Outer Dowsing Offshore Wind Preliminary Environmental Information Report

Volume 2, Appendix 7.1: Marine Processes Technical Baseline

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OUTER DOWSING OFFSHORE WIND

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Abbreviations

Acronym	Expanded name
ANS	Artificial Nesting Structure
AWAC	Acoustic Wave And Current profiler
BGS	British Geological Survey
DCO	Development Consent Order
DECC	Department of Energy & Climate Change, now the Department for Energy Security and Net Zero (DESNZ)
DTI	Department of Trade and Industry
ECC	Export Cable Route
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
ES	Environmental Statement
ETWL	Extreme Total Water Level
GIG	Green Investment Group
GT R4 Ltd	The Applicant. The special project vehicle created in partnership between Corio Generation (a wholly owned Green Investment Group portfolio company), Gulf Energy Development and TotalEnergies
HADA	Humber Aggregate Dredging Association
HAT	Highest Astronomical Tide
HPMA	Highly Protected Marine Area
JNCC	Joint Nature Conservation Committee
LAT	Lowest Astronomical Tide
MAREA	Marine Aggregate Regional Environmental Assessment
MBES	Multibeam Echosounder
MHWS	Mean High Water Springs
MLWS	Mean Low-Water Springs
MSL	Mean Sea Level
NCERM2	National Coastal Erosion Risk Mapping
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
OWFL	Offshore Wind Farm Limited
PEIR	Preliminary Environmental Information Report
PSA	Particle Size Analysis
RCP	Representative Concentration Pathway
SAC	Special Area of Conservation
SBP	Sub-bottom Profiler
SNSSTS	Southern North Sea Sediment Transport Study
SPM	Suspended Particulate Matter
SSS	Side Scan Sonar
SSSI	Site of Special Scientific Interest
SWAN	Simulating Waves Nearshore
SWLB	Seawatch Wind Lidar Buoy
TCE	The Crown Estate

Acronym	Expanded name
TKOWFL	Triton Knoll Offshore Wind Farm Limited
UHRS	Ultra High Resolution Seismic
WTG	Wind Turbine Generator
ZoI	Zone of Influence

Terminology

Term	Definition
Array area	The area offshore within the PEIR Boundary within which the generating stations (including wind turbine generators (WTG) and inter-array cables), offshore accommodation platforms, offshore transformer substations and associated cabling are positioned.
Baseline	The status of the environment at the time of assessment without the development in place.
Cumulative effects	The combined effect of the Project acting cumulatively with the effects of a number of different projects, on the same single receptor/resource.
Cumulative impact	Impacts that result from changes caused by other past, present or reasonably foreseeable actions together with the Project.
Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for a Nationally Significant Infrastructure Project (NSIP) from the Secretary of State (SoS) for Business, Energy and Industrial Strategy (BEIS)
Effect	Term used to express the consequence of an impact. The significance of an effect is determined by correlating the magnitude of an impact with the sensitivity of a receptor, in accordance with defined significance criteria.
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Directive and EIA Regulations, including the publication of an Environmental Statement (ES).
EIA Regulations	Infrastructure Planning (Environmental Impact Assessment) Regulations 2017.
Environmental Statement (ES)	The suite of documents that detail the processes and results of the EIA.
Impact	An impact to the receiving environment is defined as any change to its baseline condition, either adverse or beneficial.
Intertidal	Area where the ocean meets the land between high and low tides.
Landfall	The location at the land-sea interface where the offshore export cable will come ashore.-
Offshore Export Cable Corridor (ECC)	The Offshore Export Cable Corridor (Offshore ECC) is the area within the Preliminary Environmental Information Report (PEIR) Boundary within which the export cable running from the array to landfall will be situated.
Offshore Substation (OSS)	Platforms located within the array area which house electrical equipment and control and instrumentation systems. They also provide access facilities for work boats and helicopters.

Term	Definition
Preliminary Environmental Information Report (PEIR)	The PEIR is written in the style of a draft Environmental Statement (ES) and provides information to support and inform the statutory consultation process in the pre-application phase. Following that consultation, the PEIR documentation will be updated to produce the Project's ES that will accompany the application for the Development Consent Order (DCO).
Receptor	A distinct part of the environment on which effects could occur and can be the subject of specific assessments. Examples of receptors include species (or groups) of animals or plants, people (often categorised further such as 'residential' or those using areas for amenity or recreation), watercourses etc.
PEIR Boundary	The PEIR Boundary is outlined in Figure 3.1 of Volume 1, Chapter 3: Project Description and comprises the extent of the land and/or seabed for which the PEIR assessments are based upon.
The Applicant	GT R4 Ltd. The Applicant making the application for a DCO. The Applicant is GT R4 Limited (a joint venture between Corio Generation, TotalEnergies and Gulf Energy Development (GULF)), trading as Outer Dowsing Offshore Wind. The project is being developed by Corio Generation (a wholly owned Green Investment Group portfolio company), TotalEnergies and GULF.
The Inspectorate	Planning Inspectorate. The agency responsible for operating the planning process for Nationally Significant Infrastructure Projects (NSIPs).
The Project	Outer Dowsing Offshore Wind including proposed onshore and offshore infrastructure.
Wind Turbine Generator (WTG)	All the components of a wind turbine, including the tower, nacelle, and rotor.

7 Marine Processes Technical Baseline

7.1 Introduction

7.1.1 This technical report provides a detailed baseline description of Marine Processes in relation to the Outer Dowsing Offshore Wind Farm (“the Project”). Specifically, this report considers Marine Processes seaward of Mean High Water Springs (MHWS), which for the purposes of both this technical report and the subsequent Offshore Environmental Impact Assessment (EIA) Report, include the following elements:

- Morphology, including bathymetry, geology, surficial sediments and seabed form;
- Hydrodynamics, including tidal and non-tidal influences, and waves; and
- Sediment transport, including bedload, littoral and suspended sediment transport.

7.1.2 GT R4 Limited (trading as Outer Dowsing Offshore Wind) hereafter referred to as the ‘Applicant’, is proposing to develop the Project. The Project will include both offshore and onshore infrastructure including an offshore generating station (windfarm), export cables to landfall, onshore cables, and connection to the electricity transmission network, and ancillary and associated development.

7.1.3 This baseline description sets out the ‘conceptual understanding’ of the marine and coastal system in which the Project is located and describes how the processes operating within this system link together and evolve in response to applied natural and anthropogenic forces. This understanding underpins the assessments of potential impacts resulting from the Project (Volume 1, Chapter 7: Marine Processes).

7.2 Purpose

7.2.1 The primary purpose of this report is to provide a contemporary and comprehensive analysis of site-specific and regional Marine Processes data within the study area. This Preliminary Environmental Information Report (PEIR) document has been produced to support the statutory consultation process with local communities, statutory bodies, regulators and other interested parties. Following the completion of pre-application consultation, the Environmental Statement (ES) will be finalised and submitted alongside the application to The Inspectorate for a Development Consent Order (DCO).

7.2.2 The remainder of this report is structured in the following way:

- Definition of the study area;
- Outline of the data sources used to inform the characterisation;
- A review of the baseline (existing) conditions of the study area; and
- Identification of Designated Sites of relevance to Marine Processes.

7.2.3 This document will accompany Volume 1, Chapter 7 and should be read in conjunction with Volume 2, Appendix 7.2: Marine Processes Modelling Report.

7.3 Scope and Methodology

Study Area

7.3.1 The baseline description of the Marine Processes environment provides a regional (far-field) overview prior to focusing on the study area. This PEIR recognises the different types of project activities and marine processes present within the study area. As such descriptions are provided for the following sub-areas:

- Offshore array (including Wind Turbine Generators (WTGs), Offshore Substation Platforms (OSPs) inter-array cables and interlink cables);
- Offshore export cable route (ECC);
- Landfall; and
- Compensation areas, including search areas for Artificial Nesting Structures (ANS) and biogenic reef restoration (Figure 7.1).

7.3.2 Of note is that the offshore ECC includes the transition from offshore to nearshore marine process environmental conditions.

7.3.3 A presentation of the study area is given in Figure 7.1. These areas include buffer zones to represent a potential "Zone of Influence (ZoI)" for impacts that might be created within the main areas of activity. The buffer zones are scaled to conservatively represent the equivalent distance of tidal excursion on a mean spring tide and comprise a distance of between, approximately, 10km and 15km.

Data Sources

7.3.4 The following project specific surveys have been used to characterise the seabed and oceanographic conditions within the array and within the offshore ECC:

- Geophysical survey: carried out with an Ultra High Resolution Seismic (UHRS), multibeam echosounder (MBES), side scan sonar (SSS), and sub-bottom profiler (SBP).
- Benthic survey: including drop down camera data and grab samples to allow a characterisation of the seabed features and sediment composition. The survey additionally included sediment Particle Size Analysis (PSA) and contaminant analysis using the grab samples.
- Metocean measurements: including wave, wind and current measurements from a Seawatch Wind Lidar Buoy (SWLB) deployed within the array area. Monthly datasets are currently available from April 2022 to November 2022, and further data will be submitted as part of the ES.
- Metocean preliminary design criteria: including modelled wind, wave, and hydrodynamic (currents and water levels) data.
- Desk-based geological and geotechnical survey: including the use of client-issued and publicly available data to establish the likely ground conditions and create a preliminary ground model of the area in order to provide recommendations for future site surveys.

7.3.5 Where relevant, survey data from other Offshore Wind Farms (OWFs) and marine industries have been used to support the characterisation of the Marine Process environment. This includes:

- Race Bank OWF (Centrica, 2009) and associated surveys;
- Triton Knoll Offshore Wind Farm (Triton Knoll Offshore Wind Farm Limited (TKOWFL , 2011; 2012; 2014; 2015) and associated surveys; and
- Dudgeon and Sheringham Shoal Extensions (Equinor, 2022) and associated surveys.

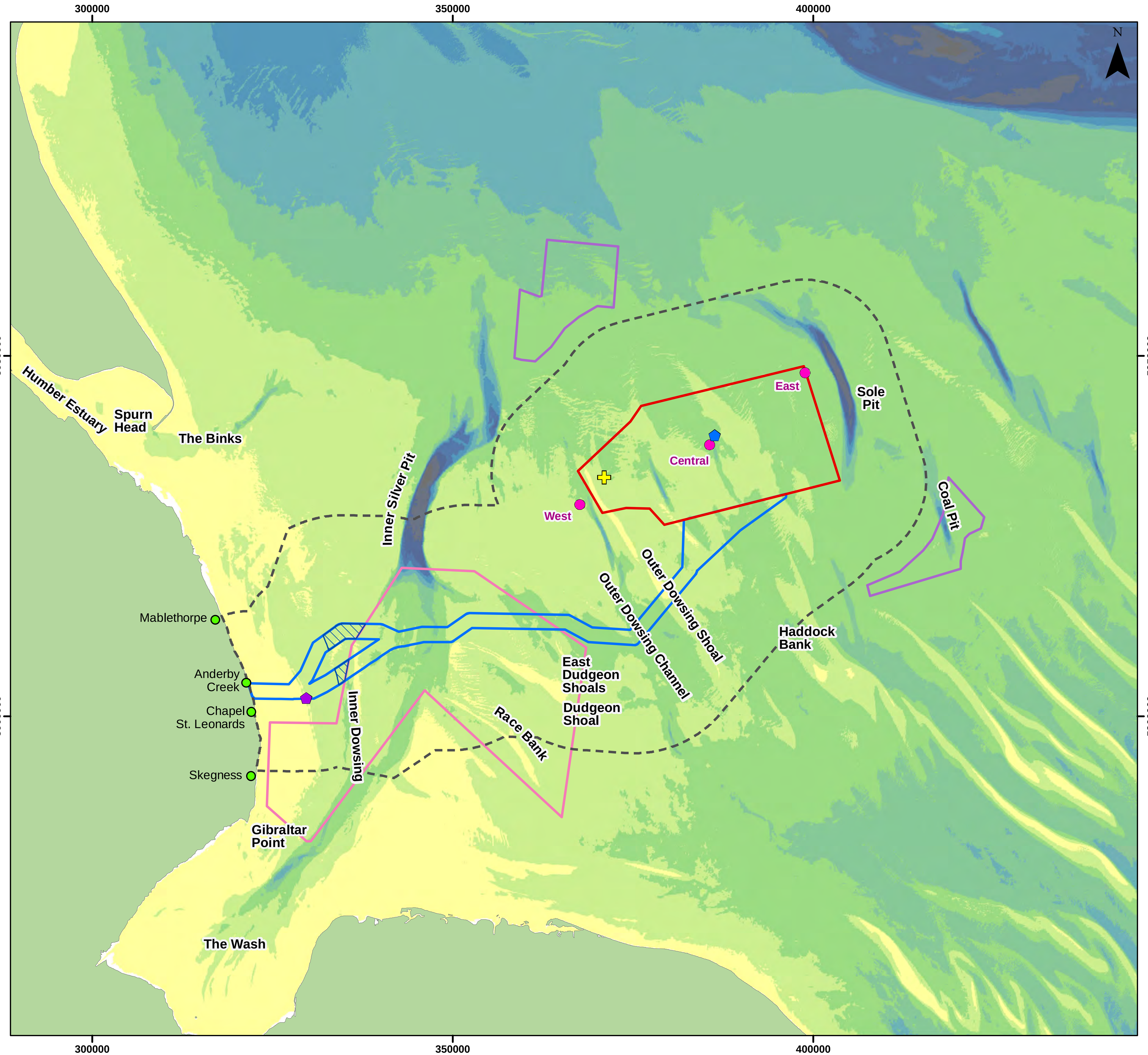
7.3.6 The age of data has been taken into account, with caution afforded to datasets older than five years old, although they have been considered within the baseline description where relevant. Comprehensive coverage of the project specific surveys within both the array area and ECC is such that data from other sources is not heavily relied upon to fill data gaps.

Table 7.1: Key sources of information for marine processes

Source	Summary	Spatial Coverage
Generic		
Marine Aggregate Regional Environmental Assessment (MAREA) of the Humber and Outer Wash Region (Humber Aggregate Dredging Association (HADA), 2012)	Regional characterisation of geology, morphology, surficial sediments, coastal processes, and hydrodynamics.	Partial coverage
Triton Knoll Offshore Wind Farm (OWF) Environmental Statement (ES) and associated technical reports (TKOWFL, 2011; 2012; 2014; 2015)	Regional and site-specific characterisation of geology, morphology, surficial sediments, coastal processes and hydrodynamics, including survey and model outputs.	Partial coverage
Race Bank OWF ES and associated technical reports (Centrica, 2009; EMU and Osiris, 2008)	Regional and site-specific characterisation of geology, morphology, surficial sediments, coastal processes and hydrodynamics, including survey and model outputs.	Partial coverage
Dudgeon and Sheringham Shoal Extensions ES and associated technical reports (Equinor, 2022)	Regional and site-specific characterisation of geology, morphology, surficial sediments, coastal processes and hydrodynamics, including survey and model outputs.	Partial coverage
The Humber Regional Environmental Characterisation Source: Tappin *et al.* (2011)	Physical processes, bathymetry, morphology and geology off the east coast of England.	Partial coverage
Offshore Energy Strategic Environmental Assessment 3 (OESEA3) Environmental Report (Department of	Regional characterisation of geology, morphology, surficial	Partial coverage

Source	Summary	Spatial Coverage
Energy and Climate Change (DECC), 2016)	sediments, coastal processes, and hydrodynamics.	
Metocean Data		
Atlas of UK Marine Renewable Energy Resources. Source: UK Renewables Atlas - ABPmer (www.renewables-atlas.info) (ABPmer *et al.*, 2008)	Low resolution modelled hindcast wave, wind and hydrodynamic data. Summary data provided only.	Full coverage
SEASTATES Metocean Data and Statistics Interactive Map (ABPmer, 2018) Source: www.seastates.net/	Modelled hindcast wave and hydrodynamic data.	Full coverage
Cefas WaveNet data Source: www.cefas.co.uk/cefas-data-hub/wavenet/	Wave records from point locations, including Chapel Point and Dowsing.	Partial coverage
Project Metocean Design Criteria (MetOceanWorks, 2021a; 2021b; 2021c; 2021d)	Numerical modelling to inform design criteria.	Partial coverage; array area but ECC not included
SWLB Metocean Measurements	Wave, wind and current data from Project array area between April and November 2022.	Partial coverage
Morphology and Sediment Transport		
Southern North Sea Sediment Transport Study Phase 2 (SNSSTS II) Source: HR Wallingford *et al.* (2002)	Information on observed and modelled littoral and seabed sediment transport.	Partial coverage
British Geological Society (BGS) Offshore GeoIndex Map Source: www.bgs.ac.uk/GeoIndex/offshore.htm	Seabed sediment maps (based on Folk classification) and borehole records from point locations. Data gaps exist in the coastal zone.	Full coverage
Cefas Suspended Sediment Climatologies around the UK	Monthly and seasonal Suspended Particulate Matter (SPM) maps.	Full coverage
Department of Trade and Industry (DTI) Technical Report: Sandbanks, sand transport and offshore windfarms Source: Kenyon and Cooper (2005)	Detail on offshore and littoral sediment transport, including morphological form and behaviour of offshore sandbanks.	Partial coverage
European Marine Observation and Data Network (EMODnet) Bathymetry Data (EMODnet, 2020)	Interactive bathymetry map.	Full coverage
Anglian Regional Coastal Monitoring Programme and associated reports (Environment Agency, 2011; 2013a; 2013b; 2019a; 2019b; 2021)	Monitoring data to inform coastal characteristics and change, including topographic survey data,	Partial coverage

Source	Summary	Spatial Coverage
Source: https://coastalmonitoring.org/anglian/	aerial imagery and oceanographic data.	
Project-specific geophysical survey (Enviros, 2022)	Geophysical survey using UHRS, MBES, SSS, and SBP.	Partial coverage; array area but ECC not included
Project-specific benthic surveys: Benthic Ecology OWF Area Results Report (Vol. 1) (GEOxyz, 2022a) and Benthic Ecology ECC Area Results Report (Vol. 2) (GEOxyz, 2022b)	Benthic sediment grab samples including PSA at locations within the array areas and offshore ECC.	Full coverage
Outer Dowsing Desktop Study and Preliminary Ground Model (Cathie, 2021)	Desk-based geological and geotechnical survey to provide recommendations for future site surveys.	Full coverage
Future Changes		
UK Climate Projections Science Report: UKCP18 Marine report. Source: Palmer et al. (2018)	Sea level rise predictions for coastal locations.	Partial coverage
UK FUTURECOAST Project (Defra, 2002)	Sea level rise predictions for coastal locations and assessments of shoreline behaviour.	Partial coverage

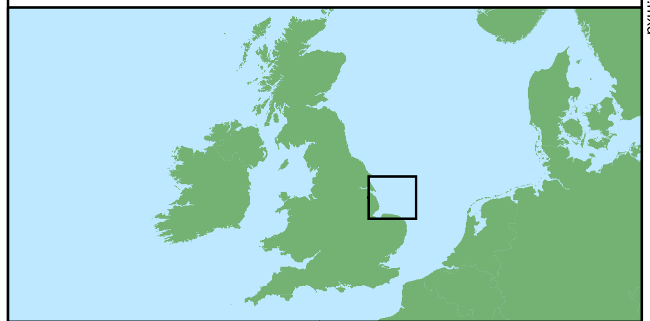


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence
- Cefas Dowsing WaveNet Site
- Chapel Point Directional Waverider Buoy
- Lidar Buoy SWLB059
- Metocean Modelling Points

Depth (m)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:500,000

Preliminary Environmental Information Report

Marine Physical Processes Study Area

Figure 7.1

OUTER DOWSING OFFSHORE WIND

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7.4 Baseline Environment

Metocean

7.4.1 This section provides an overview of the influences of tidal, non-tidal and wave processes on the study area.

Waves

7.4.2 Wave-energy is dependent on the friction action of the wind on the sea surface that drives directional sea-surface and storm surge currents. These in turn drive non-directional rotational near-bed currents when wind and swell waves interact with the seabed (Tappin *et al.*, 2011). The wave regime frequently plays an important role in the erosion, transport and deposition of sediments, although its influence on the seabed can be unpredictable due to changes in wind patterns and variation in bathymetry (HADA, 2012b).

7.4.3 Prevailing winds within the study area originate predominantly from the south-southwest, although waves from this direction have a notably limited fetch and are unlikely to develop into large waves by the time they reach the array area. The study area is therefore mainly dominated by waves generated within the North Sea basin, with long fetch generated from the northerly and north-easterly sectors (TKOWFL, 2011). In the offshore region wind and swell dominate the character of the waves, and as waves travel into shallower water interaction with the seabed causes shoaling, refraction, and eventually breaking (HADA, 2012b). The wave climate closer to the shore is complex as a result of refraction and sheltering effects associated with sandbanks and the coast, which have a focusing effect on incoming waves (TKOWFL, 2015).

