Hornsea Project Four: Environmental Statement (ES)

PINS Document Reference: A2.1
APFP Regulation: 5(2)(a)

Volume A2,
Chapter 1: Marine Geology, Oceanography and Physical Processes

Prepared Cooper Marine Advisor. July 2021
Checked GoBe Consultants Limited. August 2021
Accepted David King, Orsted. August 2021
Approved Julian Carolan, Orsted. September 2021

Doc. no. A2.1
Version B

Table of Contents

List of Tables

List of Plates

List of Figures

Annexes

Annex	Heading
A2.1.1	Marine Processes Technical Report

Glossary

Term	Definition
Amphidrome	A nodal point with minimal tidal range.
Commitment	A term used interchangeably with mitigation and enhancement measures. The purpose of Commitments is to reduce and/or eliminate Likely Significant Effects (LSEs), in EIA terms. Primary (Design) or Tertiary (Inherent) are both embedded within the assessment at the relevant point in the EIA (e.g. at Scoping, Preliminary Environmental Information Report (PEIR) or ES). Secondary commitments are incorporated to reduce LSE to environmentally acceptable levels following initial assessment i.e. so that residual effects are acceptable.
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. Cumulative impacts are those that result from changes caused by other past, present or reasonably foreseeable actions together with Hornsea Four.
Drill arisings	All material (solids and liquids) produced from the activity of drilling into the seabed.
Drill cuttings	Larger sized clasts produced from drilling that are likely to settle to the seabed (part of the drill arisings).
Far-field	An area remote from the near-field which is connected by a pathway.
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four.
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 depth contour commonly referenced to chart datum.
Landfall	The generic term applied to the entire landfall area between Mean Low Water Spring (MLWS) tide and the Transition Joint Bay (TJB) inclusive of all construction works, including the offshore and onshore ECC, intertidal working area and landfall compound. Where the offshore cables come ashore east of Fraisthorpe.
Long-term	Of several years or decades, accounting for year to year variations.
Longshore drift	Movement of (beach) sediments approximately parallel to the coastline, a process driven by the oblique approach of waves.
Maximum Design Scenario	The maximum design parameters of each Hornsea Four asset (both on and offshore) considered to be a worst case for any given assessment.
Megaripples	Bedform features commonly formed 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 or ES).
Mixed layer depth	Depth of surface mixed layer above density stratification formed by thermocline or halocline, if present.
Near-field	The area immediately associated with 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.

Term	Definition
Offshore	Generally, a more exposed and deeper water area away from any coastal influence.
Orsted Hornsea Project Four Ltd.	The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO).
Sandwave	A bedform feature commonly formed of sands, defined here with a crest to crest wavelength greater than 25 m, often superimposed with megaripples.
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
2D	Two-dimensional
AfL	Agreement for Lease
AODN	Above Ordnance Datum Newlyn
CBRA	Cable Burial Risk Assessment
CCO	Channel Coastal Observatory
CEA	Cumulative Effect Assessment
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFE	Controlled Flow Excavator (or Mass Flow Excavator, MFE)
CO_2	Carbon Dioxide
cSAC	Candidate Special Area of Conservation
DCO	Development Consent Order
DMRB	Design Manual for Roads and Bridges
DWR	Directional Wave Recorder
D_{50}	Sediment diameter representing 50% by mass larger and 50% smaller
D_{90}	Sediment diameter where 90% of the sample by mass is smaller
EA	Environment Agency
EEA	European Economic Area
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
ERYC	East Riding of Yorkshire Council
ES	Environmental Statement
EU	European Union
GBS	Gravity Base Structure
HDD	Horizontal Directional Drilling
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
H_s	Significant wave height
IECS	Institute of Estuarine and Coastal Studies, University of Hull
IPC	Infrastructure Planning Commission
JFE	Johnston Field Extension
JNCC	Joint Nature Conservation Committee
LAT	Lowest Astronomical Tide
LSE	Likely Significant Effect
LSO	Long Sea Outfall

Acronym	Definition
MCZ	Marine Conservation Zones
MDS	Maximum Design Scenario
MHWS	Mean High Water Springs
MLD	Mixed Layer Depth
MLWS	Mean Low Water Springs
MNR	Mean Neap Range
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSL	Mean Sea Level
MSR	Mean Spring Range
N/A	Not applicable
NAI	No Active Intervention
NCERM	National Coastal Erosion Risk Mapping
NPS	National Policy Statement
OSS	Offshore Substation
OWF	Offshore Wind Farm
PEIR	Preliminary Environmental Information Report
PINS	Planning Inspectorate
RCP	Representative Concentration Pathways
SAC	Special Area of Conservation
SBP	Sub-Bottom Profile
SEAL	Shearwater Elgin Area Line
SMP	Shoreline Management Plan
SPA	Special Protection Area
SPM	Suspended Particulate Matter
SSC	Suspended Sediment Concentration
SSSI	Site of Special Scientific Interest
TSHD	Trailing Suction Hopper Dredger
UKCP18	United Kingdom Climate Projections 2018
UTM	Universal Transverse Mercator
WHPS	Wellhead Protection Structure
WTG	Wind Turbine Generator

Units

Unit	Definition
kg	Kilogram
km	Kilometre
l	Litre
m	Metre
mg	Milligram
mm	Millimetre
m/s	Metres/second
s	Second
°C	Degrees Centigrade
%	Percentage

1.1 Introduction

1.1.1.1 Orsted Hornsea Project Four Limited (hereafter 'the Applicant') is proposing to develop the Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four') which will be located approximately 69 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 A1, Chapter 1: Introduction** for further details on the former 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 A1, Chapter 4: Project Description** for full details on the Project Design).

1.1.1.2 The Hornsea Four Agreement for Lease (AfL) area was 846 km^2 at the Scoping phase of project development. In the spirit of keeping with Hornsea Four's approach to Proportionate Environmental Impact Assessment (EIA), the project has due consideration to the size and location (within the existing AfL area) of the final project that is being taken forward to Development Consent Order (DCO) application. This consideration is captured internally as the "Developable Area Process", which includes Physical, Biological and Human constraints in refining the developable area, balancing consenting and commercial considerations with technical feasibility for construction.

1.1.1.3 The combination of Hornsea Four's Proportionality in EIA and Developable Area process has resulted in a marked reduction in the array area taken forward at the point of DCO application. Hornsea Four adopted a major site reduction from the array area presented at Scoping (846 km^2) to the Preliminary Environmental Information Report (PEIR) boundary (600 km^2), with a further reduction adopted for the Environmental Statement (ES) and DCO application (468 km^2) due to the results of the PEIR, technical considerations and stakeholder feedback. The evolution of the Hornsea Four Order Limits is detailed in **Volume A1, Chapter 3: Site Selection and Consideration of Alternatives** and **Volume A4, Annex 3.2: Selection and Refinement of the Offshore Infrastructure**.

1.1.1.4 This chapter of the ES presents the results of the EIA for the potential impacts of 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.

1.1.1.5 This chapter also draws on more detailed technical information contained within **Volume A5, Annex 1.1: Marine Processes Technical Report**, where appropriate.

1.2 Purpose

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

1.2.1.2 The ES has been finalised following completion of pre-application consultation (see **B1.1 Consultation Report** and **Table 1.4**) and will accompany the application to the Planning Inspectorate (PINS) for Development Consent.

1.2.1.3 This ES chapter:

- Summarises the existing environmental baseline established from desk studies, project survey data and consultation;
- Presents the potential environmental effects on Marine Processes arising from Hornsea Four, developed from an evidence-based approach and supported by additional modelling;
- 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 marine processes, 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 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 NPS EN-3 relates specifically to offshore renewable 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 ES.

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 ES
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 existing numerical modelling undertaken to support Hornsea Project One Offshore Wind Farm (Hornsea Project One), Hornsea Project Two Offshore Wind Farm (Hornsea Project Two) and Hornsea Project Three Offshore Wind Farm (Hornsea Three), alongside additional modelling commissioned for Hornsea Four.
"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 **Chapter 2: Benthic and Intertidal Ecology**, **Chapter 3: Fish and Shellfish Ecology**, **Chapter 4: Marine Mammals**, **Chapter 9: Marine Archaeology**, and **Chapter 11: Infrastructure and Other Users**.

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the ES
"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 issues relating to the determination of an application and in relation to mitigation. These issues 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 ES
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).	Effects on the coastline are assessed from **paragraph 1.11.1.114** for short-term effects of cofferdams at the landfall area, and **paragraph 1.11.2.34** for changes to waves affecting coastal morphology. **Section 1.7.11** 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 Special Area of Conservation (SAC) is reviewed in the project baseline in **paragraph 1.7.6.3**. The MCZ assessment is offered in **Volume A5, 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, **paragraph 1.11.1.95** and **1.11.1.114** provide a review of potential impacts during

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the ES
	landfall works, and **paragraph 1.11.2.34** during the operational period.
"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, other statutory consultees, Coastal Partnerships and other coastal groups, as it considers appropriate. Where this is not the case the Infrastructure Planning Commission (IPC) should consider what appropriate mitigation requirements might be attached to any grant of development consent" (Paragraph 5.5.17 of NPS EN-1).	Mitigation measures include existing design commitments (see Co44, Co45, Co82, Co83, Co181, Co187, Co188 and Co189 in **Volume A4, Annex 5.2: Commitments Register** and detailed in **Section 1.8.3**). Further mitigation measures are considered for each potential impact in **Section 1.11**, where relevant.
"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 Technical Panel 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).	Options for installing cables across the intertidal area no longer include open cut trenching. Instead, the installation of the offshore export cables at landfall will be undertaken by Horizontal Directional Drilling (HDD) or other trenchless methods (see Co187 in **Volume A4, Annex 5.2: Commitments Register**). An assessment of excavating HDD exit pits on sediment disturbance is provided from **paragraph 1.11.1.8**.
"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 from sandwave clearance are considered from **paragraph 1.11.1.16** to **1.11.1.31**, and for cable trenching from **paragraph 1.11.1.57** to **1.11.1.80**. 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 **Chapter 2: Benthic and Intertidal Ecology**.

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the ES
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 1.11.1.53**. Scouring is assessed from **paragraph 1.11.1.95**.
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 impact assessment is inclusive of construction, operation and decommissioning phases. A summary of the impacts assessed is offered in **Table 1.13**.
"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 1.11.1.95**.
"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, Co82, Co83, Co187, Co188 and Co189 in **Volume A4, Annex 5.2: Commitments Register** and 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 A1, 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) (EU 2008); 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 A full list of supporting guidance and best practice for the assessment of marine processes is provided within Section 2.7 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

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 ES
MSFD 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 process assesses anticipated changes to the seabed as a pathway. The effects on this pathway on marine ecosystems are considered in **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 1.11.2.20**. After decommissioning any semi-permanent effects would cease.
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 ES, in particular; **Chapter 2: Benthic and Intertidal Ecology**, **Chapter 3: Fish and Shellfish Ecology**, **Chapter 4: Marine Mammals**, **Chapter 9: Marine Archaeology**, and **Chapter 11: 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 1.7.11** considers climate change influences relevant to a future baseline.
"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 1.11.2.10** onwards. The potential for habitat change/ loss is discussed within **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, the EIA scoping process (Orsted 2018a) and formal consultation on the PEIR. An overview of the project consultation process is presented within **Volume A1, Chapter 6: Consultation**.

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

Table 1.4: Consultation Responses.

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
Cefas, Natural England and MMO	12 September 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 (Orsted 2020a). This review was subsequently presented to the Evidence Plan Marine Ecology & Processes Technical Panel on 30 April 2019.
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 1.11.1.98** for structures in the High Voltage Alternating Current (HVAC) Booster Station Search Area and **paragraph 1.11.1.104** 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 1.11.2.46**.
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 determining the study area with additional detail provided in Section 2.3 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.
EA	26 November 2018, Scoping Opinion	Consideration to smothering with fine suspended sediments within MCZs due to works in the offshore Export Cable Corridor (ECC).	**Section 1.11.1** considers potential sources of fine sediments during the construction phase along the ECC, including the nearshore environment. Smothering of benthic ecology is considered in **Chapter 2: Benthic and Intertidal Ecology**.
EA	26 November 2018, Scoping Opinion	No mention of nearshore processes within landfall search area.	Nearshore processes are described in **Section 1.7.2** for the landfall area.
EA	26 November 2018, Scoping Opinion	When considering cumulative impacts on the wave climate, all Hornsea project areas should be included.	**Section 1.12.4** considers the influence of all Hornsea project areas for changes in waves which draws on wave modelling (see

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
			Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report**) This review was subsequently presented to the Evidence Plan Marine Ecology & Processes Technical Panel on 30 April 2019.
EA	26 November 2018, Scoping Opinion	The nearshore 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.	Appendix B of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a comprehensive list of all data which supports the Marine Processes assessment, including the recent geophysical survey evidence in the nearshore.
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.	Potential changes to nearshore sediment pathways are discussed from **paragraph 1.11.2.46**.
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 in **paragraph 1.11.1.98** for structures in the HVAC Booster Station Search Area and **paragraph 1.11.1.104** for the offshore array. Scour protection material is described in **Volume A1, 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 geophysical survey includes site specific particle size data and supplements other data of the same type from GeoIndex and the Dogger Bank nearshore geophysical surveys. These data are presented in **Figure 1.4** for the offshore ECC and **Figure 1.12** for the offshore array. These data inform the issue related to seabed levelling.
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 presented issues for cable burial and remedial works in other wind farms.	**Table 1.12** provides details of project commitments which includes Co83 for cable burial as the preferred option (see **Volume A4, Annex 5.2: Commitments Register**). A CBRA is also outlined in **Volume A1, Chapter 4: Project Description**.

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
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 A1, 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 1.6** provides details of the receptor features of interest across the landfall, **Table 1.8** for features relevant to the offshore ECC and **Table 1.10** 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 A1, 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 effects along the Holderness Coast are assessed from **paragraph 1.11.2.34** and for nearshore pathways from **paragraph 1.11.2.46**.
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 A5, Annex 2.3: Marine Conservation Zone Assessment**.
Natural England	26 November 2018, Scoping Opinion	Based on potential blockage related impacts to (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	Turbulent wakes resulting from blockage effects are assessed from **paragraph 1.11.2.18** including the potential effects on the Flamborough Front from **paragraph 1.11.2.301.11.2.18**. The assessment presented here does not identify a requirement to assess issues in any more detail.

