Environmental Impact Assessment Report - Volume 2B

Appendix 7-1:

Marine Processes Technical Report

ORIEL WINDFARM
OFFSHORE RENEWABLE ENERGY

A TETRA TECH COMPANY

PARK WIND
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Energy for generations

ORIEL WIND FARM PROJECT

Environmental Impact Assessment Report
Appendix 7-1: Marine Processes Technical Report

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Glossary

Term	Meaning
Ebb tide	Changing of the tides from high to low.
Flood tide	Changing of the tides from low to high.
Littoral current	Flow derived from tide and wave climate.
Offshore Cable Corridor	This is where the offshore cable will be located.
Shields parameter	A nondimensional number used to calculate the initiation of motion of sediment in a fluid flow
Significant wave height	Mean wave height (trough to crest) of the highest third of the waves.
Spring tide	Tide that occurs when the sun and moon are directly in line with the Earth and their gravitational pulls reinforce each other.
Residual current	The resulting flow over the course of a tidal cycle.

Acronyms

Term	Meaning
ADCP	Acoustic Doppler Current Profiler
BERR	Department for Business Enterprise and Regulatory Reform
CD	Chart Datum (generally defined as LAT)
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CIRIA	Construction Industry Research and Information Association
DHI	Danish Hydraulic Institute
ECMWF	European Centre for Medium Range Forecasts
EMODnet	European Marine Observation and Data Network
EPA	Environmental Protection Agency
GSI	Geological Survey of Ireland
HAT	Highest Astronomical Tide
HWM	High Water Mark – the level reached by the sea at high tide
INFOMAR	Integrated Mapping for the Sustainable Development of Ireland’s Marine Resource
LAT	Lowest Astronomical Tide
LIDAR	Light Detection and Ranging
LWM	Low Water Mark – the level reached by the sea at low tide
MEDIN	Marine Environmental Data and Information Network
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MT	Mud Transport
OPW	Office of Public Works
SPM	Suspended Particulate Matter
WTG	Wind Turbine Generator

Units

Unit	Description
mm	Millimetre (distance)
m	Metre (distance)
km	Kilometre (distance)
mm/s	Millimetres per second (speed)
m/s	Metres per second (speed)
mg/l	Milligrams per litre (suspended sediment concentration)
g/l	Grams per litre (suspended sediment concentration)

1 INTRODUCTION

This Marine Processes Technical Report presents information relating to marine processes associated with the Oriel Wind Farm Project (hereafter referred to as the Project). It describes the current baseline conditions and quantifies the potential changes due to the Project for application in the Environmental Impact Assessment Report (EIAR). It covers the numerical modelling undertaken in respect of design parameters for the construction, operational and maintenance, and decommissioning phases of the Project.

The offshore wind farm area is located east of Dundalk Bay, to the east of the Dundalk Patch (as shown on Admiralty Charts), with the landfall located south of Dunany Point. The offshore wind farm area is characterised by relatively weak tidal currents with water depths ranging between approximately 16 m and 33 m. Seabed sediments within the offshore wind farm area range from muddy sand to coarse gravel, with exposed rock outcrops at some locations.

This Technical Report is presented in two main sections:

- Baseline conditions – describing current hydrography and sedimentology (see Section 2); and
- Potential environmental effects – describing changes to the baseline arising from the construction and operational phases of the Project (see Section 3).

1.1 Study area

Section 2 outlines the physical conditions associated with the Marine Processes Study Area which is based on one tidal excursion from the offshore wind farm area and the offshore cable corridor. The tidal excursion was quantified by utilising the calibrated numerical model described in section 2: Baseline conditions. Specifically, neutrally buoyant particles were released across the extent of the modelled offshore wind farm area and offshore cable corridor. The excursion of these particles was examined over the course of a spring tide cycle and used to define the extent of a typical tidal excursion.

1.2 Methodology

The study utilised a range of data types from multiple sources as summarised in Table 1-1.

The MIKE numerical modelling suite was used to assess and describe the tide, wave and sediment transport processes both individually and in combination using a single model domain as described in section 2.1. The MIKE suite of models is a widely used industry standard modelling package developed by the Danish Hydraulic Institute (DHI). It has been approved for use by industry and government bodies including the Environmental Protection Agency (EPA). The MIKE suite is a modular system that contains different but complementary modules encompassing different gridding approaches and representing different physical processes.

Table 1-1: Summary of data sources.

Sources	Study	Data type	Format
UK Hydrographic Office	Admiralty	Tidal statistics and harmonics	Tide tables
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR)	Seabed Mapping Programme	Bathymetry / Light Detection and Ranging (LIDAR)	Digital source
Office of Public Works (OPW)	Irish Coastal Protection Strategy Study	Bathymetry / LIDAR	Digital source
	Catchment Flood Risk Assessment Management Studies	Bathymetry / LIDAR	Digital source
	Wave, tide and surge forecast trial for Dundalk	Bathymetry	Digital source
	Port Oriel and Giles Quay gauge data	Water level data	Digital source
MEDIN	Seabed Mapping Programme	Bathymetry / LIDAR	Digital source
CMap	Digital Charts	Bathymetry	Digital source
RPS	Irish Sea Surge model	Water level and current speed boundary data	Digital source
European Centre for Medium Range Forecasts (ECMWF)	ERA-40	Wave data	Digital source
	ERA5	Wind data	Digital source
Marine Institute	M2 buoy	Wave and wind data	Digital source
Gavin and Doherty Geosolutions (2018)	Oriel Wind Farm Project Site Data Review	Sedimentology Information: including Geological Survey Ireland (GSI) Foreshore Licence Area survey analysis	PDF Document
Gavin Doherty Geosolutions (2020)	Oriel Ground Model Update and Cable Route Interpretation	Sedimentology Information: geophysical data, geotechnical data, grab samples and boreholes collected for Oriel wind farm	PDF Document
PARTRAC (2020)	Oriel Wind Farm – Floating LiDAR Buoy 12 Month Measurement Campaign Data Report	Wave, current and wind data	Digital source and PDF Document
European Marine Observation and Data Network (EMODnet)	Sedimentology	Seabed classification	PDF Spatial data

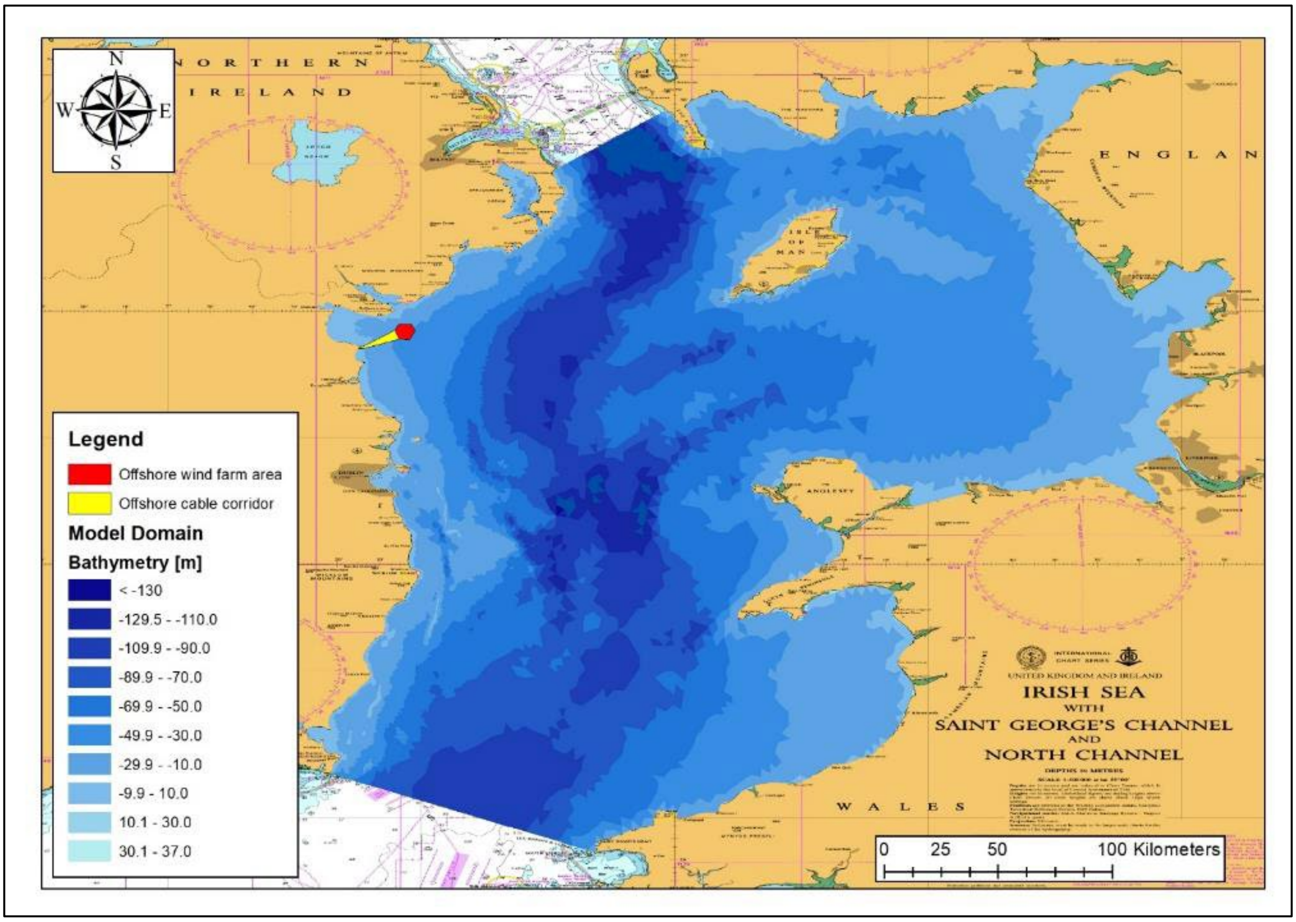

Figure 1-1: Numerical model domain used to assess marine processes in context of the Project.

2 BASELINE CONDITIONS

This section outlines the numerical modelling that was undertaken to determine baseline conditions. It describes the physical environment in terms of the sea state and existing sediment transport regime.

2.1 Bathymetry

The model domain had full bathymetry data coverage and was developed utilising data from a range of sources. This included data from the European Inspire project provided by INFOMAR, a joint programme between the GSI and the Marine Institute, which incorporated high resolution surveys which included the offshore wind farm area. Additionally, these surveys also provided coverage of the offshore banks along the east coast of Ireland which is important for the development of the wave climate in the Irish Sea.

The model also utilised Lidar and bathymetric data collected for the Irish Coastal Protection Strategy Study, the Catchment Flood Risk Assessment Management Studies and the wave, tide and surge forecast trial for Dundalk undertaken on behalf of the OPW.

Figure 2-1 illustrates a section of the bathymetric data used to develop the model whilst the inset shows the INFOMAR datasets for the Marine Processes Study Area.

Where additional data was required, digital chart data supplied by C-Map was included. The data was prioritised in order so that the most recent data was used where there was data overlay and all data was adjusted to the mean sea level datum.

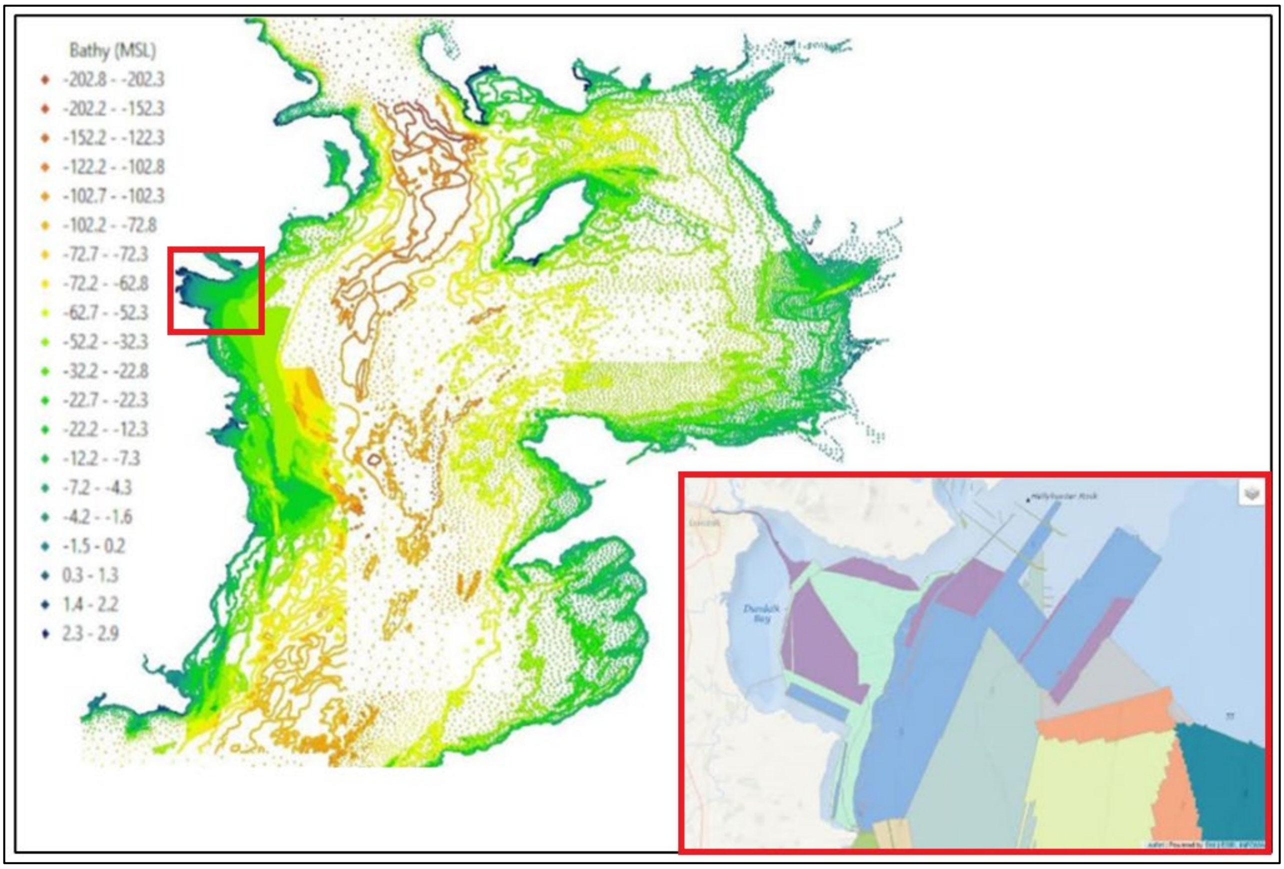

Figure 2-1: Sample of bathymetric data (left) detail of INFOMAR datasets within study area (inset).

The resolution of the model bathymetry was designed to provide accurate simulation of tidal currents. The model resolution was increased in areas where rapid changes in bathymetry occur. This included Arklow Bank, Codling Bank and Blackwater Bank to the south. Additionally, the model resolution was increased to <5 m across the offshore wind farm area in order that the influence of scour protection would be included within the sediment transport modelling in the post-construction modelling.

The extent of the domain was designed to provide a suitable basis for tide, wave and sediment transport modelling. The focus of the study is one tidal excursion from the offshore wind farm and offshore cable corridor area. However, a larger domain was required to develop wave fields and ensure that tidal currents were simulated accurately at the offshore wind farm area.

As illustrated in Figure 2-1, the model extends across the entire Irish Sea from the North Channel to Saint George's Channel. This extent ensured a stable tidal model due to the larger range and also enabled fetch limited wave modelling to be undertaken. Figure 2-2 shows the variation in bathymetry across the model domain whilst Figure 2-3 shows the detail of the Marine Processes Study Area with mesh data inset. In each case the offshore wind farm and offshore cable corridor areas are shown in red.

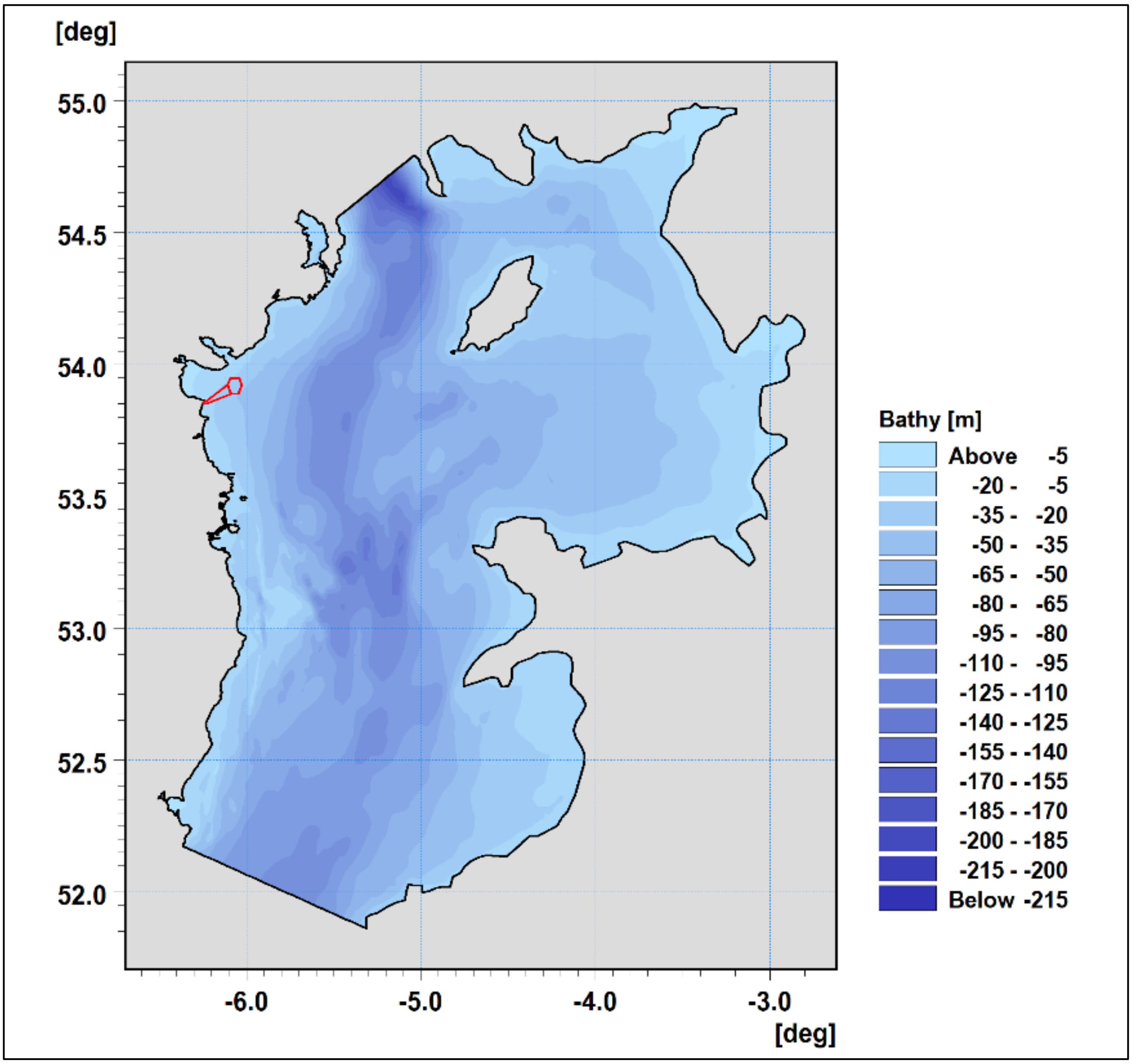

Figure 2-2: Model bathymetry to mean sea level.

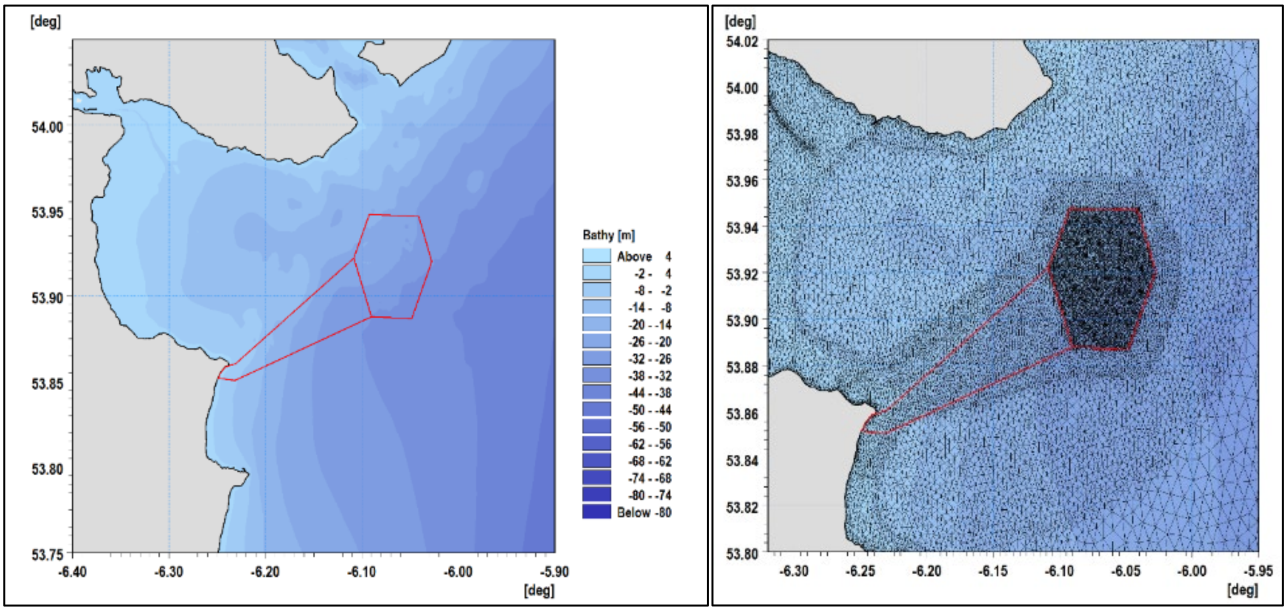

Figure 2-3: Model bathymetry within Marine Processes Study Area and with mesh detail.

2.2 Hydrography

2.2.1 Tidal flows

The UK Hydrographic Office states that the mean tidal range at the closest Standard Port of Dublin is approx. 2.65 m with the following characteristics in metres referenced to Chart Datum (CD):

- Lowest Astronomical Tide (LAT): +0.1;
- Mean Low Water Springs (MLWS): +0.7;
- Mean Low Water Neaps (MLWN): +1.5;
- Mean Sea Level (MSL): +2.4;
- Mean High Water Neaps (MHWN): +3.4;
- Mean High Water Springs (MHWS): +4.1; and
- Highest Astronomical Tide (HAT): +4.5.

Furthermore, Figure 2-4 shows the tidal ranges at the OPW gauges at Giles Quay, to the north of the offshore wind farm area and Port Oriel to the south. The flat bottom of the Port Oriel trace indicates that the gauge dried out at lower water levels.

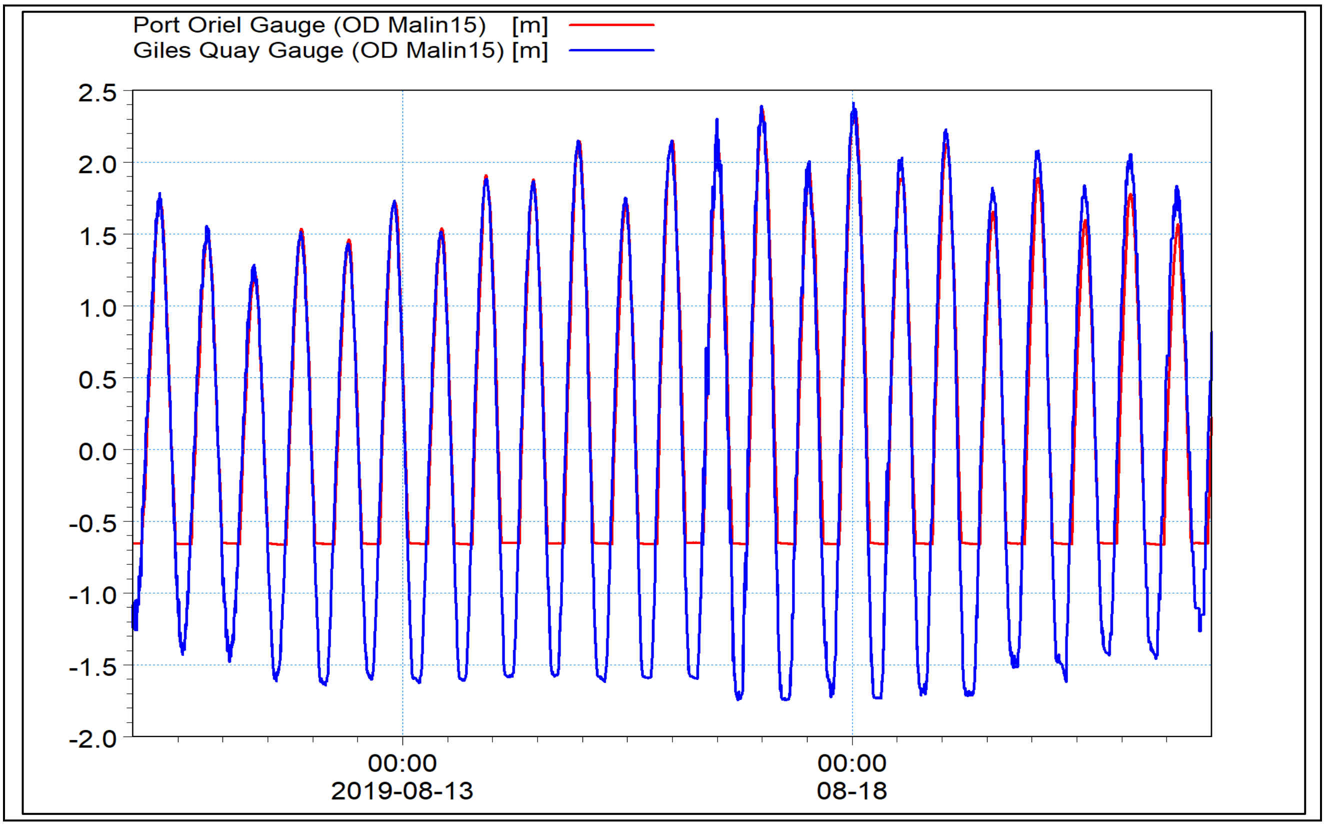

Figure 2-4: Gauge records from Port Oriel and Giles Quay.

The tidal flow simulations which form the basis of the study were undertaken using the MIKE21 Hydrodynamic (HD) module based on a Flexible Mesh (FM) modelling system. The HD Module is a 2-dimensional, depth averaged hydrodynamic model which simulates the water level variations and flows in response to a variety of forcing functions in lakes, estuaries and coastal areas. The water levels and flows are resolved on a mesh covering the area of interest when provided with bathymetry, bed resistance coefficient, wind field, hydrodynamic boundary conditions, etc.

The Marine Processes Study Area is characterised by shallower banks surrounded by deep areas of open water. The mesh resolution was therefore defined with sufficient detail to resolve the spatial variations in tidal flow. There are no counter currents or strong density stratified flows that would necessitate the use of three-dimensional modelling. Even though the model used for this assessment is depth averaged, the MIKE modules include the influence of depth of wind, bed shear and current profiles when modelling of the movement of particles within the water column.

The tidal model was driven using boundary conditions extracted from RPS' Irish Sea Surge model which is used for live storm surge forecasting on behalf of the OPW. These boundaries were fully defined 'flather' boundaries for which both surface elevation and current vectors are specified. The model was calibrated using the gauged water level data, Admiralty tidal data and field data collected as part of the OPW forecast trial for Dundalk. The model was then verified against floating Lidar and Acoustic Current Doppler Profiler (ADCP) measurements collected within the offshore wind farm area.

Across the offshore wind farm area, the tidal current floods in a northwest direction and ebbs to the southeast. The flows are relatively weak with tidal current speeds typically less than 0.2 m/s; with ebb and flood currents being of a similar magnitude. This was confirmed by ADCP survey data which showed current speeds were below 0.2 m/s for 80% of the 12 month monitoring period. This is illustrated in Figure 2-5 and Figure 2-6 which present the tidal patterns for flood and ebb tides respectively across the Marine Processes Study Area. In each case (and in all subsequent figures) the offshore wind farm area is outlined in red.

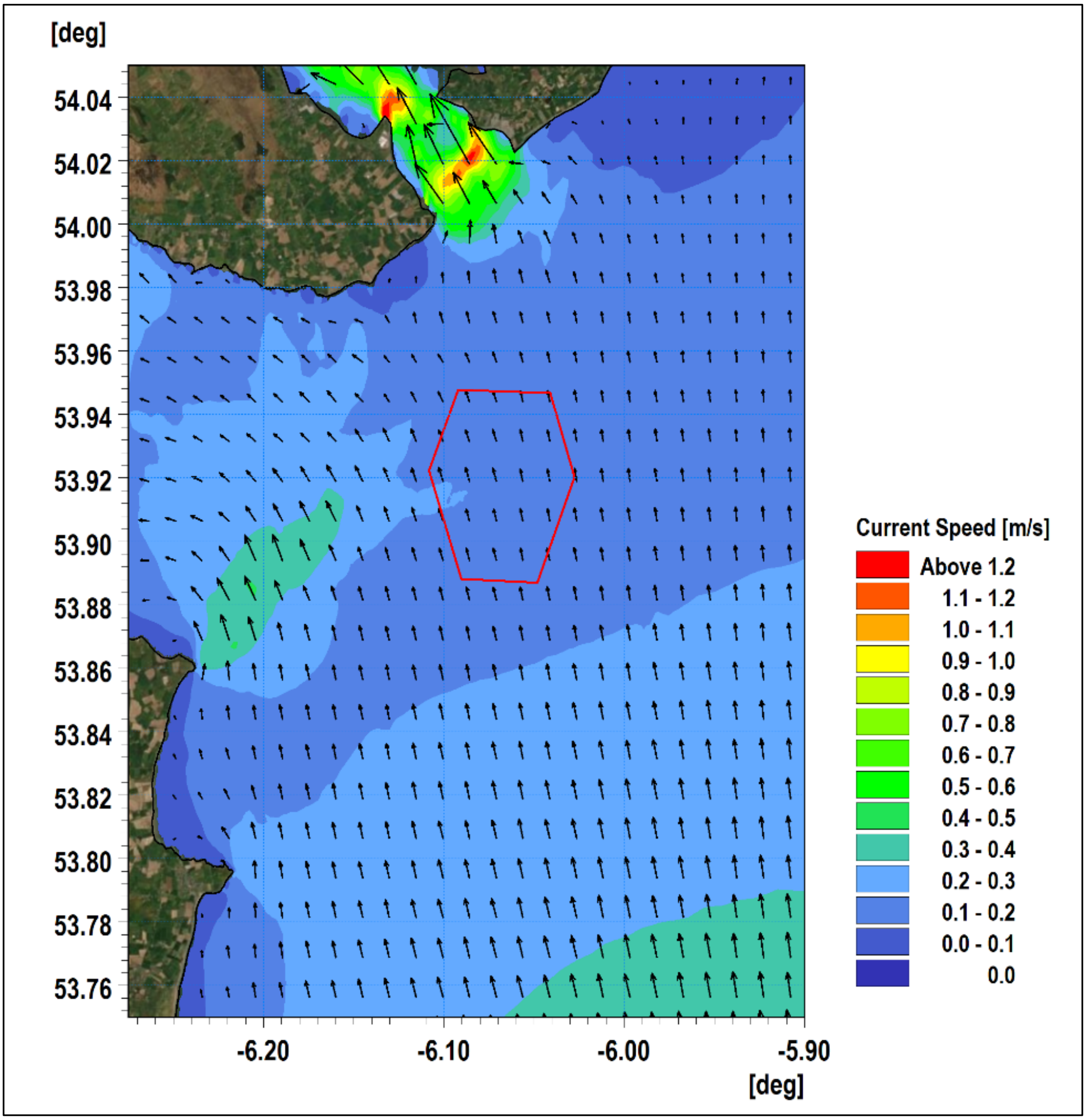

Figure 2-5: Baseline tidal flow patterns - mid-flood.

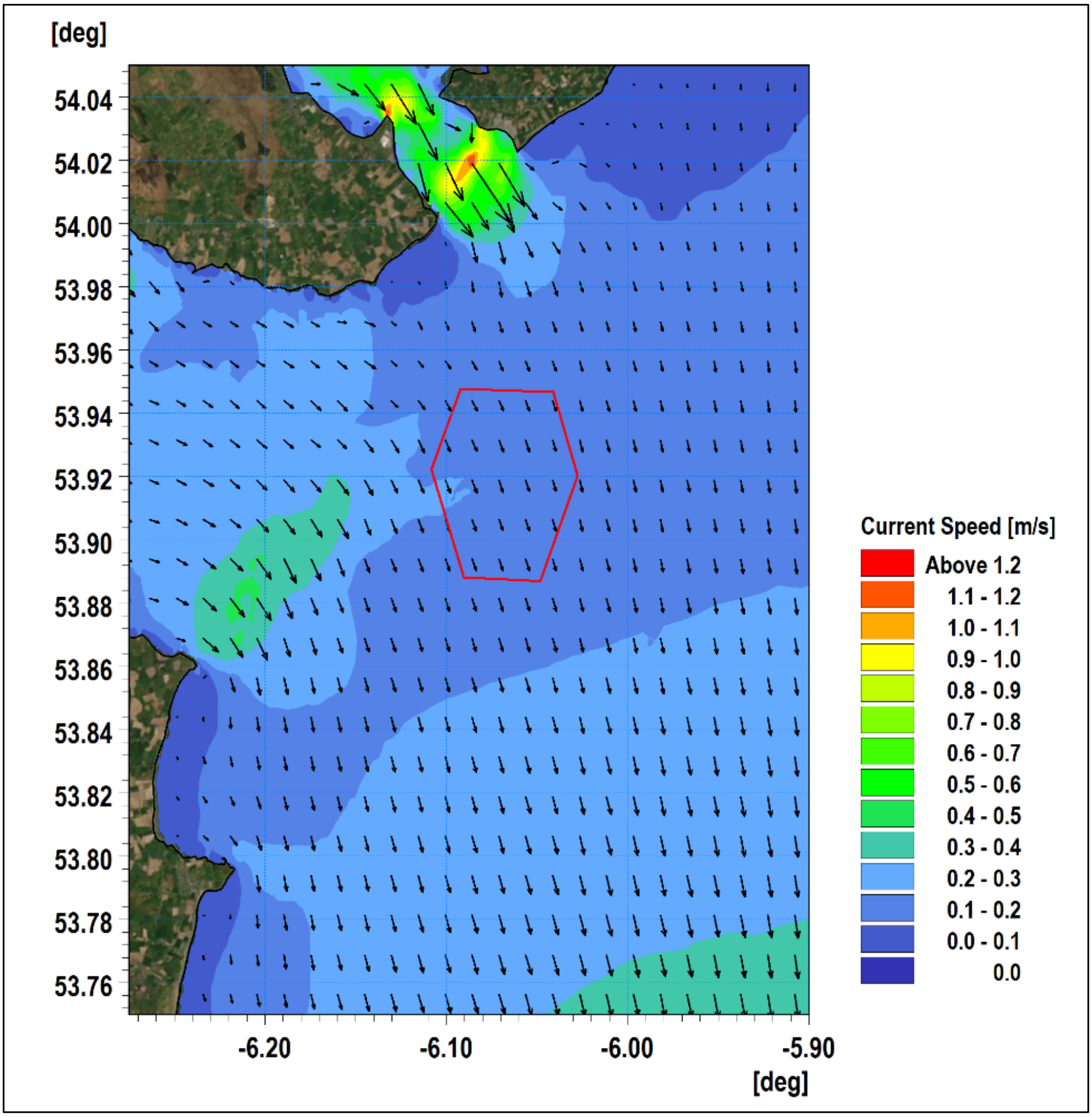

Figure 2-6: Baseline tidal flow patterns - mid-ebb.

2.2.2 Wave climate

The offshore wind farm area is sheltered from incoming waves from northerly fetches however larger waves may reach the offshore wind farm area from the south due to a greater fetch length. This is shown in Figure 2-7 which presents the significant wave height and directionality of waves in the vicinity of the Marine Processes Study Area. This wave rose was produced using data from the ECMWF ERA-40 model for a 22-year period.

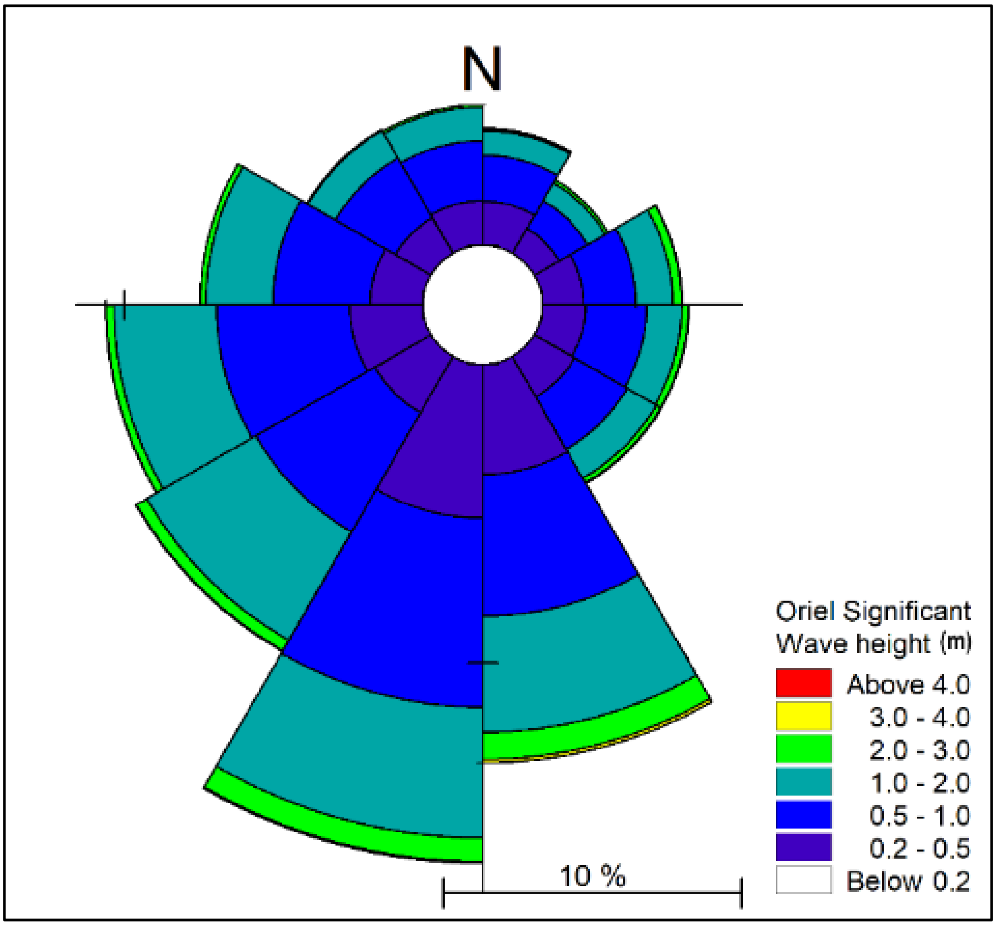

Figure 2-7: Wave rose for the offshore wind farm area based on a 22-year wave climate.

