Hornsea Project Four: Preliminary Environmental Information Report (PEIR)

Volume 2, Chapter 1: Marine Geology, Oceanography and Physical Processes

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Annexes

Annex	Heading
1.1	Marine Processes Technical Report

Glossary

Term	Definition
Amphidrome	A nodal point with minimal tidal range.
Commitment	A term used interchangeably with mitigation. Commitments are Embedded Mitigation Measures. Commitments are either Primary (Design) or Tertiary (Inherent) and embedded within the assessment at the relevant point in the EIA (e.g. at Scoping or PEIR). The purpose of Commitments is to reduce and/or eliminate Likely Significant Effects (LSE's), in EIA terms.
Cumulative effects	The combined effect of Hornsea Four in combination with the effects from a number of different projects, on the same single receptor/resource.
Far-field	An area remote from the near-field which is connected by a pathway.
Hornsea Four	The proposed Hornsea Four offshore wind farm project; the term covers all elements within the Development Consent Order (i.e. both the offshore and onshore components).
Inshore	Between the nearshore and offshore. Generally, an area with more shelter than the offshore and where some coastal influences can still be expected.
Isobath	A seabed contour commonly referencing chart datum.
Long-term	Of several years or decades, accounting for year to year variations.
Maximum Design Scenario	A description of the range of possible elements that make up the Hornsea Four design options under consideration, as set out in detail in the project description. This scenario is used to define Hornsea Four for Environmental Impact Assessment (EIA) purposes when the exact engineering parameters are not yet known. This is also often referred to as the "Rochdale Envelope" approach.
Megaripples	A series of mobile bedform formations of sands with crest to crest wavelengths between 0.5 to 25 m.
Mitigation	A term used interchangeably with Commitment(s) by Hornsea Four. Mitigation measures (Commitments) are embedded within the assessment at the relevant point in the EIA (e.g. at Scoping or PEIR).
Mixed layer depth	Depth of surface mixed layer above density stratification formed by thermocline or halocline, if present.
Near-field	The area immediately adjacent to a source of change, such as around the base of a wind turbine foundation.
Nearshore	Generally, a shallow water area closer to the coast than the inshore.
Offshore	Generally, a more exposed and deeper water area away from any coastal influence.
Sandwave	A mobile bedform formation of sands with a crest to crest wavelength greater than 25 m, most likely interspersed with megaripples and with a higher crest height.
Short-term	A sub-set of a repeating cycle, e.g. likely to be a few days, weeks or months but much less than a year.

Acronyms

Acronym	Definition
AODN	Above Ordnance Datum Newlyn
CBRA	Cable Burial Risk Assessment
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
cSAC	candidate Special Areas of Conservation
CD	Chart Datum
CEA	Cumulative effect assessment
DCO	Development Consent Order
EA	Environment Agency
EIA	Environmental Impact Assessment
ERYC	East Riding of Yorkshire Council
ES	Environmental Statement
HAT	Highest Astronomical Tide
HRA	Habitat Regulations Assessment
IECS	Institute for Estuarine and Coastal Studies
JNCC	Joint Nature Conservation Committee
LAT	Lowest Astronomical Tide
LPA	Local Planning Authority
MCZ	Marine Conservation Zone
MDS	Maximum Development Scenario
MFE	Mass Flow Excavator
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLD	Mixed Layer Depth
MMO	Marine Management Organisation
MNR	Mean Neap Range
MSFD	Marine Strategy Framework Directive
MSL	Mean Sea Level
MSR	Mean Spring Range
NCERM	National Coastal Erosion Risk Mapping
NPS	National Policy Statement
NSIP	Nationally Significant Infrastructure Project
OESEA3	UK Offshore Energy Strategic Environmental Assessment, Phase 3
PINS	The Planning Inspectorate
PSMLS	Permanent Service for Mean Sea Level
SSC	Suspended Sediment Concentration
SSSI	Sites of Special Scientific Interest
SAC	Special Area of Conservation
SCI	Sites of Community Importance
SMP	Shoreline Management Plan
SPA	Special Protection Area
SPM	Suspended Particulate Matter
ZoC	Zonal Characterisation

Units

Unit	Definition
km	kilometre
l	litre
m	metre
mg	milligram
mm	millimetre
s	second

1.1 Introduction

1.1.1.1 This chapter of the Preliminary Environmental Information Report (PEIR) presents the results to date of the Environmental Impact Assessment (EIA) for the potential impacts of the Hornsea Project Four offshore wind farm (hereafter Hornsea Four) on Marine Geology, Oceanography and Physical Processes (hereafter referred to as Marine Processes). Specifically, this chapter considers the potential impact of Hornsea Four seaward of Mean High Water Springs (MHWS) during the construction, operation and maintenance, and decommissioning phases.

1.1.1.2 Orsted Hornsea Project Four Limited (the Applicant) is proposing to develop Hornsea Four. Hornsea Four will be located approximately 65 km from the East Riding of Yorkshire in the Southern North Sea and will be the fourth project to be developed in the former Hornsea Zone please see **Volume 1, Chapter 1: Introduction** for further details on the Hornsea Zone). Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm), export cables to landfall, and connection to the electricity transmission network (please see **Volume 1, Chapter 4: Project Description** for full details on the Project Design).

1.1.1.3 This chapter summarises information contained within **Volume 5, Annex 1.1 Marine Processes Technical Report**.

1.2 Purpose

1.2.1.1 The primary purpose of the PEIR is to support the Development Consent Order (DCO) application for Hornsea Four under the Planning Act 2008 (the 2008 Act).

1.2.1.2 The EIA will be finalised following completion of pre-application consultation and the final ES will accompany the application to the Planning Inspectorate (PINS) for Development Consent.

1.2.1.3 This PEIR chapter:

- Presents the existing environmental baseline established from desk studies, and consultation;
- Presents the potential environmental effects on Marine Processes arising from Hornsea Four, based on the information gathered and the analysis and assessments undertaken to date;
- Identifies any assumptions and limitations encountered in compiling the environmental information; and
- Highlights any necessary monitoring and/or mitigation measures which could prevent, minimise, reduce or offset the possible environmental effects identified in the EIA process.

1.3 Planning and Policy Context

1.3.1.1 Planning policy on offshore renewable energy Nationally Significant Infrastructure Projects (NSIPs), specifically in relation to benthic and intertidal ecology, is contained in the Overarching National Policy Statement (NPS) for Energy (EN-1; DECC, 2011a) and the NPS for Renewable Energy Infrastructure (EN-3, DECC, 2011b).

1.3.1.2 NPS EN-1 (DECC, 2011a) applies to any onshore infrastructure situated on the coast that may lead to, or is at risk from, flooding or coastal change (physical change to the shoreline), including provisions for climate change (Paragraph 5.5.5 of NPS EN-1).

1.3.1.3 NSP EN-3 (DECC, 2011b) relates specifically to offshore renwable energy infrastructure. Guidance relevant to marine processes is provided for intertidal, subtidal and the physical environment.

1.3.1.4 **Table 1.1** summarises the NPS marine processes provisions and identifies how these are considered within the PEIR.

Table 1.1: Summary of NPS EN-1 and EN-3 provisions relevant to marine processes.

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the PEIR
Coastal Change *"Where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures"* (Paragraph 5.5.6 of NPS EN-1).	Assessments have been made through consideration of the existing numerical modelling undertaken to support Hornsea Project One, Hornsea Project Two and Hornsea Three. In addition, simple analytical assessments based on standard approaches have been used along with site specific data. Justification of the evidence-based approach is provided in **Volume 5, Annex 1.1: Marine Processes Technical Report** (**Section 2**).
"The direct effects on the physical environment can have indirect effects on a number of other receptors. Where indirect effects are predicted, the Secretary of State) should refer to relevant sections of this NPS and EN 1" (Paragraph 2.6.195 of NPS EN-3).	The predicted changes to the marine physical environment have been considered in relation to indirect effects on other receptors elsewhere in the Environmental Statement, namely **Volume 2, Chapter 2: Benthic and Intertidal Ecology**, **Volume 2, Chapter 3: Fish and Shellfish Ecology**, **Volume 2, Chapter 4: Marine Mammals**, **Volume 2, Chapter 10: Marine Archaeology**, and **Volume 2, Chapter 12: Infrastructure and Other Users**.
"The methods of construction, including use of materials should be such as to reasonably minimise the potential for impact on the physical environment" (Paragraph 2.6.196 of NPS EN-3).	Hornsea Four has proposed designs and installation methods that seek to reasonably minimise significant adverse effects on the marine physical environment. Where necessary, the assessment has set out mitigation to avoid or reduce significant adverse effects.

1.3.1.5 NPS EN-1 and NPS EN-3 also highlight several factors relating to the determination of an application and in relation to mitigation. These are summarised in **Table 1.2** below.

Table 1.2: Summary of NPS EN-1 and EN-3 policy on decision making relevant to Marine Processes.

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the PEIR
Coastal change *"The ES should include an assessment of the effects on the coast. In particular, applicants should assess:* *• The impact of the proposed project on coastal processes and geomorphology, including by taking account of potential impacts from climate change. If the development will have an impact on coastal processes the applicant must demonstrate how the impacts will be managed to minimise adverse impacts on other parts of the coast;* *• The implications of the proposed project on strategies for managing the coast as set out in Shoreline Management Plans (SMPs), any relevant Marine Plans and capital programmes for maintaining flood and coastal defences;* *• The effects of the proposed project on marine ecology, biodiversity and protected sites;* *• The effects of the proposed project on maintaining coastal recreation sites and features; and* *• The vulnerability of the proposed development to coastal change, taking account of climate change, during the project's operational life and any decommissioning period"* (Paragraph 5.5.7 of NPS EN-1).	The effects on the coastline are assessed from **paragraph 1.11.1.45** for open cut trenching across the intertidal at the export cable landfall, **paragraph 1.11.2.5** for scour around cofferdams - landfall area, **paragraph 1.11.2.40** for turbulent wakes: landfall area and **paragraph 1.11.2.60** for changes to waves affecting coastal morphology – overview. **Section 1.7.10** considers climate change influences.
"For any projects involving dredging or disposal into the sea, the applicant should consult the Marine Management Organisation (MMO) at an early stage" (Paragraph 5.5.8 of NPS EN-1).	Consultation was initiated with MMO from the project scoping phase. Further details on topic related consultation are provided in **Section 1.4**.
"The applicant should be particularly careful to identify any effects of physical changes on the integrity and special features of Marine Conservation Zones (MCZs), candidate marine Special Areas of Conservation (cSACs), coastal SACs and candidate coastal SACs, coastal Special Protection Areas (SPAs) and potential Sites of Community Importance (SCIs) and Sites of Special Scientific Interest (SSSI)" (Paragraph 5.5.9 of NPS EN-1).	Flamborough Head SAC is reviewed in the project baseline in **paragraph 1.7.6**. The MCZ Assessment is offered in **Volume 5, Annex 2.3: Marine Conservation Zone Assessment**.
"The Secretary of State should not normally consent new development in areas of dynamic shorelines where the proposal could inhibit sediment flow or have an adverse impact on coastal processes at other locations. Impacts on coastal processes must be managed to minimise adverse impacts on other parts of the coast. Where such proposals are brought forward consent should only be granted where the Secretary of State is satisfied that the benefits (including need) of the development outweigh the adverse impacts" (Paragraph 5.5.11 of NPS EN-1).	The Holderness coast is a dynamic shoreline and is recognised as a key receptor of the marine physical environment. **Section 1.7.3** provides a baseline description and **paragraph 1.11.1.45** a review of potential impacts during landfall works.
"Applicants should propose appropriate mitigation measures to address adverse physical changes to the coast, in consultation with the MMO, the Environment Agency (EA), local planning authorities (LPA)s, other statutory consultees, Coastal Partnerships and other coastal groups, as it considers	Mitigation includes existing design commitments (Co44, Co45, Co83, detailed in **Section 1.8.3**). Further mitigation measures are considered for

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the PEIR
appropriate. Where this is not the case the IPC should consider what appropriate mitigation requirements might be attached to any grant of development consent" (Paragraph 5.5.17 of NPS EN-1).	each potential impact in **Section 1.11**, where a receptor associated with the marine physical environment is identified.
"The Applicant should consult the EA, MMO and Centre for Environment, Fisheries and Aquaculture Science (Cefas) on methods for assessment of impacts on physical processes" (Paragraph 2.6.191 and 2.6.192 of NPS EN-3).	Consultation with these organisations was initiated from the project scoping phase and continued through the Evidence Plan Marine Ecology & Processes topic meetings. Further details on topic related consultation are provided in **Section 1.4**.
"The methods of construction, including use of materials should be such as to reasonably minimise the potential for impact on the physical environment" (Paragraph 2.6.196 of NPS EN-3).	Hornsea Four has proposed designs and installation methods that seek to reasonably minimise the potential for impact on the physical environment. The assessment recognises design measures as commitments (**Section 1.8.3**) as well as specific mitigation to **Section 1.11** where an impact may lead to an adverse effect.
Intertidal	
"An assessment of the effects of installing cable across the intertidal zone should include information, where relevant, about: *• disturbance during cable installation and removal (decommissioning);* *• increased suspended sediment loads in the intertidal zone during installation; and* *• predicted rates at which the intertidal zone might recover from temporary effects"* (Paragraph 2.6.81 of NPS EN-3).	Landfall works across the intertidal related to open cut trenching are reviewed in **paragraph 1.11.1.45**.
"Where adverse effects are predicted during the installation or decommissioning of cables, in coming to a judgement, the IPC should consider the extent to which the effects are temporary or reversible" (Paragraph 2.6.86 of NPS EN-3).	Cables installation effects are considered from **paragraph 1.11.1.45** to **1.11.1.77**. Decommissioning issues are considered in **Section 1.11.3**.
"Effects on intertidal habitat cannot be avoided entirely. Landfall and cable installation and decommissioning methods should be designed appropriately to minimise effects on intertidal habitats, taking into account other constraints" (Paragraph 2.6.88 of NPS EN-3).	Effects on intertidal habitats are considered in **Volume 2, Chapter 2: Benthic and Intertidal Ecology**.
Subtidal	
"Where necessary, assessment of the effects on the subtidal environment should include: *• loss of habitat due to foundation type including associated seabed preparation, predicted scour, scour protection and altered sedimentary processes;* *• environmental appraisal of inter-array and cable routes and installation methods;* *• increased suspended sediment loads during construction; and* *• predicted rates at which the subtidal zone might recover from temporary effects"* (Paragraph 2.6.113 of NPS EN-3).	Seabed preparation (sandwave clearance and levelling) which may lead to increase suspended sediment loads is reviewed from **paragraph 1.11.1.3** and seabed installation activities related to drilling and trenching are considered from **paragraph 1.11.1.42**. Scouring is assessed from **paragraph 1.11.2.2**.

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the PEIR
Physical Environment	
"Assessment should be undertaken for all stages of the lifespan of the proposed wind farm in accordance with the appropriate policy for offshore wind farm EIAs" (Paragraph 2.6.190 of NPS EN-3).	The PEIR impact assessment is inclusive to construction, operation and decommissioning phases. A summary of the impacts assessed is offered in **Table 1.14.**
"The assessment should include predictions of the physical effect that will result from the construction and operation of the required infrastructure and include effects such as the scouring that may result from the proposed development" (Paragraph 2.6.194 of NPS EN-3).	Scouring is assessed from **paragraph 1.11.2.2.**
"Mitigation measures which the IPC should expect the applicants to have considered include the burying of cables to a necessary depth and using scour protection techniques around offshore structures to prevent scour effects around them. Applicants should consult the statutory consultees on appropriate mitigation" (Paragraph 2.6.197 of NPS EN-3).	Mitigation includes existing design commitments (Co44, Co45, Co83, detailed in **Section 1.8.3**) with cable burial being the preferred option. A cable burial risk assessment (CBRA), and provisions for scour protection around offshore structures is also outlined in **Volume 1, Chapter 4: Project Description**.

1.3.2 Other relevant plans and policies

1.3.2.1 Other policies which are relevant to marine processes include:

- The East Marine Plans (MMO, 2015);
- The Marine Strategy Framework Directive (MSFD); and
- The UK Marine Policy Statement (HM Government, 2011).

1.3.2.2 Key provisions of these policies are set out in **Table 1.3**, along with details as to how these have been addressed within the assessment.

1.3.2.3 The overarching goal of the MSFD is to achieve 'Good Environmental Status' (GES) by 2020 across Europe's marine environment. Although construction of Hornsea Four will not have commenced by 2020, the goals will very likely remain in place after this date. Annex I of the Directive identifies 11 high level qualitative descriptors for determining GES. Those descriptors relevant to the marine processes assessment for Hornsea Four are listed in **Table 1.3**, including a brief description of how and where these have been addressed in the assessment.

1.3.2.4 A full list of supporting guidance and best practice for the assessment of marine processes is provided within **Volume 5, Annex 1.1: Marine Processes Technical Report** (**Section 2.7**).

Table 1.3: Summary of other plans and policies relevant to marine processes.

Summary of other plans and policies	How and where considered in the PEIR
MFSD	Marine process assesses anticipated changes to the seabed as a pathway. The effects on this pathway on

Summary of other plans and policies	How and where considered in the PEIR
MSFD high-level descriptors of Good Environmental Status relevant to marine processes. *"Descriptor 6: Sea floor integrity: Seafloor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected."*	marine ecosystems are considered in **Volume 2, Chapter 2: Benthic and Intertidal Ecology**.
"Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems."	Semi-permanent effects are considered during the operational phase of Hornsea Four, notably issues related to the Flamborough Front which are considered from **paragraph 1.11.2.50**. After decommissioning any semi-permanent effects would ceases.
Marine Plans East Inshore and East Offshore Marine Plans – ECO1: *"Cumulative impacts affecting the ecosystem of the East marine plans and adjacent areas (marine, terrestrial) should be addressed in decision-making and plan implementation."*	Cumulative effects are considered in **Section 1.12**.
East Inshore and East Offshore Marine Plans – MPA1: *"Any impacts on the overall marine protected area (MPA) network must be taken account of in strategic level measures and assessments, with due regard given to any current agreed advice on an ecologically coherent network."*	The predicted changes to marine processes have been considered in relation to indirect effects (and pathways of effects) on other receptors elsewhere in the Environmental Statement, in particular; **Volume 2, Chapter 2: Benthic and Intertidal Ecology**, **Volume 2, Chapter 3: Fish and Shellfish Ecology**, **Volume 2, Chapter 4: Marine Mammals**, **Volume 2, Chapter 10: Marine Archaeology**, and **Volume 2, Chapter 12: Infrastructure and Other Users**.
UK Marine Policy Statement *"Coastal change and coastal flooding are likely to be exacerbated by climate change, with implications for activities and development on the coast. These risks are a major consideration in ensuring that proposed new developments are resilient to climate change over their lifetime.* *Account should be taken of the impacts of climate change throughout the operational life of a development including any de-commissioning period."*	**Section 1.7.10** considers climate change influences.
"Interruption or changes to the supply of sediment due to infrastructure has the potential to affect physical habitats along the coast or in estuaries."	Potential changes to sediment supply (pathways) due to the operational presence of seabed infrastructure (in particular rock berms affecting the nearshore pathways) are considered in **paragraph 1.11.2.28** onwards. The potential for habitat change/ loss is discussed within **Volume 2, Chapter 2: Benthic and Intertidal Ecology**.

1.4 Consultation

1.4.1.1 Consultation is a key part of the DCO pre-application process. Consultation regarding Marine Processes has been conducted through Evidence Plan Technical Panel meetings as and the EIA scoping process (Hornsea Four, 2018). An overview of the project consultation process is presented within **Volume 1, Chapter 6: Consultation**.

1.4.1.2 A summary of the key issues raised during consultation to date, specific to Marine Processes, is outlined below in **Table 1.4**, together with how these issues have been considered in the production of this PEIR.

Table 1.4: Consultation Responses.

Consultee	Date, Document, Forum	Comment	Where addressed in the PEIR
Cefas, Natural England and Marine Management Organisation (MMO)	24 October 2018, Marine Processes & Ecology Technical Panel Meeting One (Pre-Scoping)	Review post-construction wave data from HOW01 to test the validity of previous wave modelling.	A review of wave data during the construction period of Hornsea Project One is given in **Appendix C** of **Volume 5, Annex 1.1 Marine Processes Technical Report**.
PINS	26 November 2018, Scoping Opinion	Scouring around foundations during operation to remain scoped in when scour protection measures not installed prior to foundation installation.	A scour assessment on this basis is provided in **paragraph 1.11.2.13** for structures in the HVAC booster area and **paragraph 1.11.2.19** for the offshore array.
PINS	26 November 2018, Scoping Opinion	Changes to sediment pathways during operation to remain scoped in for sediment pathways from Smithic Bank inshore to the level of MHWS.	Potential changes to nearshore sediment pathways are discussed from **paragraph 1.11.2.28**.
PINS	26 November 2018, Scoping Opinion	Study areas - clearly present and explain the study area used to inform the assessment. Information sources should be referenced, and it should be clear how any such information has influenced the chosen study areas. The ES should include a figure(s) to depict the extent of the study areas the location of surveys undertaken.	**Section 1.5** explains the basis of the study area with additional detail provided in **Section 2.3** of **Volume 5, Annex 1.1 Marine Processes Technical Report**.
Environment Agency	26 November 2018, Scoping Opinion	Consideration to smothering with fine suspended sediments within MCZs due to works in the ECC.	**Paragraph 1.11.1.55** assesses dispersion of fine sediments from trenching along the offshore ECC, including the nearshore environment. Smothering of benthic ecology is considered in **Volume 2,**

Consultee	Date, Document, Forum	Comment	Where addressed in the PEIR
			Chapter 2: Benthic and Intertidal Ecology.
Environment Agency	26 November 2018, Scoping Opinion	No mention of nearshore processes within landfall search area.	Nearshore processes are described in **Section 1.7.2**.
Environment Agency	26 November 2018, Scoping Opinion	When considering cumulative impacts on the wave climate, all Hornsea project areas should be included.	The issue of wave climate is considered from **paragraph 1.11.2.72**.
Environment Agency	26 November 2018, Scoping Opinion	The near shore seabed data in Table 6-1 is fairly old (2014) and should be reconsidered, with thought given to the current validity of these data given that this is quite an active coastline.	Existing data in the nearshore is now supplemented with the 2018 geophysical survey data, summarised in **Section 1.6.3**.
MMO	26 November 2018, Scoping Opinion	Due to the sensitivities of the Holderness coastline, which is rapidly eroding in some places, sediment pathways should be scoped in from Smithic Bank inshore to the level of MHWS.	Nearshore sediment pathways are scoped in and assessed from **paragraph 1.11.2.81**.
MMO	26 November 2018, Scoping Opinion	The process of scouring around structures can be scoped out. However, the inclusion of the laying of scour protection measures, including particle size, type, shape and timings of installation, should be scoped in.	A scour assessment is provided from **paragraph 1.11.2.13** for structures in the HVAC booster area and from **paragraph 1.11.2.19** for the offshore array on the basis that scour protection follows the installation of foundations. Scour protection material is described in **Volume 1 Chapter 4: Project Description**.
MMO	26 November 2018, Scoping Opinion	Site specific particle size data is required for coastal process impacts with regard to seabed levelling and suspended sediment impacts.	The 2018 geophysical survey includes particle size data and supplements other data of their type from GeoIndex and the Dogger Bank nearshore geophysical surveys (**Table 1.5**).
Natural England	26 November 2018, Scoping Opinion	A thorough consideration should be given to carrying out a realistic assessment as to how cables will be buried and what level of protection will be needed where cables cannot be buried. Cable crossings, mobile areas of seabed and harder substrates have all	**Table 1.13** provides details of project commitments which includes Co83 for cable burial as the preferred option. A CBRA is also outlined in **Volume 1, Chapter 4: Project Description**.

Consultee	Date, Document, Forum	Comment	Where addressed in the PEIR
		presented issues for cable burial and remedial works in other wind farms.	
Natural England	26 November 2018, Scoping Opinion	Consideration should be given to the likelihood of scour/cable protection being removed or left *in situ*.	**Volume 1 Chapter 4: Project Description** identifies that only foundations will be removed during the decommissioning phase.
Natural England	26 November 2018, Scoping Opinion	A clear realistic assessment of seabed preparation, levelling and boulder clearance should be conducted.	Seabed preparation is assessed from **paragraph 1.11.1.3**.
Natural England	26 November 2018, Scoping Opinion	Further clarification of the rationale behind the chosen physical process features considered as potential receptors before we can reach a conclusion on their validity.	**Table 1.7** provides details of features of interest across the landfall, **Table 1.9** for features relevant to the offshore ECC and **Table 1.11** for the offshore array area.
Natural England	26 November 2018, Scoping Opinion	Further detail on construction activities on landfall should also be provided i.e., the size and location of exit pits, if a cofferdam will be needed, and details around intertidal access since these activities might interfere with sediment transport along the coast and within the nearshore environment.	These details are given in **Volume 1 Chapter 4: Project Description**.
Natural England	26 November 2018, Scoping Opinion	Further consideration should be given to the nearshore environment, which might highlight other potential receptors, such as the Humber Estuary, Flamborough Head SAC/SPA, Holderness Inshore MCZ or geological SSSIs along the Holderness Coast. In previous projects the impact of suspended sediment not correctly assessed has shown to deposit in Bridlington Bay and causing unexpected effects hence the need to better understand the nearshore processes and account for those when identifying potential receptors.	Issues related to suspended sediment from seabed preparation (sandwave clearance and levelling) are assessed from **paragraph 1.11.1.3** and for seabed installation (trenching and drilling) from **paragraph 1.11.1.42**.
Natural England	26 November 2018, Scoping Opinion	All impacts on designated sites (i.e. direct and indirect, temporary and permanent) should be considered and addressed as far as possible.	Impacts on designated sites are provided in **Volume 5 Annex 2.3: Marine Conservation Zone Assessment**.