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
		may be required if the simple assessment indicates any issues that might require further consideration.	
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 1.11.1.98** for structures in the HVAC Booster Station Search Area and **paragraph 1.11.1.104** 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 A5, Annex 1.1: Marine Processes Technical Report** compares the environmental conditions between Hornsea Project One, Hornsea Project Two and Hornsea Three with Hornsea Four to support the applicability of evidence from these projects. Further, the Maximum Design Scenario (MDS) cases for all projects remain comparable. Comparable projects in comparable settings can expect to develop comparable impacts.
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.	The justification for the evidence-based approach is summarised in a position paper distributed to the technical panel (Orsted 2018b). The technical approach for EIA now also includes additional modelling.
Cefas, MMO and Natural England	30 April 2019, Marine Processes & Ecology Technical Panel Meeting Three	Discussion on the operational wave monitoring analysis from Hornsea Project One that had been undertaken.	Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a comprehensive review of the operational wave monitoring from Hornsea Project One.
MMO	23 September 2019, Section 42 response	The design of the slab sided HVAC stations has not been shown.	Table 4.13 of **Volume A1, Chapter 4: Project Description** provides summary details of the box-type gravity base.
MMO	23 September 2019, Section 42 response	The lack of surface sediment and sub surface geotechnical data is resulting in greater uncertainty than is normal for a PEIR.	A summary of the information applied from the 2018 and 2019 geophysical surveys is given in Appendix B of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
MMO	23 September 2019, Section 42 response	The Joint Nature Conservation Committee (JNCC) has identified Smithic Bank as a potential Annex 1 feature, and thus maintaining its form and function in terms of sediment transport is important.	Smithic Bank is identified as a marine process receptor which is described in **paragraph 1.7.6.5** to **1.7.6.10**. Furthermore, **Volume A4, Annex 5.2: Commitments Register includes** Co188 and Co189 to help mitigate concerns about cable protection and cable crossings.
MMO	23 September 2019, Section 42 response	Further details are required identifying the route of potentially three extra pipelines in the area. A further 40 cable crossings should be identified and assessed and should also be assessed in the Cumulative impacts section.	**Volume A4, Annex 4.1: Offshore Crossing Schedule** details all planned crossings. **Volume A5, Annex 1.1: Marine Processes Technical Report** indicates locations of all relevant pipeline and cable crossings.
MMO	23 September 2019, Section 42 response	Whilst a full years' worth of numerical model data has been assessed for mixed layer depth (MLD), only one snapshot is shown.	As agreed with the MMO, the work published by Peter Miller has been considered alongside the modelling of MLD (see Figure 37 of **Volume A5, Annex 1.1: Marine Processes Technical Report**).
MMO and Natural England	23 September 2019, Section 42 response	Geophysical surveys should establish if chalk is present as this may impact the size/shape of suspended sediment plumes. Geophysical surveys to be completed and shared with the Technical Panel prior to application.	Additional seabed data was collected in 2019 to support the EIA, refine proposals and avoid/minimise/reduce impacts where possible. The geophysical evidence has been considered for chalk layers. This data is presented in **Figure 1.14**. Appendix B of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides an overview of the geophysical survey outputs with specific details from the full survey integrated across relevant sections of the chapter.
Natural England	23 September 2019, Section 42 response	It is not currently clear at which point the revised designs of consented projects become legally secured in order to be considered the baseline assumption of cumulative/in combination assessment within an ES or Habitats Regulations Assessment (HRA). Guidance should be sought from the regulators on this point Discussion welcomed with the wider Steering Group.	The Applicant engaged with the Marine Ecology and Processes Technical Panel in November 2019, noting constructed projects are often of lesser extent than those described within their consented envelope. The EIA has accepted the as-built and final designs for Hornsea Project One and Hornsea Project Two as the present baseline. In addition, the scale of effects on waves from the present baseline has also been demonstrated using the

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
			available wave monitoring evidence to contrast with the MDS case for Hornsea Project One.
Natural England	23 September 2019, Section 42 response	Hornsea Project One should be included in the table. Given the connectivity along the Holderness coast and beyond, additional plans and projects should be scoped in. This should include (but not necessarily limited to), pipelines, outfalls and coastal infrastructure. Further scoping of plans and projects. This could be discussed at a technical panel meeting.	This chapter includes considerations of Hornsea Project One and Hornsea Project Two as well as relevant pipelines, outfalls and coastal infrastructure with details provided under the baseline reviews of associated parts of the study area.
Natural England	23 September 2019, Section 42 response	The lack of data to inform baseline characterisation presents significant uncertainties and therefore conclusions cannot be drawn with any confidence. Not all receptors, pressures and impacts have been identified and the MDSs are not clearly defined. Consequently Natural England cannot agree with the conclusions of the PEIR at this stage. Impacts on coastal processes and nearshore sediment pathways are likely to be key consenting risks for this project. It is therefore important that these aspects are fully assessed and that there is sufficient time to fully explore options to ideally avoid, or if not mitigate the impacts prior to application. The Project should consider options to avoid impacts to Smithic Bank completely, and to reduce/remove the potential for impacts on coastal processes.	The geophysical surveys were completed in 2019 and the entire dataset (2018 and 2019) informs the baseline, refine proposals and avoid/minimise/reduce impacts where possible. The combined and updated 2018-2019 survey data is presented in **Volume A5, Annex 1.1: Marine Processes Technical Report** and all assessments within the ES have been updated in light of this data. All project details presented in **Volume A1, Chapter 4: Project Description** and **Volume A4, Annex 5.1: Impacts Register** have been reviewed and updated where required. The importance of Smithic Bank is recognised as a feature of interest within the baseline description of the offshore ECC study area (**paragraph 1.7.6.5** to **1.7.6.10**). Offshore export cable crossings adjacent to Smithic Bank are described in **Volume A1, Chapter 4: Project Description**. Furthermore, the Applicant has committed (Co188 and Co189) to ensure offshore export cable crossings remain clear of Smithic Bank as detailed in **Volume A4, Annex 5.2: Commitment Register**. The influence of this feature on local flows and waves has also been

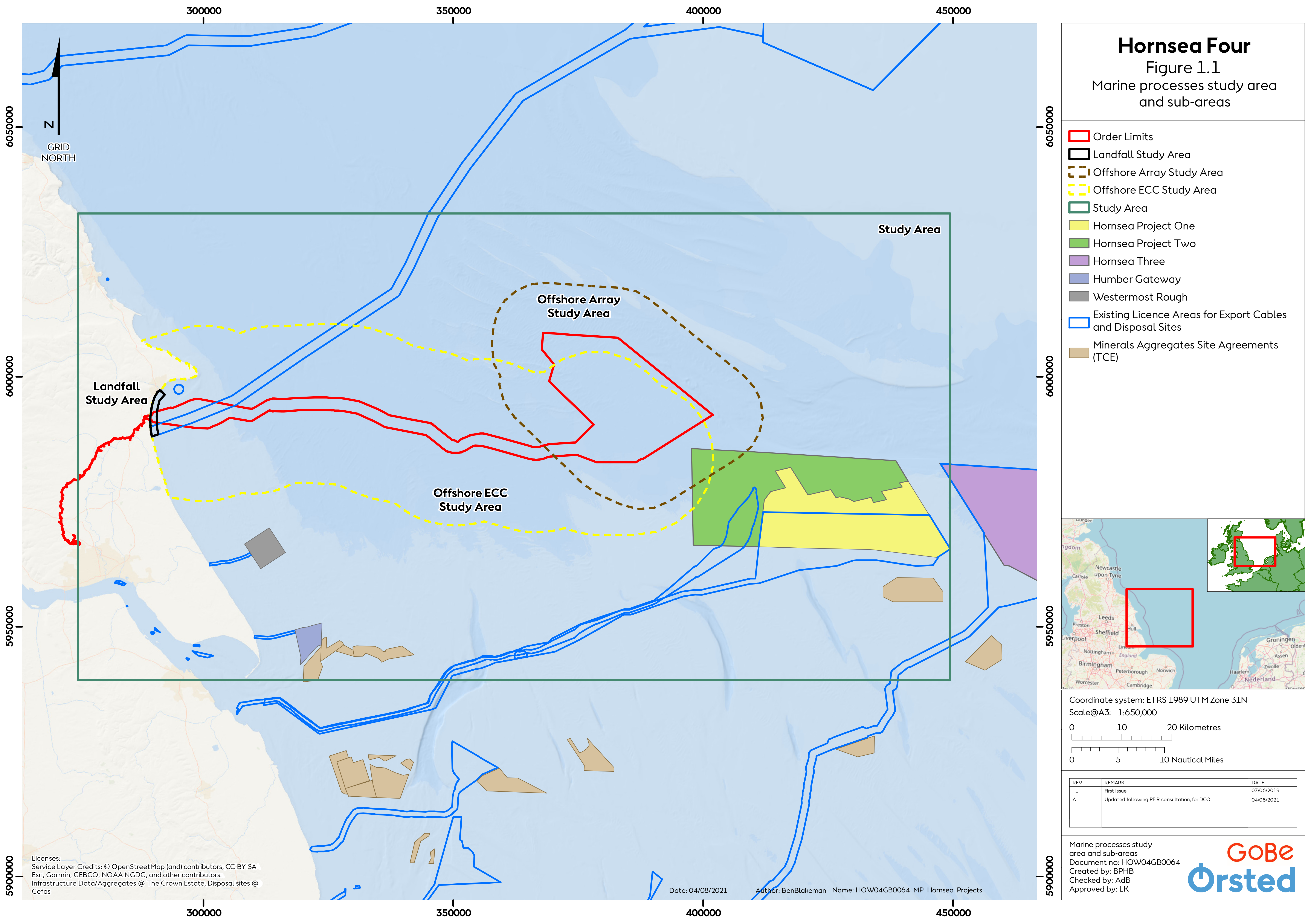
Consultee	Date, Document, Forum	Comment	Where addressed in the ES
			considered within the modelling presented in Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report**.
Cefas, MMO and Natural England	13 November 2019, Marine Processes & Ecology Technical Panel Meeting Four	Discussion to seek clarification on Section 42 Responses to marine processes in regard to geophysical survey outputs and Flamborough Front, in particular.	Appendix B of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides an overview of the geophysical survey outputs with specific details from the full survey integrated across relevant sections of the chapter. **Paragraph 3.4.3.10** to **3.4.3.11** present additional information about the probability of occurrence of the Flamborough Front.
Natural England	20 November 2020, EP consultation response	Post-PEIR and pre-DCO review of Marine Processes Chapter and Technical Report. The feedback from Natural England and MMO was discussed at the Marine Processes & Ecology Plan Technical Panel meeting on 13 May 2021 to review comments and agree actions on various common themes to help update the marine processes chapter and technical report.	Comments have been considered, as appropriate, throughout both documents with notable additions in **Volume A5, Annex 1.1: Marine Processes Technical Report**; More detail baseline review of Smithic Bank, including interpretation of sub-bottom profiles (from **paragraph 3.3.3.8**) Plume dispersion assessment for inshore ebb channel (from **paragraph 4.4.2.19**); Cable protection and Smithic Bank (from **Section 4.6.5**); and Further review of German Bight study (from **paragraph 4.7.4.18**) in relation to possible effects on Flamborough Front.
MMO	15 December 2020, consultation response		
MMO and Natural England	13 May 2021, Marine Processes & Ecology Technical Panel Meeting 4A		

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, the structures placed onto the seabed that may locally block waves and flows and the pathways which have the capacity to extend effects from the near-field across a wider area (the far-field), e.g. the excursion of sediment plumes. In addition, where there are adjacent activities which may also create a similar type of effect over a similar period then this is also included in the study area in order that cumulative effects between such activities can be considered (e.g. the relatively close proximity of Hornsea Project One and Hornsea Project Two wind turbine generator (WTG) foundations acting to block waves and flows).

1.5.1.2 The study area is described for landfall, offshore ECC and offshore array sub-areas to recognise the different types of project activity and the different types of marine process environments. In particular, the offshore ECC has a marine process environment with a transition from nearshore to offshore conditions.

1.5.1.3 **Figure 1.1** presents the spatial extent of the marine processes study area for Hornsea Four. Further details on the development of the study area are provided in Section 2.3 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.



Hornsea Four

Figure 1.1

Marine processes study area and sub-areas

Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:650,000

0 10 20 Kilometres

0 5 10 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Marine processes study area and sub-areas
Document no: HOW04GB0064
Created by: BPHB
Checked by: AdB
Approved by: LK

1.6 Methodology to inform baseline

1.6.1 Overview

1.6.1.1 The Marine Processes assessment has been delivered using an evidence-based approach which is described in Orsted (2018b) and was presented at the first meeting of the Marine Ecology & Processes Evidence Plan Technical Panel on 12 September 2018. Subsequently, site-specific geophysical surveys of the offshore ECC and array areas have now been completed with this information adding to the evidence base.

1.6.1.2 The application of an evidence-based approach to offshore wind farms (OWFs) 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).

1.6.2 Desktop Study

1.6.2.1 A desktop study of the marine processes baseline has applied the evidence base of data and information which covers the 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 informing the desktop study are summarised in Appendix B of **Volume A5, Annex 1.1: Marine Processes Technical Report**, this includes the geophysical and benthic survey data.

1.6.2.2 The application of the evidence base recognises the relative strengths and weakness between equivalent types of information based on data quality, coverage, scale and age. In this way, the most recent survey data from the geophysical survey takes precedence across the project development area with other comparable evidence providing supplementary coverage elsewhere across the wider study area. In addition, the partial coverage of the geophysical survey also serves to validate other equivalent data so that collectively complete coverage is achieved and apparent data gaps in the Hornsea Four geophysical survey are minimised.

1.7 Baseline environment

1.7.1 Overview

1.7.1.1 The baseline environment of the study area represents marine process conditions that are expected to prevail without any development of Hornsea Four taking place and for an equivalent period as the lease (35 years for the operational phase). This description provides the reference conditions 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 of the baseline is provided for landfall, offshore ECC and offshore array areas with a more detailed description available in **Volume A5, 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 intertidal sandy beach, backed by soft cliffs, gently shelving into a shallow subtidal environment (out to around 8 m below LAT, to encompass the littoral zone). The sands can be thin in places exposing an underlying clay till. This environment mainly responds to wave driven processes which erode the base of the undefended cliffs and transport mobile sandy sediments along the beach. **Plate 1** provides a view of the intertidal area at the landfall. A more detailed review of the landfall study area is provided in Section 3.2 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

Plate 1: View of the intertidal area at landfall – site ref 306 (from Institute of Estuarine and Coastal Studies (IECS), 2019 - Appendix C of Volume A5, Annex 2.1: Benthic and Intertidal Ecology Technical Report).

Intertidal sediments

1.7.2.2 A walkover survey of the landfall intertidal area qualitatively described beach material as coarse sands and in places thinning to reveal hard boulder clay (Appendix C of **Volume A5, Annex 2.1: Benthic and Intertidal Ecology Technical Report**).

Subtidal sediments

1.7.2.3 The 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 water levels. High waters on spring tides enable waves to reach the base of the soft cliffs. Further details on water levels are provided in Table 2 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

Waves

1.7.2.5 Waves in the landfall area are an important process for driving longshore drift along the coast with the drift direction determined by the angle of approach of the wave. During stormy periods waves can lead to toe erosion of the soft cliffs around periods of high water which develops a source of sediment onto the beach.

1.7.2.6 Flamborough Head shelters the landfall from prevailing northerly waves and limits wave exposure to between north-easterly to south-easterly sectors, noting waves from south-easterly sectors are relatively infrequent. The shallow profile of the sandbank feature Smithic Bank also acts to shoal larger waves providing additional sheltering.

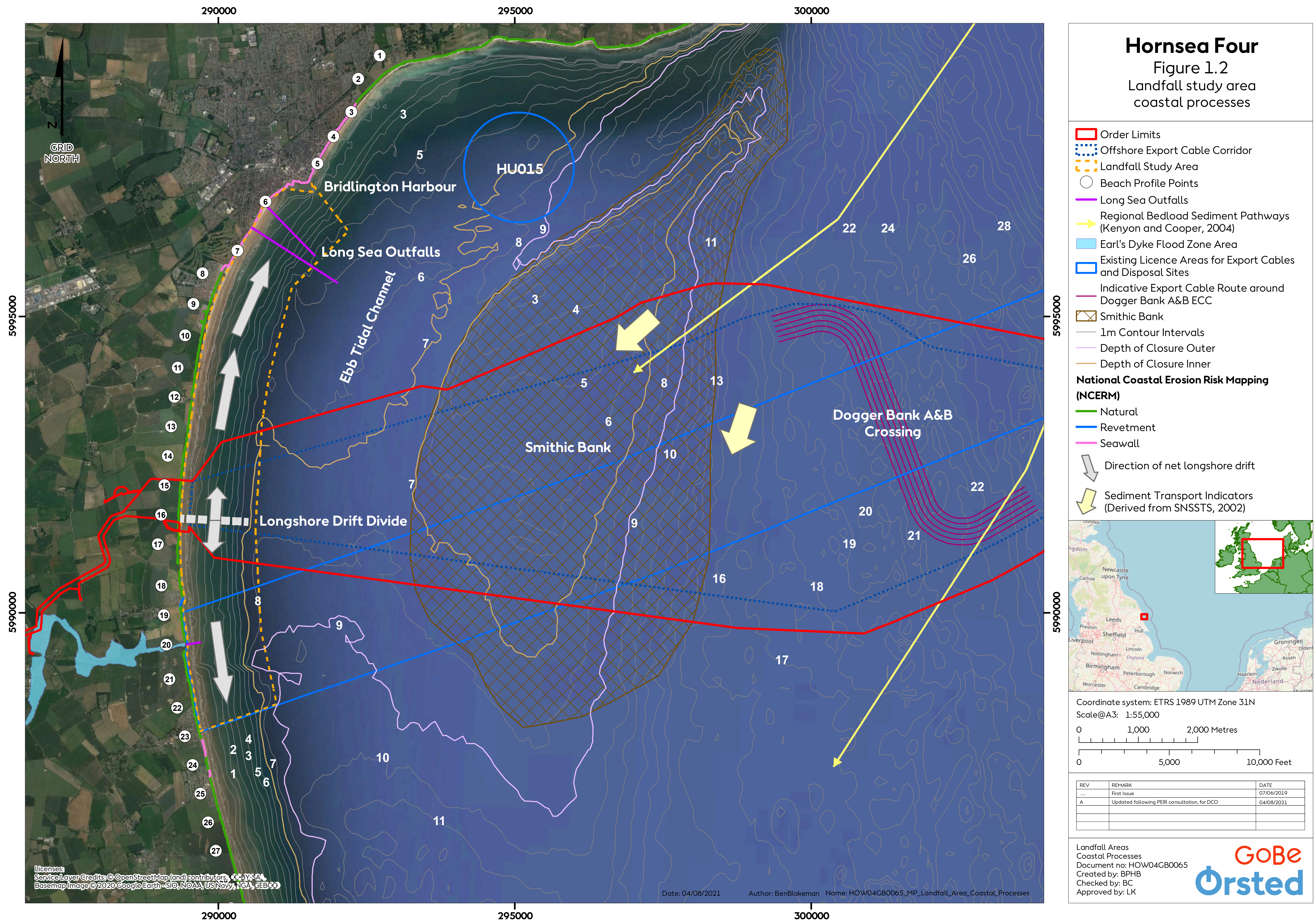
1.7.2.7 South of the landfall the coastline receives fewer sheltering effects from both Flamborough Head and Smithic Bank, increasing the prevalence of waves from northerly sectors acting along the coastline.