The waves reaching the offshore wind farm area are fetch limited. An analysis was therefore undertaken to determine the wind conditions in the Irish Sea for a number of scenarios in order to develop baseline wave conditions.

Thirty-nine years of data were obtained from the ECMWF's ERA5 reanalysis dataset for a location near to the M2 buoy location to the southeast of Dundalk Bay. The wind rose for this period is presented in Figure 2-8. An Extreme Value Analyses (EVA) was undertaken for the principal sectors to determine the 1 in 2 and 1 in 50-year wind speeds. These return periods were selected to identify the magnitude of typical events and more extreme events from the principal directions (i.e. 015°, 090° and 165°). These data were then used as boundary condition input for wave simulations to establish the potential impacts under a range of wave conditions.

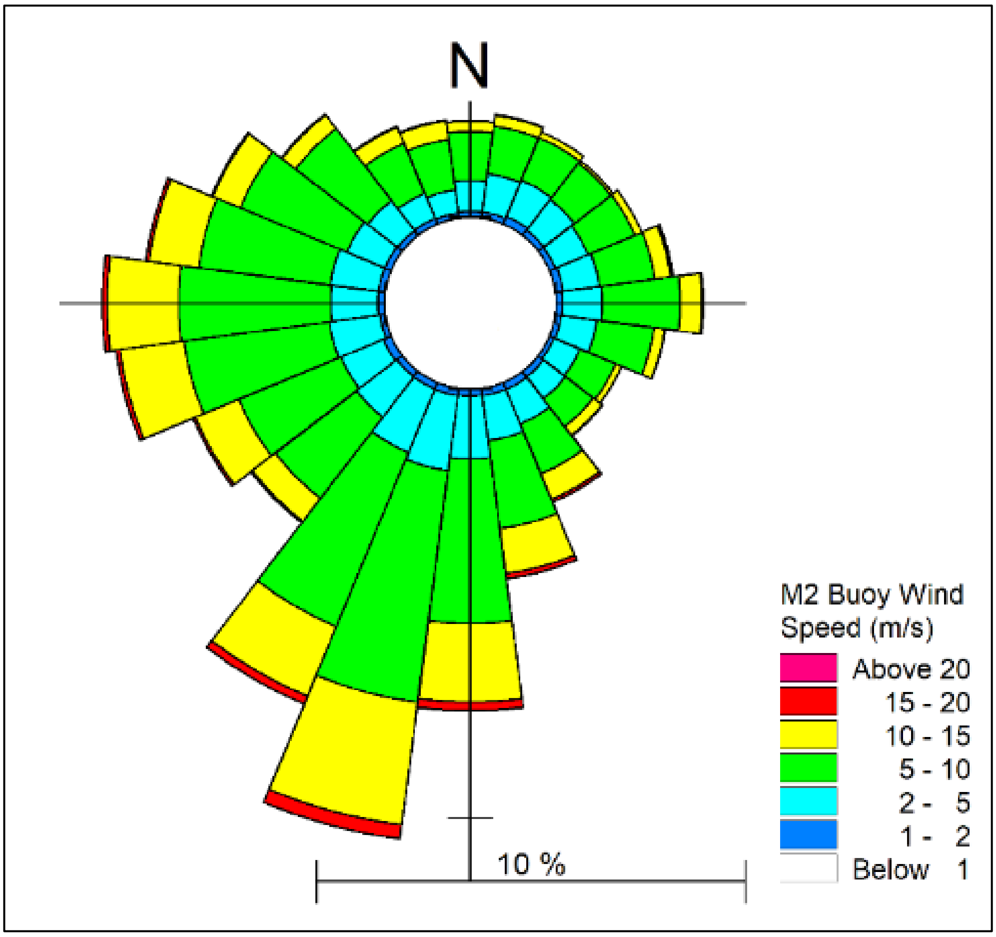

Figure 2-8: Wind rose for a location near the M2 wave buoy in the Irish Sea based on 39-year dataset.

The wave modelling was undertaken using the MIKE21 Spectral Save (SW) module. The waves were computed on the same grid as the tidal flows and were resolved by simulating wind generation of waves within the model domain. Figure 2-9 to Figure 2-14 illustrates the wave climate for three 1 in 2 and three 1 in 50 year return period events; from approximately a northerly (015°), easterly (090°) and southerly (165°) direction. These wave simulations were undertaken during a typical high water (HW) spring tide scenario.

Figure 2-9 shows the waves approaching from the north. Based on these results, significant wave heights of around 2.5 m were found to occur at the offshore wind farm area from a north-easterly direction. As illustrated in Figure 2-10, significant wave heights were larger at the offshore wind farm area during easterly storm events owing to the more exposed fetch. Storm events from the south were found to produce the largest significant waves of *c.* 3.2 m at the offshore wind farm area as illustrated in Figure 2-11.

Figure 2-12 to Figure 2-14 presents similar results for the 1 in 50-year wave events. It will be seen from these figures that the wave patterns are generally similar, albeit significant wave heights are greater. The significant wave heights in the offshore wind farm increases from 3.2 m during a 1 in 2 year event to *c.* 4.0 m during a 1 in 50 year event from the south.

The floating Lidar data was collected over a period of 12 months and therefore the magnitude and variation with direction may be utilised to confirm the model results (albeit for a reduced return period). This survey data recorded significant wave heights of 1.5 – 2 m for the largest events from the northeast. Significant wave heights of 2.5 – 3 m and 3.5 – 4 m were recorded during arduous events from the east and southeast respectively. In general, this survey data correlated well with the example events modelled.

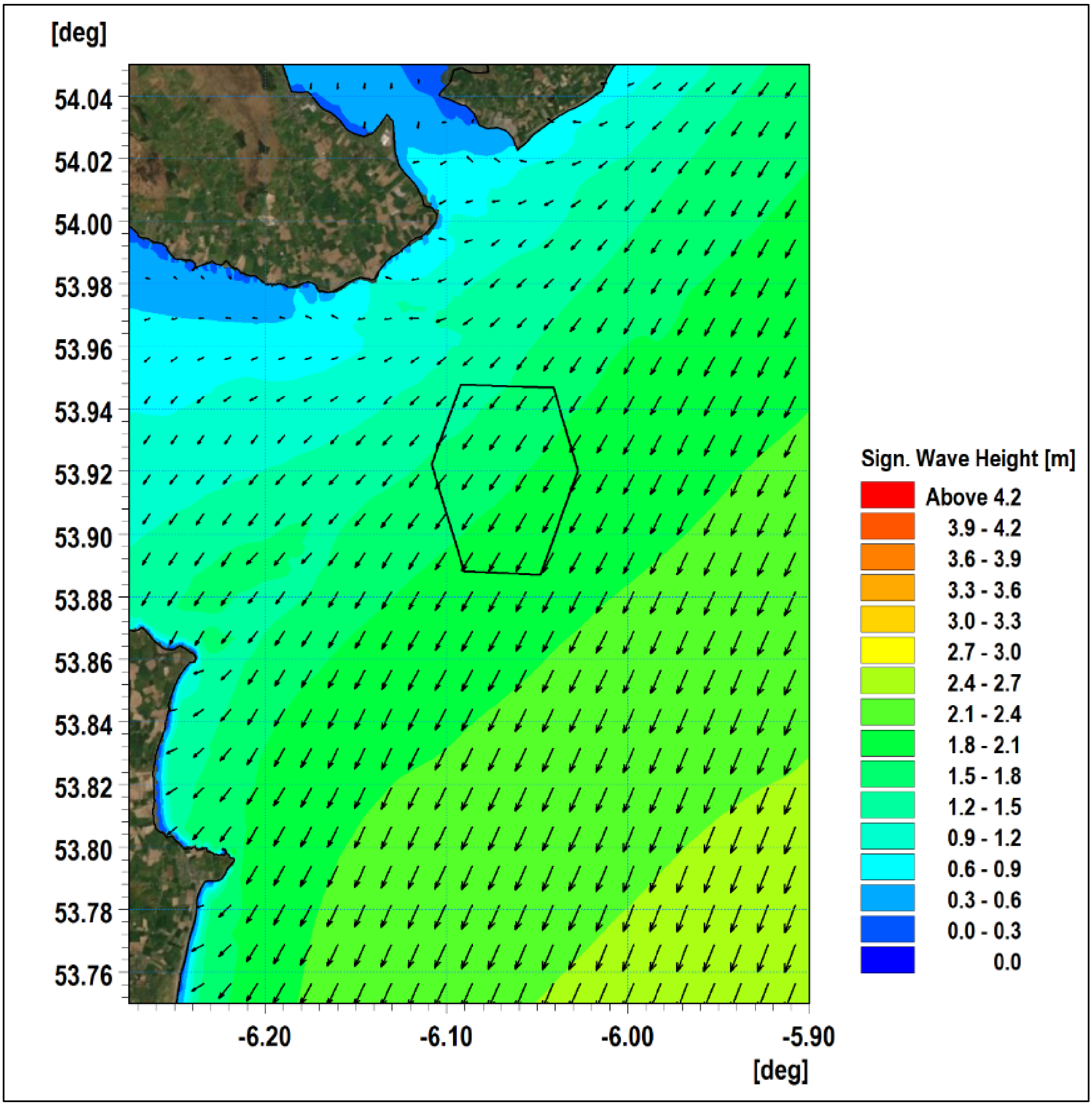

Figure 2-9: Baseline wave climate 1 in 2 year storm from 015°.

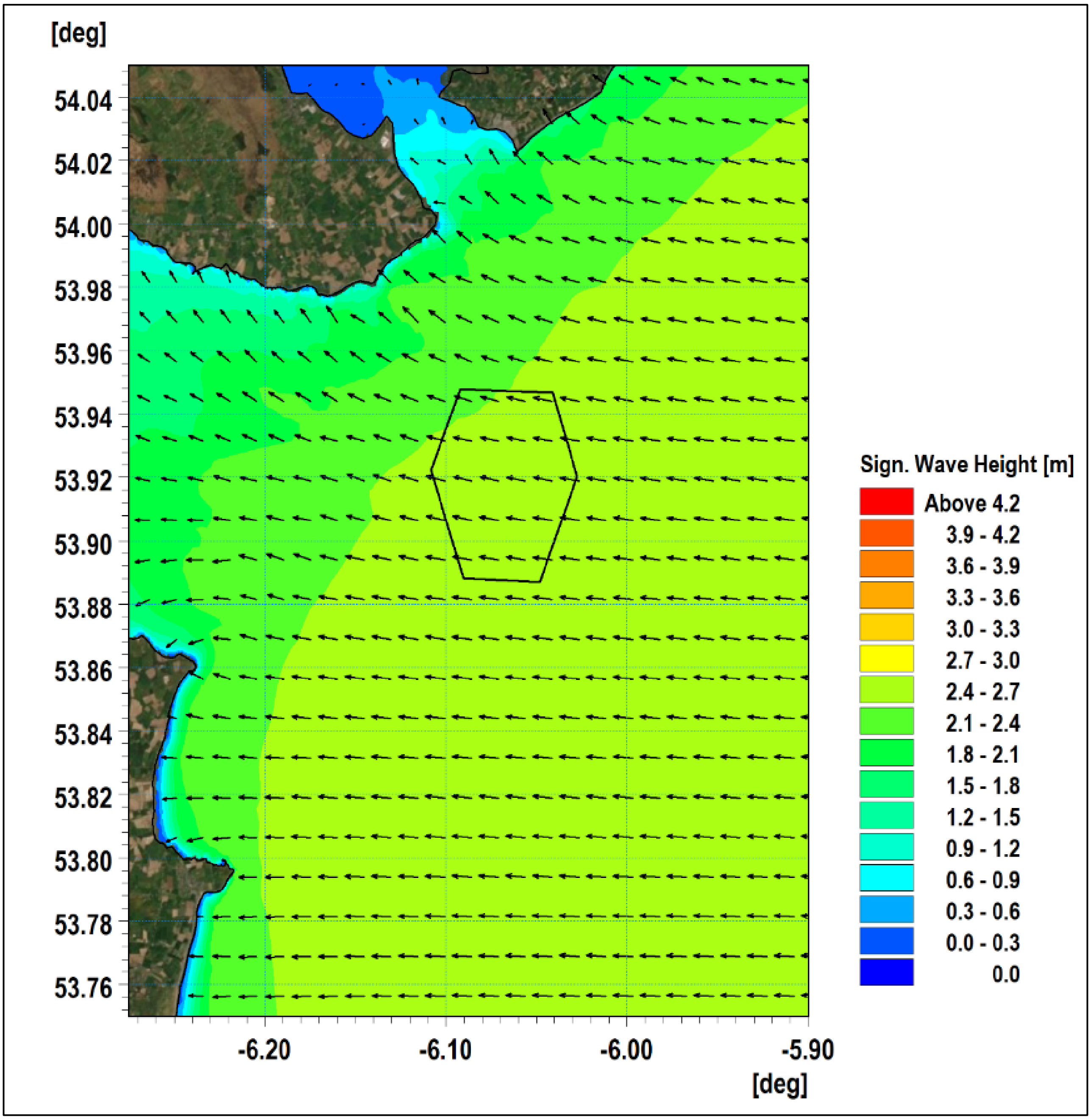

Figure 2-10: Baseline wave climate 1 in 2 year storm from 090°.

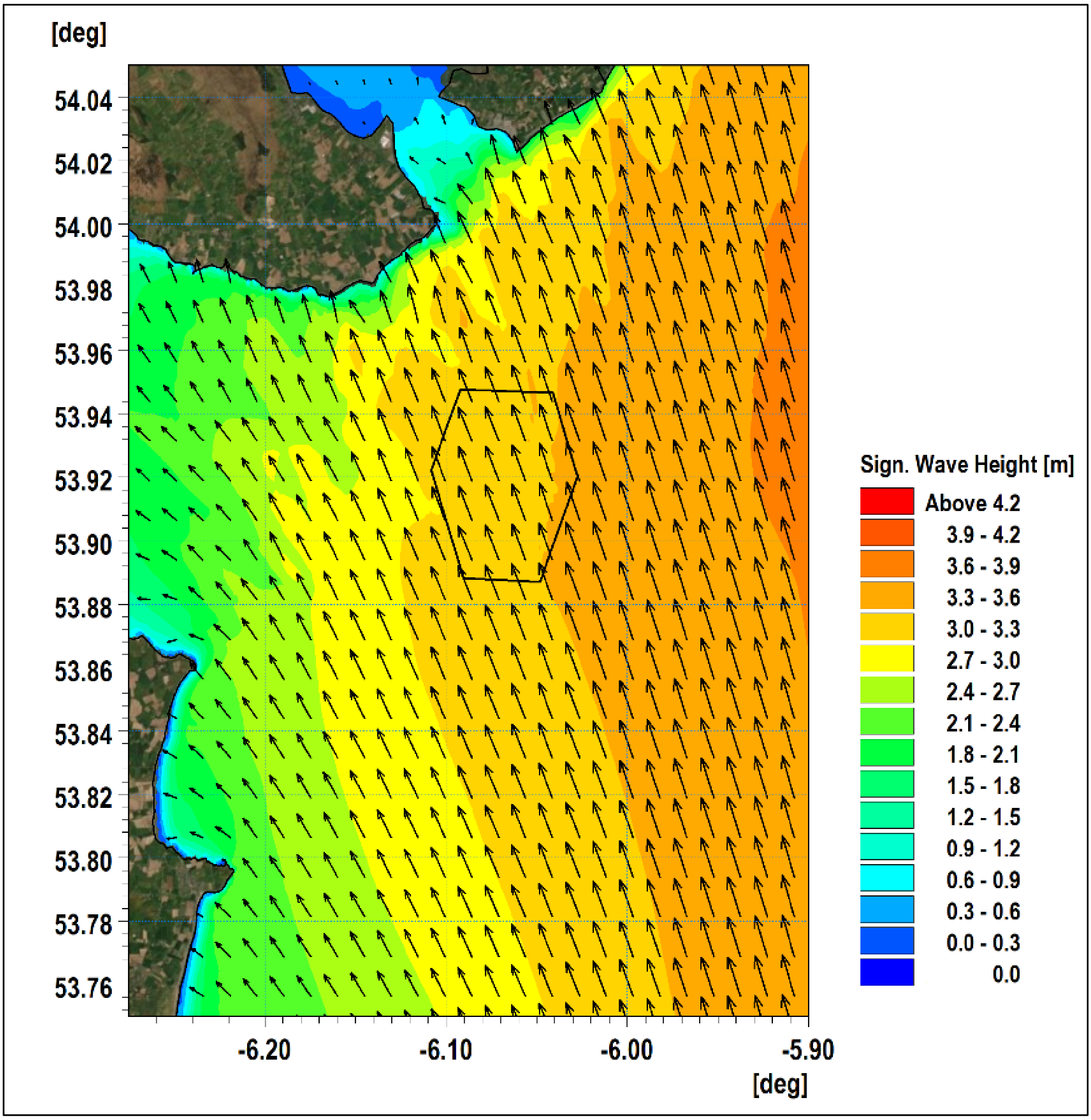

Figure 2-11: Baseline wave climate 1 in 2 year storm from 165°.

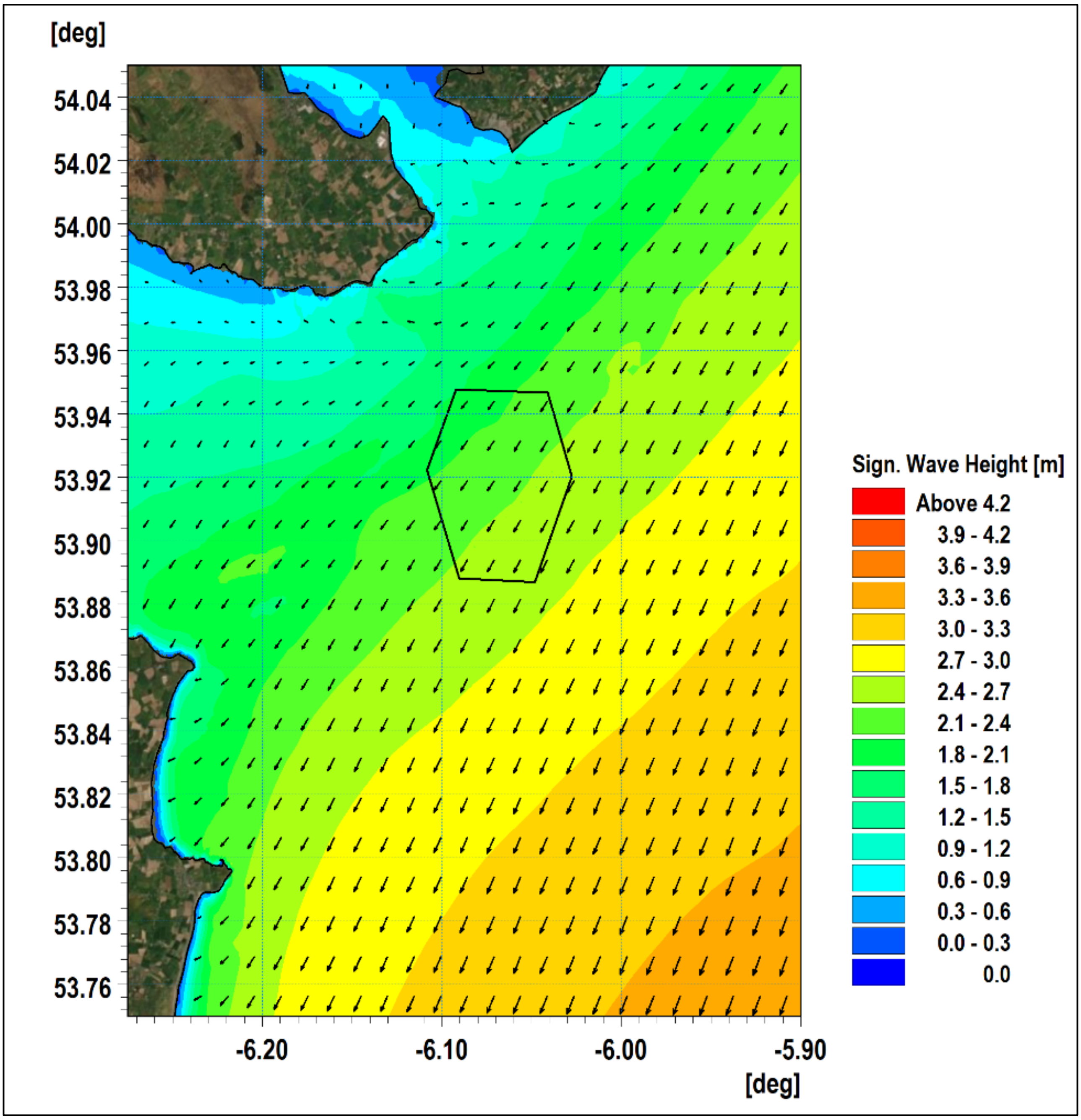

Figure 2-12: Baseline wave climate 1 in 50 year storm from 015°.

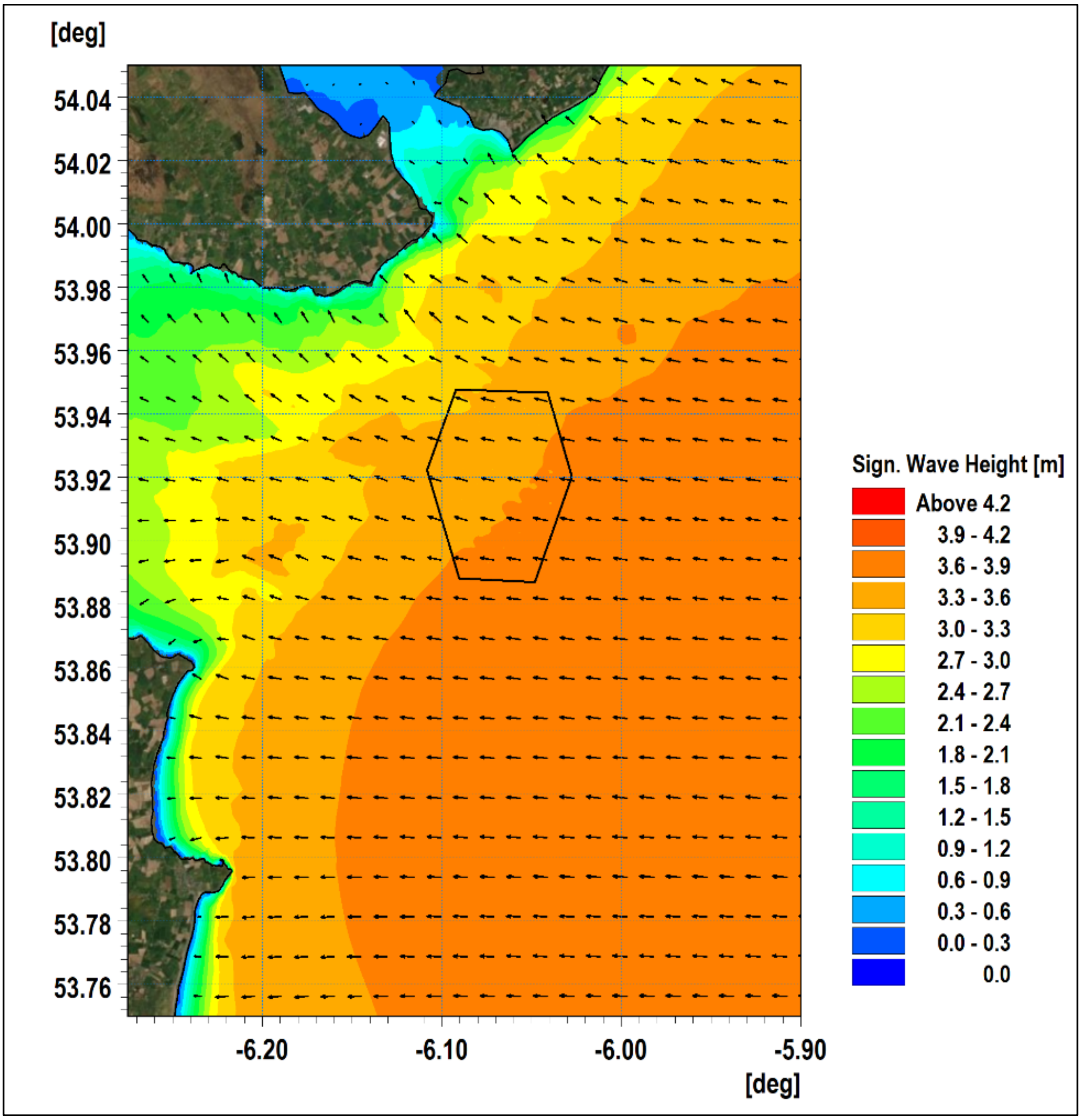

Figure 2-13: Baseline wave climate 1 in 50 year storm from 090°.

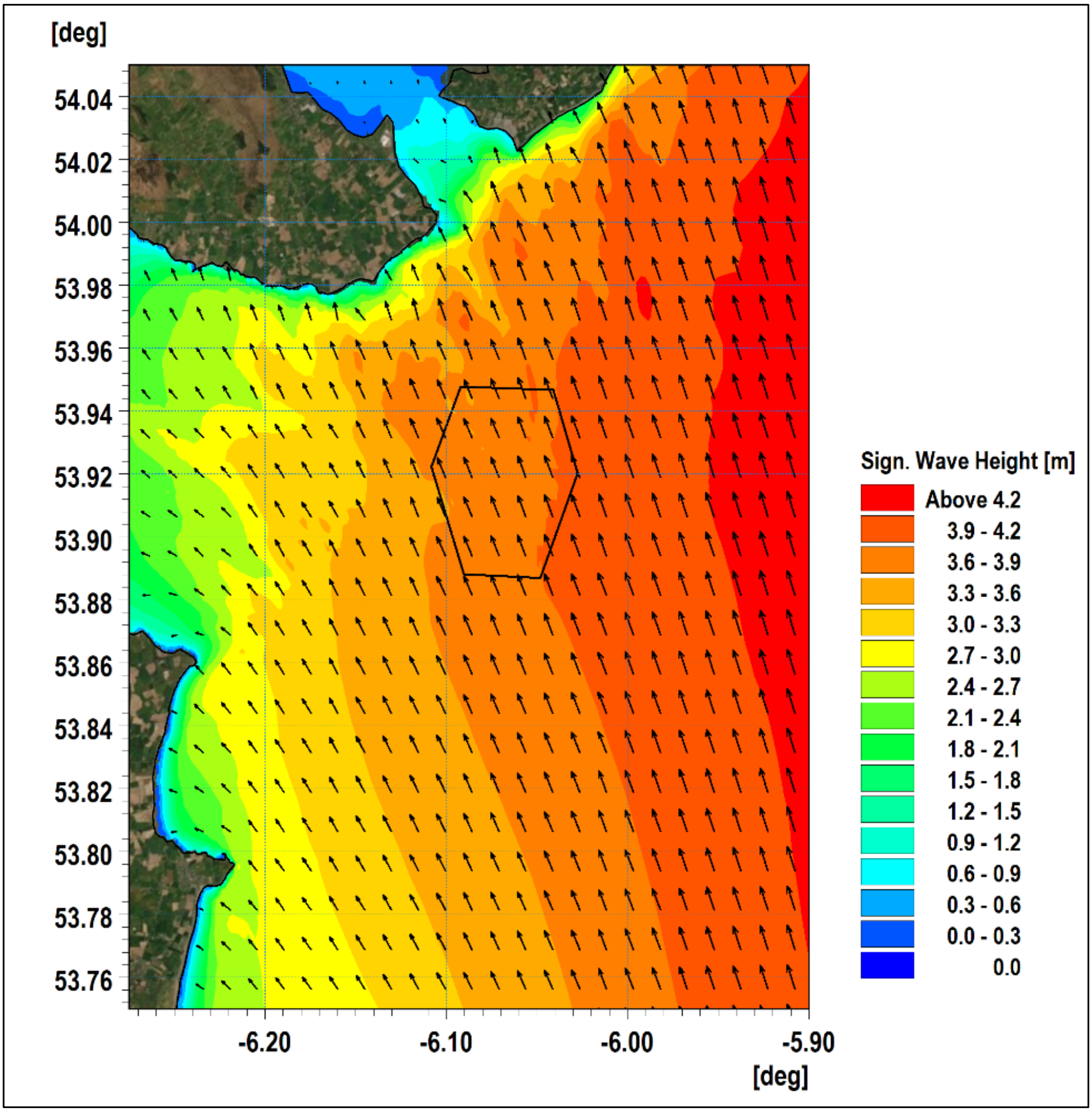

Figure 2-14: Baseline wave climate 1 in 50 year storm from 165°.

2.2.3 Littoral currents

The MIKE suite facilitates the coupling of models. The depth averaged hydrodynamic model, used for the tidal modelling, coupled with the spectral wave model provides a full wave climate incorporating the impact of water levels and currents on waves and wave breaking. Using this, the littoral currents (i.e. currents driven by tidal, wave and meteorological forces) were examined.

The 1 in 2 year storm from 165° was simulated with the inclusion of spring tides. The resultant mid-flood and mid-ebb currents are presented in Figure 2-15 and Figure 2-16 respectively. These correspond with the (calm) tidal plots presented previously in Figure 2-5 and Figure 2-6. As expected, the effect of the north going waves increase the current velocities on the flood tide whilst reducing them on the ebb. In both cases, increased velocities are seen along the coastlines and eddying is induced at headlands and promontories such as Clogher Head and Cooley Point.

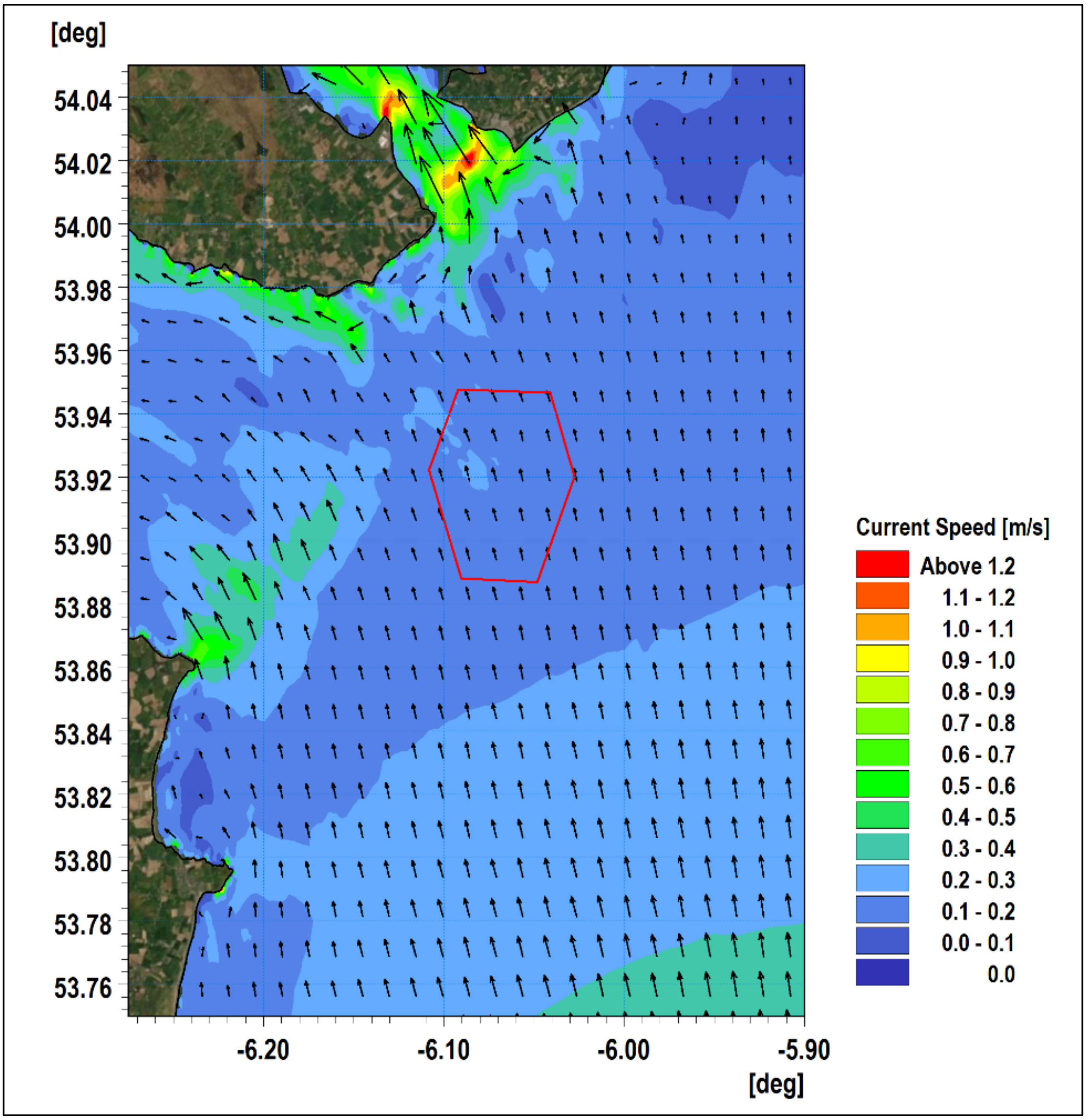

Figure 2-15: Baseline littoral current 1:2 year storm from 165° - flood tide.

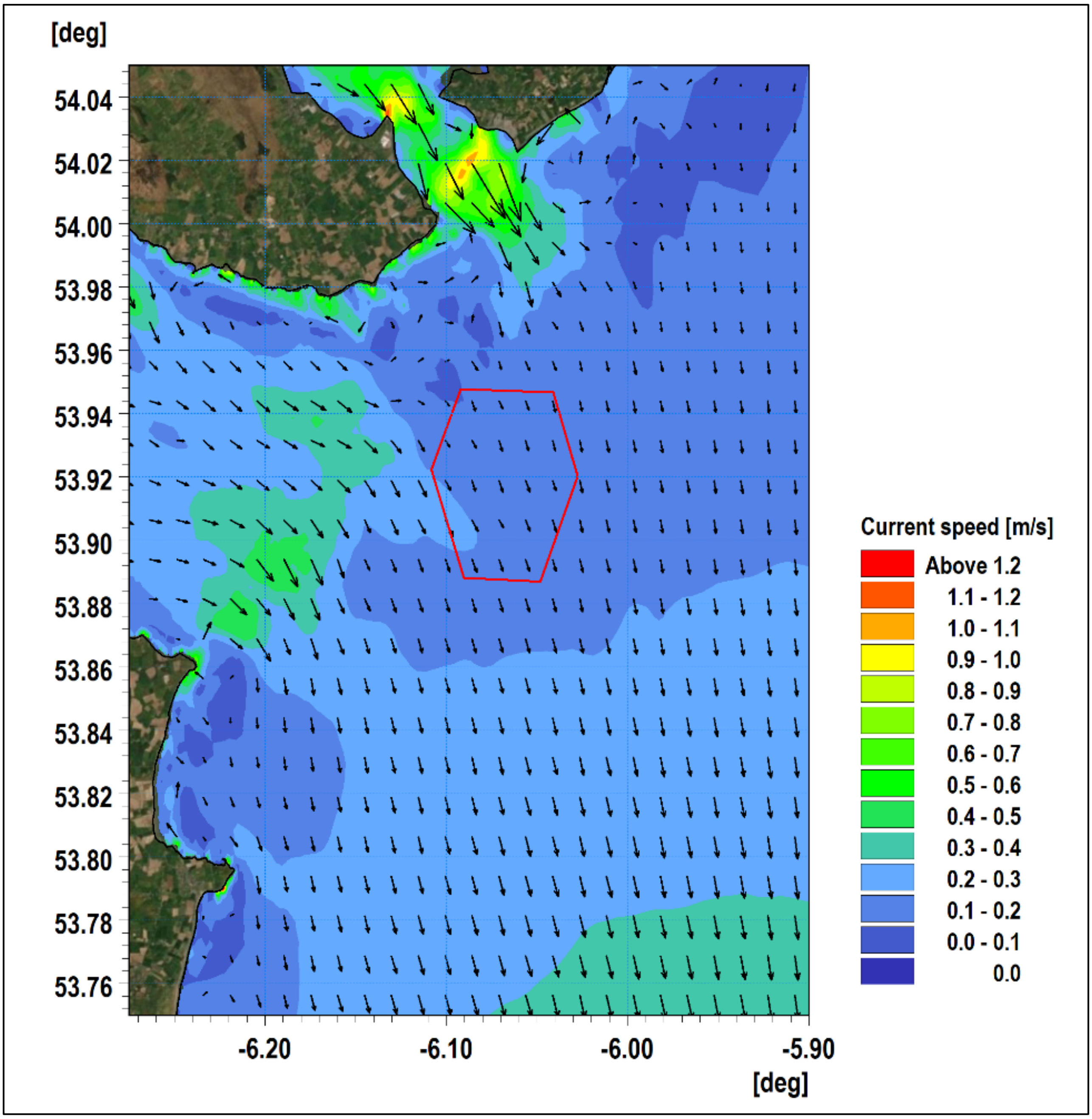

Figure 2-16: Baseline littoral current 1:2 year storm from 165° - ebb tide.

2.3 Sedimentology

2.3.1 Overview

Before undertaking sediment modelling, it was necessary to first define characteristics for the seabed sediment. To this end a number of data sources were used including site-specific sediment sampling data, as documented in Gavin and Doherty Geosolutions (2020). For the zones beyond the Offshore wind farm area, data was accessed via the EMODnet online database (also collected by GSI). The INFOMAR data on seabed substrate is shown in Figure 2-17 whilst the extended composite data from EMODnet is shown in Figure 2-18.