Consultee	Date, Document, Forum	Comment	Where addressed in the PEIR
Natural England	26 November2018, Scoping Opinion	Based on potential blockage related impacts to the (i) shoreline, (ii) offshore sandbanks and the (iii) Flamborough Front only resulting in effects of negligible or minor adverse significance for the other projects on the Hornsea zone, a simple assessment was proposed for Hornsea Four. However, a more detailed assessment may be required if the simple assessment indicates any issues that might require further consideration.	Turbulent wakes resulting from blockage effects are assessed from **paragraph 1.11.2.48**, including the potential effects on the Flamborough Front. The simple assessment presented here does not identify a requirement to assess issues in any more detail.
Natural England	26 November 2018, Scoping Opinion	Scouring around turbines should be scoped in until it is determined if scour protection will be placed prior to foundation installation.	A scour assessment on this basis is provided in **paragraph 1.11.2.13** for structures in the HVAC booster area and **paragraph 1.11.2.19** for the offshore array.
Natural England	26 November 2018, Scoping Opinion	More evidence required on why assessments for Hornsea Projects One, Two and Three concluded minor adverse significance to establish if the conditions and reasoning supporting those assessments are also applicable to Hornsea Four. A simple assessment might be able to demonstrate that the conclusions reached for the other projects in the Hornsea zone are also applicable to Hornsea Four. Furthermore, minor adverse impacts should not be automatically scoped out since in this way these impacts will not be considered cumulatively and in-combination and therefore overlooked in these assessments.	**Appendix A** of **Volume 5, Annex 1.1 Marine Processes Technical Report** compares the environmental conditions between Hornsea Project One, Two and Hornsea Three with Hornsea Four. In addition, the final options for Hornsea Project One and Project Two are now based on a fewer number of smaller foundations, than assessed within their respective EIA, which would further reduce their potential environmental impact.
Cefas, MMO and Natural England	12 December 2018, Marine Processes & Ecology Technical Panel Meeting Two (Post-Scoping)	Review of scoping comments, discussions on the scope of the Hornsea Four PEIR and the evidence-based approach	**Appendix A** of **Volume 5, Annex 1.1 Marine Processes Technical Report** compares the environmental conditions between Hornsea Project One, Two and Hornsea Three with Hornsea Four. In addition, the final options for Hornsea Project One and Project Two are now based on a fewer number of smaller foundations, than assessed within their respective EIA, which would

Consultee	Date, Document, Forum	Comment	Where addressed in the PEIR
			further reduce their potential environmental impact.
Cefas, MMO and Natural England	30 April 2019, Marine Processes & Ecology Technical Panel Meeting Three	Discussion on the operational wave monitoring analysis that had been undertaken.	**Appendix A** of **Volume 5, Annex 1.1 Marine Processes Technical Report** compares the environmental conditions between Hornsea Project One, Two and Hornsea Three with Hornsea Four. In addition, the final options for Hornsea Project One and Project Two are now based on a fewer number of smaller foundations, than assessed within their respective EIA, which would further reduce their potential environmental impact.

1.4.1.3 As identified in **Volume 1, Chapter 3: Site Selection and Consideration of Alternatives** and **Volume 1, Chapter 4: Project Description**, the Hornsea Four design envelope has been refined significantly and is anticipated to be further refined for the DCO submission. This process is reliant upon stakeholder consultation feedback.

1.4.1.4 Design amendments to landfall are of relevance to this chapter. The Hornsea Four PEIR boundary currently comprises two landfall options (shown in **Volume 1, Chapter 4: Project Description, Figure 4.13**), which have been assessed in the respective PEIR receptor chapters A decision on the preferred landfall (A3 or A4) will be made post-PEIR and the Project Description and assessments updated for the ES and DCO for the preferred 40,000 m^2 compound within the landfall location.

1.4.1.5 This process will be based on the results of the PEIR assessments, in addition to stakeholder feedback and suggestions.

1.5 Study area

1.5.1.1 The Hornsea Four marine processes study area encompasses the localised (near-field) sources created by offshore project activities that have a potential to disturb sediments as well as structures placed onto the seabed that may locally block waves and flows, as well as the pathways which have the capacity to extend effects from a source across a wider area (the far-field). In addition, where there are adjacent activities which may also create a similar type of effect over a similar period then this is also considered to be part of the study area in order that cumulative effects between such activities can be considered.

1.5.1.2 The study area is described for landfall, offshore ECC and offshore array areas to recognise the different types of project activity and the different types of marine process environment.

1.5.1.3 **Figure 1.1** presents the spatial extent of the marine processes study area for Hornsea Four, along with sub-areas established for the landfall, offshore ECC and offshore array area. Further details on the development of the study area are provided in **Section 2.3** of **Volume 5, Annex 1.1 Marine Processes Technical Report**.

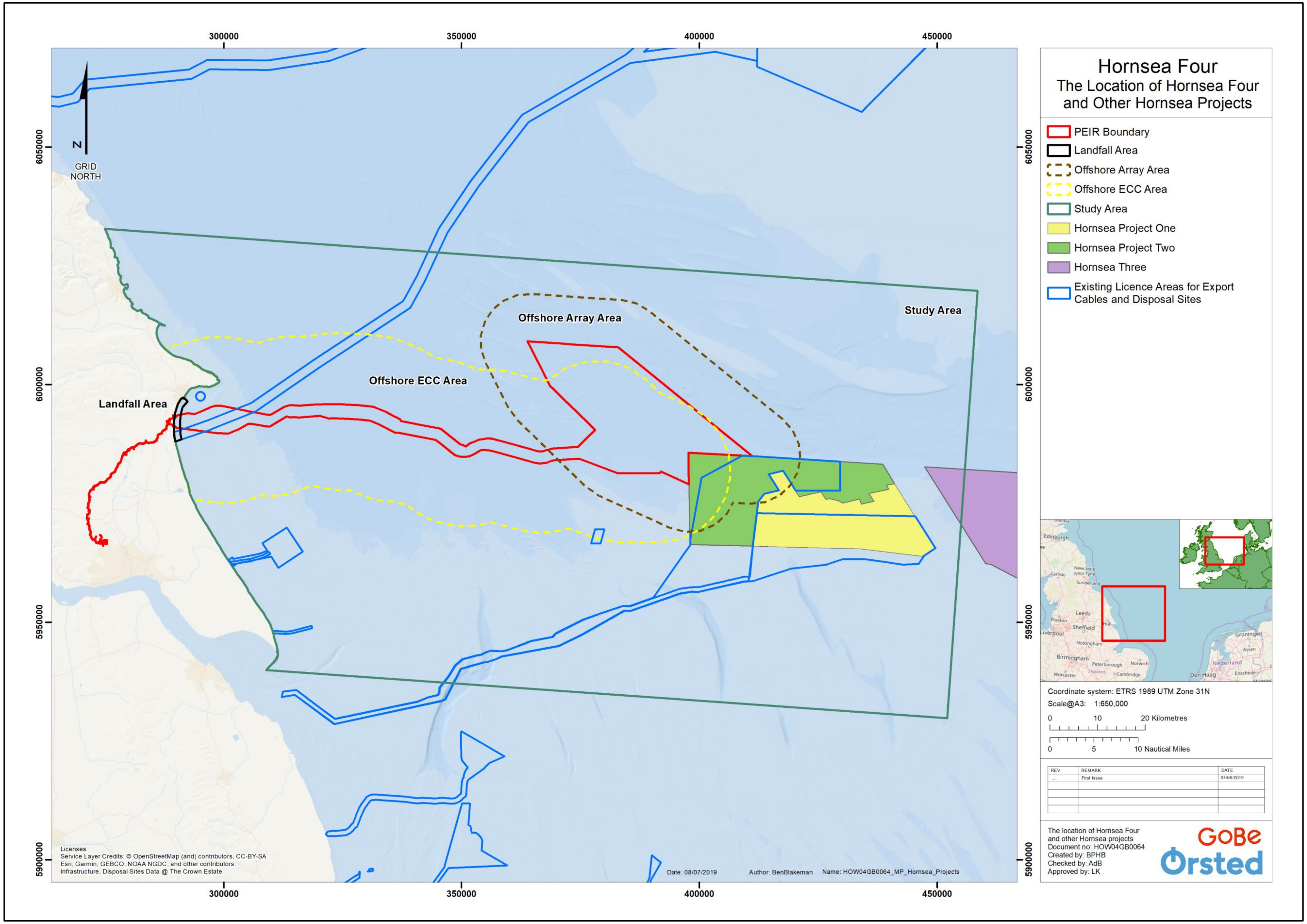

Figure 1.1: Marine Processes study area and sub-areas (not to scale).

1.6 Methodology to inform baseline

1.6.1 Overview

1.6.1.1 The Marine Processes topic has been developed using an evidence-based approach. This approach is described in Ørsted (2018) which has been shared with statutory consultees and was presented at the first meeting of the Marine Ecology & Processes Evidence Plan technical panel on 12 September 2018.

1.6.1.2 The application of an evidence-based approach to offshore wind farms is proven to be acceptable where the area of development is already provided with sufficient baseline data and information, and where comparable and adjacent developments can be drawn upon to offer relevant assessments of the likely effects on the physical environment. The evidence-based approach is consistent with present best practice for conducting coastal process studies (ABPmer and HR Wallingford, 2009). Further details on the evidence-based approach are provided in **Volume 5, Annex 1.1 Marine Processes Technical Report**.

1.6.2 Desktop Study

1.6.2.1 A desktop study of the marine processes baseline has been informed by a collation of data and information which covers the immediate landfall, offshore ECC and offshore array areas, as well as the surrounding areas which may be affected by or exert an important influence on the wind farm infrastructure. The key data and information are summarised in **Table 1.5**.

Table 1.5: Key Sources of Marine Processes Data.

Source	Summary	Coverage of Hornsea Four development area
Zonal characterisation (ZoC) including metocean, geophysical and benthic surveys (SMart Wind, 2012)	Initial broad-scale evaluation of the (former) Hornsea zone to help establish areas for development. Metocean data offers up to 12 months of water level, flow, wave, temperature, salinity and SSC observations.	Includes coverage of Hornsea Four array area and adjacent projects (Hornsea Project One, Hornsea Project Two and Hornsea Three).
Existing wave and tidal models (SMart Wind, 2015a), (SMart Wind, 2015b), and (Ørsted, 2018)	Wave and tidal models previously calibrated against ZoC metocean survey data provide existing outputs offering an expanded view of baseline conditions as well as a quantified assessment of potential impacts. Model outputs serve as a means of supporting simplified approaches for Hornsea Four.	Full study area up to the coastline.
Atlas of UK Marine Renewable Energy (DECC, 2008)	Synoptic description of waves, tidal levels and currents to complement baseline information from existing models and measurements.	Full study area up to the coastline.

Source	Summary	Coverage of Hornsea Four development area
Hornsea Project One Offshore Wind Farm (hereafter Hornsea Project One) operational wave monitoring	Wave measurements from north and south of Hornsea Project One array from pre-construction, construction and post-construction periods of foundations.	Hornsea Project One, slightly to east of Hornsea Four.
The European Marine Observation and Data Network (EMODnet) for thematic mapping of bathymetry, seabed substrate and geology	Baseline regional mapping of bathymetry, seabed substrate and sub-surface geology to provide an overview of seabed conditions, complementing site specific surveys.	Full study area up to the coastline.
United Kingdom Hydrographic Office (UKHO)	Digital hydrographic surveys, complements EMODnet bathymetry (mainly derived from same datasets) and enables derivation of greater spatial detail.	Full study area up to the coastline.
East Riding Beach Monitoring	Long-term monitoring of beach profiles along Holderness Coast from cliff line to low water.	Landfall area and wider coastline with profiles at 500 m spacing.
GeoIndex	Database of analysed surficial sediment samples providing quantification of sand, gravel and mud content, directly complements EMODnet seabed substrates	Full study area up to the coastline.
Southern North Sea Sediment Transport Study (HR Wallingford, CEFAS/UEA, Posford Haskoning, and Brian D'Olier, 2002)	An in-depth review of the sediment transport regime across the Southern North Sea, including net transport directions deduced from bedform indicators.	Full study area up to the coastline
Dogger Bank Creyke Beck Offshore Wind Farm inshore cable corridor geophysical surveys (Forewind, 2013)	Includes comprehensive mapping of seabed bathymetry, sediment lithologies, seabed features, sub-bottom profiles and particle size data.	Overlapping with nearshore part of offshore ECC.
UK Offshore Energy Strategic Environmental Assessment. Phase 3 (OESEA3) (DECC, 2016)	A regional sea description with summaries of geology, processes and sedimentology.	Full study area up to the coastline.
Sand banks, sand transport and offshore wind farms (Kenyon & Cooper, 2005)	Complements the Southern North Sediment Transport Study and includes UK-wide and regional perspective of net bedload sediment pathways.	Full study area up to the coastline.
Suspended sediment mapping (CEFAS, 2016)	Synoptic description of seasonal (monthly) variation in (surface) suspended particulate matter derived from long-term satellite observations.	Full study area up to the coastline.
3D temperature modelling from Copernicus Marine Environmental Monitoring Service	Detailed description of stratified and non-stratified water bodies to determine seasonal development of the Flamborough Front.	Full study area up to the coastline.

Source	Summary	Coverage of Hornsea Four development area
Flamborough Head to Gibraltar Point Shoreline Management Plan (Scott Wilson, 2010)	Provides coastal process understanding of shoreline behaviour.	Landfall, shoreline and immediate sub-tidal.
Nearshore seabed survey: Flamborough Head to Spurn Point (Channel Coastal Observatory, 2014)	Detailed mapping of landfall area	Landfall, shoreline and immediate sub-tidal.
UKCP18	Climate change projections	National scale resource. Ability to access data around the coast at specific points.

1.6.3 Site-Specific Surveys

1.6.3.1 To help inform the environmental baseline a geophysical survey was undertaken to cover the offshore ECC and offshore array areas. To date the geophysical survey has been able to complete the landfall area, parts of the offshore ECC and the offshore array area. The final parts of the offshore ECC survey are planned for completion in 2019 and will be included in the ES to accompany the DCO application.

1.6.3.2 The geophysical data includes details of bathymetry, sandwave crests, lithology of surface sediments, particle size data from grab samples and sub-bottom profiles.

1.7 Baseline environment

1.7.1 Overview

1.7.1.1 The baseline environmental description of the study area represents conditions that are expected to prevail without any development taking place and for an equivalent period as the Hornsea Four lifetime of 35 years. The following sections provide a summary of the baseline against which potential effects of the development are expected to occur and to help determine the magnitude and duration of any impacts.

1.7.1.2 A summary baseline description is provided for each of the study sub-areas defined under **Section 1.5** and presented in **Figure 1.1**. A more detailed description of the baseline is also provided in **Volume 5, Annex 1.1 Marine Processes Technical Report**.

1.7.2 Existing baseline – landfall study area

General description

1.7.2.1 The landfall study area is an open inter-tidal sandy beach, backed by soft cliffs, gently shelving into a shallow sub-tidal environment. The sands can be thin in places exposing an underlying clay till. This environment mainly responds to wave driven processes which erode the cliffs and transport mobile sandy sediments along the beach. **Plate 1** provides a typical view of the intertidal area at the landfall.

Plate 1: View of intertidal area at landfall (from IECS, 2019).

Intertidal sediments

1.7.2.2 A walkover survey of the landfall works area qualitatively described beach material as coarse sands, and in places this thins to reveal hard boulder clay (IECS, 2019). Any trenching works on the beach are therefore likely to be into the underlying clay.

Subtidal sediments

1.7.2.3 The 2018 offshore ECC geophysical survey identifies the subtidal sediments as sand with patches of gravelly sand. In places, this cover of sand thins to expose underlying glacial till (stiff glacial till of Bolders Bank Formation) (Bibby HydroMap, 2019).

Water levels

1.7.2.4 Water levels (tide and non-tidal) in the landfall area are expected to be equivalent to values for Bridlington (the closest reference location for tides). The mean spring range (MSR) for Bridlington is around 5 m and a mean neap range (MNR) of around 2.4 m. During periods of storms and surges, there may be additional non-tidal influences that either increase or decrease tidal levels. High waters on spring tides and periods of positive surge influence enable waves to reach the base of the soft cliffs. Further details on water levels are provided in **Section 3.2.2** of **Volume 5, Annex 1.1 Marine Processes Technical Report**.

Waves

1.7.2.5 Waves shoal from the offshore ECC onto the shallowing sub-tidal and in very shallow water they typically break to form a surf zone. This process creates longshore (wave-driven) currents which transport sandy material along the shore (longshore drift).

1.7.2.6 Flamborough Head provides some local sheltering to the landfall area for waves from northerly sectors and shallow depths across Smithic Sands provide some additional sheltering to Bridlington.

Sediment transport – longshore drift

1.7.2.7 The net annual longshore drift (sum of all drift rates and directions in a year) is effectively nil at the location of the landfall, with a balance of material transported to the north and south. South of Barmston, the coastline receives less sheltering from Flamborough Head (and Smithic Sands) leading to increased exposure to northerly waves which results in a progressively stronger net longshore drift towards Spurn Head (Pye & Blott, 2015). The area around Barmston can therefore be regarded as a drift divide for longshore sediment transport (**Figure 1.2**).

1.7.2.8 The regular tidal inundation of the beach between high and low water sweeps the finer material (and any newly released material from cliff erosion) into the sea creating a visible nearshore plume.

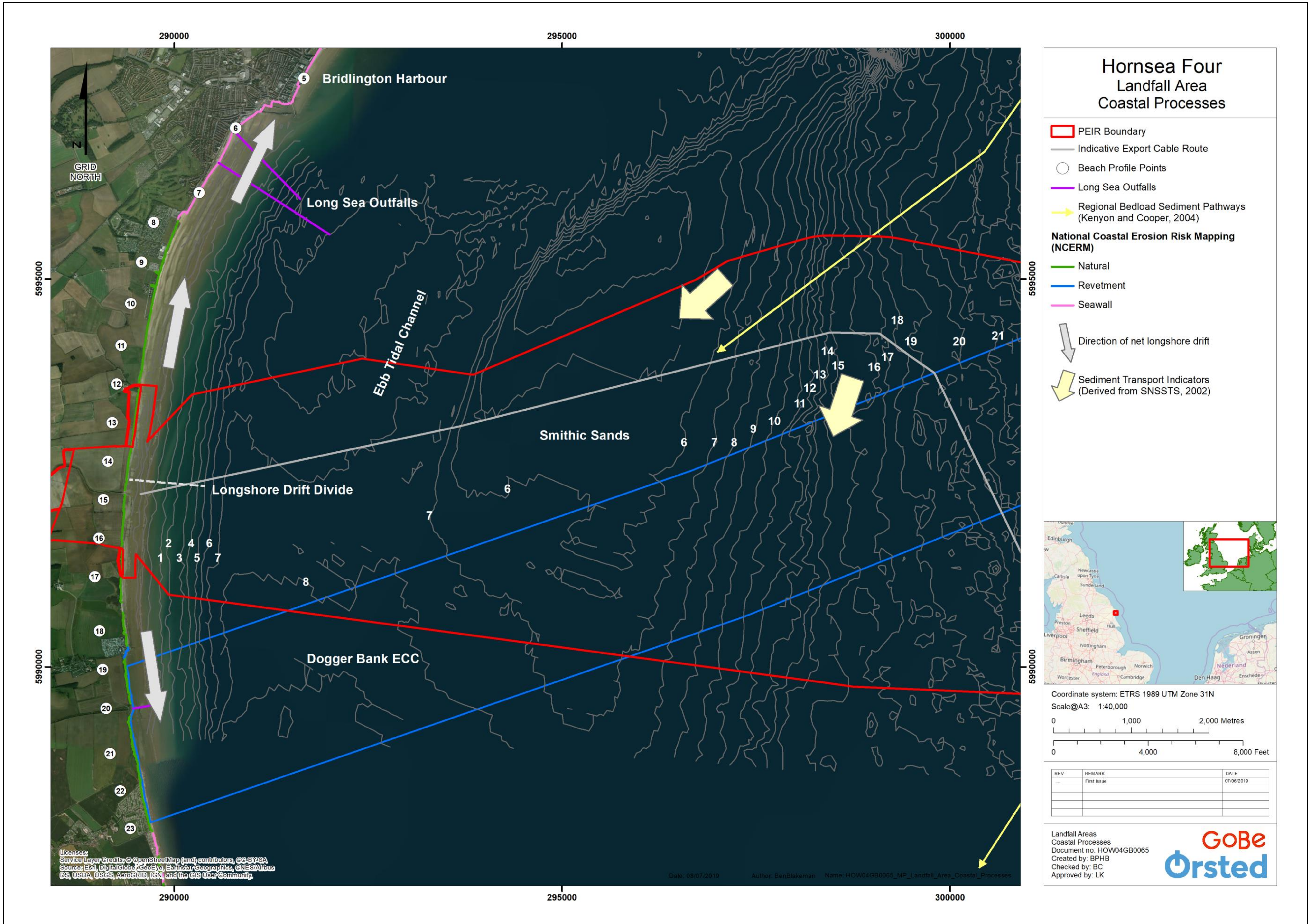

Figure 1.2: Landfall area coastal process (not to scale).

1.7.3 Marine physical environment features of interest – landfall area

Holderness Coast

1.7.3.1 The main receptor extending north and south, and including the landfall area, is the Holderness Coast. The coastline comprises of a sandy inter-tidal beach (Fraisthorpe Sands) backed by low-lying soft cliffs. These cliffs are one of the fastest eroding coastlines in Europe (Sistermans & Nieuwenhuis, 2003; JNCC, 2007; ICES, 2016).

1.7.3.2 East Riding of Yorkshire Council (ERYC) undertake routine monitoring of the Holderness Coast in spring and autumn each year which includes beach profiles from the top of the sea cliffs to low water. **Table 1.6** summarises cliff recession rates for the beach profiles (14, 15 and 16) coincident with the immediate landfall area (shown on **Figure 1.2**). Rates vary along the entire coast, as well as year-to-year, but with a general increased rate towards the more southerly section of the coast, in line with increased exposure to northerly waves.

Table 1.6: Cliff recession rates at Profiles 14, 15 and 16.

Profile	Location	Height of cliff (m AODN)	Average cliff recession (m/year)	Maximum annual recession (m)	Year of maximum
14	North of Earls Dyke – Barmston	6.7	1.14	3.53	2017
15	South of Earls Dyke – Barmston	7.2	1.22	5.00	2005
16	Watermill Grounds – north of Barmston	8.3	1.57	6.54	2007

1.7.3.3 The shoreline management plan (SMP) policy for this stretch of coast (Policy Unit C: Wilsthorpe to Atwick) is given as; "No Active Intervention" for the Short Term (present day to 2025), Medium Term (2025 to 2055) and Long Term (2055 to 2105) (Scott Wilson, 2010).

1.7.3.4 The National Coastal Erosion Risk Mapping (NCERM) identifies this frontage as natural defence and erodible. Assuming the SMP policy remains unchanged in the future, the predicted retreat distance for the short term (0 to 20 years) and medium (20 to 50 years) would be 33 and 82 m, respectively.

Creyke Beck Landfall

1.7.3.5 The consented Dogger Bank Creyke Beck Offshore Wind Farm (hereafter Creyke Beck Offshore Wind Farm) landfall is around 1.5 km to the south of the proposed Hornsea Four landfall. The anticipation is this installation is completed first and the Hornsea Four export cables will cross the Creyke Beck Offshore Wind Farm export cables at a location east of Smithic Sands.

Earls Dyke

1.7.3.6 Earls Dyke (also known as Earl's Dike) is a terrestrial feature located centrally at the back of the landfall area. This is a man-made drainage channel serving a relatively small low-lying catchment (2,555 ha) south of Bridlington. The drain is not tidally locked which means that peak sea levels during surge tides can propagate inland and lead to periods of tidal flooding. The potential area of flooding is identified as part of the Environment Agency Flood Zone 3.

Marine outfalls

1.7.3.7 Yorkshire Water operate two long sea outfalls approximately 3.5 km north of the landfall works with diffusers at their seaward ends.

Bridlington Harbour

1.7.3.8 Bridlington Harbour is around 4.5 km north of the proposed landfall works. The harbour is noted as being muddy (silts) and is considered as a sink for fine sediments. Approximately 75% of the silts are thought to be from marine sources (e.g. sediment plumes created by cliff erosion) with the remaining 25% from material discharged into the back of the harbour from the Gypsey Race (HR Wallingford, 2005). Spoil dredged from the harbour is taken to disposal ground HU015. This disposal ground is identified as a receptor within the offshore ECC study area.

1.7.4 Summary of features of interest within the landfall study area

1.7.4.1 Table 1.7 summarises the features of interest within the landfall study area.

Table 1.7: Features of interest in the landfall study area.

Feature of interest	Potential sensitivity to marine processes
Holderness Cliffs	Changes in wave energy dissipation at toe of cliff that modify rates of cliff recession and supply of material to the beach.
Fraisthorpe Sands	Changes in sediment supply from cliff erosion. Changes in wave energy dissipation (wave height and direction) on the intertidal that alter the rate and direction of longshore drift.
Earls Dyke (terrestrial feature)	Long-term increases in sea level rise that increase severity and frequency of tidal flooding.
Creyke Beck Offshore Wind Farm Landfall	Beach lowering exposing export cables.

Feature of interest	Potential sensitivity to marine processes
Marine outfalls	High rates of deposition of coarse sediment settling onto diffusers which may block effective discharge of wastewater.
Bridlington Harbour	Increased suspended sediment concentrations in the nearshore leading to higher rates of harbour siltation from marine sources.

1.7.5 Existing baseline – offshore ECC study area

General Description

1.7.5.1 The marine process environment across the offshore ECC study area varies from the shallow nearshore in the lee of Flamborough Head to more exposed offshore conditions in deeper water towards the offshore array area.

Seabed Profile

1.7.5.2 **Figure 1.3** indicates the general seabed profile along the offshore ECC from landfall to the offshore array. The nearshore region is characterised by shallow depths across Smithic Sands which then deepen to around 50 m below CD across the HVAC booster area and then shallowing slightly to around 40 m below CD meeting with the offshore array area.

Sub-tidal sediments

1.7.5.3 Regional mapping of surficial sediments (source: EMODnet Geology) indicates increasing sand content from inshore to offshore (**Figure 1.4**). Particle size information suggests the mud fraction is relatively low and typically less than 1%. The highest content of muds is around 6% in a small area classed as muddy sandy gravel around 9 km to the west of the HVAC booster area.

Water levels

1.7.5.4 MSR varies from 5 m at the landfall area to around 3.3 m at the seaward limit of the offshore ECC within the offshore array (**Figure 1.5**). Equivalent MNR values are 2.4 and 1.6 m (DECC, 2008).

1.7.5.5 The combination of water depth plus tidal variation means that waves are unlikely to be a major influence to bedload sediment transport, apart from the shallower inshore area approaching Smithic Sands and onto the shoreline (in the landfall area).

Tidal flows

1.7.5.6 In open water, tidal flows are generally to the south-east on the flood tide and north-west on the ebb. Closer inshore flows become more aligned with the orientation of the coastline, especially around Flamborough Head where they become strongest. Regional mapping of tidal flows (DECC, 2008) shows flows tend to reduce from west to east along the offshore ECC with the most sheltered conditions in the lee of the headland (**Figure 1.6**).