Sediment transport

1.7.2.8 The net annual longshore drift (sum of all drift rates and directions in a year) is effectively nil in the vicinity of the landfall, with a balance of material transported to the north and south. This location can also be regarded as a sediment divide (**Figure 1.2**) (area around Barmston). South of the landfall, the increasing exposure to prevailing northerly waves results in a progressively stronger net longshore drift of sandy material towards Spurn Head (Pye & Blott 2015).

1.7.2.9 The seaward limit of the wave driven littoral zone for longshore drift can be estimated by the theoretical "Inner – Depth of Closure". In addition, the "Outer – Depth of Closure" represents the seaward limit of the effect of wave shoaling. Based on standard expressions developed by Hallermeier (1983), and by applying relevant environmental parameters for waves and sediments, the "Inner – Depth of Closure" is estimated to be a depth of 7 m (below LAT) and the "Outer – Depth of Closure" is estimated to be a depth of 9 m (below LAT) (**Figure 1.2**).

1.7.2.10 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 elevated suspended sediment concentrations and a visible nearshore plume.


Hornsea Four
Figure 1.2
Landfall study area
coastal processes
Order Limits
Offshore Export Cable Corridor
Landfall Study Area
Beach Profile Points
Long Sea Outfalls
Regional Bedload Sediment Pathways (Kenyon and Cooper, 2004)
Earl's Dyke Flood Zone Area
Existing Licence Areas for Export Cables and Disposal Sites
Indicative Export Cable Route around Dogger Bank A&B ECC
Smithic Bank
1m Contour Intervals
Depth of Closure Outer
Depth of Closure Inner
National Coastal Erosion Risk Mapping (NCERM)
Natural
Revetment
Seawall
Direction of net longshore drift
Sediment Transport Indicators (Derived from SNSSTS, 2002)
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:55,000
0 1,000 2,000 Metres
0 5,000 10,000 Feet
Bridlington Harbour
HU015
Long Sea Outfalls
Ebb Tidal Channel
Smithic Bank
Dogger Bank A&B Crossing
Longshore Drift Divide
GRID NORTH
290000
295000
300000
5995000
5990000
Date: 04/08/2021
Author: BenBlakeman
Name: HOW04GB0065_MP_Landfall_Area_Coastal_Processes
Landfall Areas
Coastal Processes
Document no: HOW04GB0065
Created by: BPHB
Checked by: BC
Approved by: LK
GoBe
Ørsted

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 immediate coastline at the landfall comprises of a sandy intertidal 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; IECS 2016).

1.7.3.2 East Riding of Yorkshire Council (ERYC) undertake routine land-based monitoring of the Holderness Coast in spring and autumn each year (from 2003) which includes beach profiles from the top of the sea cliffs to low water. **Table 1.5** summarises cliff recession rates for the beach profiles (15 and 16) coincident with the immediate landfall area (shown on **Figure 1.2**). Recession rates vary along the entire Holderness 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. The standard land-based datum of heights Above Ordnance Datum Newlyn (AODN) is referred to here rather than a sea based datum referenced to Lowest Astronomical Tide (LAT). The conversion from AODN to LAT is +3.25 m, based on values from Bridlington.

Table 1.5: Cliff recession rates at Profiles 15 and 16.

Profile	Location	Height of cliff (m AODN)	Average cliff recession (m/year)	Maximum annual recession (m)	Year of maximum recession
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 SMP policy for this stretch of coast (Policy Unit C: Wilsthorpe to Atwick) is given as; No Active Intervention (NAI) 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) (2018 – 2021) identifies this frontage as a natural defence and erodible. Assuming the SMP policy of NAI remains unchanged in the future, the best estimates of retreat distance for the short term (0 to 20 years) and medium term (20 to 50 years) would be around 33 m and 82 m, respectively (Environment Agency 2020), based on present conditions.

Dogger Bank A and B export cable landfalls

1.7.3.5 The anticipated landfall for the Dogger Bank A and B export cables is around 1.2 km to the south of the proposed Hornsea Four landfall. These adjacent landfall works are expected to be completed prior to the installation of Hornsea Four offshore export cables.

Marine outfalls

1.7.3.6 Yorkshire Water operate two long sea outfalls (LSO) approximately 4.2 km north of the landfall works.

Bridlington Harbour

1.7.3.7 Bridlington Harbour is around 5 km north of the proposed landfall works. The bed of the harbour is noted as being muddy (silts) and is generally 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 with a typical annual disposal of between 12,000 to 14,000 tonnes from a maximum permitted disposal of 20,000 tonnes per annum. This disposal ground is identified as a receptor within the offshore ECC study area.

1.7.4 Summary of receptor features of interest within the landfall study area

1.7.4.1 **Table 1.6** summarises the receptor features of interest within the landfall study area.

Table 1.6: Receptor features of interest in the landfall study area.

Receptor	Potential sensitivity to marine processes
Holderness Cliffs	Changes in (storm) wave energy dissipation at toe of cliff that modify rates of cliff recession and supply of material to the beach. Short-term effects due to beach access ramp.
Holderness Coast / 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.
Dogger Bank A and B landfall	Beach lowering exposing export cables from Dogger Bank A and B.
LSOs	High rates of deposition of sediment settling onto outfall 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 offshore ECC study area has a marine process environment with a transition from partially sheltered and shallow nearshore conditions to more exposed offshore and deeper water conditions. A more detailed review of the offshore array study area is provided in Section 3.3 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

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 (< 6 m) across Smithic Bank which then deepen to around 22 m in the area of the Dogger Bank A & B export cable crossing, reaching around 51 m below LAT across the HVAC Booster Station Search Area (deepest section) and then shallowing slightly to around 40 m below LAT meeting with the offshore array area.

Subtidal sediments

1.7.5.3 The variation of subtidal sediments across the offshore ECC is determined by sediment grab samples, combined with the interpretation of seabed lithology from the geophysical survey (Bibby HydroMap 2019).

1.7.5.4 The inshore section (from landfall to Smithic Bank) comprises sands with patches of gravelly sands, becoming sands across the shallower Smithic Bank. As the bank shelves into slightly deeper water (>10 m below LAT) the seabed coarsens to sandy gravel, an area which extends across the location of the proposed crossing of the Dogger Bank A & B export cables to around 30 m below LAT. Further to the east, and out to the HVAC Booster Station Search Area, the seabed becomes gravelly sand to slightly gravelly sand. As the sand content further increases, there is evidence of megaripples from the HVAC Booster Station Search Area for around 32 km to the east. After this area, and up to the fan connecting with the offshore array area, the seabed is relatively featureless with grab samples showing muddy sand. For the final section (fan area) of the offshore ECC, the seabed returns to being sandy with areas of megaripples and occasional sandwaves (**Figure 1.4**).

Water levels

1.7.5.5 MSR varies from 5 m in the nearshore 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 2008a).

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

Tidal flows

1.7.5.7 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 are also strongest. Regional mapping of tidal flows (DECC 2008a) 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**).

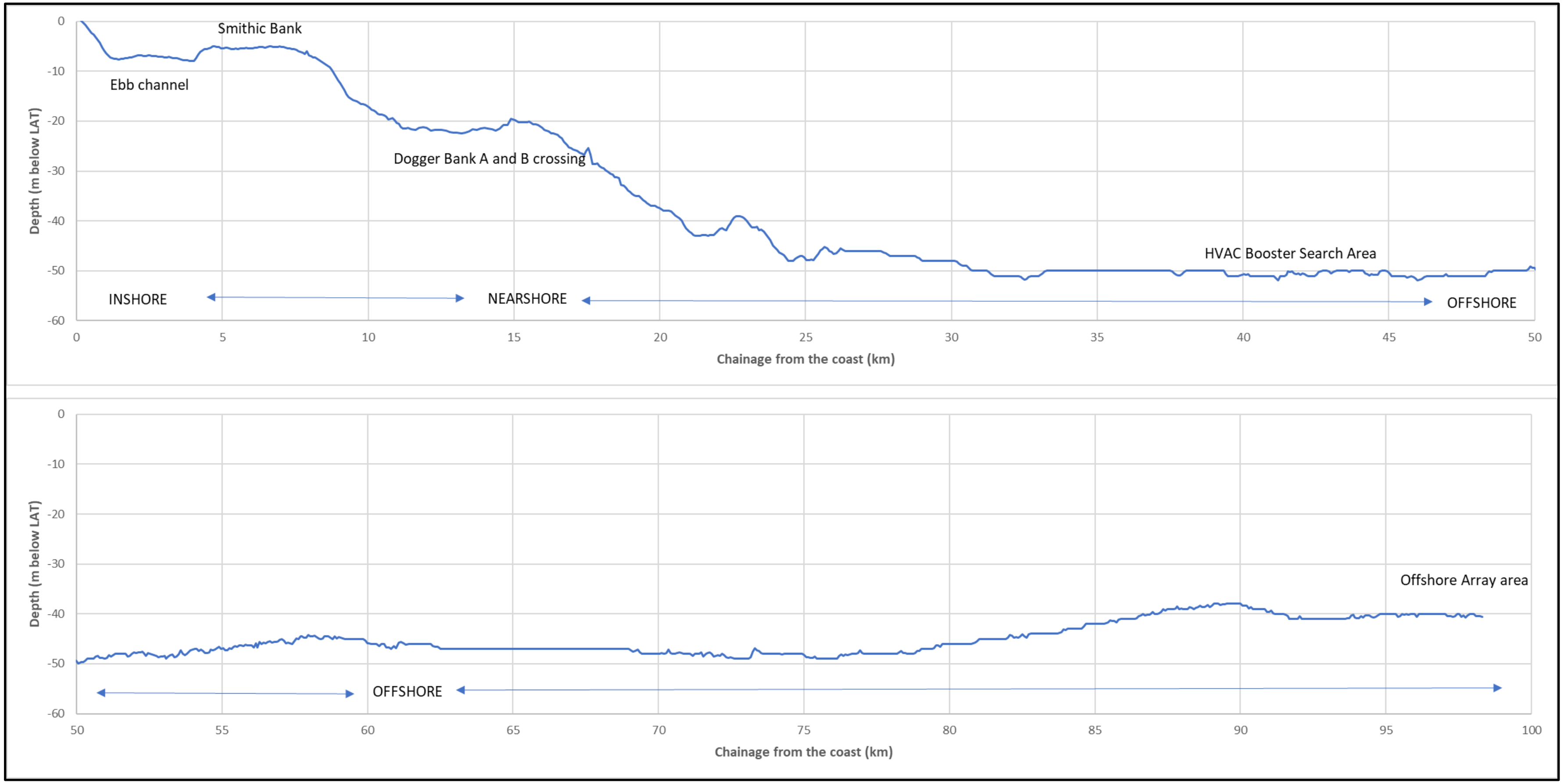
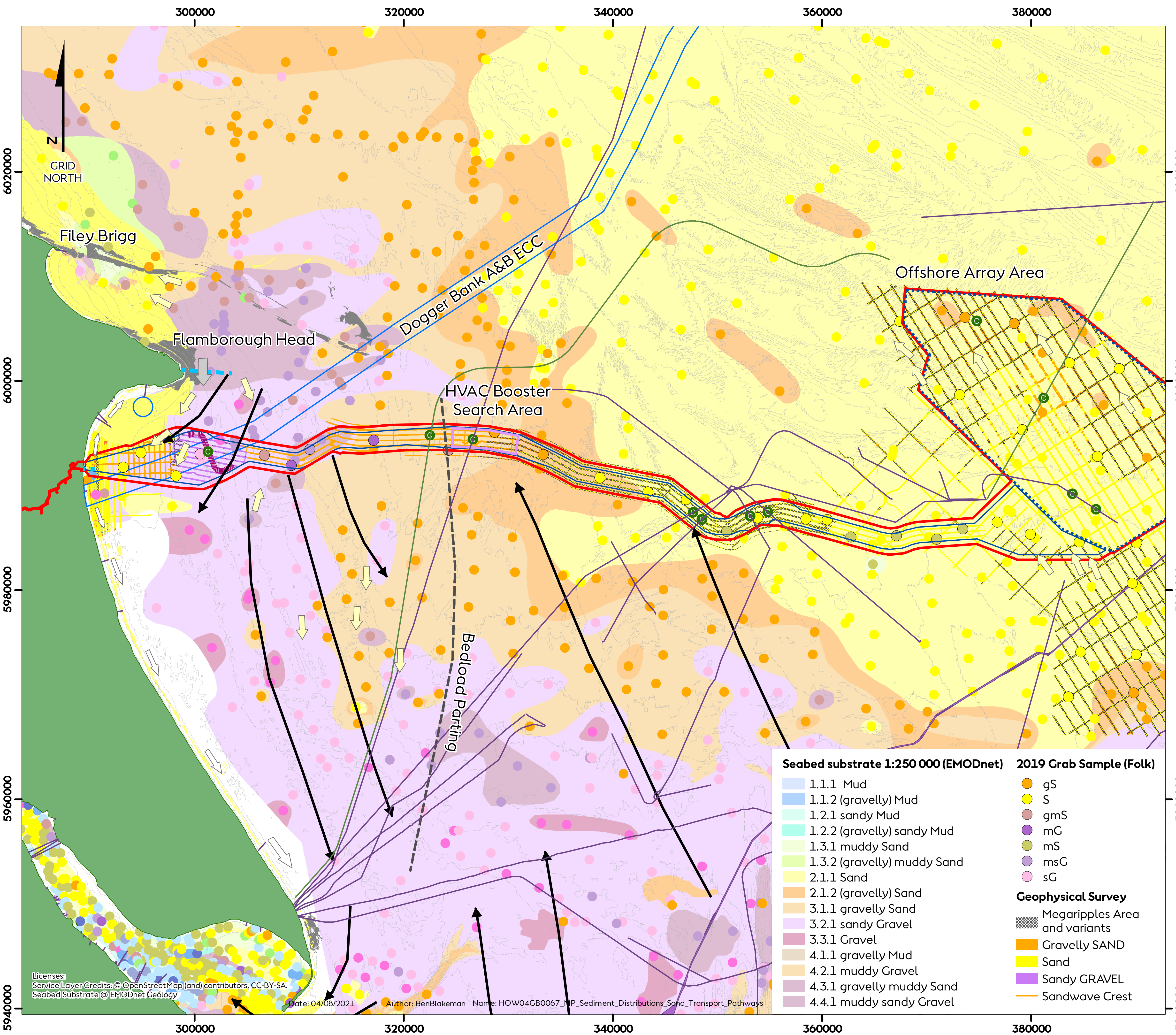


Figure 1.3: Seabed profile along offshore ECC, from landfall up to the offshore array.

