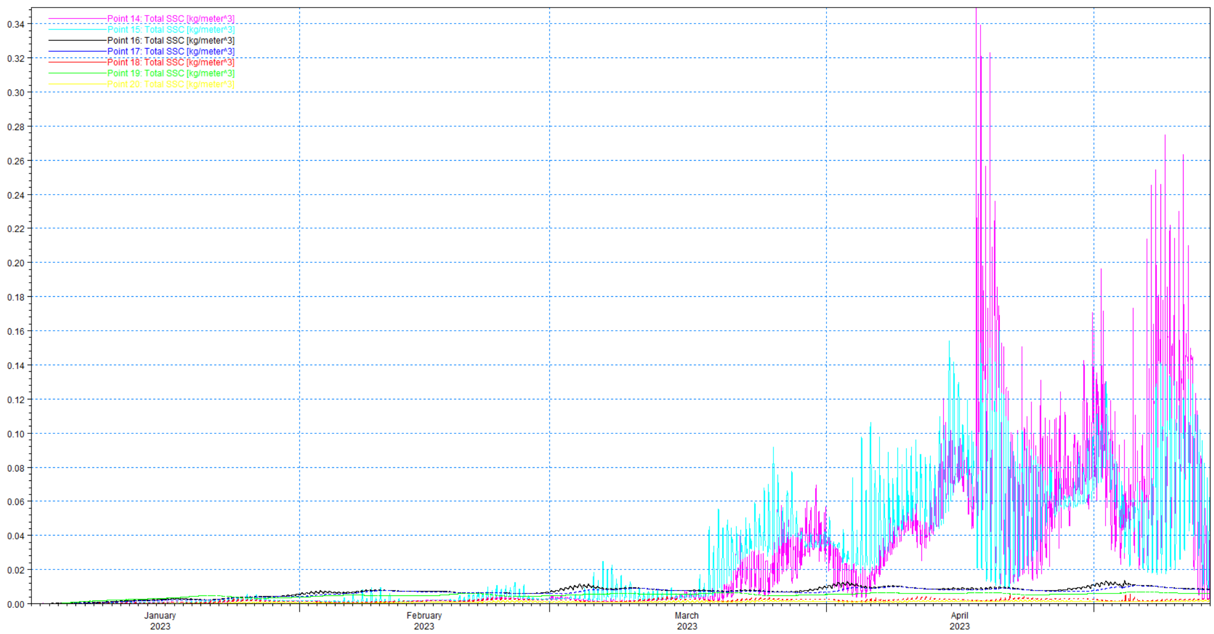

Figure 6.28: TSS at Key Locations - Full Simulation Period MT1

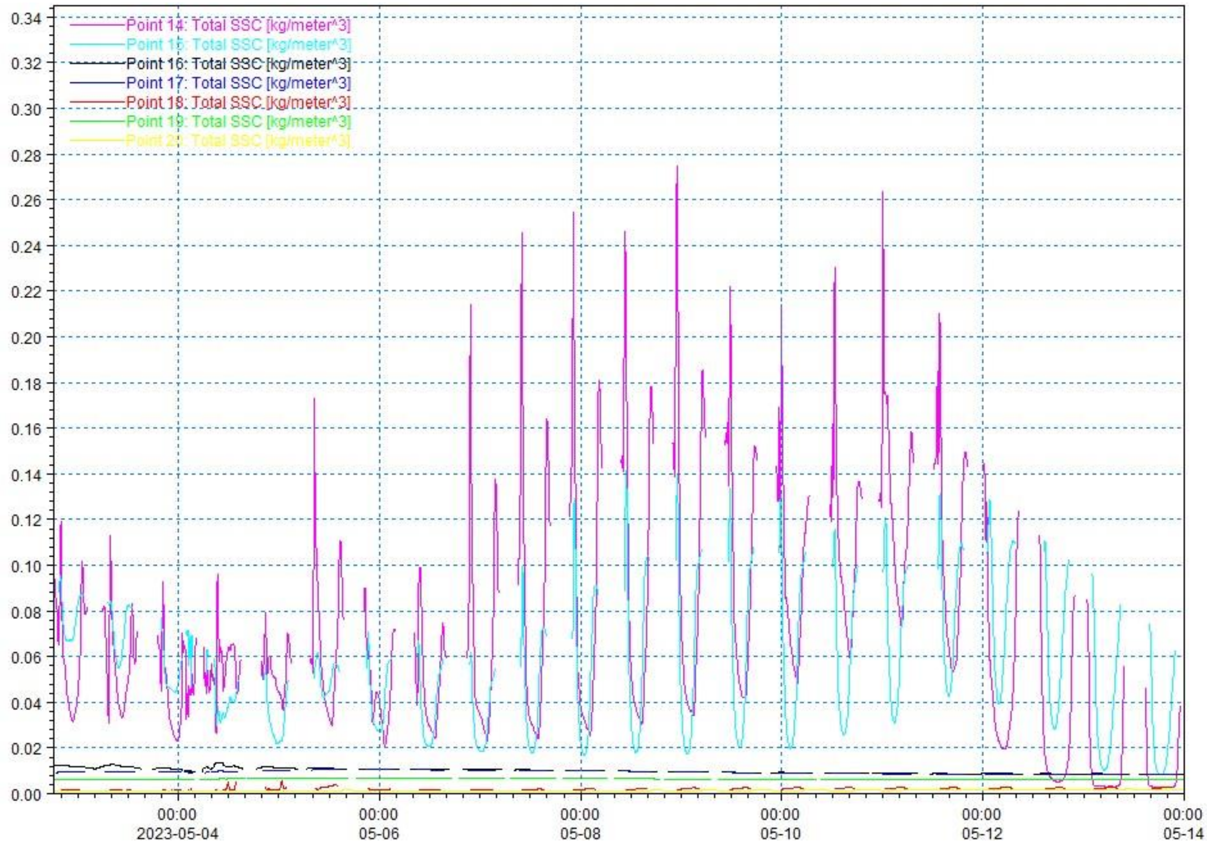

Figure 6.29: TSS at Key Locations – Final Days of Simulation (MT1)

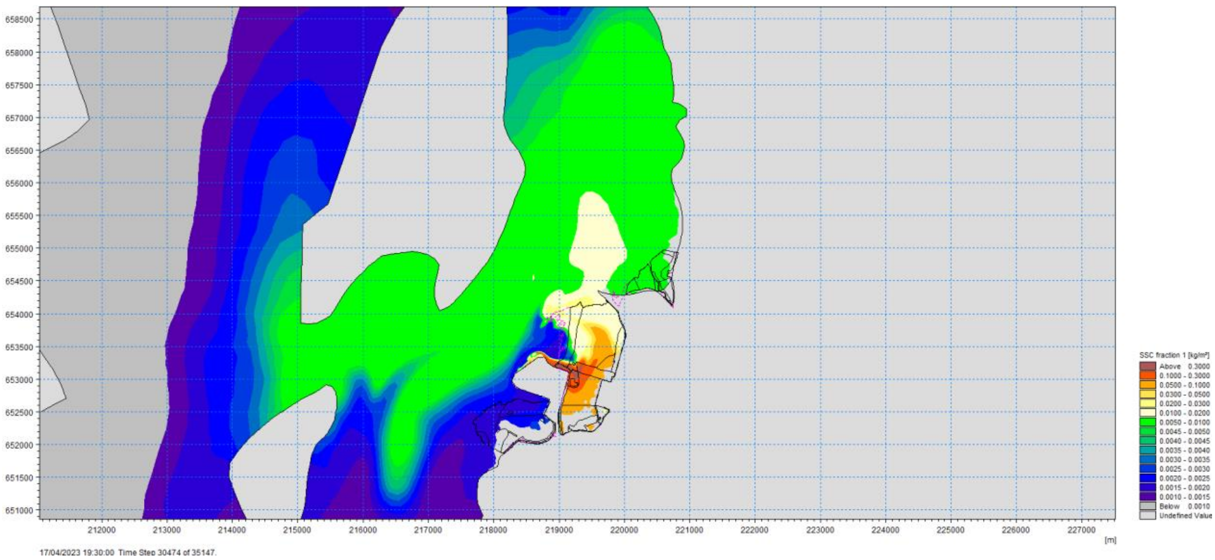

Figure 6.30: TSS During a Flood Tide (MT1)