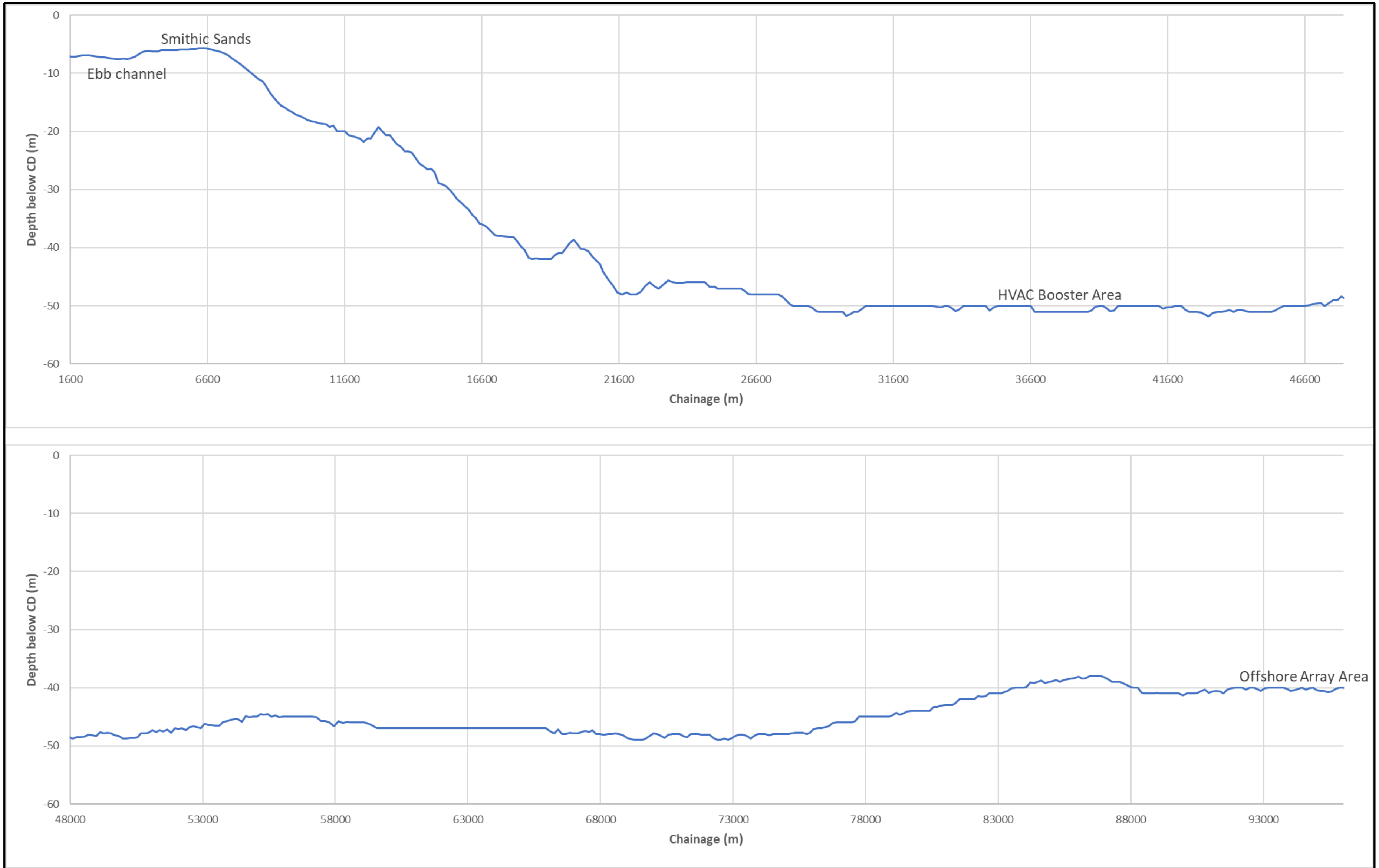

Figure 1.3: Seabed profile along offshore ECC, from landfall into offshore array.

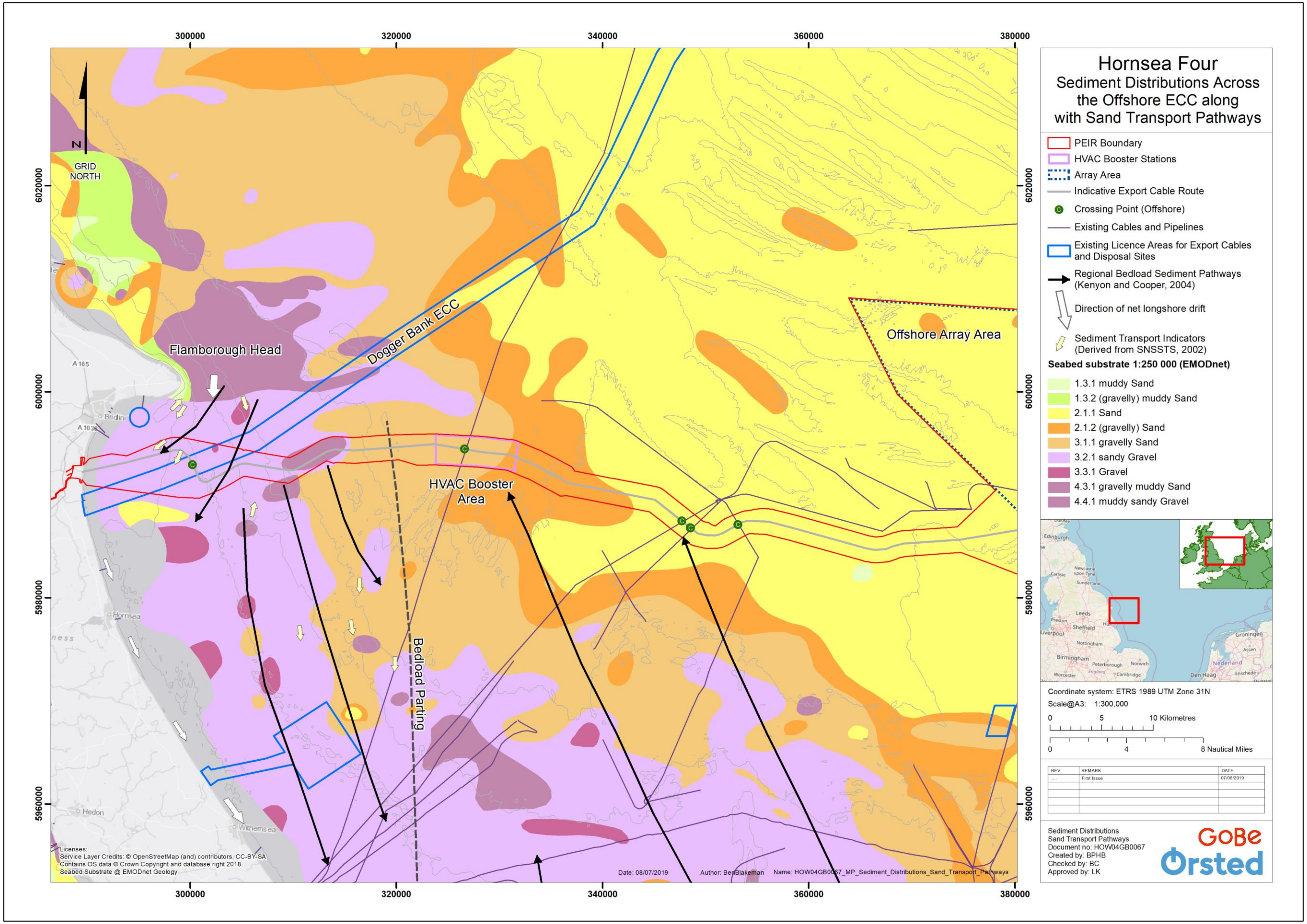

Figure 1.4: Sediment distributions across the offshore ECC based on descriptive classification by Folk (1954) (not to scale).

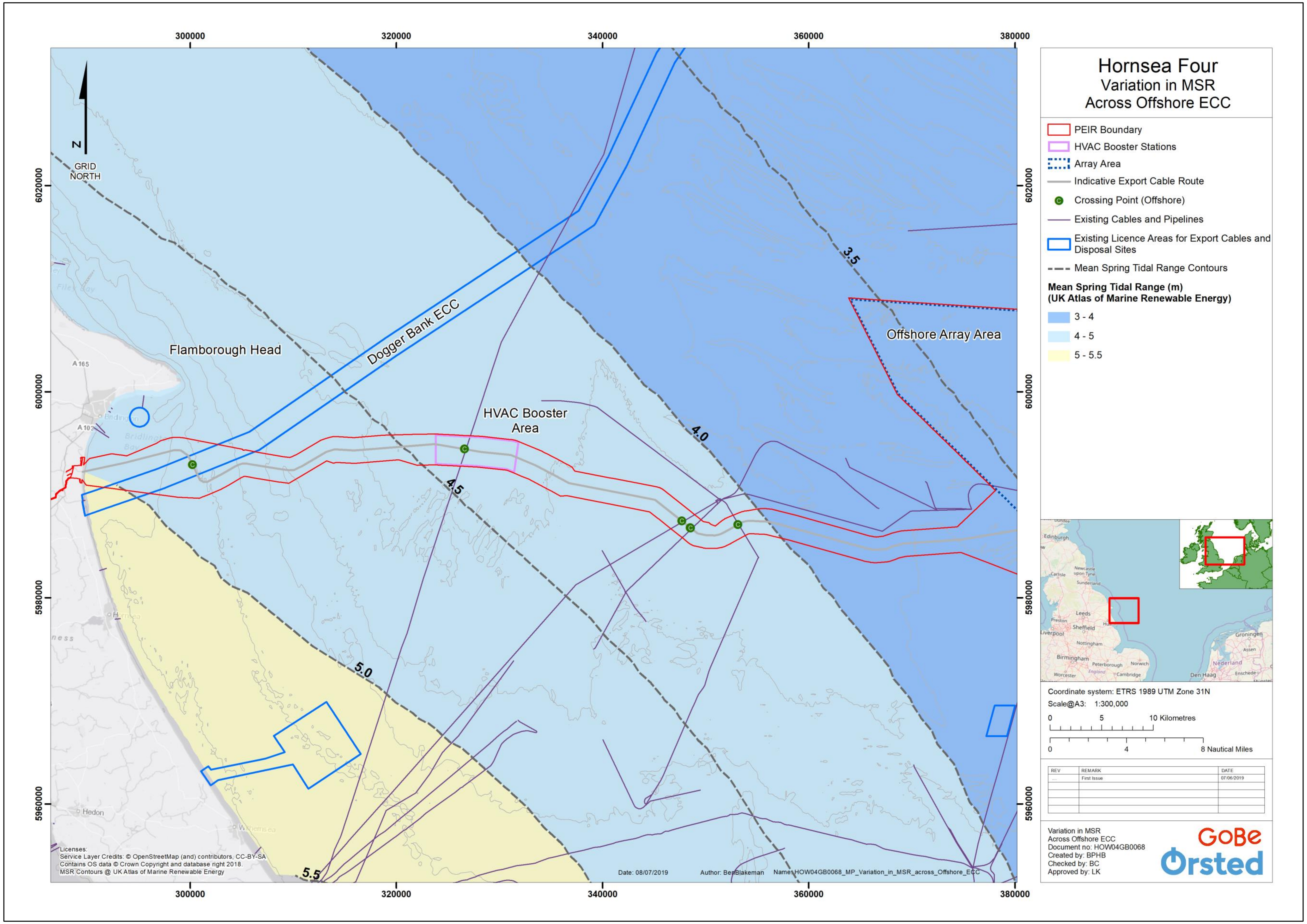

Figure 1.5: Variation in MSR across offshore ECC (not to scale).

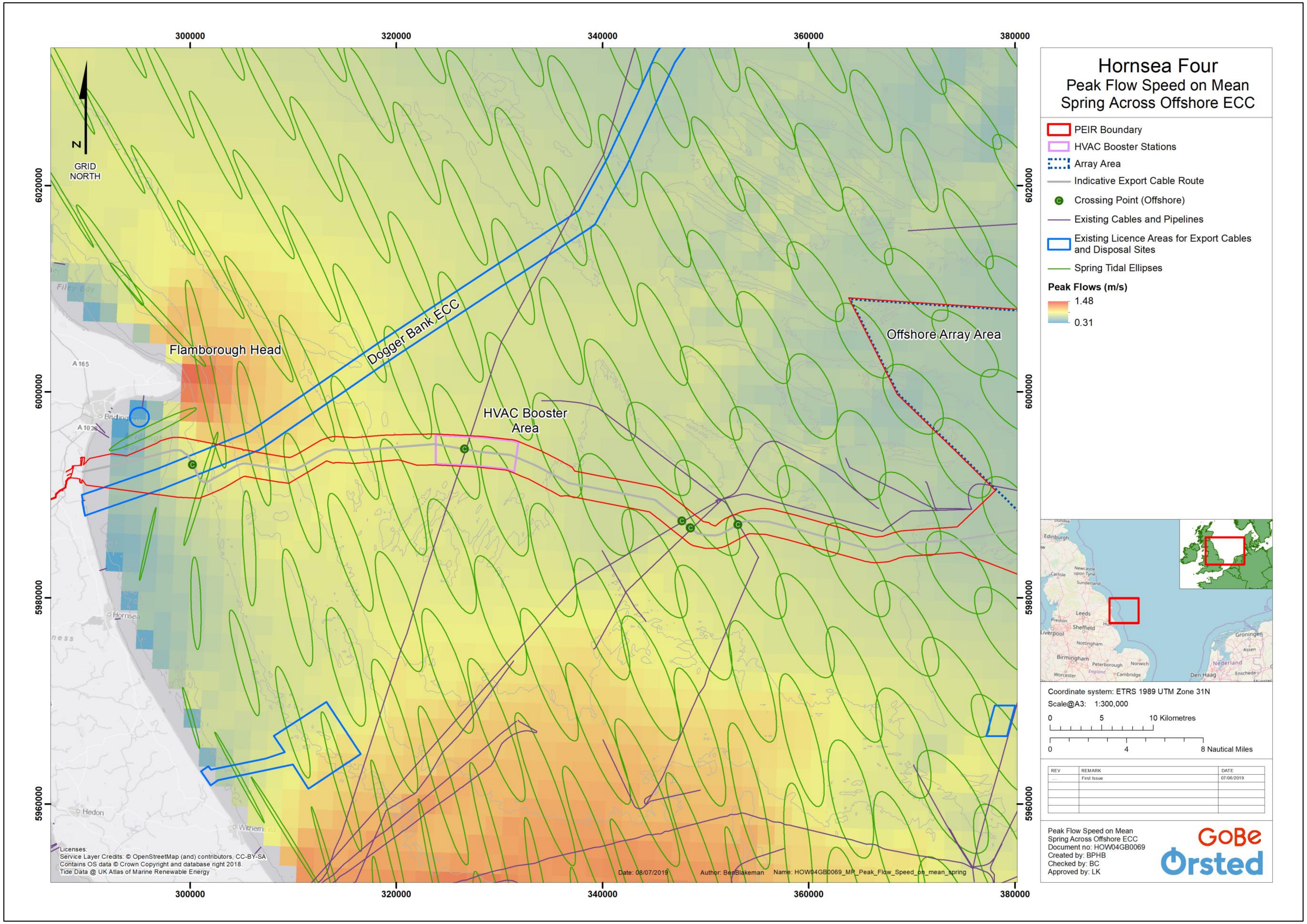

Figure 1.6: Mean spring tide, peak flow speed along with orientation of tidal ellipse scaled to represent the tidal excursion (not to scale).

Waves

1.7.5.7 For the offshore ECC study area, the general pattern is for lower wave heights closer to shore, increasing in the offshore. Seasonal variation produces largest waves during the winter months and reduced wave heights during the summer period. **Table 1.8** provides summary wave height information for three locations along the offshore ECC from inshore to offshore based on a regional wave model (DECC, 2008).

Table 1.8: Summary wave height variability at sites along the offshore ECC area.

Location	Winter Average wave height (m)	Summer Average wave height (m)
Inshore	1.20	0.79
HVAC booster area	1.84	1.06
Offshore	2.03	1.15

1.7.5.8 **Figure 1.7** presents wave roses for sites to the south of the offshore ECC; Hornsea waverider (around 12 m below CD) and L5 - Off Grounds (around 38.8 m below CD).

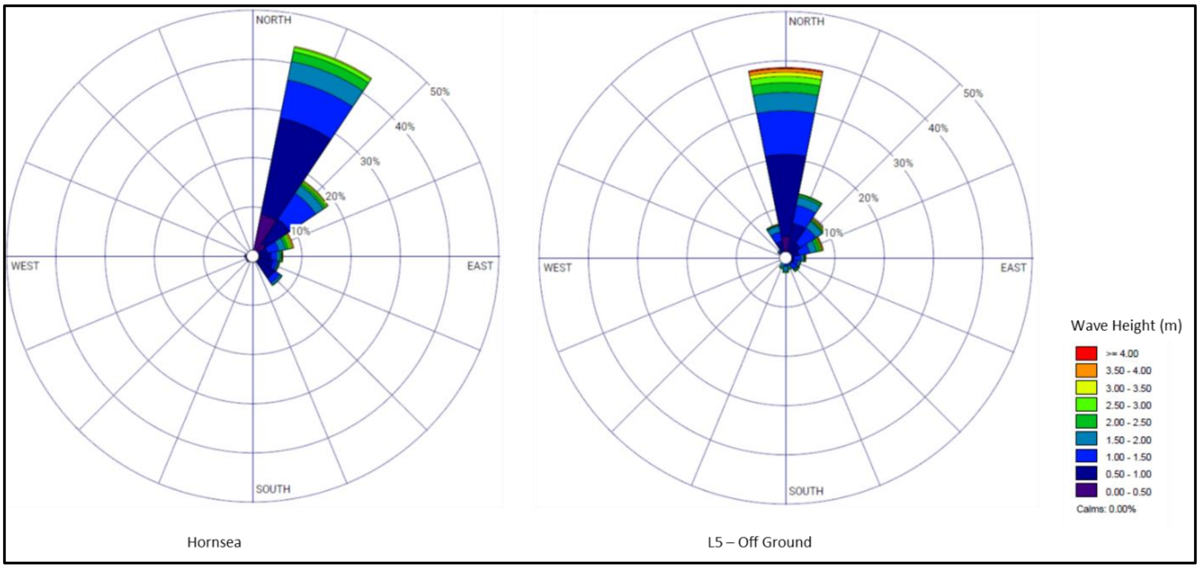

Figure 1.7: Wave roses for Hornsea waverider buoy and L5.

1.7.5.9 The Hornsea waverider buoy is slightly more exposed than conditions at the inshore end of the offshore ECC, but there is still evidence of sheltering of northerly waves by Flamborough Head and some wave height reduction due to shoaling and refraction into shallower depths. Wave periods for both locations are typically 3 to 6 s, reaching 7 to 8 s.

Bedload sediment transport pathways

1.7.5.10 Regional sand transport pathways (Kenyon & Cooper, 2005) suggests that there is a net southerly transport for the area between the coast (from Flamborough Head) and the HVAC booster area and net northerly transport from the HVAC booster area onto the offshore array area. A bedload parting zone separates these two areas (**Figure 1.4**).

Suspended particulate matter

1.7.5.11 Monthly mean SPM variations have been derived from satellite observations from 1998 to 2015 (Cefas, 2016). **Figure 1.8** presents SPM variations for February which generally represents the maximum concentrations during the year. Surface concentrations are highest for around the first 10 km from the coastline and around Flamborough Head.

1.7.5.12 Seasonally variation of SPM is in the range 2 to 14 mg/l closer inshore, reducing offshore to around 2 to 3 mg/l. The larger variations and higher concentrations for the inshore are mainly due to fine sediments cliff erosion, shallower water and locally stronger flows maintaining the material in suspension and inhibiting local deposition.

Marine physical environment features of interest – offshore ECC area

1.7.5.13 **Figure 1.9** shows the location of key features of interest across the offshore ECC area.

Spoil Ground HU015

1.7.5.14 Maintenance dredgings from Bridlington Harbour are disposed of at spoil site HU015 which is located approximately 2.3 km to the north of the offshore ECC and within the ebb tidal channel defining the western flank of Smithic Sands. HU015 mostly falls within the boundary of Flamborough Head SAC. The yearly maximum permitted disposal at HU015 is 30,000 tonnes of maintenance dredged material. The actual amount disposed of each year is often far less, with dredging returns in the period 1999 to 2009 varying between 2,550 to 21,380 tonnes (Cefas, 2010), and averaging at 9,748 tonnes.

Flamborough Head SAC

1.7.5.15 Flamborough Head SAC encompasses the entire headland, and surrounding waters, and is around 1.6 km to the north of the offshore ECC at the closest point. The SAC is designated for various Annex I habitats, including reefs (geogenic; cobles and rock) (JNCC, 2016). This habitat may be susceptible to changes in suspended sediment concentration and high rates of sediment deposition, noting there is no evidence that maintenance dredgings disposed of at HU015 within the SAC has led to any significant impact (Cefas, 2010).

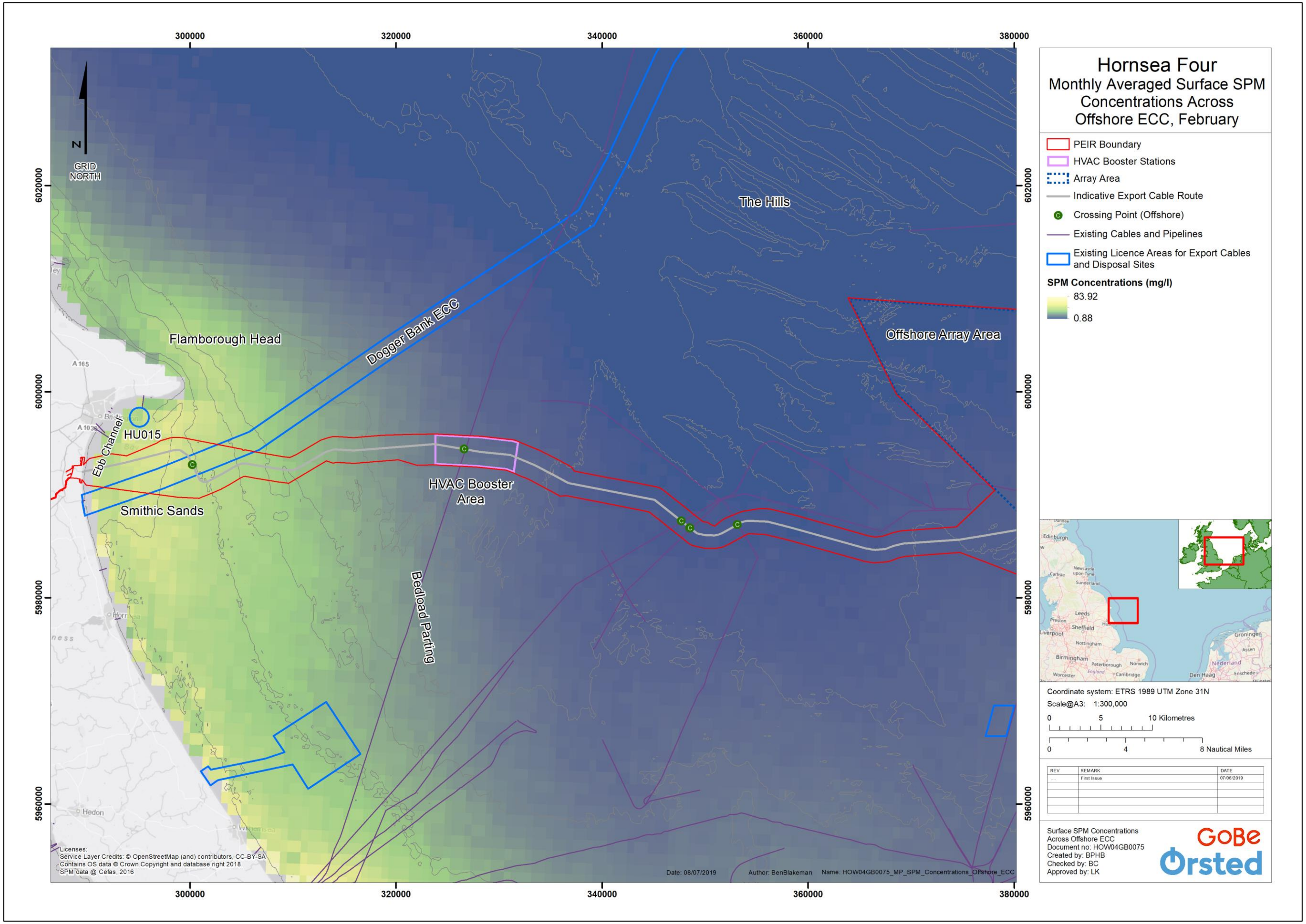

Figure 1.8: Monthly averaged surface SPM concentrations, February (not to scale).

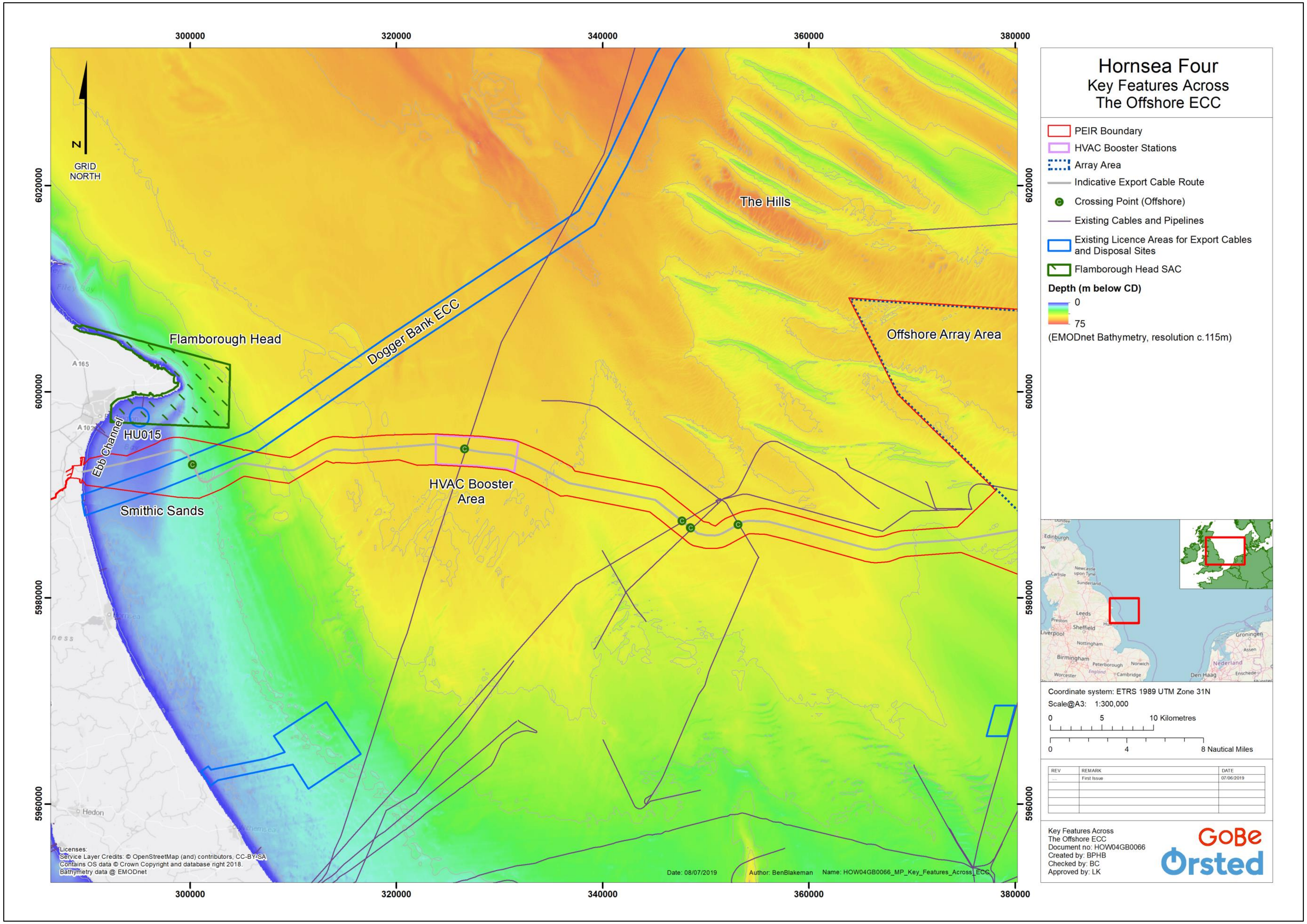

Figure 1.9: Key features of interest across the offshore ECC study area (not to scale).