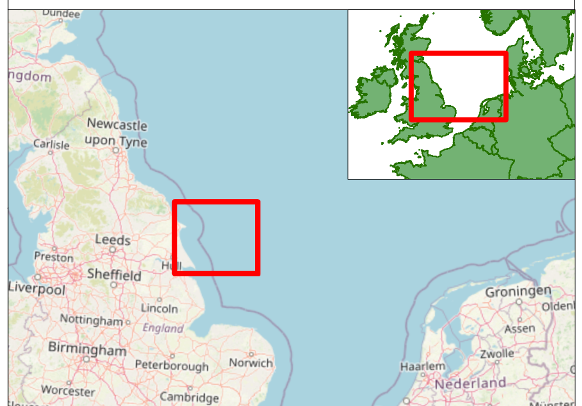


Hornsea Four

Figure 1.4

Sediment distributions across the offshore ECC based on descriptive classification by Folk (1954)

- Order Limits
- Array Area
- Offshore Export Cable Corridor
- HVAC Booster Station Works Area
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Indicative Export Cable Route around Dogger Bank A&B ECC
- Viking Link Cable
- Existing Licence Areas for Export Cables and Disposal Sites
- Drift Divide
- Regional Bedload Sediment Pathways (Kenyon and Cooper, 2004)
- 5m Contour Intervals
- Direction of net longshore drift
- Sediment Transport Indicators (Derived from SNSSTS, 2002)



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:350,000

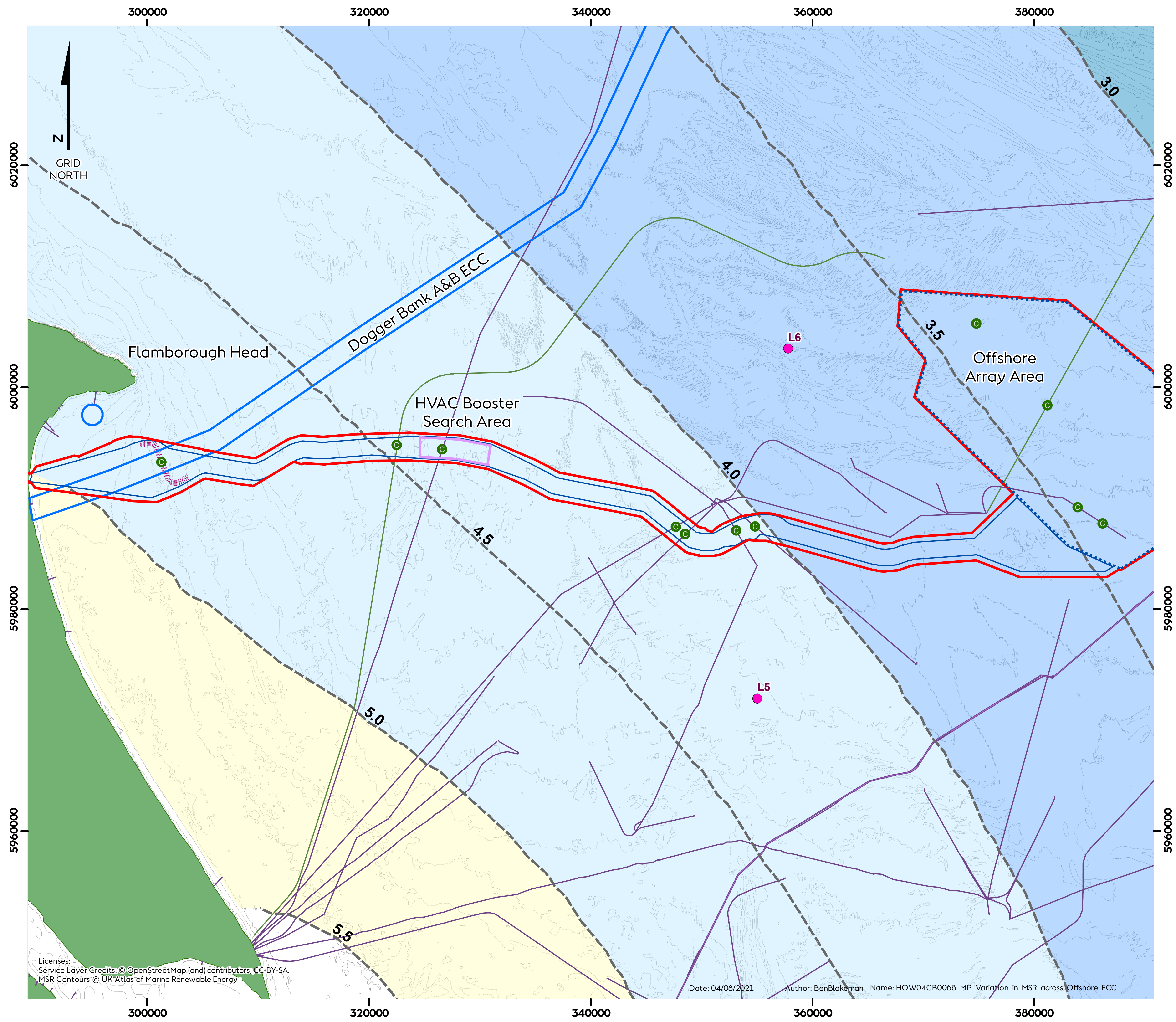
0 5 10 Kilometres

0 5 10 Nautical Miles

REV	REMARK	DATE
...	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Sediment Distributions
Sand Transport Pathways
Document no: HOW04GB0067
Created by: BPHB
Checked by: BC
Approved by: LK

GoBe
Ørsted



Hornsea Four

Figure 1.5

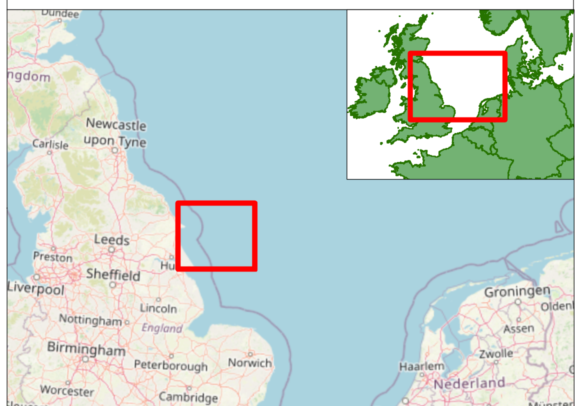
Variation in MSR across offshore ECC

- Order Limits
- Array Area
- Offshore Export Cable Corridor
- HVAC Booster Station Works Area
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Indicative Export Cable Route around Dogger Bank A&B ECC
- Viking Link Cable
- Existing Licence Areas for Export Cables and Disposal Sites
- Metocean Deployment Sites
- 5m Contour Intervals
- Mean Spring Tidal Range Contours

Mean Spring Tidal Range (m)

(UK Atlas of Marine Renewable Energy)

- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 5.5



Coordinate system: ETRS 1989 UTM Zone 31N

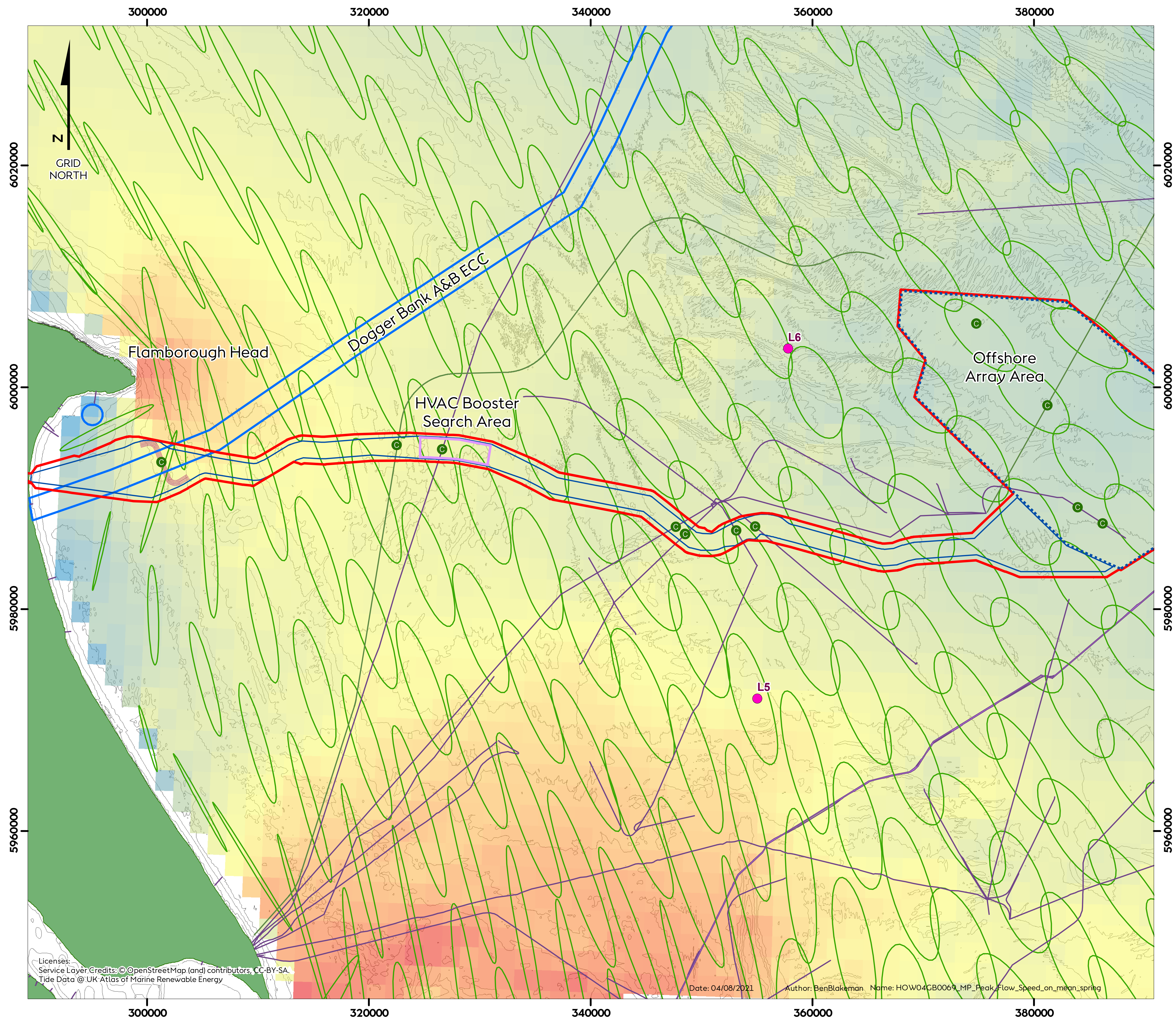
Scale@A3: 1:325,000

0 5 10 Kilometres

0 4 8 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Variation in MSR
Across Offshore ECC
Document no: HOW04GB0068
Created by: BPHB
Checked by: BC
Approved by: LK



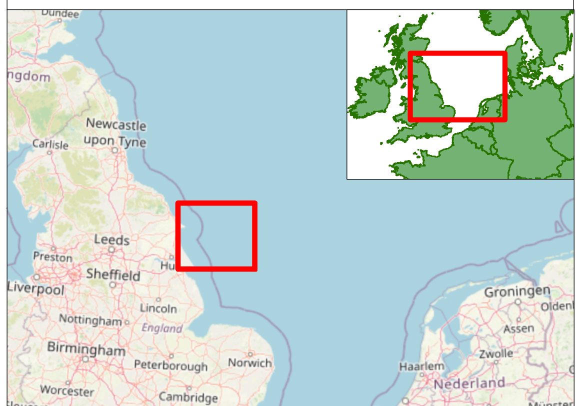
Hornsea Four

Figure 1.6

Mean spring tide, peak flow speed along with orientation of tidal ellipse scaled to represent the tidal excursion

- Order Limits
- Array Area
- Offshore Export Cable Corridor
- HVAC Booster Station Works Area
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Indicative Export Cable Route around Dogger Bank A&B ECC
- Viking Link Cable
- Existing Licence Areas for Export Cables and Disposal Sites
- Metocean Deployment Sites
- 5m Contour Intervals
- Spring Tidal Ellipses

Peak Flows (m/s)
1.48
0.31



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:325,000

0 5 10 Kilometres

0 4 8 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Peak Flow Speed on Mean Spring Across Offshore ECC
Document no: HOW04GB0069
Created by: BPHB
Checked by: BC
Approved by: LK

Waves

1.7.5.8 Figure 1.7 presents wave roses for two sites (see Figure 1.6 for locations) around 12 km to the south of the offshore ECC; (a) Hornsea Directional Wave Recorder (DWR) deployed in the nearshore in water depths of around 12 m below LAT, and (b) Site L5 - Off Grounds (an offshore site in water depths of around 38.8 m below LAT collected to support zonal characterisation (EMU 2013)). To enable a fair comparison between sites, the wave roses use the same period of data (September 2010 to July 2011). Although not as sheltered as areas further to the north, Hornsea DWR still demonstrates partial sheltering from northerly waves by Flamborough Head as well as shallow water shoaling and refraction (some northerly waves will refract across the shallower water towards this site and become accounted for in the north-easterly sector). In comparison, Site L5 demonstrates full exposure to northerly waves (the directional sector which also contains the largest wave heights). This site is also regraded as deep water for waves. Wave periods for both locations are typically 3 to 6 s, reaching 7 to 8 s during stormy conditions.

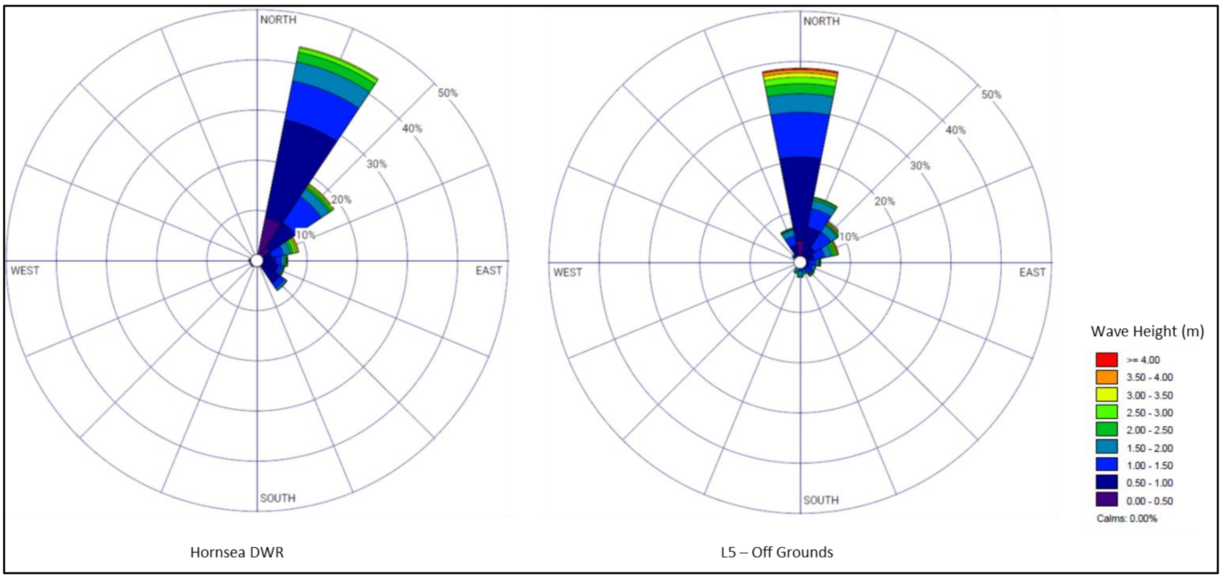


Figure 1.7: Wave roses for Hornsea DWR and Site L5.