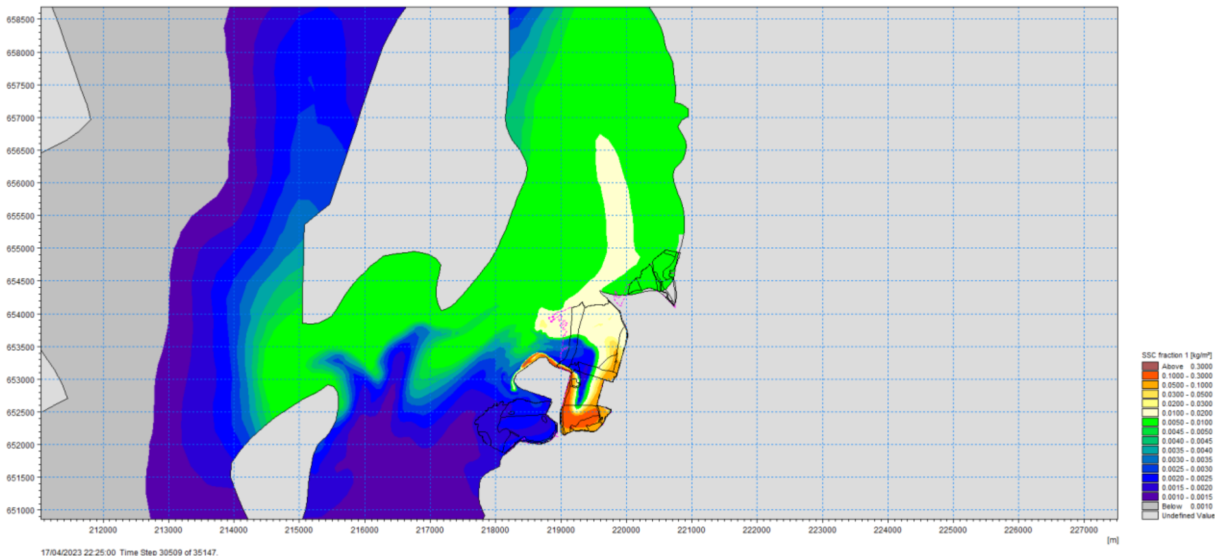

Figure 6.31: TSS at High Tide

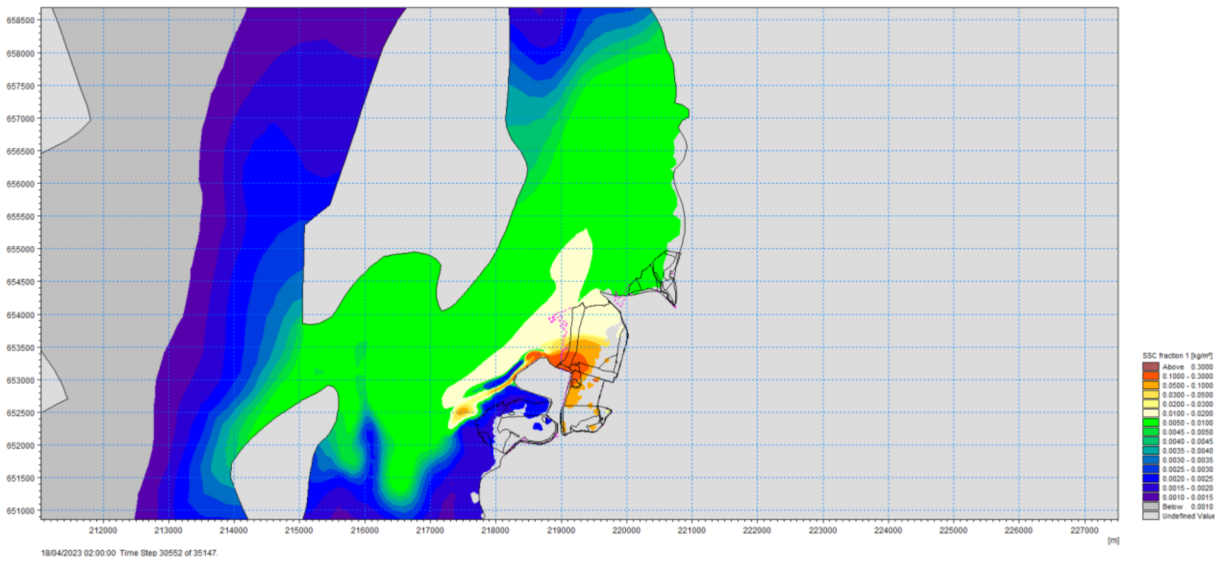

Figure 6.32: TSS During an Ebb Tide

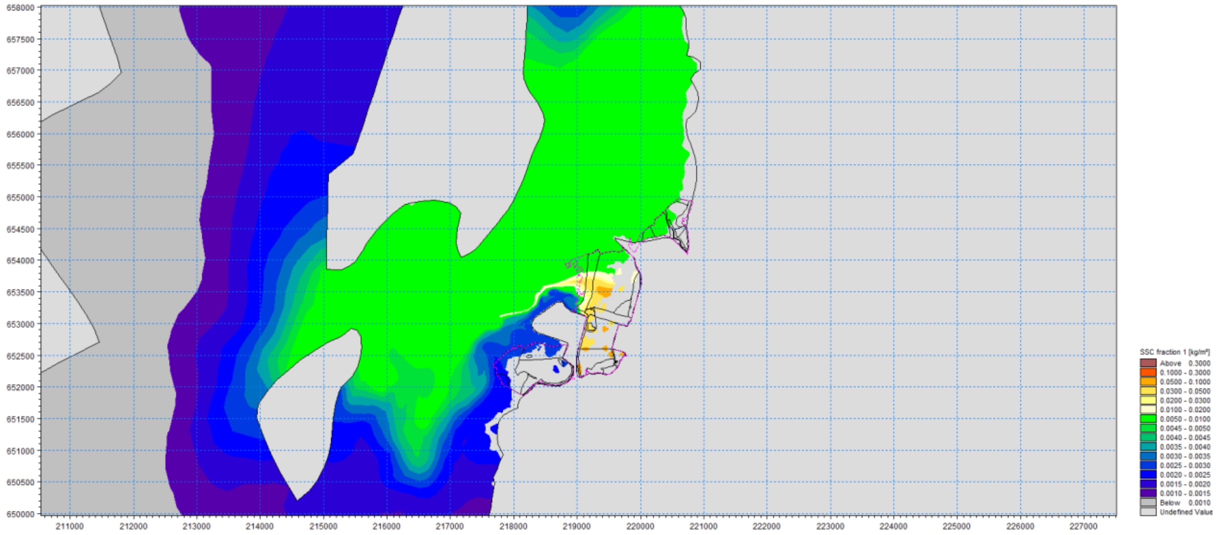

Figure 6.33: TSS End of Simulation (MT1)

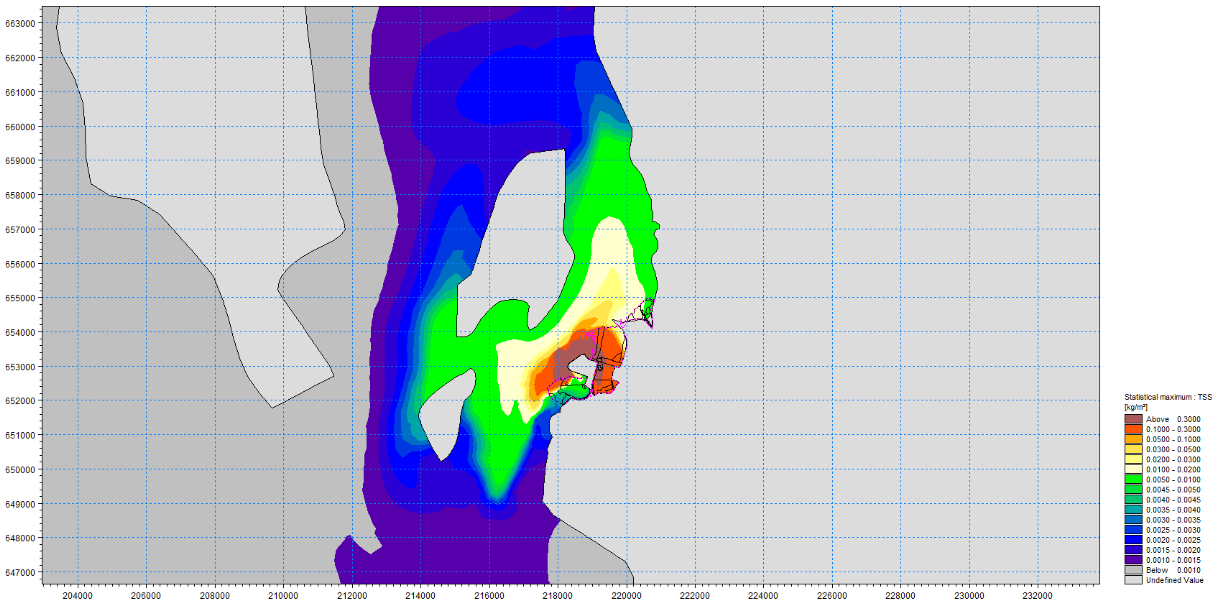

Figure 6.34: TSS Statistical Maximum Capital Dredge Campaign (MT1)