Smithic Sands

1.7.5.16 JNCC identify Smithic Sands (named as Flamborough Head 1) as a potential Annex I feature (subtidal sandbank) (JNCC, 2017). This feature extends south from the Flamborough Head SAC by over 12 km, with the southern part of the bank crossed by the offshore ECC (**Figure 1.10**).

1.7.5.17 The sandbank is maintained by local sediment supply, with cliff erosion from the south likely to be a primary source of sandy material. This supply is initially transported by northerly longshore drift (for beach areas north of the drift divide at Barmston) with the pathway then deflected eastwards by the South Pier of Bridlington Harbour into the ebb channel running between the bank and Flamborough Head. The headland is regarded as a one-way drift to the south, dominated by tidal flows (flood tide) (HR Wallingford, 1993). Sands that may initially be transported on the ebb past Flamborough Head are returned on the flood tide, along with any additional material derived from sources north of the headland. The bank then acts as a local store for these sandy sediments.

1.7.5.18 Evidence of active bedload sediment transport is most prominent at the northern end of the bank (North Smithic) where large sandwaves are observed (CCO, 2014). This area is also associated with strongest tidal flows as water is forced past the headland. The asymmetric profile of these sandwaves offers supporting evidence for net clockwise directions of bedload transport around the bank. On the eastern outer flank, the sandwave asymmetry is with the flood tide, moving sands to the southwest and onto the bank, whereas for the western inner flank the ebb tide dominates through a distinct channel between the bank and the headland to develop a net sediment pathway to the northeast (**Figure 1.10**).

1.7.5.19 The bank is shallowest (depths less than 3 m below CD) towards the northerly inshore flank where a steep slope drops around 6 m into the ebb tidal channel. The bank morphology shows evidence of responding to both waves and tides (CCO, 2014). Tidal flows are a key influence on driving sandwave migration whereas wave attenuation through refraction and shoaling are likely to be a main cause of smoothing and broadening the profile of the southern extents of the bank. The shallow profile of Smithic Sands provides some sheltering to the leeward coastline around Bridlington, especially during periods of stormy waves (Scott Wilson, 2010).

1.7.5.20 The offshore ECC crosses the southern part of Smithic Sands where the bank shoals on the seaward flank, from around 15 m below CD, to a relatively flat and wide surface with a shallow profile between 5 to 7 m below CD. The distance across the bank at this point is around 5 km. The 2018 geophysical survey offers a seabed interpretation of sand with patches of gravelly sand across the southern part of Smithic Sands and reports depths of Holocene sediment of less than 6 m (Bibby HydroMap, 2019).

1.7.5.21 The Creyke Beck Offshore Wind Farm ECC also crosses Smithic Sands just to the south of the Offshore ECC. Geophysical surveys confirm sands and gravels across the bank and some areas with active bedform features (ripples and megaripples). Between the bank and the intertidal beach the surface layer of Holocene sand is recorded as less than 1 m thick and in some places there is exposed glacial till (ForeWind, 2013).

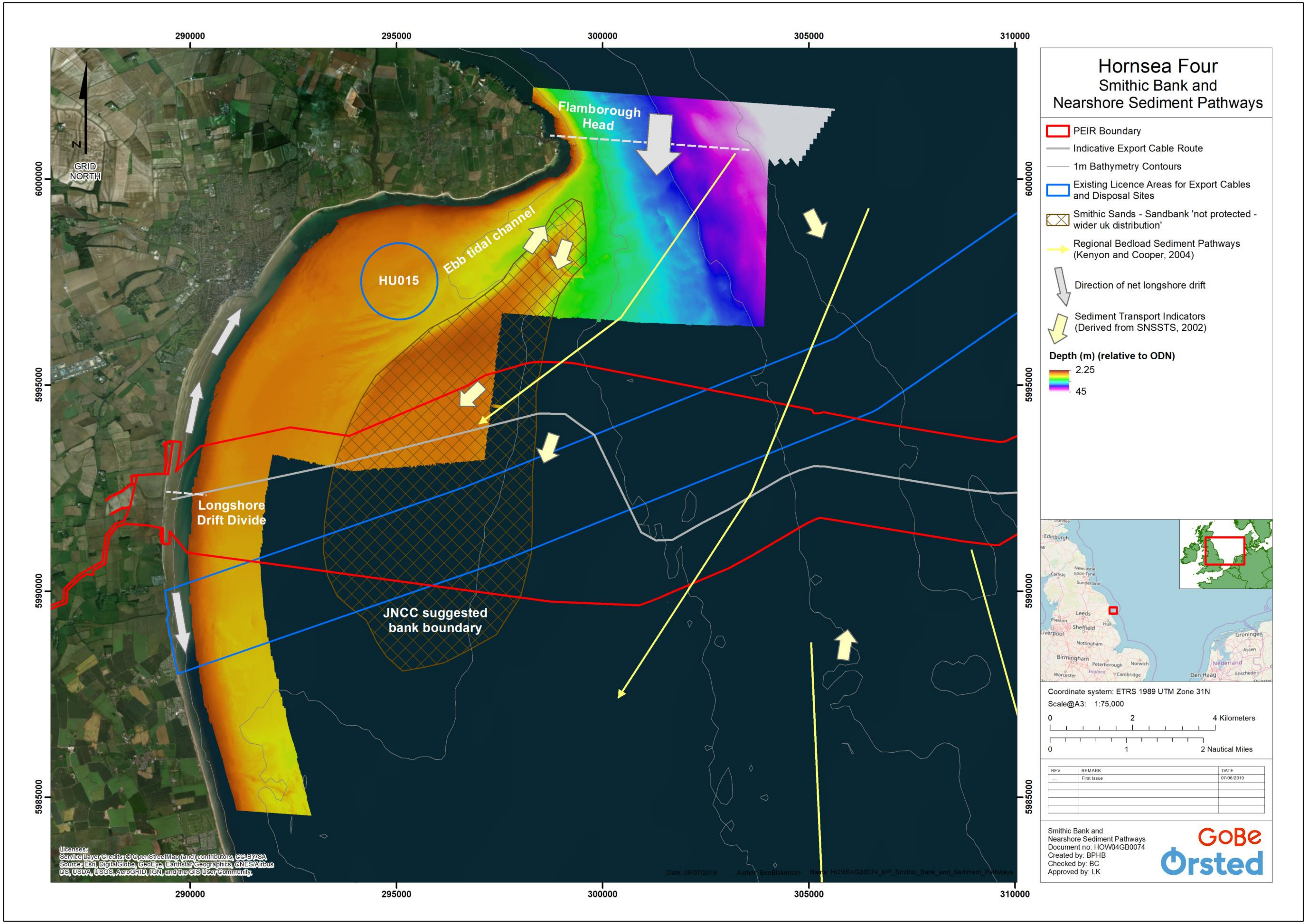

Figure 1.10: Smithic Sands and nearshore sediment pathways (not to scale).

Cable and Pipeline Crossings

1.7.5.22 There are nine existing pipelines along the proposed offshore ECC that will require cable crossings. These crossings are all relatively far offshore. The offshore ECC also requires a nearshore crossing with the export cable from the Creyke Beck offshore wind farm.

1.7.6 Summary of features of interest within the offshore ECC study area

1.7.6.1 **Table 1.9** summarises the features of interest across the offshore ECC study area.

Table 1.9: Features of interest in the offshore ECC study area.

Features of interest	Potential sensitivity to marine processes
Spoil Ground HU015	Modification to local flows altering local dispersion characteristics, as a consequence of any large-scale changes in Smithic Sands morphology. The spoil site also has the potential to act cumulative during if disposal events of maintenance dredgings occurred in the same period as export cable laying activities in the nearshore region.
Smithic Sands	Insufficient sediment supply. Long-term increase in mean sea level (due to climate change) reducing sheltering effect to coastline if bank levels not sustained by sufficient sediment supply.
Flamborough Head SAC	Deposition of sediments onto designated features.
Pipeline and cable crossings	Local scouring around ends of rock berms, potential greater level of interaction with waves and flows for the nearshore crossing.

1.7.7 Existing baseline – offshore array study area

General Description

1.7.7.1 The offshore array study area is a relatively deep water site which is remote from the coast (around 65 km east of Flamborough Head). Given the immediate proximity of Hornsea Project One and Hornsea Project Two, the offshore array study area also includes these adjacent wind farms which might lead to a potentially larger cumulative blockage effect on waves, tides and sediment pathways.

Seabed profile

1.7.7.2 The general seabed profile across the offshore array shelves into deeper water in a northerly direction from around 40 m below CD towards the southern boundary to around 55 m below CD towards the northern boundary. Outer Silver Pit, a large geological "tunnel valley" depression, establishes the north-westerly / south-easterly alignment of the eastern boundary of the offshore array (**Figure 1.11**).

1.7.7.3 The shallowest part of the offshore array is around 32 m below CD which is associated with the ridge of a sandbank feature, which is part of the larger area of sand ridges and sandbanks known as The Hills.

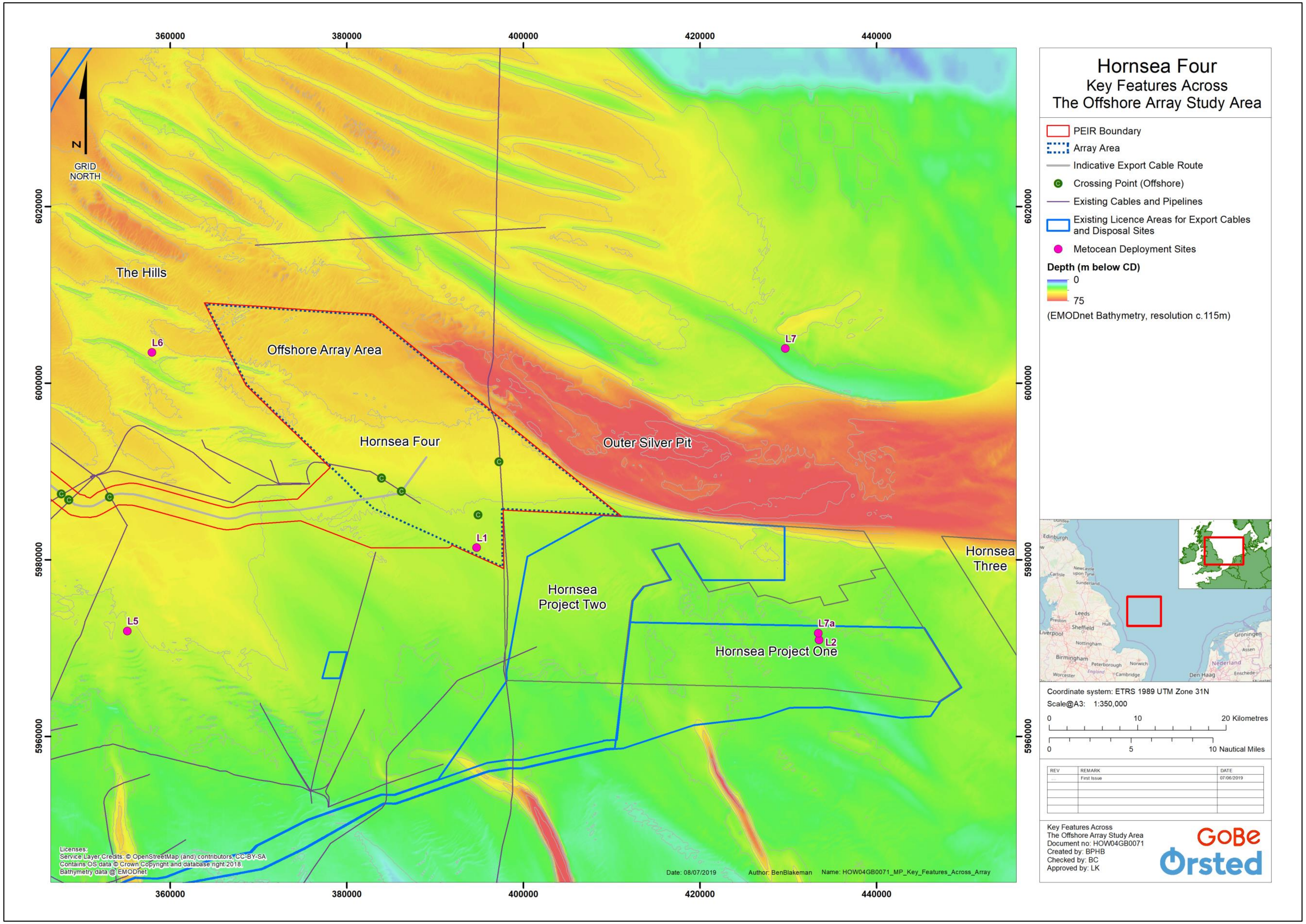

Figure 1.11: Key features across the offshore array study area (not to scale).

Sub-tidal sediments

1.7.7.4 Based on the particle size analysis of grab samples from the 2018 geophysical survey (Gardline, 2019), sands (medium size) appear to be the most abundant sediment type across the offshore array area (6 grab samples medium, 5 coarse, 1 fine sized sand). Regional mapping of surficial sediments (source: EMODnet Geology) indicates patches with a small gravel content (slightly gravelly sand and gravelly sand) (**Figure 1.12**).

1.7.7.5 The base of the seabed (Holocene) sediments has been determined using sub-bottom profiling which suggests the majority of the area is less than 2 m thick. There are some local deviations with sediment thickness greater than 18 m over sandbank features towards the western boundary. Beneath the surface layer of Holocene sands is the firm to stiff clay till of the Bolders Bank Formation (Gardline, 2019). In the north-west corner of the offshore array there may be areas of exposed Cretaceous bedrock, or layers close to the surface, which are composed of chalk (SMart Wind, 2012). The presence of chalk has not yet been confirmed with recent geophysical surveys.

Water levels

1.7.7.6 Tidal range increases slightly from east to west across the offshore array area due to increasing distance from tidal amphidromes in the Southern North Sea. MSR is around 3.0 m at the easternmost extent increasing to around 3.5 m at the westernmost extent.

Tidal flows

1.7.7.7 The most common sediment fraction present across the offshore array area is medium sands (particle size in the range 0.25 to 0.50 mm) (Gardline, 2019). This sediment size requires flows in excess of 0.5 to 0.6 m/s to become mobilised, based on standard theoretical expressions (Soulsby, 1997). Tidal mapping from the Atlas of UK Marine Renewable Energy suggests this magnitude is generally limited to peak flows during spring tides (**Figure 1.13**) and is not attained during neap tides.

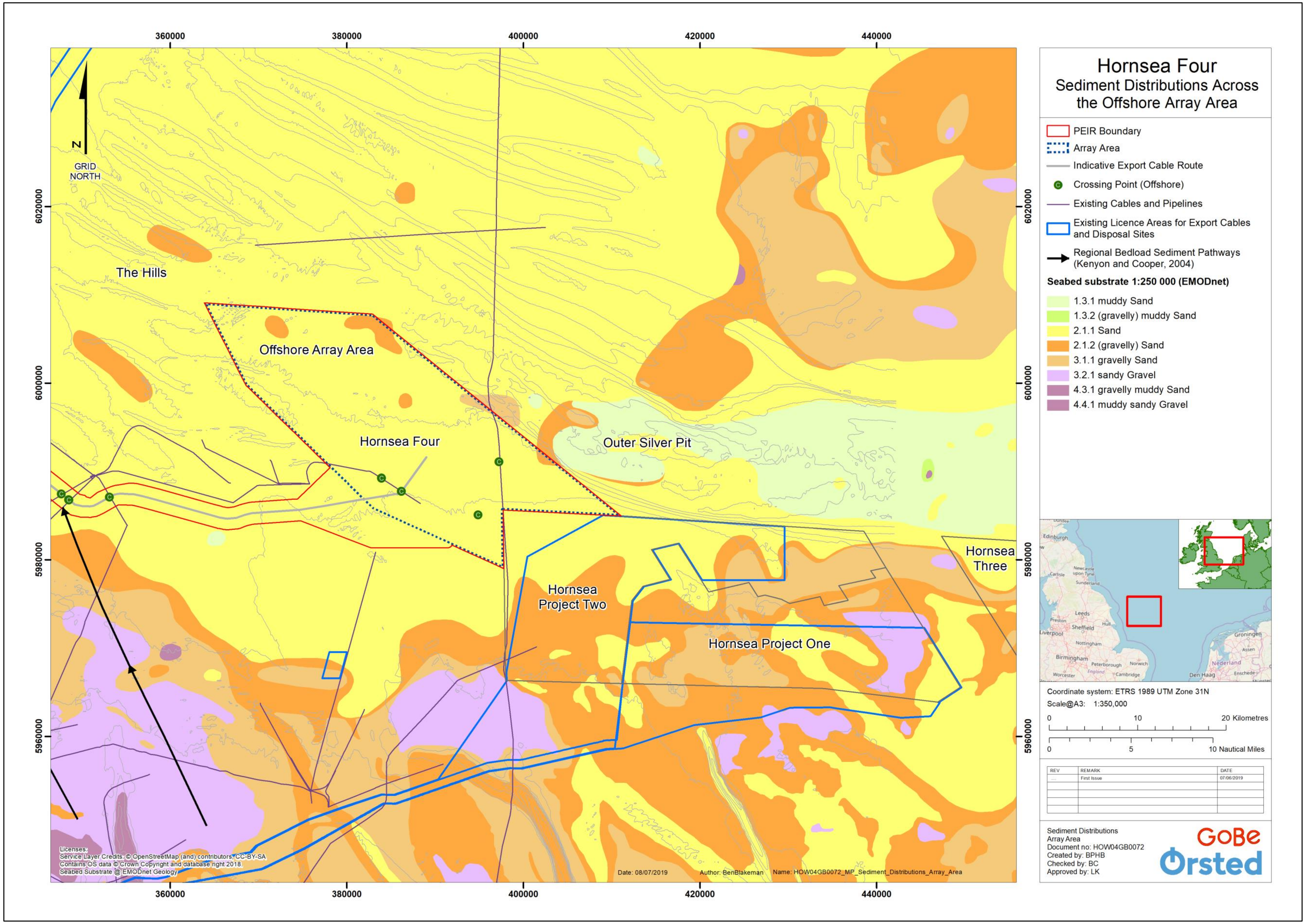

Figure 1.12: Sediment distributions across the offshore array area (not to scale).

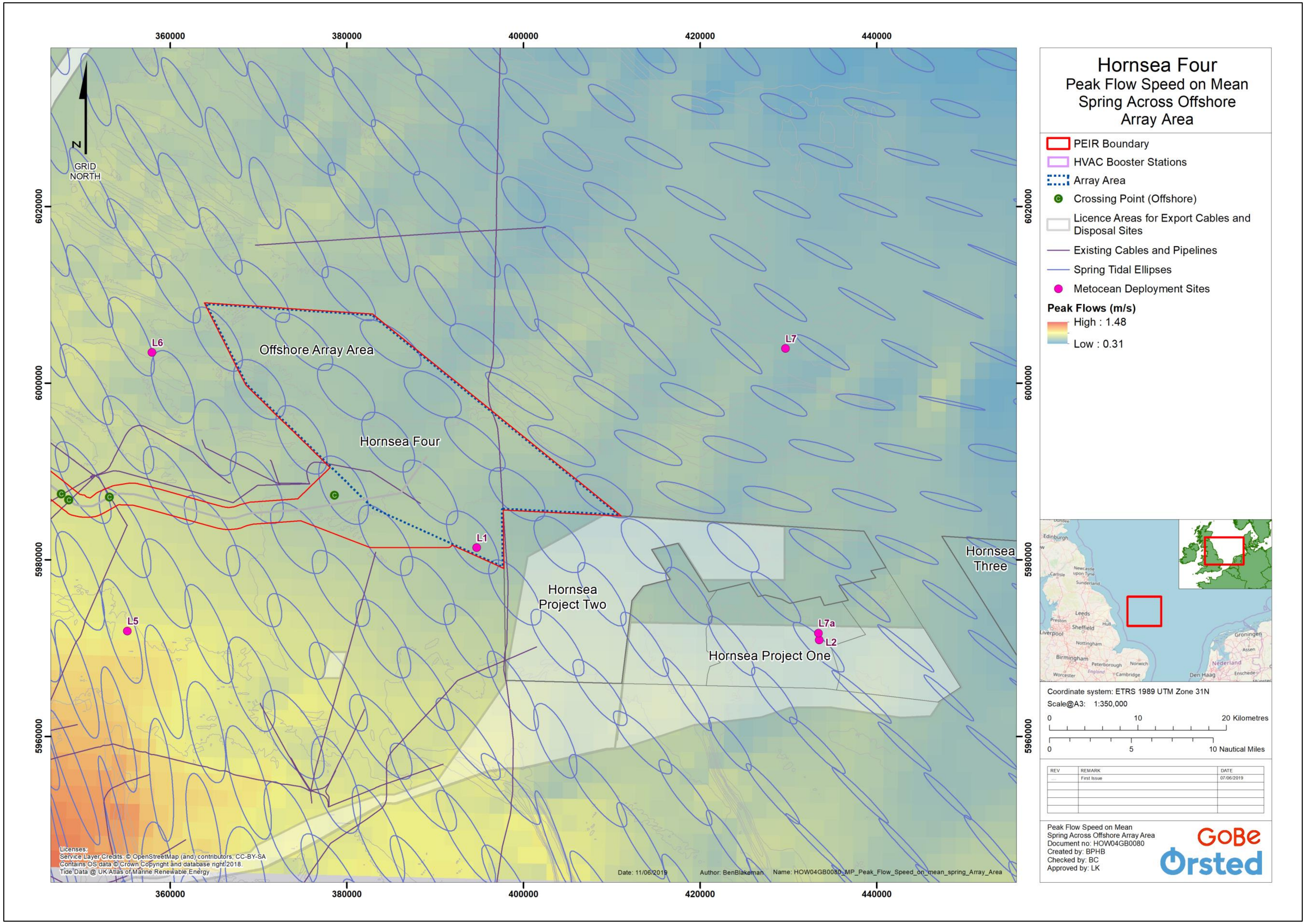

Figure 1.13: Peak flow speed on mean spring across offshore array area (with orientation of tidal ellipse) (not to scale).

Waves

1.7.7.8 Waves measured at Site L1 (southerly part of offshore array area shown on (**Figure 1.13**), for the period June 2010 to July 2017, indicate wave periods (T_z, zero up-crossing period) in the range 3 to 6 s, and typically around 4 s. Wave heights (H_s, significant wave height) were typically less than 1.0 m but reached 4.5 m during a storm event in November 2011 (EMU, 2013). The wave period, T_z at this time was 6 s and from a south-westerly wave direction of 240°N. The equivalent maximum wave induced orbital seabed velocity would have been 0.07 m/s. For the shallowest area at 32 m below CD, the equivalent wave orbital velocity would be 0.13 m/s. On this basis, even the largest measured wave event was incapable of stirring local sediments alone. This means peak tidal currents during spring tides are the main mechanism for developing sediment transport across the offshore array area.

Bedload sediment transport pathways

1.7.7.9 Sandwave crests are evident across much of the offshore array, apart from the southern extents. These crests are generally aligned perpendicular to the axis of tidal flows, a feature which is observed in both the zonal geophysical survey (SMart Wind, 2011) as well as the 2018 geophysical survey (Gardline, 2019).

Suspended particulate matter

1.7.7.10 Surface turbidity (represented by SPM) is relatively low across the offshore array area, with monthly averaged concentrations typically less than 5 mg/l across the whole year (Cefas, 2016). The relatively low concentrations are due to both a low content of fine material in the seabed sediments and the area being distant from any terrestrial sources, such as the Humber Estuary and the Holderness Cliffs. **Figure 1.14** provides a synoptic view of long-term SPM concentrations averaged for the month of February (generally the month with the higher SPM concentrations). This information is based on satellite data.

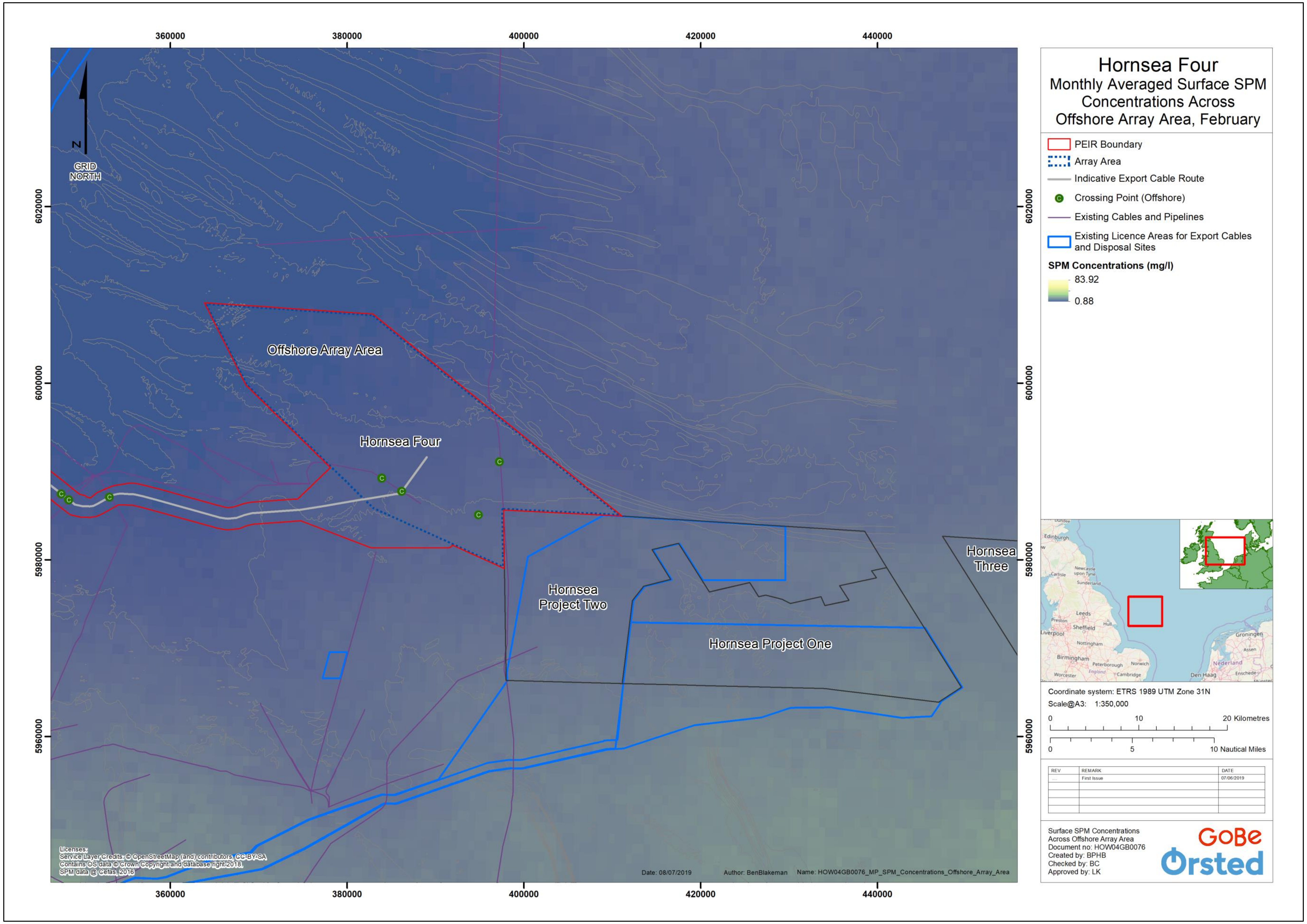

Figure 1.14: Monthly averaged surface SPM concentrations across offshore array area, February (not to scale).