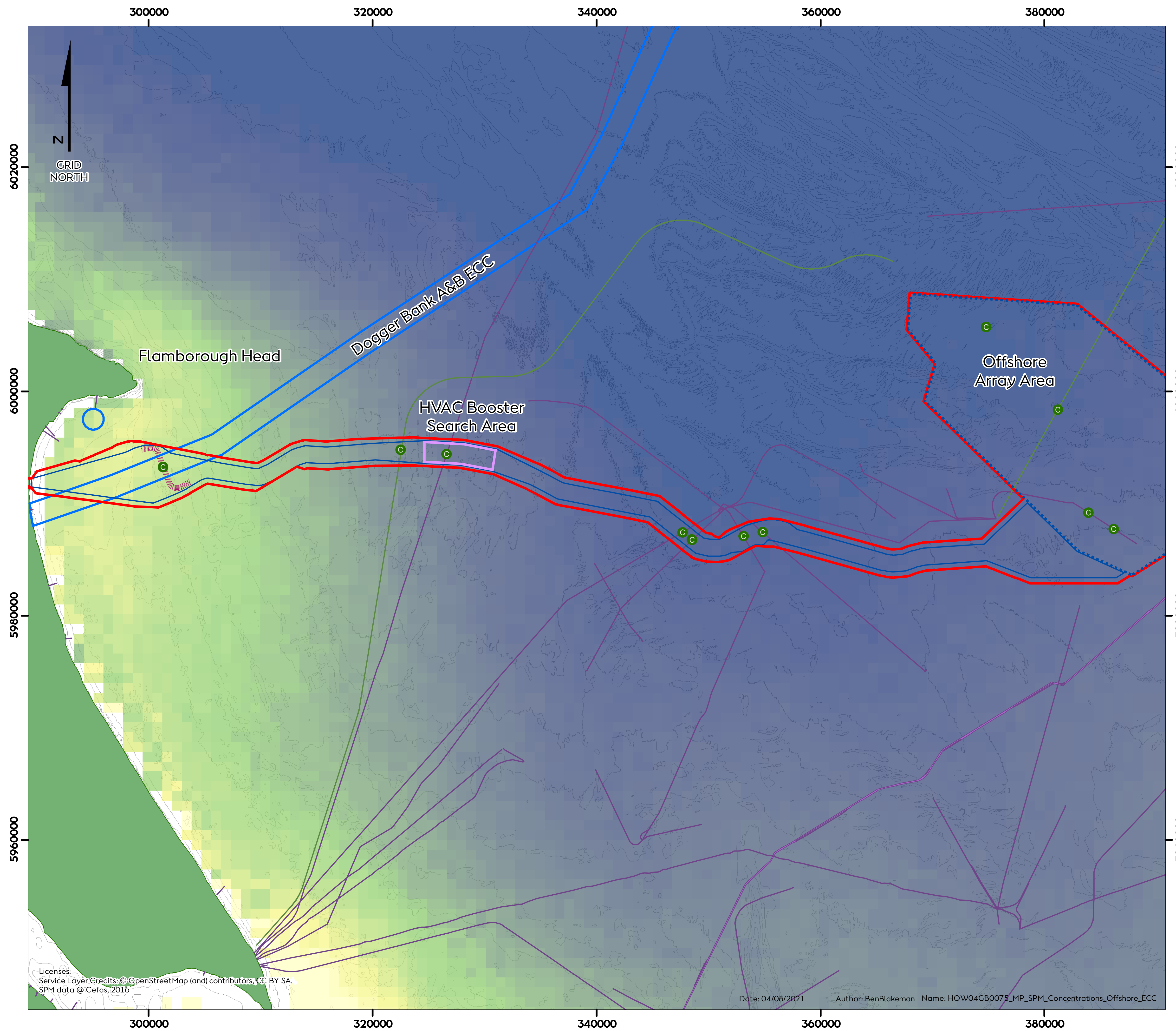
Bedload sediment transport pathways

1.7.5.9 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 Station Search Area and net north-easterly transport from the HVAC Booster Station Search Area onto the offshore array area. A bedload parting zone separates these two areas (Figure 1.4).

Suspended particulate matter (SPM)

1.7.5.10 Monthly mean SPM variations are established from satellite observations over the 18-year period 1998 to 2015 (Cefas 2016). Inherently, these data represent near-surface concentrations, but for well-mixed water bodies the variation over depth is expected to be minimal. Figure 1.8 presents SPM variations for February which generally represents the maximum concentrations during the year. Concentrations are highest for around the first 10 km from the coastline and for the area around Flamborough Head. This is mainly in response to fine sediments from the beach being washed into the sea and wave stirring influences.

1.7.5.11 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 arising from cliff erosion, shallower water and locally stronger wave and tidal stirring influences maintaining the fine material in suspension and inhibiting local deposition.



Hornsea Four

Figure 1.8

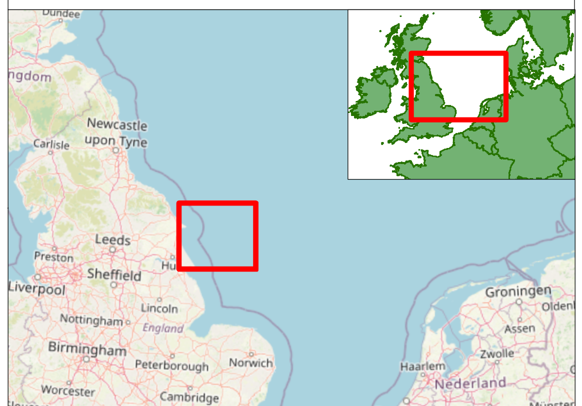
Monthly averaged surface SPM concentrations, February

- Order Limits
- Array Area
- Offshore Export Cable Corridor
- HVAC Booster Station Works Area
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Indicative Export Cable Route around Dogger Bank A&B ECC
- Viking Link Cable
- Existing Licence Areas for Export Cables and Disposal Sites
- 5m Contour Intervals

SPM Concentrations (mg/l)

83.92

0.88



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:325,000

0 5 10 Kilometres

0 4 8 Nautical Miles

REV	REMARK	DATE
...	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Surface SPM Concentrations Across Offshore ECC

Document no: HOW04GB0075

Created by: BPHB

Checked by: BC

Approved by: LK

GoBe

Ørsted

1.7.6 Marine physical environment receptor features of interest – offshore ECC area

1.7.6.1 **Figure 1.9** shows the location of key receptor features of interest across the offshore ECC area. This includes; spoil ground HU015, Flamborough Head SAC, Smithic Bank and various cable crossings.

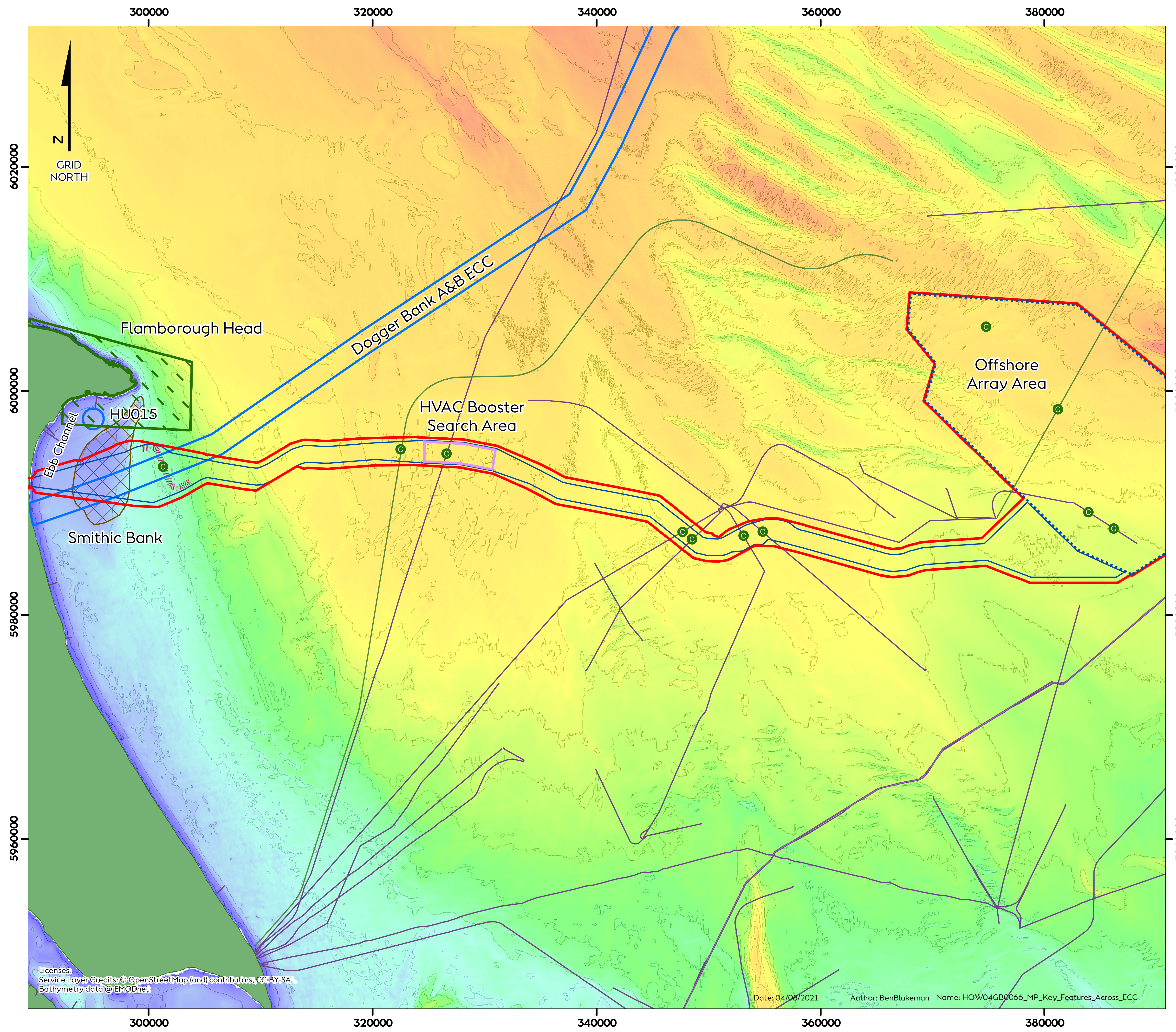
Spoil Ground HU015

1.7.6.2 Maintenance dredgings of mainly silts 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 Bank. 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

1.7.6.3 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 on these habitats at this time (Cefas 2010).

1.7.6.4 The seabed substrate around the headland is mainly rock (**Figure 1.4**), indicating an area scoured of mobile sediments by locally faster flows.



Hornsea Four

Figure 1.9

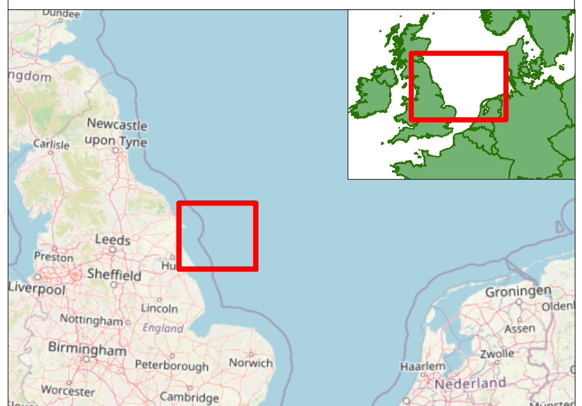
Key features across the offshore ECC

- Order Limits
- Array Area
- Offshore Export Cable Corridor
- HVAC Booster Station Works Area
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Indicative Export Cable Route around Dogger Bank A&B ECC
- Viking Link Cable
- Existing Licence Areas for Export Cables and Disposal Sites
- Flamborough Head SAC
- Smithic Bank
- 5m Contour Intervals

Depth (m below LAT)

0

75



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:325,000

0 5 10 Kilometres

0 4 8 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Key Features Across The Offshore ECC
Document no: HOW04GB0066
Created by: BPHB
Checked by: BC
Approved by: LK

Smithic Bank

1.7.6.5 The Joint Nature Conservation Committee (JNCC) identify Smithic Bank as a potential Annex I habitat feature (subtidal sandbank) (JNCC 2017), noting this feature is not presently designated and there are currently no proposals to designate it. The bank extends south from Flamborough Head by over 12 km, with the southern part of the bank crossed by the offshore ECC as well as the Dogger Bank A & B export cables (**Figure 1.10**).

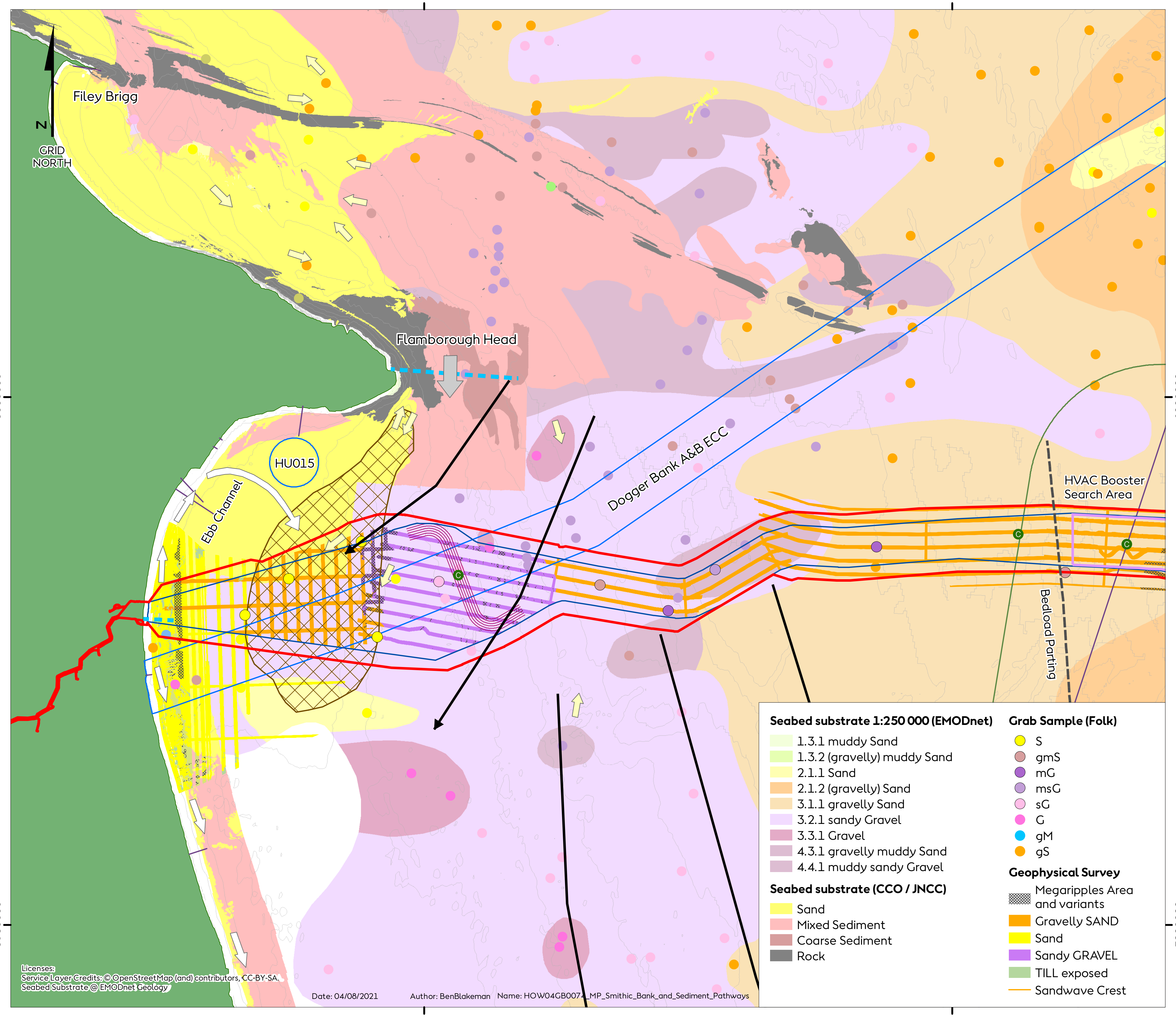
1.7.6.6 The typology for Smithic Bank is a headland-associated banner type bank (HR Wallingford, Cefas/UEA, Posford Haskoning, and D'Olier B. 2002) formed in the lee of Flamborough Head by clockwise tidal gyre); flood tide dominance on the outer flank and ebb tide dominance on the inner flank.

1.7.6.7 The bank is maintained by local sediment supply with cliff erosion from the south is likely to be a primary source of sandy material. This supply is initially transported by northerly longshore drift and ebb tides (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. 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 within a tidal gyre.

1.7.6.8 The bank is shallowest (depths less than 3 m below LAT) towards the northerly inshore flank (North Smithic) 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 (Channel Coastal Observatory (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 more wave exposed southern extents of the bank. The shallow profile of Smithic Bank provides some sheltering to the leeward coastline around Bridlington, especially during periods of stormy waves (Scott Wilson 2010).