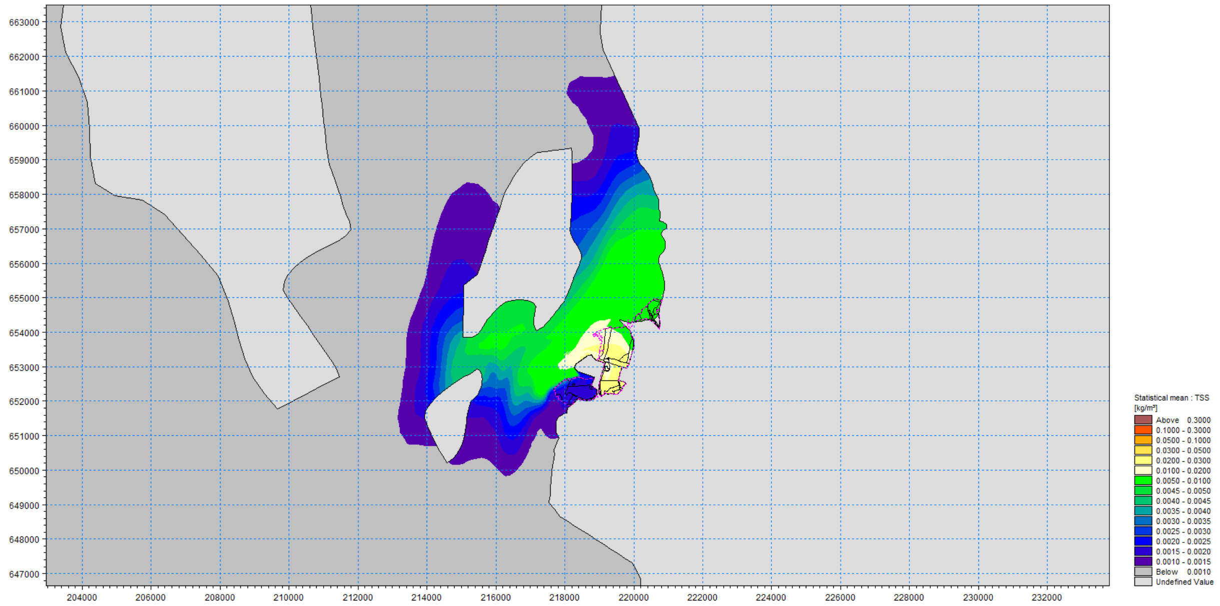

Figure 6.35: TSS Statistical Mean Capital Dredge Campaign (MT1)

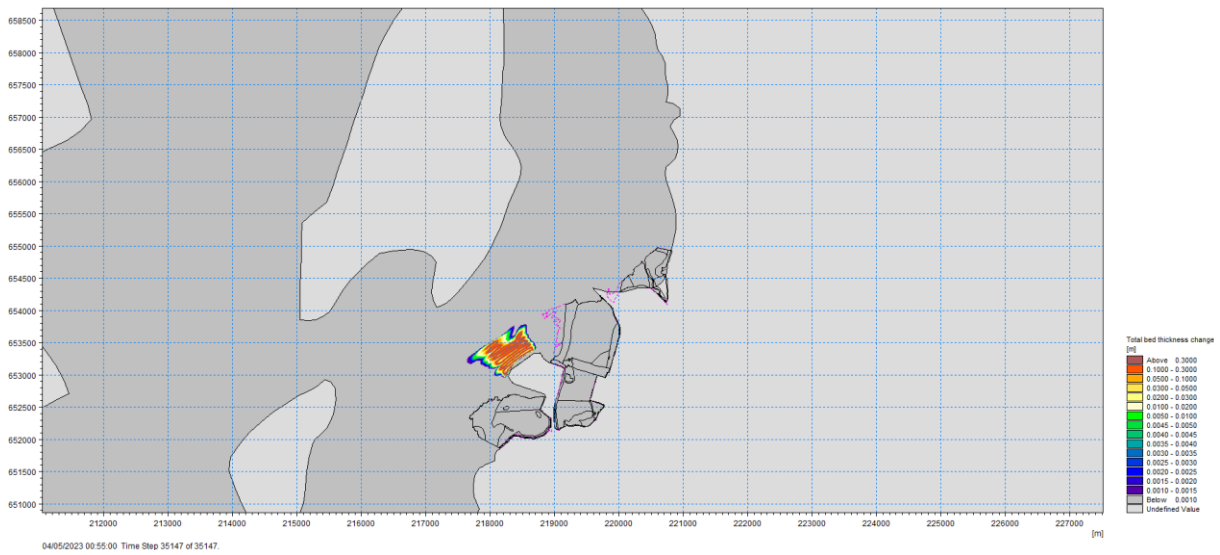

Figure 6.36: Total Deposition Thickness (m) Towards End of Capital Dredge (MT1)

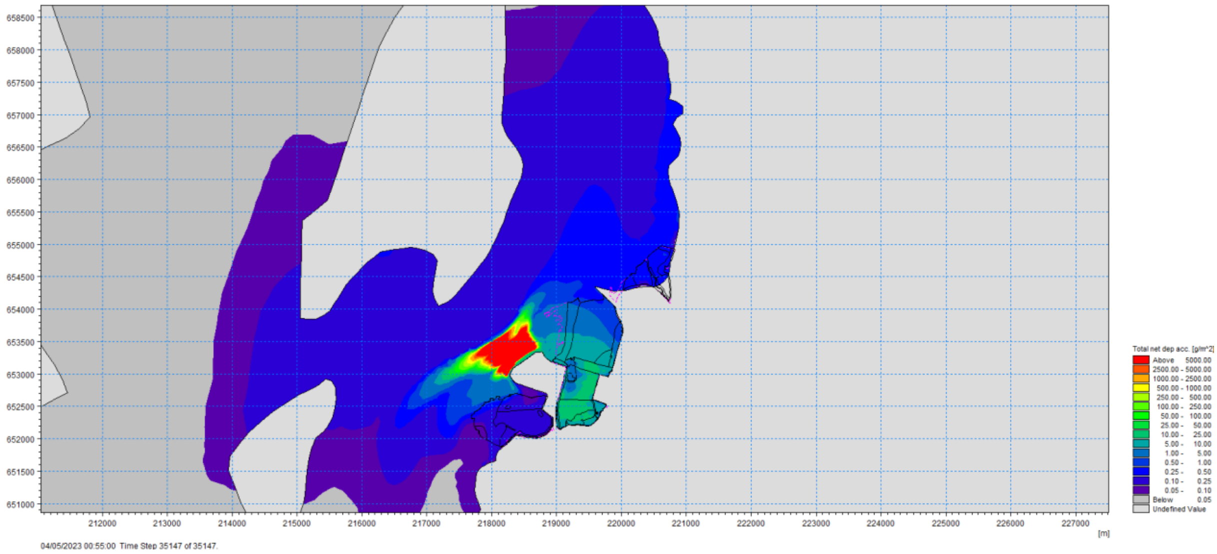

Figure 6.37: Total Net Deposition Accumulation (g/m^2) Towards End of Capital Dredge (MT1)

6.4.2 Capital Dredge Wave and Wind Sensitivity (MT2)

Figure 6.38, Figure 6.39 and Figure 6.40 present the input wave forcing, significant wave height, and wave direction respectively, to the capital dredge wave and wind sensitivity simulation (MT2). Figure 6.41 presents a time-series plot of the resultant predicted TSS values at key point output locations (14 – 20) for the simulation duration. To allow for comparison, Figure 6.42 presents the equivalent TSS predictions for the corresponding duration from the full capital dredge simulation (MT1). Figure 6.43 presents an area plot of TSS at the end of the sensitivity simulation (MT2), whilst Figure 6.44 presents a similar plot at the equivalent model timestep from the full capital dredge simulation (MT1).