Offshore Array

7.4.4 The wave climate within the Project array area has been characterised generally using regional-scale information from the UK Atlas of Marine Renewable Energy Resources (ABPmer *et al.*, 2008), as well as hindcast data from ABPmer's SEASTATES database (ABPmer, 2018). This is supported by data from project-specific metocean design criteria, which used a bespoke Simulating Waves Nearshore (SWAN) model validated against measured regional datasets, including the Cefas Dowsing wave buoy located to the west of the array area (MetOceanWorks, 2021a). Data is provided at three locations, details of which are outlined in Table 7.2 and shown on Figure 7.1. This is further supported by measurements from the Cefas Dowsing wave buoy and Project SLWB, the locations of which are shown on Figure 7.1.

Table 7.2: Approximate location and water depth of three model points from MetOceanWorks (2021b; 2021c; 2021d), shown on Figure 7.1

Location ID	Latitude	Longitude	Mean Sea Level (MSL) Depth (m)
West	53.4964° N	1.0040° E	23
Central	53.5750° N	1.2720° E	23
East	53.6672° N	1.4690° E	28

7.4.5 Annual mean wave heights within the array area are approximately between 1.37m and 1.46m, decreasing in a shoreward direction. Wave heights are highest during the winter months, as shown on Figure 7.2, ranging between around 1.70m in the west of the array area to 1.95m in the east (ABPmer *et al.*, 2008).

7.4.6 Annual total significant wave height[1], or H_{m0}, statistics for each model point (shown on Figure 7.1) are provided in Table 7.3. In the centre of the array area, mean significant wave heights are approximately 1.3m. Both mean and maximum significant wave heights increase with distance offshore, as shown in Figure 7.2, whilst minimum values are generally similar. An analysis of approximately 16 years of measurements from the Cefas Dowsing wave buoy (location shown on Figure 7.1) provides a mean significant wave height of 1.2m, with a peak wave height of 6.5m (Cefas, 2021). Data recorded at the SWLB (see Figure 7.1) between April and November recorded a mean significant wave height of 1.1m, a peak wave period[2] of 5.6 seconds, and a maximum wave height[3] of 1.6m. Further data from the SWLB will be submitted as part of the ES.

Table 7.3: Annual total significant wave height statistics for three model points across the array area

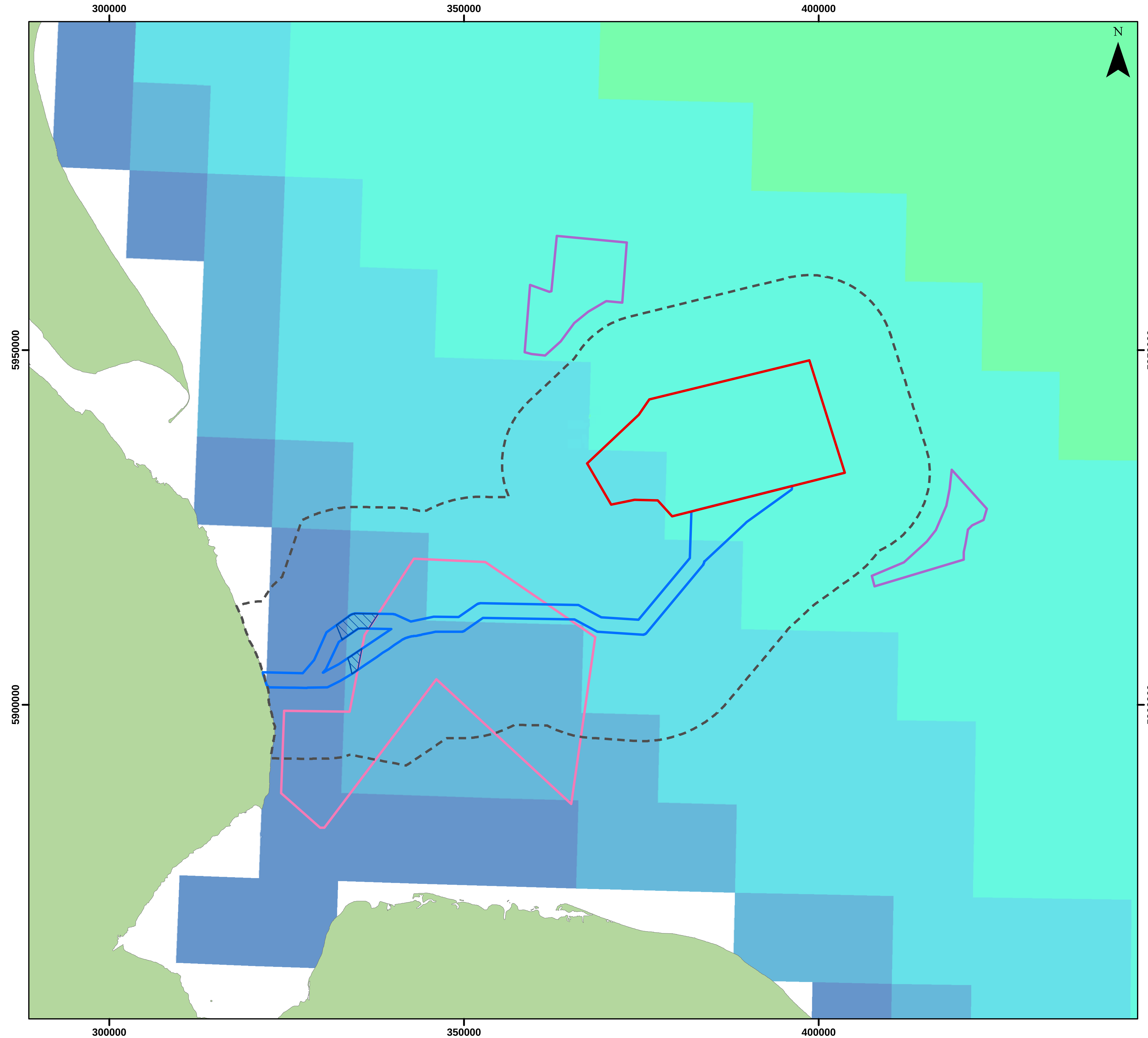
Model point	Minimum (m)	Mean (m)	Maximum (m)
West	0.1	1.3	6.6
Central	0.1	1.3	7.7
East	0.1	1.4	8.1

7.4.7 A frequency analysis of significant wave heights and directions at each model point in the array area (shown in Figure 7.1) is presented in Figure 7.3. The main characteristics of the wave regime are summarised in Table 7.4 and Table 7.5, using data from MetOceanWorks (2021b; 2021c; 2021d) modelling.

Table 7.4: Wave characteristics across three model points in the array area

Model Point	Prevailing Wave Direction	Most Frequent H_{m0} and Associated Parameters			Highest H_{m0}[4] and Associated Parameters		
		H_{m0} (m)	T_p (s)	Direction	H_{m0} (m)	T_p (s)	Direction
West	North (N) (12.9%) and North-northwest (NNW) (11.9%)	0.5 – 1.0 (35.4%)	4 – 6 (15.1%)	N	5.5 – 6.0 (0.03%)	10 – 12 (0.02%)	NNW
Central	N (12.9%) and NNW (10.7%)	0.5 – 1.0 (33.0%)	4 – 6 (16.6%)	N	6.0 – 6.5 (0.02%)	10 – 14 (0.02%)	NNW
East	N (12.0%) and NNW (10.7%)	0.5 – 1.0 (31.6%)	4 – 6 (17.1%)	N	6.5 – 7.0 (0.01%)	12 – 14 (0.01%)	NNW

[1] Significant wave height, H_{m0}, refers to the approximately the average height of the highest one third of the waves in a defined period, estimated from the wave spectrum as $4\sqrt{m_0}$.
[2] Spectral peak period, T_p, the period at which most energy is present in the wave spectrum.
[3] Maximum wave height, H_{max}, maximum individual wave height occurring within a defined period.
[4] Values <0.01% have not been considered

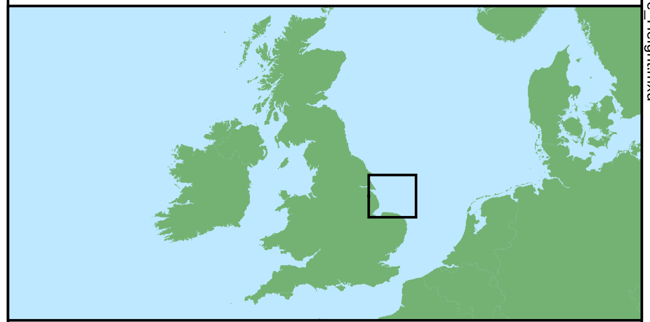


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence

Mean Winter Wave Height (m)

- < 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- 2 - 2.25



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:500,000

Preliminary Environmental Information Report

Winter Wave Height (ABPmer *et al.*, 2008)

Figure 7.2

OUTER DOWSING OFFSHORE WIND

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Contains ESRI Basemapping; EMODnet 2020 bathymetry

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7.4.8 Although the wave regime is generally similar across the array area, differences can be identified between the three model points. The main characteristics are as follows:

- In the centre of the array area, the most frequent wave direction is from the north (12.9%) and north-northwest (10.7%), with a smaller fraction from the southwest (7.6%) and north-northeast (7.5%) (as shown in Figure 7.3). This coincides with the longest fetch distances extending out into the northern North Sea, as well as the prevailing wind direction from the southwest. Across the three model points, this pattern is generally similar, although the dominance of the north-northwestern direction is most pronounced in the west of the array area (Table 7.4). Further offshore, there is an increasing proportion of waves from the south-southeast, with a difference of 1.5% over the three model points.
- In the centre of the array area, 33.0% of waves have a significant wave height between 0.5m and 1m, with a further 28.7% between 1.0m and 1.5m. The largest waves arrive from the north-northwest with a significant total wave height of 6.0m to 6.5m, although these comprise just 0.02% of the record (values under 0.01% have been excluded). The most frequent significant wave height is between 0.5m and 1.0m for all model points, although the proportion within this range decreases further offshore, as significant wave heights become generally higher. This is reflected in the highest significant wave heights, which increase from between 5.5m and 6.0m in the west to between 6.5m and 7.0m in the east (Table 7.4).
- The majority of the record (43.8%) in the centre of the array area comprises waves with a peak wave period, or T_p, of between 4 and 6 seconds, and a further 28.4% with a peak wave period between 6 to 8 seconds. The largest peak wave period is between 16 and 18 seconds, which occurs in 0.02% of the record. Across the model points from west to east, peak wave periods generally increase, with the proportion of waves between 6 and 8 seconds increasing from 23.9% in the west to 32.0% in the east.
- For the centre of the array area, significant wave heights are of the order of 5.3m, 6.8m, and 8.3m and maximum wave heights are 9.7m, 12.3m, and 14.9m for return periods of 1, 10, and 100 years, respectively. These are associated with peak wave period values of 11, 12.8, and 14.5 seconds. Both values increase with distance from the shore, as shown in Table 7.5.
- Overall, waves further offshore within the array area are generally higher, with longer peak wave periods and higher extreme total wave heights. This is likely to reflect generally shallowing bathymetry close to the shore, although these changes are minor and the model points are located in broadly similar water depths (Table 7.2). Waves further offshore within the array area occur slightly more from the south-southeast and other directions, with the dominance of the north and north-northwestern directions increasing closer to shore (Figure 7.3). Closer to shore, along the offshore ECC, the waves generally become more oriented from the north and northeast, as outlined in Paragraph 7.4.10 *et seq*.

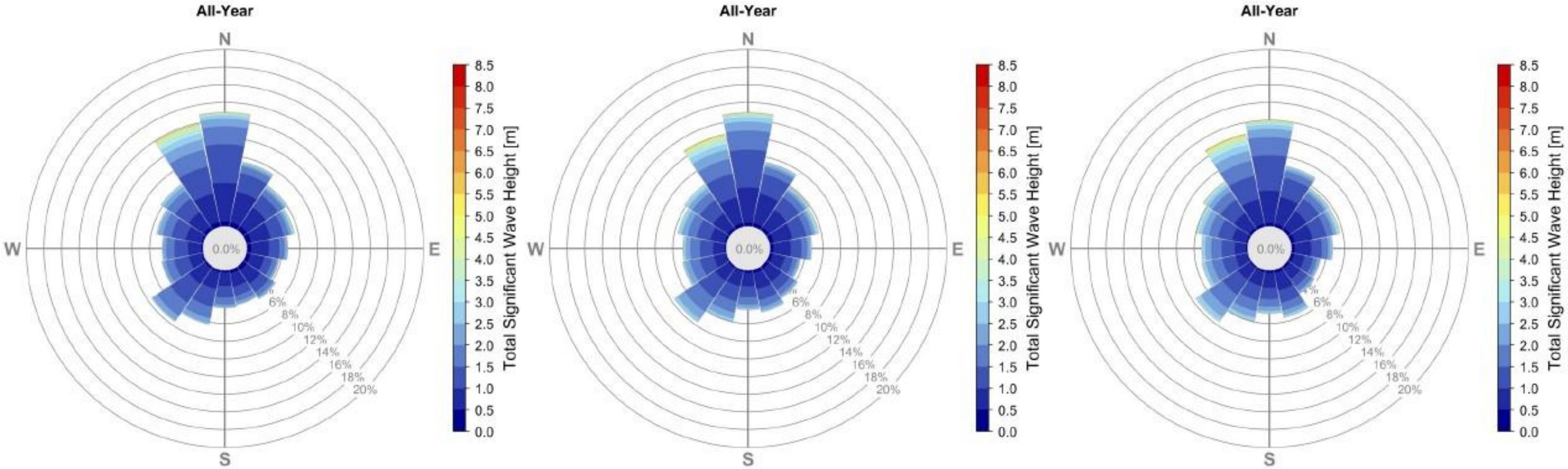


Figure 7.3: Array area annual wave rose for H_{m0} and direction at the three model points (from left to right: West, Central, and East, as shown on Figure 7.1) (MetOceanWorks, 2021b; 2021c; 2021d)

Table 7.5: Annual omni-directional extreme total wave heights and associated parameters for three model points across the array area

Return Period (years)	West			Central			East		
	H_{m0}[5] (m)	T_p[6] (s)	H_{max}[7] (m)	H_{m0} (m)	T_p (s)	H_{max} (m)	H_{m0} (m)	T_p (s)	H_{max} (m)
1	5.0	11.3	9.5	5.3	11.0	9.7	5.4	10.9	10.1
5	5.8	12.3	10.7	6.3	12.2	11.5	6.5	12.2	11.9
10	6.2	12.7	11.4	6.8	12.8	12.3	7.0	12.8	12.9
50	6.9	13.7	12.7	7.8	14.0	14.1	8.2	14.1	14.9
100	7.2	14.1	13.3	8.3	14.5	14.9	8.7	14.6	15.8
500	7.9	14.9	14.5	9.3	15.6	16.7	9.8	15.9	17.9

Offshore Export Cable Corridor

7.4.9 Hindcast data from ABPmer's SEASTATES database has been used to characterise wave conditions within the Offshore ECC (ABPmer, 2018), along with data from other OWF ES reports and observational wave records from a Directional Waverider Buoy situated off Chapel Saint Leonards, known as the Chapel Point Directional Waverider Buoy.

7.4.10 Waves in the most offshore part of the Offshore ECC originate mainly from the north, with smaller components from the southeast and southwest, and can reach over 2m in significant wave height (ABPmer, 2018). Further west along the ECC the wave climate is complex, with refraction and sheltering effects occurring due to the presence of sandbanks, including Inner Dowsing (TKOWFL, 2014). Prevailing waves continue to originate from the north and northeast, with smaller components from the southwest and east (TKOWFL, 2014; ABPmer, 2018). Available records show that the largest waves are observed in more offshore waters, decreasing in a landwards direction. The most frequently observed wave periods are typically between 3 and 4 seconds, generally indicative of locally generated wind waves, corresponding to a significant wave height between 0.5 and 1.0m (TKOWFL, 2014).

7.4.11 Closer to the shore, the wave regime has been characterised using data from the Chapel Point Directional Waverider Buoy, which is located approximately 6.2km offshore and around 1km south of the Offshore ECC. Waves occur most frequently from the north-northeast and northeast, with the largest waves coming from these directions, coinciding with long fetch distances into the North Sea. The annual mean wave height recorded is 0.8m, with wave heights highest during the winter months, and the most common peak wave periods are between 4 and 6 seconds. Significant wave heights have been calculated as 3.3m, 3.9m, and 4.2m for return periods of 1, 10, and 100 years, respectively (Environment Agency, 2021).

[5] Significant wave height, H_{m0}, refers to the approximately the average height of the highest one third of the waves in a defined period, estimated from the wave spectrum as $4\sqrt{m_0}$.

[6] Spectral peak period, T_p, the period at which most energy is present in the wave spectrum.

[7] Maximum wave height, H_{max}, maximum individual wave height occurring within a defined period.

Coast

7.4.12 The dominant wave direction along the Lincolnshire coast is from the northeast, with the majority of waves having an annual significant wave height between 0 and 1.0m (ABPmer, 2018; Figure 7.4). A nearshore acoustic wave and current meter (AWAC) deployed at Chapel Point from 2006 to 2009, at an approximate water depth of 5m, logged an overall mean wave height of 0.65m (Environment Agency, 2013b). Modelled wave statistics show little variation in the nearshore wave height over a range of return periods, suggesting that wave shoaling is limited up the coast (TKOWFL, 2012).

7.4.13 The wave regime exerts the dominant forcing to littoral transport within the nearshore zone, with the wave direction leading to a generally southward drift of sediments towards the Wash (HR Wallingford *et al.*, 2002; Environment Agency, 2010; 2011). The wave regime only influences offshore sediment transport during extreme events. A 1-year return period significant wave height at the Lincolnshire coast has been modelled as 4.5m (Environment Agency, 2011; TKOWFL, 2012).

Compensation Areas

7.4.14 Mean significant wave heights in the ANS search areas are of the order of 1.5m throughout the year, with mean winter wave heights of between, approximately, 1.8m to 1.9m (ABPmer *et al.*, 2008). Waves at the northerly ANS search area originate primarily from the north, whereas the dominant wave direction at the southerly ANS search areas is from the northwest, with a smaller proportion from the north and south (ABPmer, 2018). The wave regime within the biogenic reef restoration search area is generally similar to that of the offshore ECC, characterised in paragraph 7.4.9 *et seq.*, with annual significant wave heights generally between 0.75m (in the nearshore zone) and 1.35m (further offshore), with waves arriving primarily from the north. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.

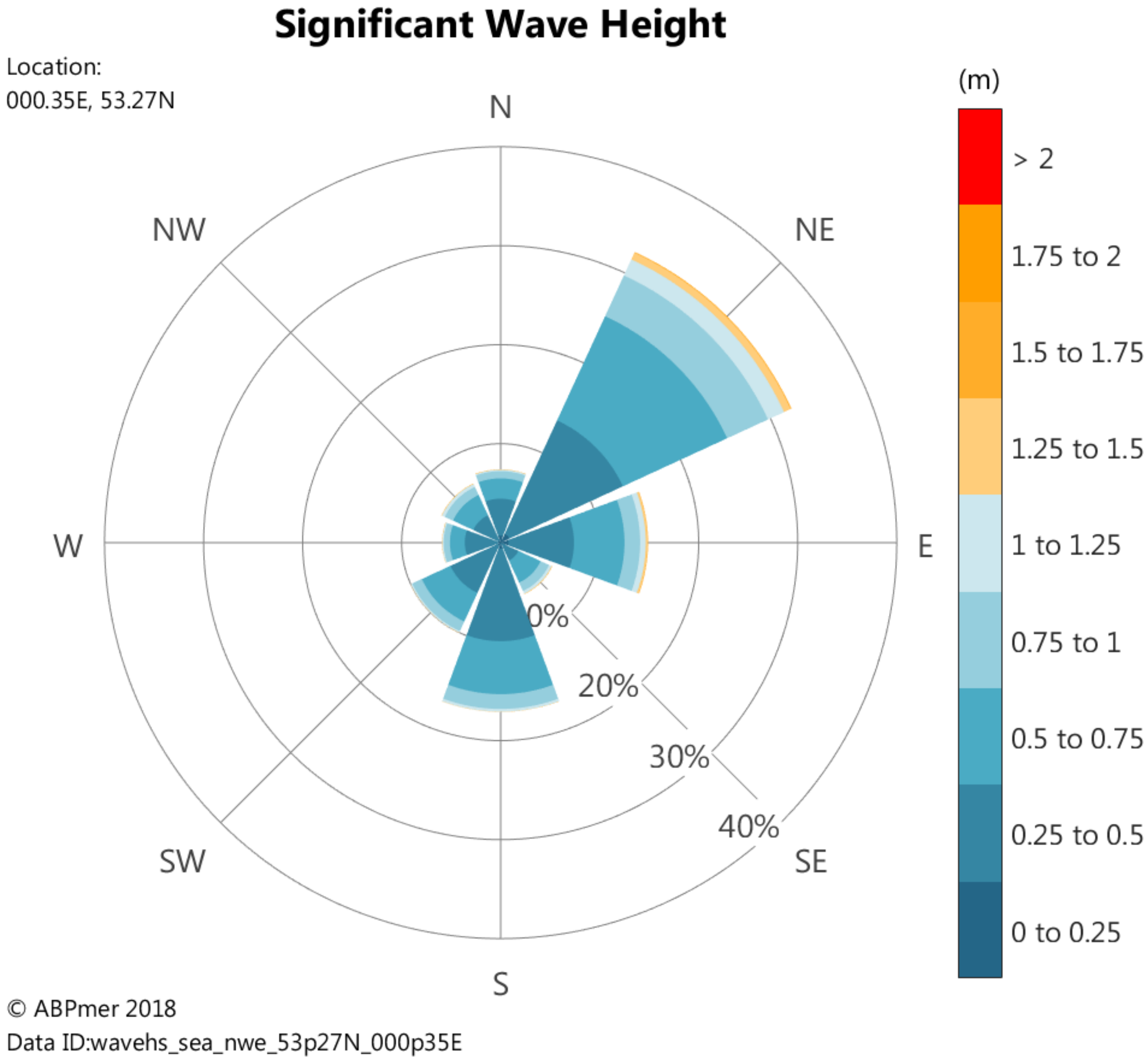


Figure 7.4: Wave rose of significant wave height and direction around the landfall site (ABPmer, 2018)

Tides

7.4.15 The tidal regime in the southern North Sea is under the influence of two amphidromic points, at which the tidal range is near zero. These points are located off the west coast of Denmark and between East Anglia and the Netherlands, with the first having the greatest influence at the Project location (Sündermann and Pohlmann, 2011). Tides rotate anti-clockwise around these points, resulting in a semi-diurnal tide flooding to the southeast and ebbing to the northwest (HADA, 2012a; Orsted, 2021). Tidal ranges increase in a shoreward direction with distance from the amphidrome, from approximately 2.5m in the eastern extent of the study area to around 5.5m along the coast (Figure 7.5; ABPmer *et al.*, 2008).