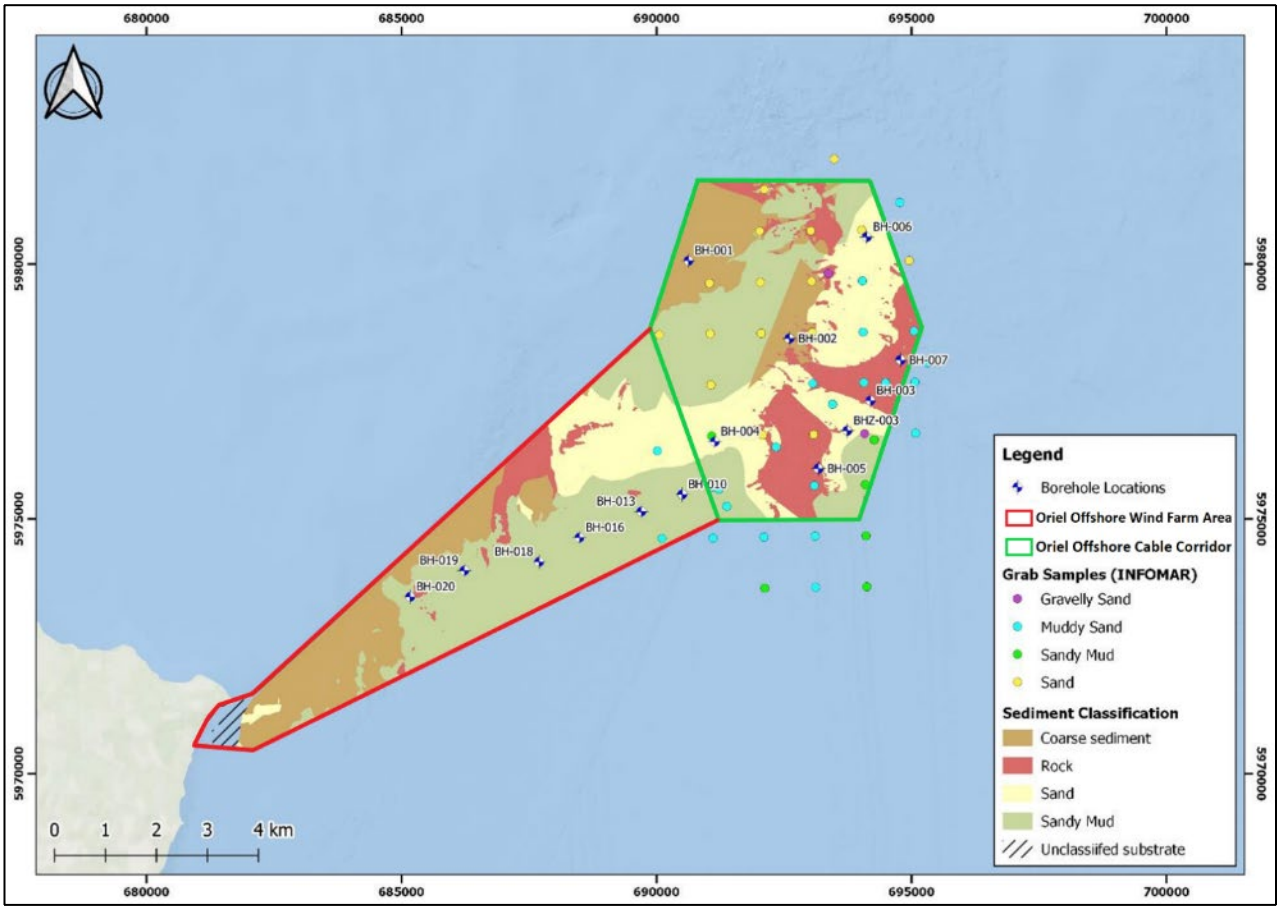

Figure 2-17: INFOMAR Sediment classification with Grab Samples used to ground-truth (Source: Gavin and Doherty Geosolutions, 2020).

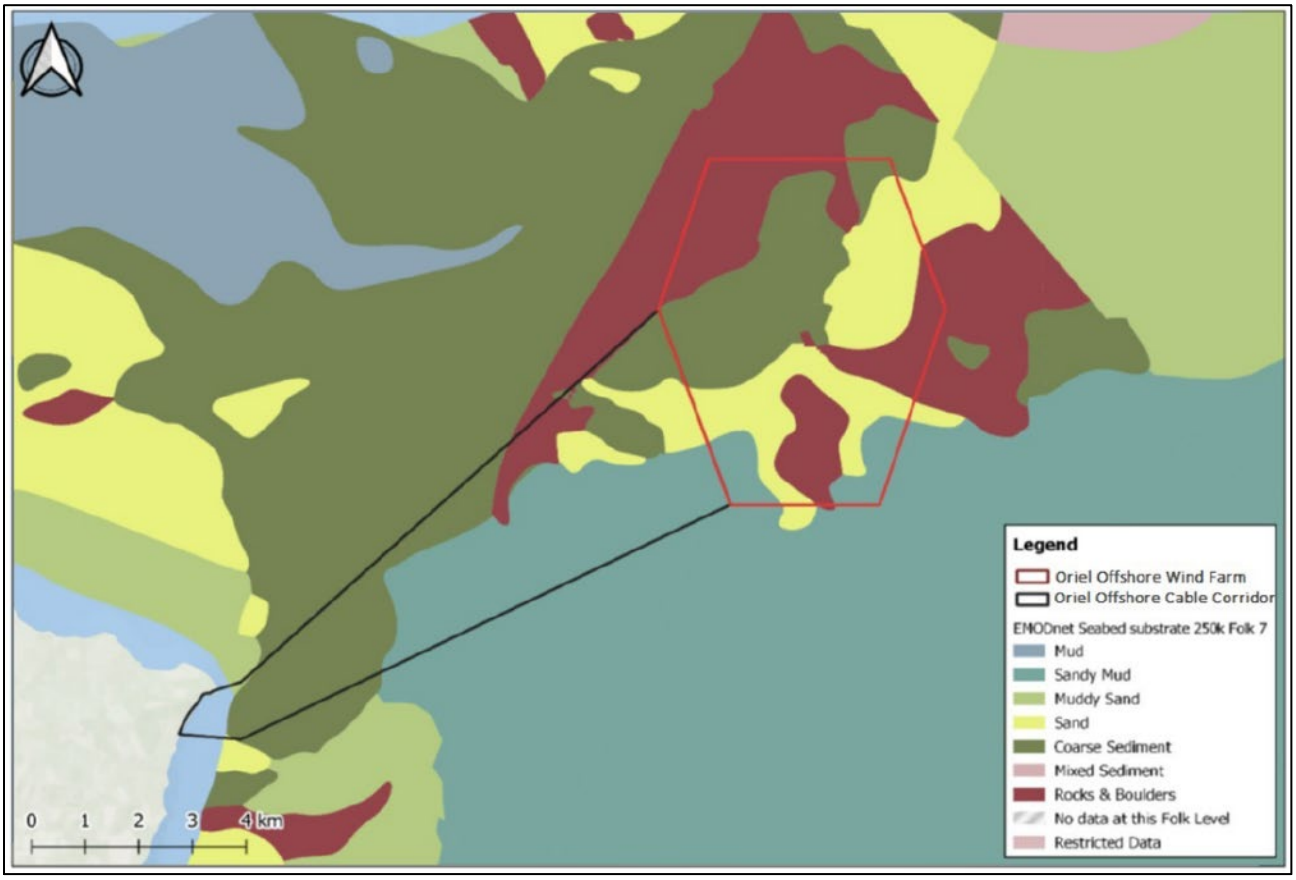

Figure 2-18: Sediment classification EMODnet.

2.3.2 Sediment transport

Seabed sediments within the offshore wind farm area range from muddy sand to coarse gravel, with exposed rock outcrops at some locations. It has been noted however that there is little evidence of significant sediment transport within this area as average current speeds of less than 0.2 m/s would not be sufficient to mobilise and transport the coarse sandy material. The Shields critical shear parameter indicates the typically coarse sand (1 mm diameter) requires bed currents greater than those present for sediment to be mobilised. This is corroborated by the smooth bed formation and lack of significant sand wave features in the field data within the offshore wind farm area although some sand waves are visible to the south of the offshore wind farm area.

The MIKE 21 Sediment Transport (ST) module enables assessment of seabed sediment transport rates and initial rates of seabed level change for non-cohesive sediment resulting from currents or combined wave-current flows. It was used to determine the sediment transport pattern in the Marine Processes Study Area. The model combines inputs from both the hydrodynamic model and, if required, the wave propagation model. The model was setup using a layer of mobile bed material based on the sediment types (sizes and gradation) as illustrated in Figure 2-18.

Two sediment transport scenarios were examined, one relating to calm conditions and a second relating to the 1 in 2 year return period event from 165°. In each case the evaluations were undertaken over the course of a spring tide. These simulations included a period for the hydrodynamics and wave fields to stabilise and develop across the domain, i.e. a “warm-up” period.

For each scenario three aspects were examined. Firstly, the residual current, which is the net flow over the course of the tidal cycle. This is effectively the driving force of the sediment transport. The second aspect was the potential annual sediment transport as a result of this residual current. The net sediment transported during the tidal cycle was used to assess the annual net load. The use of an annual figure is standard when presenting sediment transport data however it does assume the same hydraulic conditions persist for an entire year. Whilst this is unrealistic for individual storm events, the magnitudes are still useful for comparative purposes. The unit of transport is $m^3/yr/m$; this represents the volume of material displaced over a period of one year and is presented per metre width perpendicular to the direction of that movement. These net values do not provide a full picture of the transport mechanism. Therefore, the third aspect considered in this assessment was sediment transport rates at different phases of the tidal cycle.

For the tidal current alone the depth average residual current is presented in Figure 2-19. It is characterised by minimal residual current at the offshore wind farm area, as anticipated, and elevated values along the coastline. The resultant transport rate as illustrated in Figure 2-20 further demonstrates that there is very little movement of sediment at the offshore wind farm area due to the low current speed.

When a storm approaches from 165°, the flood tide currents are enhanced by the wave climate. This is reflected in an increase in the residual currents along the coastline as illustrated in Figure 2-21. There is movement of the sandy material in the centre of the offshore wind farm area however the magnitude of the transport is smaller than that along the coastline as illustrated in Figure 2-22.

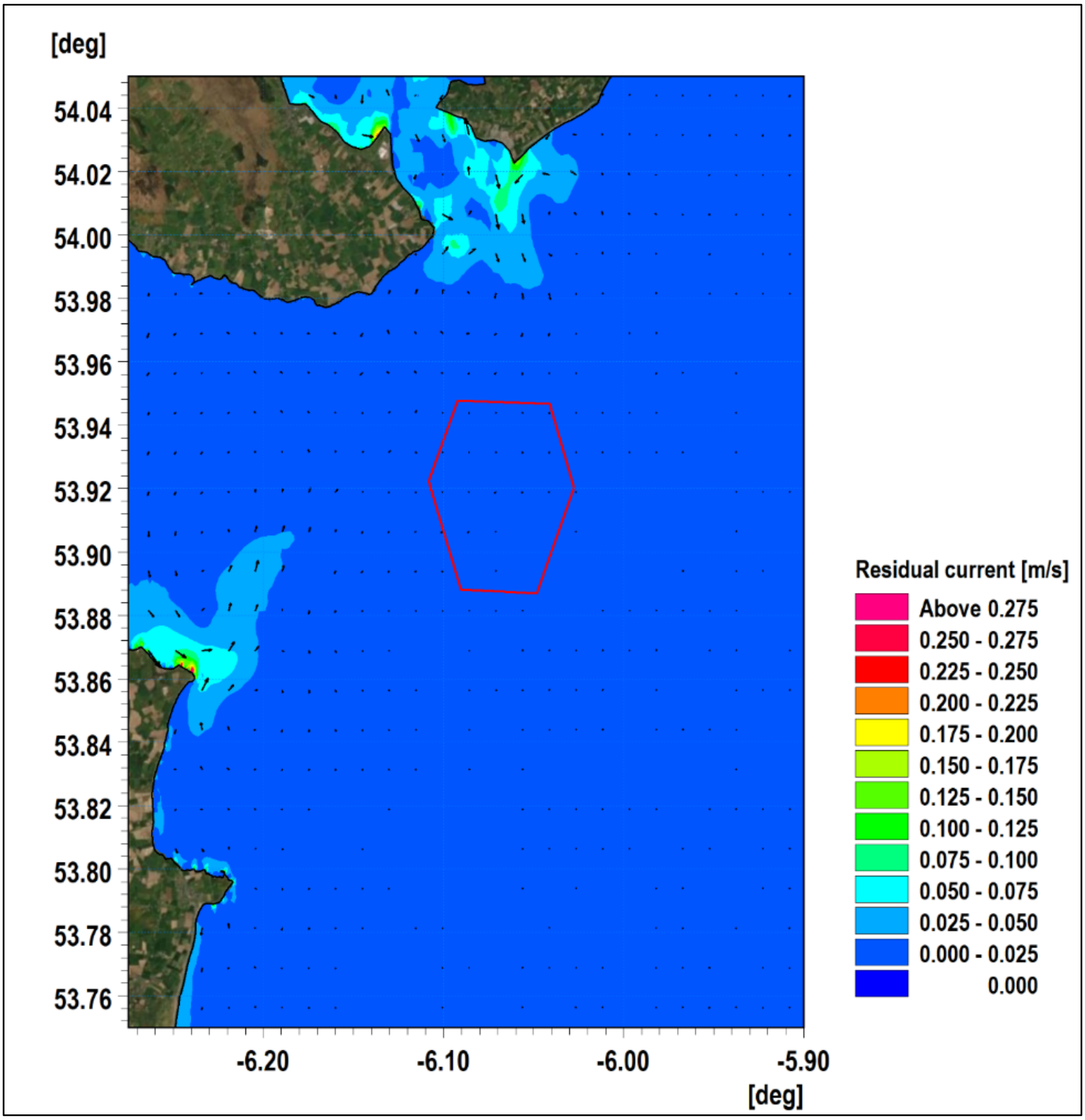

Figure 2-19: Baseline residual current spring tide.

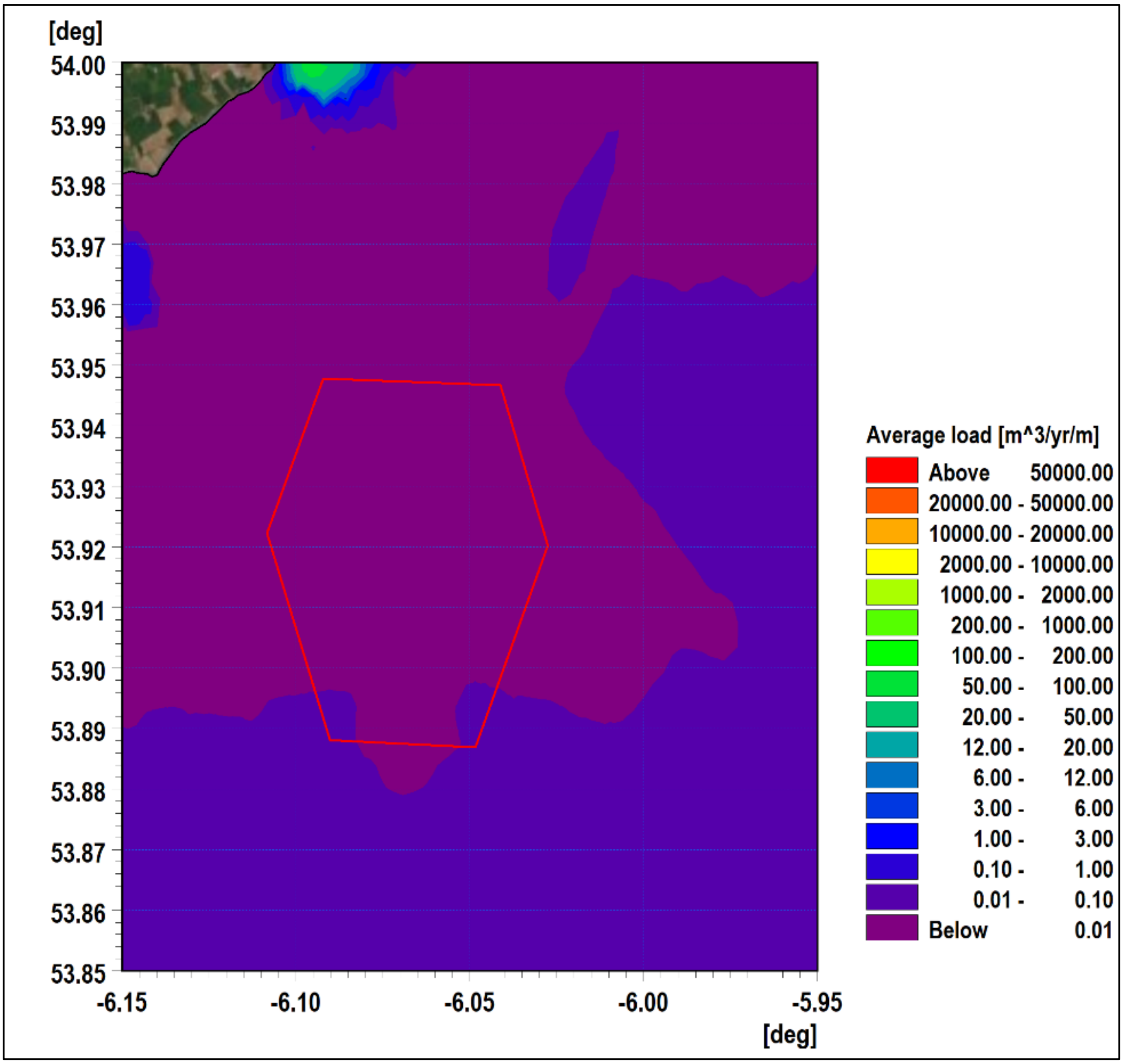

Figure 2-20: Baseline potential net sediment transport - spring tide.

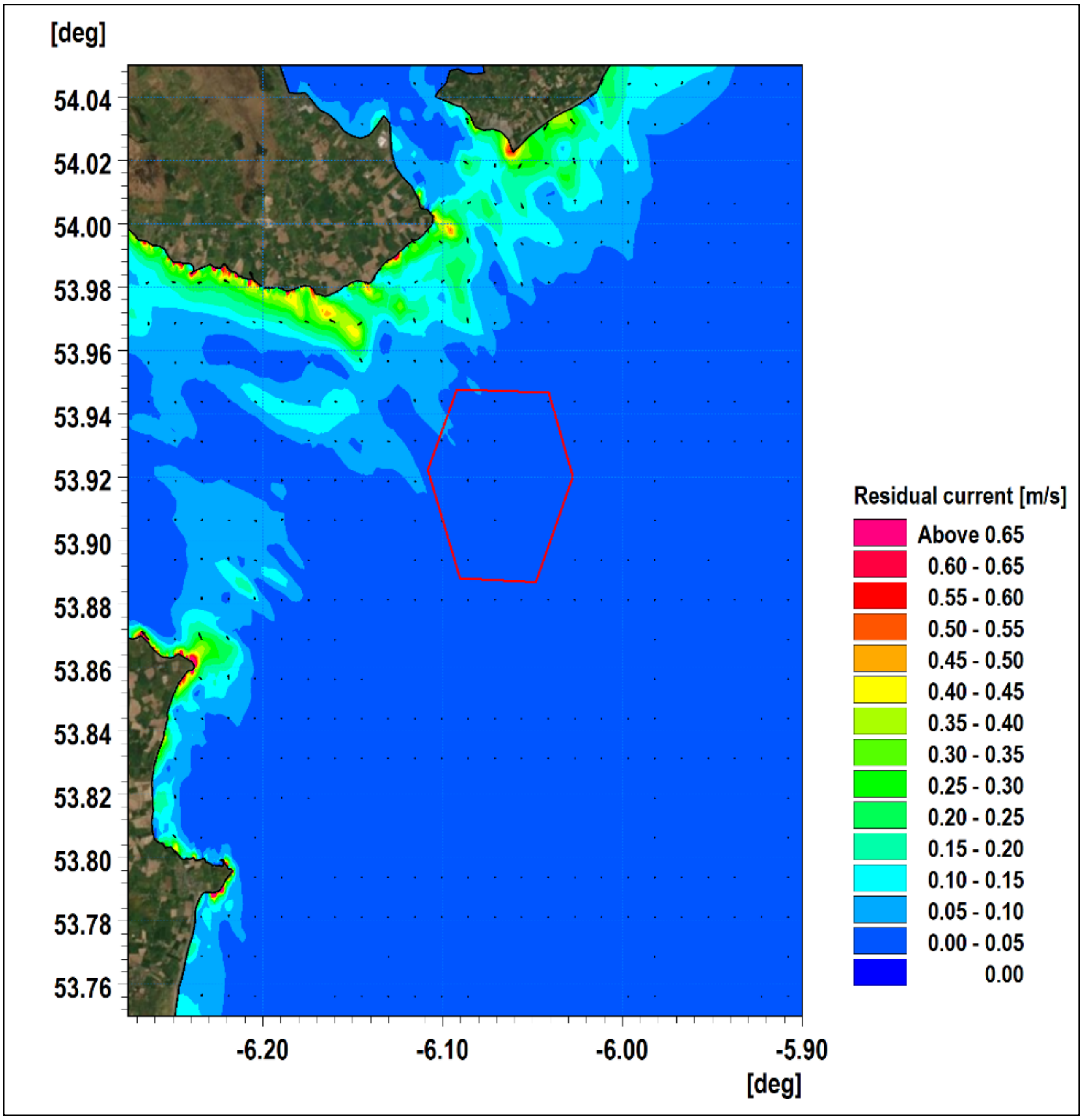

Figure 2-21: Baseline residual current spring tide with 1:2 year storm from 165°.

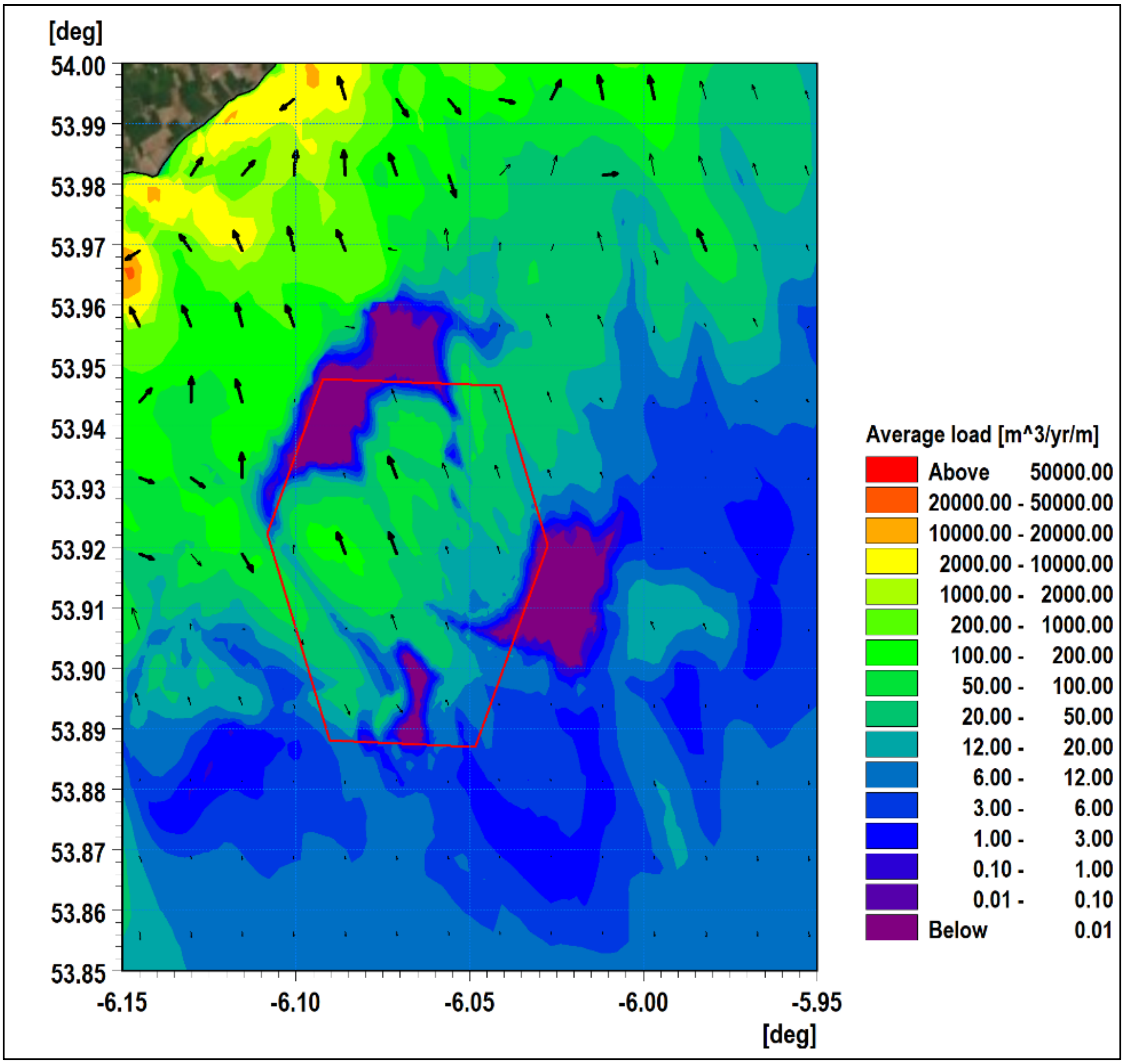

Figure 2-22: Baseline potential net sediment transport - spring tide with 1:2 year storm from 165°.

2.3.3 Suspended sediments

Sediment in the Marine Processes Study Area is dominated by sand and gravel and it has been seen that tidal currents are not sufficiently strong to give rise to high turbidity. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Climatology Report 2016 (CEFAS, 2016) shows the spatial distribution of average non-algal Suspended Particulate Matter (SPM) for the majority of the UK continental shelf.

For the period 1998-2005 the largest plumes are associated with large rivers such as the Thames Estuary, the Wash and Liverpool Bay, which show mean values of SPM above 30 mg/l. Based on this information it is estimated that the average SPM within Dundalk Bay over this period is *c.* <3 mg/l as shown in Figure 2-23.

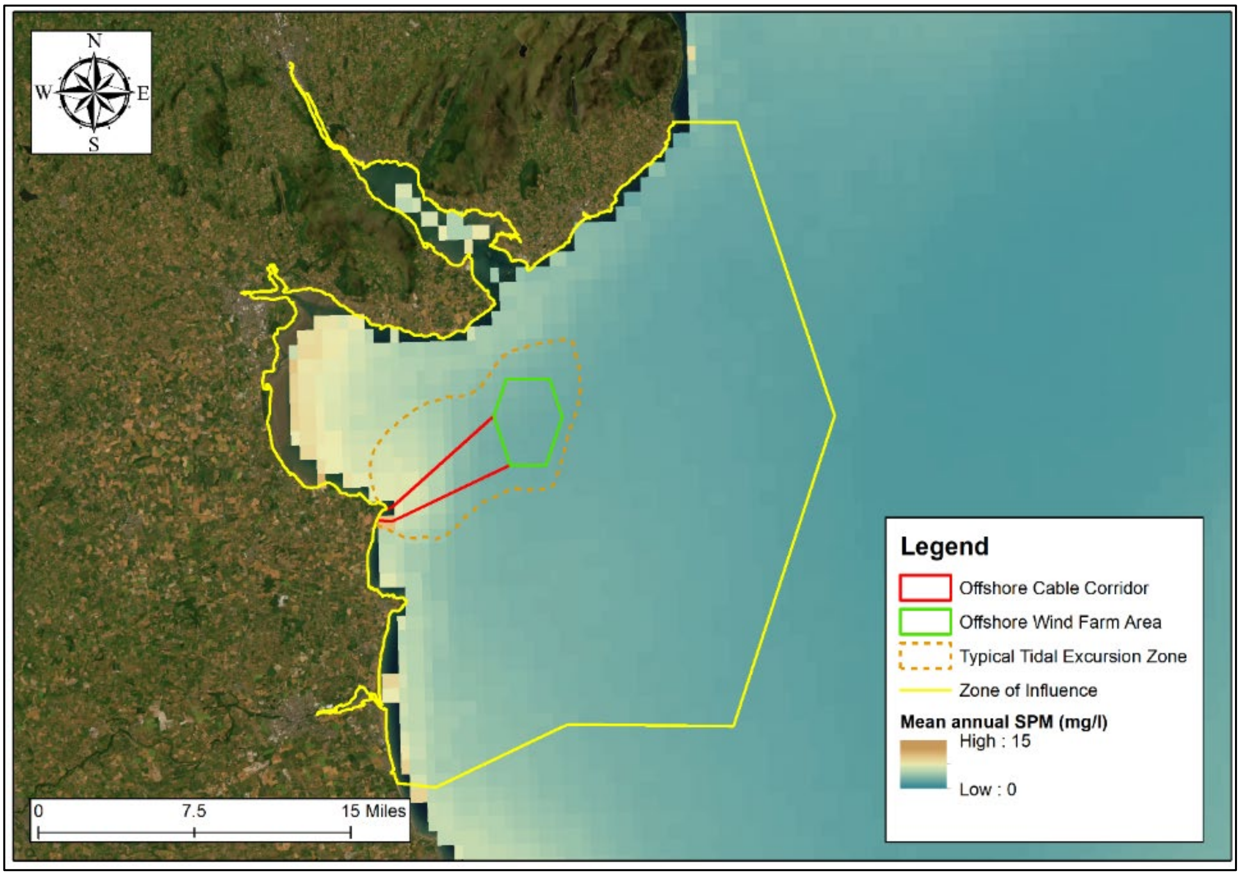

Figure 2-23: Distribution of average non-algal Suspended Particulate Matter.

3 POTENTIAL ENVIRONMENTAL EFFECTS

3.1.1 Overview

The potential changes to baseline conditions as a result of the construction and operation of the Project are quantified in the following sections. The potential changes to sea state and sediment transport regime were established by repeating the modelling undertaken in the previous section with the proposed turbine and OSS foundation structures in place. The foundation structures were modelled by including sub-grid structures within the model at each location and, in the case of sediment transport, the scour protection was simulated using an area of fixed seabed around each structure.

For the purposes of modelling, the offshore wind farm layout as described in volume 2A chapter 5: Project Description was used to define the location of structures within the numerical model. It should be noted that the scale of the model mesh meant that the general flow and sediment patterns around the structures could be observed on the wider scale.

However, the localised nature of the scour meant that a detailed assessment of the effectiveness of the scour protection at each foundation structure was not undertaken as this was not the purpose of the computational modelling. The scour protection does not have implications on the global scale and is restricted to reducing sediment erosion in the vicinity of the foundation structures; there would be larger implications if scour protection were not provided, as detailed by Whitehouse *et al.* (2006).

A description of the modelling methodology used to assess impact of the offshore wind farm on specific marine processes, i.e. tidal regime, wave climate and sediment transport regime, is outlined in the following Sections.

3.1.2 Post-construction hydrography

Tidal Flow

The obstruction created by monopile foundations has the potential to alter tidal flows within the offshore wind farm area. Therefore, each of the 26 structures (25 turbines and one offshore substation as described in volume 2A chapter 5: Project Description) were defined in the numerical model as sub-grid features. The geometry and locations used to define each monopile are summarised in Figure 3-1 and Figure 3-2 respectively. This approach enabled potential changes in tidal flows to be resolved at an appropriate scale that accounted for the presence of the structures. Using this method, the baseline spring tide simulation described in section 2.2.1 was repeated but with the offshore wind farm in place.

Figure 3-3 and Figure 3-4 illustrate the post-construction flood tide flow patterns during mid-flood and mid-ebb tidal flows respectively. Due to the limited magnitude of the changes relative to baseline conditions, difference plots have also been provided for post-construction mid-flood and mid-ebb flows in Figure 3-4 and Figure 3-6 respectively. Difference plots are produced by subtracting baseline conditions from conditions with the Project in place. Thus, positive changes in difference plots reflect areas whereby the magnitude of that process (i.e. tidal currents, waves or sediment transport rates) have increased as a result of the Project and vice versa for negative changes. The same procedure for calculating differences has been implemented throughout this Technical Report.

This assessment found that the Project resulted in a localised acceleration of tidal flows within the immediate vicinity of the structures. However, it should be noted that these values (i.e. changes to velocity; magnitude and direction) are generally <4 mm/s which constitutes less than 2% at the peak flows. These changes are also limited to the immediate Project offshore wind farm area.

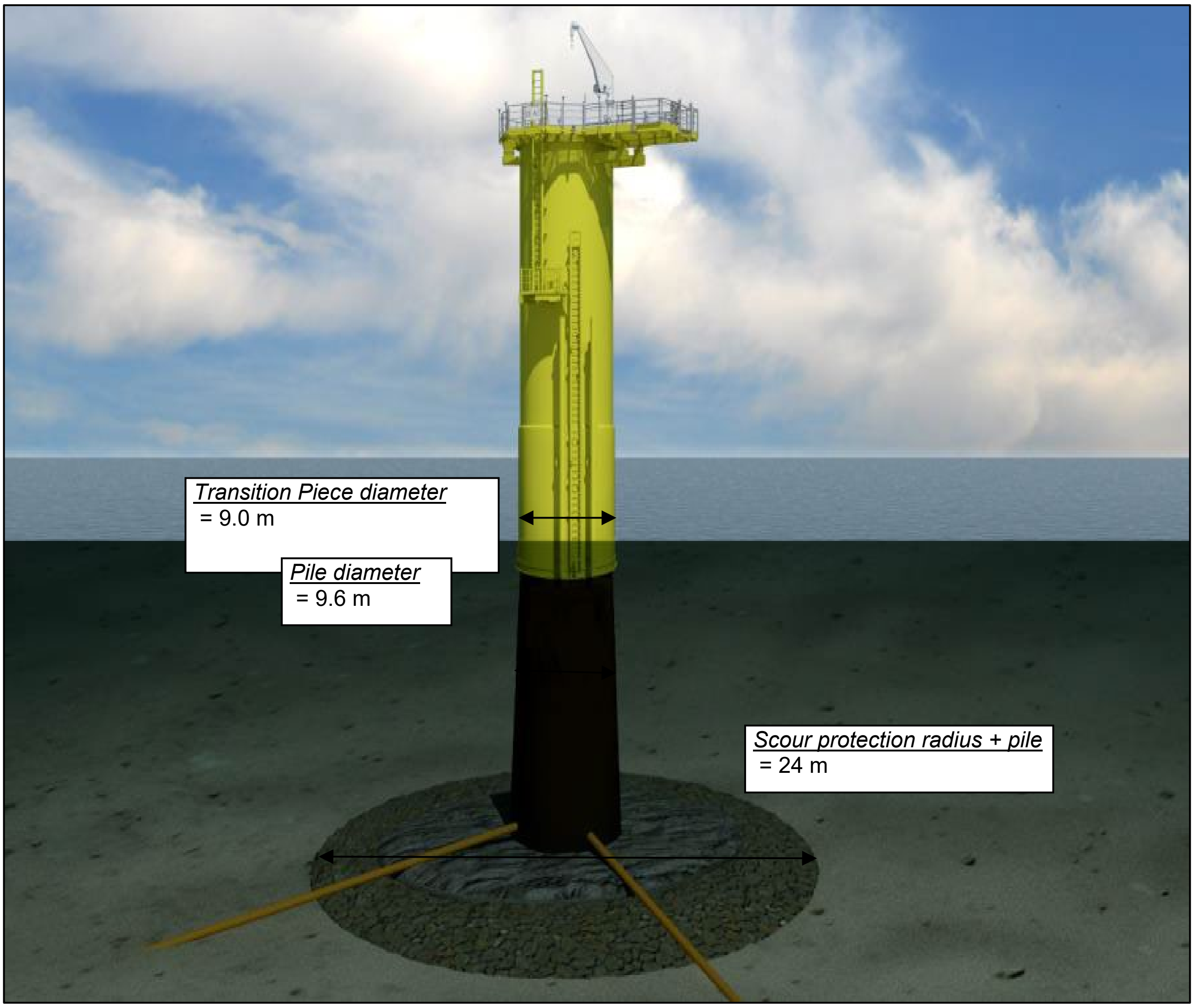

Figure 3-1: Geometry of a monopile foundation (not to scale).

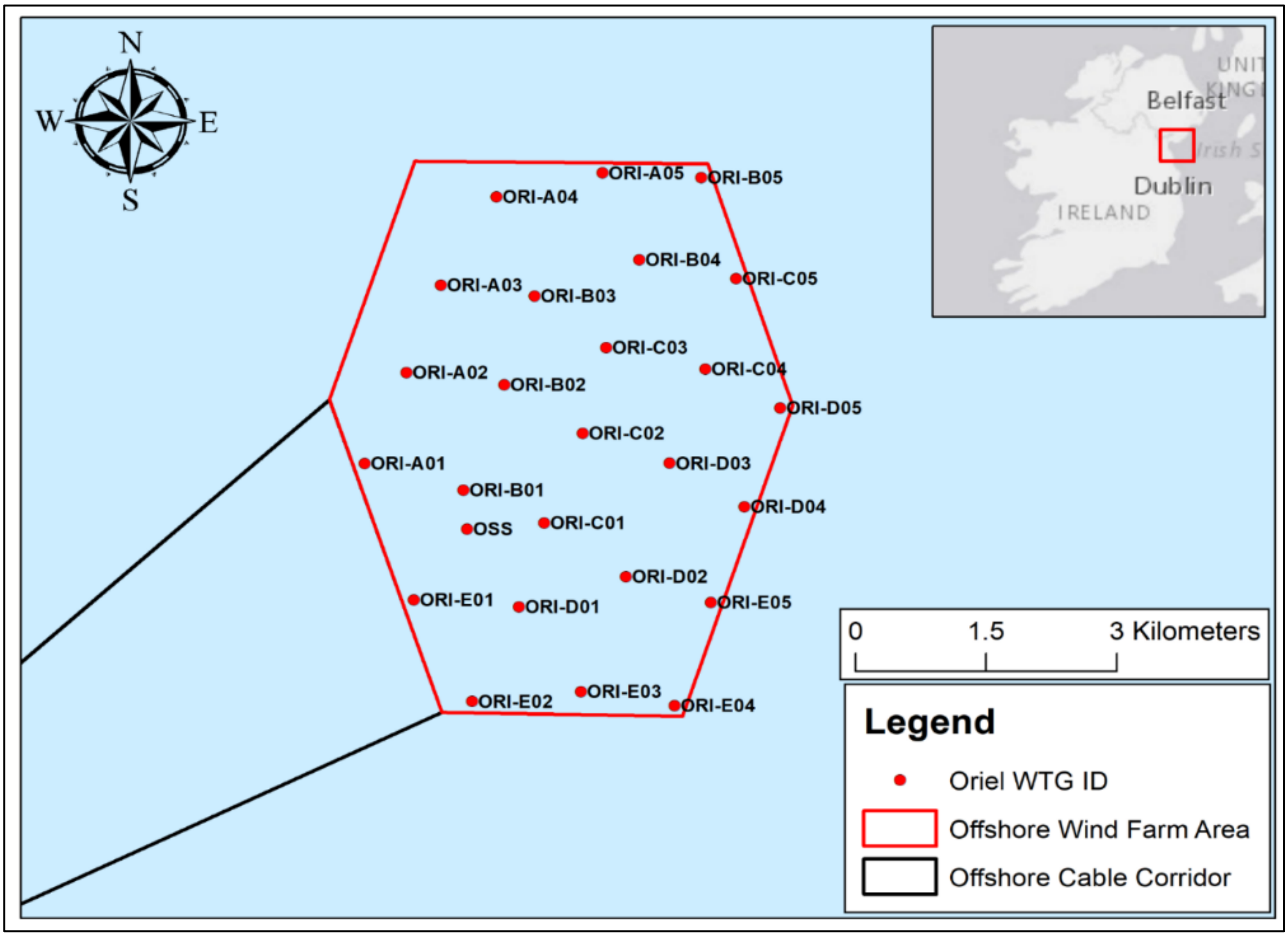

Figure 3-2: WTG and OSS locations within the offshore wind farm area.