On review of the MT2 simulation results, the following points summarise the key findings of the wave and wind sensitivity scenario:

- Wind and wave forcing acts to disrupt the regular patterns of plume dispersal observed through tidal only forcing (MT1);
- Plume extents and TSS concentrations will vary in response to wind and wave forcing, with the magnitude and direction of forcing, as well as the timing of that forcing relative to the tidal phase, important to magnitude of impact;
- Due to the natural variability and unpredictability, in both space and time, of wind and wave forcing, the resultant impacts to dredge plume dispersal are also considered variable and unpredictable;
- The results of MT2 suggest that, whilst wind and wave forcing may result in short duration peaks in TSS at particular locations, generally these forces will act to disperse the dredge plume and prevent the build up of consistently higher TSS concentrations in particular locations;
- On this basis the simulation of dredge plume dispersal in the absence of wave and wind forcing (MT1) is considered a conservative scenario with respect to TSS concentration predictions.

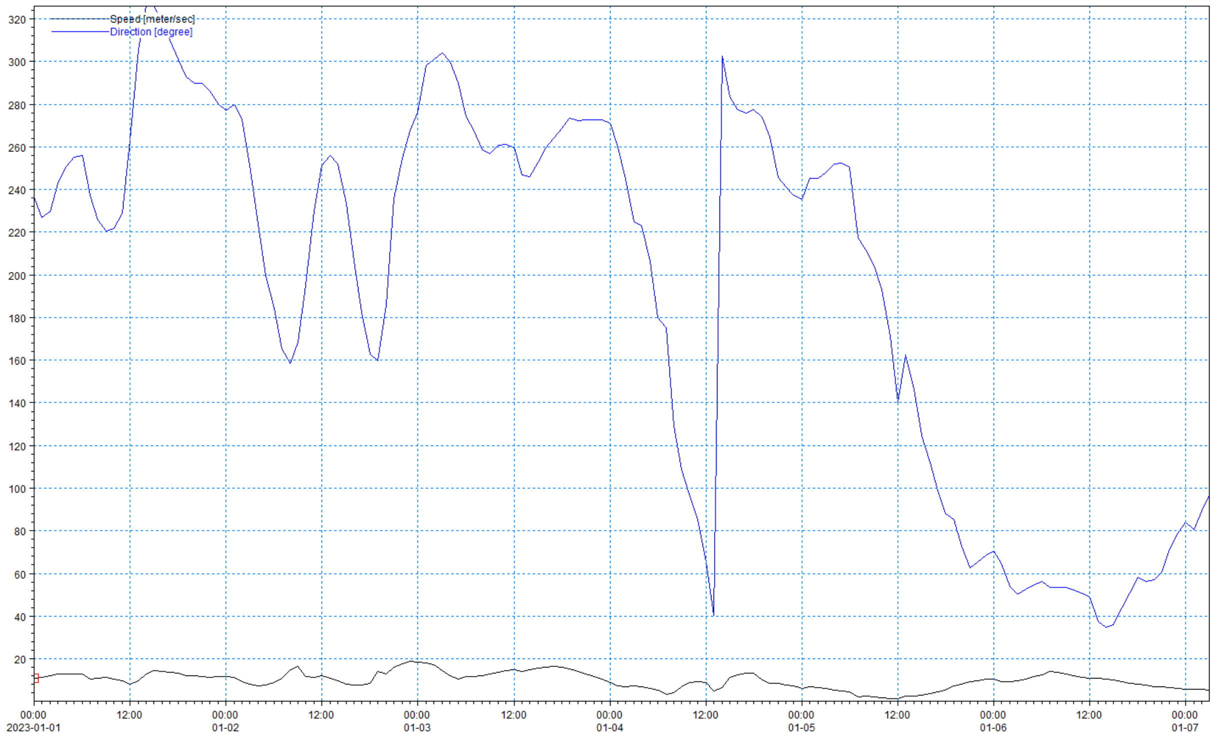

Figure 6.38: Wind Forcing Speed and Direction – Duration MT2 Simulation

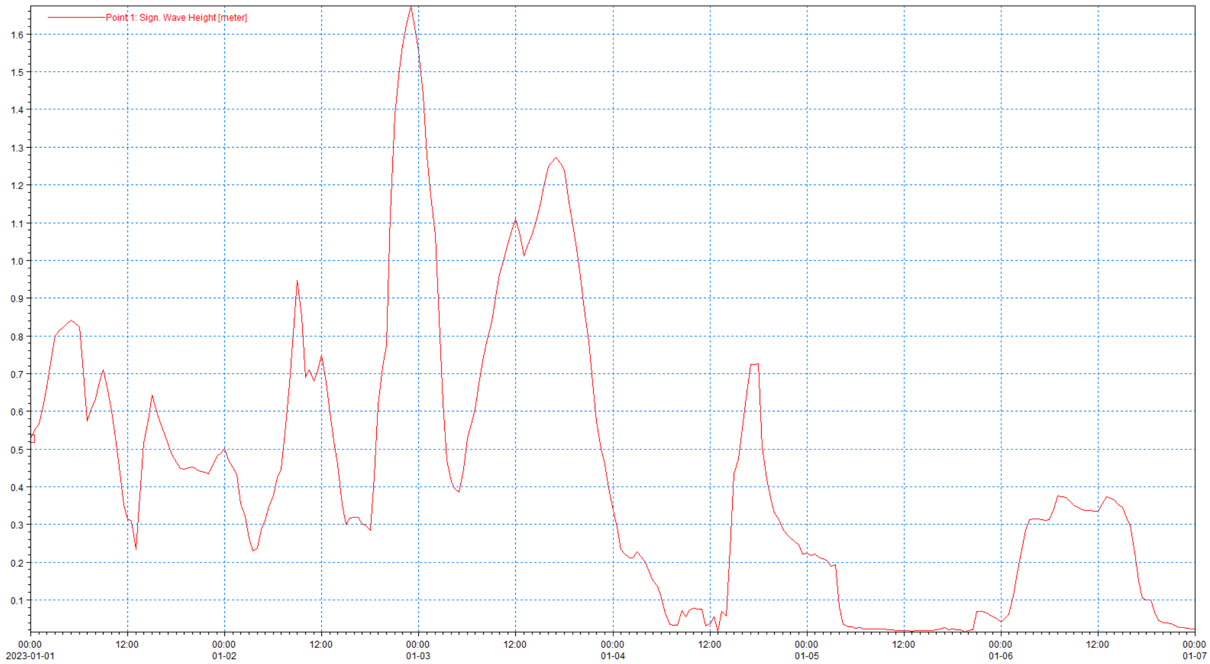

Figure 6.39: Significant Wave Height – Duration MT2 Simulation

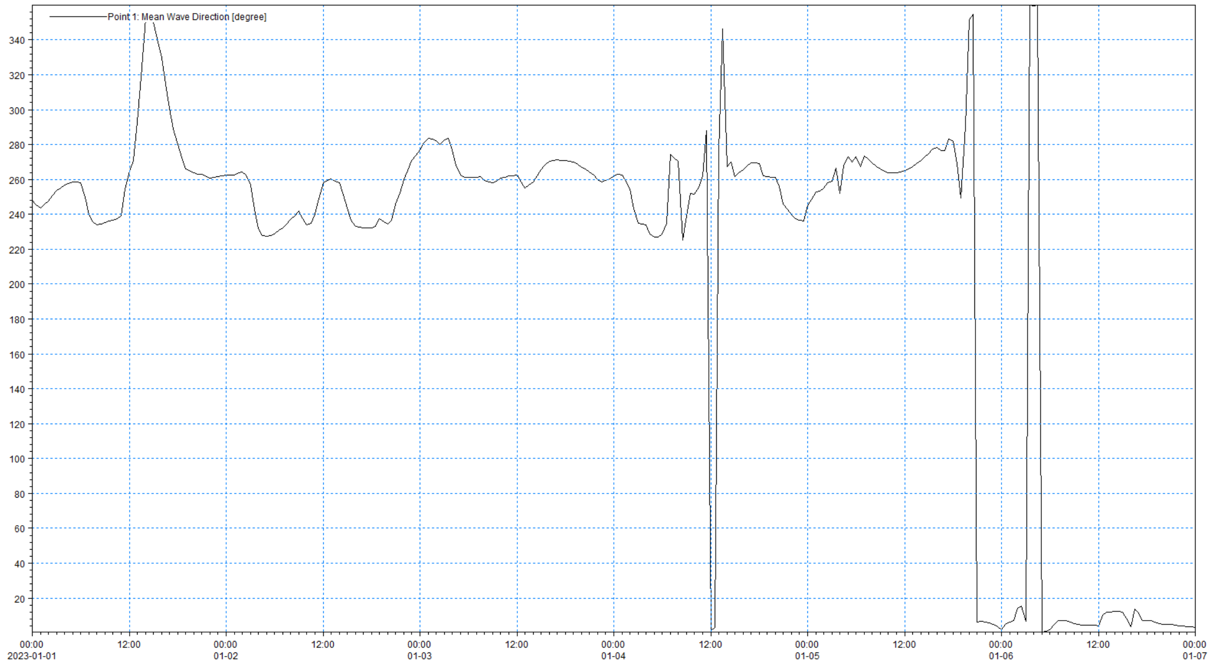

Figure 6.40: Mean Wave Direction – Duration MT2 Simulation

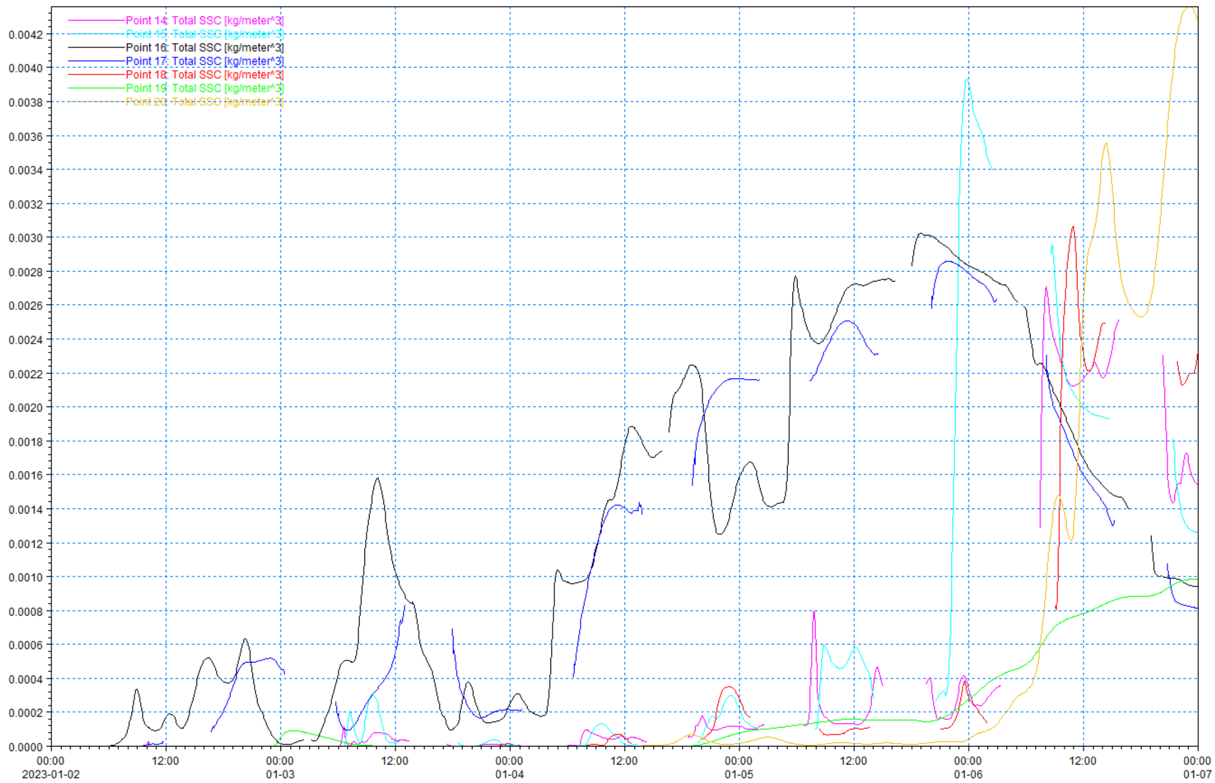