7.4.16 Modelled regional tidal ellipses, available from the UK Atlas of Marine Renewable Energy Resources (ABPmer *et al.*, 2008), provide some indication of current flow direction across the site, showing that flows are orientated northwest to southeast in the east of the study area (indicated by the model output in Figure 7.6). Towards the west, they become less rectilinear and more rotary, and are mainly oriented north to south to the west of Inner Silver Pit. The influence of bathymetry can also be seen in modelled depth-average spring tidal current speeds shown in Figure 7.6, with faster currents occurring in areas with deeper water channels.

Offshore Array

7.4.17 Tidal water levels throughout the array generally increase in range from the northeast to southwest, transitioning from a meso-tidal to macro-tidal[8] regime. Spring and neap tidal ranges in the centre of the array are 3.62m and 1.76m, respectively. Summary tidal statistics for three locations within the array area are shown in Table 7.6, with locations marked on Figure 7.1 and outlined in Table 7.2 (MetOceanWorks, 2021b; 2021c; 2021d).

Table 7.6: Tidal water level descriptors relevant to MSL (m) at three locations around the array area

Datum	Description	West	Central	East
MSR	Mean Spring Range	4.14	3.62	3.28
MNR	Mean Neap Range	2.00	1.76	1.58
HAT	Highest Astronomical Tide	2.61	2.33	2.15
MHWS	Mean High Water Springs	2.07	1.81	1.64
MHW	Mean High Water	1.65	1.45	1.32
MHWN	Mean High Water Neaps	1.00	0.88	0.79
MSL	Mean Sea Level	0.00	0.00	0.00
MLWN	Mean Low Water Neaps	-1.00	-0.88	-0.79
MLW	Mean Low Water	-1.62	-1.43	-1.30
MLWS	Mean Low Water Springs	-2.07	-1.81	-1.64
LAT	Lowest Astronomical Tide	-2.72	-2.42	-2.22

7.4.18 Data recorded at the SWLB (see Figure 7.1) between April and August recorded a mean current speed at 1m depth of 0.51m/s, and a maximum of 1.30cm/s. Further data from the SWLB will be submitted as part of the ES. Surface and near-bed (1m above bed) current flows have been modelled at three locations across the array area (as shown in Figure 7.1; MetOceanWorks, 2021a). In the centre of the array area, annual mean and 1 in 50-year return period surface current speeds are 0.53m/s and 1.49m/s, respectively, with current speeds showing a generally increasing trend from northeast to southwest. A similar pattern is found in near-bed current speeds, with mean and 1 in 50-year return period speeds of 0.34m/s and 0.95m/s, respectively. (MetOceanWorks, 2021b). A frequency analysis of this data, shown in Figure 7.7, shows that:

- Both surface and near-bed currents flow primarily towards the southeast (21.8%) and northwest (20.3%), with currents flowing towards the northwest being slightly faster;

[8] Defined by spring tidal range: micro-tidal, tidal range <2m; meso-tidal, tidal range 2 – 4m; macro-tidal, tidal range >4m.

- At both depths, there is a smaller current component flowing towards the north-northwest (17.5%) and south-southeast (16.7%). These current speeds are both generally faster than the main current component, with the fastest currents flowing towards the north-northwest; and
- Current speeds decrease towards the seabed due to drag effects.

7.4.19 Modelled current speeds at other locations within the array area show a similar, if not identical pattern. At the eastern model point (shown on Figure 7.1), the main current component is more dominant, with 29.9% towards to the southeast and 27.4% towards the northwest, and currents towards the south-southeast and north-northwest only 12.2% and 11.8% respectively (MetOceanWorks, 2021c). In contrast, currents at the western model point primarily flow towards the south-southeast (21.2%) and north-northwest (22.2%), with the northwest and southeast components being smaller (MetOceanWorks, 2021d).

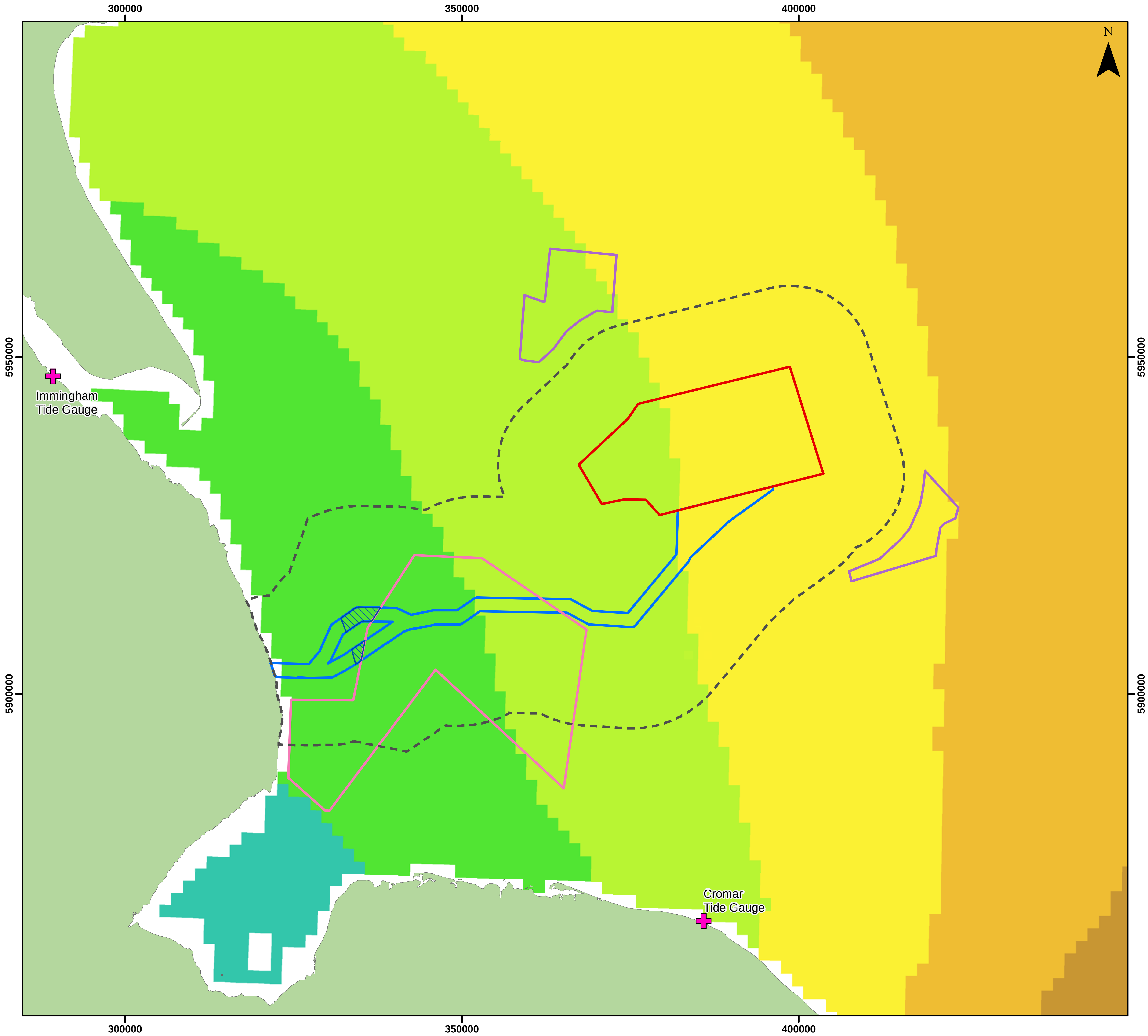
Offshore Export Cable Corridor

7.4.20 In the eastern half of the ECC, tidal flows are generally oriented to the southeast on the flood tide and northwest on the ebb tide, as in the array area. Closer inshore flows become oriented north to south, with the Inner Silver Pit approximately marking a transition (ABPmer *et al.*, 2008; TKOWFL, 2015; Figure 7.6). Here, tidal flows are oriented towards the south on the flood tide and north on the ebb (TKOWFL, 2015). In close proximity to the coast, tidal flows are oriented closer to the orientation of the coastline (ABPmer *et al*., 2008; Figure 7.6).

7.4.21 Modelled maximum depth-averaged spring tidal current speeds generally increase from east to west along the export cable, from around 1.2m/s to 1.3m/s close to the array area to over 1.4m/s south of Inner Silver Pit before reducing slightly close to the shore, as shown on Figure 7.6. Faster current speeds occur where deeper water channels are present, for example on the flanks of the Outer Dowsing Channel and Sole Pit, where speeds reach over 1.4m/s. This is supported by the literature, with hydrodynamic modelling for the Inner Silver Pit by Pingree and Griffiths (1979) suggesting that current velocities are increased within bathymetric deeps (HADA, 2012a). More benign current speeds, of the order of 0.6m/s to 1.0m/s occur within the northern extents of the Inner Silver Pit, in particular where it is oriented from the northeast to the southwest (Figure 7.6).

Coast

7.4.22 The Lincolnshire coast is a macro-tidal environment, with tidal currents generally following the orientation of the coastline with a flood tide to the south and an ebb tide to the north (Environment Agency, 2013b). The mean spring and neap tidal ranges adjacent to the Triton Knoll landfall area approximately 500m north of the Project landfall are 5.8m and 2.9m, respectively, and at Skegness the mean spring and neap ranges are 6.1m and 3.0m, respectively (HADA, 2012a; TKOWFL, 2014; Figure 7.5). Peak flow speeds are found to be more than 0.8m/s generally, exceeding 1.0m/s in places (TKOWFL, 2015).

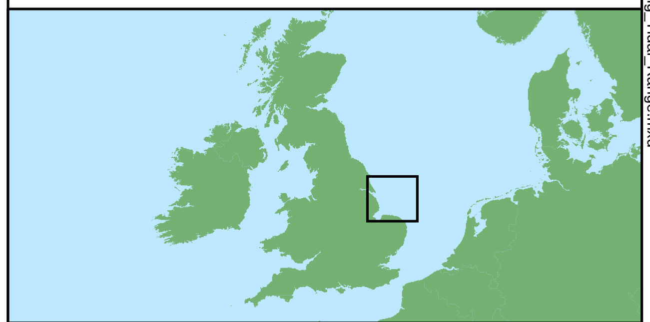


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence
- Tide Gauge Location

Mean Spring Tidal Range (m)

- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:525,000

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Mean Spring Tidal Range
(ABPmer *et al.*, 2008)

Figure 7.5

OUTER DOWSING OFFSHORE WIND

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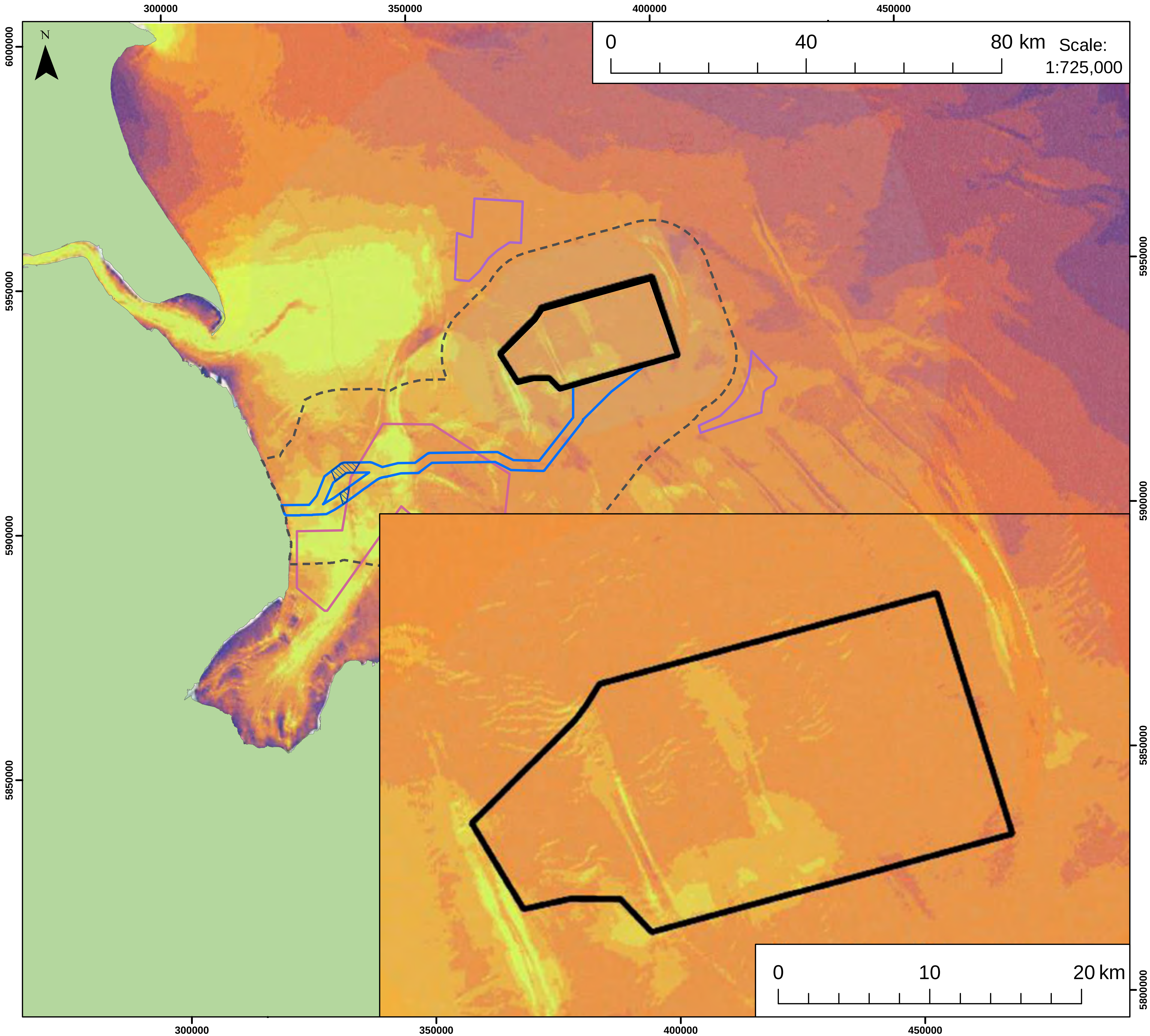
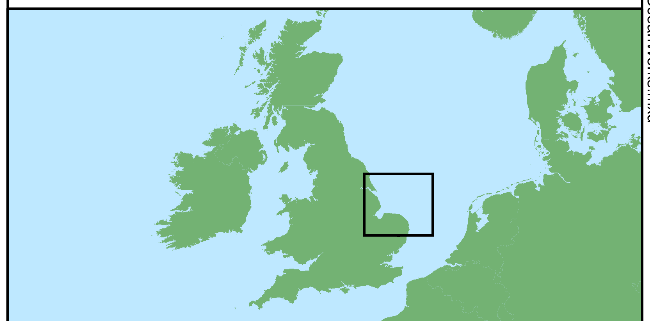


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence

Depth-averaged Current Speed (m/s)

- < 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.9
- 0.9 - 1
- 1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- > 1.4



Coordinate System: WGS 1984 UTM Zone 31N

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Maximum Modelled Depth-Averaged Spring Tidal Current Speeds (MetOceanWorks, 2021)

Figure 7.6

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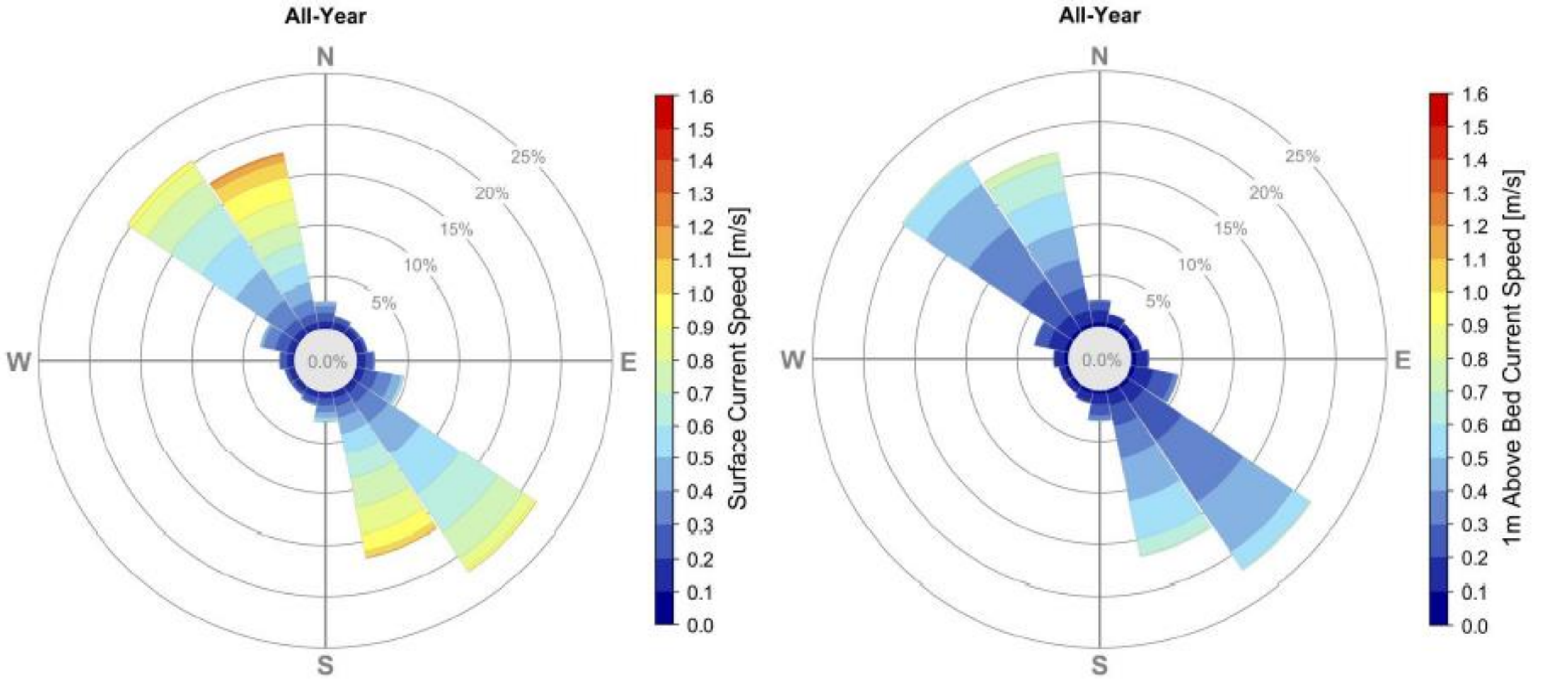


Figure 7.7: Annual rose plot of modelled surface and near bed current speed and direction in the centre of the array area (MetOceanWorks, 2021b)

Compensation Areas

7.4.23 Modelled mean tidal ranges for the northern ANS search area are approximately 4.1m and 2.1m for spring and neap, respectively. Tidal flows are generally oriented to the south-southeast on the flood tide and north-northwest on the ebb. For the southern ANS search area modelled mean tidal ranges are of the order of 3.1m and 1.6m for spring and neap, respectively, with tidal flows oriented southeast to southwest (ABPmer *et al.*, 2008). Modelled maximum depth-averaged spring tidal current speeds are generally between 1.0m/s and 1.2m/s, as indicated in Figure 7.6. Within the biogenic reef restoration search area, mean spring tidal ranges increase from approximately 4.0m in the east to up to 5.7m close to the coast (ABPmer *et al.*, 2008). Current speeds are generally faster and more complex than further offshore, as characterised in paragraph 7.4.21. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.