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

1.7.6.10 The proposed Dogger Bank A and B export cables also cross Smithic Bank just to the south of the Hornsea Four offshore ECC. Geophysical surveys for this project confirmed sands and gravels across the bank and some areas with active bedform features (ripples and megaripples). Between the bank and the beach the surface layer of Holocene sand is recorded as < 1 m thick and in some places there is exposed glacial till (ForeWind 2013), consistent with the latest geophysical surveys obtained for Hornsea Four.

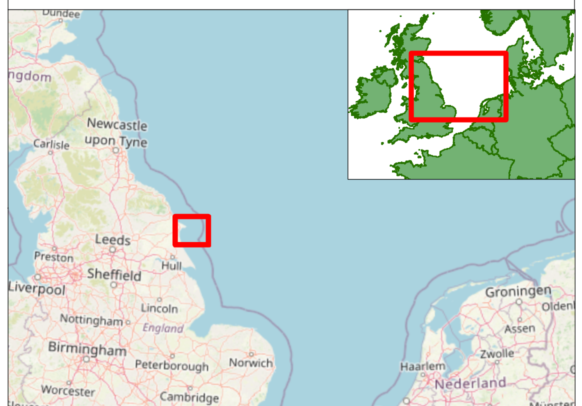


Hornsea Four

Figure 1.10

Smithic Bank and nearshore sediment pathways

- Order Limits
- Offshore Export Cable Corridor
- HVAC Booster Station Works Area
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Indicative Export Cable Route around Dogger Bank A&B ECC
- Existing Licence Areas for Export Cables and Disposal Sites
- One-way Drift Divide
- 5m Contour Intervals
- Regional Bedload Sediment Pathways (Kenyon and Cooper, 2004)
- Smithic Bank
- Direction of net longshore drift
- Sediment Transport Indicators (Derived from SNSSTS, 2002)



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:140,000

0 3 6 Kilometres

0 2 4 Nautical Miles

REV	REMARK	DATE
...	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Sediment Distributions
Sand Transport Pathways
Document no: HOW04GB0067
Created by: BPHB
Checked by: BC
Approved by: LK

GoBe
Ørsted

Cable and Pipeline Crossings

1.7.6.11 **Table 1.7** summarises the locations for cable crossings (of other cables or pipelines) along the offshore ECC shown on **Figure 1.9**. These details exclude a further two locations where there is a section of the offshore ECC within the offshore array area. Where the separation with an adjacent crossing is small then only a single larger crossing is likely to be required to cross multiple assets.

Table 1.7: Summary details for cable crossing locations along the offshore ECC study area.

Easting (m) UTM 31N	Northing (m) UTM 31N	Type of Obstacle	Name	Number of cable crossings	Local depth (m LAT)	Lithology	Comment
301,284	5,993,244	Offshore Wind Export Cables	Dogger Bank Cable	12	21 to 22	sandy gravel	Up to two High Voltage Direct Current (HVDC) cable pairs.
322,502	5,994,805	CO_2 pipeline to Easington	Endurance	6	50	Gravelly sand	In planning
326,617	5,994,417	44" Gas Pipeline	Langeled Pipeline	6	51	gravelly sand	HVAC Booster Station Search Area
347,696	5,987,435	36" Gas Pipeline	Cleeton CP to Dimlington	6	46 to 47	sand	
348,524	5,986,778	5.75" Chemical Pipeline	Cleeton to Minerva Umbilical	18	46 to 47	sand with megaripples	38 m apart
348,554	5,986,754	16" Condensate Pipeline	Minerva to Cleeton Gas Export		46 to 48		0.5 m apart
348,554	5,986,754	3" Chemical Pipeline	Minerva to Cleeton Piggy		46 to 48		
353,135	5,987,079	16" Gas Pipeline	Neptune to Cleeton Pipeline	6	47 to 48	sand with megaripples	
354,833	5,987,442	12" Gas Pipeline	Platypus Pipeline	6	40	sand with megaripples	Due for construction between 2020 and 2022.

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

1.7.7.1 **Table 1.8** summarises the features of interest across the offshore ECC study area.

Table 1.8: Receptor features of interest in the offshore ECC study area.

Receptor	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 Bank morphology. The spoil site also has the potential to act cumulatively during if disposal events of maintenance dredgings from Bridlington occurred in the same period as export cable laying activities in the nearshore region.
Smithic Bank	Impact of storm waves. Insufficient sediment supply / interruption of sediment supply. Long-term increase in mean sea level (due to climate change) reducing sheltering effect to the adjacent section of coastline if bank levels are not sustained within the tidal frame by sufficient sediment supply.
Flamborough Head SAC	Deposition of sediments onto designated features (Annex I reefs).
Pipeline and cable crossings	Local scouring around ends of rock berms where the local seabed demonstrates active seabed mobility. Potential greater level of interaction with waves and flows for the nearshore Dogger Bank A and B crossing.

1.7.8 Existing baseline – offshore array study area

General Description

1.7.8.1 The offshore array area covers 468 km^2 in relatively deep water at a location which is remote from the coast (around 69 km east of Flamborough Head at the closest point). Given the relative close proximity of Hornsea Project One and Hornsea Project Two (around 3.4 km to the south-east at the closet point), the offshore array study area also includes a consideration of these adjacent wind farms which might lead to a potentially larger cumulative blockage effect on waves, flows and sediment pathways due to the presence of foundations on the seabed (**Section 1.12**). A more detailed review of the offshore array study area is provided in Section 3.4 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

Seabed profile

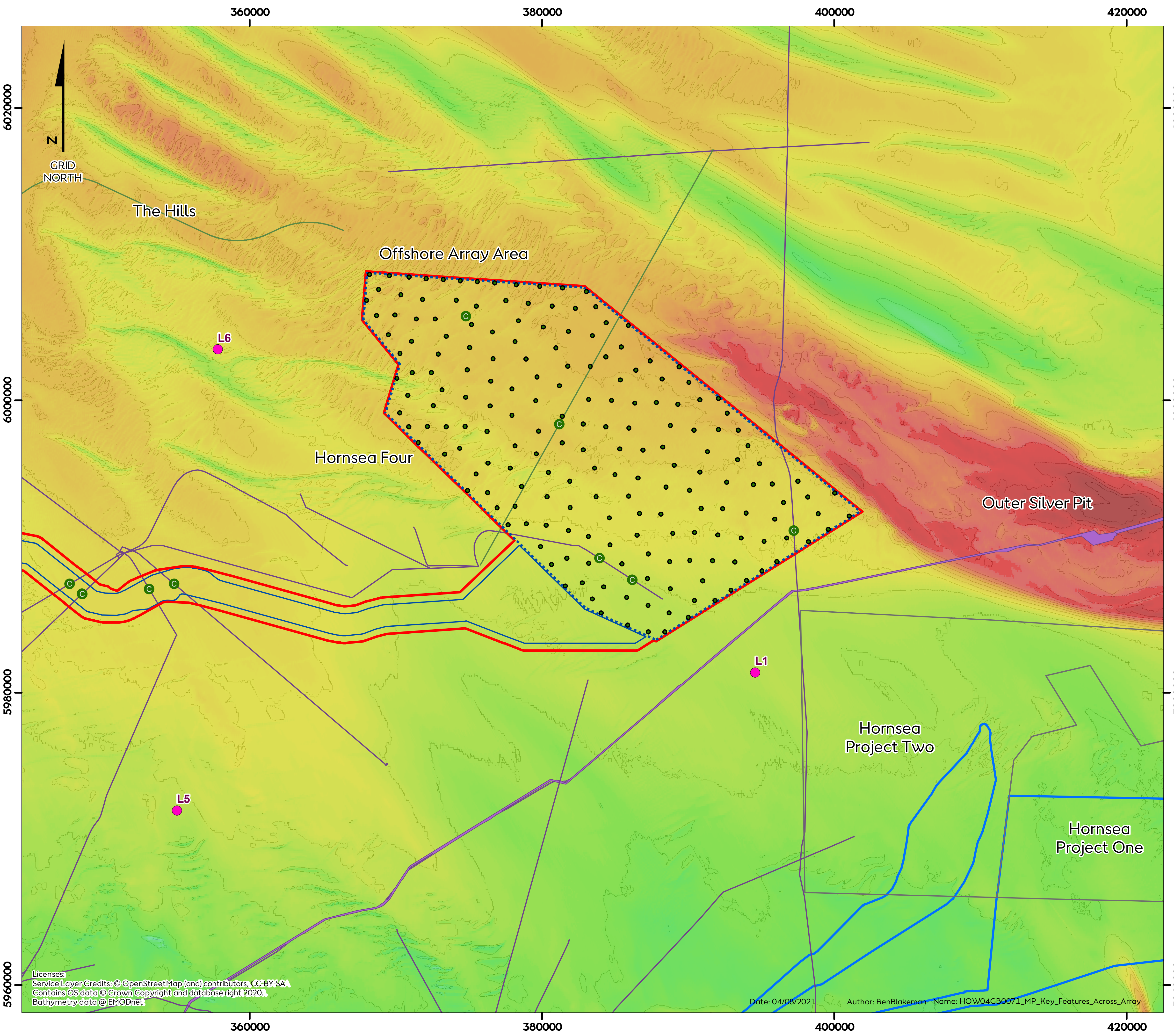
1.7.8.2 The general seabed profile across the offshore array area is relatively deep and shelves from < 40 to 45 m below LAT along the southern boundary to around 50 to 55 m below LAT along the northern boundary. Outer Silver Pit, a large geological "tunnel valley" depression, establishes the north-westerly / south-easterly alignment of the eastern boundary of the offshore array (**Figure 1.11**).

1.7.8.3 The shallowest recorded depth from the geophysical survey is around 34 m below LAT associated with sand ridge feature in the north-western part of the offshore array area. This feature is associated with a larger area of sand ridges and sandbanks to the north and west known as The Hills.

Hornsea Four

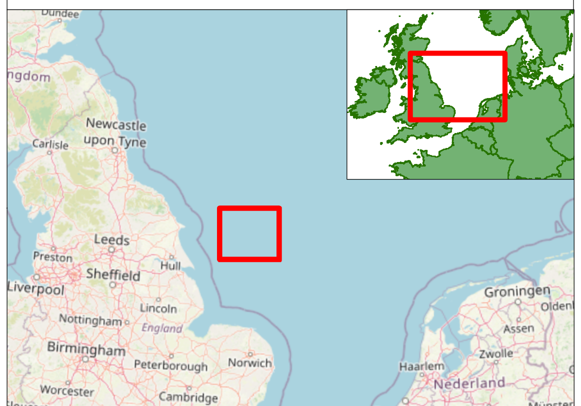
Figure 1.11

Key features across the offshore array study area



Order Limits
Array Area
Offshore Export Cable Corridor
Indicative Turbine Layout
Crossing Point (Offshore)
Existing Pipelines
Proposed Pipelines
Viking Link Cable
Existing Licence Areas for Export Cables and Disposal Sites
Metocean Deployment Sites
5m Contour Intervals

Depth (m below LAT)
0
90



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:250,000

0 5 10 Kilometres

0 2.5 5 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Key Features Across
The Offshore Array Study Area
Document no: HOW04GB0071
Created by: BPHB
Checked by: BC
Approved by: LK

Subtidal sediments

1.7.8.4 Figure 1.12 presents the collated view of seabed lithology across the offshore array area, along with identified sand crests and inferred directions of net sediment transport deduced by sandwave asymmetry. The geophysical survey (Gardline 2019) interprets the seabed lithology as mainly sandy with a few patches of gravelly sand (Holocene sands at the sea surface). There is also an area bordering Outer Silver Pit of gravelly muddy sand . The geophysical survey is largely consistent with the regional scale mapping which provides the generalised interpretation over the wider area.

Sub-bottom profiles

1.7.8.5 An interpretation of sub-bottom profiles across the offshore array area is provided by the geophysical survey (GeoSurveys 2019).

1.7.8.6 The base of the Holocene sands is typically < 1 m thick with local higher deviations across larger bedforms, such as sandwaves and sand ridges (Figure 1.13). Beneath the surface layer of Holocene sands is the firm to stiff clay till of the Bolders Bank Formation (Gardline 2019).

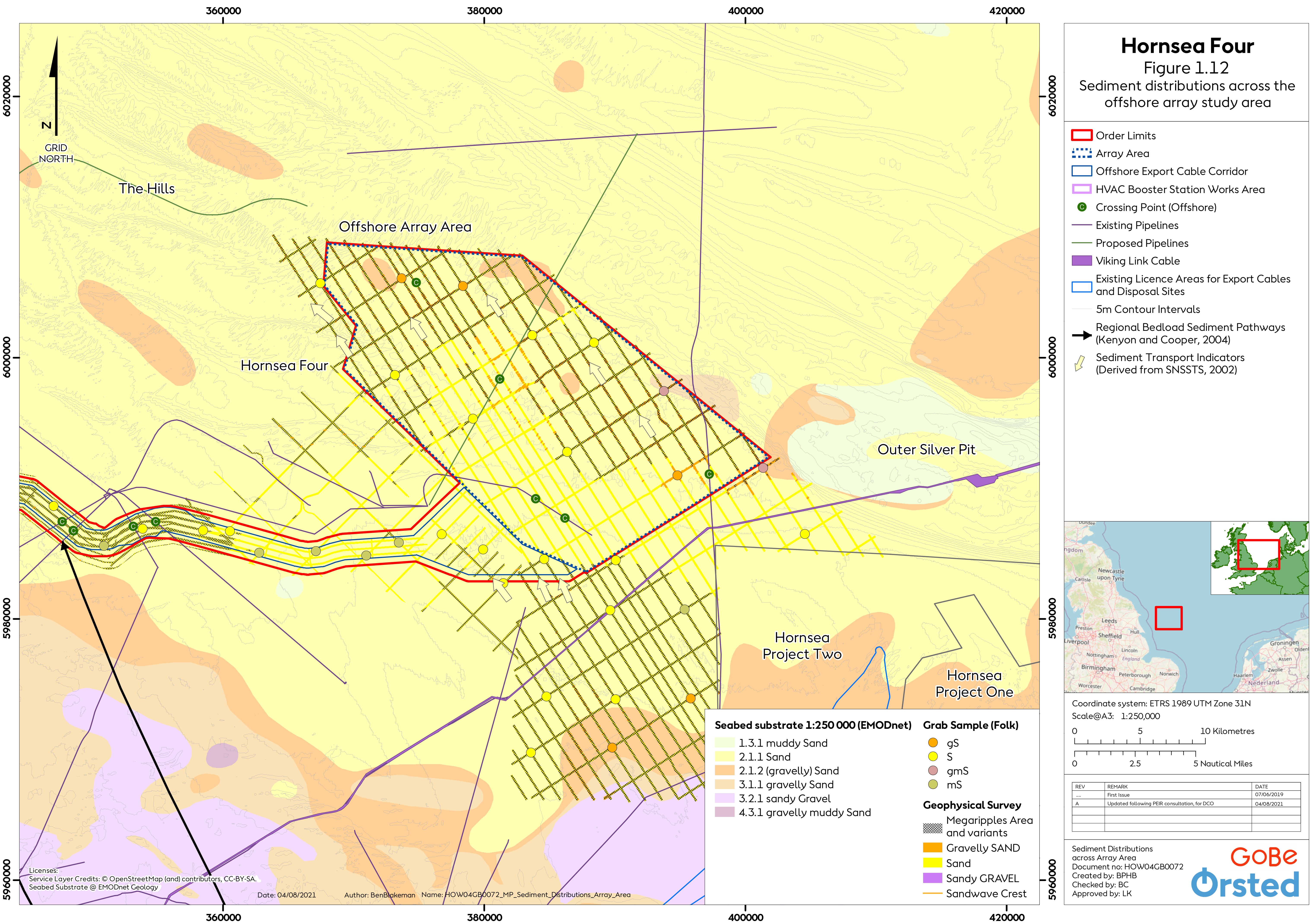
1.7.8.7 The Bolders Bank Formation is present across for the majority of the array area, however, there are instances where this layer becomes very thin and, at times, absent leaving the Holocene sediments directly overlying the Cretaceous Chalk and pre-chalk sediments. Figure 1.14 presents an interpretation of the depth below seabed to the top of the chalk layer along with indicative locations of offshore foundations. Sub-surface chalk appears to be absent in the northern and western parts of the offshore array area, as well as some of the eastern part, but most evident in the central to southern parts with increasing depths below seabed from around 3 to 100 m. For monopiles, the pile depth is up to 40 m, for piled jacket foundations the equivalent pin pile embedment depth would be up to 70 m.