Figure 6.41: TSS at Key Locations – Duration of Wind/Wave Sensitivity Simulation

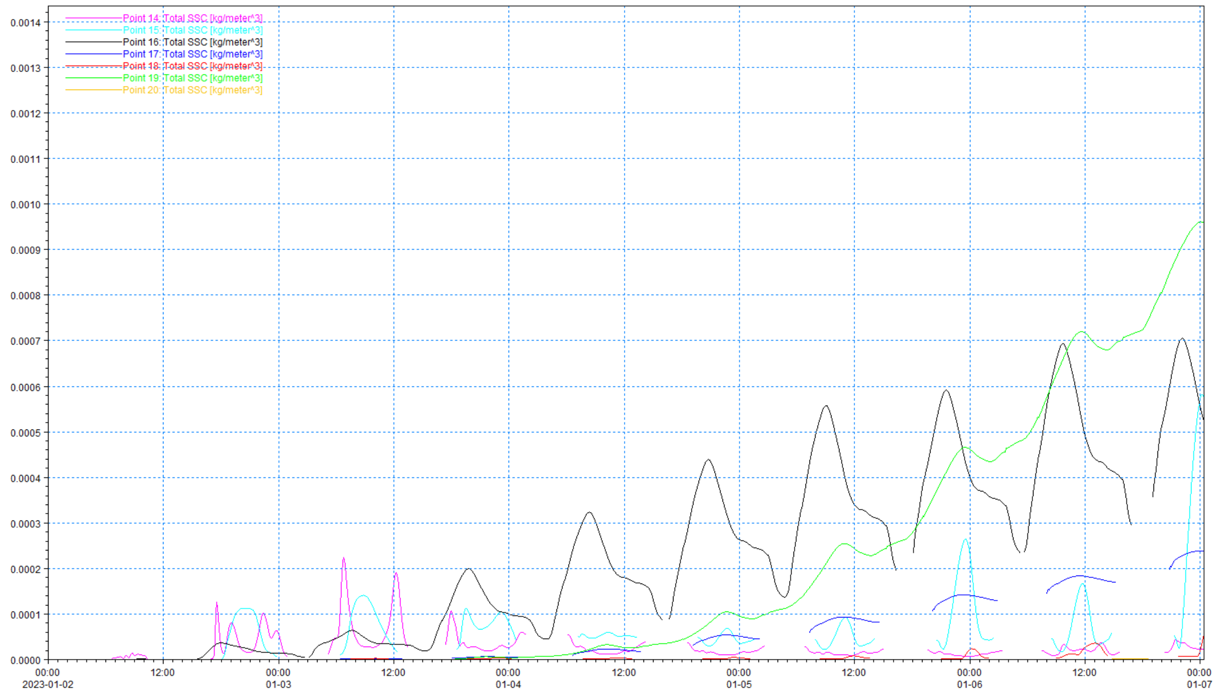

Figure 6.42: TSS at Key Locations – Equivalent Timesteps MT1

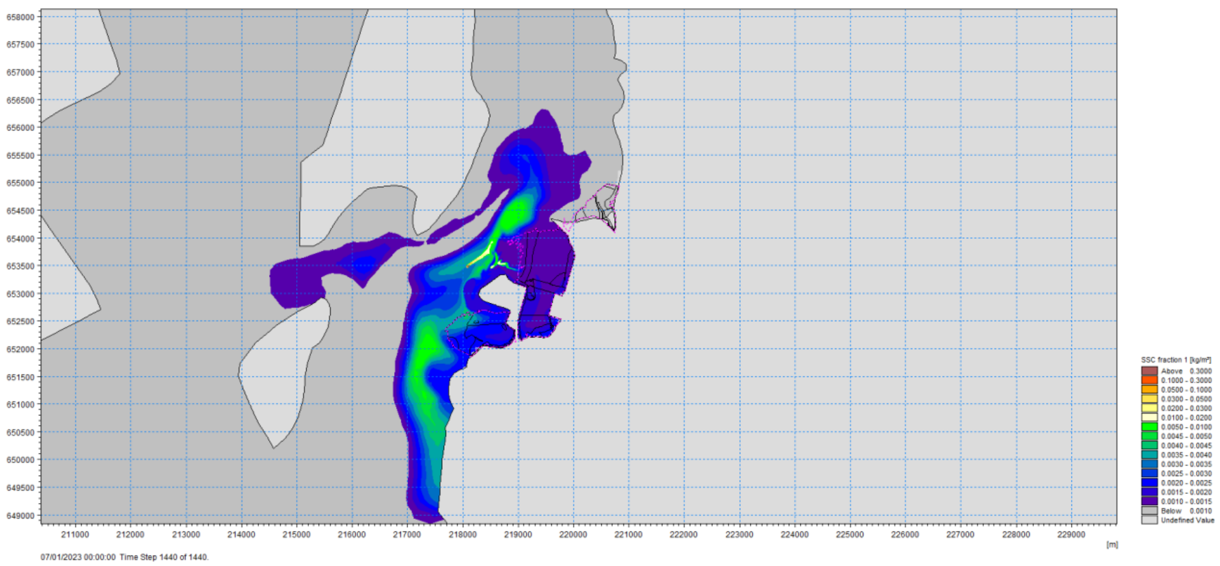

Figure 6.43: TSS at End of Simulation – MT2

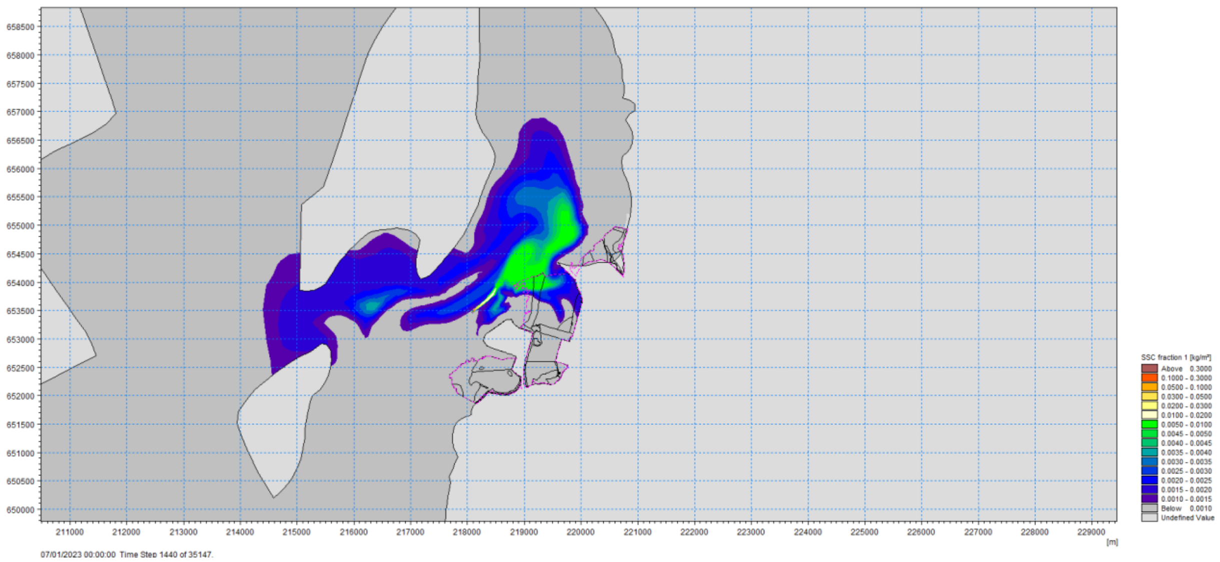

Figure 6.44: MT1 TSS at Equivalent Timestep (End of MT2 Simulation)

6.4.3 Maintenance Dredge (MT3)

Figure 6.45 presents a time-series plot of TSS at key point output locations (14 – 20) for the full simulation duration. Figure 6.46, Figure 6.47, and Figure 6.48 present area plots of TSS at model time-steps during a flood tide, high tide and ebb tide. Figure 6.49 shows TSS at the end of the model simulation, 5 days following completion of the maintenance dredge event. Figure 6.50 presents an area plot of deposition thickness at the end of the maintenance dredge simulation, whilst Figure 6.51 presents an area plot of total net deposition accumulation at the same model timestep.

On review of the above model results, the following points summarise the key findings of the maintenance dredge simulation (MT3):

- As per the capital dredge scenario, the position of the dredge plume moves in response to the circulation of the tidal currents around Hunterston Construction Yard, with highest concentrations of TSS found within the dredge extent and immediate surrounds;
- Whilst the dredger is working in the outer (western) areas of the dredge pocket the dredge plume remains generally within the immediate surrounds and adjacent Hunterston Channel;