Non-tidal

7.4.24 Superimposed upon regular tidal behaviour are various non-tidal influences, which mainly originate from meteorological effects. An example is surges, formed by rapid changes in atmospheric pressure causing the water levels to fluctuate considerably above or below the tidal level. The geometry and location of the North Sea Basin makes it particularly susceptible to large surge events (Flather and Williams, 2000; Environment Agency, 2011).

7.4.25 Storm surges in this region are usually external surges, generated by pressure gradients travelling from the deep Atlantic waters onto the shallow continental shelf by strong winds to the north causing an increase in tidal levels. As the resultant water movements propagate into the North Sea they are affected by the Earth's rotation and rapidly decreasing depth causing a storm surge (HADA, 2012a). A notable major storm surge in the region occurred in December 2013, with water levels reaching between 5.0m and 5.5m (Ordnance Datum Newlyn (ODN)[9]) at the Lincolnshire coast (Spencer *et al.*, 2015).

Offshore Array

7.4.26 Modelled extreme water levels for the centre of the array area are shown in Table 7.7 (with the location of the modelled point shown in Figure 7.1 and outlined in Table 7.2).

Table 7.7: Extreme water levels in the centre of the array area (MetOceanWorks, 2021b)

Return Period (Years)	Positive Surge (m)	Wave Crest height (m)	Extreme Total Water Level (ETWL) Relative to MSL (m)
1	1.09	6.23	7.68
5	1.41	7.83	9.53
10	1.55	8.62	10.43
50	1.88	10.55	12.64
100	2.01	11.40	13.61
500[10]	2.01	14.99	17.16

[9] 0.0m ODN approximates to mean sea level.

[10] 100-year return period surge used (in the ISO 19902 equation) for return periods of 100 years and greater.

Offshore Export Cable Corridor

7.4.27 When surge currents are superimposed on astronomical tidal currents, they can combine to enforce short-term controls on the sediment regime. This is most pronounced in the shallow nearshore environment. In this region peak surge currents are in the range of 0.6m/s to 0.8m/s for a 1 in 50-year surge events, with currents directed towards the east (HR Wallingford *et al.*, 2002; TKOWFL, 2014).

Coast

7.4.28 As well as influencing sediment transport, storm surges can result in increased coastal erosion. The Environment Agency has produced a national dataset of "design sea levels" based on analysis of tide gauge data which incorporates the effect of surges. Extreme sea levels at Immingham, within the Humber Estuary, have been calculated as 4.17m, 4.53m, and 4.93m for return periods of 1, 10, and 100 years, respectively, although this will be amplified by the estuary's morphology. The closest tide gauge to the south of the landfall site is located at Cromer, on the North Norfolk coast (shown on Figure 7.5), where extreme sea levels have been calculated as 3.07m, 3.48m, 3.93m for 1, 10, and 100-year return periods, respectively (Environment Agency, 2018).

Compensation Areas

7.4.29 Modelled extreme water levels resulting from storm surges in the ANS search areas are likely to be analogous to those modelled for the array area, provided in paragraph 7.4.26. Surge currents within the biogenic reef restoration area are likely to be generally similar to those characterised in paragraph 7.4.27 and 7.4.28. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.

Frontal Systems and Stratification

7.4.30 Frontal zones mark boundaries between water masses, including tidally mixed and stratified areas, and are numerous on the European continental shelf (DECC, 2016). The Flamborough Front is a seasonal tidal mixing front which marks the transition between the well-mixed southern North Sea and stratified northern North Sea water bodies (Figure 7.8). This seasonal feature develops during summer months, approximately, 10km offshore from Flamborough Head and generally follows the 50m isobath (Hill *et al.*, 1993). This feature is located approximately 24km from the array area, as shown on Figure 7.8, and is therefore outside the zone of influence for the Project.

Seabed

Geology

7.4.31 Shown in Figure 7.9, the bedrock geology across the west of the study area is composed of Upper Cretaceous fine-grained limestones of the Chalk Group, with Late Triassic to Late Jurassic limestone, mudstones, and sandstones in the east. These include the Lias, West Sole and Humber groups (BGS, 1995; HADA, 2012a). Bedrock exposures are present within bathymetric deeps including the Sole Pit and Inner Silver Pit, outlined further in subsequent sections (Tappin *et al*., 2011; Cathie, 2021).

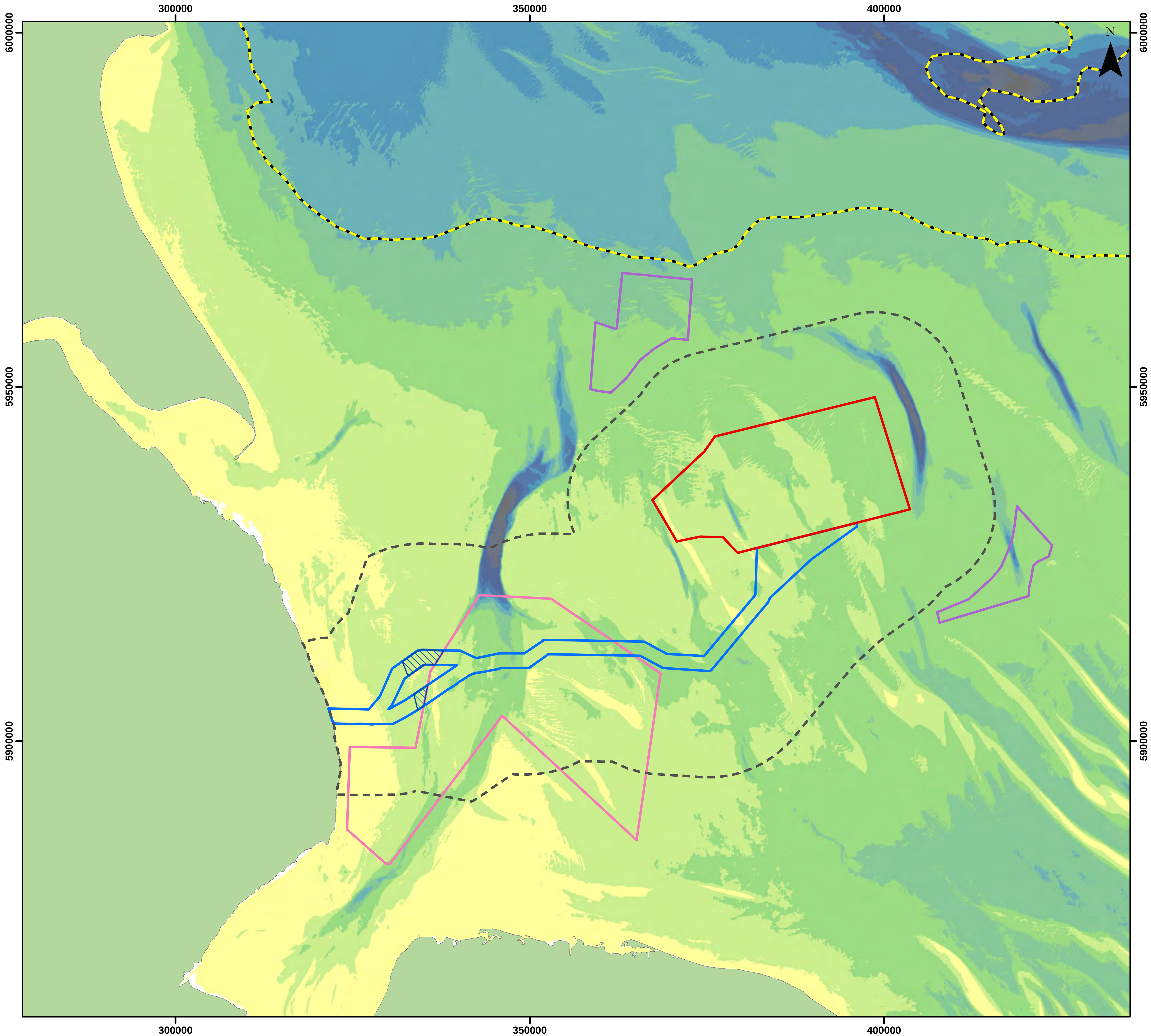
7.4.32 The bedrock geology is overlain by Quaternary sediments, including both early Pleistocene deltaic sediments as well as later Pleistocene sediments deposited during alternating glacial and interglacial conditions. Of the deltaic sediments, only the Winterton Shoal and Yarmouth Roads formation are exposed at seabed, mainly along the flanks of deep channels such as the Sole Pit (as shown on Figure 7.10). Later glacial and interglacial deposits include (in order of decreasing age): the Swarte Bank, Egmond Ground and Sand Hole, Bolders Bank and Botney Cut formations, shown on Figure 7.10. The Bolders Bank Formation, a glacial till (clay, sand and gravel debris deposited from ice sheets), is present throughout the majority of the study area and is exposed at the seabed in the Inner Silver Pit.

7.4.33 These deposits are overlain by a generally thin veneer of Holocene marine sediments. This layer rarely exceeds 5m, except for areas with tidal sandbanks and large sandwaves (Tappin *et al.*, 2011). In areas overlying the Bolders Bank Formation this layer is generally less than 1 to 2m thick (Cathie, 2021). The Quaternary sediment thickness varies throughout the study area between <5m to more than 50m, with the greatest thicknesses observed to the east of the array area and on either side of the Inner Silver Pit (shown on Figure 7.11).

Offshore Array

7.4.34 The western half of the Project array area is underlain by Cretaceous Chalk, with Lias, West Sole and Humber groups present in the east (Figure 7.9). The depth of sediment cover overlying the bedrock is spatially variable, with BGS datasets suggesting Quaternary sediment thicknesses generally between 5m to 20m in the western part of the array area and increasing towards the east, with the thickest deposits, between 30 and 50m, in the middle of the array area and on the eastern edge (Figure 7.11; Cathie, 2021). The chalk bedrock to the west of the array area will therefore be located approximately between 5m and 30m below the seabed (BGS, 2022). A more comprehensive description will be provided within the ES once Project-specific geotechnical surveys are complete.

7.4.35 These Quaternary sediments comprise Pleistocene deposits as well as a layer of Holocene marine sediments. A desk-based study by Cathie (2021) concluded that Holocene sediment cover, Bolders Bank Formation, and Swarte Bank Formations are expected within the top 100m below seabed of the array area (Figure 7.10). The Bolders Bank Formation is described as firm to stiff, slightly gravelly clay with pockets of sand and gravel, occasional sandy horizons and some boulders (TKOWFL, 2014; Cathie, 2021). Due to the firm to stiff clay content, the widespread presence of Bolders Bank Formation under Holocene sediments could limit the development of deeper scour (> 5m) (Orsted, 2021). The Swarte Bank Formation is a valley infill deposit composed of chalky till, glacio-lacustrine mud and marine clay, and marine interglacial sediments (Tappin et al., 2011).

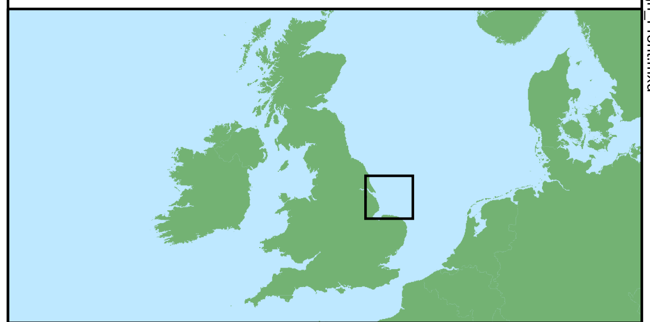


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence
- Location of Flamborough Front - July 2018

Depth (m)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:500,000

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Flamborough Front Location

Figure 7.8

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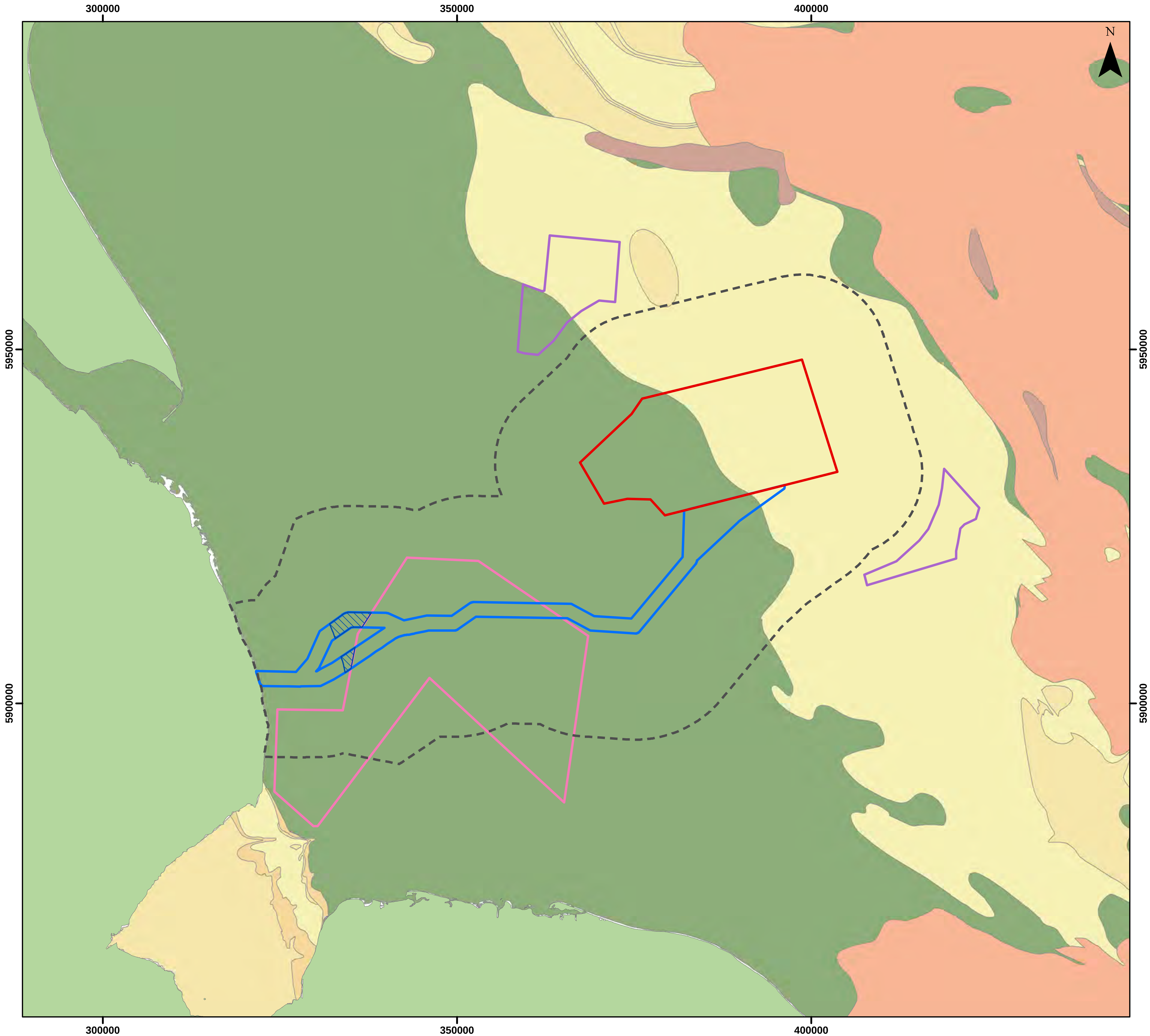
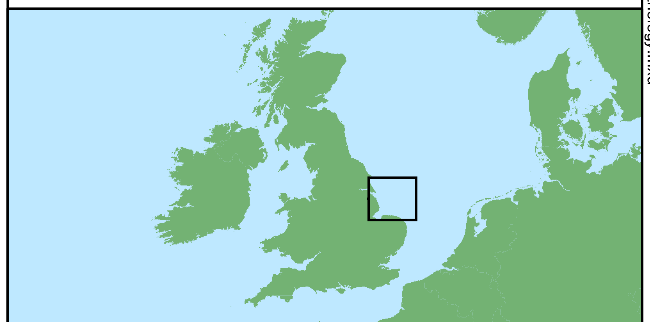


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence

Bedrock Summary Lithologies (BGS)

- Chalk
- Mesozoic interbedded
- Mesozoic mudstones
- Mesozoic sandstones and limestones
- Palaeozoic sedimentary
- Tertiary interbedded



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Bedrock Lithology

Figure 7.9

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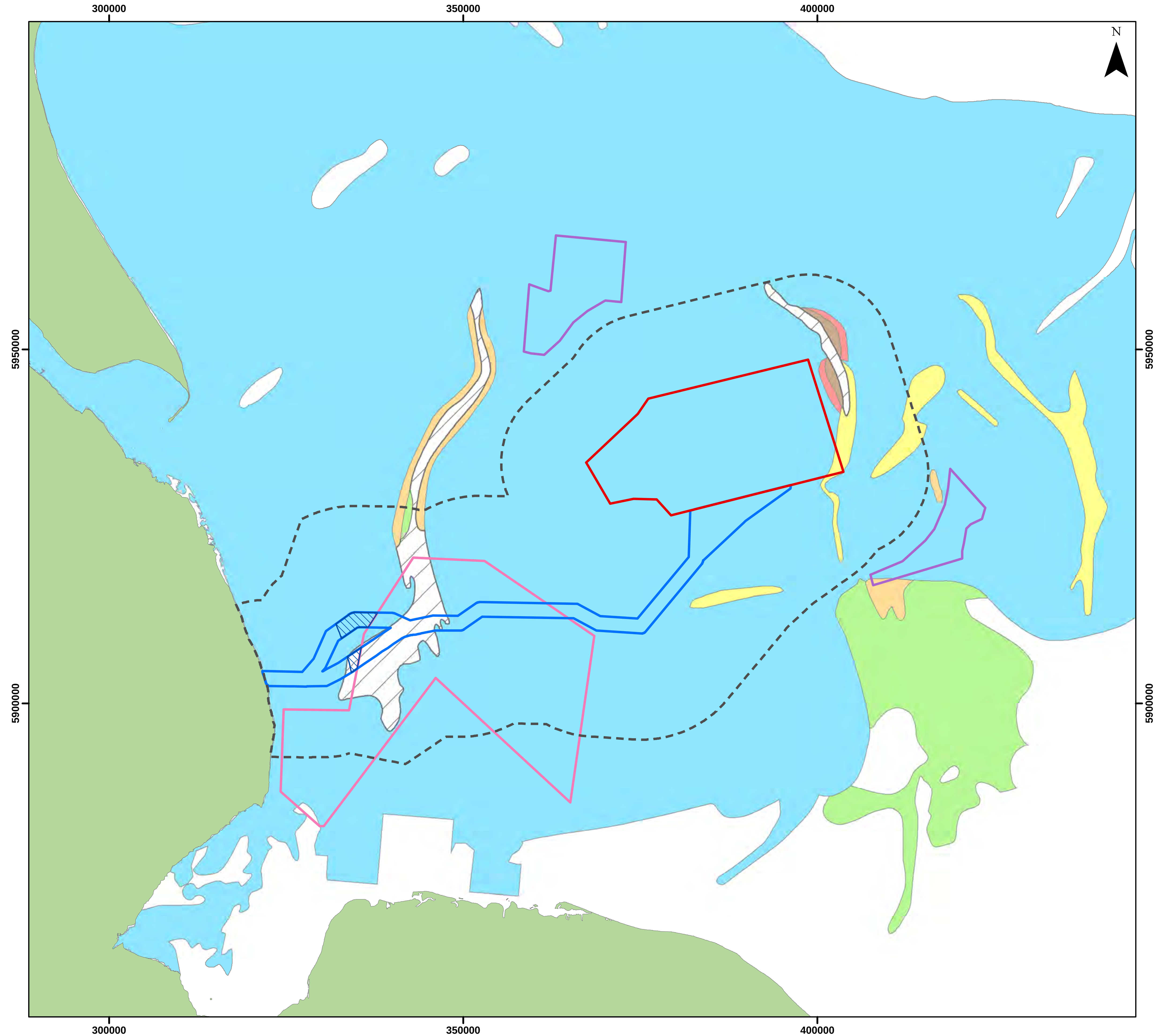


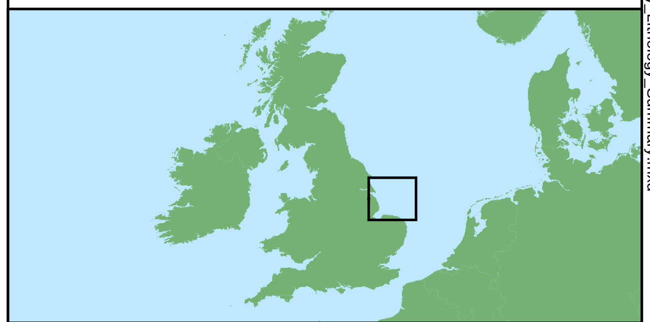
Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Offshore Export Cable Corridor
- Artificial Nesting Structure Search Area
- Physical Processes Zone of Influence