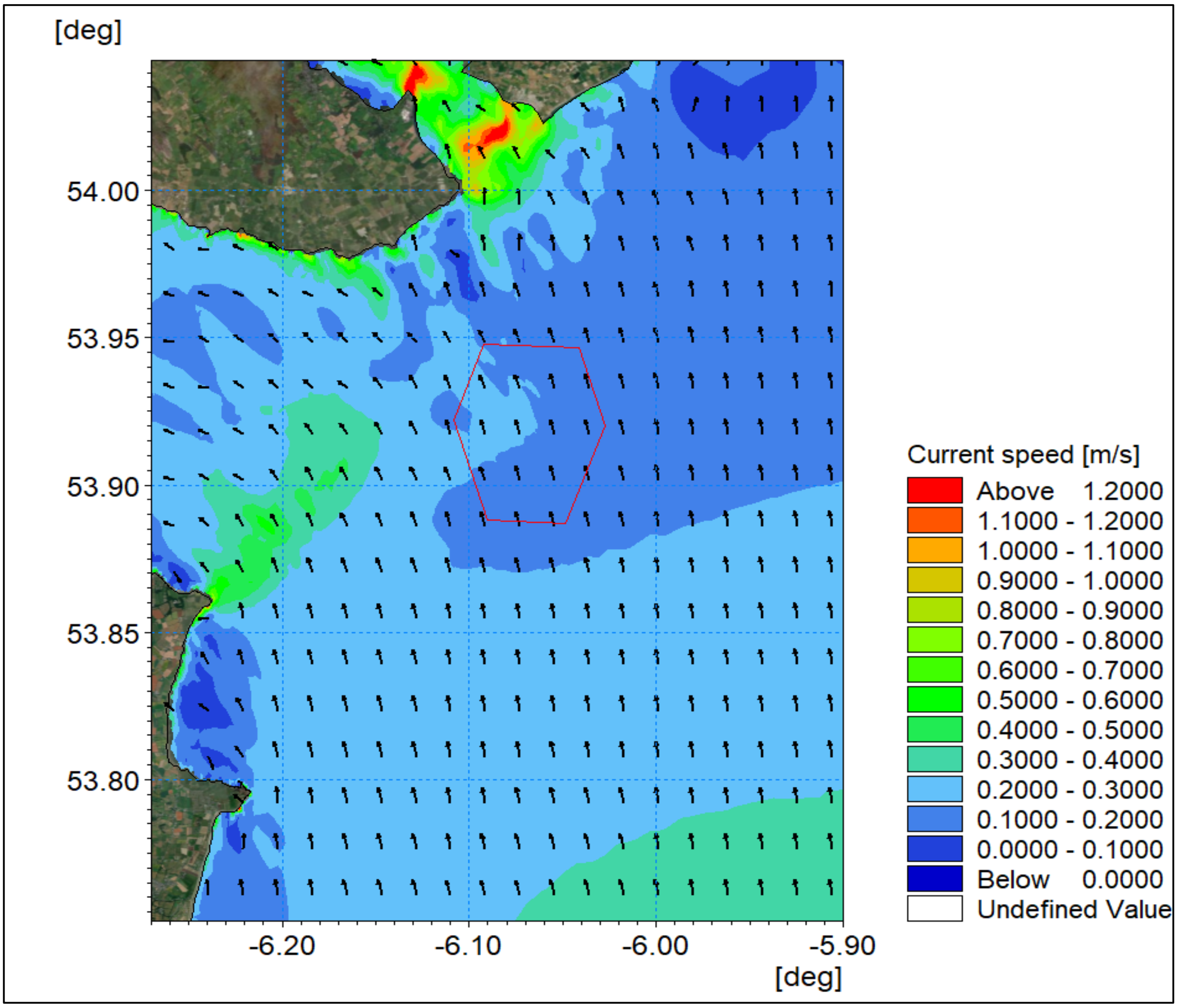

Figure 3-3: Post-construction tidal flow patterns - mid-flood.

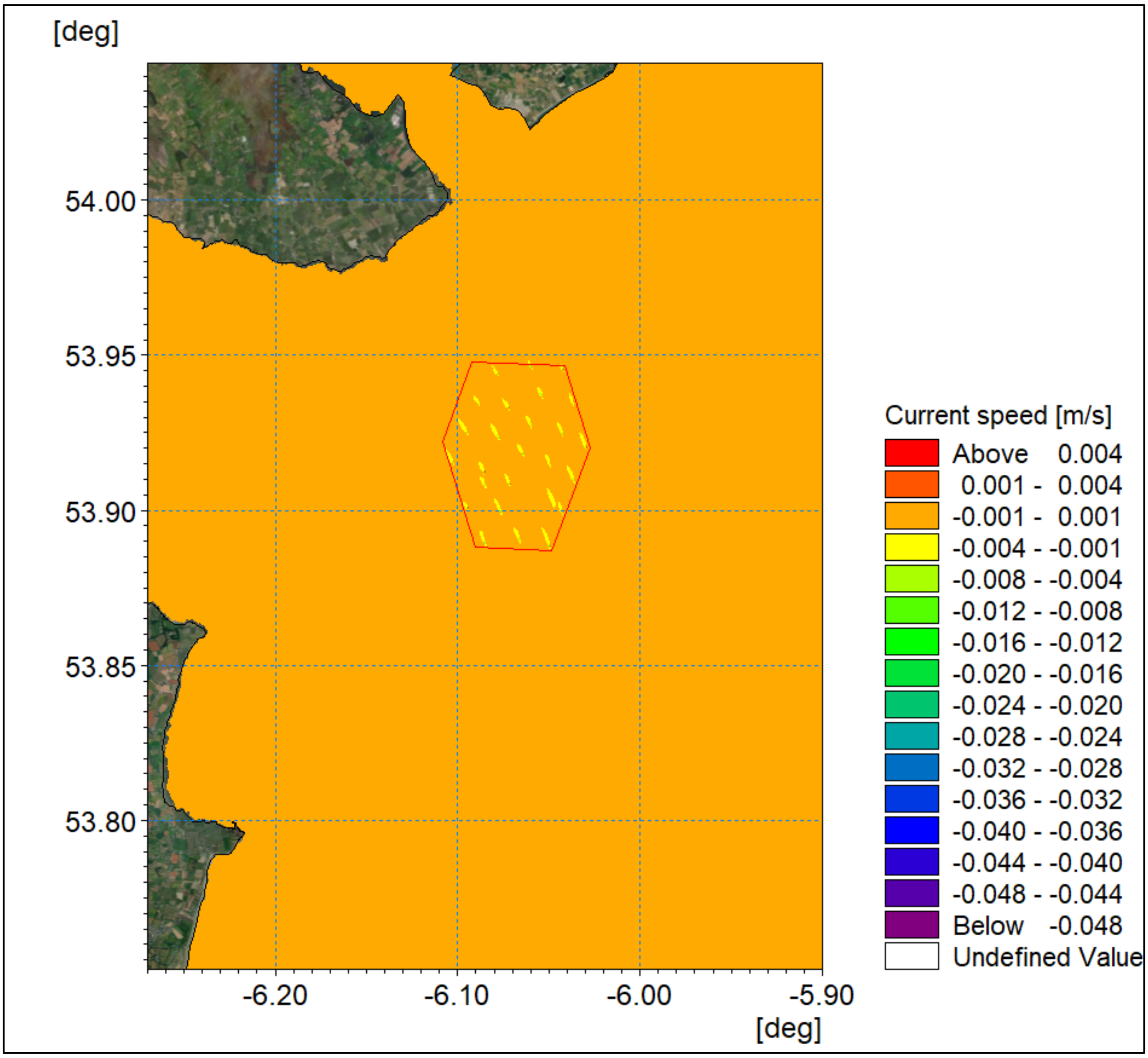

Figure 3-4: Change in tidal flow (post-construction minus baseline) - mid-flood.

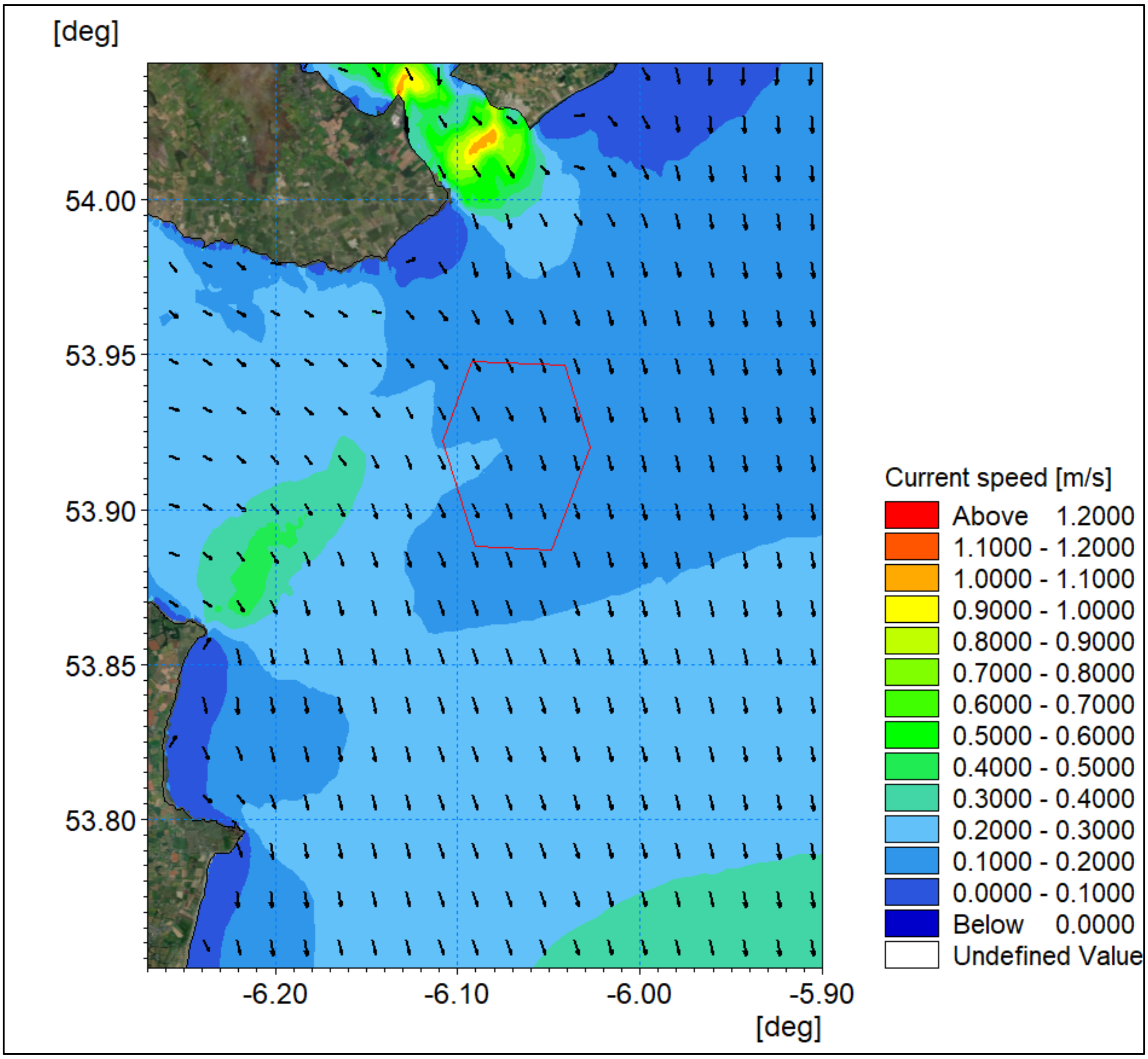

Figure 3-5: Post-construction tidal flow patterns - mid-ebb.

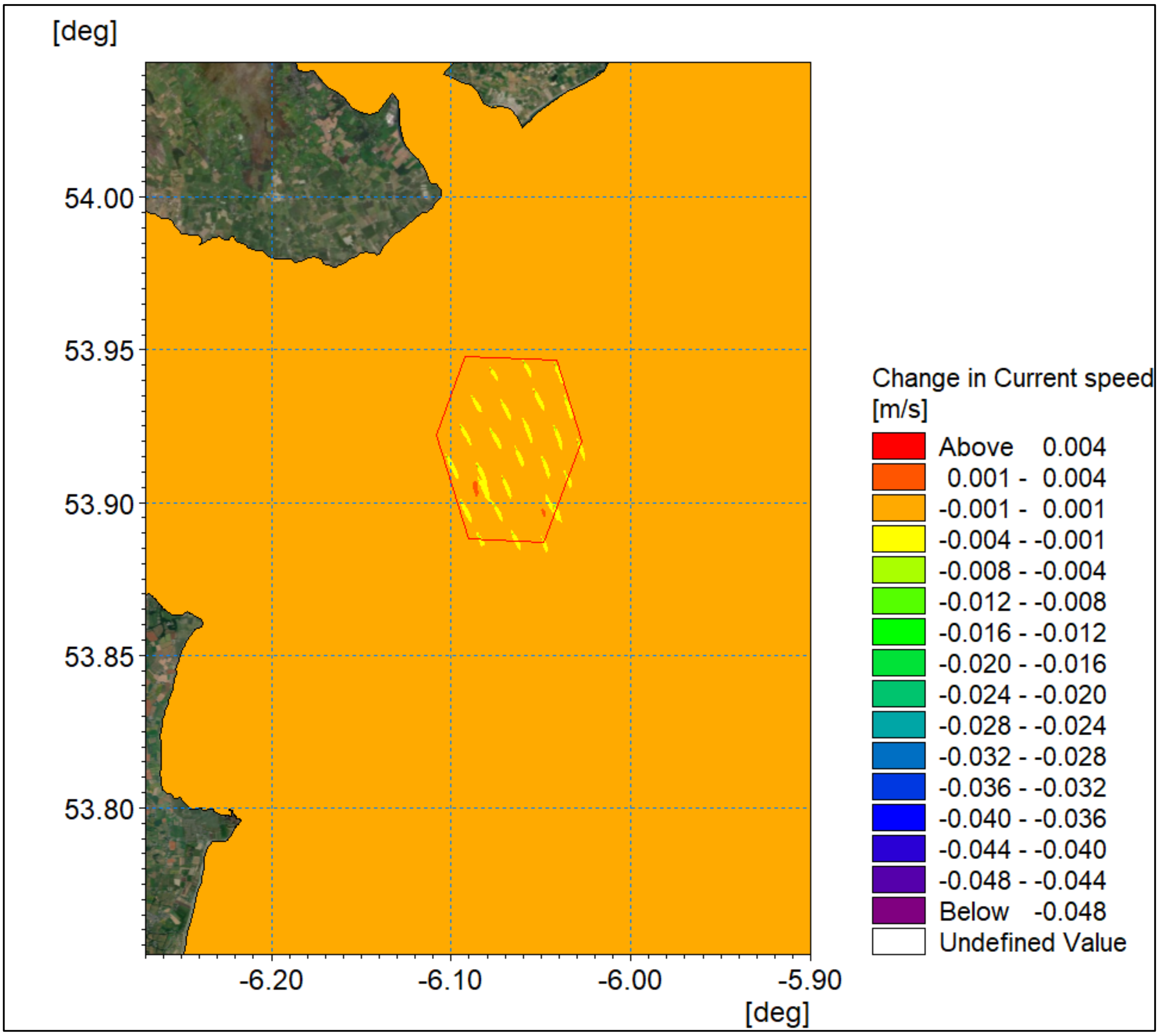

Figure 3-6: Change in tidal flow (post-construction minus baseline) - mid-ebb.

Wave Climate

Using the same principle as for the tidal modelling, the wave climate modelling was repeated with the 25 turbines and one offshore substation defined in the numerical model as sub-grid features. Again, changes were found to be indiscernible from the baseline scenario by visual inspection therefore difference plots have been provided.

The 1 in 2 year storms for the three principal directions (015°, 090° and 165°) are presented in Figure 3-7, Figure 3-9 and Figure 3-11 respectively. It should be noted that these correspond to the baseline wave climate figures presented in Figure 2-9, Figure 2-10 and Figure 2-11 for each direction respectively.

For all wave scenarios, the reduction in significant wave height is around 40 mm, typically less than 2% and is limited to the vicinity of the structure. The difference in baseline and post construction wave climates is presented in Figure 3-8, Figure 3-10 and Figure 3-12 for the three principal directions 015°, 090° and 165° respectively. It should be noted that a log scale palette has been used to accentuate differences in these results.

Further modelling was undertaken for a more severe 1 in 50-year storm, with the results presented in Figure 3-13 to Figure 3-18. In each case the post-construction wave climate is followed by the difference plot and, as indicated with the 1 in 2-year plots, the larger the wave climate the less significant the changes resulting from the structures (i.e. the changes in wave height magnitude remain similar whilst the baseline increases).

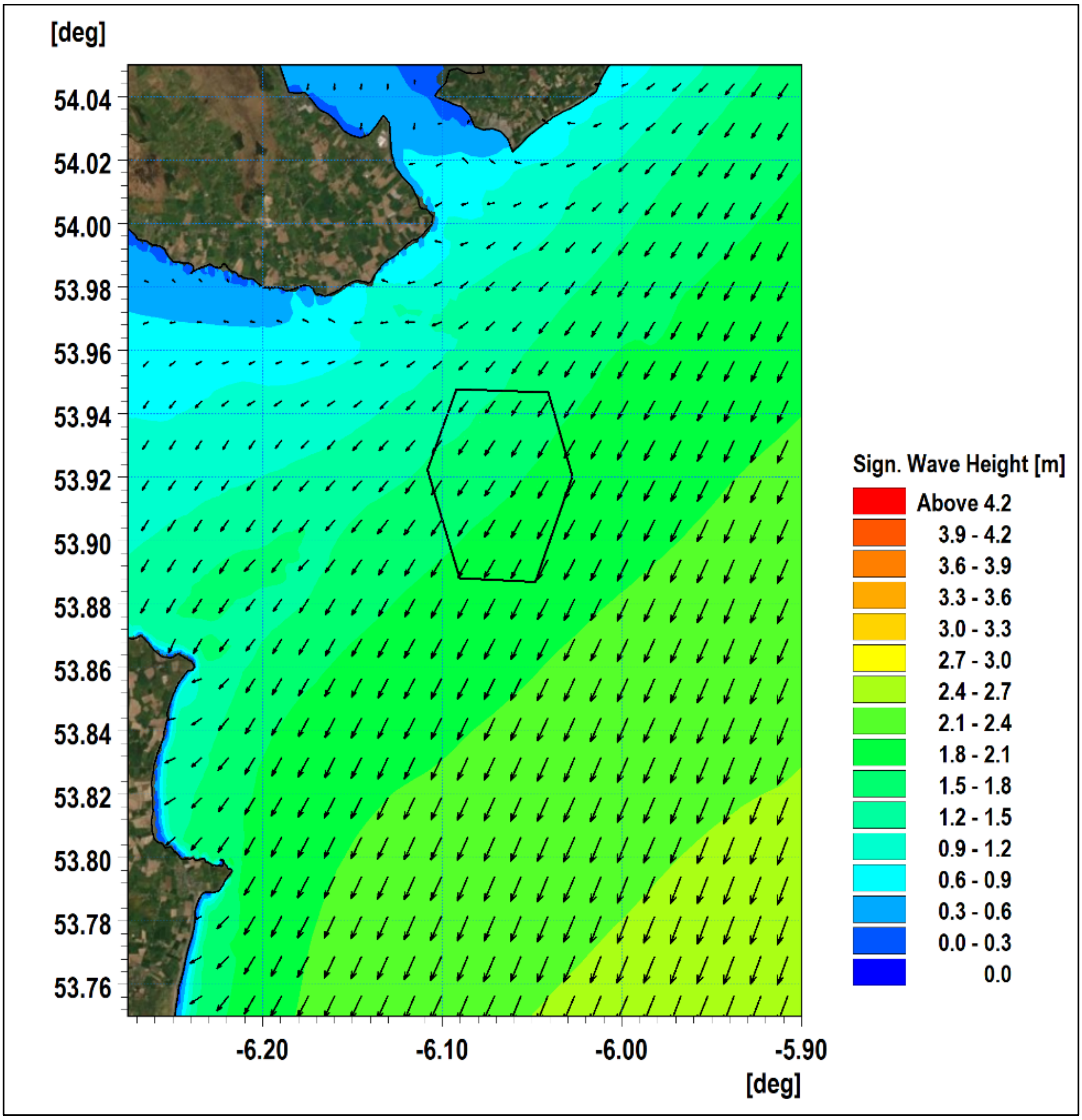

Figure 3-7: Post-construction wave climate 1 in 2 year storm 015°.

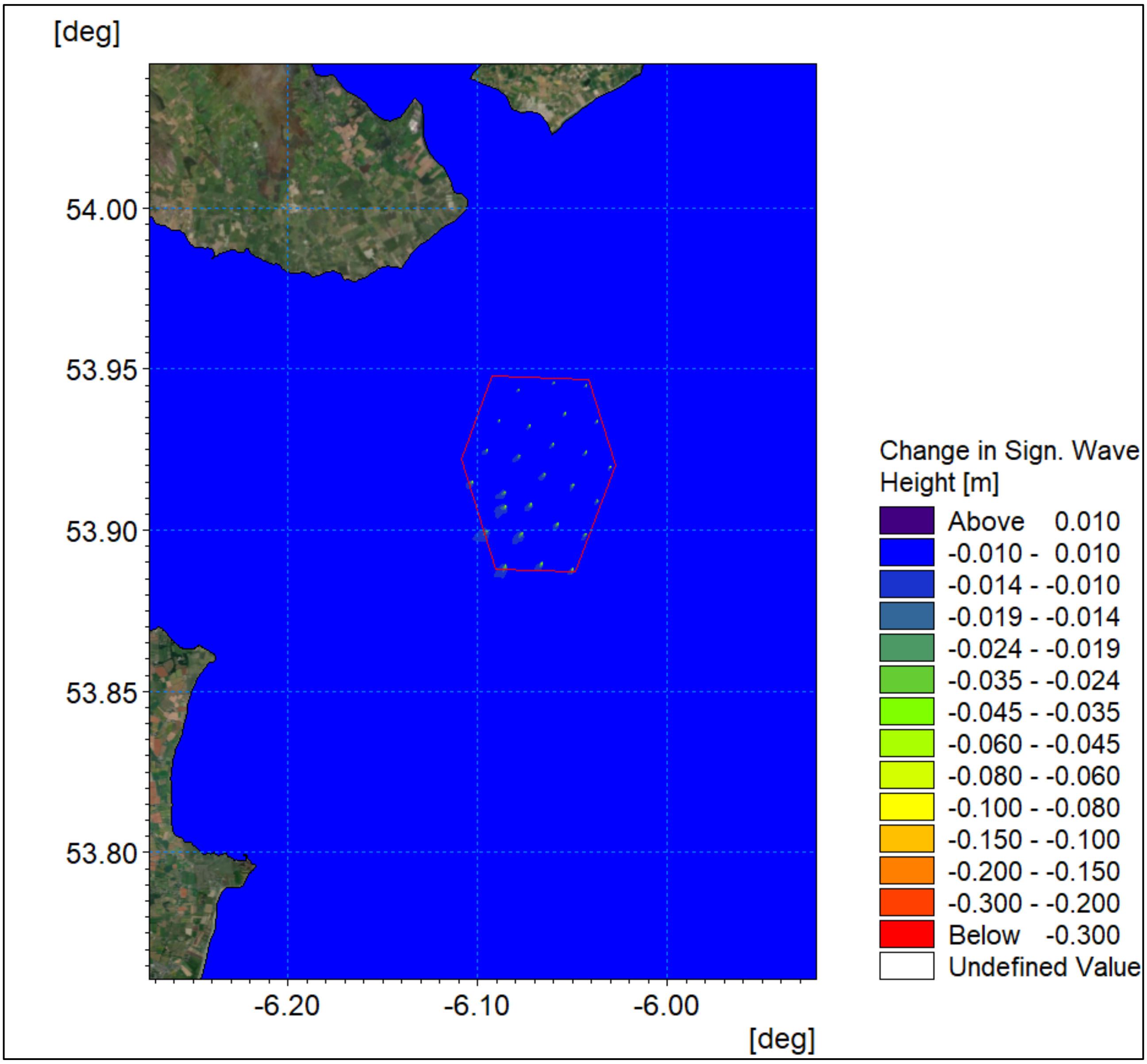

Figure 3-8: Change in wave climate 1 in 2 year storm 015° (post-construction minus baseline).

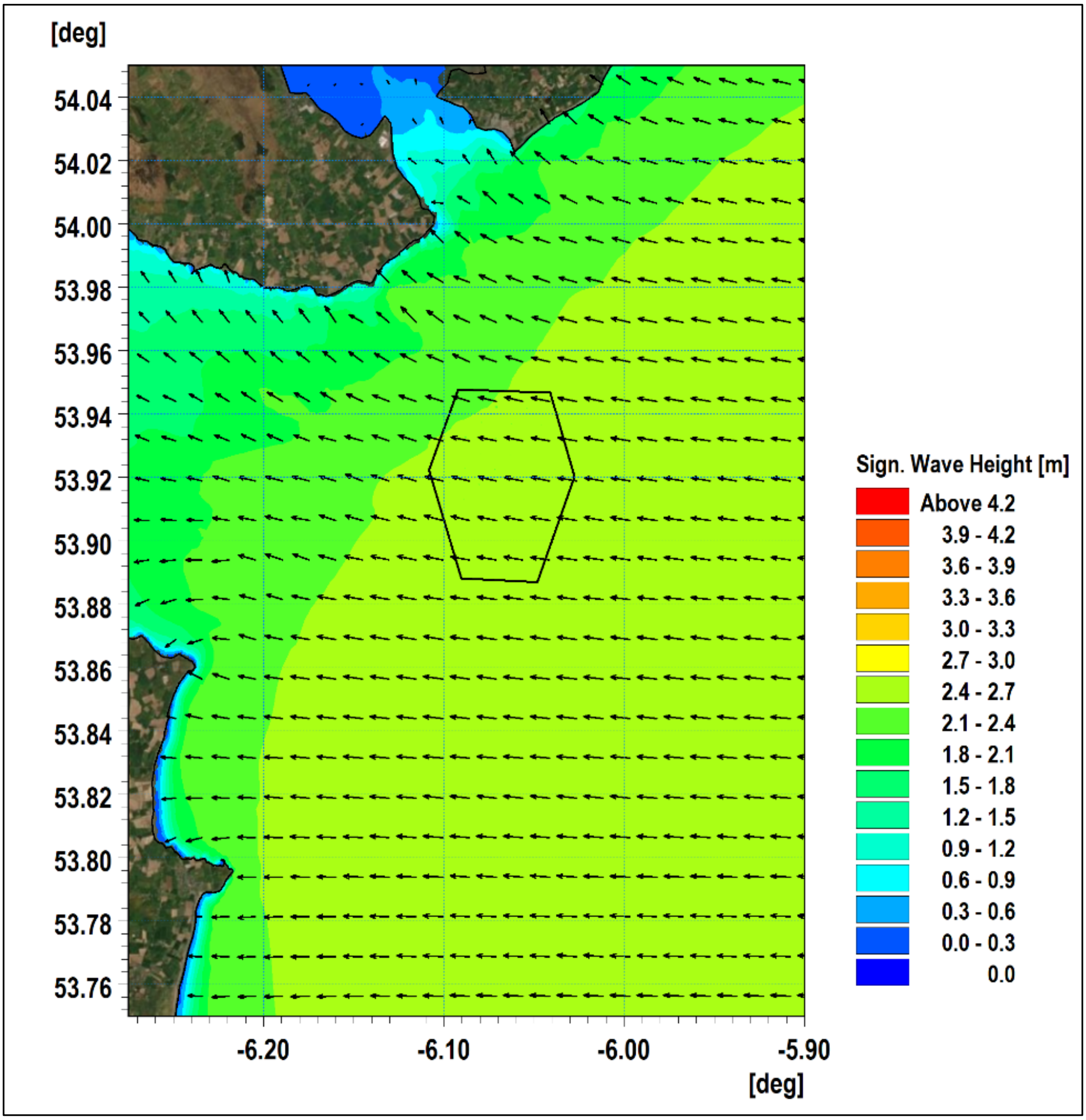

Figure 3-9: Post-construction wave climate 1 in 2 year storm 090°.

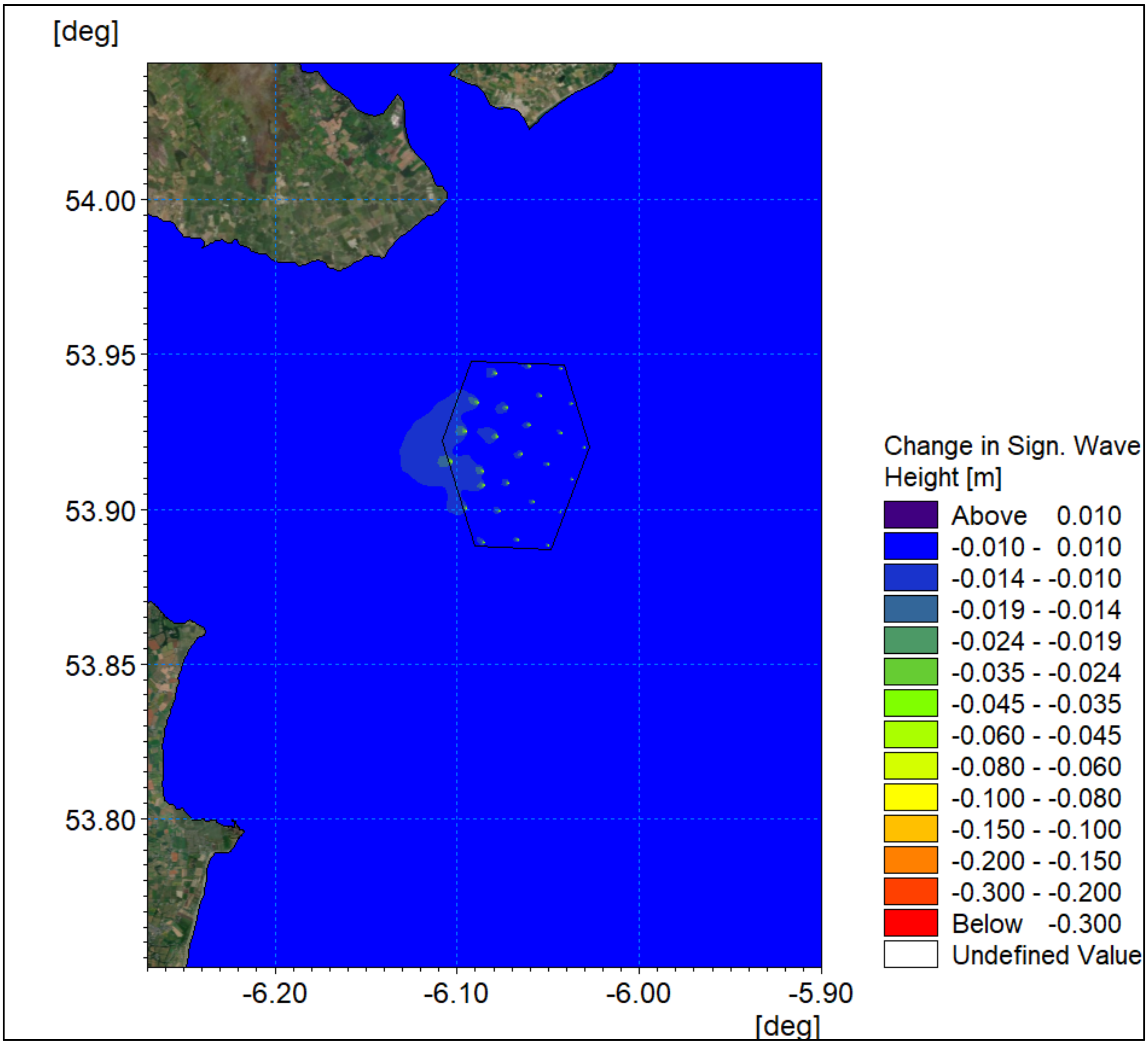

Figure 3-10: Change in wave climate 1 in 2 year storm 090° (post-construction minus baseline).

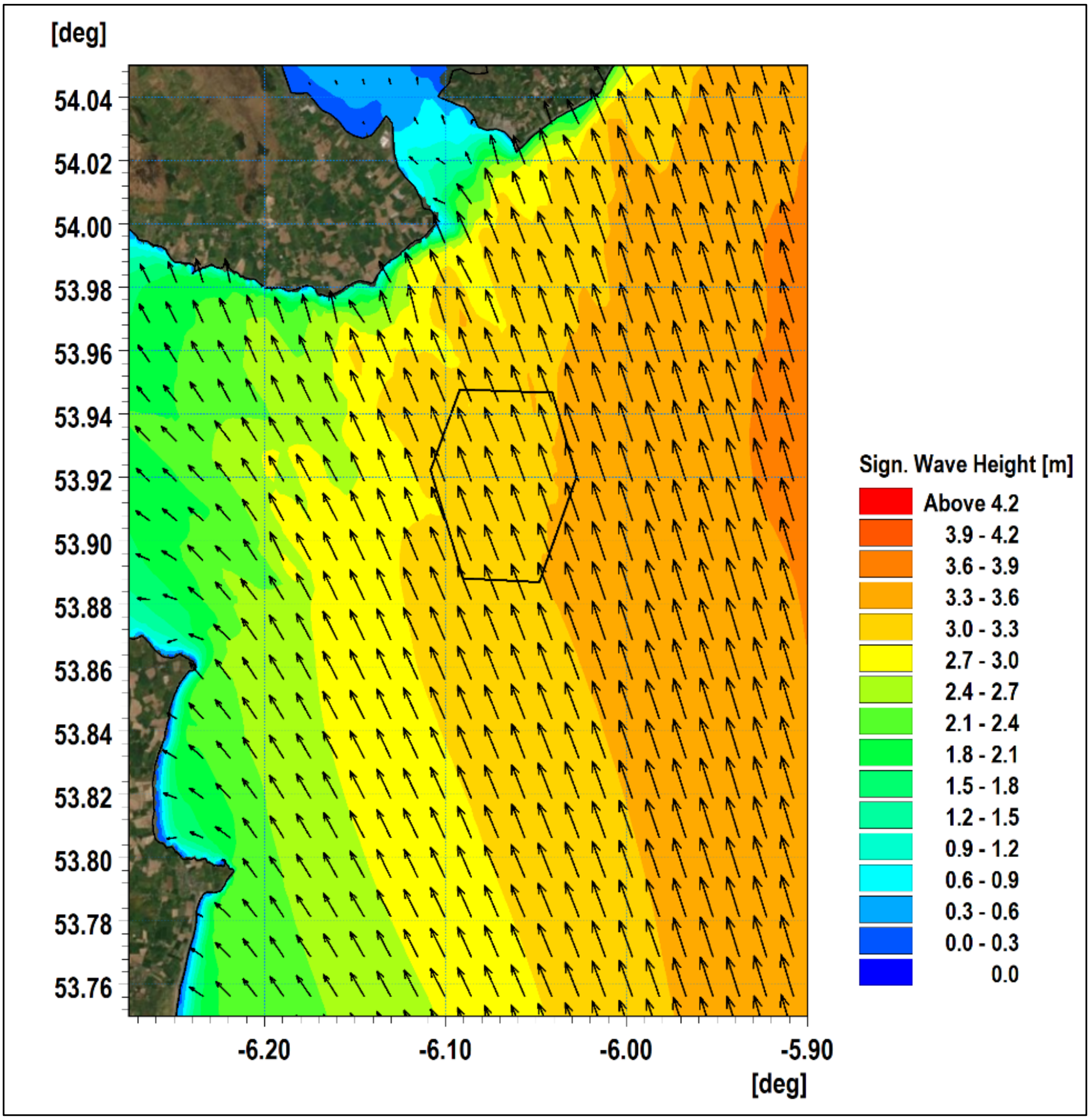

Figure 3-11: Post-construction wave climate 1 in 2 year storm 165°.

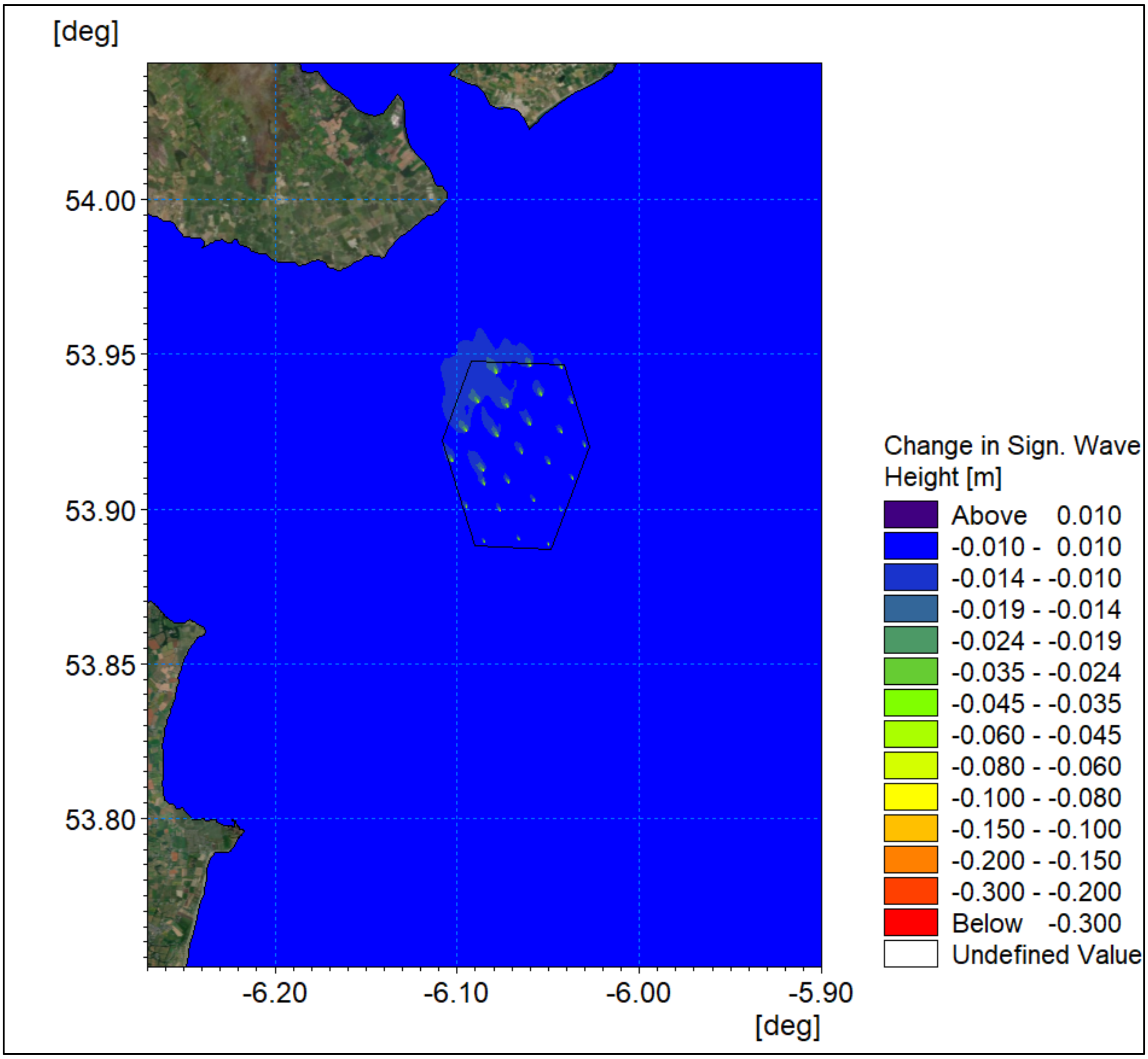

Figure 3-12: Change in wave climate 1 in 2 year storm 165° (post-construction minus baseline).