- As the dredger works closer to the quay wall and north eastern extent of the dredge pocket the plume increasingly moves on to the southern areas of Southannan Sands during the flood tide to high water, and back out again on the ebb tide;
- TSS values in excess of 0.01 kg/m^3 (10 mg/l) are restricted to the immediate surrounds of Hunterston Construction Yard, including the adjacent Hunterston Channel;
- TSS values remain below 0.005 kg/m^3 (5 mg/l) at most sensitive receptor locations (key output locations 16 – 20) for the duration of the maintenance dredge campaign, with the exception of locations 14 and 15, where TSS levels increase beyond this threshold after a couple of days of the dredge campaign, in response to the working position of the dredger;
- TSS values remain below 0.06 kg/m^3 (60 mg/l) at locations 14 and 15 for all of the maintenance dredge campaign;
- Periods of elevated TSS values in excess of 0.01 kg/m^3 (10 mg/l) at sensitive receptors (locations 14 and 15) are for short duration towards the latter stages of the maintenance dredge;
- On completion of the dredge campaign elevated TSS levels are observed to steadily reduce towards background levels over a period of days;

- Sediment deposition depth outwith the immediate dredge zone, and at all sensitive receptors, is less than 0.001 m (1 mm);
- Total net deposition accumulation is less than 0.1 g/m^2 at all sensitive receptors (locations 14 – 20).