1.7.8 Marine physical environment features of interest – offshore array study area

Pipelines

1.7.8.1 There are two existing pipelines which coincide with the offshore array area; the Ravenspurn North Gas Field and the Shearwater – Bacton SEAL pipeline. In addition, a further three new pipelines are proposed which plan to pass through the offshore array area. Assuming all new pipelines are in place at the time of construction this would require around 40 cable crossings for the array and interconnector cables.

Flamborough Front

1.7.8.2 The Southern North Sea is generally described as a well-mixed water body. These well-mixed conditions are mainly due to relatively shallow depths and the ability of winds and tides to continually stir water sufficiently to prevent the onset of any stratification (DECC, 2016). In contrast, the Northern North Sea is relatively deeper with slightly weaker currents, this helps temperature stratification develop from the spring into the summer months. During this period, a transition between these two water bodies develops from about 10 km offshore of Flamborough Head in the form of a temperature front. The deeper stratified water to the north tends to remain aligned with the 50 m isobath (Hill, et al., 1993). The surface waters of the front tend to move around this alignment with the scale of tidal advection. The front becomes nutrient rich and is considered to be ecologically important. During autumn / winter the front dissipates due to increased wind and wave related stirring effects which re-establish well-mixed conditions for this part of the Northern North Sea.

1.7.8.3 An assessment of the period of development and location of the Flamborough Front, relative to Hornsea Four, has been informed by the forecast model; NORTHWESTSHELF_ANALYSIS_FORECAST_PHY_004_013 (Tonani, et al., 2019). The latest full year of daily mean values from 2018 has been assessed for variation in near-bed and near-surface temperature, as well as mixed layer depth (MLD), this analysis being set out in **Volume 5, Annex 1.1 Marine Processes Technical Report**.

1.7.8.4 The location of the front can be defined as the spatial transition between mixed and thermally stratified water. **Figure 1.15** shows the MLD for the period of maximum stratification identified towards the end of July. Where the MLD is minimal the water is stratified, for well-mixed areas the MLD tends to represent the total water depth. On the date considered, the front was around 10 km offshore of Flamborough Head and appears to closely follow the 40 m isobath where an east-west alignment develops which continues to run south of the array area by approximately 3.5 km.

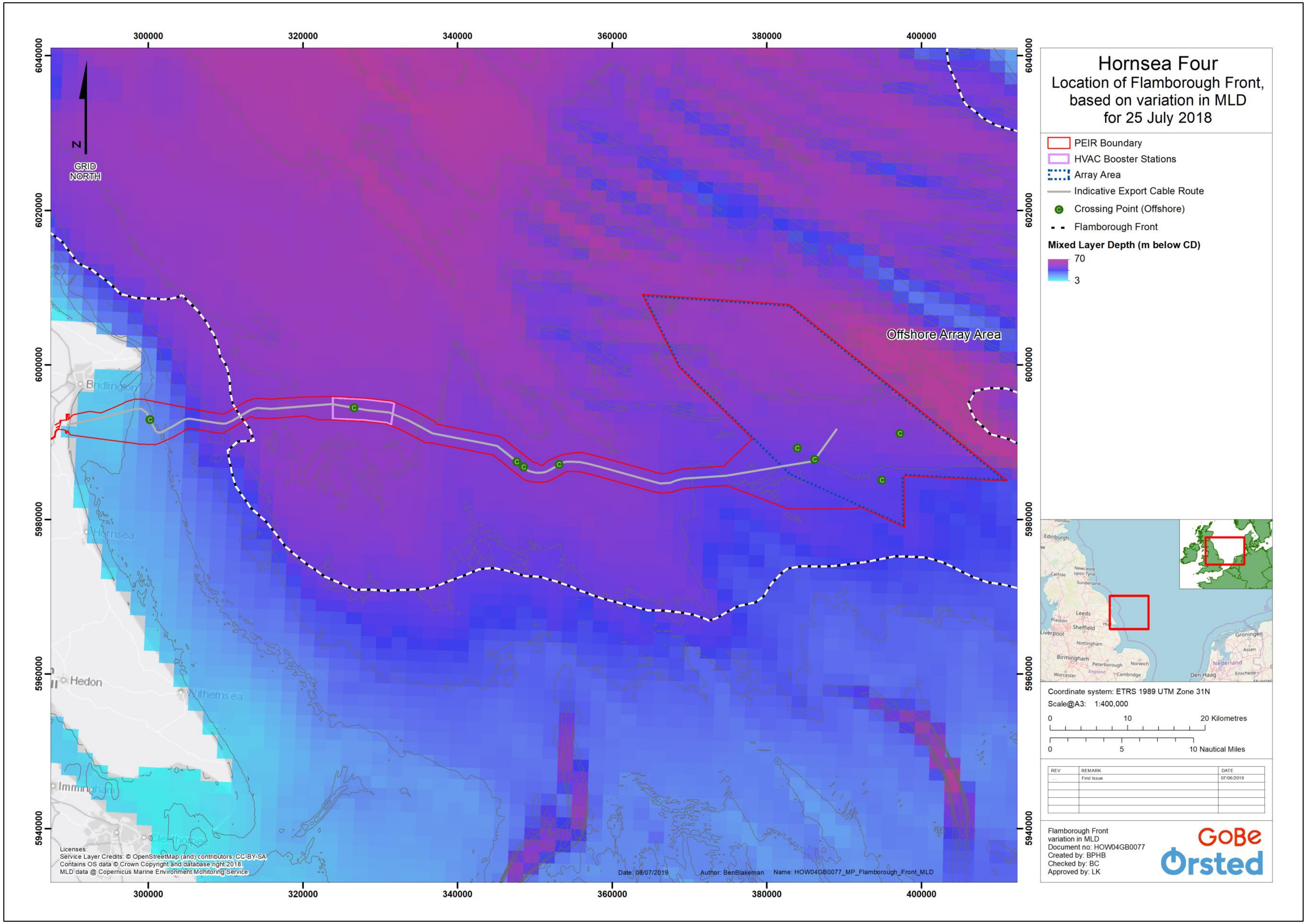

Figure 1.15: Location of Flamborough Front, based on variation in MLD for July 2018 (not to scale).

Hornsea Project One and Hornsea Project Two

1.7.8.5 At the time of producing the PEIR, all of the wind turbine foundations for Hornsea Project One have been installed. This project is located around 5.5 km to the south east of Hornsea Four, with the intervening area planned for Hornsea Project Two. Hornsea Three is located approximately 36 km to the east of Hornsea Four (**Figure 1.11**).

1.7.8.6 Hornsea Project One modifies the previous baseline by adding 174 8.1 m diameter monopile foundations across an area of around 407 km^2. These foundations individually create local blockage type effects on passing waves and tidal flows. Whilst the actual scale of any blockage effects on flows is unknown at this time, the assumption remains that this is less than the conservative assumptions presented in the ES for Hornsea Project One and proportional to the smaller diameter structures. In this case, the EIA assessment was based on a greater number (334) of larger diameter gravity base structure (GBS) foundations assumed to be placed closer together than they have been. Offshore works for Hornsea Project Two are expected to commence in 2020 with the installation of 165 monopile foundations, also a reduction on the number (258) and scale (58 m diameter GBS) assessed in the respective EIA.

1.7.8.7 A review of array blockage effects on waves between pre- and post-construction observations to the north and south of the array is presented in **Appendix C** of **Volume 5, Annex 1.1 Marine Processes Technical Report** and concluded no discernible changes in wave heights due to the presence of the monopile foundations of Hornsea Project One.

1.7.9 Summary of features of interest within the offshore array study area

1.7.9.1 **Table 1.10** summarises the receptors associated with the offshore array area along with the potential sensitivity of each feature.

Table 1.10: Features of interest in the offshore array area.

Feature of interest	Potential sensitivity to marine processes
Pipeline and cable crossings	Local scouring around rock berms
Flamborough Front	Changes in tidal mixing process which may inhibit formation of the front
Hornsea Project One (and Hornsea Project Two Offshore Wind Farms)	Cumulative blockage effects with Hornsea Four

1.7.10 Predicted future baseline

Climate change

1.7.10.1 The main issue likely to influence the marine processes baseline into the future is climate change. Climate change is a global-scale issue which will modify existing weather patterns and increase average temperatures. One influence of increased temperature is melting icecaps and glaciers which increase average sea levels. The most up to date resource of climate change projections for the UK is provided by UKCP18, along with their marine report (Palmer, et al., 2018). These projections are drawn together as an ensemble from different models which may show contrasting results. The main marine process parameters from UKCP18 of interest are:

- Sea level rise;
- Skew surge; and
- Waves.

Sea level rise

1.7.10.2 Over the period of the 35 year project life, mean sea level is expected to increase. UKCP18 provides climate projections for sea level rise up to the year 2100 based on different emission scenarios (representative concentration pathways (RCP)). Based on the 50th percentile for low (RCP 2.6) and high emission (RCP 8.5) scenarios, an illustrative change in mean sea level after 35 years would be between +0.15 to +0.22 m.

Surge

1.7.10.3 A skew surge is the difference between the maximum observed water level and the maximum predicted tidal level regardless of their timing during the tidal cycle. The best estimate of projected 21st century change in skew surge is no change, although some high-end (conservative) projections could result in some increase. This means all of the change in extreme sea levels during this period would be a product of changes in mean sea level.

Waves

1.7.10.4 Due to the inherent uncertainty in projections of storm track changes, projections of future wave climate should be considered as indicative of the potential changes and associated with a low confidence level. Regional wave model projections (based on RCP8.5 - the highest emission scenario) assessed changes in mean significant wave height and annual maximum wave height for the end of the 21st century period, 2081 to 2100.

1.7.10.5 **Figure 1.16** shows difference plots for the projected change in mean significant wave height and annual maxima. Where there is no masking (grey) then there is a higher than 75% chance that future conditions will be different to past records. Blue refers to a net reduction and red an increase. For the area of the North Sea of interest, there appears to be a slight reduction in wave heights values.

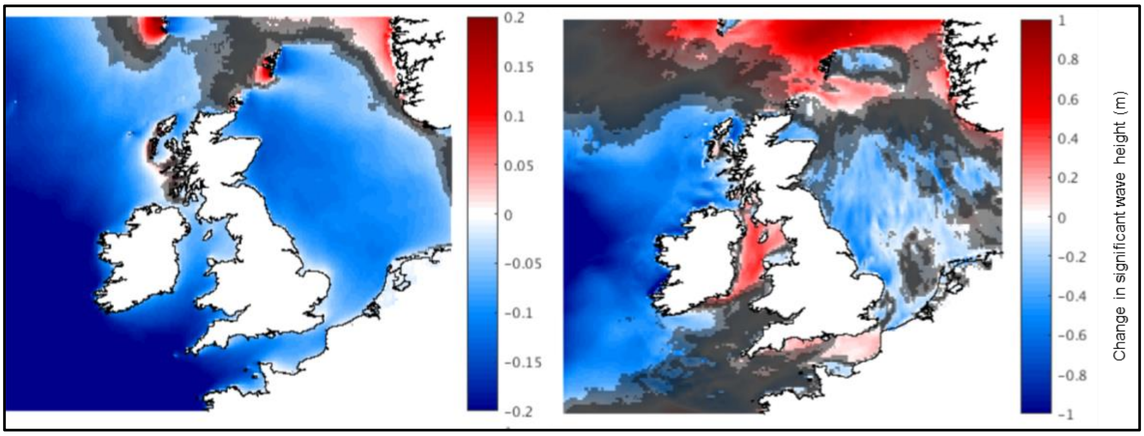

Figure 1.16: Projected change in mean significant wave height at end of 21st Century for (left) mean significant wave height and (right) annual maxima (Palmer, et al., 2018).

Isostatic Rebound

1.7.10.6 In addition to climate change, isostatic (glacial) rebound from the last Ice-Age continues to adjust some land and seabed levels, with the southern part of the UK still slowly sinking (negative uplift) whereas the northern part of the UK, which was subject to greater glacial influence, is still rising (positive uplift) (Figure 1.17). For the offshore area relevant to Hornsea Four, this adjustment is around -0.6 to -0.8 mm/yr.

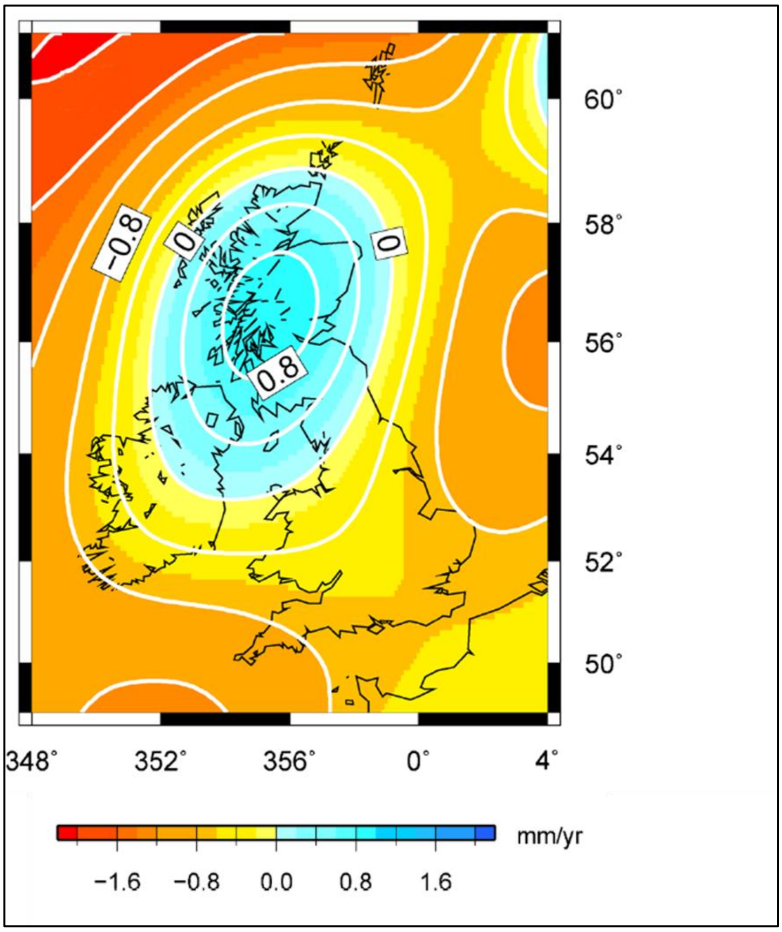

Figure 1.17: Predicted isostatic uplift rate (Bradley, Milne, Shennan, & Edwards, 2011).

Likely response to relative sea level rise

1.7.10.7 Relative sea level rise is the product of isostatic rebound and climate change driven sea level rise. Changes in relative sea level are the main issue of relevance to the future baseline related to the lease period for Hornsea Four.

1.7.10.8 Coastal tide gauges used to derive mean sea level will experience a relative sea level rise. Tide gauge data from the Permanent Service for Mean Sea Level (PSMSL, 2019) indicates Immingham to the south has a present day trend in MSL of +0.54 mm/year (+/-0.45 mm and based on 54 years or records) and Whitby to the north +7.48 mm/year (+/- 0.99 mm and based on 33 years).

1.7.10.9 Any increase to mean sea level in the future would expect to increase the rate of erosion[1] since the position of a higher mean sea level would translate landwards with a corresponding move of the high water line. Cliff erosion rates would also respond to any changes in the frequency and severity of storm surges. **Paragraph 1.7.3.4** suggests existing cliff erosion rates would lead to a retreat distance to the medium-term (next 20 to 50 years) would be around 82 m, even before increased rates of sea level rise are considered.

1.7.10.10 Over the longer-term any increase in mean sea level also has the potential to place the vertical profile of Smithic Sands lower in the tidal frame which would lead to a partial reduction in wave sheltering effects and potentially increased cliff erosion. However, if increased cliff erosion lead to increased sediment supply to the bank, then the profile may be able to be maintained in a new dynamic equilibrium.

1.7.11 Data Limitations

1.7.11.1 The baseline data collated for the marine processes topic is considered to be comprehensive and complete for regional scale coverage and provides a sound basis for developing a regional overview for landfall, offshore ECC and the offshore array study areas.

1.7.11.2 Site specific data from the 2018 geophysical survey campaign is incomplete at this time, resulting in some data limitations in describing sediment grain size of surficial sediments and depth of surface sediments along the offshore ECC (although, other existing data sources help to augment this apparent data gap, such as the Creyke Beck Offshore Wind Farm inshore geophysical survey and previous sampling available from GeoIndex). A further geophysical survey is scheduled for 2019 to address the remaining gaps from the 2018 geophysical survey with the additional information informing the EIA assessment.

1.7.11.3 An understanding of the long-term behaviour of Smithic Sands is limited by a lack of routine historical surveys. The sandbank is recognised as a morphological relevant feature with observed bedforms and being dynamically linked to surrounding sediment sources and pathways.

[1] (https://www.eastriding.gov.uk/environment/sustainable-environment/looking-after-our-coastline/coastal-change-in-the-east-riding/)

1.8 Project basis for assessment

1.8.1 Source-pathway-receptor

1.8.1.1 The assessment of the potential impacts on the marine physical environment is based on the "source-pathway-receptor" approach;

- Source – a local (near-field) change attributable to a development activity interpreted from the Project Description;
- (impact) Pathway – the process which is able to distribute the effect from a source over the wider area (far-field); and
- Receptor – a feature of interest (in either the near-field or far-field) that is connected to the source by a pathway and is sensitive to the impact and may be affected.

1.8.1.2 In some cases, the receptor is directly related to the marine physical environment and in some cases the receptor is related to a biological or human environment receptor with the marine processes pathway applied to the impact assessment of such a receptor.

1.8.1.3 The issues which have been assessed have been established from a full review of the Scoping Opinion provided by PINS (The Planning Inspectorate, 2018) and are summarised in **Table 1.11.** These issues are identified as impact pathways and receptors and can be grouped by project phase and type of effect as either:

- Short-term (discrete events (hours to days) over several months) sediment disturbance events during construction, maintenance and decommissioning periods which may lead to sediment plumes of elevated suspended sediment concentration and the associated areas of the seabed with increased levels of deposition once the material settles out of the water column; or
- Long-term (several years) blockage related effects during the operational period of the wind farm which are due to foundation or rock berm structures being placed on the seabed which have a sufficiently large profile to individually and/or collectively interfere with waves or flows to develop wake effects, as well as interrupt sediment pathways.

Table 1.11: Summary of assessed impact pathways and receptors.

Project Phase	Impact pathway	Marine processes receptor
Construction	Sediment disturbance caused by seabed preparation activities (e.g. levelling around foundations, sandwave clearance for cable installation, etc.) which may lead to a requirement for removal of sediment and spoil disposal elsewhere creating elevated suspended sediment and potential smothering by deposition.	Bridlington Harbour Spoil ground HU015
Construction	Sediment disturbance caused by activities that may lead to locally raised suspended sediment concentrations at source (drilling, cable laying, seabed levelling, etc).	Bridlington Harbour Spoil ground HU015
Operation	Blockage of flows causing local (near-field) scouring around foundations (assumes scour protection is not pre-installed).	The coastline (related to cofferdams)
Operation	Blockage of flows from foundations leading to increased turbulence interfering with far-field receptors.	Flamborough Front.

Project Phase	Impact pathway	Marine processes receptor
Operation	Blockage and modification to wave energy transmission and nearshore wave climate affecting coastal morphology, including cumulative effect with Hornsea Project One and Hornsea Project Two.	The coastline, including Holderness Cliffs Smithic Sands
Operation	Blockage to nearshore sediment pathways from rock armouring over cables.	Smithic Sands
Decommissioning	Sediment disturbance during decommissioning activities that may lead to locally raised suspended sediment concentrations at source. Removal of foundations with cessation of blockage related effects on waves and tidal flows, reversing to a (future) baseline condition.	Bridlington Harbour Spoil ground HU015

1.8.1.4 In addition, impact pathways, such as sediment plumes, may relate to other receptors. In these cases, the scales of pathways created by sources are considered within the marine processes impact assessment but the sensitivity on any associated receptor types is considered in **Volume 2, Chapter 2: Benthic and Intertidal Ecology**, **Volume 2, Chapter 3: Fish and Shellfish Ecology**, **Volume 2, Chapter 4: Marine Mammals**, **Volume 2, Chapter 10: Marine Archaeology**, and **Volume 2, Chapter 12: Infrastructure and Other Users**, as appropriate.

1.8.2 Impact register and impacts "scoped out"

1.8.2.1 With consideration of the baseline environment, the Project Description outlined in **Volume 1, Chapter 4** and the Commitments in **Volume 4, Annex 5.2**, a number of impacts have been "scoped out" of the PEIR assessment for Marine Processes. These impacts are outlined, together with a justification for scoping them out, in **Table 1.12**. Further detail is provided in the Impacts Register in **Volume 4, Annex 5.1**.

1.8.2.2 Please note that the term "scoped out" relates to the Likely Significant Effect (LSE) in EIA terms and not "scoped out" of the EIA process *per se*. All impacts "scoped out" of LSE are assessed for magnitude, sensitivity of the receiving receptor and conclude an EIA significance in the Impacts Register (see **Volume 4, Annex 5.1**). This approach is aligned with the Hornsea Four Proportionate approach to EIA (see **Volume 1, Chapter 5: EIA Methodology**).

Table 1.12: Marine processes – issues scoped out of assessment.

Project activity and impact	Likely significance of effect	Approach to assessment	Justification
Changes to offshore sediment pathways (MP-O-7)	Minor adverse significance	Scoped Out	Previous impact assessments for Hornsea Project One (SMart Wind, 2013), Hornsea Project Two (SMart Wind, 2015) and Hornsea Three (Ørsted, 2018) have each indicated that impacts on sediment pathways are

Project activity and impact	Likely significance of effect	Approach to assessment	Justification
			likely to be of minor adverse significance, at least for the offshore array areas.

Notes:
Grey - Potential impact is scoped out and both PINS and Hornsea Four agree.

1.8.2.3 The scoping out of offshore sediment pathways has been confirmed by the Scoping Opinion (PINS, 2018).

1.8.3 Commitments

1.8.3.1 Hornsea Four has made several commitments (primary design principles inherent as part of the project, installation techniques and engineering designs/ modifications as part of their pre-application phase, to avoid a number of impacts or reduce impacts as far as possible). Further Commitments (adoption of best practice guidance) are also embedded as an inherent aspect of the EIA process.

1.8.3.2 **Table 1.13** summarises the marine processes commitments adopted by Hornsea Four. Full details of the Commitments are provided within the Commitments Register (see **Volume, Annex 5.2**).

Table 1.13: Relevant marine processes commitments.

Commitment ID	Measure Proposed	How the measure will be secured
Co44	Primary: The Holderness Inshore Marine Conservation Zone (MCZ) will not be crossed by the offshore export cable corridor including the associated temporary works area.	DCO Schedule 1, Part 1 Authorised Development
Co45	Primary: The Holderness Offshore MCZ will not be crossed by the offshore export cable corridor including the associated temporary works area.	DCO Schedule 1, Part 1 Authorised Development
Co82	Tertiary: A Scour Protection Management Plan will be developed. It will include details of the need, type, quantity and installation methods for scour protection.	DCO Schedule 11, Part 2 - Condition 12(1)(e) and; DCO Schedule 12, Part 2 - Condition 12(1)(e) *(Scour Protection Management Plan)*
Co83	Primary: Where possible, cable burial will be the preferred option for cable protection.	DCO Schedule 11, Part 2 - Condition 12(1)(h) and; DCO Schedule 12, Part 2 - Condition 12(1)(h) (*Cable specification and installation plan*)

1.9 Maximum Design Scenario

1.9.1.1 Where multiple options remain for project development activities, the definition of sources for marine processes is based on the Maximum Design Scenario (MDS). The MDS option represents the conservative case of any of the design options with an alternative option to the MDS considered to have a lesser environmental effect. The MDS for marine processes has been determined from a review of the Project Description for Hornsea Four (**Volume 1 Chapter 4: Project Description**).

1.9.1.2 The MDS is considered for activities that are planned for construction, operation and decommissioning phases.

1.9.2 MDS for Construction Phase

1.9.2.1 The MDS for construction related issues is defined by the greatest volumes of disturbed sediment occurring in the shortest period (highest rates of disturbance) from various seabed preparation activities which may create elevated levels of suspended sediment and subsequent deposition (smothering risk on a seabed receptor). These activities include:

- Levelling for foundations;
- Sandwave clearance for cable installation;
- Cable installation;
- Drilling for foundation piles; and
- Spoil disposal.

1.9.3 MDS for Operation Phase

1.9.3.1 During operation of the wind farm (the longest phase of the development) the main consideration for marine processes is blockage effects on waves, flows and sediment pathways from structures placed in the water column (including; foundations, subsea structures and rock armour at cable crossings), as well as consequential local scouring (if no scour protection is provided prior to installation of foundation).

1.9.3.2 Blockage can lead to the formation of wakes (retardation of flows with increased turbulence in a wake, flow separation around large obstacles, diffraction and scattering of wave energy, etc.) and the potential to modify sediment transport pathways in the far-field, including longshore transport.

1.9.3.3 The MDS for any array blockage effect is a product of the greatest number of closest spaced and widest foundations (with high solidity ratio[2]) that could potentially interfere with the normal passage of currents, waves and sediment pathways.

1.9.3.4 During the operation phase there may also be various maintenance activities which have the potential to create short-term periods of disturbed sediments; however, these are considered to be minor in comparison to those occurring during either the construction or decommissioning phase.

1.9.4 MDS for Decommissioning Phase

1.9.4.1 The MDS for decommissioning relates to foundation removal which may create the greatest volumes of disturbed sediment in the shortest period (highest rates of disturbance), along with a consideration of seabed recovery to conditions which would have occurred at this time in a baseline environment without the development.

1.9.5 Summary of MDS options for marine processes

1.9.5.1 **Table 1.14** provides details of the MDS options for marine processes.

[1] **Solidity ratio** is defined as the ratio of effective area (projected area of all the individual elements of a structure) of a frame normal to the wave, tidal flow or sediment transport direction divided by the area enclosed by the boundary of the frame. A solid structure will have a solidity ratio of 1, whereas an open frame lattice structure (e.g. jacket type) will generally have a much lower solidity ratio towards 0.2 (typical values between 0.1 and 0.3).