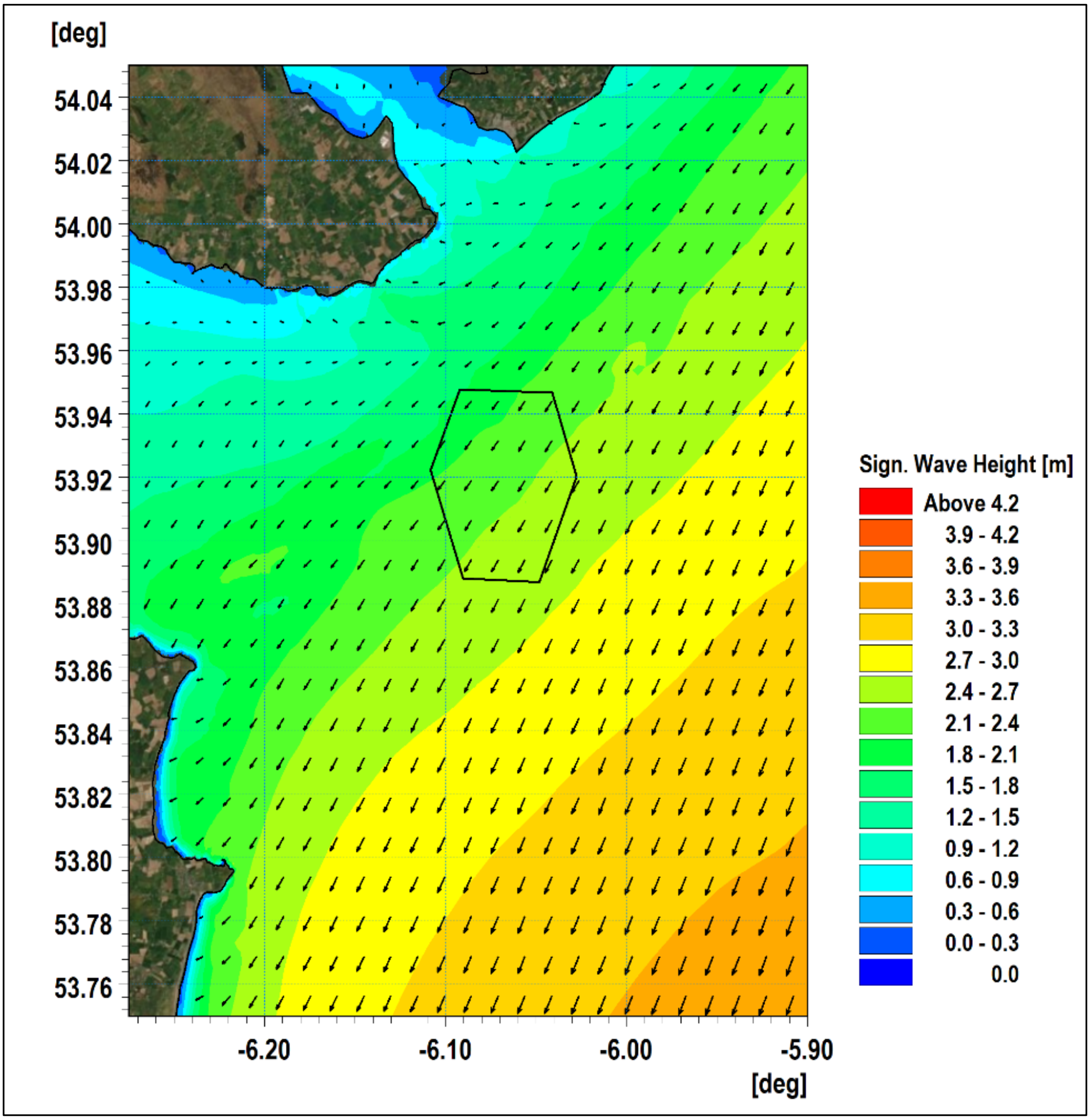

Figure 3-13: Post-construction wave climate 1 in 50 year storm 015°.

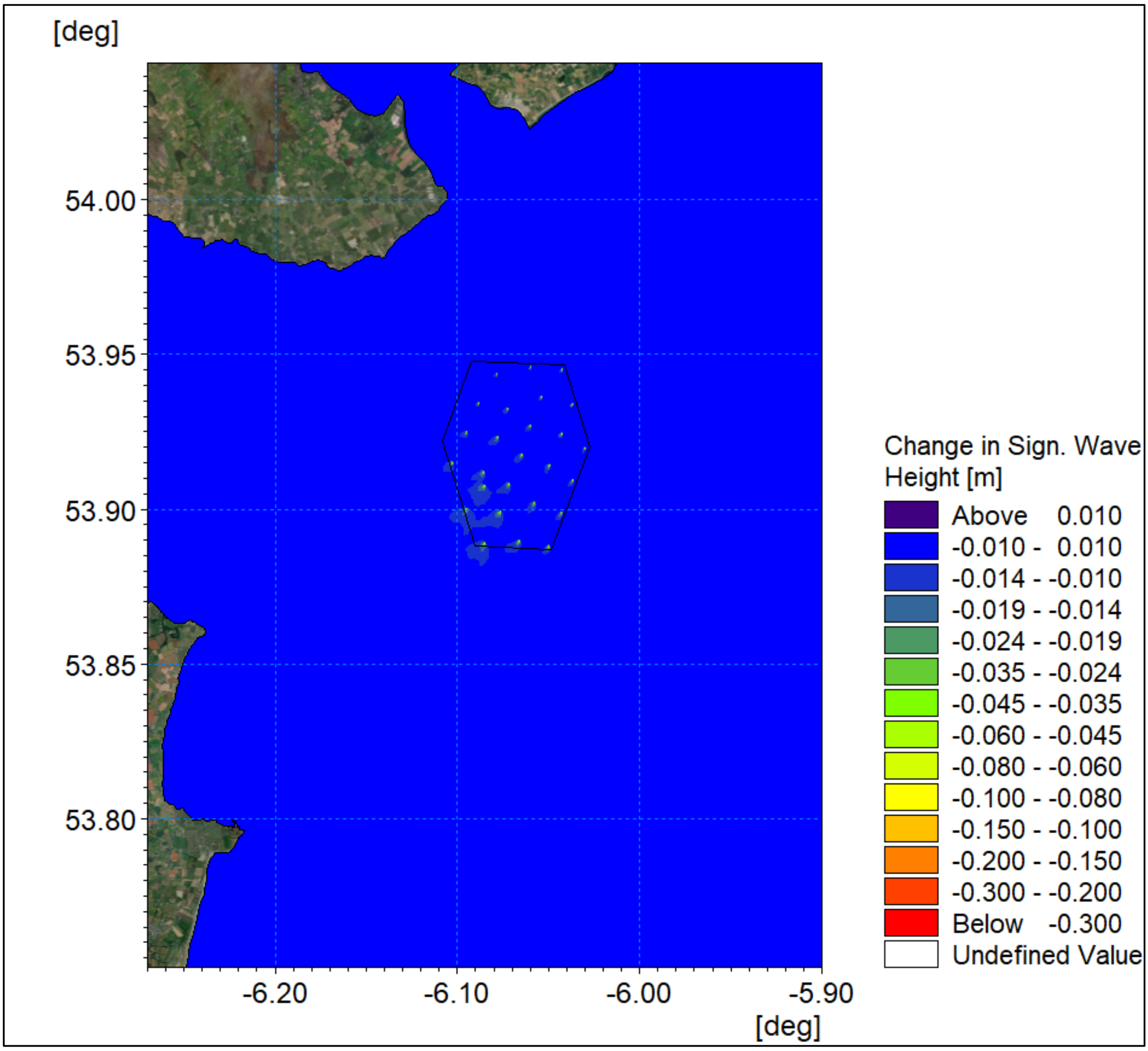

Figure 3-14: Change in wave climate 1 in 50 year storm 015° (post-construction minus baseline).

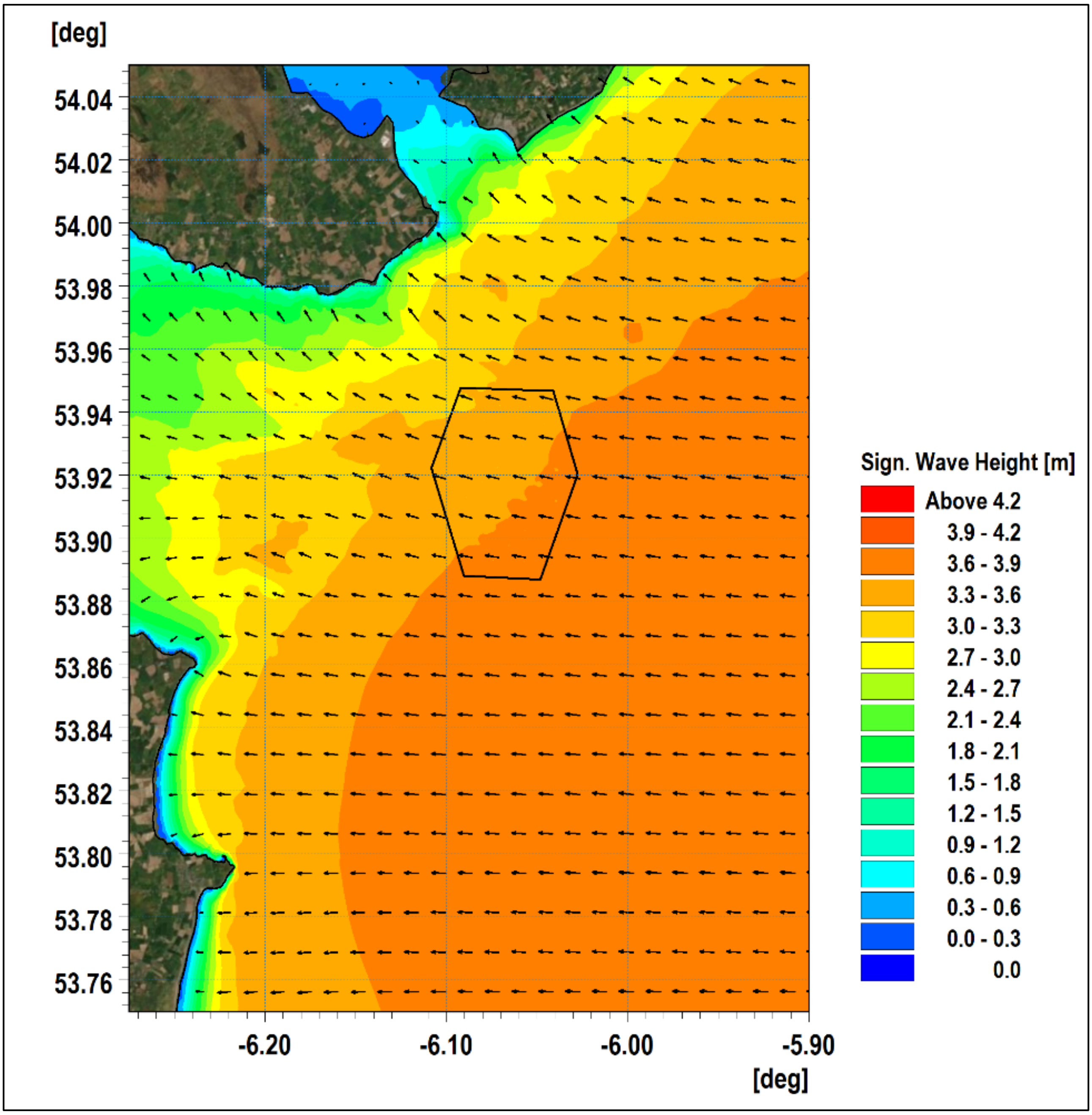

Figure 3-15: Post-construction wave climate 1 in 50 year storm 090°.

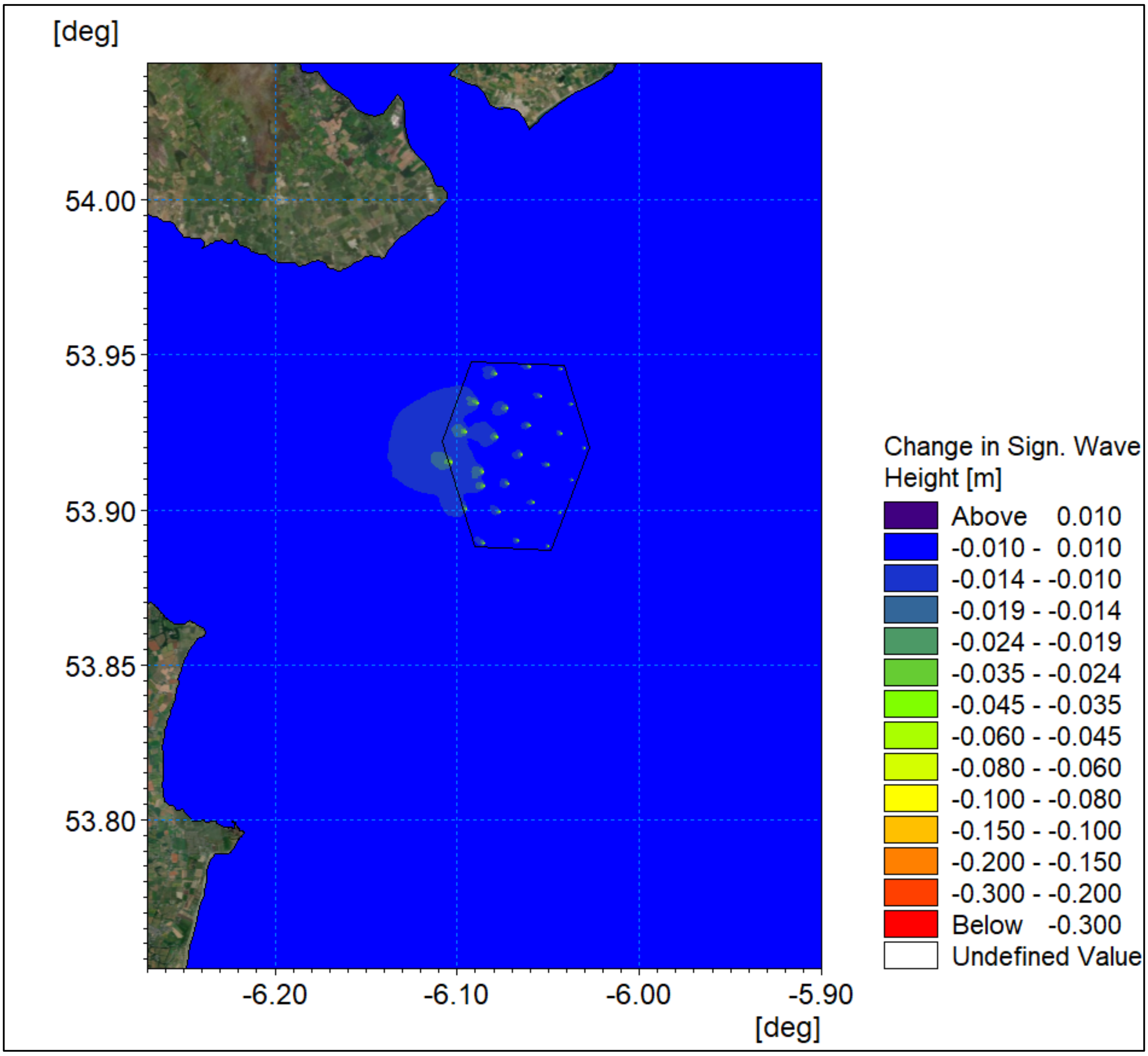

Figure 3-16: Change in wave climate 1 in 50 year storm 090° (post-construction minus baseline).

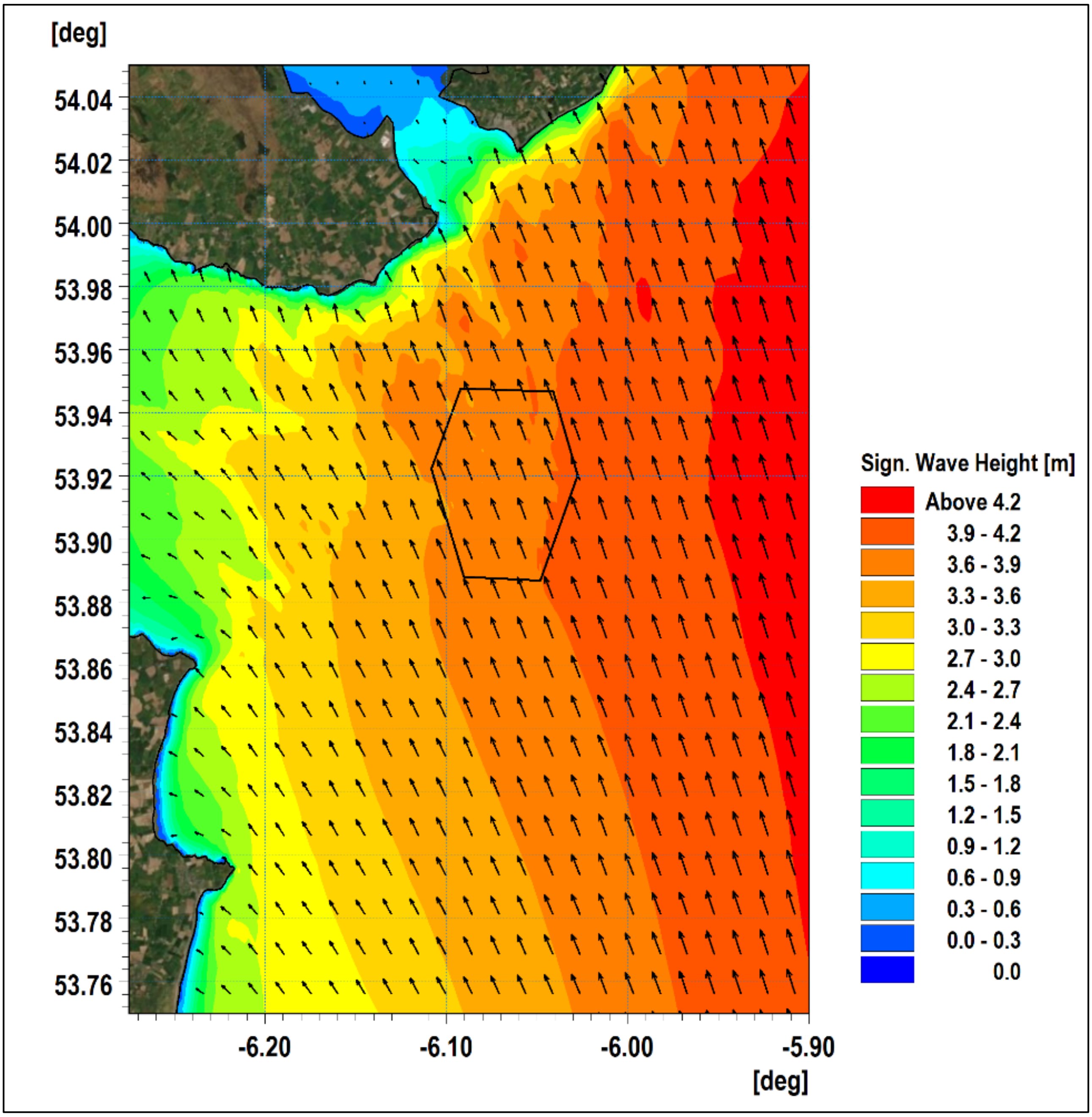

Figure 3-17: Post-construction wave climate 1 in 50 year storm 165°.

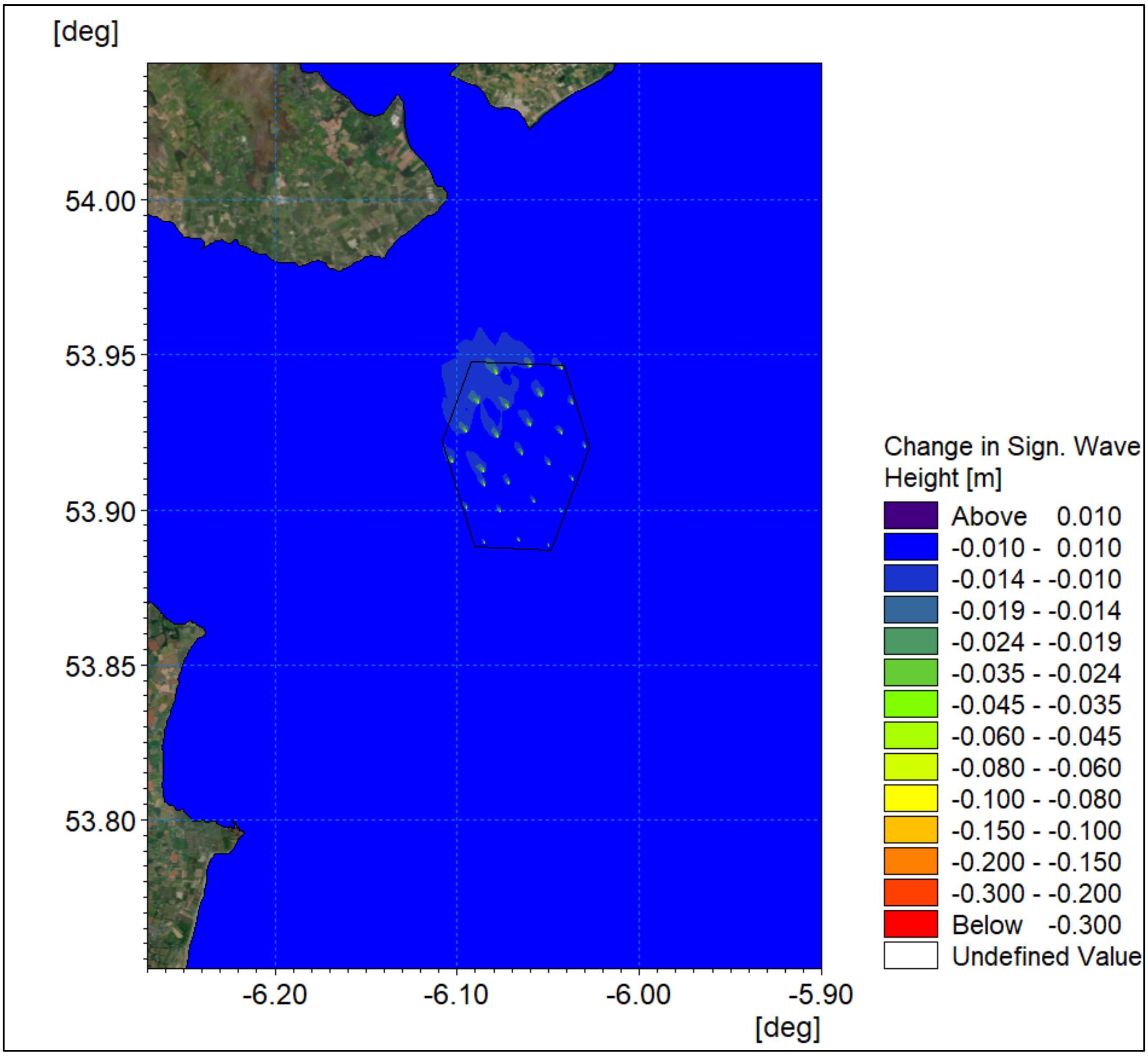

Figure 3-18: Change in wave climate 1 in 50 year storm 165° (post-construction minus baseline).

Littoral Currents

The previous sections established the magnitude of the changes in tidal currents and wave conditions individually. However, sediment transport regime are driven by a combination of these factors. For completeness, the influence on littoral currents was examined and has been presented in this section.

The modelling was extended to include the Project design parameters for the post-construction period, i.e. with 26 structures in place for a 1 in 2 year storm from 165°. The baseline littoral currents for mid flood and mid ebb are presented in Figure 2-15 and Figure 2-16 respectively whilst the equivalent post-construction littoral currents are shown in Figure 3-19 and Figure 3-20 for the flood and ebb tides respectively.

During the flood tide the direction of tidal flow is aligned with the wave climate and the difference in littoral currents from the baseline to post-construction is presented in Figure 3-21. These changes are both limited in magnitude (to around 30 mm/s) and also spatially, with the alteration in flows limited to the offshore wind farm area. During ebb tide the tidal flow is in opposition to the wave direction and the resulting flow field is more unsteady. The changes in littoral currents due to the structures were found to be smaller than the convergence criteria for the mode (i.e. indiscernible).

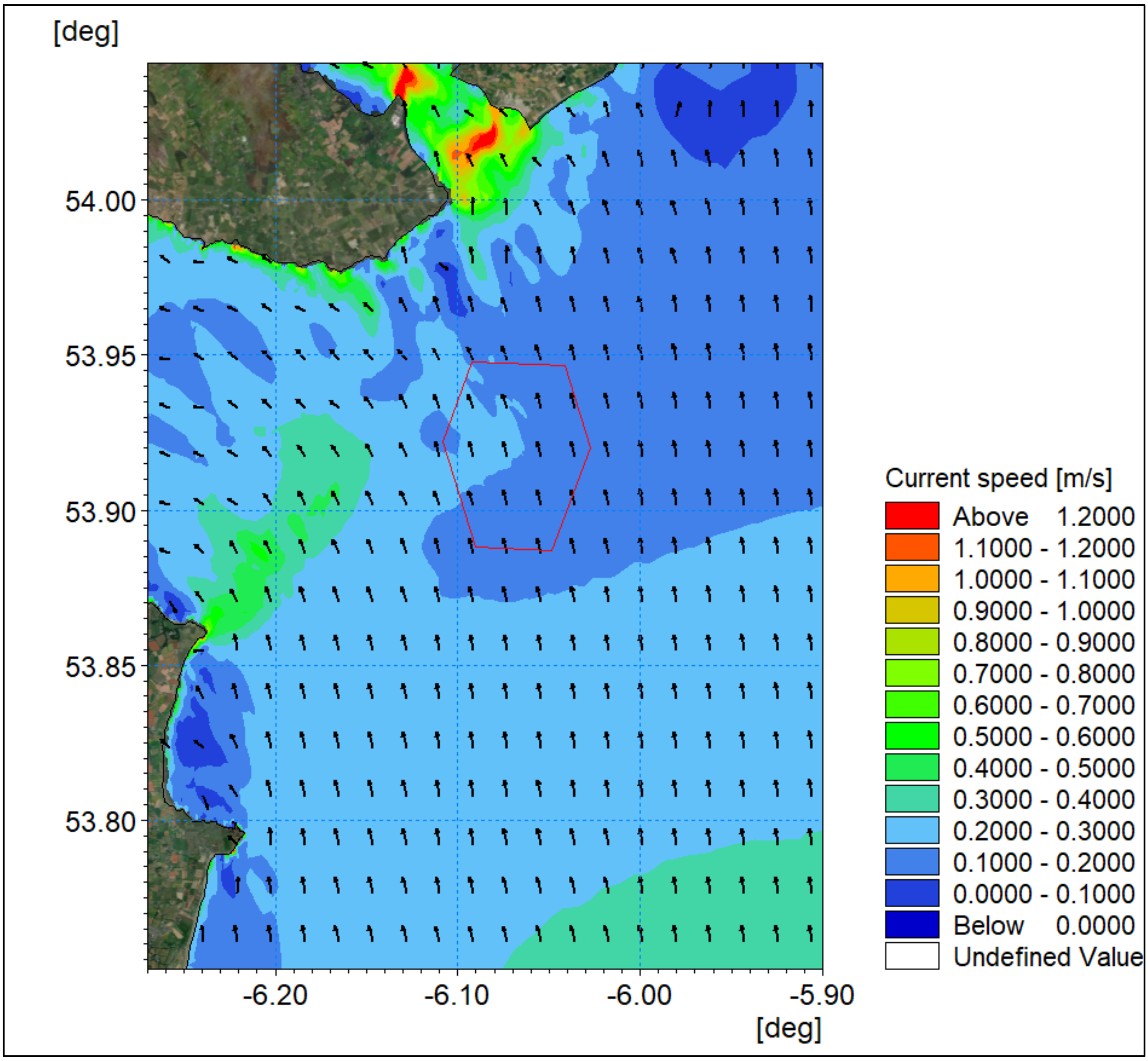

Figure 3-19: Post-construction littoral current 1 in 2 year storm from 165° - flood tide.

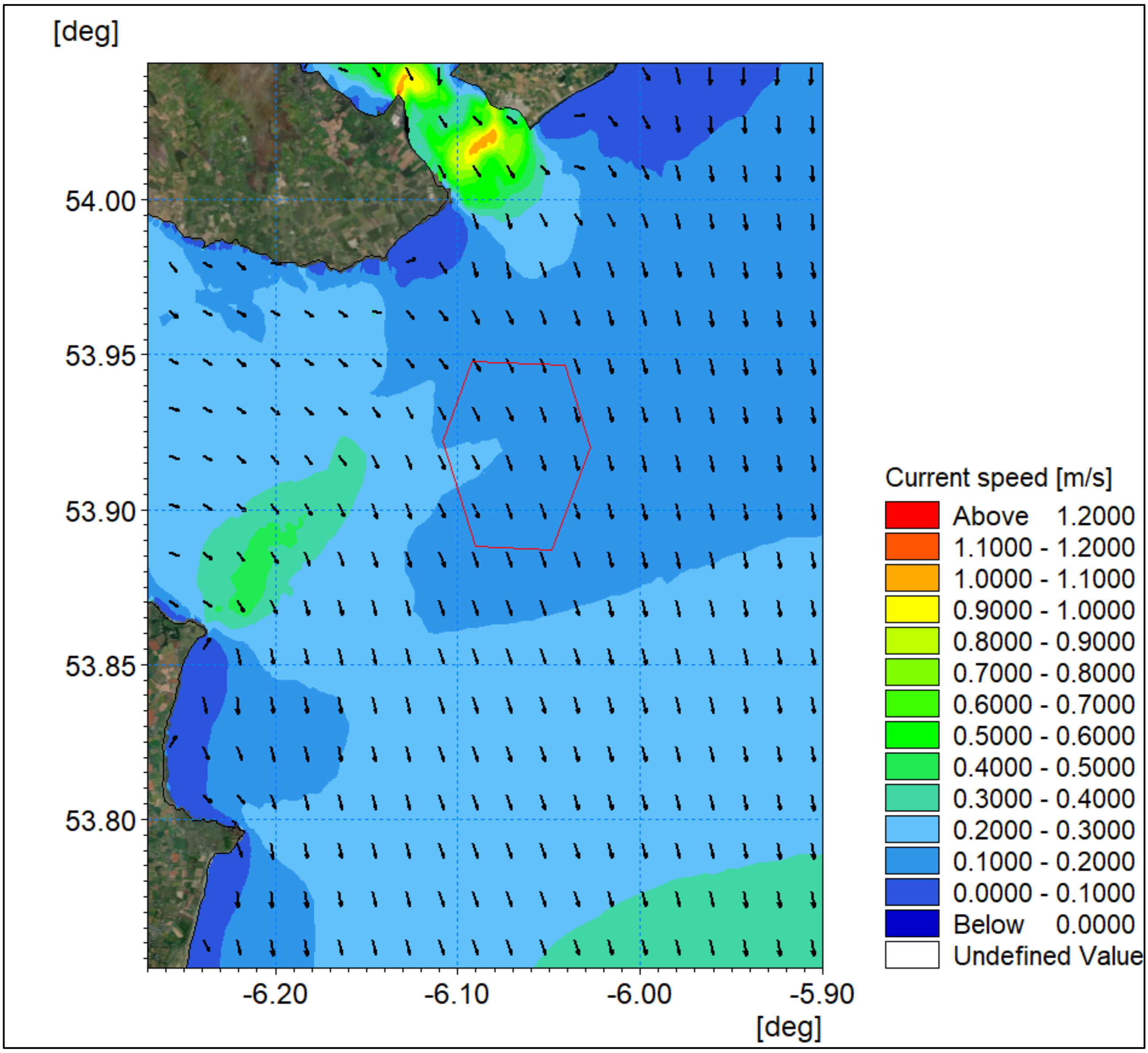

Figure 3-20: Post-construction littoral current 1 in 2 year storm from 165° - ebb tide.

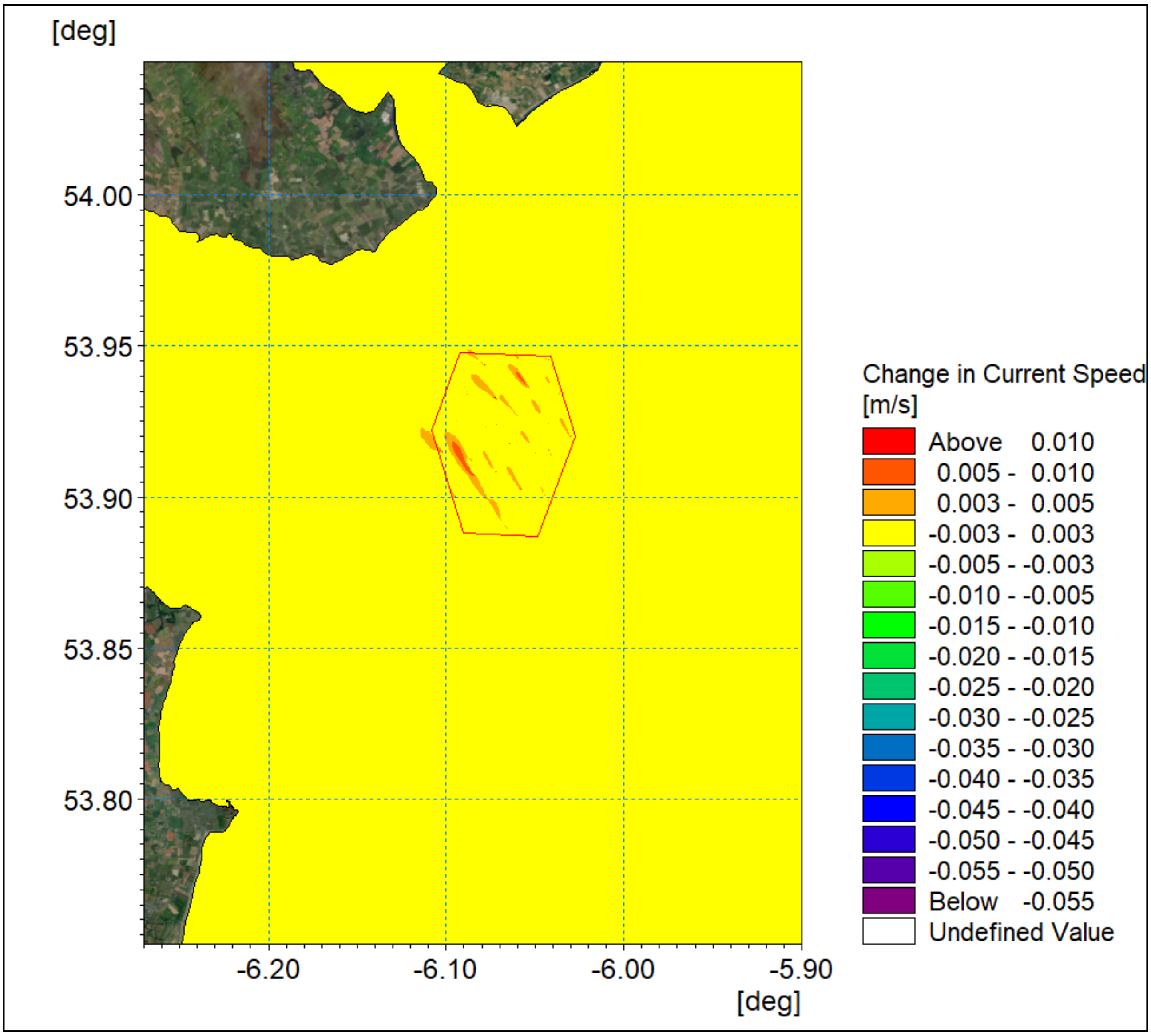

Figure 3-21: Change in littoral current 1 in 2 year storm from 165° - flood tide (post-construction minus baseline).

3.1.3 Post-construction sedimentology

Sediment Transport

The numerical modelling methodology for sediment transport was described in section 2.2. For the post-construction scenario, in addition to the structures being included in the tide and wave models, the seabed material map was edited to include a non-erodible hard layer to represent the scour protection.

An area of fixed seabed was overlain with a thin layer of sand to initialise the model and avoid instabilities. The scour protection was defined as described in volume 2A chapter 5: Project Description (i.e. scour protection radius + pile =24 m). The models were then re-run for a spring tide under calm conditions and also for a 1 in 2 year storm from 165°.

For this analysis the post-construction residual current was calculated over the course of one complete typical tidal cycle and compared with the baseline (Figure 2-19). The post-construction residual current and changes from the baseline are shown in Figure 3-22 and Figure 3-23 respectively. These figures demonstrate that the structures have little influence on the flow domain under calm conditions.

The residual currents are the driving force for sediment transport and if the structures do not have a significant influence on either tide or wave conditions, they cannot therefore have a significant effect on the sediment transport regime. For completeness the sediment transport was simulated with the structures in place and then factored to indicate the loading over the course of one year to provide representative quantities. The baseline annual sediment transport rate is shown in Figure 2-20, whilst the post-construction rate is shown in Figure 3-24. As anticipated these figures demonstrate that the regime remains unchanged with little sediment transport potential across the domain.