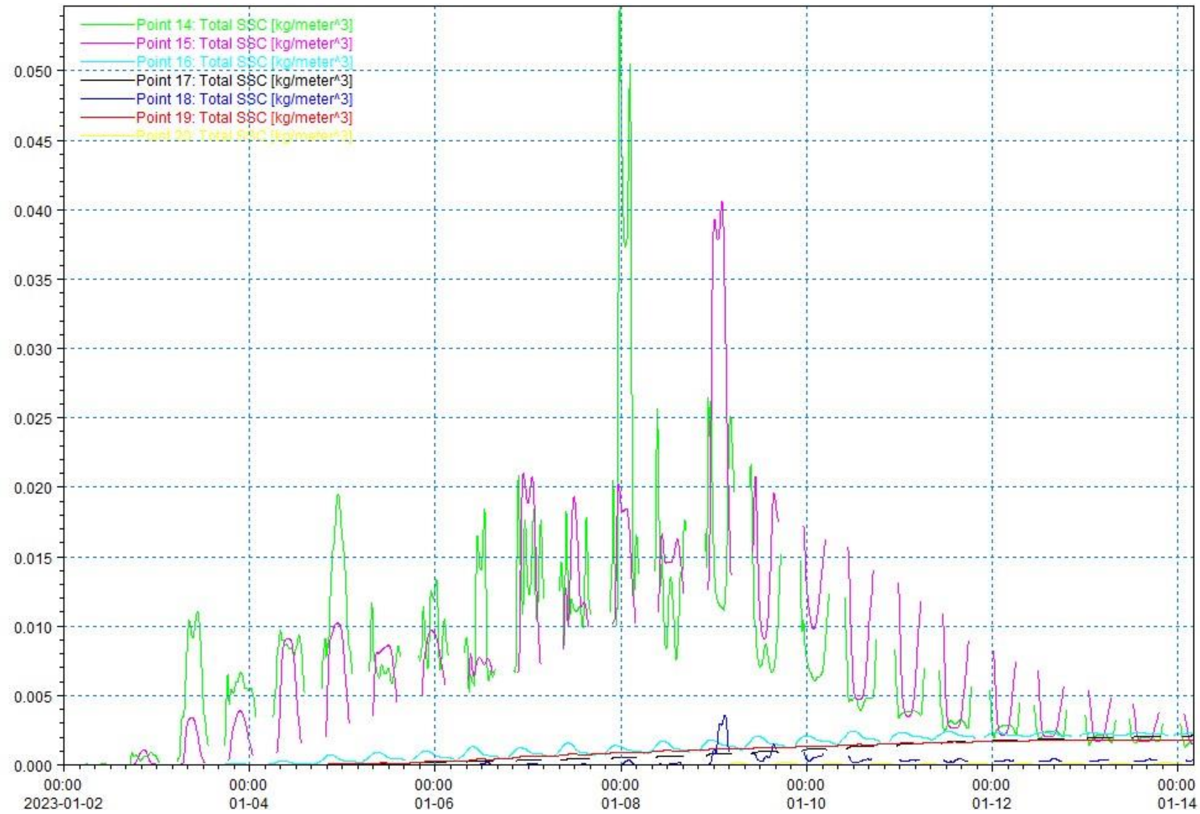

Figure 6.45: TSS at Key Locations – Full Simulation Period (MT3)

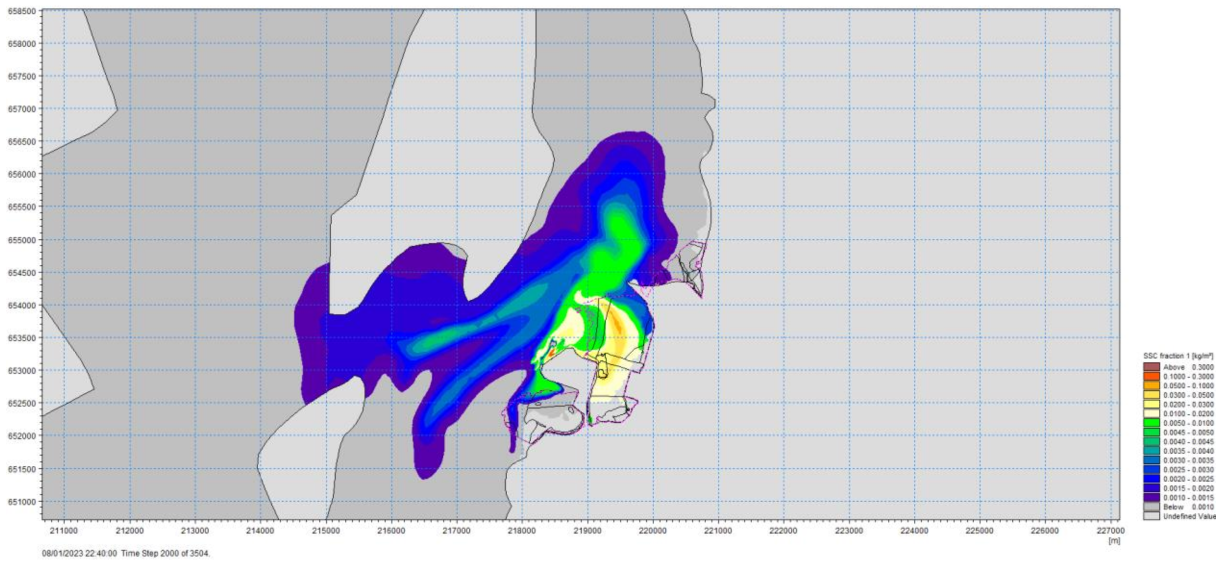

Figure 6.46: TSS During a Flood Tide (MT3)

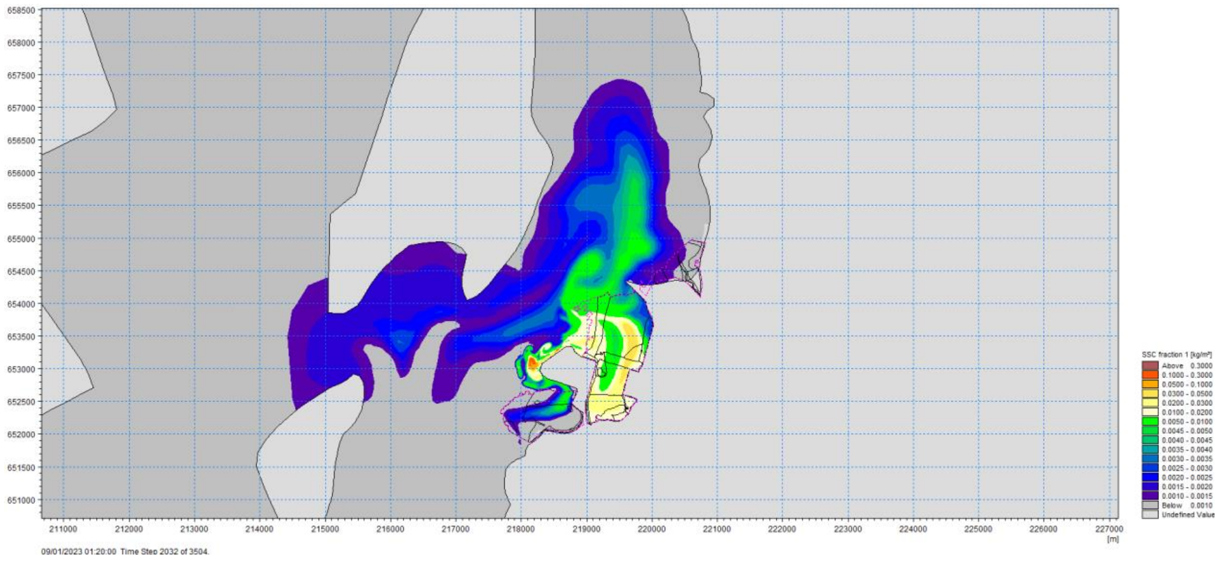

Figure 6.47: TSS at High Tide (MT3)

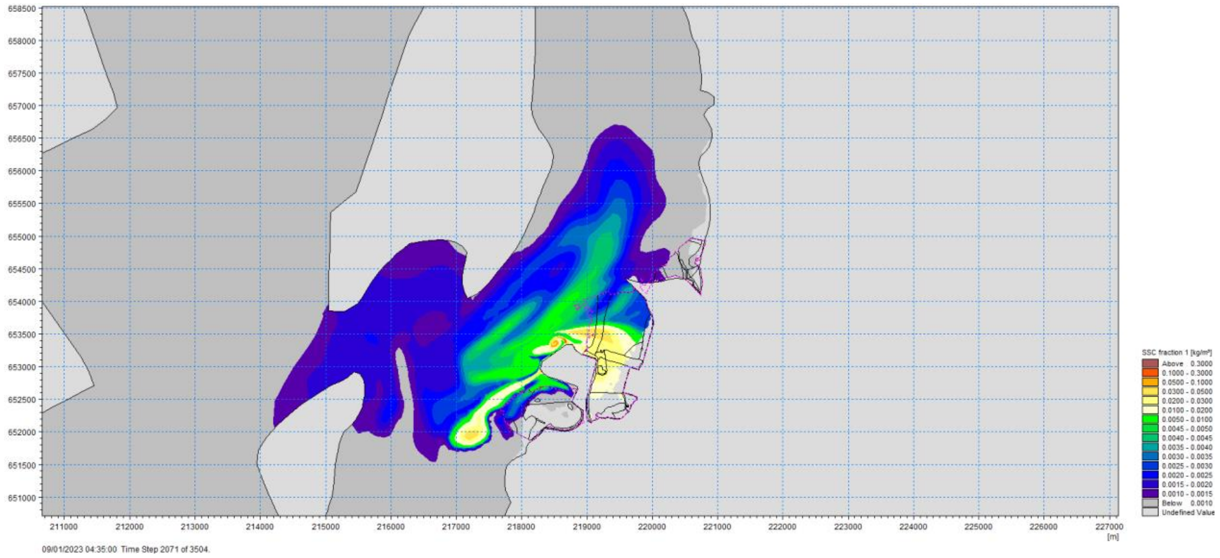

Figure 6.48: TSS During an Ebb Tide (MT3)