Quaternary Deposits Summary Lithologies (BGS)

- Botney Cut Formation
- Bolders Bank Formation
- Egmond Ground and Sand Hole Formations
- Swarte Bank Formation
- Yarmouth Roads Formation (Deltaic)
- Winterton Shoal Formation (Deltaic)
- Undivided Mesozoic

Quaternary Geology (Cameron *et al.*, 1986; Tappin, 1991)



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

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Preliminary Environmental Information Report

Quaternary Lithology Summary

Figure 7.10

OUTER DOWSING OFFSHORE WIND

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Contains ESRI Basemapping; EMDOnet 2020 bathymetry

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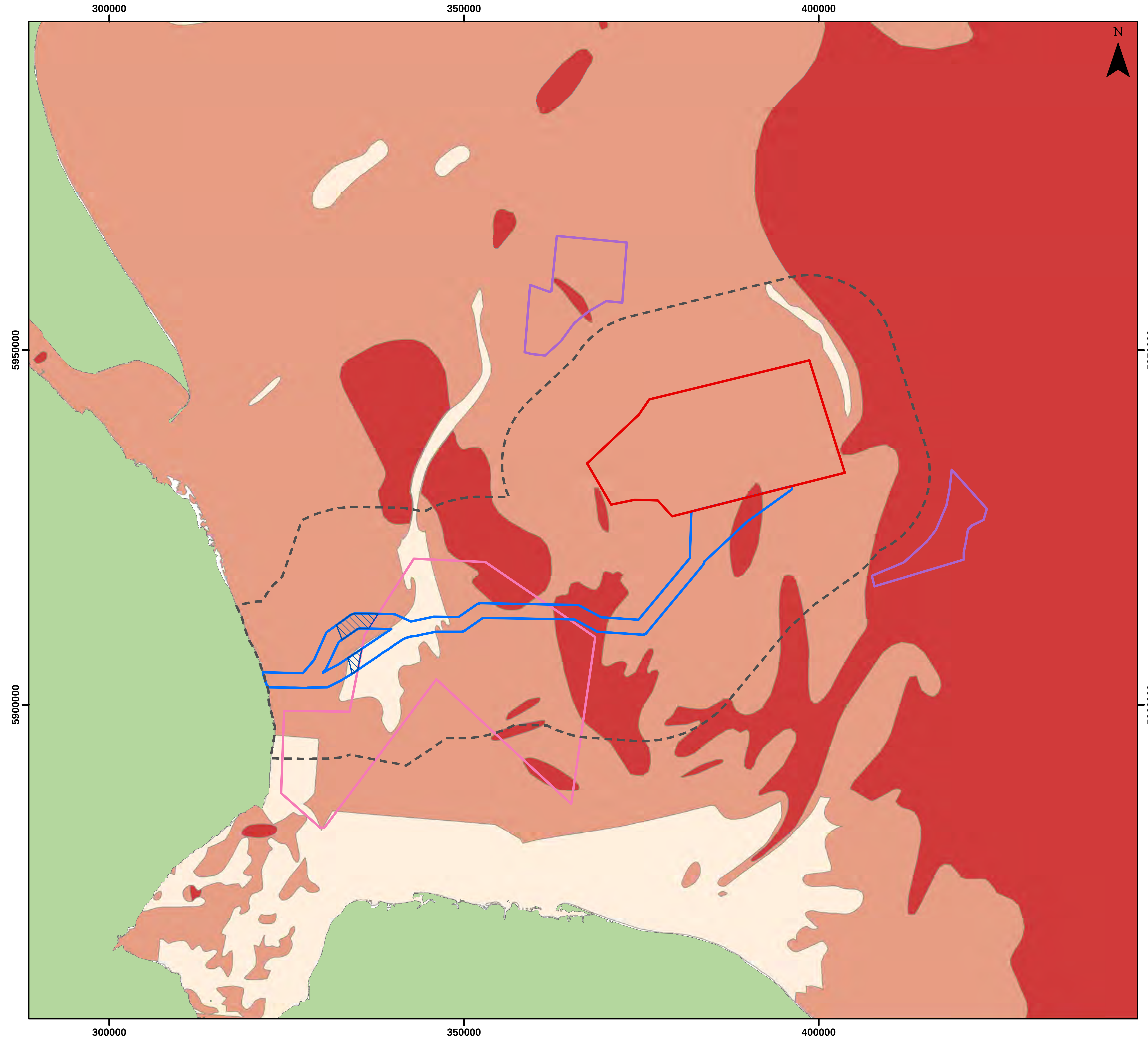
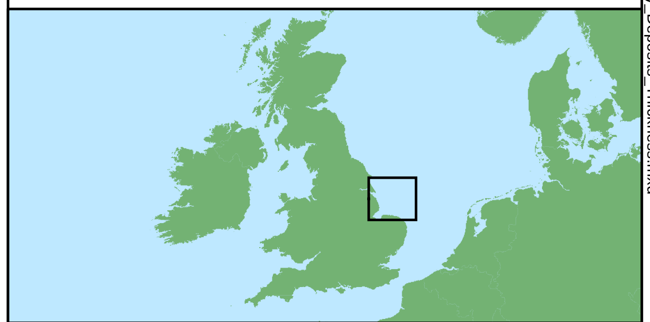


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence

Quaternary Deposit Thickness (BGS)

- < 5m
- 5m - 50m
- > 50m



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:500,000

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Quaternary Deposit Thickness

Figure 7.11

OUTER DOWSING OFFSHORE WIND

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Contains ESRI Basemapping; EMDOnet 2020 bathymetry

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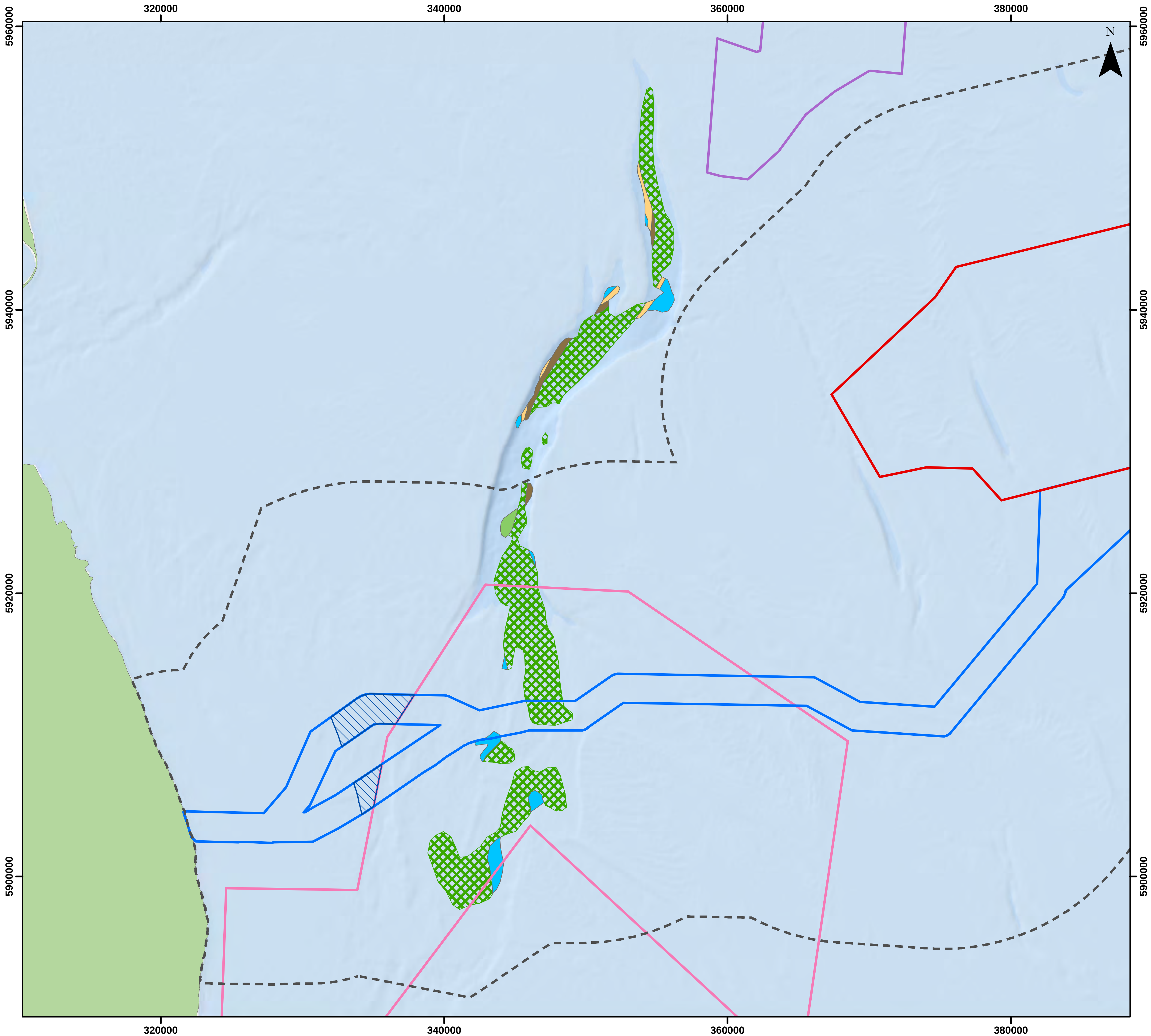
Offshore Export Cable Corridor

7.4.36 The Offshore ECC is characterised mainly by Pleistocene deposits present above Cretaceous Chalk bedrock, overlain in turn by a veneer of Holocene sediments of variable thickness. As outlined above, Pleistocene deposits across the area include a complex sequence of Egmond Ground and Swarte Bank formations, extensively incised by channelling and infilling with Botney Cut Formations and overlain in much of the region by Bolders Bank Formation (Tappin *et al.*, 2011; Equinor, 2022). The thicknesses of these, as well as the overlying Holocene sediments, vary across the ECC, and a combination of geophysical investigations have been used to characterise specific areas (EMU and Osiris, 2008; Centrica, 2009; Tappin *et al.*, 2011; TKOWFL, 2011; Dove *et al.*, 2017; Equinor, 2022). A more comprehensive description will be provided within the ES once Project-specific geotechnical surveys are complete.

7.4.37 Seismic stratigraphy information is presented in Dove *et al.* (2017) of a profile extending south from just west of the Project array area, crossing the offshore ECC approximately one third of the way west along its length. At the approximate location of the offshore ECC, the seabed geology comprises of thick Holocene sediments of over 10m in some areas, representing a local sandbank feature, underlain by a combination of Bolders Bank, Sand Hole, and Egmond Ground formations approximately 15m to 20m thick (Dove *et al.*, 2017). Assuming a cable burial depth of up to 5m, the offshore ECC at this point along the route would be located primarily in mixed Holocene sands and gravels.

7.4.38 Geotechnical investigations at the Race Bank OWF array area, combined with BGS information, were interpreted as a sequence of surficial sands overlying the Bolders Bank Formation, which in turn overlies a layer of mixed Egmond Ground and Swarte Bank deposits. The superficial Holocene sands range in thickness, with a maximum of 18m within the Race Bank feature. However, in the far northwest of the Race Bank array area, which is closest to the Project Offshore ECC, there is no layer of superficial sands, with the Bolders Bank Formation extending approximately 10m to 15m below the seabed (EMU and Osiris, 2008). This supports regional-scale information from Tappin *et al.* (2011), which identifies a generally thin veneer of Holocene sediments apart from areas with large sandbank and sandwave features. This suggests that areas of the offshore ECC will have a very thin or non-existent Holocene sediment layer, particularly across areas of flat bathymetry. A full consideration of cable installation and protection options is provided in Volume 1, Chapter 3: Project Description with impacts on Marine Process receptors assessed in Volume 1, Chapter 7: Marine Processes.

7.4.39 Further west, to the south of the Inner Silver Pit, the Quaternary sediment thickness is generally less than 5m, as shown in Figure 7.11. Chalk bedrock, as well as Bolders Bank till, is exposed in the Inner Silver Pit and its associated glacial outwash feature to the south, shown in Figure 7.12. These outcrops either have no surficial sediment cover or it is thin (less than one metre) (Tappin *et al.*, 2011). Upper chalk units recovered in geotechnical investigations carried out for the Triton Knoll ECC, to the north of the Project ECC, were almost all classified as either weak or very weak and of low to medium density (TKOWFL, 2011).

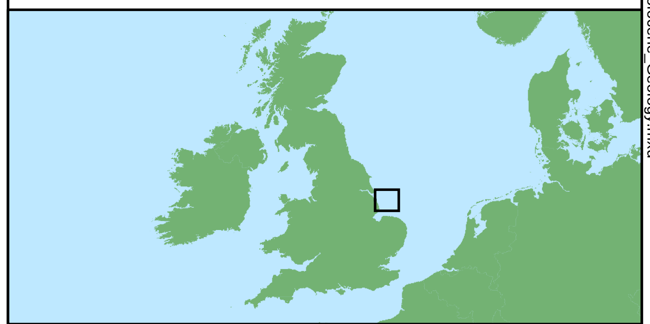


Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence

Pre-Holocene Geology at/near Seabed (Tappin, 2011)

- Mesozoic - Chalk Group - Early to Late Cret.
- Quaternary - Bolders Bank Formation
- Quaternary - Egmond Ground Formation
- Quaternary - Sand Hole Formation
- Quaternary - Swarte Bank Formation



Coordinate System: WGS 1984 UTM Zone 31N

0 5 10 km

Scale: 1:250,000

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Exposure of Pre-Holocene Geology at or Near Seabed in Inner Silver Pit and Associated Glacial Outwash Feature (Tappin *et al*., 2011)

Figure 7.12

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Coast

7.4.40 The onshore bedrock geology is composed of Burnham Chalk, overlain by marine sand deposits. Historical boreholes (1994) from the intertidal area at the landfall site contain medium density, slightly silty sandy gravel and silty, fine sandy clay shallow marine deposits to a depth of approximately 9m. Beyond this depth, sand and gravel with stiffer clay and chalk begin to occur with occasional boulders, with no evidence of bedrock within the first 12m (BGS, 2022).

Compensation Areas

7.4.41 The northern ANS search area is located in an area of Cretaceous chalk bedrock overlain by Quaternary sediments between, approximately, 5m and 50m in thickness, which are in turn overlain by a veneer of Holocene sediments. The southern ANS search area overlies Late Triassic to Late Jurassic bedrock, similar to the eastern half of the Project array area (Figure 7.9), overlain by a generally thicker (>50m) layer of Quaternary glacial and valley infill sediments (Figure 7.11). The biogenic reef restoration search area can be characterised using the information provided in paragraph 7.4.36 *et seq.*, with Cretaceous chalk close to the seabed surface in some areas as indicated on Figure 7.12. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.

Seabed

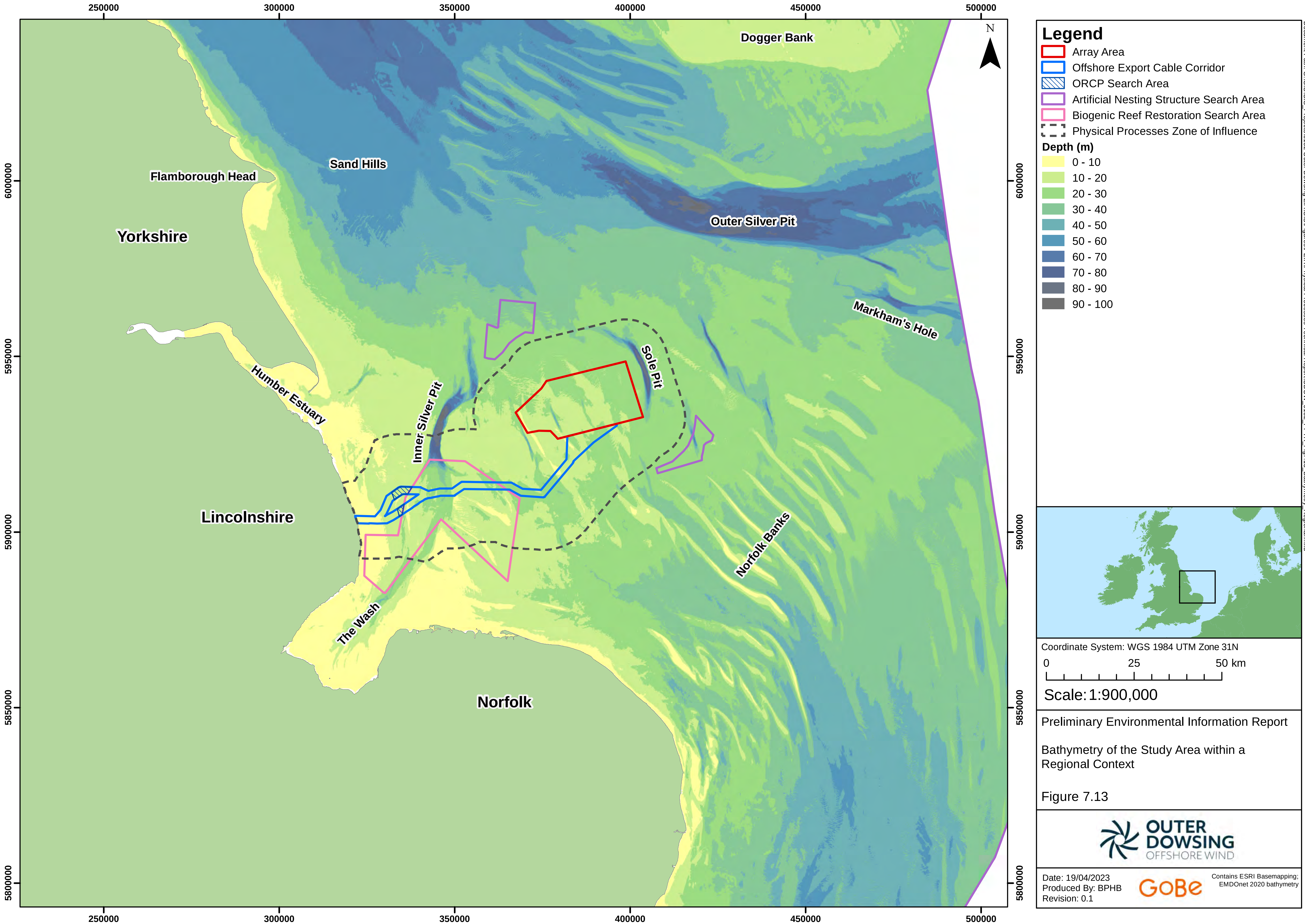
7.4.42 Water depths across the region vary widely, from 0m to 94.6m depth (Lowest Astronomical Tide (LAT)), with an average depth of 15.5m. The region is characterised by generally flat bathymetry punctuated by a number of large-scale glacial landforms (shown on Figure 7.13), for which information is provided in Paragraph 7.4.65 *et seq.*, as well as a number of large sandbanks. These features lead to the large variation in water depth across the study area (Cathie, 2021).

7.4.43 As outlined previously, Holocene sediment forms a thin veneer over Pleistocene or older deposits, rarely exceeding 5m thickness apart from in areas of sandbanks (Cameron *et al.*, 1992; Tappin *et al.* 2011). The majority of these sediments are derived from the reworking of Quaternary deposits, with limited contribution from modern fluvial sources. As shown on Figure 7.14, the region is characterised by a mix of mainly sand and gravel, with a higher proportion of sand to the east (Tappin *et al.*, 2011; BGS, 2022). The distribution of sediments is strongly influenced by the underlying geology and bathymetry, particularly the presence of landforms such as Inner Silver Pit (TKOWFL, 2014).

7.4.44 Gravel rich sediments (gravel, sandy gravel, and muddy sand gravel) dominate the western part of the study area forming large-scale bathymetric features that reflect pre-existing glacial, fluvioglacial, fluvial and coastal processes. Elsewhere the gravel layer is mostly less than a few tens of cm thick and overlies Bolders Bank Formation till or chalk bedrock (near the coast) (HADA, 2012a). The presence of muddy sediments is typically restricted to within bathymetric deeps such as Inner Silver Pit, as well as at localised areas in shallower water depths (DECC, 2016), with the offshore ECC crossing through an area of muddy sandy gravel located to the south of the Inner Silver Pit, as shown on Figure 7.14.

Offshore Array

7.4.45 Water depths in the array area range from 6.1m to 43.5m, with over 90% between 15m and 25m (LAT). Several bathymetric lows are present in the centre and west of the array area (see Figure 7.1), reaching a maximum depth of 25m below the seabed (45m from sea level). A series of sandbanks and sandwave features are present in the north of the array area, with amplitudes of 10m to 12m and 2m to 3m, respectively. Variations in water depth across the array area correspond with these features, about which further information is provided in paragraph 7.4.67 *et seq*. Four bathymetric profiles across the array area are shown in Figure 7.15, on which the bathymetric lows and sandbank features are clearly visible (Cathie, 2021).