Table 1.14: Maximum design scenario for impacts on marine processes.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
Construction			
Seabed preparation activities (MP-C-1)	Primary Co44 Co45	**Landfall area** Eight offshore cofferdam HDD exit pits require excavation of 2,500 m^3 which will be side-cast onto the adjacent seabed. Backfilling of exit pits will recover a similar amount to be from the surrounding seabed, as required. **Offshore ECC** **Sandwave clearance** - Total sandwave clearance of 757,000 m^3 along a corridor of 99 km in length. **HVAC foundations** Seabed preparation for Suction Caisson Jacket foundations requires removal of 171,735 m^3 for 3 * HVAC booster station foundations. **Offshore array area** **Sandwave clearance** –Total sandwave clearance of 961,000 m^3 which includes 77,000 m^3 for an additional 10 km of export cable within the offshore array. **180 WTG Foundations** Seabed preparation for Suction Bucket Jacket foundations requires removal of 2,134,440 m^3 for 180 wind turbine foundations. **9 OSS foundations** Seabed preparation for Suction Caisson Jacket (Small OSS) & GBS (Large OSS) requires removal of 737,130 m^3 of spoil for 9 offshore sub-station foundations. **Offshore accommodation foundation** Seabed preparation for Suction Caisson Jacket (Medium OSS) requires removal of 57,245 m^3 of spoil for a single offshore accommodation platform foundation. **Total spoil in offshore array area = 3,889,915 m^3**	Seabed preparation (seabed levelling and sandwave clearance) assumes excavation using a trailer suction hopper dredger (TSHD) which collects a large volume of sediment and then releases this as spoil onto the seabed leading to the highest risk of smothering. These impact pathways are separated from seabed installation because they require disposal of spoil away from the point of excavation.
Seabed installation activities	Primary Co44 Co45	**Landfall area** Open cut trenching across the intertidal with tidal exchange (low water to high water to low water) flushing away lose materials determining a potential source of	All direct sediment disturbance activities that may lead to locally raised suspended

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
(MP-C-2)		sediment from the trench and from any beach material cast aside. **Offshore ECC** **Cable trenching** – Cable installation along a length of 109 km for up to 6 cables releasing 3,903,000 m^3 into suspension by a Mass Flow Excavator (MFE). Values include the 10 km of export cable falling within offshore array area. Total duration of 24 months with a maximum trenching rate of 300 m/hr in soft soils. **HVAC Booster area** – drilling for Piled Jacket (Medium OSS) foundation option, releasing 4,618 m^3 for 3 foundations, representing 10% (of depth). **Offshore array area** **Cable trenching** - releasing 4,140,000 m^3 into suspension by MFE for array and interconnector cables. Single trenching vessel assumed for a sequential activity. **Drilling:** **180 WTG Foundations** – drilling for monopile foundation option, 127,235 m^3 for 180 foundations, representing 10% (of sites). Drilling activity considered to be sequential between sites. **9 OSS foundations** – drilling for Piled Jacket (Small OSS) 13,854 m^3 for 9 foundations, representing 10% (of depth). Drilling activity considered to be sequential between sites. **Offshore accommodation** - drilling for Piled Jacket (Medium OSS) & Piled Jacket (Medium OSS), 1,540 m^3 for 1 foundation, representing 10% (of depth). **Total drill cutting arisings in offshore array area = 142,629 m^3**	sediment concentrations at source (e.g. drilling, cable trenching, etc). Largest disturbed volume and highest trenching rate produces the greatest rate of sediment release at source. MFE is selected as the MDS option for trenching due to similarities with jetting releasing sediments into the water column, but involving larger volumes of sediment. For drilling, the greatest amount of arisings represents the MDS irrespective of the foundation type. These impact pathways are separated from seabed levelling and sandwave clearance because they occur at source.
Operation			
Scouring around foundations and rock berms (MP-O-3)	Tertiary Co82	**Landfall** The MDS configuration for scour around the base of 8 cofferdams would be when they are closely spaced (at their minimum spacing of 10 m) with separate scour pits that also overlap to lead to wider group scour. The dimension of a single cofferdam is 10.6 by 10.6 m (square).	Installed foundation, or other sub-sea structures proud of the seabed (e.g. rock berms), may lead to local scouring around their base if scour protection has not already pre-armoured the seabed. Depending on the

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		<u>Offshore ECC</u> **Rock berms at nearshore cable crossings** – Hornsea Four (up to 6 cables) will cross the export cable (up to 4 cables) for Creyke Beck Offshore Wind Farm seaward of Smithic Sands. **HVAC booster area** – risk for scouring in pre-scour protection period around three 75 m wide GBS (Box-type) foundations. **Rock berms at offshore cable crossings** – 9 crossings over existing assets, potential for scouring dependent on rock size and grading to perimeter with heights up to 1.5 m. **<u>Offshore array area</u>** **180 WTG Foundations** – 3-legged suction bucket jacket with 20 m diameter buckets 5 m proud of seabed, with potential for group scour between legs. **9 OSS foundations** – 150 m wide GBS (box-type). **Offshore accommodation** – 75 m wide GBS (box-type). **Rock berms at cable crossings** – 40 potential crossings over new pipelines, potential for scouring dependent on rock size and grading to perimeter. Some alignments may locally inhibit bedload transport.	seabed material, the scouring process may erode material into bedload and/or suspended load transport until an equilibrium condition is reached. In general, the largest foundation with the greatest solidity ratio will have the largest blockage effect on flows and will develop the most amount of scour, rather than the greatest depth of scour.
Turbulent wakes from foundations interfering with remote receptors, e.g. Flamborough Front (MP-O-4)	N/A	**<u>Landfall</u>** Wakes will form locally around the cofferdams used to protect offshore HDD exit pits. Wave and tidal flows will be longshore so the MDS arrangement is likely to be a closely spaced staggered arrangement leading to 8 independent wakes which also overlap. The equivalent dimension of a single pit is 10.6 by 10.6 m (square), providing a total area of 900 m^2 for all 8 pits.. **<u>Offshore ECC</u>** **HVAC booster area** – largest solid structure in the vertical plane is the 75 m width GBS (Box-type). The wake formation may depend on the orientation of this structure to incident flows and waves as well as the minimum spacing between structures and the layout of structures. A minimum separation distance of 100 m is likely to result in wake-wake interactions and a larger cumulative effect between all 3 structures. **Rock berms** – all in water depths between 40 to 50 m CD. No likely wake effects.	Typically, greatest amounts of turbulence will occur from the largest foundation width with the highest solidity ratio which blocks the passage of incident flows and waves (as well as sediment transport moved by these processes). For open structures like jacket foundations there is a reduced solidity and a reduced blockage for the equivalent width of a fully solid structure.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		<u>Offshore array area</u> **180 WTG Foundations** – The foundation considered to have the greatest blockage effect for MDS is the 3-legged suction bucket jacket with 20 m diameter buckets 5 m proud of the seabed with a leg separation of 65 m at the seabed tapering to 25 m at the sea surface. **9 OSS foundations** – 150 m GBS (box-type) foundation has the greatest blockage. **Offshore accommodation** – 75 m GBS (box-type) foundation has the greatest blockage. The total blockage effect for the whole array is also a function of the number, spacing and layout of all 190 foundations. The principles for the array layout are based on a minimum WTG separation of 810 m.	Rock berms in deeper water are unlikely to have sufficient vertical profile to develop wakes, however, if there were equivalent structures in shallower water, they may have a proportionally larger influence and develop partial wakes.
Changes to waves affecting coastal morphology (MP-O-5)	N/A	**<u>Landfall</u>** Cofferdams used to protect offshore HDD exit pits will have a temporary effect on waves reaching the coastline. The MDS configuration would be when they are at their minimum spacing of 10 m in a shore parallel arrangement that acts like a long, semi-permeable breakwater. **<u>Offshore ECC</u>** **Rock berms at nearshore cable crossings** - Creyke Beck Offshore Wind Farm cable crossing in around 20 m below CD. **HVAC booster area** – largest solid structure in the vertical plane is the 75 m width GBS (Box-type). These structures have the potential to block, reflect and scatter incident waves. A minimum separation distance of 100 m is likely to result in interactions and a larger cumulative effect between structures. **Rock berms at offshore cable crossings** – 9 pipeline crossings further offshore in water depths between 40 to 50 m below CD. **<u>Offshore array area</u>** **180 WTG Foundations** – The foundation considered to have the greatest blockage effect for MDS is the 3-legged suction bucket jacket with 20 m diameter buckets 5 m	This is a specific impact related to blockage of waves on the coastline as a receptor prone to high cliff erosion rates and strong longshore transport. The previous selection of MDS for largest blockage related effects apply.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		proud of the seabed with a leg separation of 65 m at the seabed tapering to 25 m at the sea surface. **9 OSS foundations** –150 m width GBS (box-type) foundation has the greatest blockage. **Offshore accommodation** –75 m width GBS (box-type) foundation has the greatest blockage.	
Changes to nearshore sediment pathways (MP-O-6)	N/A	**Rock berms at cable crossings** – Hornsea Four will cross the export cable for Creyke Beck offshore wind farm seaward of Smithic Sands. Maximum berm height of 1.5 m placed in around 20 m CD. Rock protection assumed for 10% of offshore ECC cable length in addition to any cable crossings. **HVAC Booster area** – three (3) large BGS box-type foundations closely spaced at 100 m may modify nearshore waves and longshore transport.	This issue relates to the consequence of changes to nearshore flows and waves that drive nearshore sediment pathways
Decommissioning			
Sediment disturbance - all direct sediment disturbance activities during decommissioning that may lead to locally raised SSC at source (MP-D-2)	N/A	The assumption is for comparable or lesser rates of sediment disturbance determined for installation of cables (trenching) and foundations (seabed levelling) but without any further requirements for spoil disposal. Removal of structures will also remove their blockage effects. Scour protection and rock berms at cable crossings are planned to remain in situ.	The assumption is based on equivalent methods being used as those required for cable trenching. Foundation removal is likely to involve cutting off any piles and lift of the main structure and would involve a smaller footprint than any seabed preparation activity.

1.10 Assessment methodology

1.10.1.1 The assessment of source, pathways and receptors is largely developed using simple assessments qualified against comparable evidence of effects drawn from other similar developments, notably Hornsea Project One and Two. No additional modelling of effects has been undertaken at this time given that there is considered to be appropriate and adequate previous considerations of similar issues by comparable projects and that these projects did not quantify any marine process effects as being significant to their respective receptors (N.B. Hornsea Four has both common and separate receptors and these may have a different source-pathway-receptor relationship).

1.10.1.2 The evidence-based approach, supported by simple assessments, is considered to be proportionate. The evidence-based approach is also consistent with present best practice for conducting coastal process studies (ABPmer and HR Wallingford, 2009). This approach is described in Ørsted (2018) which has been shared with statutory consultees and was presented at the first meeting of the Marine Ecology & Processes Evidence Plan technical panel on 12 September 2018. The approach is also consistent with **Volume 1, Chapter 5 Environmental Impact Assessment Methodology**.

1.10.2 Impact assessment criteria

1.10.2.1 The criteria for determining the significance of effects is a two-stage process that involves defining the sensitivity of the receptors and the magnitude of the impacts. This section describes the criteria applied in this chapter to assign values to the sensitivity of receptors and the magnitude of potential impacts. The terms used to define sensitivity and magnitude are based on those used in the DMRB methodology, which is described in further detail in **Volume 1, Chapter 5: Environmental Impact Assessment Methodology**.

1.10.2.2 The criteria for defining sensitivity for marine process receptors are provided in **Table 1.15**.

Table 1.15: Definition of terms relating to receptor sensitivity.

Sensitivity	Definition used in this chapter
Very High	Receptor is high value or critical importance to local, regional or national economy or environment. Receptor is highly vulnerable to impacts that may arise from the project and recoverability is long term or not possible.
High	Receptor is of moderate value with reasonable contribution to local, regional or national economy or environment. Receptor is generally vulnerable to impacts that may arise from the project and / or recoverability is slow and/or costly.
Medium	Receptor is of minor value with small levels of contribution to local, regional or national economy or environment. Receptor is somewhat vulnerable to impacts that may arise from the project and has moderate to high levels of recoverability.
Low	Receptor is of low value with little contribution to local, regional or national economy or environment. Receptor is not generally vulnerable to impacts that may arise from the project and/or has high recoverability.

1.10.2.3 The criteria for defining magnitude in this chapter are outlined in Table 1.16 below.

Table 1.16: Definition of terms relating to magnitude of an impact.

Magnitude of impact	Definition used in this chapter
Major	Total loss of function. Impact is of extended temporal or physical extent and/or of long-term duration (i.e. approximately >20 years duration).
Moderate	Loss or alteration to significant portions of key components of current function. Impact is of moderate temporal or physical extent and/or of medium-term duration (i.e. two to 20 years).
Minor	Minor shift away from baseline, leading to a change in function. Impact is of limited temporal or physical extent and/or of short-term duration (i.e. less than two years).
Negligible	Very slight change from baseline condition. Physical extent of impact is negligible and / or of short-term duration (i.e. less than two years).

1.10.2.4 The significance of the effect upon marine processes is determined by correlating the magnitude of the impact and the sensitivity of the receptor. The method employed for this assessment is presented in Table 1.17. Where a range of significance of effect is presented in Table 1.17, the final assessment for each effect is based upon expert judgement.

1.10.2.5 For this assessment, any effects with a significance level of minor or less have been concluded to be not significant in terms of the EIA Regulations.

Table 1.17: Matrix used for the assessment of the significance of the effect.

		Magnitude of Impact/Degree of Change			
		Negligible	**Minor**	**Moderate**	**Major**
Value, Importance, Sensitivity	**Low**	Not Significant	Not Significant or Minor (Not Significant)	Minor (Not Significant)	Minor (Not Significant) or Moderate (Significant)
	Medium	Not Significant	Minor (Not Significant)	Moderate (Significant)	Moderate (Significant) or Major (Significant)
	High	Not Significant	Minor (Not Significant) or Moderate (Significant)	Moderate (Significant) or Major (Significant)	Major (Significant) or Substantial (Significant)
	Very High	Not Significant	Moderate (Significant) or Major (Significant)	Major (Significant) or Substantial (Significant)	Substantial (Significant)

1.10.2.6 The assessments of potential change to pathways are not accompanied by a conclusion regarding the significance of effect. Instead the significance of effect is considered in the various relevant Chapters within the PEIR, namely; **Volume 2, Chapter 2: Benthic and Intertidal Ecology**, **Volume 2, Chapter 3: Fish and Shellfish Ecology**, **Volume 2, Chapter 4: Marine Mammals**, **Volume 2, Chapter 10: Marine Archaeology**, and **Volume 2, Chapter 12: Infrastructure and Other Users**.

1.11 Impact assessment

1.11.1 Construction

1.11.1.1 The impacts of the offshore construction of Hornsea Four have been assessed on marine processes. The environmental impacts arising from the construction of Hornsea Four are listed in **Table 1.14** along with the MDS against which each construction phase impact has been assessed.

1.11.1.2 A description of the potential effect on marine process pathways and receptors caused by each identified impact is given below.

Seabed preparation activities (MP-C-1)

1.11.1.3 Seabed preparation is defined as activities which may excavate material from source with a requirement for spoil disposal elsewhere. The excavation and disposal activities may each create elevated levels of suspended sediment and spoil disposal may lead to rapid smothering by large volumes of sediment falling to the seabed.

1.11.1.4 Seabed preparation activities planned for the construction phase include provisions for:

- Seabed excavation to install cofferdams at landfall for eight HDD exit pits;
- Sandwave clearance prior to cable laying along the offshore ECC and within the offshore array. This process will target mobile bedforms that are unfavourable to cable installation due to their gradient; and
- Seabed preparation (levelling) for foundations in both the HVAC booster area and offshore array area. This activity aims to level the seabed to aid the installation of foundation bases that need an even surface.

1.11.1.5 **Section 4.3** of the **Volume 5, Annex 1.1: Marine Processes Technical Report** provides further details of the seabed preparation assessment.

Seabed preparation in landfall area (MP-C-1)

1.11.1.6 The MDS sediment volume for the cofferdam excavation option in the landfall area is a total of up to 2,500 m^3 for up to eight exit pits (six exit pits plus two for contingency) within the intertidal. This equates to an average volume of up to 312.5 m^3 per pit.

1.11.1.7 The excavation for each pit is likely to be sequential, limiting the chance for one large spill event. The time required to excavate each pit and the time between the next excavation are not known at this time.

1.11.1.8 The preferred option is to side-cast the excavated material onto the adjacent seabed close to each exit pit as a spoil mound. Backfilling of exit pits will then recover the required amount of sediment from the surrounding seabed to infill each pit.

1.11.1.9 In the two-month period between excavation and infilling of each pit there is potential for some of the spoil mound to be winnowed down by wave and tidal action. Unconsolidated sands and silts in the spoil will become assimilated into the general nearshore transport process. The coarse gravels and any consolidated clay till are likely to be less affected and will mainly remain in place.

1.11.1.10 The further MDS assumption is that the amount of sediment required to infill the exit pits from the surrounding seabed is likely to include some of the legacy spoil but also some freshly excavated material to make good for any losses to the spoil mound. This infilling process will create further periods of sediment spill causing temporary and locally elevated suspended sediment concentrations, as well as some local lowering of the seabed. Local lowering may be naturally infilled by sandy material that is locally mobile.

Magnitude of impact

1.11.1.11 This is anticipated to be a small-scale, highly localised and intermittent activity limited to the short-term. The magnitude of impact leading to any elevated levels of siltation in the vicinity of the landfall area would be **negligible**.

1.11.1.12 Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Figure 5.3: Deriving the Level of Significance of an Impact; Volume 1, Chapter 5: EIA Methodology**) and is not considered further in this assessment.

Further mitigation

1.11.1.13 No further mitigation is considered necessary since there are no likely significant effects.

Seabed Preparation – Sandwave Clearance (MP-C-1)

1.11.1.14 The MDS volume for sandwave clearance is a total of up to 757,000 m^3 across up to 6 export cables and sweeping a width of 30 m per cable. In addition, sandwave clearance in the offshore array area accounts for up to 961,000 m^3, this includes a 10 km section of the export cable. The MDS assumption is this activity would be achieved with a trailer suction hopper dredger (TSHD) which would initially lead to overspill at source and then spoil disposal at a site elsewhere leading to a higher discharge volume as the hopper is emptied.

1.11.1.15 The efficiency of the dredger discharging overspill means that less than 100% of the excavated material remains in the hopper and the rest is discharged with the overspill (overflow losses) across the areas being dredged. Overspill losses depend on many issues, not least hopper filling rates and sediment types. For sandwave sediments (presumed to be mainly medium sand) the overspill losses are likely to be relatively low and limited to marginal amounts of finer grained sands and silts present in the sediment.

1.11.1.16 Overspill will form a plume from the marginal amount of fine sediments present, which will be advected away by tidal flows. The duration of the overspill event per dredging cycle is likely to be comparable to the time required to fill the hopper. An indicative period of 4 hours is assumed to fill a 11,000 m^3 hopper.

1.11.1.17 The main axis of the plume trajectory will be governed by tidal advection with reduced concentrations around this axis due to dispersion and diffusion mixing processes spreading the plume. Plume concentrations will reduce over distance due to increased mixing and material falling out of suspension. During a neap tide the plume will be advected over a shorter distance than a spring tide, and since the rate of mixing will be less at these times due to weaker flows, then suspended sediment concentrations can be expected to be proportionally higher. On spring tides, the plume will spread further and have a proportionally lower concentration. Winds would expect to have some influence on surface material, either by increasing mixing and/or modifying the plume trajectory.

1.11.1.18 As a general consideration, suspended sediment concentrations within sediment plumes can be in the order of hundreds of mg/l in the vicinity of the dredger, reducing to tens of mg/l with distance (CIRIA, 2000), but also quickly dissipating in time after release to further reduce concentrations. Only the very fine sediments (likely to be a marginal amount of the total volume of material removed from the seabed) in the overspill may remain in suspension for relatively long periods due to slow settling rates and the effect of (re)mobilising flows keeping material in suspension. This material is likely to become undiscernible from the background sediment load within a few tidal cycles. Given the likely loading and dumping cycle each overspill event is expected to disperse away as a separate plume.

1.11.1.19 Once the dredger moves to discharge a full hopper load close by, the majority of the finer sediments are expected to have already been lost as overspill. The remaining sediments in the hopper should be predominantly composed of the coarser sediment fractions, meaning that the disposal of the spoil is likely to have a lesser concern in the formation of any sediment plume. In contrast, the majority of the spoil will fall more quickly to the seabed with limited opportunity to disperse (but correspondingly leading to a greater depth of accumulation at the seabed).

1.11.1.20 The depth of deposition and area covered will be determined by the volume of the hopper load, the course of the vessel in the period of opening hopper doors, the tidal flows at the time and the relative composition of the sediment being disposed of. The vessel speed could also act as means to ensure the deposition of spoil is more widely dispersed than opening the hopper doors when the vessel is stationary. Comparable assessments for Hornsea Project One (SMart Wind, 2013) and Hornsea Project Two (SMart Wind, 2015) suggested an area of deposition of up to 49,000 m^2 (diameter of 120 m up to 250 m) for each spoil mound with sediment depths from less than 1 m up to 1.5 m.

1.11.1.21 Once deposited, the sand removed from sandwaves is likely to re-join the same transport environment that originally created and moved the bedforms. Over a period of time, this process may winnow down any spoil mound; however, in the offshore array area sediment mobility is typically limited to the spring tides which may lead to a slower winnowing process. For the shallower nearshore environment where flows are typically stronger, the mobility can be expected to be higher and will also become influenced by waves.

1.11.1.22 Impacts related to overspill and spoil disposal from sandwave clearance are considered to be marine processes pathways for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.1.23 Uncertainties in the assessment relate mainly to the partially complete geophysical survey which is yet to confirm the presence of sandwaves along the offshore ECC. The present MDS assumption is for sandwaves along all of the offshore ECC, however, this is likely to become much reduced once the second part of the geophysical survey is complete in 2019 and confirms those areas without sandwaves, as appears to be indicated by existing evidence.

Seabed levelling – HVAC booster area (MP-C-1)

1.11.1.24 The MDS volume for seabed levelling within the HVAC booster area is up to 171,735 m^3 for the three six-legged Suction Caisson Jacket (Small OSS) foundation option. The excavation of this volume of sediment will create overspill from the 111 by 111 m area being dredged for each foundation, followed by a period of spoil disposal nearby.

1.11.1.25 The anticipated surficial sediment types in the area being levelled are gravely sand with the potential for slightly gravelly sand for sites on the eastern side of the HVAC booster area. Sediment samples (from Geoindex; **Table 1.5**) which are in the general area suggest the mud content is typically between 0.4 to 2%, although the mud content may be higher in material slightly below the surface of the seabed. The gravel content generally represents 1.2 to 26% of the sample with particle sizes mainly in the range 4 to 8 mm. The remaining sand content is characteristically fine to medium sized sands. No allowance is made here for variability of sediment types over the excavation depth.

1.11.1.26 Overspill will form a plume largely made up of the finer sediment which will be advected away by tidal flows. The duration of the overspill event per dredging cycle is likely to be comparable to the time required to fill the hopper. An indicative period of 4 hours is assumed to fill a 11,000 m^3 hopper.

1.11.1.27 The main axis of the plume trajectory will be governed by tidal advection with reduced concentrations around this axis due to dispersion and diffusion mixing processes spreading the plume. Plume concentrations will reduce over distance due to increased mixing and material falling out of suspension. During a neap tide the plume will be advected over a shorter distance (up to 6 km) than a spring tide (up to 12 km), and since the rate of mixing will be less at these times due to weaker flows, then suspended sediment concentrations can be expected to be proportionally higher. On spring tides, the plume will spread further and have a proportionally lower concentration, i.e. more dispersed over a wider area. Winds would expect to have some influence on surface material, either by increasing mixing and/or modifying the plume trajectory.

1.11.1.28 Once the dredger moves to discharge a full hopper load close by, the majority of the finer sediments are expected to have already been lost as overspill. The remaining sediments in the hopper should be predominantly composed of the coarser sediment fraction, meaning that the disposal of the spoil is likely to have a lesser concern in the formation of any sediment plume. In contrast, the majority of the spoil will fall more quickly to the seabed (within a few minutes, and less than one hour, to fall around 50 m to the seabed) with limited opportunity to disperse, leading to a greater depth of accumulation at the seabed and therefore a higher risk of smothering of any benthic receptors.

1.11.1.29 The depth of deposition and area covered will be determined by the volume of the hopper load, the course of the vessel in the period of opening hopper doors, the tidal flows at the time and the relative composition of the sediment being disposed of between sands and gravels (which will determine the angle of repose, nominally 25 to 30° for sandy gravel). The vessel speed could also act as means to ensure the deposition of spoil is more widely dispersed than opening the hopper doors when the vessel is stationary. Comparable assessments for Hornsea Project One (SMart Wind, 2013) and Hornsea Project Two (SMart Wind, 2015) suggested an area of deposition of up to 49,000 m^2 (diameter of 120 m up to 250 m) for each spoil mound with sediment depths from less than 1 m up to 1.5 m.

1.11.1.30 Once deposited, the coarse sand and fine gravel are unlikely to be remobilised by the local tidal flows, whereas the medium sands are only likely to be remobilised when flows exceed mean neap tides and for material that is not covered and armoured by the relatively immobile coarser sediment sizes.

1.11.1.31 Overspill and spoil disposal from seabed levelling in the HVAC booster area are considered to be pathways for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.1.32 Uncertainties in the PEIR assessment relate mainly to the part-complete 2018 geophysical survey which is yet to confirm the local sediment composition in areas likely to require levelling. Existing data sources have been referred to enable a general description of this area. The 2019 geophysical survey will enable confirmation of present assumptions to support the EIA assessment.

Seabed levelling – offshore array area (MP-C-1)

1.11.1.33 The MDS volume for seabed levelling within the offshore array area is up to 2,134,440 m^3 for 180 Suction Bucket Jacket (WTG-type) foundations, equivalent to up to 11,858 m^3 per foundation. In addition, levelling is also required for the offshore substations and an accommodation platform. In this case, up to 794,375 m^3 for six Suction Caisson Jacket (Small OSS), three GBS (Large OSS) and one Suction Bucket Jacket (Small OSS) for the accommodation platform. This equates to total of up to 2,928,815 m^3 of sediment removal.

1.11.1.34 The anticipated surficial sediment types in the offshore array area are mainly sands with some patches of slightly gravelly sand and gravelly sand. The content of fines (material < 0.063 mm) determined by grab samples across the offshore array area is generally low (0 to 10.1%, and typically < 5%) apart from two locations on the eastern boundary where the content of fines increases to 13.7 and 15.3%. These areas are described as gravelly muddy sand and represent an area without any cover of Holocene sands and are interpreted as firm to stiff glacial till of the Bolders Bank formation (Gardline, 2019). No allowance is made here for variability of sediment types over the excavation depth.

1.11.1.35 Overspill will form a plume largely made up of the finer sediment which will be advected away by tidal flows. The duration of the overspill event per dredging cycle is likely to be comparable to the time required to fill the hopper. An indicative period of 4 hours is assumed to fill a 11,000 m^3 hopper.

1.11.1.36 The main axis of the plume trajectory will be governed by tidal advection with reduced concentrations around this axis due to dispersion and diffusion mixing processes spreading the plume. Plume concentrations will reduce over distance due to increased mixing and material falling out of suspension. During a neap tide the plume will be advected over a shorter distance (up to 4 km) than a spring tide (up to 8 km), and since the rate of mixing will be less at these times due to weaker flows, then suspended sediment concentrations can be expected to be proportionally higher. On spring tides, the plume will spread further and have a proportionally lower concentration, i.e. more dispersed over a wider area. Winds would expect to have some influence on surface material, either by increasing mixing and/or modifying the plume trajectory.