This process was repeated for the 1 in 2 year storm. The baseline residual current (Figure 2-21) and annual potential sediment transport (Figure 2-22) were compared with the equivalent post-construction residual current pattern as shown in Figure 3-25 with the difference in Figure 3-26. As discussed previously, the changes due to the presence of the structures are very small (often in the order of the model convergence criteria). During storm conditions the variation in residual littoral currents and therefore sediment transport processes is limited both in magnitude and spatially. The post-construction sediment transport regime presented in Figure 3-27 shows virtually no difference from the baseline scenario.

This analysis demonstrates that the Project will have no discernible effect on sediment transport, given that the baseline transport is limited and that any changes to the residual currents which drive transport are minimal.

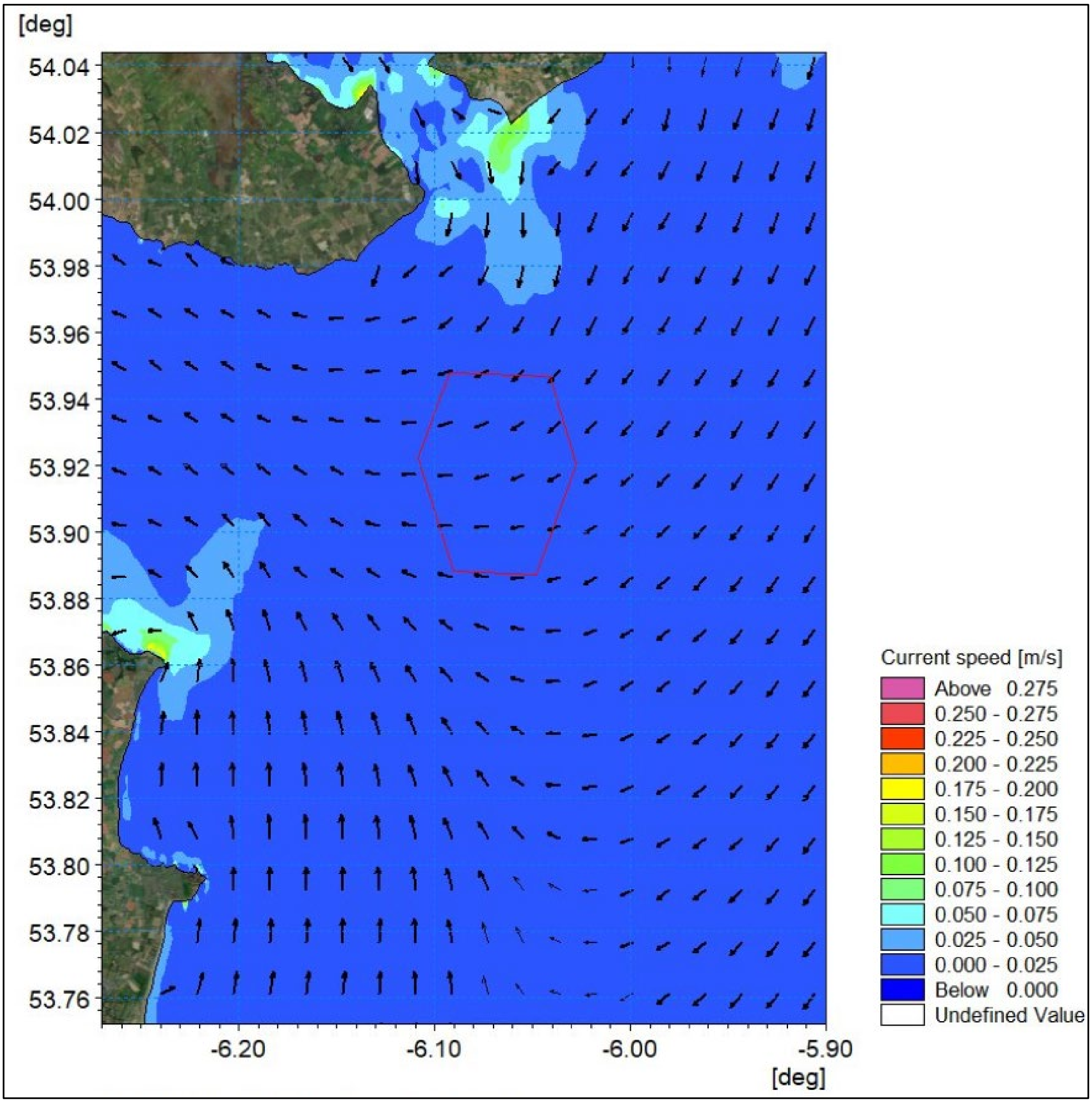

Figure 3-22: Post-construction residual current spring tide.

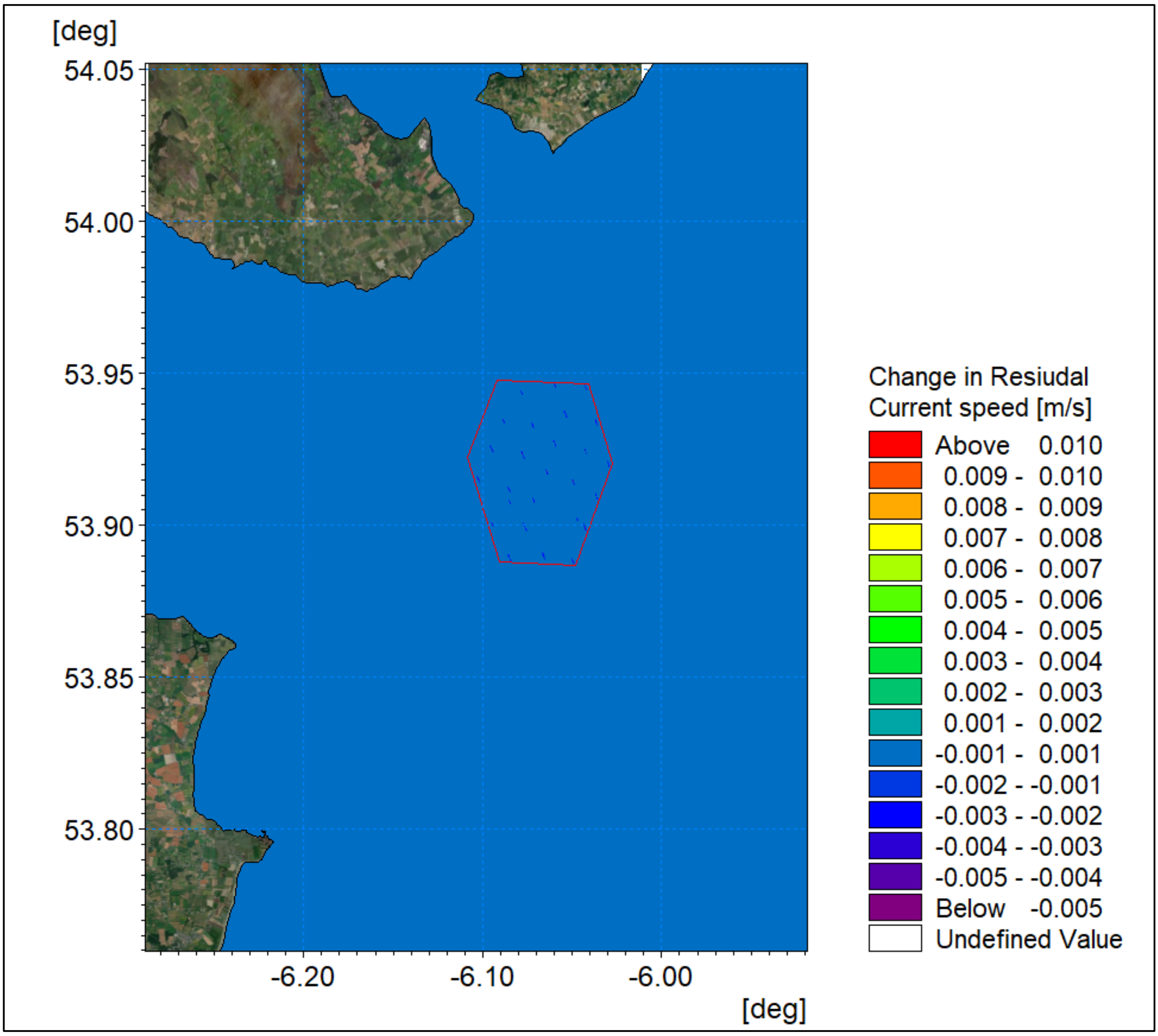

Figure 3-23: Change in residual current spring tide (post-construction minus baseline).

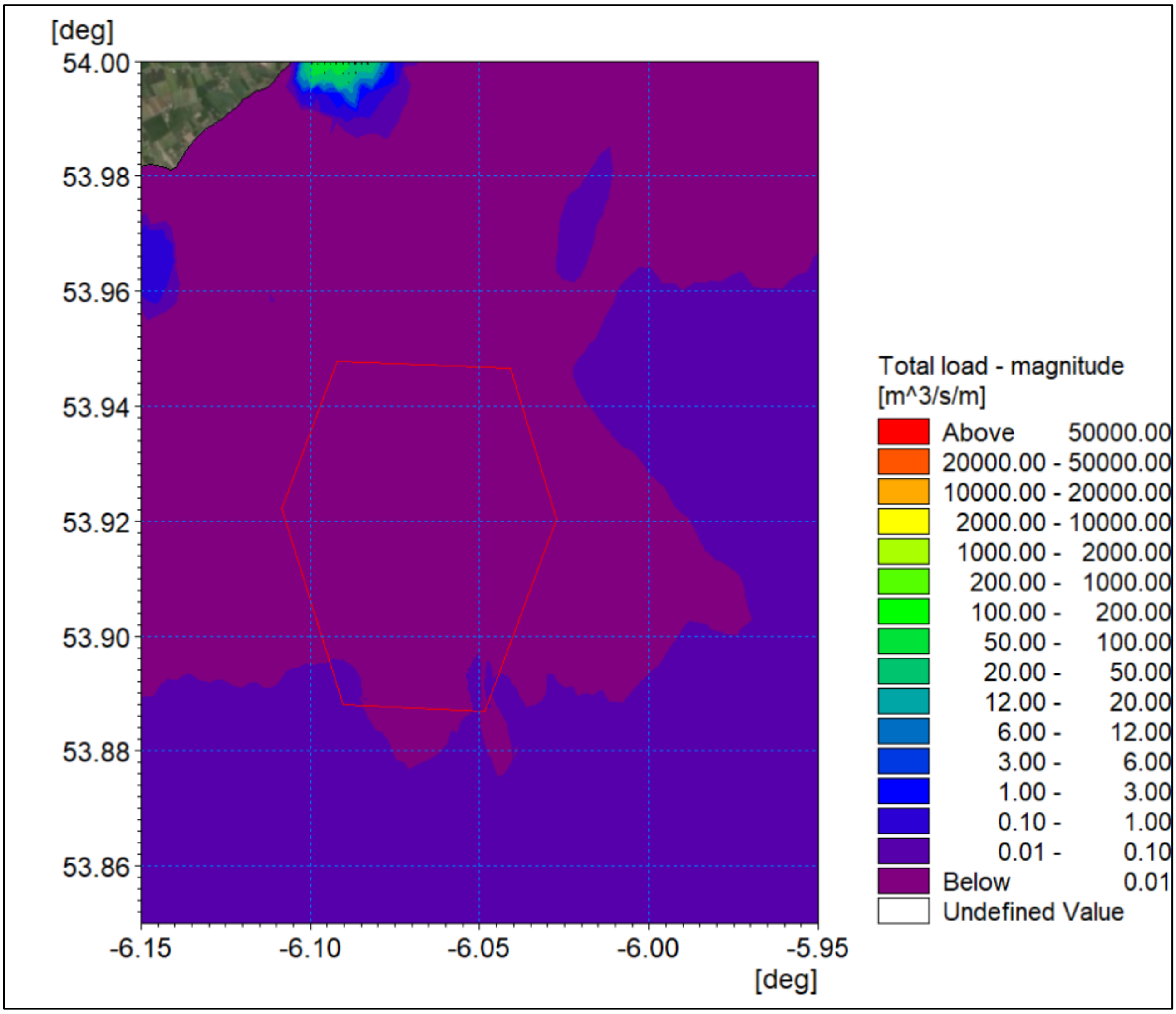

Figure 3-24: Post-construction net sediment transport - spring tide.

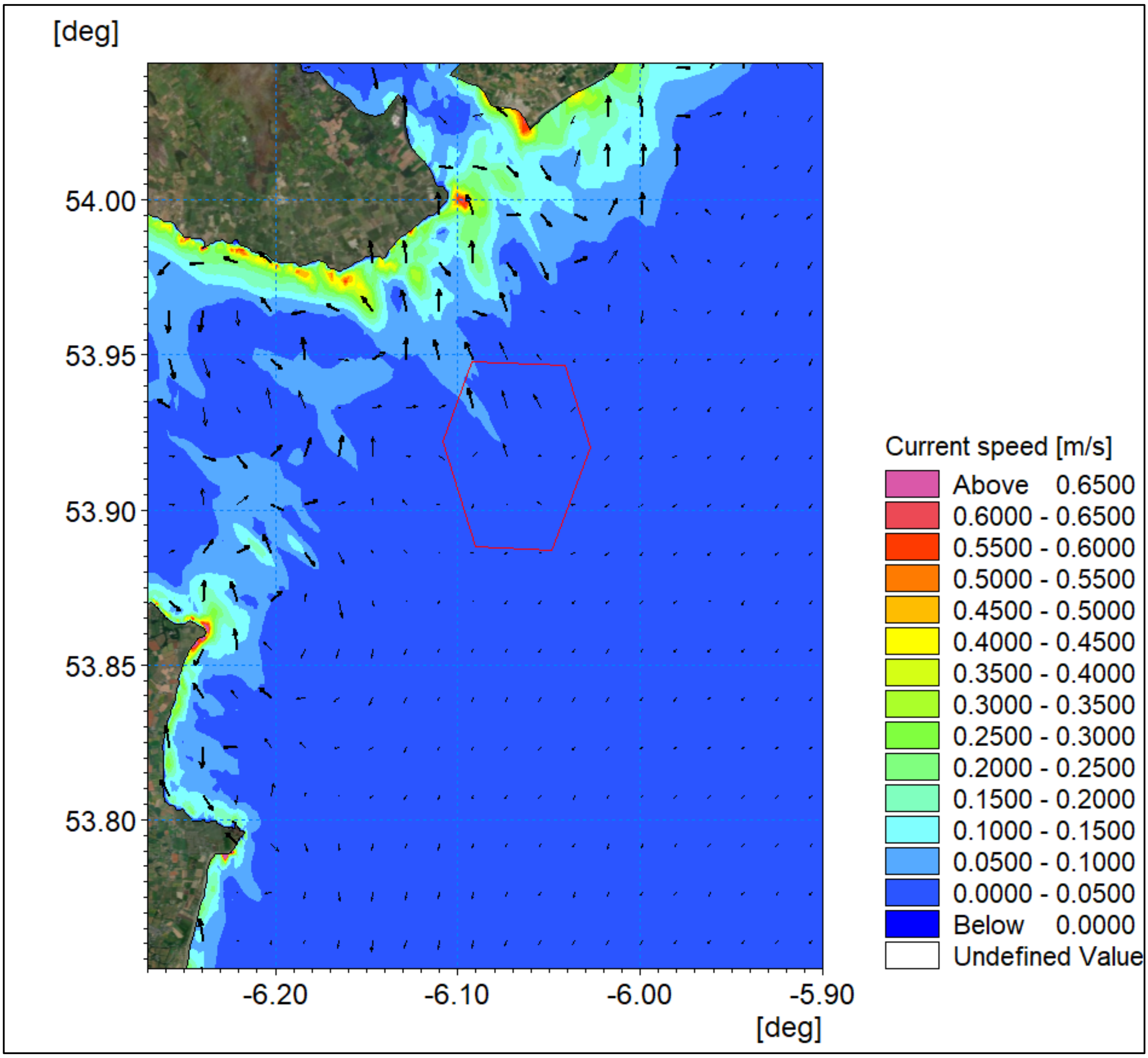

Figure 3-25: Post-construction residual current 1 in 2 year storm from 165° spring tide.

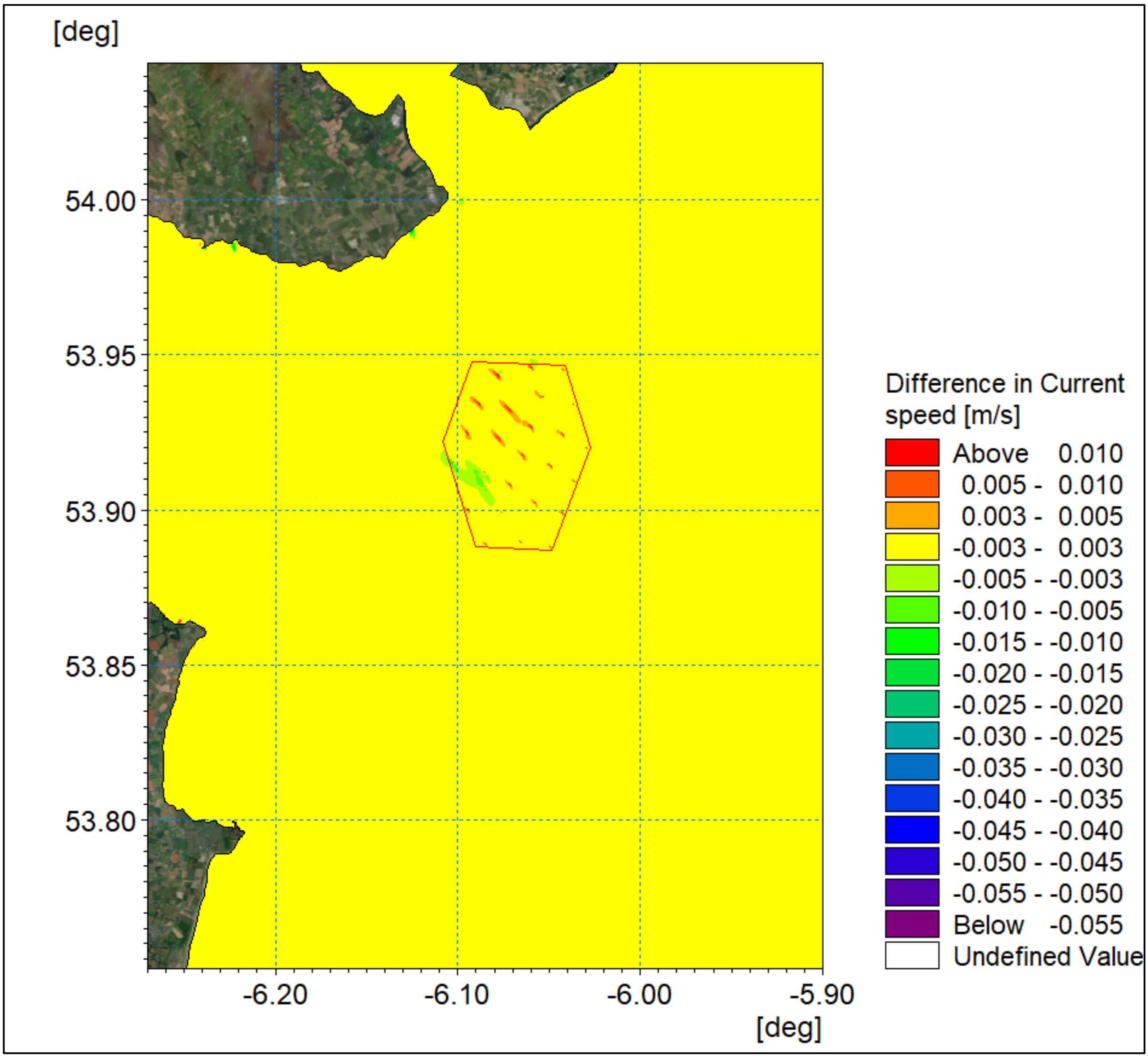

Figure 3-26: Change in residual current 1 in 2 year storm from 165° spring tide (post-construction minus baseline).

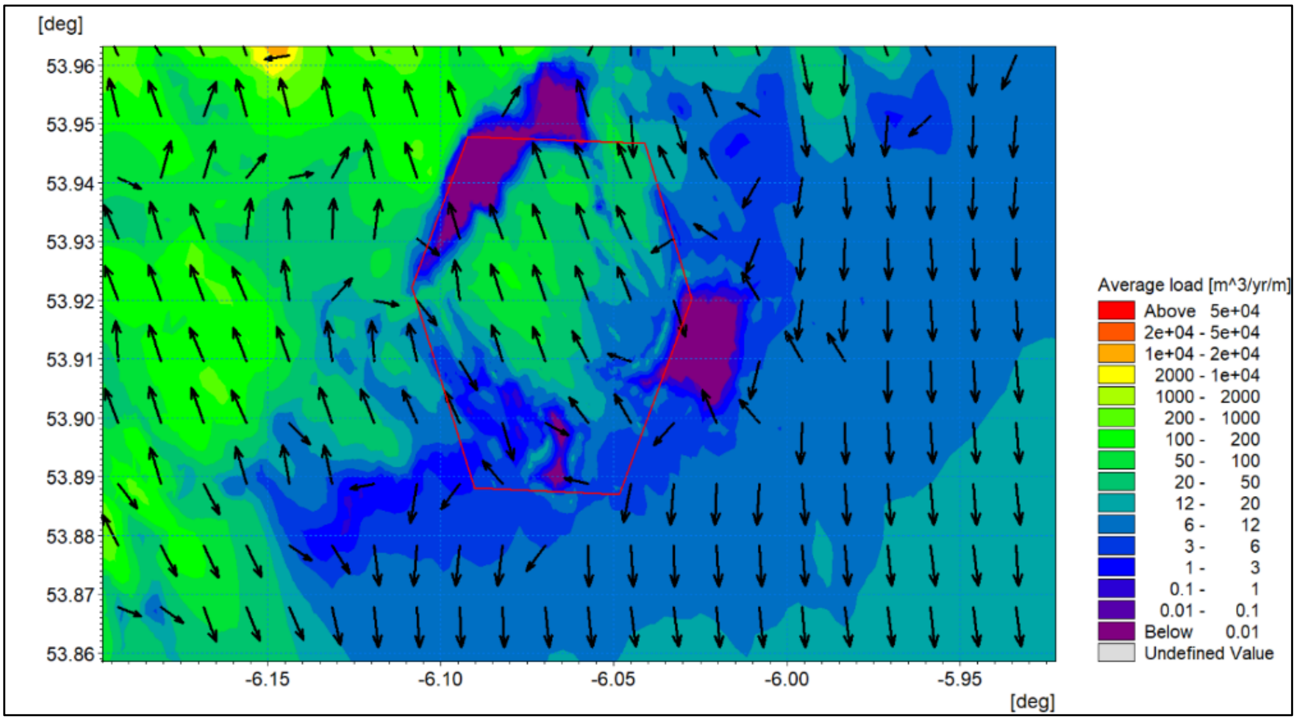

Figure 3-27: Post-construction net sediment transport - spring tide with 1 in 2 year storm from 165°.

3.1.4 Potential changes during construction

In addition to the changes in marine processes resulting from the operational phase of the Project, the potential construction phase impacts associated with the Project design parameters were also quantified by means of numerical modelling. The principal construction elements relate to the transport and fate of sediment brought into suspension due to the installation of the structures and associated foundations and the laying of the inter-array and offshore cables.

This section provides information on suspended sediment concentrations and subsequent sedimentation relating to the Project. The parameters used in the modelling are based on the Project design parameters and described in volume 2A chapter 5: Project Description. This Technical Report presents the findings of:

- Drilled pile installation – across a range of hydrodynamic conditions;
- Inter-array cable installation – for a zone of sandy bed sediment; and
- Offshore cable installation – through sandy beds.

In Figure 3-28, the solid yellow line indicates the Marine Processes Study Area whilst the dashed line represents the extent of one spring tidal excursion. The modelled offshore cable corridor in context of the overall cable installation plan is shown in pink. This modelled offshore cable corridor traverses the offshore wind farm area passing through the range of water depths and tidal currents and will therefore provide the range of suspended sediment plumes. In this and each subsequent figure, the offshore wind farm area is outlined in red.

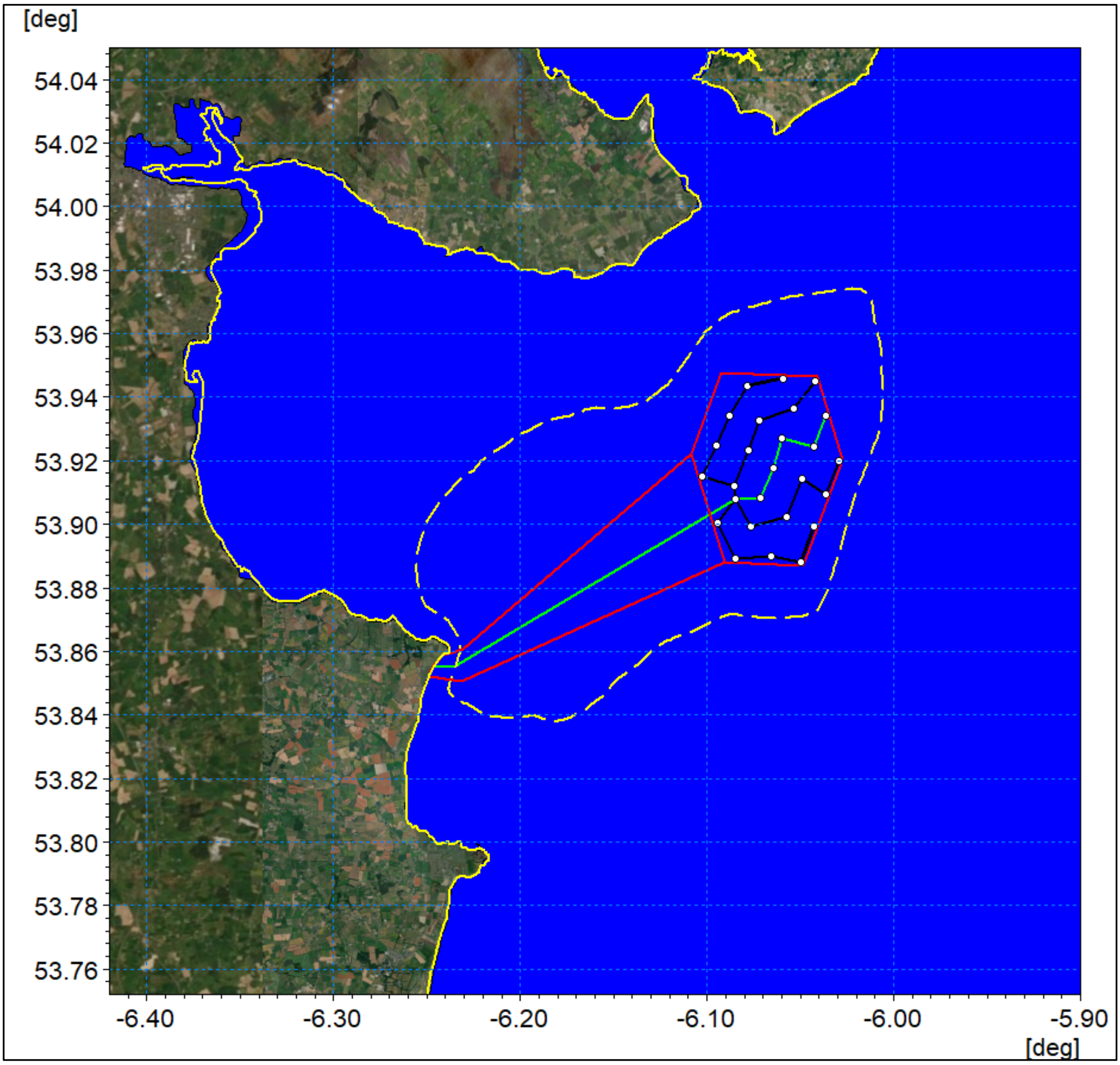

Figure 3-28: Location of the sediment source term (green line) used to model a representative dredging route.

Foundation Installation

To assess the impact of the installation of monopiles, the structures were considered in terms of the volume of material which could potentially be released into the water column based on both a volumetric assessment of the data provided and the specified construction technique. This modelling was undertaken using the Project layout which is comprised of 25 turbines and one offshore substation (OSS) as illustrated in Figure 3-28.

Whilst piles may be driven into the seabed with minimal release of sediment material, this assessment has assumed that piles would be augured (i.e. drilled) and that material would subsequently be jetted and dispersed into the water column as a plume.

This modelling assessment assumed the following characteristics as outlined in volume 2A chapter 5: Project Description:

- Pile diameter 9.6 m;
- Pile depth 35 m; and
- Drilling rate 0.25 m/h and therefore a Maximum drilling duration (per pile) of six days

A sample of six pile installations were selected for this assessment. These six pile locations as illustrated in Figure 3-29 were selected as they covered a range of water depth and current conditions. Furthermore, these six locations were nearest to the outer extent of the Project Wind farm area meaning that the resultant sediment plumes would represent the greatest possible dispersion characteristics.

The modelling was undertaken using the MIKE21 Mud Transport (MT) module which allows the modelling of erosion, transport and deposition of cohesive and cohesive/granular sediments. This model is suited to sediment releases in the water column as it represents sediment sources which can vary spatially and temporally. The cohesive functions were not utilised as the material released comprised sand.

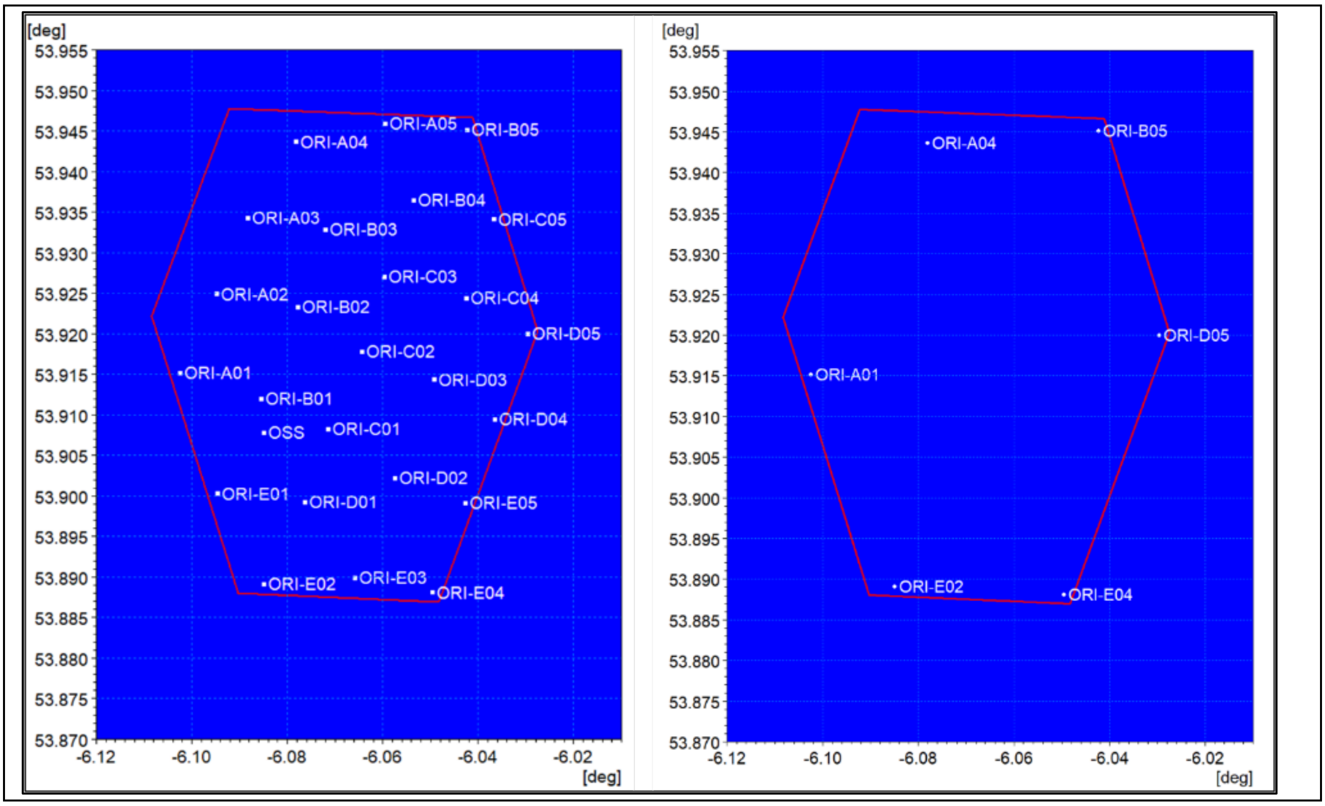

Figure 3-29: Overall wind farm layout (left) with the WTG monopiles selected to assess suspended sediments (right).

To undertake the modelling, it was necessary to define characteristics for the seabed sediment. A number of data sources were employed as previously described in section 2.3. The data collected by GSI was accessed via the EMODnet online database and used as illustrated in Figure 3-30.

The grab sample data from EMODnet was used as a basis for the sediment grading however more fine material would be released relating to bentonite used in the drilling process. The drilling was modelled as being undertaken over six days per pile which covered a period of both spring and neap tides. It was assumed that all cuttings were released into the water column with the following characteristics:

- 40% fines/bentonite 0.05 mm diameter;
- 30% sandy mud 0.1 mm diameter;

- 20% medium sand 0.5 mm diameter; and
- 10% cuttings 1 mm diameter.

It was assumed that all material would be suspended, however in practice there is likely to be a greater proportion of larger cuttings material. This material would not be widely dispersed therefore a conservative approach was taken in terms of suspended sediments and dispersion.

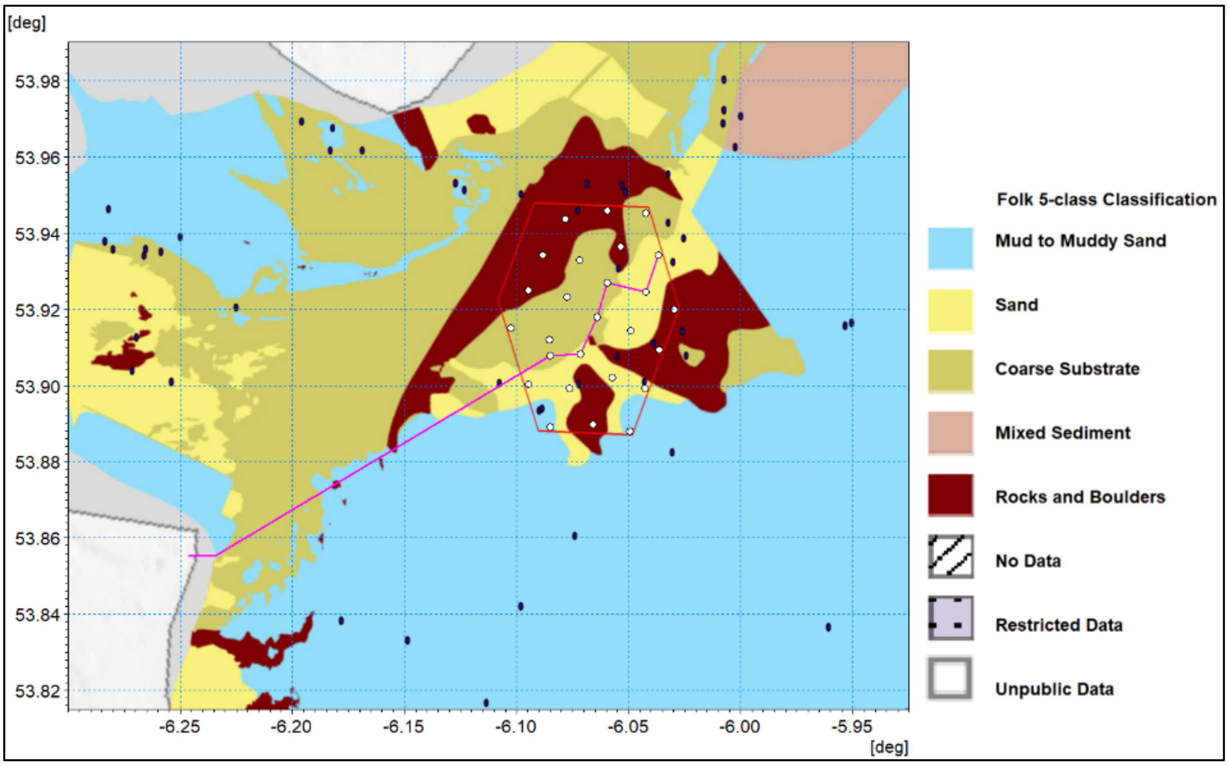

Figure 3-30: EMODnet portal data (blue dots indicate EMODnet sample locations).

For each simulation described in the sections below, a set of figures are presented, as follows:

- **Suspended sediment:** The maximum and average suspended sediment plumes are presented where the maximum shows the largest value encountered in each cell over the modelling period. These elevated values would not occur concurrently or necessarily persist for a prolonged period of time, hence the average values over the installation period are presented to provide context. Due to the variation in suspended sediment levels the plots require the use of a log scale to cover this range and provide clarity. However, all plots use the same scale for ease of comparison. It should be noted that the minimum value presented is 1 mg/l which would be indiscernible from background levels.

- **Sedimentation:** The second set of plots relate to sedimentation. The first figure in each set shows the sediment levels one day following the completion of the activity and therefore relates to a specific point in time. Again, the maximum plot shows the greatest amount of sedimentation experienced in each cell over the course of the operation. It should be noted that this is a statistical value and does not relate to a specific point in time. Thus, material which has settled in multiple areas on successive tides would be accounted for more than once in this figure. Therefore, average values are also provided to indicate the period of time over which the sedimentation persists. It should be noted that for the drilled piles sedimentation levels are very low. A log scale has therefore been used throughout as reducing the minimum values (0.01 mm) would be incongruous.

ORI-E04

ORI-E04 is located to the southeast of the offshore wind farm area in the deeper water where current speeds are marginally higher. Within the plume the maximum suspended sediment levels are 100 mg/l, these levels are localised and only persist for a short period. The average values are much lower, typically one tenth of peak values. The data are illustrated in the left and right plots in Figure 3-31 respectively. Following the cessation of drilling the turbidity levels reduce within a few hours. Some of the finer material associated with the drilling process is re-suspended during successive tides as it is redistributed but turbidity levels remain low.

The sedimentation plots in Figure 3-32 show the sedimentation levels one day after the completion of works (left) and maximum sedimentation (right), whilst Figure 3-33 presents the average value. In all cases the sedimentation beyond the immediate drilling location is indiscernible. This is due to the relatively slow drilling rate (0.25 m/hour) allowing the fines to be widely dispersed while the larger material settles at the release point due to the limited current speed.