Coordinate System: WGS 1984 UTM Zone 31N

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Scale: 1:900,000

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Bathymetry of the Study Area within a Regional Context

Figure 7.13

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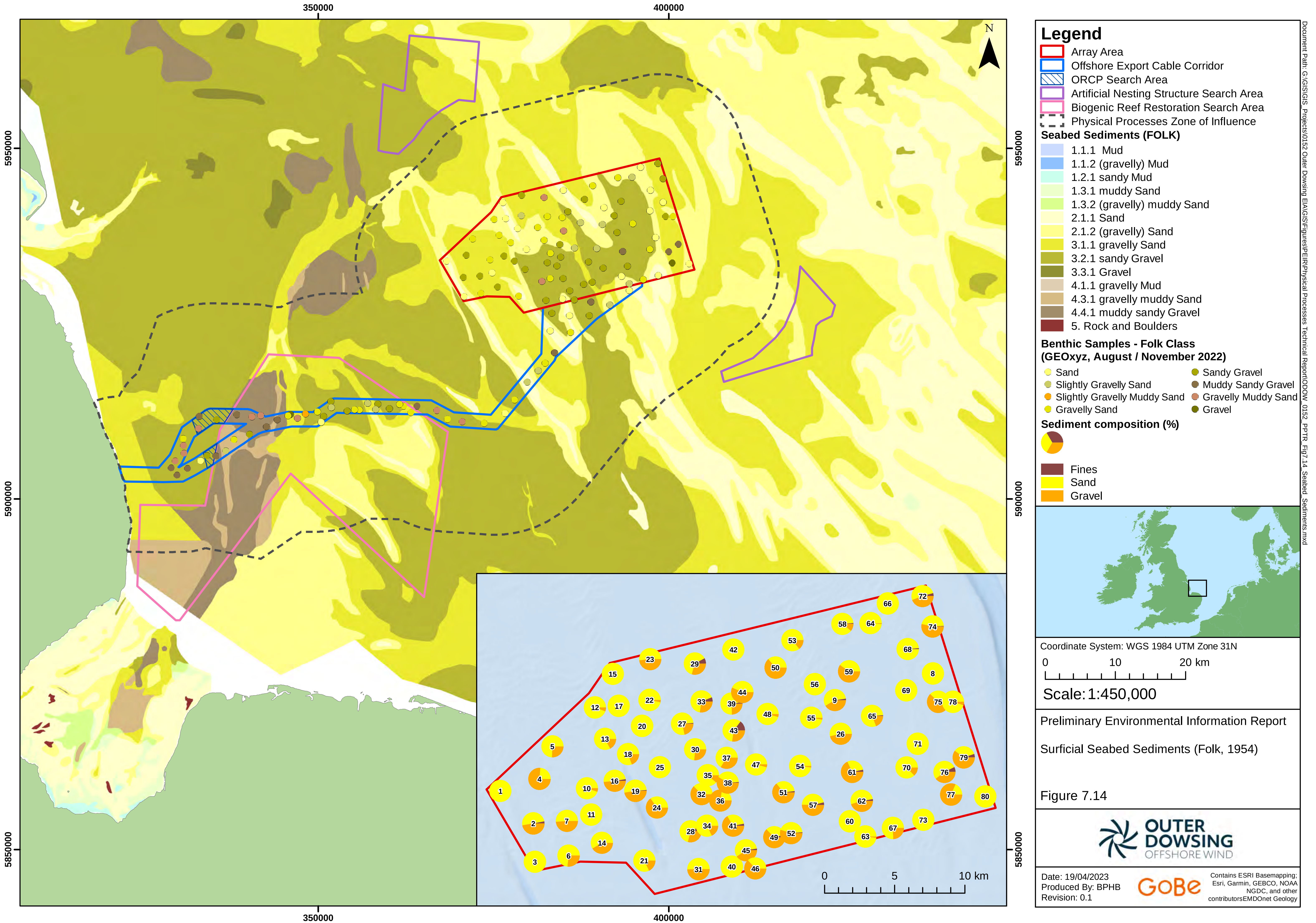

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Surficial Seabed Sediments (Folk, 1954)

Figure 7.14

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Contains ESRI Basemapping; Esri, Garmin, GEBCO, NOAA NGDC, and other contributorsEMDOnet Geology

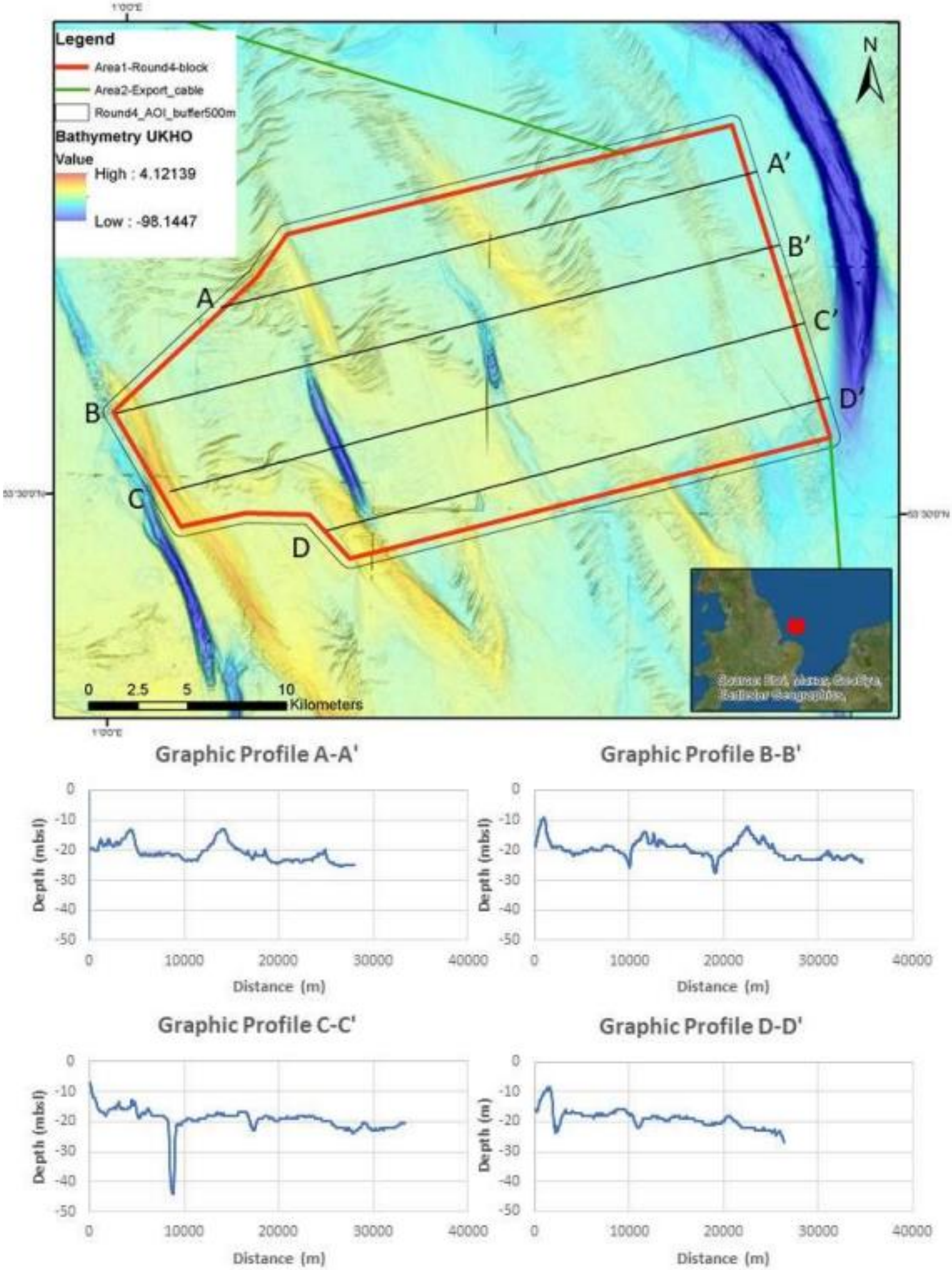


Figure 7.15: Bathymetric profiles across the Project array area, from Cathie (2021)

7.4.46 Particle size analysis has been carried out across the array area (in addition to the offshore ECC, see paragraph 7.4.48) as part of the Project benthic ecology characterisation, details of which are shown in Figure 7.14 and outlined in Table 7.8 (GEOxyz, 2022a). The results of this analysis indicate a variable sediment type across the array area with a general sand dominance, lower proportion of gravel and minimal proportion of fines. The proportion of sand increased at shallower depths associated with sandbank features, although a high sand content was found in high proportions at one sample point located within a seabed canyon, reflecting the general dominance of sand across the array area. The proportion of fines was generally low, with a slightly higher content observed at deeper sample points. A significant correlation was found between the sorting coefficient and depth, indicating that sediments within the deeper areas of the survey were generally more variable than sediments sampled from sandbank crests (GEOxyz, 2022a). This is likely to be a result of sediment transport processes.

Table 7.8: Summary of particle size analysis across the array area (GEOxyz, 2022a)

Sediment Type	Minimum Fraction (%)	Mean Fraction (%)	Maximum Fraction (%)	Standard Deviation
Fines	0.00	1.32	14.53	2.34
Sands	18.58	70.34	99.99	25.96
Gravel	0.01	28.35	81.08	25.23

Offshore Export Cable Corridor

7.4.47 Bathymetry along the Offshore ECC has been characterised using EMODnet data, to be supplemented with Project-specific geophysical information when it becomes available. Moving southwest from the array area, water depths range generally between 10m to 30m (LAT). This is dependent on bathymetric features, with the lowest depths corresponding to the Outer Dowsing Shoal (see Figure 7.1). The ECC then crosses through an area of relatively flat seabed with depth of 20m to 25m (LAT), before crossing the Triton Knoll and Dudgeon Shoal sandbanks, which at their highest point have water depths of around 10m (LAT). South of the Inner Silver Pit, water depths generally range between 10m and 30m (LAT) within the glacial outwash feature, described further in paragraph 7.4.72. From around 12km offshore, water depths typically shallow uniformly from around 14m towards the coast (EMODnet, 2022).

7.4.48 Surficial sediments in the Offshore ECC area are characterised mainly by sandy gravel, with some mud component to the south of Inner Silver Pit (Figure 7.14; BGS, 2022). The offshore area of the Triton Knoll ECC is comprised of silty gravelly sand and gravelly sand dominating, with poorly sorted gravelly sand identified from the Triton Knoll bank. In addition, a large number of boulders were identified along the ECC, the largest of which are over 1m in diameter (TKOWFL, 2014). The results of PSA along the Project ECC are shown in Table 7.9 (GEOxyz, 2022b). The results indicate a variable sediment type with a general dominance of sand, with higher fines content than the array area, consistent with the BGS data presented in Figure 7.14. Closer to the coast, the proportion of sand generally decreases, with a corresponding increase in gravel and fines content.

Table 7.9: Summary of particle size analysis across the offshore ECC (GEOxyz, 2022b)

Sediment Type	Minimum Fraction (%)	Mean Fraction (%)	Maximum Fraction (%)	Standard Deviation
Fines	0.00	6.38	26.03	7.43
Sands	6.74	71.57	99.94	19.65
Gravel	0.02	23.37	98.11	17.92

Coast

7.4.49 Water depths typically shallow uniformly towards the coast, from around 14m (LAT) at 12km offshore (EMODnet, 2020). The present form of the Lincolnshire beaches has been directly influenced by an annual beach nourishment scheme which has involved the placement of almost 17 million square metres of sand since 1994 (Environment Agency, 2019a; 2019b). Prior to the nourishment scheme, the beach consisted of a thin veneer of sand overlying clay, which matches historical borehole data described previously in paragraph 7.4.40. Analysis of the nourishment material has shown that it can be best described as poorly sorted gravelly sand, with a mean grain size considerably coarser than the natural beach sediment, although considerable variation was identified within each dredger load and at different locations along the coast (Blott and Pye, 2004).

Compensation Areas

7.4.50 Water depths in the northern ANS search area are generally between approximately 20m to 30m (LAT) (Figure 7.1), with surficial sediments comprising of mainly gravel and sandy gravel (Figure 7.14; BGS, 2022). The southern ANS search area has similar water depths across the majority of it, although it overlies the Coal Pit channel, within which depths may reach up to, approximately, 70m LAT (Figure 7.1) and is characterised by gravelly sand. The bathymetry and surficial sediment cover within the biogenic reef restoration search area may be generally characterised using the information provided in paragraph 7.4.47 and 7.4.48. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.

Sediment Transport

7.4.51 Sediment transport is a crucial link in the interaction between hydrodynamic regime and coastal morphological evolution. There are two main mechanisms of sediment transport:

- Bedload transport, which refers to the movement of grains along the seabed by currents, which primarily relates to coarse material including sands and gravels; and
- Suspended load transport, which refers to particles of sediment carried in suspension in the water column.

7.4.52 The sediment transport regime across the study area has been characterised using region scale assessments including the Southern North Sea Sediment Transport Study Phase 2 (SNSSTS II) (HR Wallingford *et al*., 2002), the work of Kenyon and Cooper (2005), and Tappin *et al.* (2011), in addition to modelling studies for other OWFs in the area.

7.4.53 Modelling studies and analysis of bedform indicators, such as sandwaves and tidal banks, have demonstrated that tidal currents are the dominant mechanisms responsible for bedload transport in the Humber region (van der Molen, 2002; Kenyon and Cooper, 2005). Offshore, some areas show evidence of surge current dominance, which also have the ability to temporarily reverse or reinforce tidally-driven sediment transport pathways (TKOWFL, 2011). Waves tend to only influence offshore sediment transport during extreme events but exert the dominant forcing to littoral transport within the nearshore zone (HADA, 2012a).

7.4.54 The main pattern is of a northerly/north-westerly directed offshore stream and a southerly inshore stream, separated by a bedload parting between just south of Sand Hole, across the Silver Pit and through the Race Bank – North Ridge – Dudgeon Shoal (Kenyon and Cooper, 2005; Tappin *et al.*, 2011; Figure 7.16). Superimposed on this are numerous smaller scale pathways and circulatory systems, particularly in areas of complex bathymetry such as around sandbank features (HADA, 2012b).

7.4.55 Suspended Particulate Matter (SPM) provides an indication of turbidity and is highly variable according to water depth and the marine processes in the area (*i.e.,* tide, current and wind regimes). The offshore region of the study area is generally characterised by low surface concentrations of SPM due to distance from terrestrial sources and low seabed fines content. Fines transported southwards from the erosion of the Holderness Cliffs combine with muds transported out of the Humber Estuary, forming a plume which moves offshore to the south-east and towards the southern North Sea. The majority of the plume's suspended load is deposited outside UK Territorial Waters (Defra, 2002).

Offshore Array

7.4.56 Regional-scale assessments identify a net north-westerly direction of bedload transport for the Project array area, which is located seaward of the bedload parting zone, as shown in Figure 7.16 (Kenyon and Cooper, 2005). This is supported by modelled near-bed current velocities from the centre of the array, which have a residual direction towards the northwest (Figure 7.7). Areas of mobile sediment waves are present across the array area, particularly in the north and northeast as well as on the north-eastern flanks of sandbank features, as shown on Figure 7.19 (Dove *et al.*, 2017). These sediment waves generally face towards the north and northwest, further supporting net bedload transport towards this direction (Tappin *et al.*, 2011).

7.4.57 A tidal current time-series from the SWLB has been used to estimate the potential sediment mobility of sediments within the array area during a spring and neap tidal phase in May 2022. The bed shear stresses and corresponding critical depth-averaged current speed values required for the transportation of different sediment grain sizes have been calculated using standard methods described by Soulsby (1997), and are provided in Table 7.10.

Table 7.10: Estimated potential sediment mobility within the array area

Size Class	Grain Size (upper boundary) (mm)	Threshold of Bed Shear Stress (N/m^2)	Corresponding Critical Depth-averaged Current Speeds (m/s)	Sediment Mobility[11] (Spring)	Sediment Mobility (Neap)
Granule gravel	4.0	3.007	1.32	0%	0%
Very coarse sand	2.0	1.166	0.908	0%	0%
Coarse sand	1.0	0.481	0.643	5%	0%
Medium sand	0.5	0.262	0.524	13%	0%
Fine sand	0.25	0.189	0.492	15%	0%
Very fine sand	0.125	0.153	0.489	15%	0%
Coarse silt	0.0625	0.120	0.477	16%	0%

7.4.58 Suspended sediment in the region is mainly sourced from the eroding Holderness cliffs, which consist of 67% mud (Tappin *et al.*, 2011). As a result of distance from these terrestrial sources, combined with a generally low fine seabed sediment signature, low surface concentrations of up to 5mg/l were recorded between the period 1998 to 2015 (Cefas, 2016) within the Project array area (see Figure 7.17). Higher values will occur during spring tides and storm conditions, with the greatest concentrations encountered close to the bed.

Offshore Export Cable Corridor

7.4.59 Bedload sediment transport in the most offshore part of the ECC is directed towards the northwest, as in the Project array area. Where the flow is diverted, such as around the margins of the Triton Knoll and Inner Dowsing sandbanks, localised changes to the broad scale sediment transport paths occur (TKOWFL, 2014). The ECC crosses a bedload parting approximately 35km offshore, with bedload transport directed to the south (Figure 7.16). Further inshore, there is a dominant southwards bedload sediment transport direction pathway, with an inshore direction into the Wash. Littoral transport diverges along the Lincolnshire coastline such that sediment is transported towards the mouth of the Wash and the Humber Estuary, with a southward transport direction at the landfall site (Figure 7.16).

7.4.60 Estimates of potential sediment mobility for the Triton Knoll ECC found that silt and sand is expected to be mobile during both spring and neap tides, except for very coarse sand (~1,500µm), which is only expected to be mobile during spring tides. Gravel sized material is predicted to be immobile or only mobilised during the highest spring tides (TKOWFL, 2014).

[11] Percentage of time that sediment is mobile.

7.4.61 Surface SPM levels within the nearshore zone of the Offshore ECC are directly under the influence of terrestrial sources from the Humber Estuary and Holderness Cliffs, such that concentrations reach around 60mg/l, between the period 1998 to 2015 (Cefas, 2016). Maximum values coincide with the winter months when a greater frequency of storm events and fluvial inputs (including storm runoff) can be expected to occur. During the summer months, for example July, maximum values are of the order of 12mg/l (Figure 7.17). There is an east to west gradient in SPM throughout the year, although this is most pronounced during the winter.

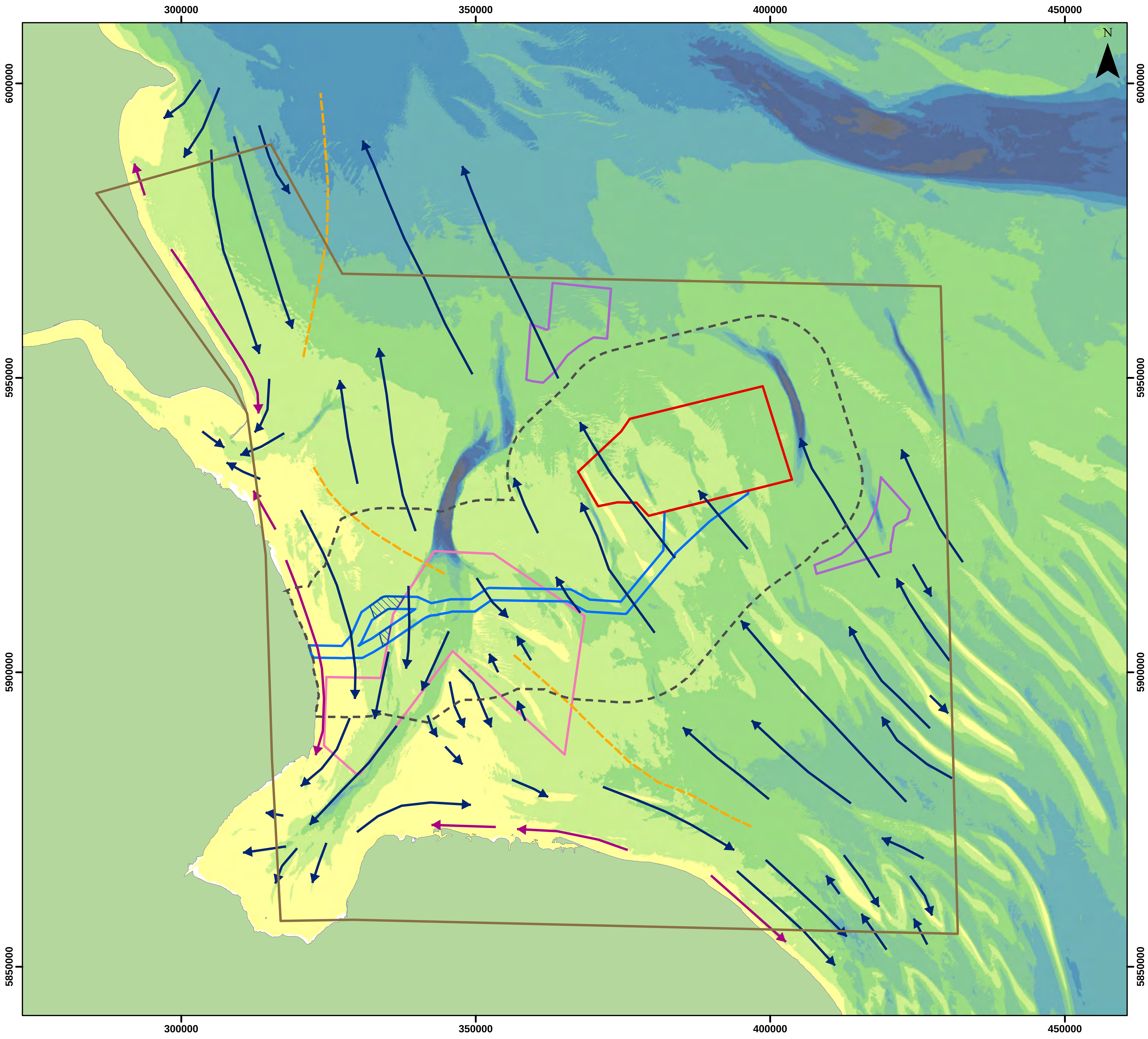
Coast

7.4.62 As outlined previously, the dominant wave direction along the Lincolnshire coast is from the northeast, which produces a net southerly drift of beach material along the Lincolnshire coast and into the Wash (HR Wallingford *et al*., 2002; Environment Agency, 2011). The wave regime is the dominant driver of littoral transport in the nearshore zone and is an important determinant of beach morphology in the area, outlined further in Paragraph 7.4.77

7.4.63 Between 0.1 and 0.3 million cubic metres of sediment derived from the Holderness cliffs is deposited on the Lincolnshire coast each year, in addition to the combined riverine input from the Humber Estuary, which provides approximately 0.1 million m^3/year to the system, and the beach nourishment scheme carried out on the Lincolnshire coast, which represents an important artificial source of sediment to beaches in this area (Environment Agency, 2019a). The majority of the sediments crossing the Humber Estuary are retained at Donna Nook, a sediment sink, with the potential mean longshore transport rate of only 12,000m^3/annum to the south (HR Wallingford *et al*., 2002; HADA, 2012b).