Water levels

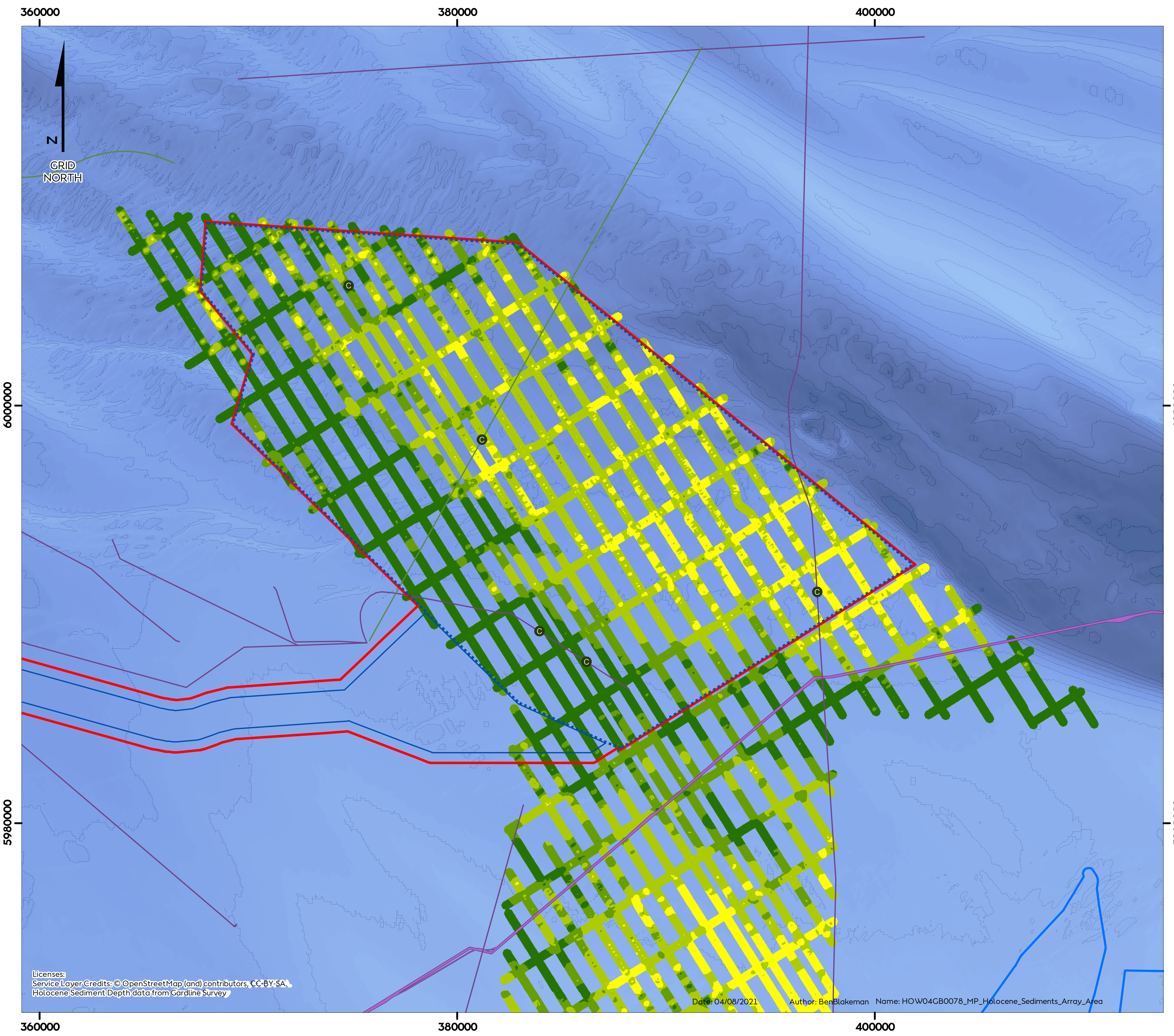
1.7.8.8 Tidal range increases slightly from east to west across the offshore array area due to increasing distance from tidal amphidromes in the Southern North Sea. MSR is around 3.1 m at the easternmost extent increasing to around 3.6 m at the westernmost extent.

Tidal flows

1.7.8.9 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). Flow measurements from Site L1 and tidal mapping from the Atlas of UK Marine Renewable Energy both indicate this magnitude is generally limited to peak flows during spring tides (and larger tidal ranges) (Figure 1.15) and is not attained during neap tides.



Hornsea Four
Figure 1.12
Sediment distributions across the offshore array study area
Order Limits
Array Area
Offshore Export Cable Corridor
HVAC Booster Station Works Area
Crossing Point (Offshore)
Existing Pipelines
Proposed Pipelines
Viking Link Cable
Existing Licence Areas for Export Cables and Disposal Sites
5m Contour Intervals
Regional Bedload Sediment Pathways (Kenyon and Cooper, 2004)
Sediment Transport Indicators (Derived from SNSSTS, 2002)
Seabed substrate 1:250 000 (EMODnet)
1.3.1 muddy Sand
2.1.1 Sand
2.1.2 (gravelly) Sand
3.1.1 gravelly Sand
3.2.1 sandy Gravel
4.3.1 gravelly muddy Sand
Grab Sample (Folk)
gS
S
gmS
mS
Geophysical Survey
Megaripples Area and variants
Gravelly SAND
Sand
Sandy GRAVEL
Sandwave Crest
N
GRID NORTH
The Hills
Offshore Array Area
Hornsea Four
Outer Silver Pit
Hornsea Project Two
Hornsea Project One
C
360000
380000
400000
420000
6020000
6000000
5980000
5960000
Newcastle upon Tyne
Leeds
Sheffield
Hull
Liverpool
Birmingham
Peterborough
Norwich
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:250,000
0 5 10 Kilometres
0 2.5 5 Nautical Miles
REV | REMARK | DATE
.... | First Issue | 07/06/2019
A | Updated following PEIR consultation, for DCO | 04/08/2021
Sediment Distributions across Array Area
Document no: HOW04GB0072
Created by: BPHB
Checked by: BC
Approved by: LK
Licenses:
Service Layer Credits: © OpenStreetMap (and) contributors, CC-BY-SA.
Seabed Substrate @ EMODnet Geology
Date: 04/08/2021
Author: BenBlakeman
Name: HOW04GB0072_MP_Sediment_Distributions_Array_Area



Hornsea Four

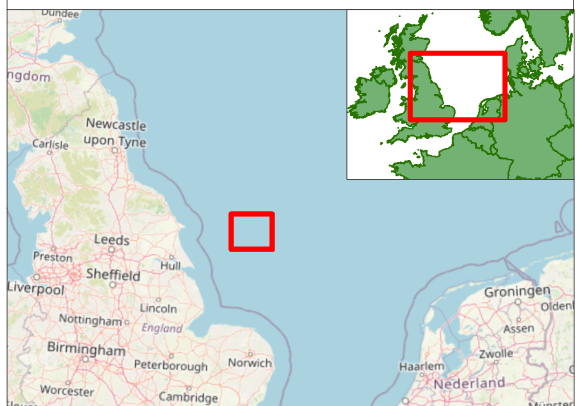
Figure 1.13

Depth below seabed to base of Holocene sediments

Order Limits
Array Area
Offshore Export Cable Corridor
Crossing Point (Offshore)
Existing Pipelines
Proposed Pipelines
Viking Link Cable
Existing Licence Areas for Export Cables and Disposal Sites
5m Contour Intervals

Depth of Holocene Sediment (metres below sea bed)
27
0

Depth (m below LAT)
15
80



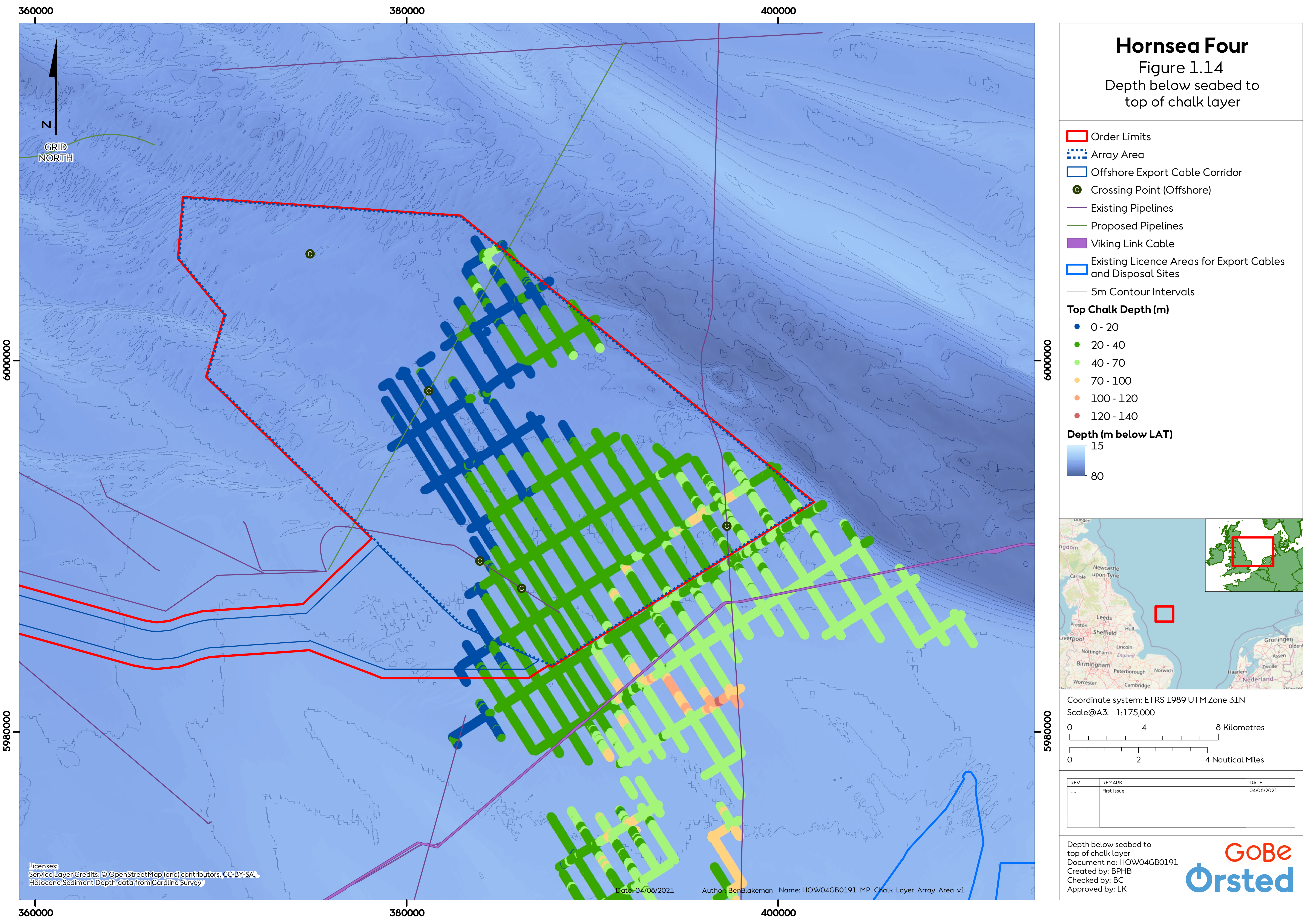
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:175,000

0 4 8 Kilometres
0 2 4 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Isopach Depths of Holocene Sediment Offshore Array
Document no: HOW04GB0078
Created by: BPHB
Checked by: BC
Approved by: LK

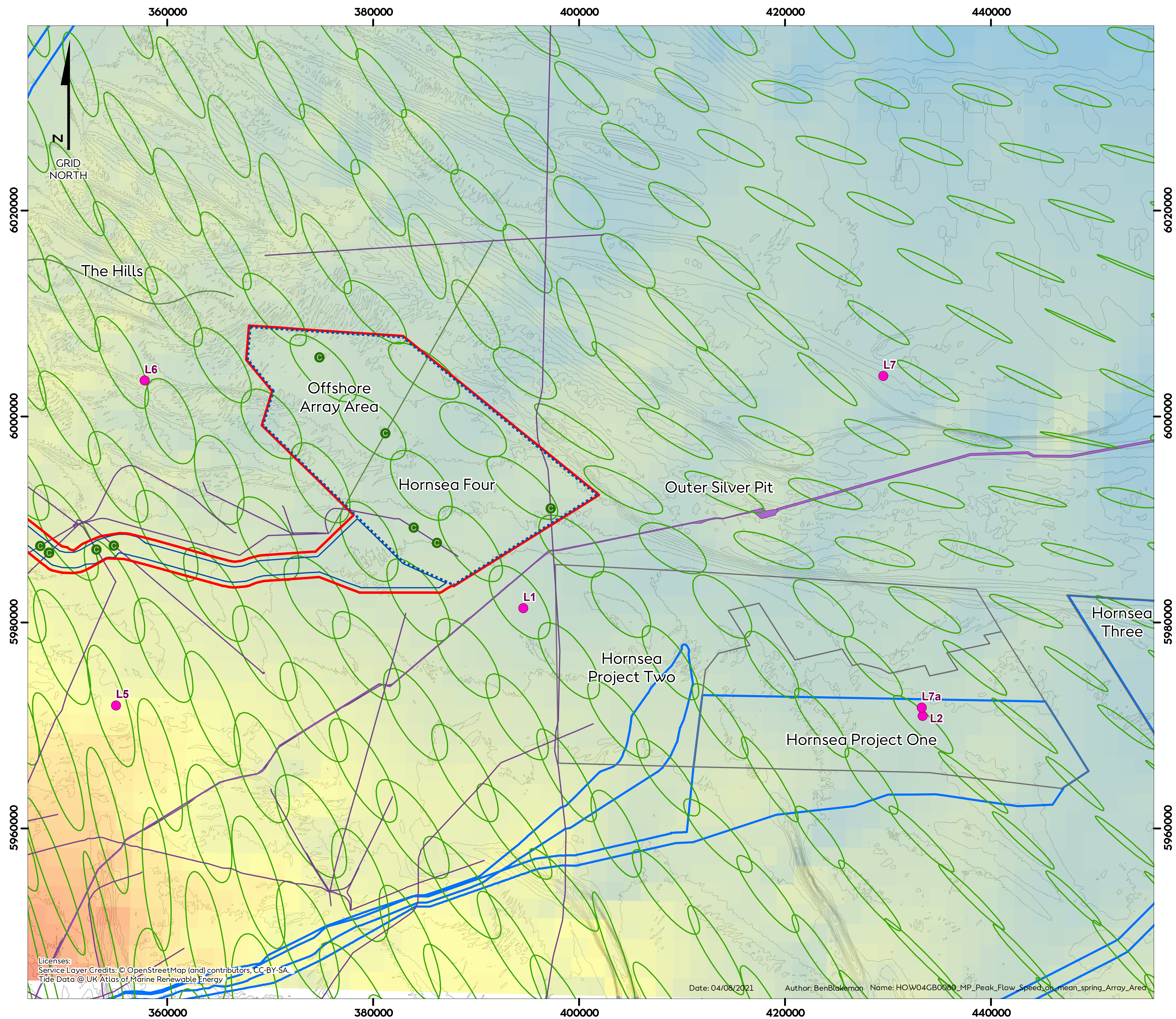
GoBe
Ørsted


Hornsea Four
Figure 1.14
Depth below seabed to top of chalk layer
Order Limits
Array Area
Offshore Export Cable Corridor
Crossing Point (Offshore)
Existing Pipelines
Proposed Pipelines
Viking Link Cable
Existing Licence Areas for Export Cables and Disposal Sites
5m Contour Intervals
Top Chalk Depth (m)
0 - 20
20 - 40
40 - 70
70 - 100
100 - 120
120 - 140
Depth (m below LAT)
15
80
360000
380000
400000
6000000
5980000
GRID NORTH
N
Newcastle upon Tyne
Carlisle
Leeds
Preston
Sheffield
Hull
Liverpool
Lincoln
Nottingham
England
Birmingham
Peterborough
Norwich
Worcester
Cambridge
Groningen
Assen
Zwolle
Haarlem
Nederland
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:175,000
0 4 8 Kilometres
0 2 4 Nautical Miles
REV
REMARK
DATE
First Issue
04/08/2021
Licenses:
Service Layer Credits: © OpenStreetMap (and) contributors, CC-BY-SA
Holocene Sediment Depth data from Gardline Survey
Date: 04/08/2021
Author: Ben Blakeman
Name: HOW04GB0191_MP_Chalk_Layer_Array_Area_v1
Depth below seabed to top of chalk layer
Document no: HOW04GB0191
Created by: BPHB
Checked by: BC
Approved by: LK
GoBe
Ørsted