1.11.1.37 Once the dredger moves to discharge a full hopper load close by, the majority of the finer sediments are expected to have already been lost as overspill. The remaining sediments in the hopper should be predominantly composed of the coarser sediment fraction, meaning that the disposal of the spoil is likely to have a lesser concern in the formation of any sediment plume. In contrast, the majority of the spoil will fall more quickly to the seabed with limited opportunity to disperse, leading to a greater depth of accumulation at the seabed and therefore a higher risk of smothering of any benthic receptors.

1.11.1.38 The depth of deposition and area covered will be determined by the volume of the hopper load, the course of the vessel in the period of opening hopper doors, the tidal flows at the time and the relative composition of the sediment being disposed of. The vessel speed could also act as means to ensure the deposition of spoil is more widely dispersed than opening the hopper doors when the vessel is stationary. Comparable assessments for Hornsea Project One (SMart Wind, 2013) and Hornsea Project Two (SMart Wind, 2015) suggested an area of deposition of up to 49,000 m^2 (diameter of 120 m up to 250 m) for each spoil mound with sediment depths from less than 1 m up to 1.5 m.

1.11.1.39 Once deposited, the coarse sand and fine gravel are unlikely to be remobilised by the local tidal flows, whereas the medium sands are only likely to be remobilised when flows exceed mean neap tides and for material that is not covered and armoured by the immobile coarser sediment sizes.

1.11.1.40 Overspill and spoil disposal from seabed levelling in the offshore array area are considered to be pathways for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.1.41 Uncertainties in the assessment relate mainly to the assumptions in sediment composition over the depth of levelling. Further assumptions are that all spoil disposal events within the offshore array area target a separate area of seabed and there is no cumulative depth of deposition from overlapping spoil sites.

Seabed installation activities (MP-C-2)

1.11.1.42 Seabed installation considers activities which lead to sediment disturbance at source and does not require removal of sediment for disposal elsewhere.

1.11.1.43 Seabed installation activities planned for the construction phase include:

- Open cut trenching across the intertidal (landfall area);
- Cable trenching along offshore ECC (for export cables) and through offshore array area (for array cables); and
- Drilling for foundation options requiring piles to be inserted into the seabed in the HVAC booster area (up to three foundations) and offshore array area (up to190 foundations).

1.11.1.44 **Section 4.4** of the **Volume 5, Annex 1.1: Marine Processes Technical Report** provides further details of the assessment of seabed installation activities.

Open cut trenching across the intertidal at the export cable landfall (MP-C-2)

1.11.1.45 The option for open cut trenching across the intertidal area (an alternative to the HDD option) has the potential to temporarily interrupt longshore drift for a short period (up to 32 weeks), before the beach is re-instated.

1.11.1.46 The potential disturbance corridor from plant movements, excavation, etc. for each cable is an approximate width of 60 m, with a separation of approximately 30 m between cables, a total disturbance width of approximately 210 m. Each trench would be dug to a depth of between 1 to 3 m and take approximately two weeks to complete.

1.11.1.47 The configuration of landfall works across the intertidal, the method of trenching and location of stockpiles for excavated material will determine the types of impacts that might occur.

1.11.1.48 The assumption is that these works will take place after any similar landfall works required for Creyke Beck offshore wind farm. This assumption removes the opportunity for cumulative impacts between two activities occurring in a similar timescale and close together.

1.11.1.49 Sediment disturbance will occur during the trenching works and any loosened fine material remaining in an open trench will tend to be transported away when the tide washes in and out of the trench. This is likely to introduce a relatively low volume of sediment into the marine environment comparable to background levels where the waves and tide already sweep the intertidal of mobile material.

1.11.1.50 If installation works create a barrier effect between high and low water (e.g. due to equipment, vessels, spoil mounds, etc.), then there is a potential for longshore drift to be temporality interrupted in the vicinity of the works (e.g. due to excavated volumes being cast aside to create a mound) for a short period. In addition, longshore drift at the landfall is relatively low, given that this location is regarded as a drift-divide with a balance between up and down-drift rates (**Figure 1.10**).

1.11.1.51 Once the works are completed, and beach levels are re-instated, then a normal beach level is expected to return very quickly.

Magnitude of impact

1.11.1.52 This is anticipated to be a small-scale, highly localised and intermittent activity limited to the short-term. The magnitude of impact to leading to any elevated levels of siltation in the vicinity of the landfall area or changes to longshore drift would be **negligible**.

1.11.1.53 Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Figure 5.3: Deriving the Level of Significance of an Impact; Volume 1, Chapter 5: EIA Methodology**) and is not considered further in this assessment.

Further mitigation

1.11.1.54 No further mitigation is considered necessary since there are no likely significant effects.

Cable trenching – offshore ECC (MP-C-2)

1.11.1.55 Cable trenching will occur after sandwave clearance is completed. Up to six export cables will be laid along the 109 km offshore ECC.

1.11.1.56 The trench depths will be confirmed by a CBRA. Present assumptions are based on a maximum burial depth of 3 m (2 m in the case of installation using MFE) with a maximum installation width of 15 m (within the 30 m sandwave and boulder clearance corridor).

1.11.1.57 The optimal method to achieve trenching generally corresponds to soil strength characteristic and may require jetting and / or ploughing. In addition, consideration is being given to the use of a MFE which is similar to jetting in that both use hydraulic forces to push away unconsolidated sediments. MFE is considered as the conservative/ worst case installation option because of the greater volume of sediments likely to be (fluidised) disturbed and the type of disturbance which injects material into suspension (leading to sediment plumes) in comparison to ploughing which will simply cast material to the side.

1.11.1.58 Trenching rates determine how much material is released per second. Trenching rates depend as much on the trenching tool as the soil characteristics, however, some general rates can be suggested:

- 55 m/hour for hard soils;
- 125 m/hour for medium soils; and
- 300 m/hour for soft soils.

1.11.1.59 Up to three cable laying vessels may be operating at the same time creating the potential for these vessels to be operating in a similar area which may compound concentrations of suspended sediment from sediment disturbance effects.

1.11.1.60 The maximum sediment volume expected to be displaced by MFE along the offshore ECC is approximately 3,903,000 m^3 (i.e. 100% fluidised by the hydraulic pressure displacing material from the trench). The assumption is this amount of sediment is apportioned between each of the six cables which equates to an average sediment volume of 6 m^3 per metre of excavation.

1.11.1.61 The majority of the excavated material is expected to be coarse sediments (sands and gravels) which will drop back to the seabed relatively quickly and close to the point of disturbance. The content of fine sediments (silts and muds) is generally expected to be low (< 1 % to < 7%) limiting the potential for sediment plumes to be formed with high concentrations. The main exception is the nearshore ebb channel where areas of exposed glacial tills are likely to have a higher content of fine sediments (< 48 %).

1.11.1.62 During the ebb phase of both a spring and neap tide, there is a theoretical pathway for the sediment plume formed during nearshore trenching activity across the ebb channel to reach Bridlington Harbour. On springs tides only, this plume could extend to disposal site HU015 and Flamborough Head SAC. The conditions at HU015 and the SAC are highly dispersive for muds and silts, so there is no expectation for material to settle in this location, however, within the harbour, the water conditions are expected to be calm and conducive to settling for any material reaching this location. The harbour already has an existing exposure to siltation from marine sources.

1.11.1.63 Since the ebb channel is around 1 km wide, trenching across this channel at a rate of 125 m/hr would take approximately 4 hours. In this period, the amount of muds brought into suspension could be around 3,000 tonnes (i.e. 100% of the excavated volume becoming fluidised by hydraulic pressure from the MFE). This activity is required six times, with the possibility of three vessels working together, although safety consideration may restrict nearshore operations to single vessels. For the purposes of developing a conservative assumption, up to 9,000 tonnes of material could be released in this period by trenching activity from the three vessels.

1.11.1.64 Current uncertainties in the PEIR assessment relate mainly to the assumptions in sediment composition over the depth of trenching along the offshore ECC and the logistics of vessels operating in the nearshore. Additional information from the 2019 geophysical assessment will help to improve the detailed understanding of sediment composition over depth.

Magnitude of impact

1.11.1.65 The nearshore section of the offshore EEC trenching is anticipated to be a small-scale, highly localised and intermittent activity limited to the short-term. The magnitude of impact to leading to any elevated levels of siltation in the nearshore area would be **negligible**.

1.11.1.66 Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Figure 5.3: Deriving the Level of Significance of an Impact; Volume 1, Chapter 5: EIA Methodology**) and is not considered further in this assessment.

Further mitigation

1.11.1.67 No further mitigation is considered necessary since there are no likely significant effects.

Cable trenching – offshore array area (MP-C-2)

1.11.1.68 Cable trenching will occur after sandwave clearance is completed. Within the offshore array area there will be up to 600 km of array cables and 90 km of interconnector cables.

1.11.1.69 Similar assumptions are made for burial depth, trench size and excavation tool as the offshore ECC.

1.11.1.70 The 2018 geophysical survey (Gardline, 2019) has resolved a depth of Holocene sand which shows that the majority of the offshore array area is covered by surficial sediments to a depth < 2 m. Deeper sediment depths are mainly along the western, northern and southern boundaries, but the central area and along the western boundaries only have a thin cover of sediment which in some places is less than 0.5 m.

1.11.1.71 Given trenching depths are up to 2 m and given sandwave clearance may have removed some sand cover prior to trenching, then the expectation is that sub-soils will encountered by the trenching activities which are expected to have a much higher content of fines than the mobile surface sands.

1.11.1.72 The maximum sediment volume expected to be displaced by MFE across the offshore array is approximately 4,140,000 m^3.

1.11.1.73 The majority of the excavated material is expected to be coarse sediments (sands and gravels) which will drop back to the seabed relatively quickly and close to the point of disturbance. The content of fine sediments (silts and muds) being disturbed into suspension by MFE is expected to be low for the surface layer but potentially higher when trenching involves sub-soils composed of glacial till.

1.11.1.74 The trajectory of any sediment plume will be governed by tidal advection at the point of release with reduced concentrations around this axis due to dispersion and diffusion mixing processes spreading the plume. Plume concentrations will reduce over distance due to increased mixing. During a neap tide the plume will be advected over a shorter distance (4 to 4.3 km excursion) than a spring tide (8 to 8.5 km excursion), and since the rate of mixing will be less at these times due to weaker flows, then suspended sediment concentrations can be expected to be proportionally higher. On spring tides, the plume will spread further and have proportionally lower concentrations, i.e. more dilute over a wider area.

1.11.1.75 The sediment plume will eventually become fully dispersed to the extent that concentrations are undiscernible against the ambient SPM levels. There is unlikely to be any permanent deposition of fine (silts and muds) sediments within the offshore array.

1.11.1.76 Any sediment plumes, and associated deposition, in the offshore array area are considered to be pathways for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.1.77 Uncertainties in the assessment relate mainly to the assumptions in sediment composition over the depth of trenching.

Foundation installation: drilling at HVAC booster area (MP-C-2)

1.11.1.78 Drilling may be required for foundation options which install pin piles into the seabed and where these piles cannot be installed solely using percussive piling through harder sub-soils or rock. The anticipation is that drilling will only be required for up to 10% of pile installations (or up to 10% of the depth across all installations).

1.11.1.79 Drilling produces drill arisings that will be brought back to the drilling vessel prior to surface discharge into the sea. Up to two drilling rigs may be operating at the same time. If this occurred at adjacent sites along a tidal excursion, then there is the potential for sediment plumes to disperse together and lead to higher overall increases in SSC, i.e. the plumes overlapping.

1.11.1.80 The composition and particle size of drill arisings is unknown at present and depends on many variables, not least; local rock type(s), size of drill, drill speed, drill pressure, etc. The typical conservative assumption is to treat 100% of material as fines, although existing evidence of drill cutting piles suggests this is unlikely, and in some cases semi-permanent cuttings piles have formed of relatively large clasts, for example at North Hoyle (DECC, 2008).

1.11.1.81 The MDS foundation option related to drill arisings in the HVAC booster area is the six-legged piled Jacket (Small OSS) with four pin piles per leg, each pin pile with a 4 m diameter an embedment depth of up to 100 m. Provisions for drilling these piles assumes up to 4,618 m^3 of drill arisings for all pin-piles and foundations. This potential volume of sediment release is comparable to seabed levelling and the potential release of fines from the same location in overspill which has a higher estimated total volume of up to 8,578 m^3. The conservative assumption is drilling would produce similar (but lesser) sediment plumes in comparison to the seabed levelling activity in this area,

1.11.1.82 Any sediment plumes, and associated deposition, in the offshore array area are considered to be pathways for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.1.83 Uncertainties in the assessment relate mainly to the assumptions in drill cutting sizes and production rates. Present assumptions are therefore considered to offer a conservative assessment to offset these uncertainties.

Foundation installation: drilling at offshore array area (MP-C-2)

1.11.1.84 The MDS considerations for drilling in the offshore array area are based on the information presented in **Table 1.18**. In comparative terms, these quantities of drill arisings are lower than the overall volume requirements for seabed levelling at the same locations.

Table 1.18: Summary of drill arisings for foundations across the offshore array.

Unit	Foundation type	Number	Maximum drill arising volume (m^3)	Equivalent volume per foundation (m^3)
WTG	Monopile	180	127,235	Either 707 for each foundation or 7070 for 18 foundations
OSS	Piled jacket (Small OSS)	9	13,854	1,540
Offshore Accommodation	Piled jacket (Small OSS	1	1,540	1,540
	Total	**190**	**142,629**	

1.11.1.85 Presently available details, and assumed drilling rates, would suggest comparable sediment plumes and deposition effects to those previously considered for seabed levelling (which were considered to not be significant in EIA terms) and potentially less in proportion due to the smaller release volumes.

1.11.1.86 Any sediment plumes, and associated deposition, in the offshore array area are considered to be pathways for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.1.87 Uncertainties in the assessment relate mainly to the assumptions in drill cutting sizes and production rates.

1.11.2 Operation and Maintenance

1.11.2.1 The impacts of the offshore operation and maintenance of Hornsea Four have been assessed on marine processes. The environmental impacts arising from the operation and maintenance of Hornsea Four are listed in **Table 1.14** along with the maximum design scenario against which each operation and maintenance phase impact has been assessed.

Scouring around foundations and rock berms (MP-O-3) - Overview

1.11.2.2 The existing design option may place scour protection on the seabed prior to foundation installation. In this case scouring is mitigated. The other option is to install the foundations first and then add scour protection. In this case, the period between foundation installation and placement of scour protection leaves the structure prone to scouring. The amount of scour that may take place in this period depends on many factors, including; the local sediment types, flow environment and structure shape.

1.11.2.3 The potential for any environmental impact related to scouring is likely to be minimal when the local scale of change is largely limited to each foundation. The separation distance between foundations is also typically sufficient to remove any risk of group scour occurring over the scale of a wind farm array which may lead to the risk of destabilising a large morphological feature, such as when a wind farm is co-located on a sandbank (e.g. Scroby Sands).

1.11.2.4 The main environmental change is likely to be related to the introduction of rock armour as scour protection around the periphery of the structure, e.g. situations where rock armour changes a sandy substrate into a much coarser substrate. Apart from any ecological relevance, this change would also locally modify the roughness of the seabed.

Scour around cofferdams - landfall area (MP-O-3)

1.11.2.5 Up to eight cofferdams are proposed in the nearshore area to accommodate HDD exit pits. For a conservative assumption, each cofferdam is assumed to be square in shape with a length and width of approximately 10.6 m, although the width facing incident waves or flows depends on the orientation of the structure. If the structure were at 45° to incident flows or waves, then the effective width becomes 14.1 m.

1.11.2.6 The minimum spacing between cofferdams is given as 10 m, so the potential to act together and create group scour is a possibility. Collectively, all cofferdams cover an area of up to 900 m^2.

1.11.2.7 These cofferdams are short-term, temporary installations with the intention of being in place for up to four months (all cofferdams). There is no plan to include scour protection at these locations.

1.11.2.8 The precise locations of the cofferdams within the PEIR boundary are unknown at this time with more refined details to be presented within the final DCO application, but the likelihood is they will be dug into the glacial till, a sediment layer which is likely to be slow to scour, whereas any surface layer of sands would expect to rapidly scour away under the combined action of waves and tidal flows.

1.11.2.9 Uncertainties in the assessment relate mainly to the assumptions in the location and configuration of cofferdams. Accordingly, conservative assumptions have been offered in the present PEIR assessment.

Magnitude of impact

1.11.2.10 Any scouring around an individual cofferdam is likely to be small-scale, highly localised and limited to the short-term. There also remains a potential for group scour if the cofferdams are separated by the minimum 10 m spacing. Potentially, the depth and extent of any scouring could be limited by the less-erodible sub-soils. Once cofferdams are removed, and exit pits are back-filled, the seabed would like recover. The magnitude of impact from scouring in the nearshore area would be **negligible**.

1.11.2.11 Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Figure 5.3: Deriving the Level of Significance of an Impact; Volume 1, Chapter 5: EIA Methodology**) and is not considered further in this assessment.

Further mitigation

1.11.2.12 No further mitigation is considered necessary since there are no likely significant effects.

Foundation scour – HVAC booster area (MP-O-3)

1.11.2.13 The MDS option for the HVAC booster area is based on three large 75 m wide GBS (Box-type) foundations in an area of 24 km^2 located around 34 to 42 km offshore and within the offshore ECC (**Figure 1.4**). The precise location of each foundation within the HVAC booster area is yet to be determined and their orientation with respect to incident flows also remains unknown. If flows are at 45° to the structure, then the effective width of this type of foundation increases to 106 m.

1.11.2.14 The base of each foundation will occupy an area of approximately 5,625 m^2 with provisions for scour protection adding an additional 25,000 m^2. If the foundations are close together, at the minimum separation of 100 m, then flow interactions between structures are likely and more complex group scour might occur.

1.11.2.15 The amount of material that may be scoured from around the base is likely to be lower than the quantities considered for seabed levelling at the same location (which was not considered to be significant in EIA terms). Material that is susceptible to being scoured is likely to be limited to sand content with the gravel fraction remaining *in situ* and helping to armour the seabed. This sand will be mobile during peak flows on spring tides.

1.11.2.16 Deeper scour could be limited by the underlying sediment layers. The depth of these layers and type of sediments remain unknown at this time.

1.11.2.17 There are no marine process receptors in the vicinity of the HVAC booster area. Any scouring in the HVAC booster area is considered to be a pathway for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.2.18 Uncertainties in the PEIR assessment relate mainly to the assumptions in local seabed sediments and the location and the final arrangement of foundations. The 2019 geophysical survey data is expected to provide suitable information to address this uncertainty for the EIA assessment.

Foundation scour – offshore array area (MP-O-3)

1.11.2.19 The MDS foundation scour options for the offshore array area are based on the structures which are considered to exert the greatest amount of blockage to incident flows and therefore create the largest amounts of turbulence which has the potential to induce scouring of the local seabed. Relative scales of blockage for each foundation type have been assessed using indicative solidity ratios applicable across the vertical face of the foundation presented to incident flows. For example, a solid structure will have a solidity ratio of 1 whereas an open lattice jacket will have a solidity ratio of around 0.3.

1.11.2.20 **Table 1.19** summaries the MDS foundation options for blockage for the offshore array area.

Table 1.19: Summary of MDS foundation options for blockage.

Unit	Foundation type	Number	Base Width (m)
WTG	Suction bucket jacket (3-legged)	180	65
OSS large	GBS (Large OSS)	3	150
OSS small	GBS (Medium OSS)	6	75
Offshore Accommodation	GBS (Medium OSS)	1	75

1.11.2.21 The effective base width for 75 and 150 m box-type GBS increases when the incident flow is at 45°, this leads to effective widths of 106 and 212 m, respectively. Scour protection is planned around the periphery of these foundations over a distance of 50 m.

1.11.2.22 The vertical face of WTG suction bucket jacket has three 20 m diameter bases which will be up to 5 m proud of the seabed. The spacing between the three legs (above buckets) at the seabed is 45 m, with a total width across buckets of 65 m. The effective solidity ratio at the seabed is close to 1.0 (0.92).

1.11.2.23 The likely extent of scour is taken to be less than the planned extent for scour protection, which in the case of the box-type gravity bases is 50 m from the edge of the structure. All foundations are considered to be sufficiently separated to mitigate the chance of group scour between foundations, other than the group-scour which would be expected between the three buckets of the suction bucket jacket.

1.11.2.24 The amount of material that may be scoured from any foundation base is likely to be lower than the quantities considered for seabed levelling at the same location. Once any scouring has removed the surface layer of sands, deeper scour is likely to be moderated by the underlying till which is expected to have a much slower rate of scouring.

1.11.2.25 The surface sands that become susceptible to being scoured away will quickly assimilate into the wider sediment transport regime.

1.11.2.26 There are no marine process receptors in the vicinity of the offshore array. Any scouring within the offshore array area is considered to be a pathway for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.2.27 Uncertainties in the assessment relate mainly to large box-type foundations, their orientation to incident flows and the actual form of scour development around their bases, although this may not alter the overall assessment of potential effects.

Cable crossing scour – offshore ECC (MP-O-3)

1.11.2.28 Rock armour is the MDS option for cable crossings as well any requirement for cable protection / reburial. Cable crossings are identified over existing assets as well as proposed assets in both the offshore ECC and offshore array area. Reburial requirements remain as a provision and the sites are unspecified. A CBRA would expect to identify vulnerable sites based on sediment mobility, although reburial requirements may also arise from other causes or events such as anchor drags.

1.11.2.29 The Project Description for Hornsea Four (**Section 4.8.5** of **Volume 1, Chapter 4: Project Description**) provides a generic example for the creation of rock berms at cable crossings. The existing cable or pipeline will first be covered with a pre-lay rock berm of a typical length of around 55 m in length and 12.4 m in width and to a depth of around 0.3 m. The cable will be laid at right-angles over this material and then covered with a post-lay rock berm which is notionally 500 m in length and 10.4 m in width. The final profile of the rock berm will be a trapezium shape, up to approximately 1.5 m above the seabed with a 3:1 gradient. This rock grading generally has a typical rock size in the range of 90 to 125 mm, up to maximum rock size up to 250 mm.

1.11.2.30 The potential concerns for marine processes for rock berms at cable crossings are related to the change of substrate which may locally increase drag forces as well as the effects the height, length and orientation of the rock berm may have to locally modify wave propagation, flows, develop scour around the margins, and the potential to locally interrupt sediment pathways, notably bedload transport.

1.11.2.31 There are nine existing pipelines along the offshore ECC which require cable crossings (**Figure 1.4**). These sites are all distant from the coastline (> 37 km) and in relatively deep water (> 40 m depth). None of these crossings would not expect to interfere with wave energy transformation onto the coast. Some local scouring may occur around the periphery of each rock berm but only where the local seabed is mainly sandy which would be for crossings to the east of the HVAC booster area.

1.11.2.32 In addition, to the offshore pipeline crossings there is a need for a nearshore cable crossing with the export cables from the Creyke Beck offshore wind farm at a planned location just seaward of Smithic Sands. Up to six export cables from Hornsea Four and four export cables from Creyke Beck could potentially lead to a MDS of up to 24 unique crossings, but also spaced relatively closely across the seabed. The local seabed is mainly sandy gravel suggesting a limited capacity for scouring.

1.11.2.33 Any scouring from cable crossings along the offshore ECC is considered to be **minor** and a pathway for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes. The potential for the nearshore crossing to interrupt sediment pathways is considered separately.

1.11.2.34 Uncertainties in the assessment relate mainly to sediment types along the offshore ECC which are expected to be further addressed in the 2019 geophysical survey.

Cable crossing scour – offshore array area (MP-O-3)

1.11.2.35 Provisions for cable crossings are also required within the offshore array area and may need to account for two new pipelines which would increase the potential number of cable crossings to up to 40 separate locations.

1.11.2.36 The seabed is mainly sandy across the offshore array and some local scouring many be possible around the periphery of each crossing, however, there are no marine processes receptors related to this effect. Scouring is considered to be a pathway for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

1.11.2.37 Uncertainties in the PEIR assessment relate mainly to the location and the final arrangement of rock berms.

Turbulent wakes from foundations interfering with remote receptors, e.g. Flamborough Front (MP-O-4) - Overview

1.11.2.38 Turbulent wakes (rather than wakes that increase turbidity) are an extension of the near-field scour related blockage affects. Wakes occur on the leeward side of a foundation and are generally represented in models as a reduction in the time-averaged flow speed. At the same time, the intensity of turbulence within the wake increases which can also lead to faster rates of dispersion and mixing. The extent of a flow reduced wake can be considered as a proxy for the area which is also affected by more intense turbulence.

1.11.2.39 Turbulent wakes propagate away from a structure and have the potential to influence the far-field with higher levels of turbulence. The main consideration for turbulent wakes is in regard to potential disruption to the Flamborough Front.

Turbulent wakes: landfall area (MP-O-4)

1.11.2.40 Blockage induced turbulent flow and wave wakes will form locally around the eight cofferdams used to protect the HDD exit pits in the landfall area. Flow wakes would be directed along the shoreline and will probably be relatively small-scale, proportional to the low magnitude nearshore flows.

1.11.2.41 Depending on the location of the HDD exit pits, larger waves may break against the cofferdams, dissipating energy before reaching the shoreline. If the arrangement of the 8 cofferdams were shore parallel with a minimum spacing of 10 m then this would equate to an 155 m long, semi-permeable breakwater which would effectively shelter the adjacent beach from waves and inhibit longshore transport from this local area, leading to the potential for sediment to build up behind the breakwater in a tombolo-type formation.

Magnitude of impact

1.11.2.42 Any disruption to waves, flows or sediment transport in the nearshore due to the presence of cofferdams is likely to be short-term, small-scale and highly localised. When removed any effects on the beach and sub-tidal areas are expected to recover relatively quickly. Accordingly, the magnitude of any impact is considered **minor**.

Sensitivity of the receptor

1.11.2.43 The main feature of interest with a potential concern from nearshore blockage of waves and flows would be a small section of Fraisthorpe Sands (and cliffs) and due to potential modifications to the balance in longshore drift (and potential changes to cliff erosion rates). The sensitivity of this receptor to changes in waves over the duration of the construction period is considered **low**.

Significance of the effect

1.11.2.44 Overall, the predicted sensitivity of the receptor is **low**, and the magnitude of impact is **minor**. The effect is **minor** adverse significance which are not significant in EIA terms.

Further mitigation

1.11.2.45 No further mitigation is considered necessary since there are no likely significant effects.

Turbulent wakes: HVAC booster area (MP-O-4)

1.11.2.46 Flow (and wave) related wakes will form locally around the three 75 m wide box-type gravity bases.

1.11.2.47 Due to the scale of this foundations, incident flows will be decelerated onto the face of the structure and then become separated around the structure, most likely to create localised faster flows and separate vortices around edges. In the near-field, the flow related wakes will be responsible for scour development around the corners of the structure. The expectation is the turbulent flow wakes would quickly dissipate and decay in intensity thereafter along the axis of the tidal ellipse (north-east on the ebb and to south-west on the flood) with no further influences on the seabed. Ambient flows will also contain some turbulence, and this may help the rate of dissipation of foundation related turbulence.

1.11.2.48 The precise form of these wakes remains dependent on the relative orientation of each foundation to incident flows and their relative spacing, noting that a minimum spacing of 100 m is specified.