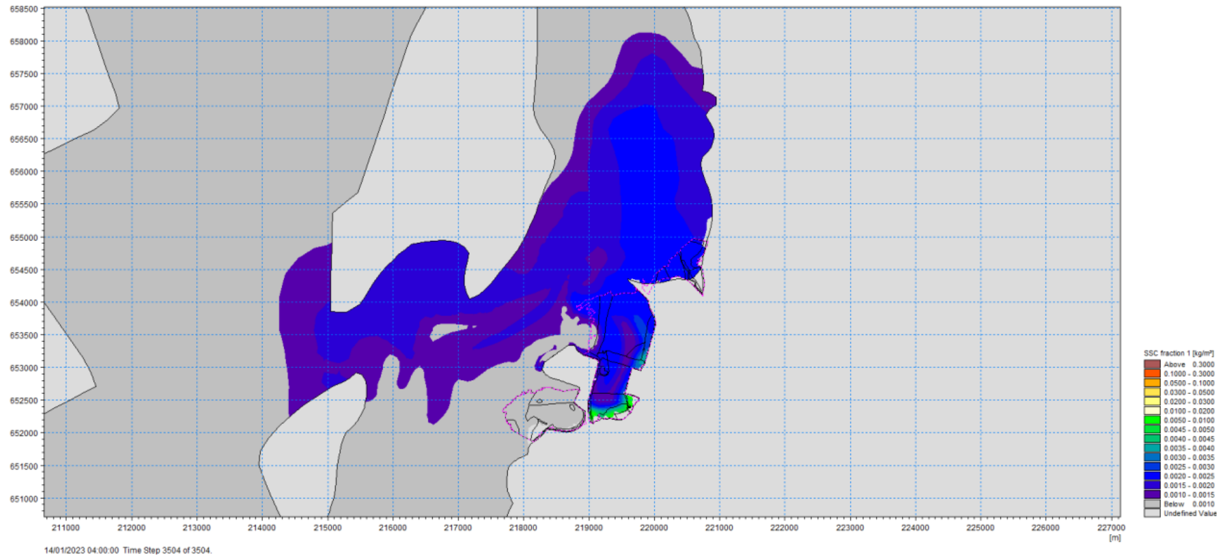

Figure 6.49: TSS End of Simulation (5 Days Post Dredge)

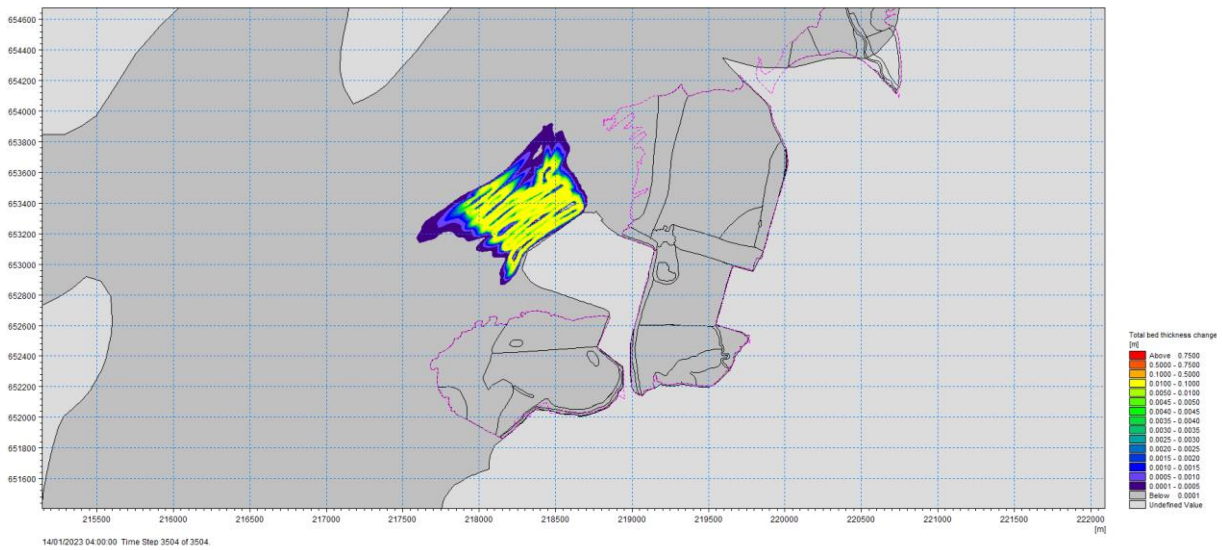

Figure 6.50: Total Deposition Thickness (m) End of Maintenance Dredge (MT3)

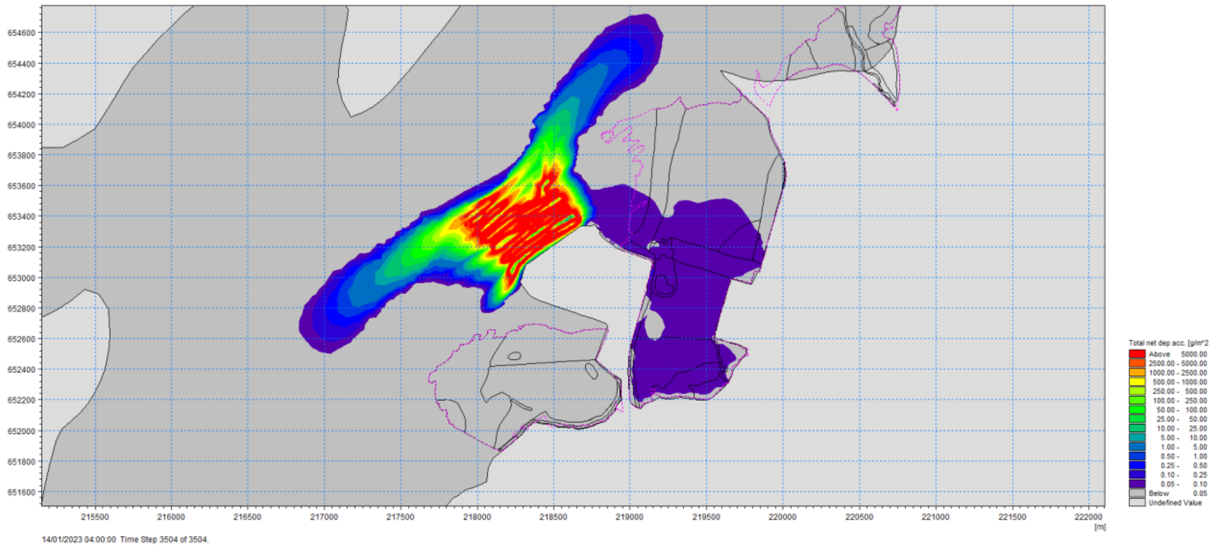

Figure 6.51: Total Net Deposition Accumulation (g/m^2) End of Maintenance Dredge (MT3)

7 CONCLUSIONS

The existing baseline tidal regime, wave climate and sediment dynamics in the vicinity of the proposed development works at the Hunterston Construction Yard have been characterised using available information, supported by a coastal modelling study.

Given the proximity of the Southannan Sands SSSI to the proposed development, it is considered a sensitive receptor to any potential changes to the coastal regime resulting from the development.

The baseline coastal conditions are observed to be relatively stable and the recently assessed condition of the SSSI is ‘Favourable Maintained’.

The proposed works are within an area where similar activities have occurred in the past and they represent a reworking or extension of these previous activities.

The coastal hydrodynamics and wave modelling undertaken has identified that any predicted changes to the tidal regime, wave climate and sediment transport processes will be local to the proposed works and will be relatively minor, resulting in no significant impacts.

The modelling of dredge plume dispersal undertaken has identified that for both capital and maintenance dredge scenarios any notable depth of sediment deposition, resulting from sediment spill and the associated plume, will be limited to the extent of the dredge pocket and immediate surrounds, with model predictions of less than 0.001m (1mm) of deposition within the SSSI. The most significant impact identified from the dredge plume modelling is the impact to water quality resulting from elevated TSS concentrations. However, this impact is of limited extent and short duration.

Based on the present status of the Southannan Sands SSSI, it is considered that the anticipated changes identified within this study do not present a risk or threat to the nature conservation designation interest of the site.