Compensation Areas

7.4.64 Regional-scale assessments indicate a net north-westerly direction of bedload sediment transport for the ANS search areas, as shown in Figure 7.16, with generally low suspended sediment concentrations. The biogenic reef restoration search area crosses a bedload parting, as characterised in paragraph 7.4.59 and shown in Figure 7.16, with increasing suspended sediment concentrations closer to the coast. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.



Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence
- Longshore Transport
- Bed Load Transport
- Bed Load Parting
- SEA Boundary

Depth (m)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100

Longshore Transport, Bed Load Transport and Bed Load Parting from Kenyon and Cooper, 2005

Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:600,000

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Bedload Sediment Pathways
(adapted from Kenyon and Cooper, 2005)

Figure 7.16

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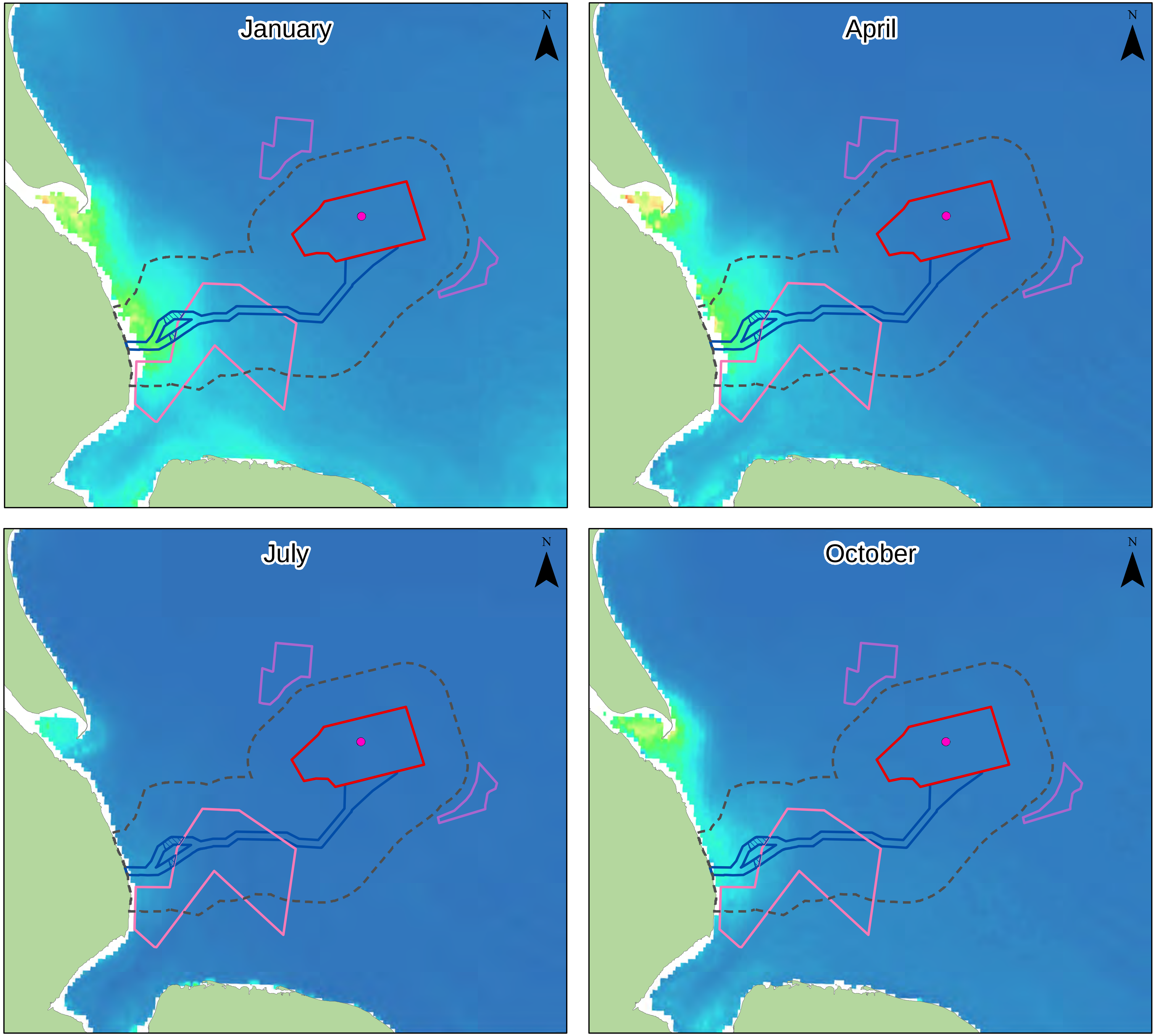


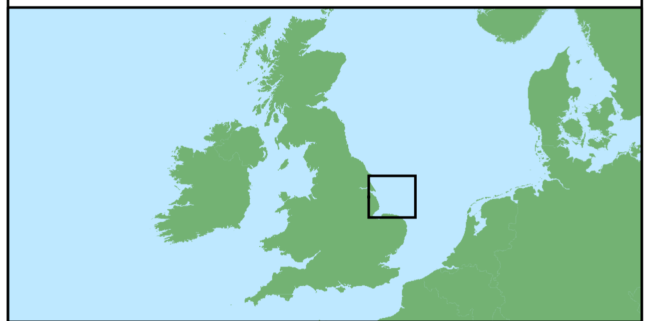
Legend

- Array Area
- Offshore Export Cable Corridor
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence
- Lidar Buoy SWLB059

SPM Concentrations (mg/l) (CEFAS, 1998-2015)

High : 100

Low : 0



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Average Suspended Particulate Matter (Cefas, 2016)

Figure 7.17

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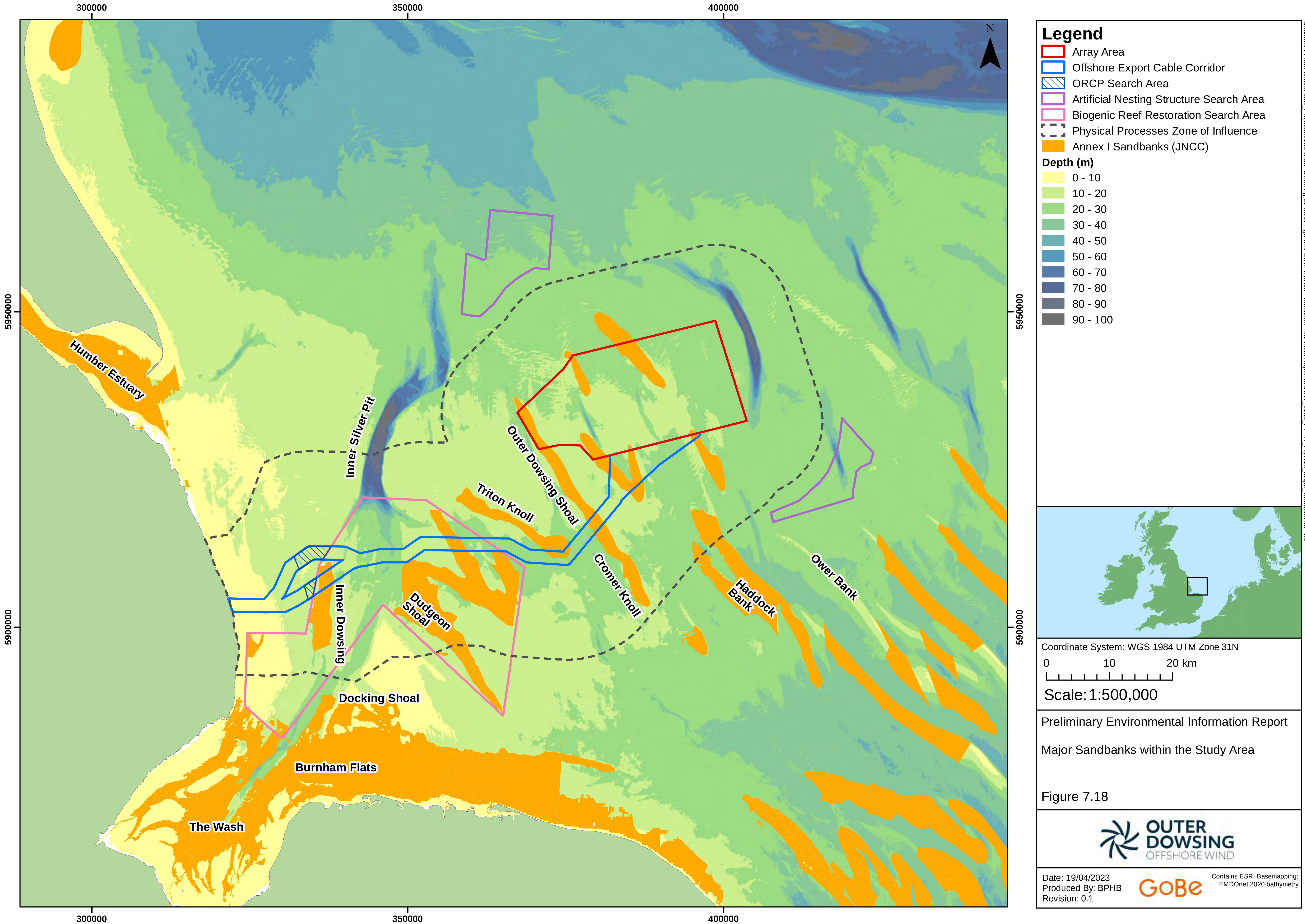
Morphology

7.4.65 The large-scale seabed morphology in the ZoI is characterised by a broad, arcuate, low-relief bathymetric high extending eastwards from the Holderness and Lincolnshire coasts, with a series of large valleys incised approximately perpendicularly into this high (Dove *et al.*, 2017). The ZoI is bordered to the northwest by the Outer Silver Pit, and to the southwest by the major embayment of the Wash. To the south are the Norfolk Banks, a series of northwest to southeast trending sandbanks (Tappin *et al.*, 2011; Figure 7.13). Water depths generally increase eastward from the coast with a gently undulating character, apart from areas of prominent, localised relief formed by a number of large-scale features (Tappin *et al.*, 2011). This conspicuous variation in the region's seabed morphology is largely due to the presence of glacial landforms, with the exception of superficial Holocene sediment banks and waves (Cathie, 2021).

7.4.66 The most prominent of these landforms are the major deeps of Inner Silver Pit and Sole Pit, which form elongate, curvilinear submarine valleys up to 90m deep (Tappin *et al.*, 2011). These 'tunnel valleys', as well as smaller deeps across the study area, are generally aligned with the tidal currents and form geomorphological divides, with sediment being transported parallel to them rather than across them (see Figure 7.16). The floors of these deeps typically remain unfilled with contemporary sediments, and instead have exposures of bedrock and Pleistocene deposits as shown in Figure 7.10 (HADA, 2012a). A series of large-scale sediment banks is also present across the region, generally oriented northwest to southeast, which form sinuous features in the southwest (HADA, 2012a; Figure 7.18). The present-day seabed morphology has been interpreted as the result of a combination of glacial processes and the post-glacial reworking of outwash deposits (Tappin *et al.*, 2011).

Offshore Array

7.4.67 The array area is bound to the eastern (seaward) edge by Sole Pit, and on the western (landward) boundary by the Outer Dowsing Channel, as shown in Figure 7.1. Several sandbanks are located within the array area, as identified on the geophysical survey and shown in Figure 7.19, with heights from seabed of between 10m and 12m, as well as areas of northwest-facing sand waves with wave heights of 2m to 3m. The sandwaves within the array area are complex, characterised both by symmetrical and asymmetrical (lee sides with angles of 5°) sandwaves, some with superimposed megaripples indicating a current direction of north-northwest to south-southeast. In addition, two deeps known as the Dowsing Deeps are located in the centre of the array area, reaching a maximum depth of 45m (LAT). They are aligned in a north-northwest to south-southeast direction and extend up to 10km in length (Figure 7.19; Cathie, 2021). These features are likely to have been formed by similar processes to larger-scale submarine valleys in the region such as the Sole and Inner Silver Pits (Tappin *et al.*, 2011).



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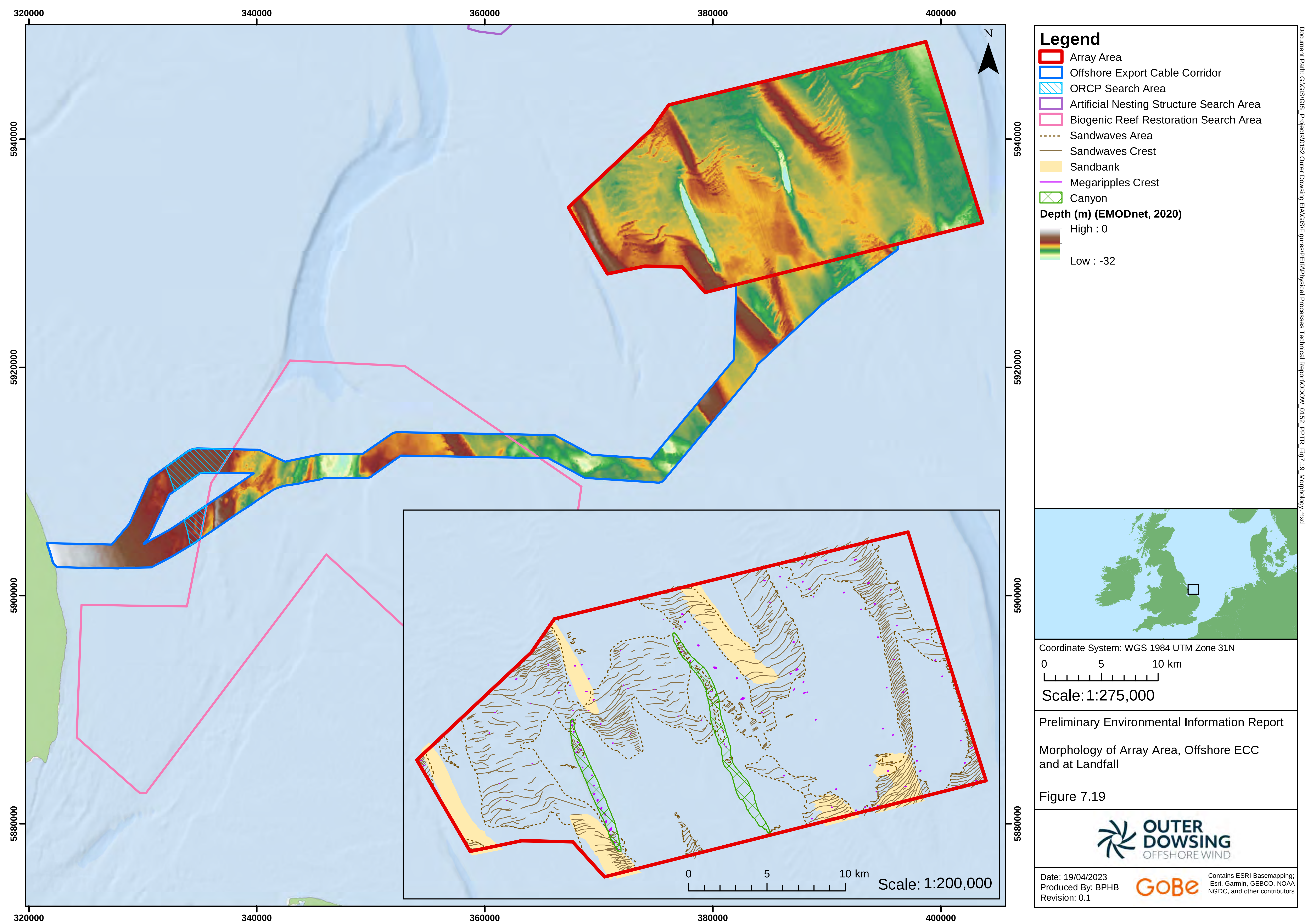
Major Sandbanks within the Study Area

Figure 7.18



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Morphology of Array Area, Offshore ECC and at Landfall

Figure 7.19

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7.4.68 Sole Pit is an offshore depression considered to have formed during Quaternary glaciations, specifically by erosion underneath grounded ice sheets and later by tidal scour (Balson, 1999; Briggs *et al.*, 2007). Approximately 34km long, 2.5km wide and 80m deep, with marginal slope gradients of up to 12°, it is curvilinear in shape, with marginal channels entering at inflexions on its flanks. Jurassic bedrock and earlier Pleistocene deposits are exposed within the Sole Pit either at seabed or beneath a thin sediment cover (Figure 7.10), likely due to erosion increased tidal current speeds (Tappin *et al.*, 2011).

7.4.69 The Outer Dowsing Channel, as well as the other smaller deeps in the region, is mainly linear. It is oriented mainly north-northwest to south-southeast and has steep flanks of between 7° and 10° (Tappin *et al.*, 2011). To the east, partially located within the western extent of the array area, the Outer Dowsing Shoal is a shallow water bank aligned north-northwest to south-southeast, which shallows to a depth of 4m with associated gravel and sand deposits (Museum of London Archaeology, 2010). Combining with Cromer Knoll to the southeast, it forms a single morphologic feature approximately 50km long, rising 5m to 6m above the surrounding seabed, with the steepest flanks towards the southwest (Tappin *et al.*, 2011).

7.4.70 In the southeast of the ZoI and extending into the southern part of the array area, Haddock Bank has an irregular plan shape and exhibits complex fining patterns across an uneven seabed topography (Holmes and Wild, 2003). The surficial medium to very coarse sands exhibit a generally steady decrease in mean grain size from the south-west to the north-east across the bank (Holmes and Wild, 2003).

Offshore Export Cable Corridor

7.4.71 The Race Bank – North Ridge – Dudgeon Shoal and Inner Dowsing Annex I sandbank systems are located across the western half of the offshore ECC (Figure 7.1; Figure 7.18). The former is an example of an active sinusoidal sandbank feature located at a sediment transport bedload parting which exhibits clockwise sediment transport in response to tidal forcing (TKOWFL, 2010). The banks are approximately 15km to 20km long, 1.5km to 3km wide and around 10m high, with sandwaves trending southeast to northwest (HADA, 2012a). Sediment transport modelling undertaken as part of the Race Bank OWF ES illustrated predominantly north-westerly sediment transport pathways across the majority of the site in question (Centrica, 2008). The Inner Dowsing sandbank is considered to be a relict feature, although it has experienced some changes in crest level, and is maintained by tidal currents (Centrica, 2007; JNCC, 2010). It is approximately 14km long with an undulating crest 5m to 10m above the general level of the seabed, with megaripples and sandwaves associated (HADA, 2012a).