1.11.2.49 There are no marine process receptors in the vicinity of the HVAC booster area. Any scouring in the HVAC booster area is considered to be a pathway for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

Turbulent wakes: offshore array area (MP-O-4)

1.11.2.50 Flow (and wave) related wakes will form locally around the 190 foundations in the offshore array area.

1.11.2.51 There are three types of foundations in the offshore array area which will develop different scales of wakes in proportion to their size and shape (and orientation to incident flows with respect to box-type GBS):

- 180 three-legged suction bucket jackets with 20 m diameter buckets up to 5 m above the seabed;
- Three large GBS box-type with 150 m width base; and
- Seven small GBS box-type with 75 m width base.

1.11.2.52 The distribution of these foundations across the indicative layout is unknown at this time, neither is the orientation nor spacing between any of the box-type GBS foundations. However, the minimum spacing between the centres of all infrastructure will not be less than 810 m.

1.11.2.53 A layout comprising of only suction bucket jackets foundations would expect to lead to individual wakes around each structure that could also interact if the ebb and flood wake alignments reached an adjacent foundation. The inclusion of ten GBS box-type foundations with greater widths (75 and 150 m), and also non-cylindrical shapes, increases the potential for wake to wake interactions across parts of the array which are in the leeward path of the larger foundations. However, since there is only a limited number of these larger foundations the area involved will be limited.

1.11.2.54 Based on detailed temperature modelling, and times when there is development of thermal stratification in the northern North Sea from spring to summer, Hornsea Four has been assessed to be within the area of stratification and around 5 km to the north of the divide (at the closest point) with the area to the south remaining well-mixed (**Figure 1.15**). The (seasonal) divide is regarded as the location of the Flamborough Front, which is the area of main biological interest. Wakes from very southern extent of Hornsea Four could theoretically reach the front on the flood tide and during periods of spring tides, but any affect is both spatially limited and time limited.

1.11.2.55 Increased seasonal mixing from autumn to winter, due to stronger winds, increases wave stirring effects as well as surge related currents which act together to de-stabilises the stratification and the front dissipates at these times.

Magnitude of impact

1.11.2.56 The scale of the effect from multiple turbulent flow wakes is expected to largely remain within the offshore array and only in a small area can a limited number of wakes expect to develop over a sufficient length to reach the Flamborough Front and then only on the flood phase of spring tides. The additional turbulent mixing caused by wakes within the offshore array is also considered to be insufficient to breakdown thermal stratification and create a well-mixed area during the spring and summer periods. The magnitude of any impact on the Flamborough Front is considered to be **minor** (overall) because the influence is likely to be spatially limited and intermittent, although the effect will occur throughout the life of the project.

Sensitivity of the receptor

1.11.2.57 The main feature of interest with a potential concern from turbulent wakes is the Flamborough Front. The sensitivity of this receptor to any turbulent wake effects is considered **medium**.

Significance of the effect

1.11.2.58 Overall, the predicted sensitivity of the receptor is **medium**, and the magnitude of impact is **minor**. The effect is **minor** adverse significance which is not significant in EIA terms.

Further mitigation

1.11.2.59 No further mitigation is considered necessary since there are no likely significant effects.

Changes to waves affecting coastal morphology (MP-O-5) – Overview

1.11.2.60 Waves acting on the coastline are an important mechanism for eroding the base of the cliffs and transporting sandy material along the beach as longshore drift. The oblique direction of waves arriving at the coastline determines if the longshore transport is to the north or south. The sands that are transported in a northerly direction provide a supply of sediment to help develop and maintain the profile of Smithic Sands. In turn, the profile of this sandbank feature also acts to dissipate wave energy from large storm waves moving towards Bridlington with some wave energy dissipated onto the bank, due to shoaling, before reaching the coastline. Substantial modification to waves arriving at the coastline has the potential to affect the balance in these nearshore processes.

1.11.2.61 There will always be some intra-annual and inter-annual variability in wave conditions. In addition, climate change may also modify the frequency, magnitude and direction of storm tracks, although there is limited certainty at this time on the how these changes may be manifested.

1.11.2.62 Offshore structures can also interfere with the transmission of wave energy reaching the coastline through various forms of interaction, most notably through reflection and scattering off the vertical surface and through drag forces (skin friction) as waves pass around structures. The added effect of diffraction depends on the relative scale of the obstacle versus the wavelength of the passing wave. For slender monopiles, the diameter of the obstacle is generally too small for diffraction to occur. When the (effective) diameter (D) is large relative to the incident wavelength (L) then diffraction effects become important. The criterion for diffraction is generally accepted to be when the ratio of D/L > 0.2 (Isaacson, 1979). Collectively, the interactions between an incident wave and a structure are regarded as blocking type effects with a downwind change possible in wave height, period and direction. The downwind change is also referred to as a (wave) wake.

1.11.2.63 Array scale blocking can also form when a foundation develops a wake that extends to a down-wind structure which then adds to the wake. Wake recovery normally occurs beyond the array through dissipative effects with wave recovery also possible by further wind related stresses.

Changes to waves affecting coastal morphology – HVAC booster area (MP-O-5)

1.11.2.64 The HVAC booster area is situated in the offshore ECC from around 34 to 42 km from the coast. Within this area there is an option for up to three 75 m wide box-type GBS foundations. When these structures are at 45° to incident waves their effective width becomes 106 m. Water depths at this location are generally 50 m below CD.

1.11.2.65 The precise location, spacing and orientation of the three foundations remains unknown at this time; however, there is a stated minimum separation of 100 m between foundations.

1.11.2.66 Waves moving towards the coastline from the HVAC booster area are likely to be similar to measurements further offshore since water depths are generally too deep to lead to any shoaling or refraction effects modifying wave energy transformation and there are no sheltering influences from the coastline. Indicative wavelengths for wave periods in the range 4 to 8 s are 26 to 100 m. The ratio of D/L indicates diffraction is important for the large structures.

1.11.2.67 The worst-case effect of the HVAC booster station foundations on waves is for the situation when their combined effective width and separations are aligned to become an effective barrier to waves over a total width of more than 300 m. Waves would reflect and scatter off the incident faces of structures and diffraction would occur around the structures redistributing wave energy into the shadow zone created by the structure.

1.11.2.68 Whilst waves will undoubtably locally interact with these structures their distance offshore is considered to be sufficient for any wave modifications to be fully dissipated before a measurable effect reaches the coast.

Magnitude of impact

1.11.2.69 Changes to waves from the HVAC booster area are likely to be small-scale, highly localised and medium-term. The magnitude of impact from changes in waves remote from the HVAC booster area would be **negligible**. Intra and inter-annual variability in waves is likely to dominate over any effects in the far-field.

1.11.2.70 Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Figure 5.3: Deriving the Level of Significance of an Impact; Volume 1, Chapter 5: EIA Methodology**) and is not considered further in this assessment.

Further mitigation

1.11.2.71 No further mitigation is considered necessary since there are no likely significant effects.

Changes to waves affecting coastal morphology – offshore array area (MP-O-5)

1.11.2.72 There are three types of foundations in the offshore array area which will each interact with waves. The type of interaction will depend on their size and shape as well as the incident wave characteristics:

- 180 three-legged suction bucket jackets with 20 m diameter buckets up to 5 m above the seabed;
- Three large GBS box-type with 150 m width base; and
- Seven small GBS box-type with 75 m width base.

1.11.2.73 The size and shape of the suction bucket jackets is expected to have a much lesser interaction with waves than a GBS with the same base diameter due to the open lattice arrangement of the jacket structure.

1.11.2.74 Additional interaction of waves may occur across the array between adjacent foundations. This type of interaction depends on the relative spacing and orientation to incident waves that also allows a wake effect to pass along and reach the downwind foundation. The array scale interaction represents the aggregate of all foundation interactions and becomes the more relevant consideration for effects on the far-field.

1.11.2.75 The distribution of foundation types across the indicative layout for Hornsea Four is unknown at this time, neither is the orientation nor spacing between any of the box-type GBS foundations which are expected to lead to the greatest modification to incident waves. However, the minimum spacing between all infrastructure in the array is 810 m between centres.

1.11.2.76 A comparison of the relative blockage at the scale of an array for all projects within the former Hornsea Zone is offered based on the scale occupied by all foundation per array area (**Table 1.20**). Although this first order metric of relative blockage for array scale effects ignores the shape of each array, the foundation layouts and scales of any specific foundation type, the comparison between projects remains useful to indicate likely scales of effect on waves for comparable sized arrays. Hornsea Four has a low relative array blockage in comparison to other projects based on their consented configurations.

Table 1.20: Comparison of relative blockage for projects within the former Hornsea Zone.

Project	Status	Array Area (km^2)	Number of foundations	Footprint of all foundations (m^2)	Relative blockage for array (%)
Hornsea Project One	Consented	407	335	0.65	0.162
Hornsea Project One	Final	407	174	0.01	0.002
Hornsea Project Two	Consented	462	258	0.68	0.148

Project	Status	Array Area (km^2)	Number of foundations	Footprint of all foundations (m^2)	Relative blockage for array (%)
Hornsea Project Two	Final	462	165	0.01	0.003
Hornsea Three	Application	696	319	0.77	0.111
Hornsea Four	PEIR	600	190	0.38	0.063

1.11.2.77 Based on previous wave modelling for Hornsea Project One, Hornsea Project Two and Hornsea Three, any wave height reductions from Hornsea Four would not expect to reach the adjacent coastlines and lead to any effects on coastal morphology.

Magnitude of impact

1.11.2.78 Changes to waves from the offshore array area are likely to be small-scale, localised to the footprint of the array and medium-term. The magnitude of impact from changes in waves remote from the offshore array area would be **negligible**. Intra and inter-annual variability in waves is likely to dominate over any effects in the far-field.

1.11.2.79 Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Figure 5.3: Deriving the Level of Significance of an Impact; Volume 1, Chapter 5: EIA Methodology**) and is not considered further in this assessment.

Further mitigation

1.11.2.80 No further mitigation is considered necessary since there are no likely significant effects.

Changes to nearshore sediment pathways (MP-O-6)

1.11.2.81 The nearshore is considered here as the shallowing area within the shelter of Flamborough Head up to the coast, including Smithic Sands. The important nearshore sediment (bedload) pathways are summarised on **Figure 1.10**. Cliff erosion by storm waves provides an important source of beach material which is moved along the coast by wave driven longshore drift. Some of this material is transported offshore into an ebb dominant tidal channel where the pathway moves material towards Flamborough Head. Ebb flows, reinforced by wave driven current from north of the headland, maintain a one-way drift to the south which then forms a pathway for sands onto Smithic Sands. Waves help to limit the profile of the bank with larger waves dissipating some of their energy onto the bank creating a southern section of the bank which is wider and smoother than the northern part of the bank where tidal flows accelerate around the headland and act to develop distinct sandwaves.

1.11.2.82 The main activities that might lead to a change in nearshore sediment pathways are considered to include:

- Cable crossings with Creyke Beck offshore wind farm export cables; and
- Requirements for remedial measures to rebury cables.

1.11.2.83 Up to six export cables from Hornsea Four and four export cables from Creyke Beck could potentially lead to a MDS of up to 24 unique crossings at a site around 1.5 km to the east of Smithic Sands in around 20 m water depth (below CD).

1.11.2.84 Each of the 24 rock berms at this crossing may have a height of up to 1.5 m which has the potential to reduce local water depths by 7.5%. Each crossing could also be 500 m in length, which to span four export cables from Creyke Beck offshore wind farm could be a total distance of around 2 km (n.b. 2 km is also the full width of the export cable corridor for Creyke Beck offshore wind farm) and with a similar width. In addition, the rock material would also roughen the local seabed and increase drag forces on passing waves and flows. These potential dimensions of the crossings can be compared to the length of Smithic Sands which is around 12 km.

1.11.2.85 The rock berms may partly interfere with nearshore sediment pathways which move sands as bedload onto the southern part of Smithic Sands. Storm waves may also dissipate some energy on the berm ahead of shoaling onto the bank. Over time, the rock berms may become buried by build-up of sands enabling the (direct) sediment pathways to the southern part of Smithic Sands to re-establish.

1.11.2.86 Smithic Sands represents a nearshore morphological feature which is in dynamic equilibrium with the existing baseline conditions. This dynamism (and therefore sensitivity of the feature) is a function of sediment supply and tidal circulations developing and sustaining the profile of the bank against higher energy storm events which may lead to periods of levels of higher sediment mobility and temporary redistribution of sands which could lower the bank height. Consequently, burial depths across Smithic Sands (to be established as part of the CBRA) need to account for the risk of variation in bank levels. The nearshore section of the export cable across Smithic Sands is therefore considered to be a potential area where additional cable protection measures may be required during the operational period if adequate burial depths are not achieved.

1.11.2.87 Uncertainties in the assessment relate mainly to the likely configuration of the 24 rock berms required for this nearshore cable crossing. In contrast, the nearshore geophysical survey from the Creyke Bank offshore wind farm is complete. In addition, present evidence is relatively limited on the variation in seabed levels across Smithic Sands, either intra-annually or longer-term.

1.11.2.88 Sufficient project details on these cable crossings are not available in order to provide a meaningful assessment as present details on the alignment and spacing of each set of export cables at the crossing location between Creyke Beck offshore wind farm and Hornsea Four are not yet available and remain provisional at this time. A detailed assessment will be provided once cable crossing parameters from both projects are defined and discussed with the Evidence Plan process, with a full assessment presented in the final DCO application.

1.11.3 Decommissioning

1.11.3.1 The impacts of the offshore decommissioning of Hornsea Four have been assessed on marine processes. The environmental impacts arising from the decommissioning of Hornsea Four are listed in **Table 1.14** along with the MDS against which each decommissioning phase impact has been assessed.

Sediment disturbance activities during decommissioning (MP-D-2)

1.11.3.2 Decommissioning issues include sediment disturbance events during removal of foundations and cables. Rock berms are expected to remain *in situ*.

1.11.3.3 Disturbance from decommissioning foundations is limited to the HVAC booster area and the offshore array area;

- Piled foundations would be cut around 1 m below seabed;
- Suction foundations and gravity bases would be completely removed; and
- Scour protection would also be removed, where practical and necessary.

1.11.3.4 All these activities are likely to lead to a far smaller level of sediment disturbance than any activity described during construction for seabed preparation or installation of foundations (which were not found to be significant in EIA terms). Accordingly, the level of any impacts from decommissioning can be considered smaller than those described for construction.

1.11.3.5 Any sediment disturbance during decommissioning is considered to be a pathway for effects which are considered for impacts in related chapters. Consequently, no impact assessment is offered here for marine processes.

Blockage

1.11.3.6 Once foundations are removed their associated blockage effects will also cease. This returns the wave and tidal conditions back to a condition that represents a future baseline. Most blockage effects from the array and HVAC booster area are remote from any receptors, so a potential reinstatement of a higher energy situation is unlikely to lead to any concern.

1.12 Cumulative effect assessment (CEA)

1.12.1 Cumulative Effect Assessment Methodology

1.12.1.1 Cumulative effects can be defined as effects upon a single receptor from Hornsea Four when considered alongside other proposed and reasonably foreseeable projects and developments. This includes all projects that result in a comparative effect that is not intrinsically considered as part of the existing environment and is not limited to offshore wind projects.

1.12.1.2 A screening process has identified a number of reasonably foreseeable projects and developments which may act cumulatively with Hornsea Four. The full list of such projects that have been identified in relation to the offshore environment are set out in **Volume 4, Annex 5.3: Offshore Cumulative Effects** and **Volume 4, Annex 5.4 Location of Offshore Cumulative Schemes** and are presented in a series of maps within the same documents.

1.12.1.3 In assessing the potential cumulative impacts for Hornsea Four, it is important to bear in mind that some projects, predominantly those 'proposed' or identified in development plans, may not actually be taken forward, or fully built out as described within their MDS. There is, therefore, a need to build in some consideration of certainty (or uncertainty) with respect to the potential impacts which might arise from such proposals. For example, those projects under construction are likely to contribute to cumulative impacts (providing effect or spatial pathways exist), whereas those proposals not yet approved are less likely to contribute to such an impact, as some may not achieve approval or may not ultimately be built due to other factors.

1.12.1.4 With this in mind, all projects and plans considered alongside Hornsea Four have been allocated into 'tiers' reflecting their current stage within the planning and development process. This allows the cumulative impact assessment to present several future development scenarios, each with a differing potential for being ultimately built out. This approach also allows appropriate weight to be given to each scenario (tier) when considering the potential cumulative impact. The proposed tier structure that is intended to ensure that there is a clear understanding of the level of confidence in the cumulative assessments provided in the Hornsea Four PEIR. An explanation of each tier is included in

1.12.1.5 **Table** 1.21.

Table 1.21: Description of tiers of other developments considered for CEA (adapted from PINS Advice Note 17).

Tier 1	Project under construction.
	Permitted applications, whether under the Planning Act 2008 or other regimes, but not yet implemented.
	Submitted applications, whether under the Planning Act 2008 or other regimes, but not yet determined.
Tier 2	Projects on the Planning Inspectorate's Programme of Projects where a Scoping Report has been submitted.
Tier 3	Projects on the Planning Inspectorate's Programme of Projects where a Scoping Report has not been submitted.
	Identified in the relevant Development Plan (and emerging Development Plans with appropriate weight being given as they move closer to adoption) recognising that much information on any relevant proposals will be limited.
	Identified in other plans and programmes (as appropriate) which set the framework for future development consents/approvals, where such development is reasonably likely to come forward.

1.12.1.6 The plans and projects selected as relevant to the cumulative effect assessment (CEA) of impacts to marine processes are based on an initial screening exercise undertaken on a long list (see **Volume 4, Annex 5.3: Offshore Cumulative Effects** and **Volume 4, Annex 5.4 Location of Offshore Cumulative Schemes**). A consideration of effect-receptor pathways, data confidence and temporal and spatial scales has been given to select projects for a topic-specific short-list.

1.12.1.7 For marine processes, planned projects were screened into the assessment based on the potential for a comparable activity developing an overlapping pathway. For sediment disturbance and flow related blockage issues this equated to the excursion on a spring tide along the same axis. For wave related blockage, this equated to the direction of wave energy transmission which would encounter successive modifications.

1.12.1.8 The specific projects scoped into the CEA for marine processes, as well as the tiers into which they have been allocated are presented in **Table 1.22** below. The operational projects included within the table are included due to their completion/ commissioning subsequent to the data collection process for Hornsea Four and as such not included within the baseline characterisation. Note that this table only includes the projects screened into the assessment for marine processes based on the criteria outlined above. For the full list of projects considered, including those screened out, please see **Volume 4, Annex 5.3: Offshore Cumulative Effects** and **Volume 4, Annex 5.4 Location of Offshore Cumulative Schemes**.

Table 1.22: Projects screened into the marine processes cumulative assessment.

Tier	Project/plan	Details/ relevant dates	Distance to Hornsea Four Array	Distance to Hornsea Four ECC	Distance to Hornsea Four HVAC Booster Area	Reason for inclusion in CEA
1	Spoil disposal at HU015	Active	69	2	28	Potential temporal overlap of spoil disposal at HU015 and increased suspended sediment concentrations during cable trenching within nearshore area.

Tier	Project/plan	Details/ relevant dates	Distance to Hornsea Four Array	Distance to Hornsea Four ECC	Distance to Hornsea Four HVAC Booster Area	Reason for inclusion in CEA
1	Creyke Beck Offshore Wind Farm export cable landfall works	Planned	77	1.4	34	Comparable adjacent works to landfall area
1	Hornsea Project Two	Consented	0	7.5	53	Adjacent foundation structures with turbulent wakes.

1.12.1.9 The cumulative MDS described in **Table 1.22** have been selected as those having the potential to result in the greatest cumulative effect on an identified receptor group. The cumulative impacts presented and assessed in this section have been selected from the details provided in the project description for Hornsea Four (summarised for marine processes in **Table 1.14**, as well as the information available on other projects and plans in order to inform a cumulative maximum design scenario. Effects of greater adverse significance are not predicted to arise should any other development scenario, based on details within the project design envelope to that assessed here, be taken forward in the final design scheme.

1.12.2 Spoil disposal activities

1.12.2.1 The spoil site HU015 (**Figure 1.9**) is used to dispose of maintenance dredging material (typically related to the build-up of silts) from Bridlington Harbour. During these times, plumes will form at the disposal site as the silts are rapidly dispersed away. The use of the spoil site is expected to be relatively infrequent and on demand.

1.12.2.2 If Hornsea Four is discharging overspill of fine silts and sands in the nearshore from cable trenching by MFE on an ebb tide period at the same time as spoil disposal is occurring at HU015 then a larger combined sediment plume may form, however, this will also quickly disperse given the location of the spoil site in an area of faster flows. The cumulative impact is considered to be negligible due to the low likelihood of occurrence and relatively short-term impacts.

1.12.3 Creyke Beck export cable landfall works

1.12.3.1 The assumption is that all landfall works for Creyke Beck Offshore Wind Farm will be completed and the area will be made good before similar activities occur for Hornsea

Four. On this basis there are not expected to be any larger cumulative effects on the integrity of the local beach.

1.12.4 Hornsea Project One and Hornsea Project Two

1.12.4.1 Hornsea Project One and Hornsea Project Two are immediately adjacent offshore wind farms to Hornsea Four. The consented layouts and foundation types for both Hornsea Project One and Hornsea Project Two assumed GBS foundations with wide bases that would have had a blockage effect on waves and flows which could have acted cumulatively with Hornsea Four, on the basis of the MDS option for foundations being comparable (mono-suction bucket). The moderation of this potential concern for a greater level of blockage now exists because both Hornsea Project One and Hornsea Project Two are being developed with an alternative layout with a fewer number of smaller diameter foundations which will dramatically reduce the effective scale of blockage for both an individual foundation and for all foundations at the arrays scale.

1.12.4.2 Hornsea Three is considered to be less relevant to possible cumulative interactions for blockage because of:

- (i) the further distance from Hornsea Four;
- (ii) no common flow or sediment pathways passing between these two projects; and
- (iii) waves are mainly from the northerly sector limiting the opportunity for waves to pass through both projects.

1.12.4.3 On this basis Hornsea Three is excluded from the cumulative effects with Hornsea Four.

1.13 Transboundary effects

1.13.1.1 A screening of potential transboundary effects was undertaken at Scoping (see **Annex L** of the **Scoping Report**, (Ørsted, 2018)) which concluded that impacts on marine processes would be limited to the UK EEZ. Based on current understanding of the baseline environment, along with modelling work carried out at Hornsea Project One, Hornsea Project Two and Hornsea Three (which are all located closer to the boundaries of other EEA states), any transboundary effects were screened out of further assessment.

1.14 Inter-related effects

1.14.1.1 The inter-related effects assessment considers the effects of multiple impacts arising from the construction, operation and decommissioning of Hornsea Four upon the same receptor. Inter-related effects can be divided into project lifetime effects (effects over multiple project phases) and receptor-led effects (the additive effect of multiple impacts occurring at the same time).

1.14.1.2 Marine processes are considered to be fundamental to the assessment of other impacts, with many of the impacts assessed being pathways for effects on benthic ecology and fish and shellfish ecology (e.g. increases in SSC and deposition). In turn, these receptors also have knock on effects for other receptor groups, for example as prey resources for ornithology and marine mammals.

1.14.1.3 As pathways, there is limited potential for inter-related effects to occur upon marine processes. An inter-related effects screening was undertaken at Scoping (Annex J of the Scoping Report), which screened out inter-related effects associated with marine processes.

1.15 Conclusion and summary

1.15.1.1 **Table 15.1** presents a summary of the potential impacts assessed within this PEIR. All impacts which have been assessed are listed for completeness, however, some remain as pathways for consideration in related chapters.

Table 1.23: Summary of potential impacts assessed for marine processes.

Impact and Phase	Receptor and value/sensitivity	Magnitude and significance	Mitigation	Residual impact
Construction				
Seabed preparation in landfall area (MP-C-1)	Bridlington Harbour Low	Negligible Negligible adverse	None proposed beyond existing commitments	Not significant
Seabed preparation - sandwave clearance (MP-C-1)	Pathway n/a	n/a	n/a	n/a
Seabed preparation: Seabed levelling – HVAC booster area (MP-C-1)	Pathway n/a	n/a	n/a	n/a
Seabed preparation: Seabed levelling – offshore array area (MP-C-1)	Pathway n/a	n/a	n/a	n/a
Seabed installation activities: Open cut trenching across the intertidal at the export cable landfall (MP-C-2)	Holderness Coast (Fraisthorpe Sands) Low	Negligible Negligible adverse	None proposed beyond existing commitments	Not significant
Seabed installation activities: Cable trenching – offshore ECC (nearshore section) (MP-C-2)	Bridlington Harbour Low	Negligible Negligible adverse	None proposed beyond existing commitments	Not significant
Seabed installation activities: Cable trenching – offshore array area (MP-C-2)	Pathway n/a	n/a	n/a	n/a
Seabed installation activities: Foundation installation: drilling at HVAC booster area (MP-C-2)	Pathway n/a	n/a	n/a	n/a
Seabed installation activities: Foundation installation: drilling at offshore array area (MP-C-2)	Pathway n/a	n/a	n/a	n/a

Impact and Phase	Receptor and value/sensitivity	Magnitude and significance	Mitigation	Residual impact
Operation				
Scour around cofferdams - landfall area (MP-O-3)	Holderness Coast (Fraisthorpe Sands) Low	Negligible Negligible adverse	None proposed beyond existing commitments	Not significant
Foundation scour – HVAC booster area (MP-O-3)	Pathway n/a	n/a	n/a	n/a
Foundation scour – offshore array area (MP-O-3)	Pathway n/a	n/a	n/a	n/a
Cable crossings scour – offshore ECC (MP-O-3)	Pathway n/a	n/a	n/a	n/a
Cable crossings scour – offshore array area (MP-O-3)	Pathway n/a	n/a	n/a	n/a
Turbulent wakes: landfall area (MP-O-4)	Holderness Coast (Fraisthorpe Sands) Low	Minor Minor adverse	None proposed beyond existing commitments	Not significant
Turbulent wakes: HVAC booster area (MP-O-4)	No receptors n/a	n/a	n/a	n/a
Turbulent wakes: offshore array area (MP-O-4)	Flamborough Front Medium	Minor Minor adverse	Review any changes to indicative layout that increase likelihood of increased wake-wake interaction	Minor adverse
Changes to waves affecting coastal morphology – HVAC booster area (MP-O-5)	Holderness Coast (Fraisthorpe Sands and cliffs) Medium	Negligible Negligible adverse	None proposed beyond existing commitments	Not significant

Impact and Phase	Receptor and value/sensitivity	Magnitude and significance	Mitigation	Residual impact
Changes to waves affecting coastal morphology – offshore array area (MP-O-5)	Holderness Coast (Fraisthorpe Sands and cliffs) Medium	Negligible Negligible adverse	None proposed beyond existing commitments	Not significant
Changes to nearshore sediment pathways (MP-O-6)	Smithic Sands – Full assessment to be undertaken once project details have been further refined and will be provided within the final DCO application.			
Decommissioning				
Sediment disturbance activities during decommissioning (MP-D-2)	Pathway n/a	n/a	n/a	n/a

1.16 References

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