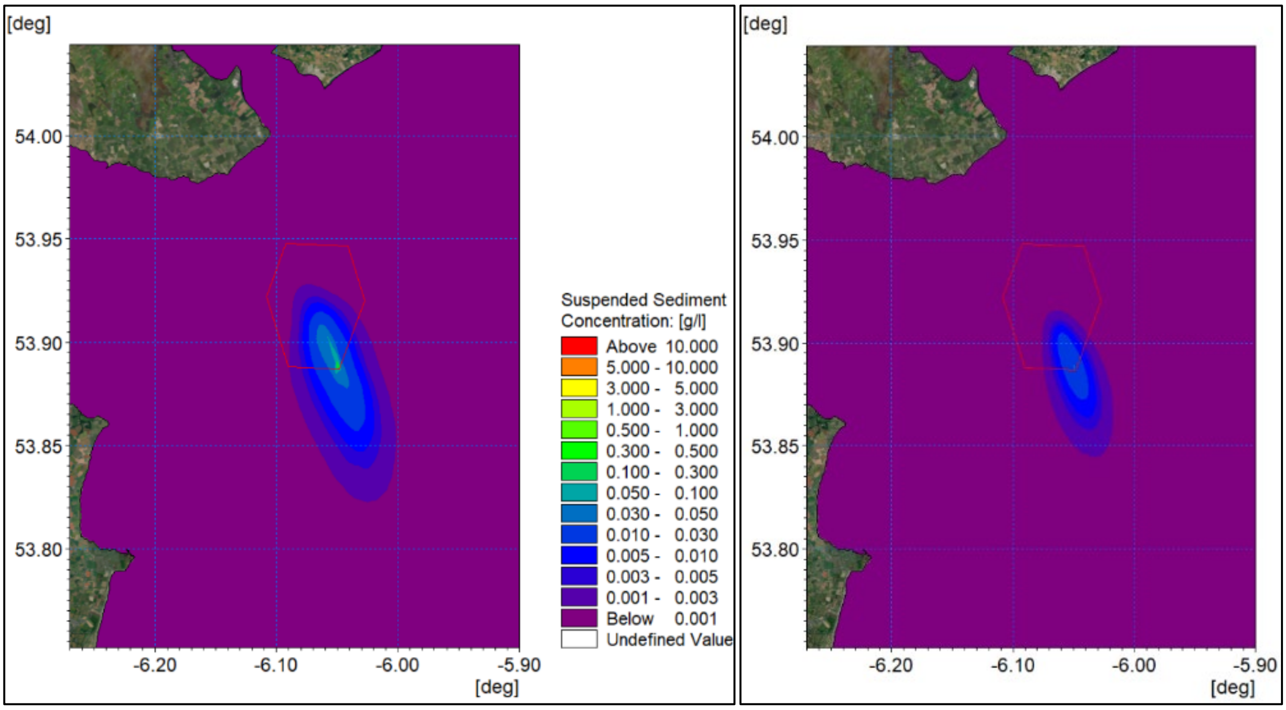

Figure 3-31: Maximum (left) and average (right) suspended sediment concentration at ORI-E04.

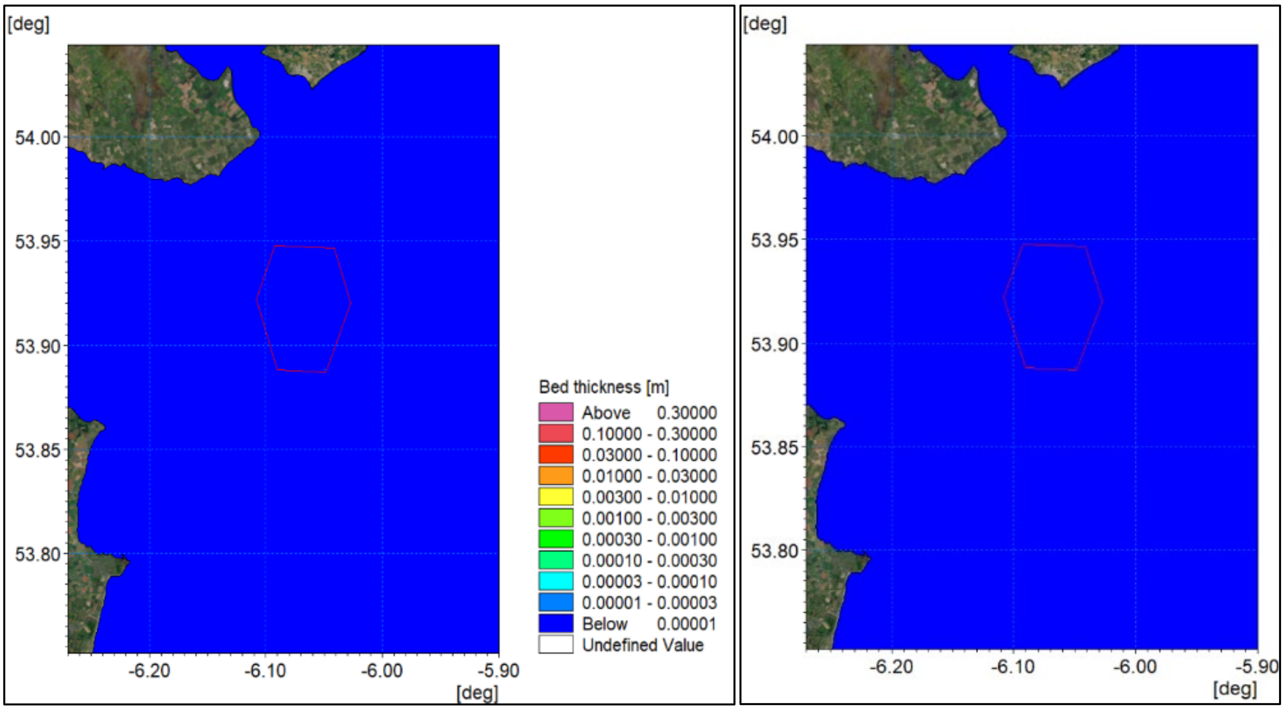

Figure 3-32: Final (left) and maximum (right) sedimentation at ORI-E04.

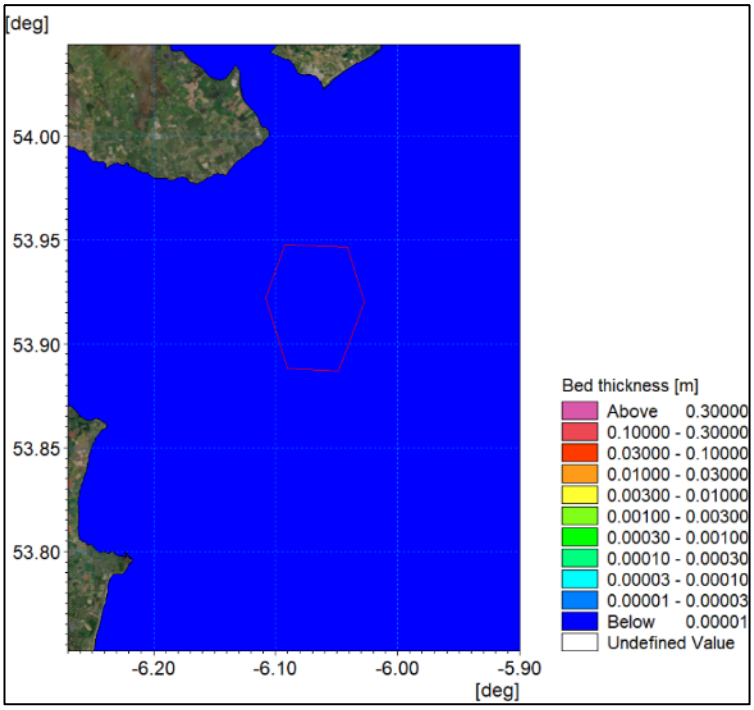

Figure 3-33: Average sedimentation at ORI-E04.

ORI-D05

ORI-D05 is the most easterly Wind Turbine Generator (WTG) and experiences current speeds of similar magnitude to ORI-D05. The maximum and average sediment plumes presented in Figure 3-34 are therefore of similar magnitude and spatial extent with typical average suspended sediment levels being 5 mg/l.

As with the previous location settlement would be imperceptible from the background activity. This is illustrated by Figure 3-35 and Figure 3-36 for the final, maximum and average sedimentation results. In each case the settlement of the coarsest material at the auger site is the only discernible deposit.

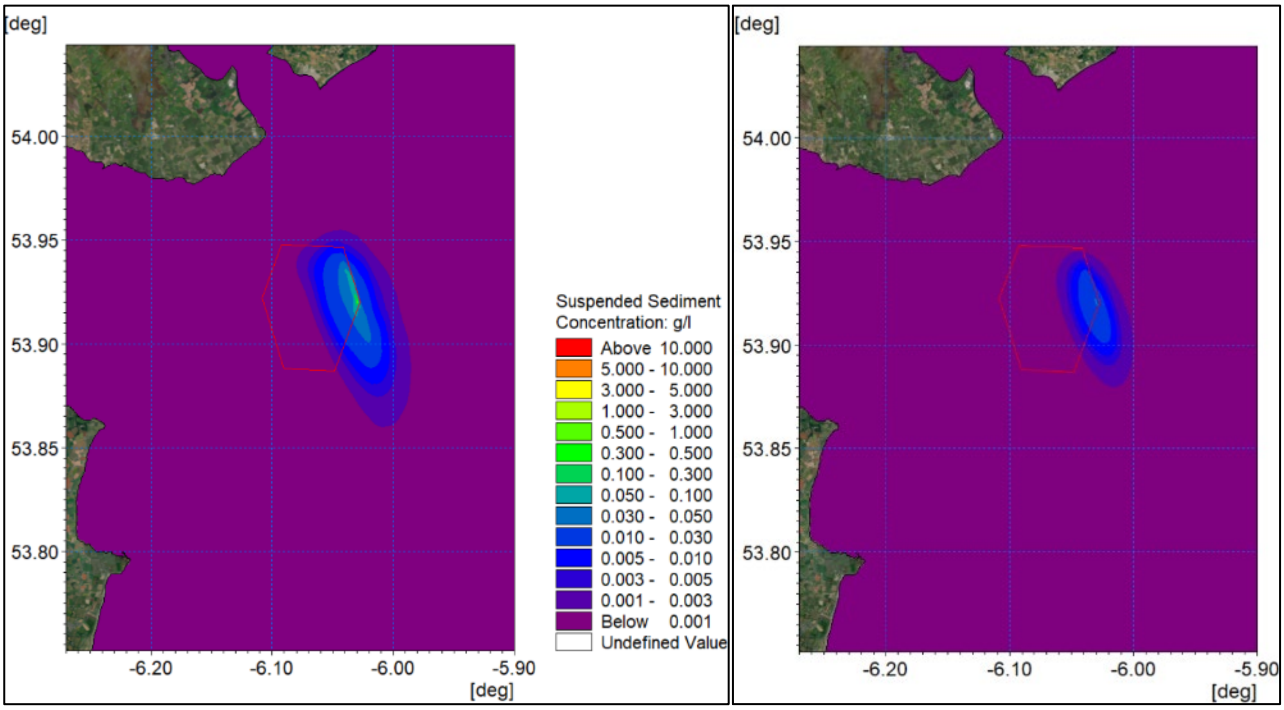

Figure 3-34: Maximum (left) and average (right) suspended sediment concentrations at ORI-D05.

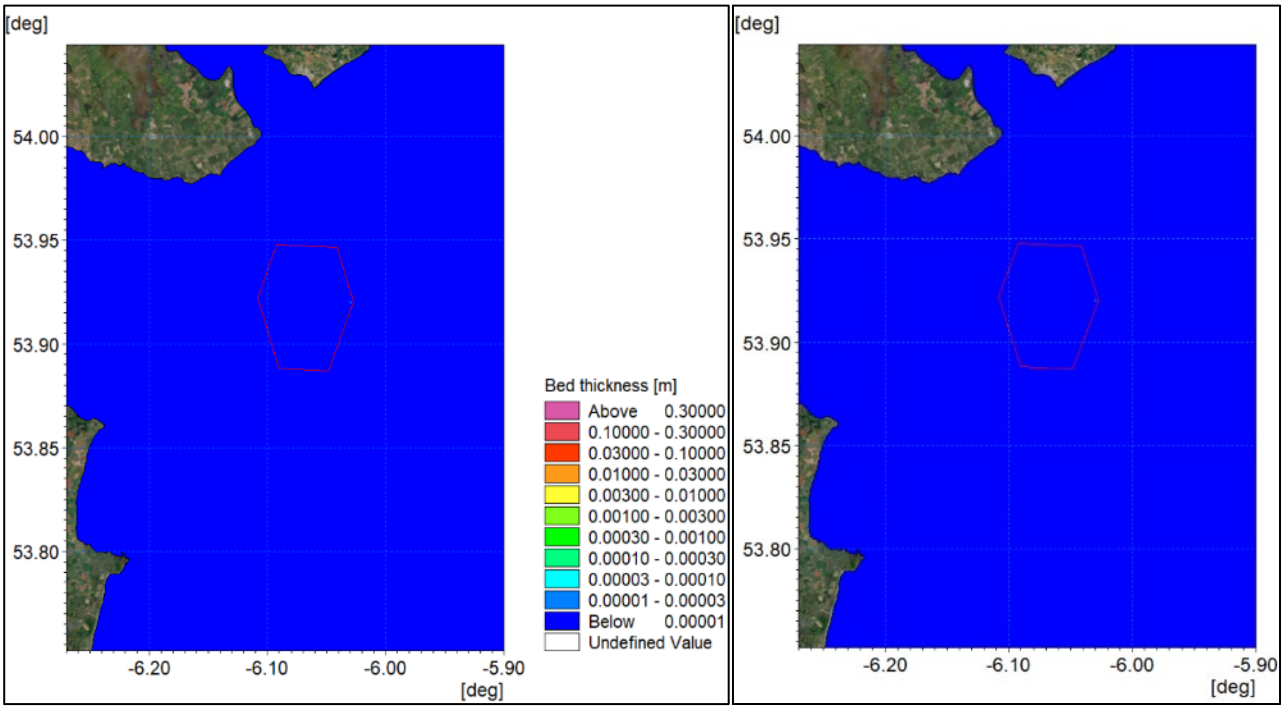

Figure 3-35: Final (left) and maximum (right) sedimentation at ORI-D05.

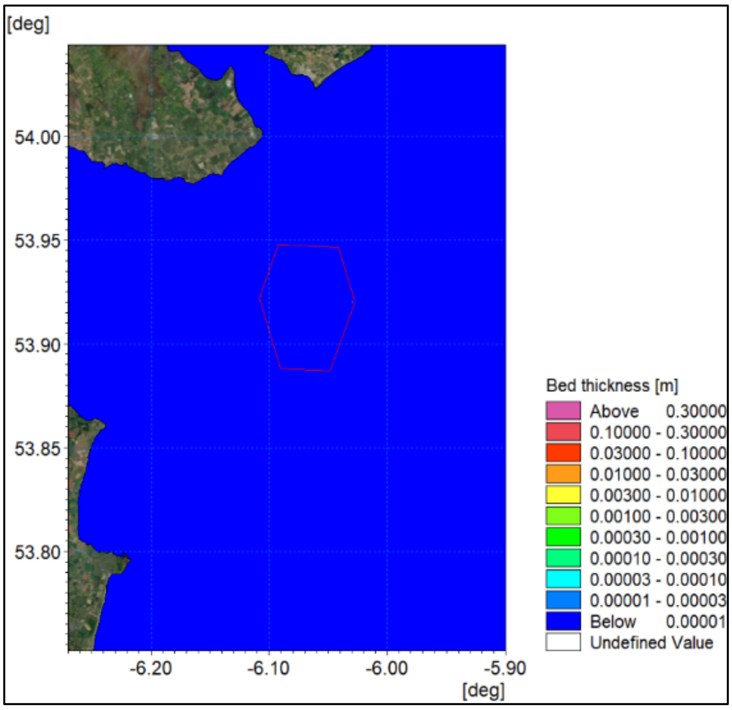

Figure 3-36: Average sedimentation at ORI-D05.

ORI-E02

ORI-E02 is positioned in the southwest of the offshore wind farm area at a shallow location where the tidal currents are lower, therefore the initial concentrations would be larger than those for the deeper sites. Figure

3-37 shows the maximum concentration in the left-hand plot, with plume extents and sediment concentrations being very similar to those associated with ORI-EO4.

Common to the other sites the sedimentation levels are seen to be very limited as Figure 3-38 and Figure 3-39 demonstrate for the range of sediment parameters.

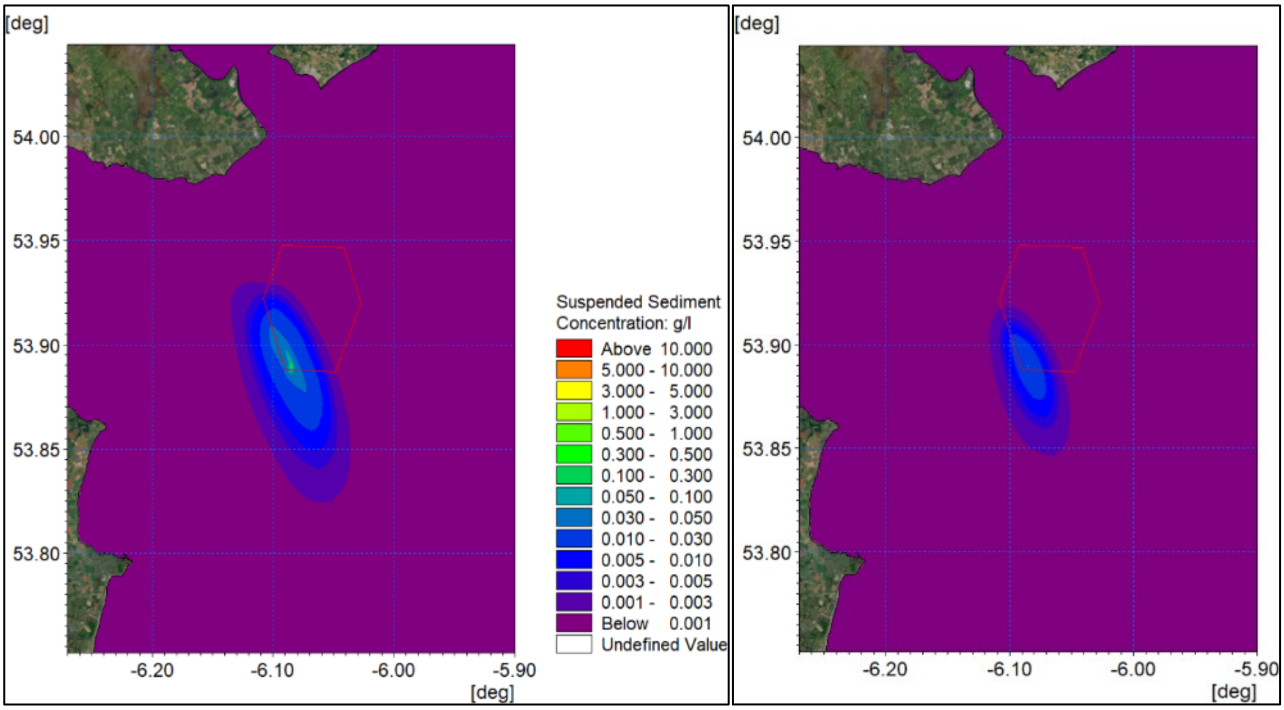

Figure 3-37: Maximum (left) and average (right) suspended sediment concentrations at ORI-E02.

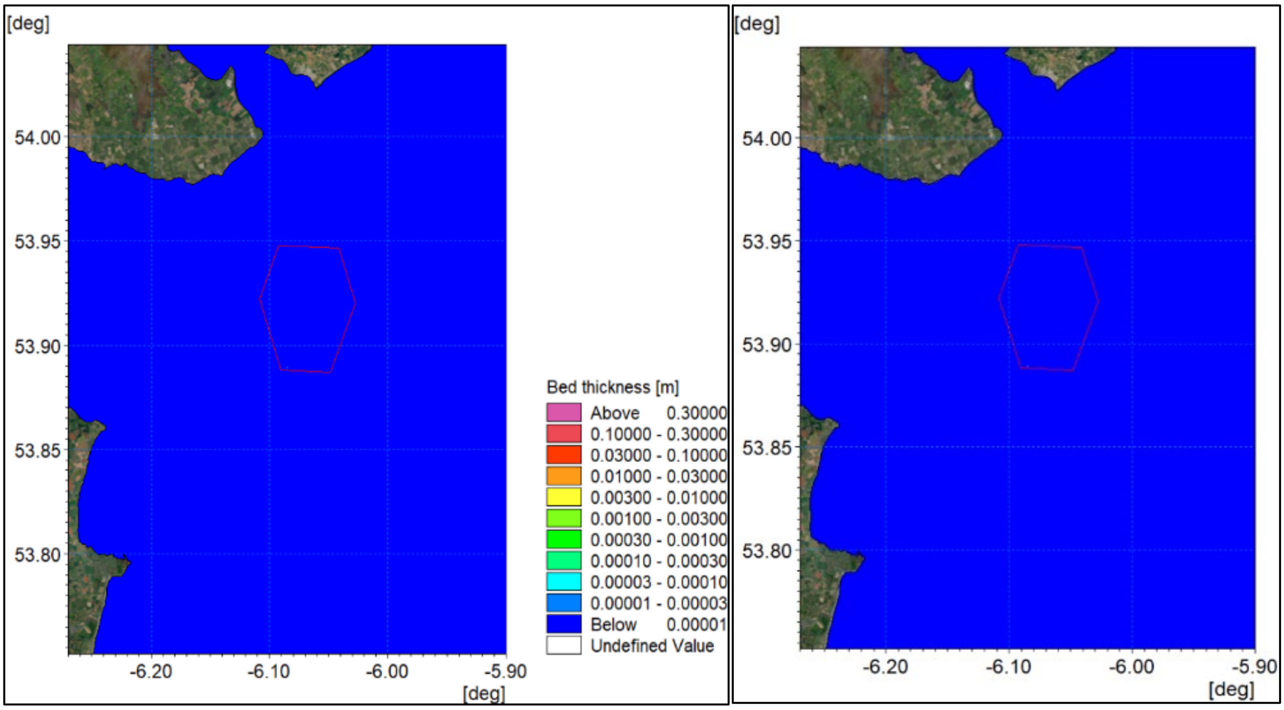

Figure 3-38: Final (left) and maximum (right) sedimentation at ORI-E02.

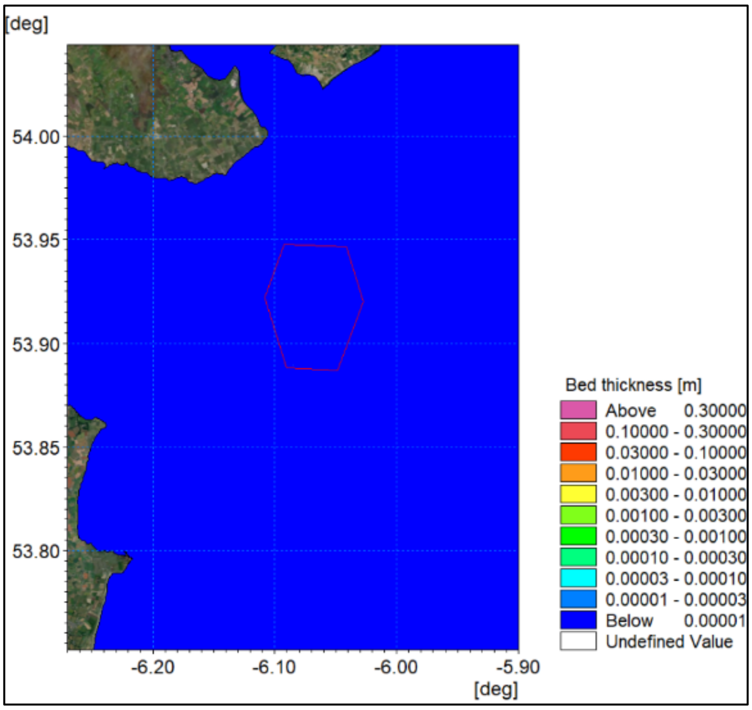

Figure 3-39: Average sedimentation at ORI-E02.

ORI-AO1

ORI-AO1 is located at the shallowest location within the offshore wind farm area. Figure 3-40 shows the maximum and average concentrations, it can be seen that the plume does reach the coastline at maximum sediment concentrations, with typical concentrations of 1.5 mg/l. It can however be seen from the average values (displayed in right plot) that this occurrence is infrequent.

Sedimentation levels are again limited as Figure 3-41 and Figure 3-42 demonstrate for the range of sediment parameters.

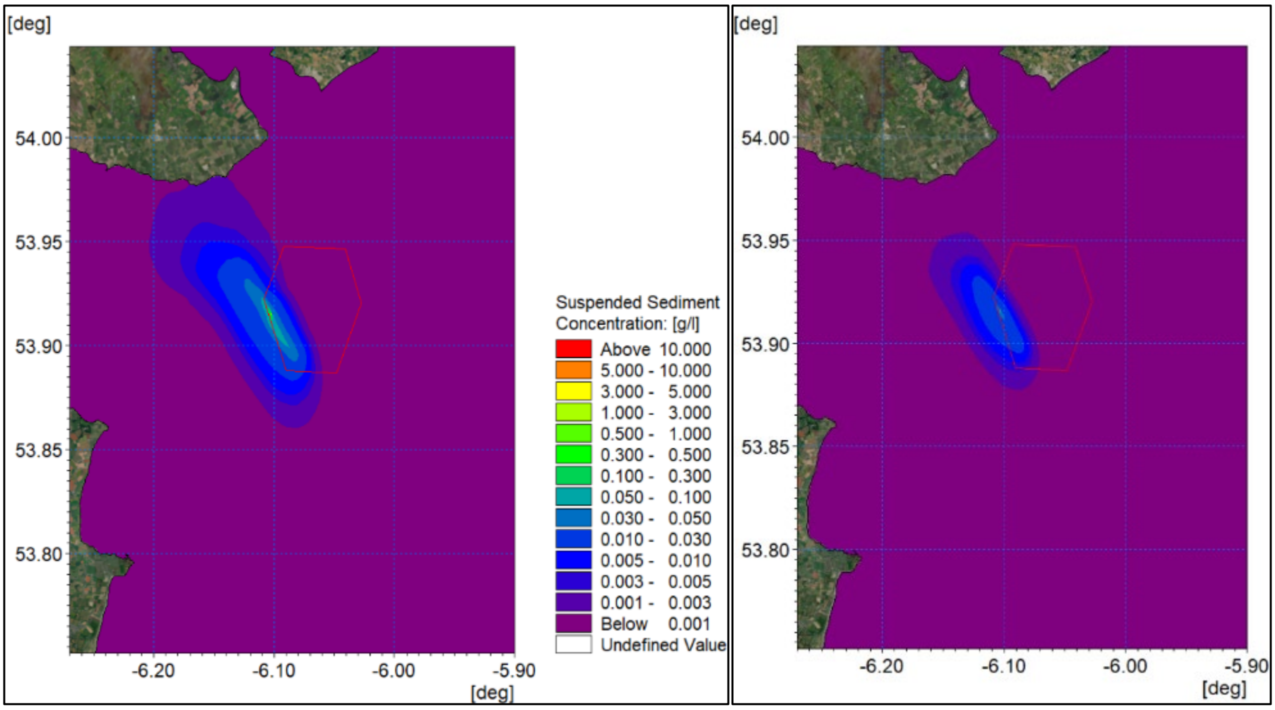

Figure 3-40: Maximum (left) and average (right) suspended sediment concentrations at ORI-AO1.

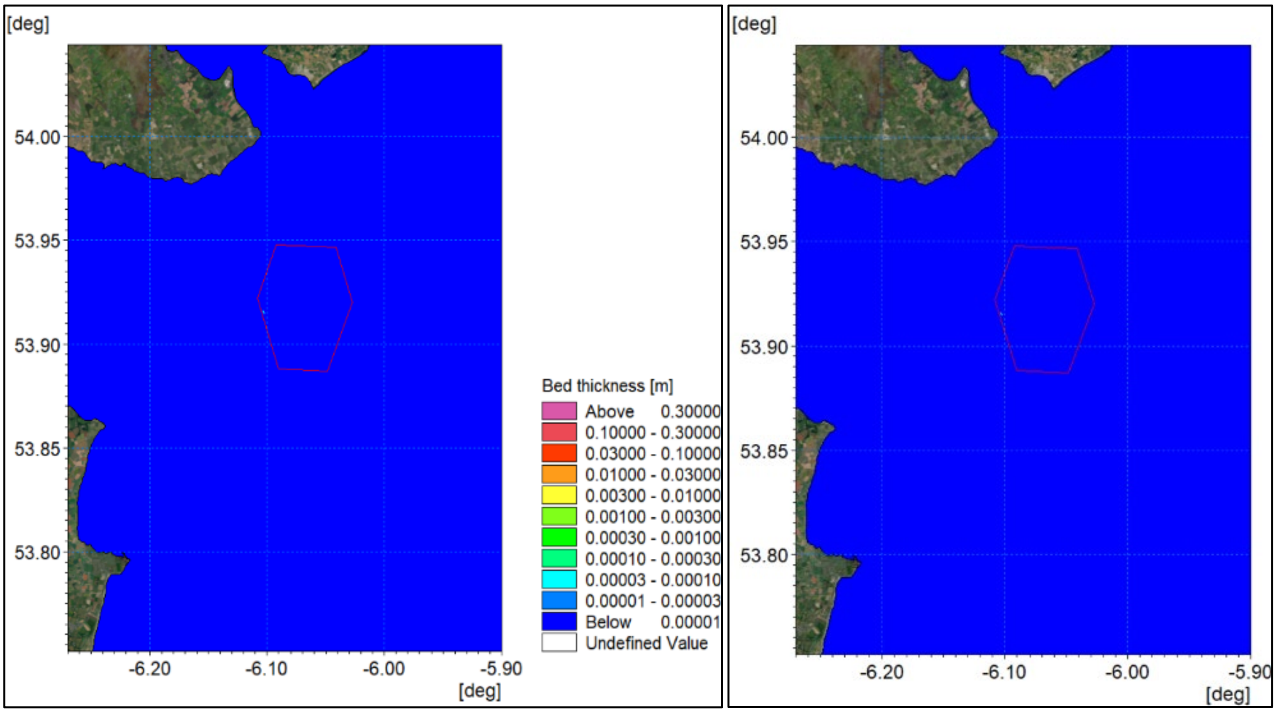

Figure 3-41: Final (left) and maximum (right) sedimentation at ORI-AO1.

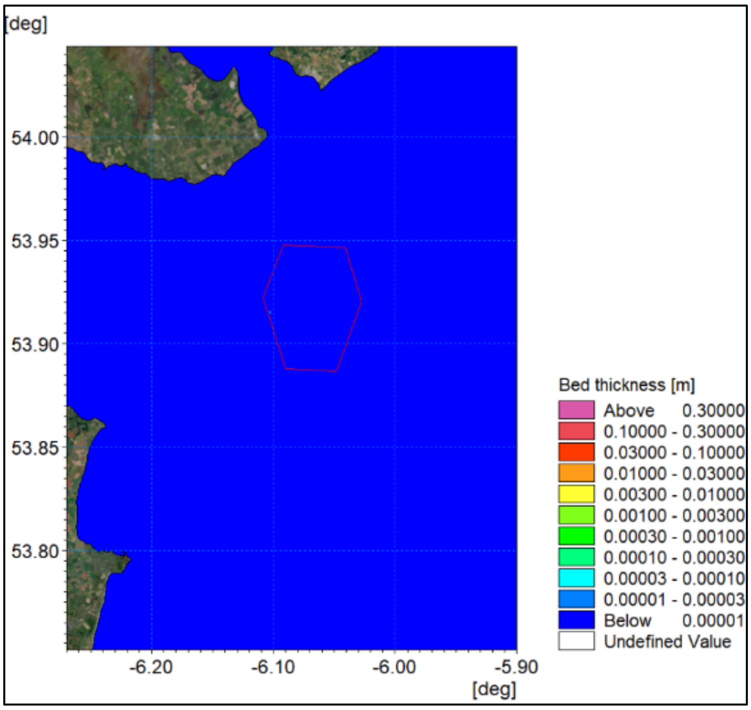

Figure 3-42: Average sedimentation at ORI-AO1.

ORI-A04

ORI-A04 is located at the northwest of the offshore wind farm area. This site presents the widest plume due to the circulatory nature of currents, and experiences landfall concentrations of around 3 mg/l. Again, average values are approximately an order of magnitude smaller than the maximum values.

For completeness the sediment data is presented in Figure 3-43 and Figure 3-44 for the final and maximum levels while Figure 3-45 shows the average value throughout the drilling campaign.

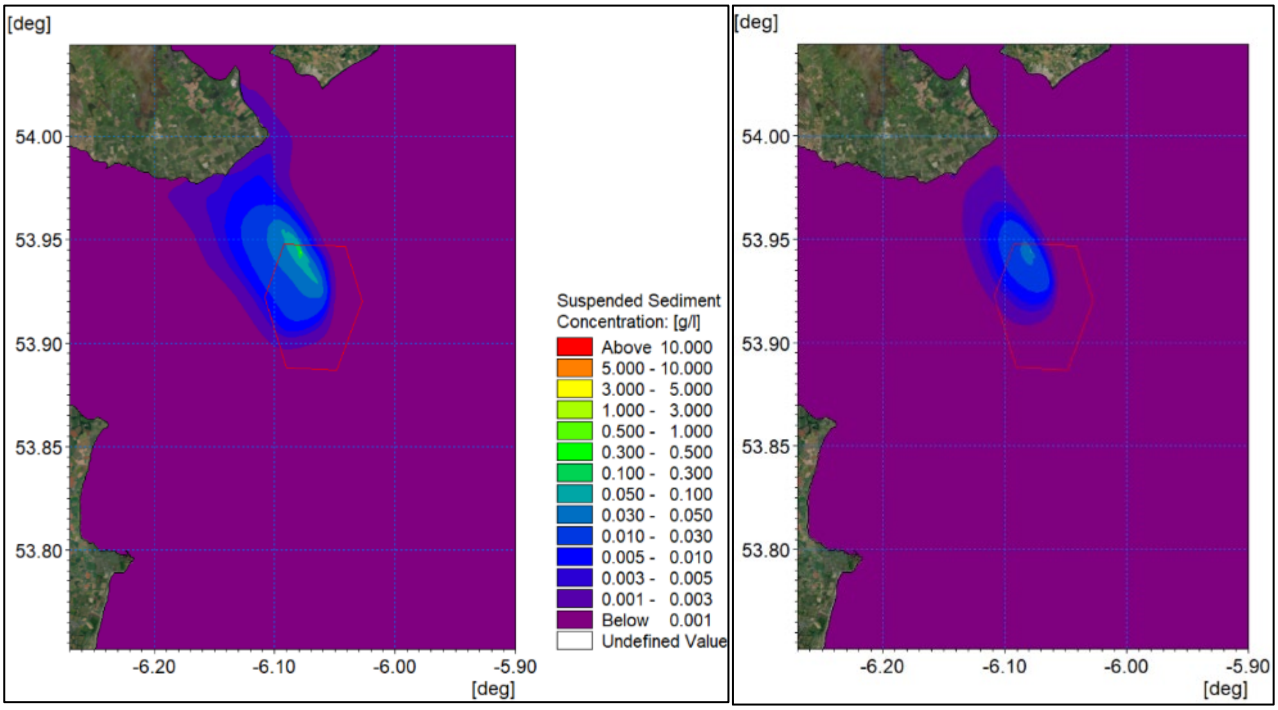

Figure 3-43: Maximum (left) and average (right) suspended sediment concentrations at ORI-AR4.

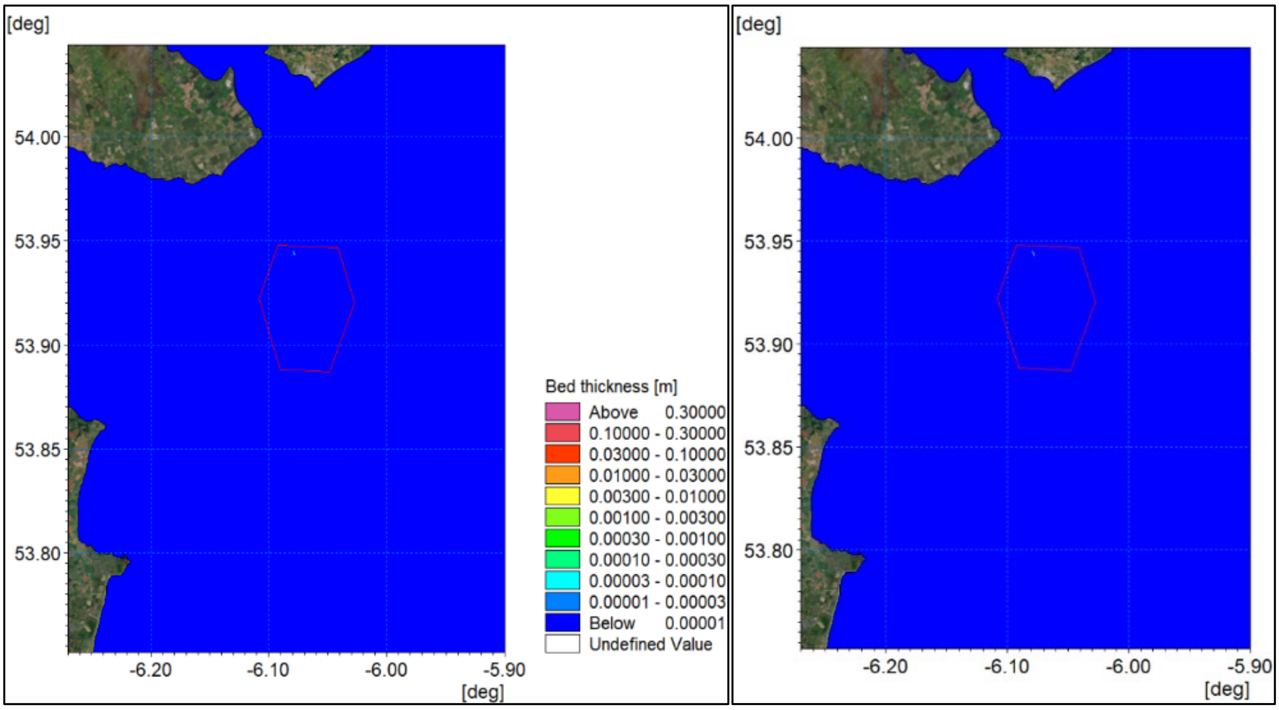

Figure 3-44: Final (left) and maximum (right) sedimentation at ORI-AR4.