7.4.72 Inner Silver Pit, located landward of the array area and on the northern boundary of the offshore ECC, is an elongated, over-deepened and enclosed paleo-valley partly filled with unconsolidated sediments (Figure 7.1). Geological evidence suggests that this bathymetric deep may have been formed by similar processes as Sole Pit, specifically by erosion underneath a grounded ice sheets and later by tidal scour, although Tappin *et al.* (2011) highlights the complex, polygenetic origin of these bathymetric features. It is approximately 38km long, 2.5km wide and 100m deep, with changes in water depth in excess of 60m over 0.5km (Tappin *et al.*, 2011). Proctor *et al.* (2001) suggest that the depth enables tidal currents of sufficient strength to erode most materials, including gravels, that are deposited there, meaning there is little to no sediment accumulation. These sediments are moved along the Inner Silver Pit both to the north and south where they are transported out of the depression by tidal currents. This mechanism is enhanced by wave activity, particularly storm events, which can mobilise sediments throughout most of the deepest parts of the valley (TKOWFL, 2011).

7.4.73 An extensive channel system is located at the southern end of Inner Silver Pit and extends southwards towards the Lynne Deeps and the Wash, interpreted as a glacio-fluvial outwash fan (Tappin *et al.*, 2011). As with other deeps in the area, such as Sole Pit, erosion exposes bedrock at the seabed within the Inner Silver Pit, with chalk strata with a strike of east-northeast to west-southwest well defined on geophysical survey data as shown in Figure 7.12 (Tappin *et al.*, 2011).

Coast

7.4.74 The Lincolnshire coast has a roughly convex outline, bound by the River Humber to the north and the Wash in the south (Environment Agency, 2011). The coast is characterised generally by wide sandy beaches, overlying Bolder Clay, which reduce in width towards the south. Gibraltar Point is located at a distinct orientation change of the coastline into the Wash, and represents a spit maintained by sediment transport from the Lincolnshire and North Norfolk coasts, in addition to that from offshore sandbanks just offshore of Skegness (Environment Agency, 2010). Between Mablethorpe and Skegness, a stretch of coast approximately 24km, the coast has a convex outline and is east-facing, increasing its exposure to the prevailing north-easterly waves. The wave regime is the main driver of sediment transport in the nearshore zone, with the inner depth of closure[12], corresponding to the seaward limit of the upper shoreface, calculated as approximately 7.1m[13].

7.4.75 This section of coast has historically been highly sensitive to wave action and has suffered from long-term erosion, with an estimated erosion rate of approximately 1.3m/year (HADA, 2012a; TKOWFL, 2015). Much of the surficial beach layer has been removed by contemporary hydrodynamic processes, and an annual beach nourishment scheme has been in operation since 1994 (as outlined previously in paragraph 7.4.49), increasing the stability of the coast (Environment Agency, 2019a; 2019b).

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[12] The inner depth of closure marks the transition from upper to lower shoreface and corresponds to the depth where only 12 hours per year wave action is strong enough to produce substantial suspended sediment transport.

[13] Using Houston's (1995) expression of Hallermeier's (1981) formula for inner closure depth, using annual mean significant wave height from the Chapel Point Waverider Buoy (Environment Agency, 2021).

7.4.76 The coast between Anderby Creek and Chapel St Leonards (indicated on Figure 7.1) shows less variability than further north along the coast, although the general trend is erosion and beach levels have been regularly renourished since the late 1990s. The coastal frontage at the proposed landfall site is characterised by the presence of a sandy beach backed by vegetated sand dunes (HADA, 2012a).

7.4.77 Similarly to many beaches along the Lincolnshire coast, there is a distinctive ridge and runnel pattern on the beach as seen on Figure 7.20, with ridges becoming more prominent in calm, low energy conditions following a storm event, and are understood to return sediment removed offshore during storms (Environment Agency, 2011). However, these features vary over spatial and temporal scales, partly driven by variation in the wave regime, with steeper waves during winter transporting sands offshore and less steep waves during summer returning sands to the beach (TKOWFL, 2015). An outfall located in the northern half of the offshore ECC shown on Figure 7.20, acts as a groyne, with sediment build-up on the northern side, reflecting the southerly direction of sediment transport.

7.4.78 Annual topographic surveys, collected by the Environment Agency, have been used to give an indication of morphology and trends along this area of the coast. An analysis of topographic surveys taken between 1991 and 2006 found that the beach nourishment programme successfully led to accreting beach profiles, however between annual nourishment events the beach continued to erode, demonstrating a continuing natural erosional trend (Environment Agency, 2011).

7.4.79 This pattern is ongoing, with the beach at Wolla Bank displaying a distinctive seasonal shift in the foreshore width, the timing of which is affected by nourishment activities. The difference in the foreshore, as shown from surveys, at 25m intervals between 2010 and 2011, before and after nourishment activities is presented in Figure 7.21. Elevation changes between 2011 and 2013, with an erosional trend in the mid-beach region, with accretion on the upper beach are shown in Figure 7.22 and Figure 7.23 (Environment Agency, 2013a). This is thought to be partly due to the pooling of standing water on the beach, which is slow to percolate through the sand and drain into the sea, as indicated on Figure 7.20.

Compensation Areas

7.4.80 The northern ANS search area is located close to the northern reaches of the Inner Silver Pit, characterised previously in paragraph 7.4.72 , and in an area of sandwaves with amplitudes ranging generally from 2m to 8m and crests oriented roughly east-northeast to west-southwest (Tappin *et al.*, 2011; EMODnet, 2020). The southern ANS search area overlies the Coal Pit, a linear submarine valley likely to have formed in a similar manner to other tunnel-valleys across the region, as outlined in paragraph 7.4.66. The morphology within the biogenic reef restoration search area may be generally characterised using the information provided in paragraph 7.4.65 *et seq*. The compensation areas will be assessed within the ES following refinement of the proposed areas and once details of the works to be undertaken have been finalised.

Figure 7.20: Aerial photograph of the beach at transect L048 (see **Error! Reference source not found.**), showing outfall and wet sand with channels running out to sea on the lower beach. Photo from 26 May 2012 (Environment Agency, 2013a). Transect is located in the northern half of the offshore ECC

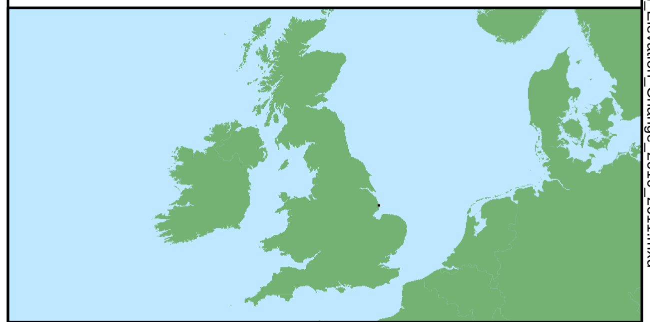
Legend

Offshore Export Cable Corridor

Survey Transects

Difference (m)

- >=4.5
- 3 - 4.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0.25 - 0.5
- -0.25 - 0.25
- -0.5 - -0.25
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- -3.5 - -3
- <= -3.5



Coordinate System: British National Grid

0 100 200 m

Scale: 1:5,000

Preliminary Environmental Information Report

Beach Elevation Change from Surveys at 25m Intervals between 2011 and 2010 (Pre and Post Nourishment Activities) at Wolla Bank

Figure 7.21

OUTER DOWSING OFFSHORE WIND

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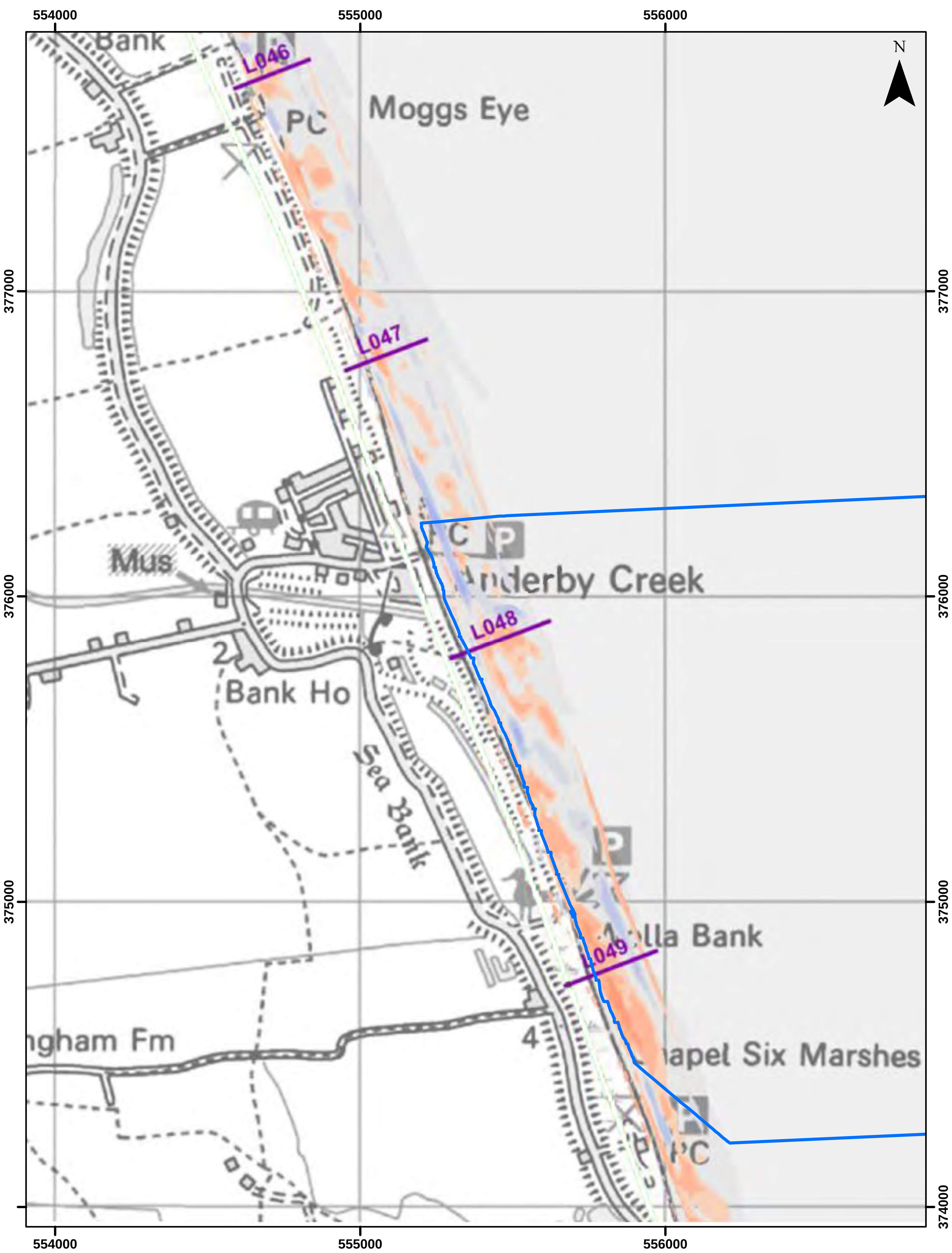

Legend

- Offshore Export Cable Corridor
- Survey Transects

Difference (m)

- >=4.5
- 3 - 4.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0.25 - 0.5
- -0.25 - 0.25
- -0.5 - -0.25
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- -3.5 - -3
- <= -3.5

Coordinate System: British National Grid

0 500 1,000 m

Scale: 1:15,000

Preliminary Environmental Information Report

Beach Elevation Change between 2013 and 2011 between Moggs Eye and Wolla Bank

Figure 7.22

OUTER DOWSING OFFSHORE WIND

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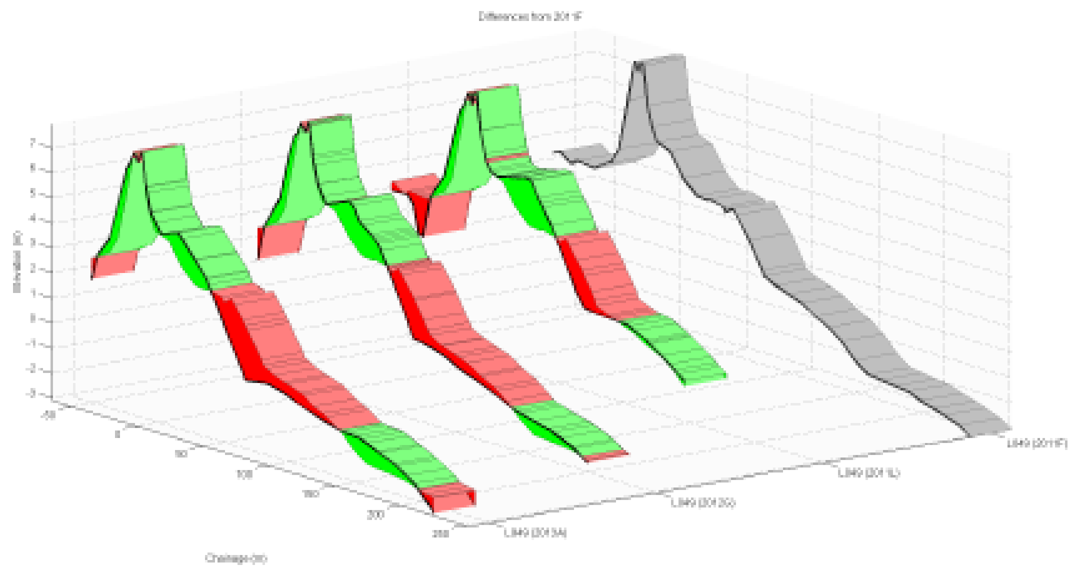


Figure 7.23: Difference in the beach profile at transect L049 (see Figure 7.22) over the last three surveys compared to the beach in June 2011. Lowering is shown in red (Environment Agency, 2013a)

7.5 Future Baseline Environment

7.5.1 A consideration of the future baseline, including the associated variation, is provided in the context of the operating lifetime of the Project. For the current purposes of this scoping document, the Representative Concentration Pathway (RCP) 8.5 (high emissions) scenario (Palmer *et al.*, 2018) has been presented.

7.5.2 UPCP18 suggests an increase in mean sea level (MSL) of over 0.7m by 2100 along the Lincolnshire coast (Palmer *et al.*, 2018). This effect would also redefine both tidal levels and extreme water levels presented in Table 7.6 and Table 7.7, respectively, translating the position of high water further landward and increasing the potential of coastal erosion and flooding events. However, the tidal response along this part of the coastline is predicted to be small (less than 5% change in standard deviation of tide) even under a large time-mean sea level increase (Palmer *et al.*, 2018). Future changes in storm surges are predicted to be undistinguishable from background variation (Lowe *et al.*, 2009).

7.5.3 Wave energy is predicted to decrease, such that by 2100 a decrease larger than 10% has been modelled in the North Sea (RCP8.5 scenario; Bonaduce *et al.*, 2019; Meucci *et al.,* 2020). Inter-decadal variability may be largely due to the influence of local weather in the North Sea (EDF ENERGY, 2021).

7.5.4 The preferred management strategy in place along this part of the coast from 2025 to 2055 is to maintain flood defences in their current position and to raise and improve them to counter sea level rise as required (Environment Agency, 2019a). Beach nourishment is currently ongoing, and it is predicted that the levels and frequency of sand required will increase due to climate change impacts. The proposed strategy over the next 100 years is therefore to implement a combination of rock structures and beach nourishment. This will be a phased process with beach nourishment continuing in its current form until 2024, with structures to be implemented between 2025 and 2030 (Environment Agency, 2019). The launch of the National Coastal Erosion Risk Mapping (NCERM2) in 2023 will provide updates to erosion risks and will be included as part of the ES if available.

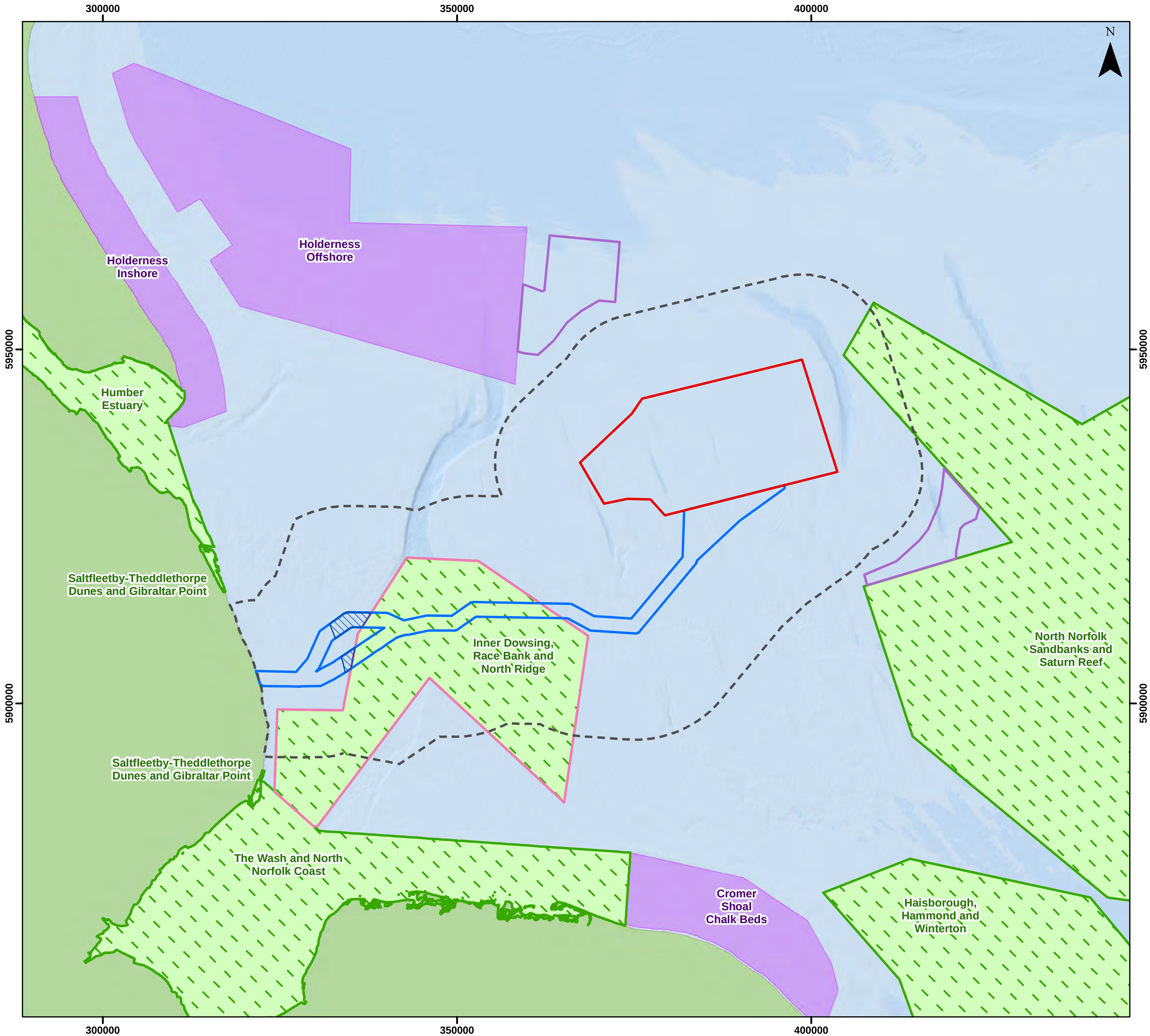
7.6 Designated Sites and Protected Species

7.6.1 Designated sites in the vicinity of the study area, which are designated for the protection and conservation of marine habitats up to MHWS are shown in Figure 7.24. A list of designated sites within the Marine Processes ZoI, with detail of the relevant protected features, is provided below:

- North Norfolk Sandbanks and Saturn Reef Special Area of Conservation (SAC):
  - Reefs; and
  - Sandbanks which are slightly covered by sea water all of the time.
- Inner Dowsing, Race Bank and North Ridge SAC:
  - Reefs; and
  - Sandbanks which are slightly covered by sea water all of the time.

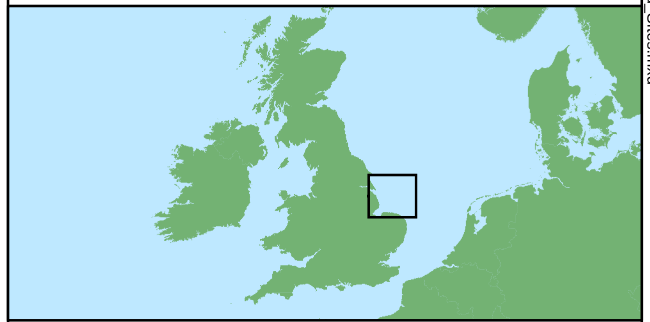
7.6.2 One coastal (Sites of Special Scientific Interest (SSSI)) site is also present:

- Chapel Point – Wolla Bank SSSI: national importance in the Geological Conservation Review.



Legend

- Array Area
- Offshore ECC Boundary
- ORCP Search Area
- Artificial Nesting Structure Search Area
- Biogenic Reef Restoration Search Area
- Physical Processes Zone of Influence
- Marine Conservation Zones
- Special Areas of Conservation



Coordinate System: WGS 1984 UTM Zone 31N

0 10 20 km

Scale: 1:500,000

Preliminary Environmental Information Report

Designated Sites of relevance to Marine Physical Processes

Figure 7.24

OUTER DOWSING OFFSHORE WIND

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