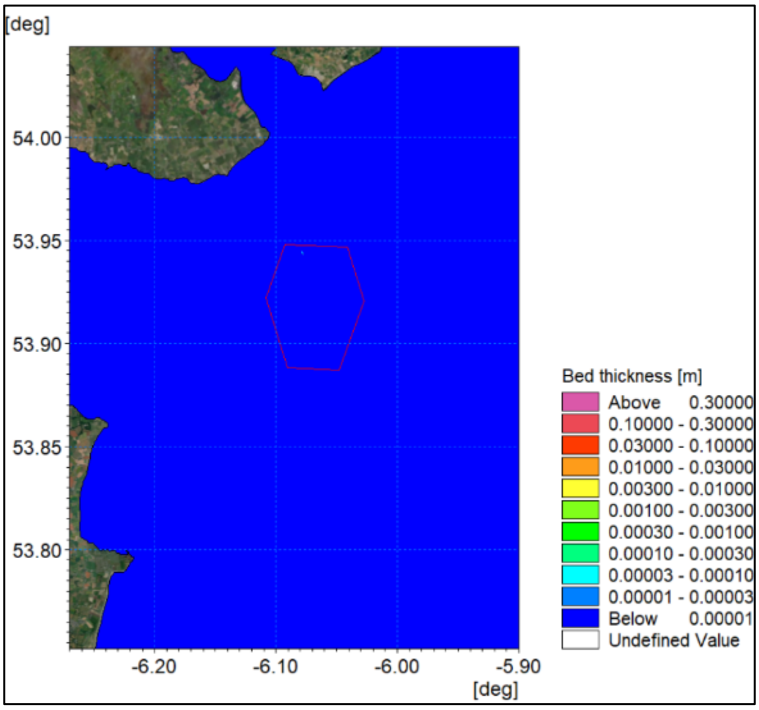

Figure 3-45: Average sedimentation at ORI-AR4.

ORI-B05

The final drill site modelled was ORI-B05 which is located at the northeast of the offshore wind farm area. As anticipated, the shape and magnitude of the concentration plumes shown in Figure 3-46 lie between that experienced for the ORI-A04 and ORI-D05 sites and demonstrates the relatively homogeneous nature of the offshore wind farm area.

For completeness the sediment data is presented in Figure 3-47 for the final and maximum levels while Figure 3-48 shows the average value throughout the drilling campaign.

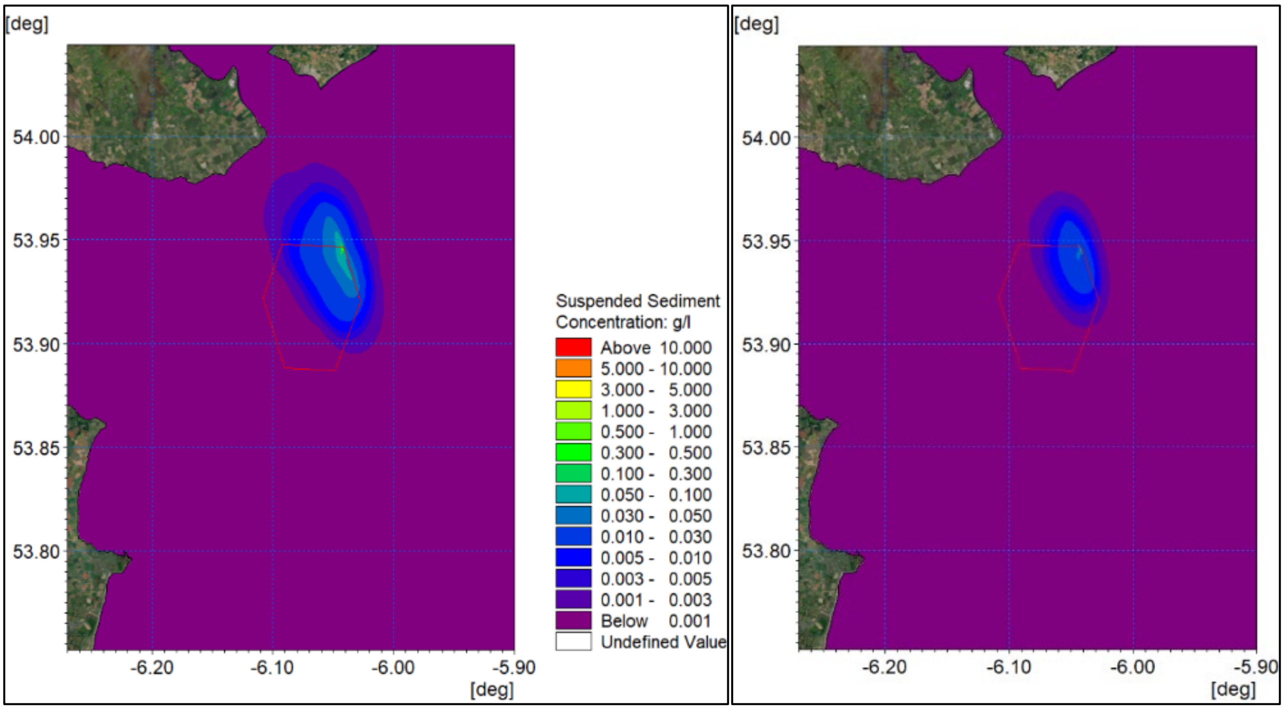

Figure 3-46: Maximum (left) and average (right) suspended sediment concentration at ORI-B05.

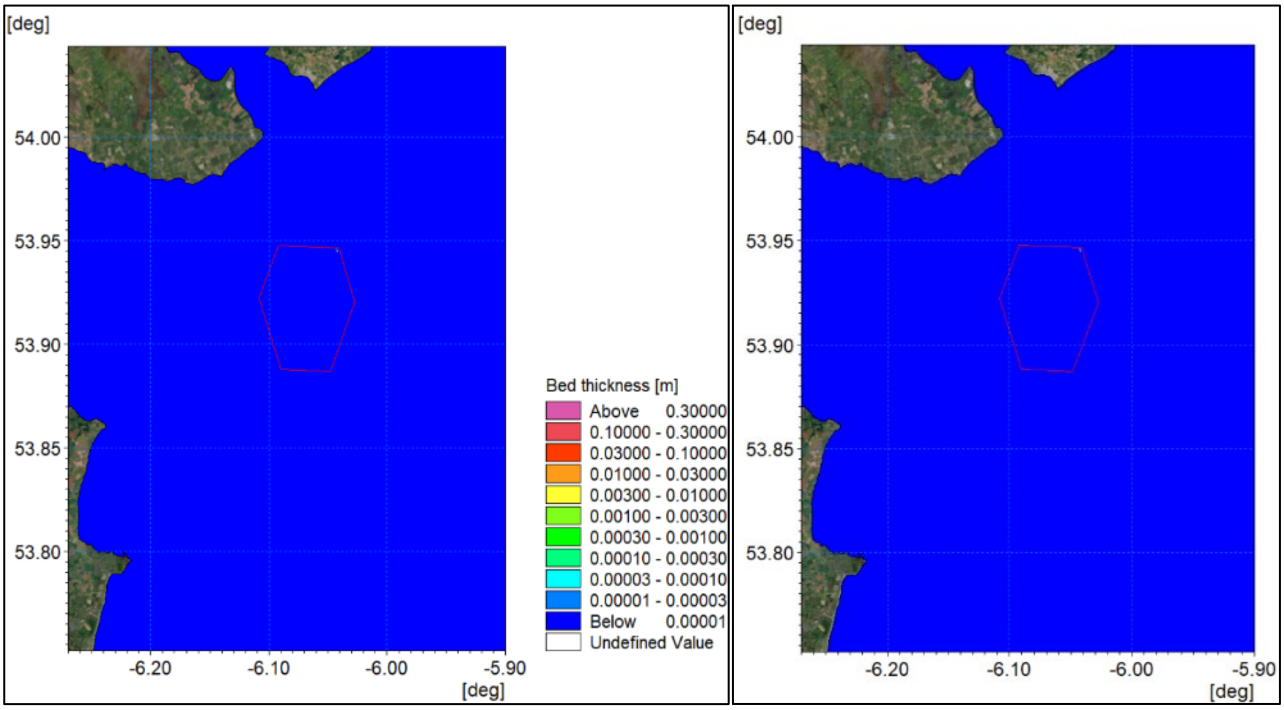

Figure 3-47: Final (left) and maximum (right) sedimentation at ORI-B05.

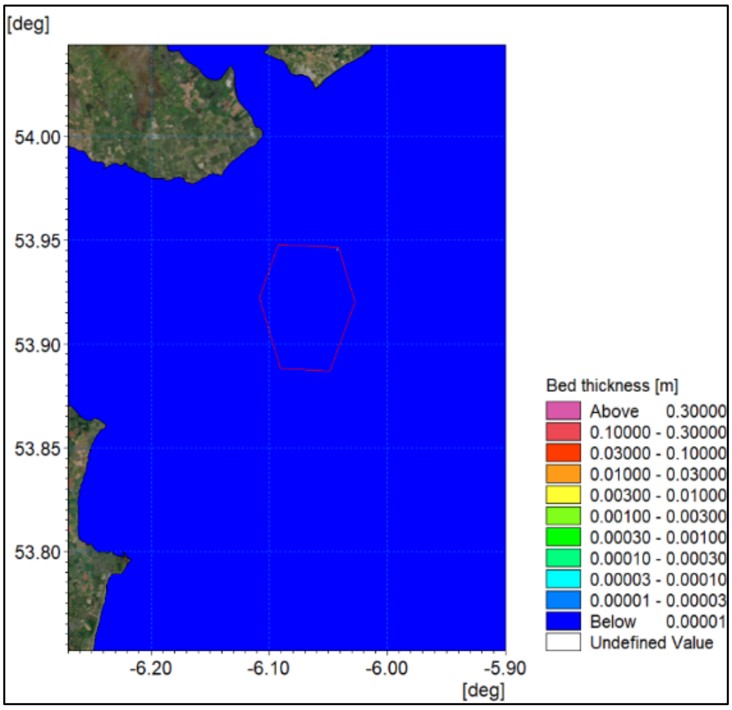

Figure 3-48: Average sedimentation at ORI-B05.

Cable Installation

Volume 2A chapter 5: Project Description presents the installation parameters for the inter-array cables and the offshore cable. Both cable types are to be installed to a depth of 3 m in an excavation 1 m wide for inter-array cables and 3 m wide for offshore cables; although cable laying equipment may disturb a surface width of 10 m.

For the purposes of this modelling assessment, it was assumed that a wedge of material (i.e. represented by the maximum width of 3 m at the surface and able to accommodate the maximum external cable diameter of 0.25 m and 0.35 m at the base for inter-array and offshore cables respectively) was mobilised into the lower water column as a result of the burial process in line with the guidelines (BERR, 2008).

Similarly, to pile installation, the model simulations used the sediment grading determined from sediment sampling. However, in this instance, the modelling was undertaken using the MIKE21 Particle Tracking (PT) module. This module was considered more applicable as sediment could be released at discrete points in the water column as opposed to being introduced on a depth averaged basis. In this way the dispersion would not be over-estimated, or the corresponding sedimentation underestimated by the application of a current profile through the water column.

Installation rates can vary widely depending on the seabed material and equipment used; typically, rates are between 25 m/h and 780 m/h. For the simulation a relatively low rate of 120 m/hour was used ensuring that material was released at all tidal states over a number of tides whilst not so low that release rates and initial concentrations were underestimated.

Inter-array cables

A consecutive section of cabling from the offshore substation (OSS) and between ORI-C01 and ORI-C05 as illustrated in Figure 3-49 was modelled for this assessment. This route was chosen as the sediment along this corridor has the greatest potential for mobilisation and thus dispersion. As noted above the Project design parameters includes for a trench of 3 m depth and 1 m in width at the seabed. The modelling assumed that a wedge of material was displaced and reintroduced at 1 m above the seabed, in line with the installation process.

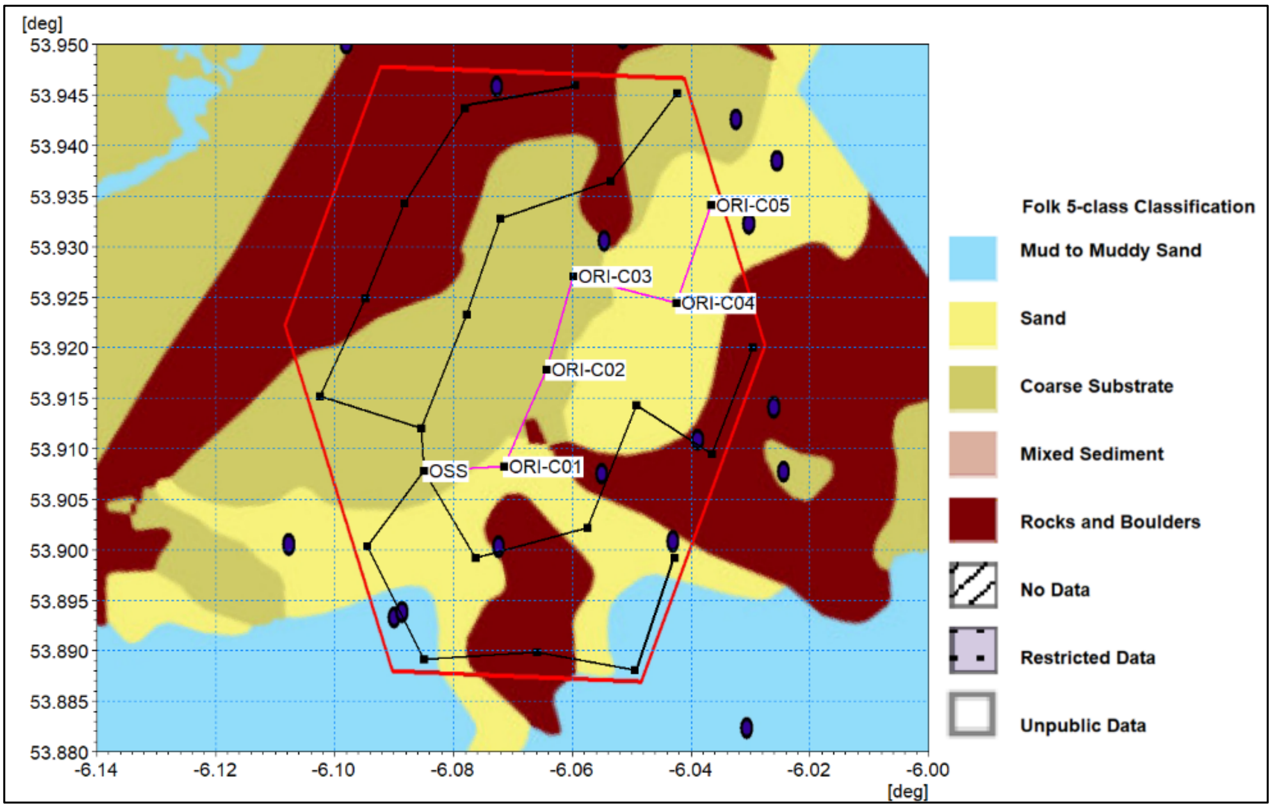

Figure 3-49: Location of the sediment source term (pink line) used to model a representative dredging route for the inter-array cables.

The GSI sampling data indicated the following sediment characteristics:

- 45% silt/clay 0.05 mm diameter;
- 15% sandy mud 0.1 mm diameter; and
- 40% medium sand 0.5 mm diameter.

The model results presented follow the same format as those for foundation installation described in the previous section. It should be noted that the maximum and average suspended sediment contour palette in Figure 3-50 has been accentuated using a log scale for clarity. The average values on the right are typically one tenth of the maximum value on the left. The sediment plumes are much smaller than those seen for the auger pile installation. The reason for this is twofold, firstly there is no fine bentonite material associated with the cable installation activities which was utilised in the foundation drilling process; and secondly the material is mobilised at the seabed where current speeds are significantly lower.

Maximum plume concentrations are around 2,000 mg/l but these values are not sustained, as average values are less than 3 mg/l which is comparable to background levels. The sediment plume will only persist for a maximum period of *c.* three hours in any location as the installation moves on and the tide turns. Following the completion of the works the turbidity levels return to background within several of tidal cycles. It would however be anticipated that spring tides following the works may mobilise and redistribute unconsolidated material which would then re-settle at later stages of the construction phase.

Figure 3-51 shows the final sedimentation levels one day after completion in the left hand plot whilst the maximum values are shown on the right. Figure 3-52 illustrates the average sedimentation. If these three plots are considered together it can be determined that the native seabed material settles close to where it is mobilised and remains *in situ* as these results are very similar. This would be expected as the baseline modelling indicated that sediment transport potential is limited across the offshore wind farm area.

The sedimentation is seen to be concentrated along the installation route as material effectively returns to the site from where it is disturbed. Beyond 50 m the sedimentation levels are in the order of 1 mm and at the offshore wind farm area boundary <1 mm and therefore indiscernible from the existing seabed sediment.

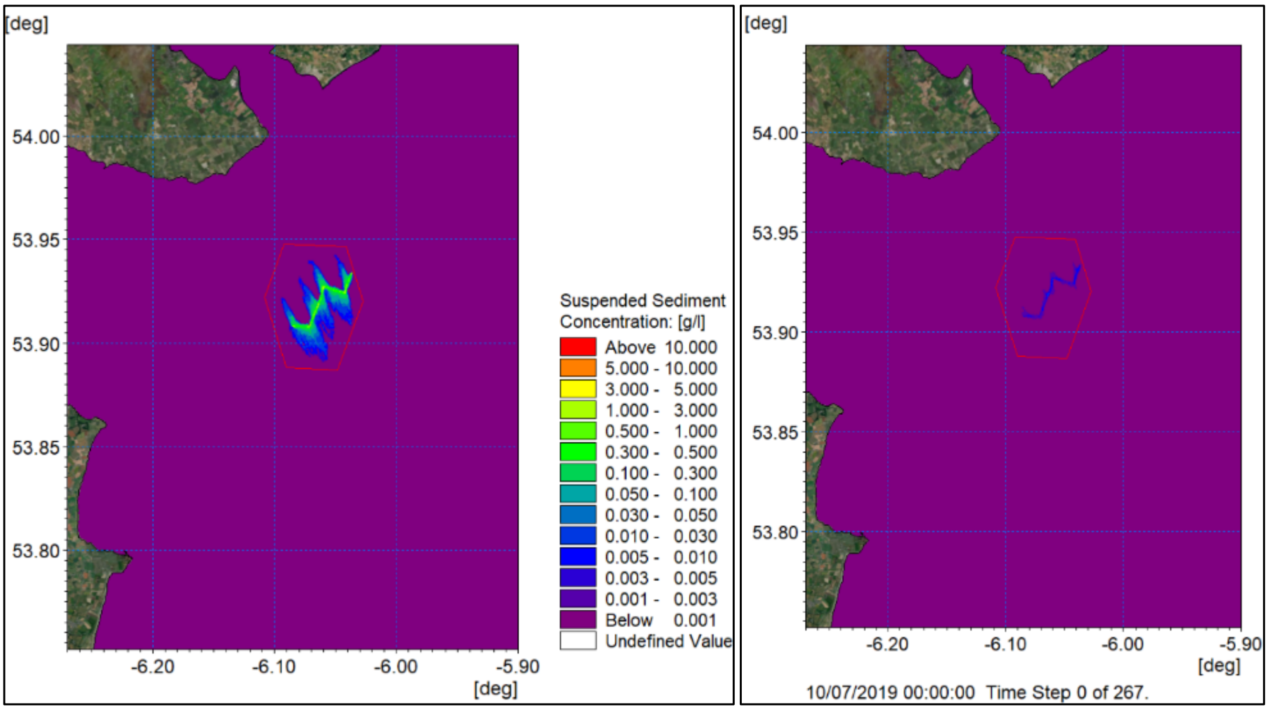

Figure 3-50: Maximum (left) and average (right) suspended sediment concentration for inter-array cable trench.

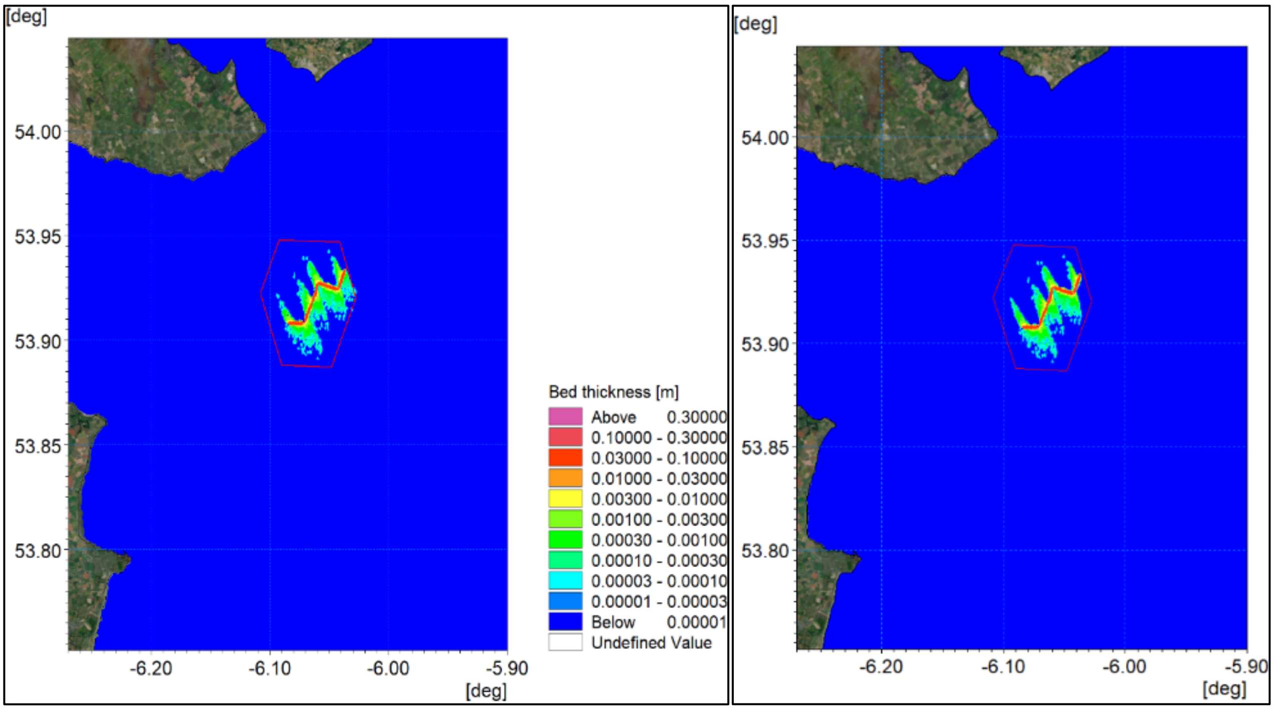

Figure 3-51: Final (left) and maximum (right) sedimentation for inter-array cable trenching.

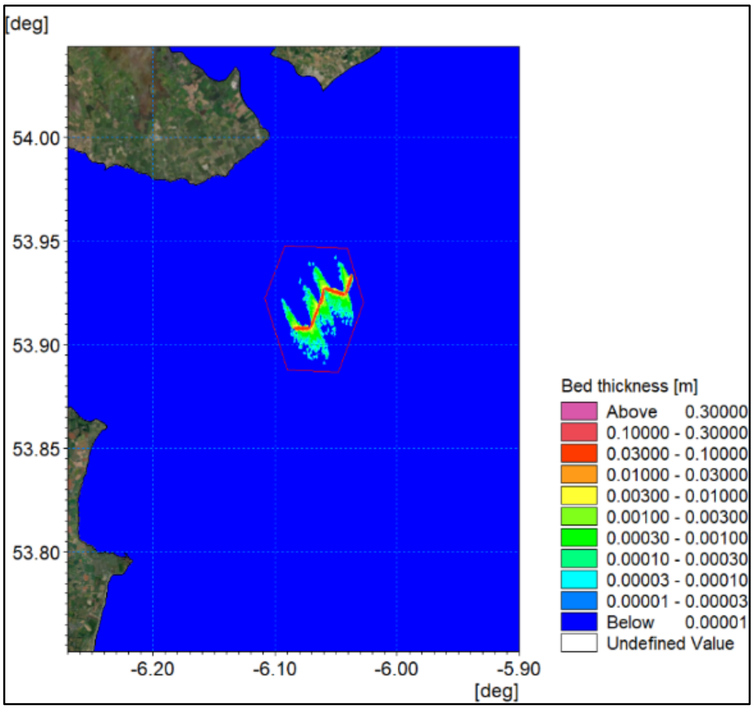

Figure 3-52: Average sedimentation for inter-array cable trenching.

Offshore Cable

Modelling was undertaken of the installation of the offshore cable between the OSS and the landfall location as indicated by the pink trace in Figure 3-53. As for inter-array cables, the Project design parameters include for a trench of 3 m depth and 3 m in width at the seabed. This was represented by a wedge of material being released into the lower water column as described in the previous section.

The modelling was undertaken with the sediment released along the full length of the offshore cable corridor, running offshore to inshore. The release continued through the intertidal zone to the High Water Mark, to represent the installation of the intertidal section of the cable by open trenching. The modelling assumed that this volume of material was displaced and reintroduced at 1 m above the seabed, in line with the installation process. The simulation assumed the same trenching rate as with the inter-array cables.

The GSI sampling data indicated the following sediment characteristics:

- 45% silt/clay 0.05 mm;
- 15% sandy mud 0.1 mm; and
- 40% medium sand 0.5 mm.

Figure 3-54 shows the suspended sediment plumes with a log scale to accentuate result for the maximum (left) and average (right) values. Nearshore tidal currents are stronger than those in the offshore locations and water depths are limited, therefore much higher suspended sediment levels would be expected in these areas. The sediment plume is seen to extend both north and south of the offshore cable corridor as it is dispersed by tidal flows.

Generally, peak values are around 300 mg/l which is akin to turbidity levels experienced during storm conditions. Towards the landfall these peaks increase due to the limited depth into which the material is dispersed. However, these areas are localised, and average concentrations are less than 50 mg/l. As with the inter-array cable scenario the plume does not remain stationary, and these elevated levels do not persist for more than three to four hours as material settles and the tide turns. Following completion of the work material would be re-suspended on successive tides and be drawn into the existing transport regime in nearshore regions.

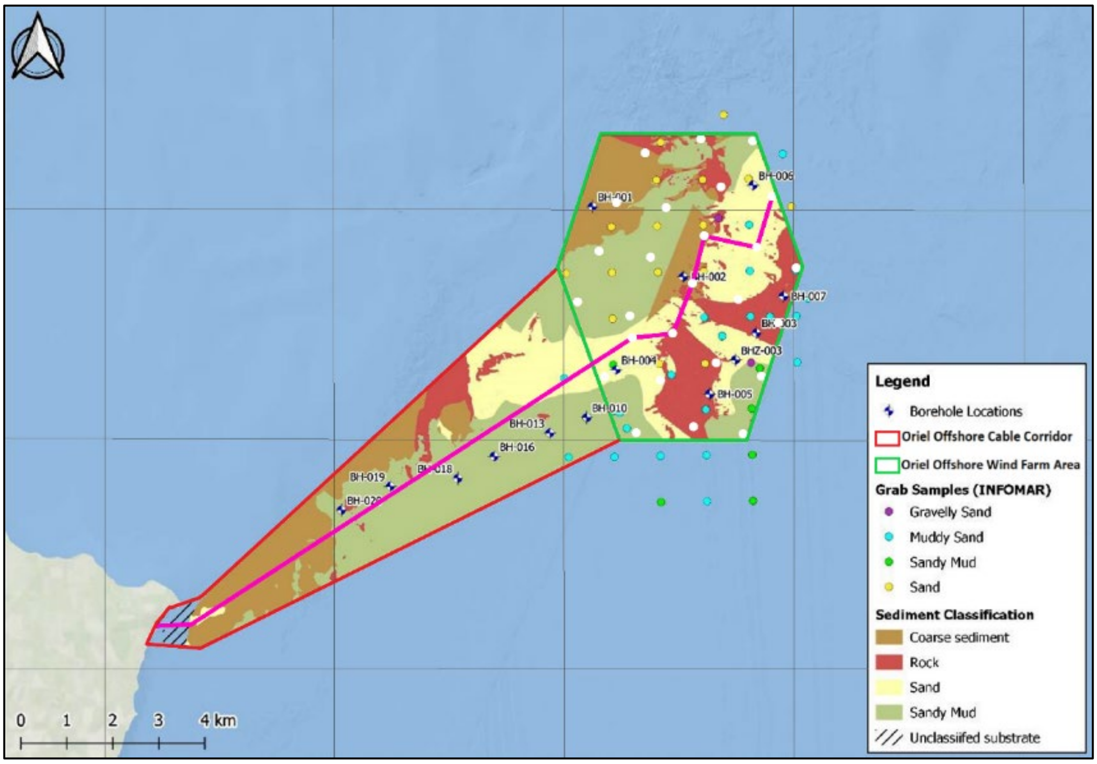

Figure 3-53: Location of modelled offshore cable corridor.

The left hand plot in Figure 3-55 shows the sediment thickness one day after completion of the cable installation. It demonstrates the influence of the eddy south of Dunany Head and how material will be incorporated into the existing transport patterns. The maximum values are shown on the right hand plot however, care must be taken when interpreting this data as material which is repeatedly settled on slack water and re-suspended may be double counted. Figure 3-56 shows the average sedimentation over the course of the cable installation.

The distribution of the sediment which is released during the operation is typically less than 20 mm in depth. Most material settles in the vicinity of the offshore cable corridor, within 200 m either side of the works, with final settled depth being less than 5 mm outside the offshore cable corridor. It should be noted that installation is continued through the intertidal zone and under calm conditions.

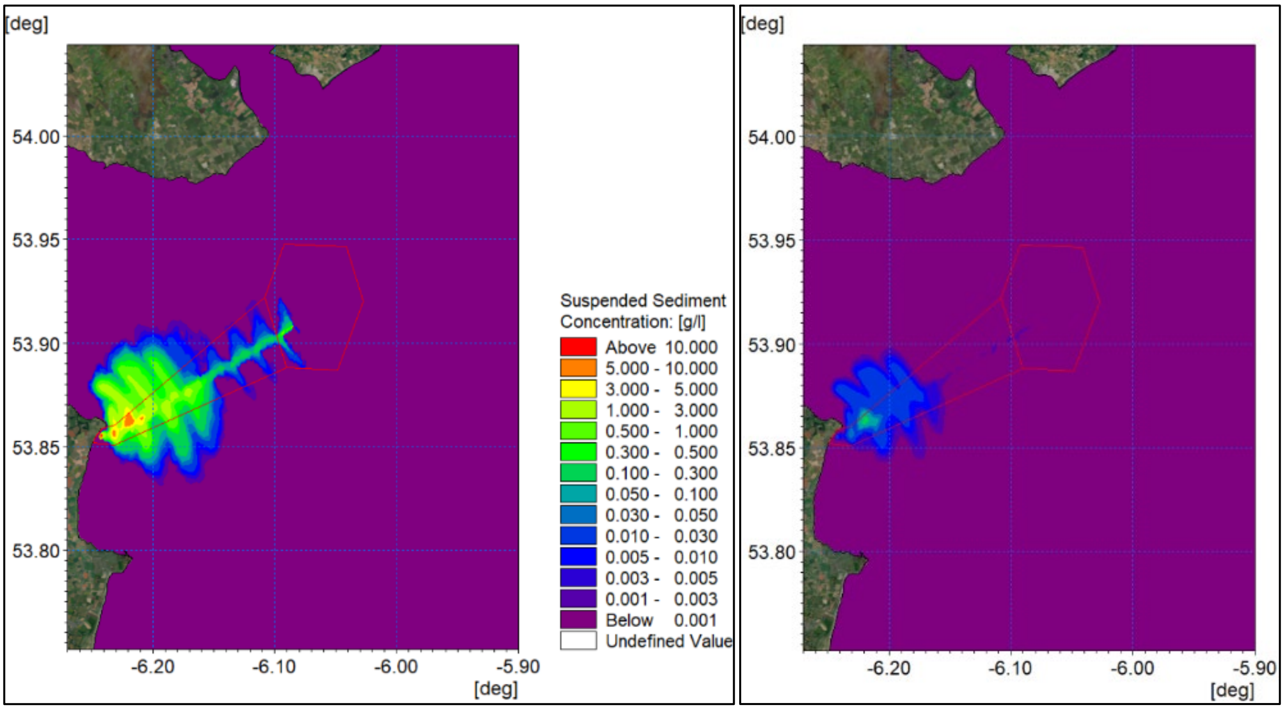

Figure 3-54: Maximum (left) and average (right) suspended sediment concentration for offshore cable jetting.

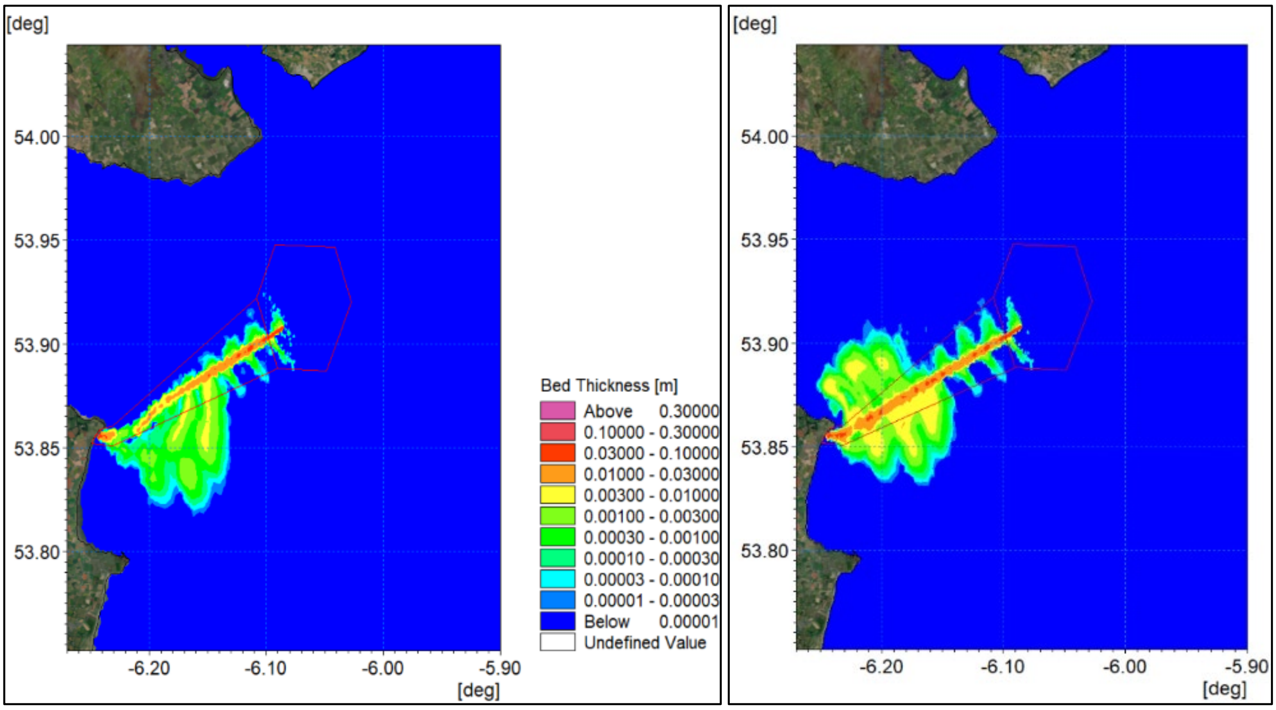

Figure 3-55: Final (left) and maximum (right) sedimentation for offshore cable jetting.

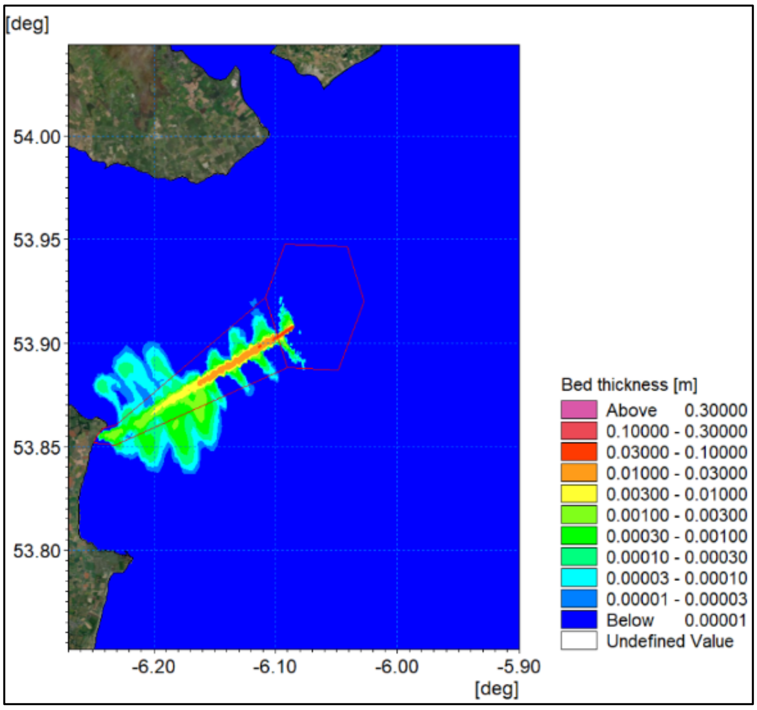

Figure 3-56: Average sedimentation for offshore cable jetting.

4 SUMMARY

This Technical Report has quantified the baseline marine processes that characterise the Marine Processes Study Area. This includes tidal current, wave climate and sediment transport under both calm and storm conditions. The numerical modelling has supported the theory that sediment transport in the offshore wind farm area is limited due to the reduced current speed and nature of the seabed material and sediment supply.

Numerical modelling has been used to quantify the changes in tidal currents, wave climate and sediment transport due to the installation of the Project. Results from this modelling programme demonstrated that the presence of the turbine and offshore substation foundation structures has little effect on tidal currents and sediment transport potential. Likewise, the installation of the foundations was found to marginally alter wave heights within the Marine Processes Study Area with little influence beyond the immediate vicinity of the offshore wind farm area.

Finally, suspended sediment plumes associated with foundation drilling and cable installation activities were quantified. In most cases the material released was native to the existing seabed and although average turbidity levels were found to increase for short periods of time during installation, the increased levels were comparable to those experienced during storm conditions. The material released nearshore was subsequently assimilated into the existing sediment transport regime.

The Project is therefore not expected to have a significant effect on marine processes or make a significant change to the existing sediment transport regime.

References

BERR (2008). Review of Cabling Techniques and Environmental Effects applicable to the Offshore Windfarm Industry. Technical Report, Department for Business Enterprise and Regulatory Reform (BERR), in association with Defra, 164pp.

CEFAS (2016) Suspended Sediment Climatologies around the UK.

Gavin Doherty Geosolutions (2020) Oriel Ground Model Update & Cable Route Interpretation. PARTRAC (2020) Oriel Wind Farm – Floating LiDAR Buoy 12 Month Measurement Campaign Data Report

Whitehouse, R.J.S., Sutherland, J. & O'Brian D., (2006), Seabed scour assessment for offshore windfarm, 3rd International Conference on Scour and Erosion, CURNET, Gouda, The Netherlands.