Hornsea Four

Figure 1.15

Peak flow speed on mean spring across offshore array study area (with orientation of tidal ellipse)

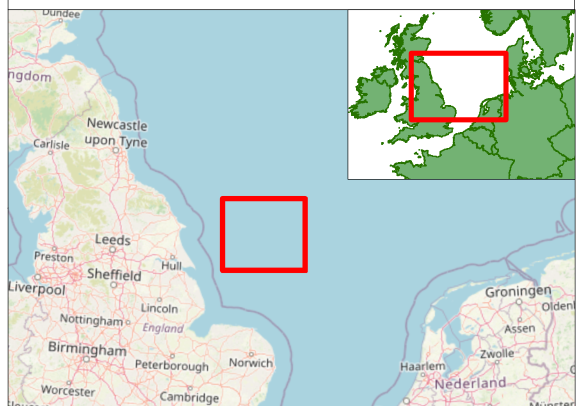


- Order Limits
- Array Area
- Offshore Export Cable Corridor
- Crossing Point (Offshore)
- Existing Pipelines
- Proposed Pipelines
- Viking Link Cable
- Existing Licence Areas for Export Cables and Disposal Sites
- Metocean Deployment Sites
- 5m Contour Intervals
- Spring Tidal Ellipses

Peak Flows (m/s)

1.48

0.31



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:350,000

0 5 10 Kilometres

0 5 10 Nautical Miles

REV	REMARK	DATE
....	First Issue	07/06/2019
A	Updated following PEIR consultation, for DCO	04/08/2021

Peak Flow Speed on Mean Spring Across Offshore Array Area

Document no: HOW04GB0080

Created by: BPHB

Checked by: BC

Approved by: LK

Waves

1.7.8.10 An assessment of an annual period of waves measured just to the south of the offshore array area (Site L1 shown on **Figure 1.15**) indicated that even the largest events are incapable of developing a near bed orbital flow of sufficient magnitude to stir the seabed sediments. This means that sediment transport across the offshore array area is mainly driven by peak tidal currents during spring tides, with the possible additional and infrequent influence of storm surge currents.

Bedload sediment transport pathways

1.7.8.11 Sandwave crests are resolved from the geophysical survey across the majority of the offshore array apart from the southerly region (Gardline 2019). These crests are aligned perpendicular to tidal flows (**Figure 1.12**). The asymmetric cross-section of sandwaves suggests a net transport direction in a north-westerly direction driven by a flood dominant tidal flow.

Suspended particulate matter

1.7.8.12 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.

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

Cables and Pipelines

1.7.9.1 Due to sections of the Johnston Field Extension (JFE) and Shearwater to Bacton (Shearwater Elgin Area Line - SEAL) gas pipelines being present within the offshore array area, as well as two new proposed pipelines, there is provision for up to 32 cable crossings (**Volume A4, Annex 4.1: Offshore Crossing Schedule**). These crossings would be in relatively deep water (> 40 m) and on a sandy seabed (**Figure 1.12**).

Flamborough Front

1.7.9.2 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. 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. The front gives rise to nutrient-rich water, increased primary production and fisheries providing a feeding ground for birds (English Nature 2004).

1.7.9.3 The offshore array area is located north of the Flamborough Front when this seasonal feature develops.

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

1.7.10.1 Table 1.9 summarises the key receptor features of interest associated with the offshore array area along with the potential sensitivity of each feature.

Table 1.9: Receptor features of interest in the offshore array area.

Receptor	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**

1.7.11 Predicted future baseline

1.7.11.1 The current baseline description above provides an accurate reflection of the state of the existing environment. The earliest possible date for the start of construction (onshore) is August 2026, with an expected operational life of 35 years, and therefore there exists the potential for the baseline to evolve between the time of assessment and point of impact. Outside of short-term or seasonal fluctuations, changes to the baseline in relation to Marine Processes usually occur over an extended period of time (considered in the sections below). Based on current information regarding reasonably foreseeable events over the next six years, the baseline is not anticipated to have fundamentally changed from its current state at the point in time when impacts occur. The baseline environment for operational / decommissioning impacts is expected to evolve as described in the next sections, with the additional consideration that any changes during the construction phase will have only locally modified the baseline environment (as set out in this chapter).

1.7.11.2 The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 require that "an outline of the likely evolution thereof without implementation of the development as far as natural changes from the baseline scenario can be assessed with reasonable effort on the basis of the availability of environmental information and scientific knowledge" is included within the ES (EIA Regulations, Schedule 4, Paragraph 3). From the point of assessment, over the course of the development and operational lifetime of Hornsea Four (operational lifetime anticipated to be 35 years), long-term trends mean that the condition of the baseline environment is expected to evolve. The following sections provide a qualitative description of the evolution of the baseline environment, on the assumption that Hornsea Four is not constructed, using available information and scientific knowledge of marine processes.

Climate change

1.7.11.3 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 climate change projections are provided by United Kingdom Climate Projections 2018 (UKCP18), along with their marine report (Palmer et al. 2018). These projections are drawn together as an ensemble from different models which may also show contrasting results. The main marine process parameters from UKCP18 of interest are:

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

Sea level rise

1.7.11.4 Over the 35-year operational period of the project, mean sea level is expected to slightly increase. UKCP18 provides climate projections for sea level rise up to the year 2100 based on different emission scenarios described as 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 (average annual rates of sea level rise of 4 to 6 mm/year)

Skew surge

1.7.11.5 A skew surge is the difference between the maximum observed water level and the maximum predicted tidal level regardless of the relative 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 any change in extreme sea levels during this period would most likely be a product of changes in mean sea level.

Waves

1.7.11.6 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.

1.7.11.7 **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 height values.

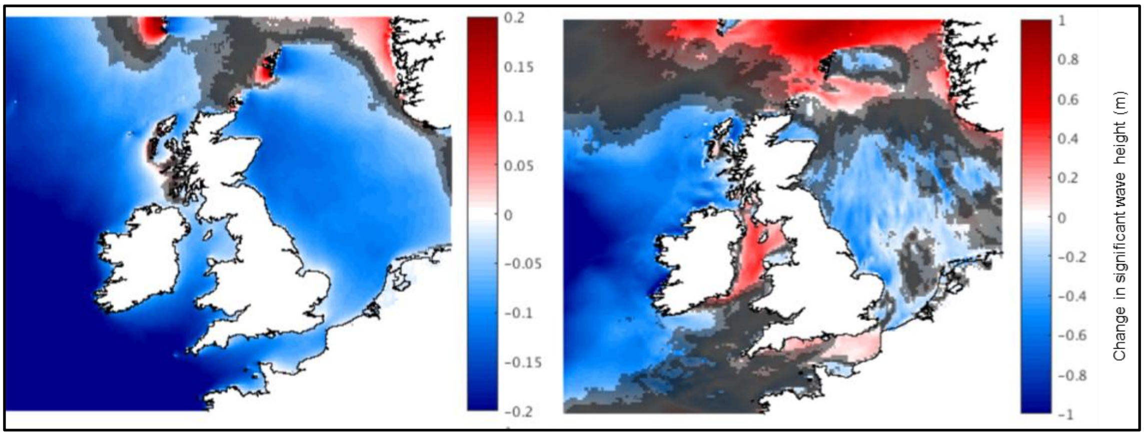


Figure 1.16: Projected change in mean significant wave height at end of 21st Century for (left) mean significant wave height and (right) annual maxima (Palmer et al. 2018).

Isostatic Rebound

1.7.11.8 In addition to climate change, isostatic (glacial) rebound from the last Ice-Age continues to adjust some land and seabed levels. The southern part of the UK is 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.

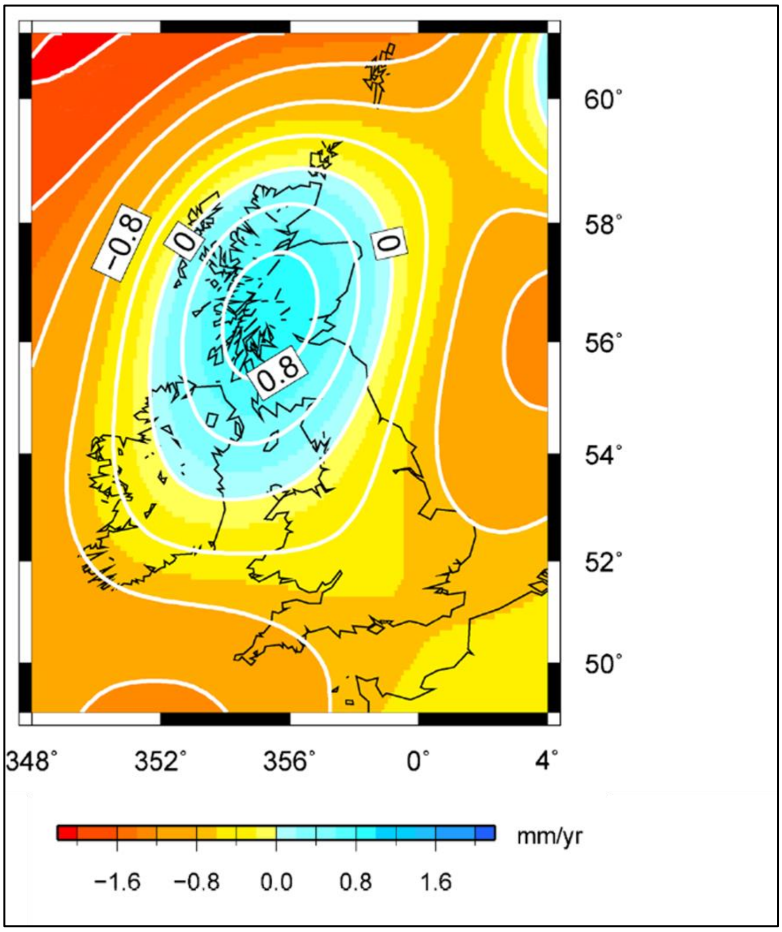


Figure 1.17: Predicted isostatic uplift rate (Bradley et al. 2011).

Likely response to relative sea level rise

1.7.11.9 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.

1.7.11.10 Any increase to Mean Sea Level (MSL) in the future would expect to increase the rate of coastal erosion[1] since the position of a higher mean sea level would translate landwards with a corresponding shift 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 over the medium-term (next 20 to 50 years) of around 82 m, even before increased rates of sea level rise are

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

considered.

1.7.11.11 Over the long-term any increase in mean sea level also has the potential to place the vertical profile of Smithic Bank 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 led to increased sediment supply to the bank, then the profile may be able to be maintained in a new dynamic equilibrium.

1.7.12 Data Limitations

1.7.12.1 Appendix B of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a list of the key data and information collated to inform the baseline understanding of Hornsea Four. The data comprises full regional coverage drawn from existing publications along with local validation from surveys performed across the landfall, offshore ECC and offshore array areas. These surveys include geophysical and metocean data collected for the former Hornsea Zone as well as recent geophysical surveys specifically provided for Hornsea Four (Gardline 2019 and Bibby HydroMap 2019).

1.7.12.2 The recent geophysical survey (Gardline 2019 and Bibby HydroMap 2019) offers less than 100 % site coverage which introduces a partial limitation. For example, some small scale features such as sandwaves may fall between survey lines or may only be partially resolved, especially if the alignment of the feature is oblique to the survey lines.

1.7.12.3 Particle size information from grab samples describes surficial sediments typically to depths below seabed of around 0.1 m (i.e. the penetration depth of grab). The application of this data (e.g. to removal of sediment volumes over depth due to trenching, etc.) generally assumes sediment gradings remain consistent over depth. This is considered a fair assumption in most cases unless the depth of the surface layer of sediments is assessed to be less than the depth of excavation.

1.7.12.4 An understanding of the long-term behaviour of Smithic Bank is limited by a lack of routine historical surveys. The sandbank is recognised as a morphologically active feature dynamically linked to surrounding sediment sources and pathways.

1.8 Project Basis for Assessment

1.8.1 Source-Pathway-Receptor

1.8.1.1 The assessment of 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 **Volume A1, Chapter 4: Project Description**;
- Pathway (impact) – 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 other cases the receptor may be 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 1.10**. These issues are identified as impact pathways and receptors and can be grouped by project phase and type of effect as either:

- Short-term and localised sediment disturbance events during construction, maintenance and decommissioning periods which may lead to sediment plumes (risk of increased turbidity) and the subsequent settlement on the seabed (risk of smothering); or
- Long-term (decadal) blockage related effects during the operational period of the wind farm which are due to an array of foundations 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 1.10: 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 LSOs
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 LSOs
Construction	Blockage of flows causing local (near-field) scouring around foundations (assumes scour protection is not pre-installed).	The coastline (related to nearshore cofferdams)
Operation	Blockage of flows from foundations leading to increased turbulence interfering with far-field receptors.	Flamborough Front
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.	Holderness Coast and soft cliffs Smithic Bank
Operation	Blockage to nearshore sediment pathways from installed rock armour over cables, plus additional rock armour provisions to address maintenance requirements.	Smithic Bank
Decommissioning	Sediment disturbance during decommissioning activities that may lead to locally raised suspended sediment concentrations at source.	Bridlington Harbour Spoil ground HU015 LSO
Decommissioning	Removal of foundations with cessation of blockage related effects on waves and tidal flows, reversing to a (future) baseline condition.	Holderness Coast and soft cliffs Smithic Bank

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 **Chapter 2: Benthic and Intertidal Ecology**, **Chapter 3: Fish and Shellfish Ecology**, **Chapter 4: Marine Mammals**, **Chapter 9: Marine Archaeology**, and **Chapter 11: Infrastructure and Other Users**, as appropriate.

1.8.2 Impact Register and Impacts Not Considered in Detail in this ES

1.8.2.1 Upon consideration of the baseline environment, the project description outlined in **Volume A1, Chapter 4: Project Description**, the Hornsea Four Commitments detailed within **Volume A4, Annex 5.2: Commitments Register**, and in response to formal consultation on the PEIR), a number of impacts are "not considered in detail" in the ES. All impacts assessed within the PEIR for marine processes have been further considered in the ES, with no impacts falling into the category "not considered in detail in the ES". **Table 1.11** details impacts that were agreed to be scoped out during the Scoping phase. Further detail is provided in the Impacts Register in **Volume A4, Annex 5.1: Impacts Register**.

1.8.2.2 In July 2019, Highways England issued an update to the Design Manual for Roads and Bridges (DMRB) significance matrix (see **Volume A1, Chapter 5: Environmental Impact Assessment Methodology**). Impacts resulting in effects on marine processes that were formerly assessed within the category medium sensitivity and minor magnitude, as Minor (Not Significant), under the new guidance are now within the significance range of Slight or Moderate and, therefore, require professional judgement. Following a review of the relevant potential impacts, it was considered that the changes do not alter the overall significance of the effects assessed at Scoping and in the PEIR (see **Volume A4, Annex 5.1: Impacts Register**).

Table 1.11: 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)	No likely significant effect	Scoped Out	Scoped out based on PINS Scoping Opinion (PINS Scoping Opinion, November 2018, ID: 4.1.2) Given the anticipated localised nature of the changes in tidal currents and waves for Hornsea Four, there is expected to be no local or regional changes in the sediment transport regime. Furthermore, Hornsea Four is situated updrift of the net sediment pathway related to the Norfolk Banks SAC.

Notes:
Grey – Scoped Out – Agreement reached between the Applicant and the Planning Inspectorate at Scoping.

1.8.2.3 Please note that the term "scoped out" in **Table 1.11** 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 A4, Annex 5.1: Impacts Register**). This approach is aligned with the Hornsea Four Proportionate approach to EIA (see **Volume A1, Chapter 5: EIA Methodology**).

1.8.3 Commitments

1.8.3.1 Hornsea Four has adopted commitments (primary design principles inherent as part of Hornsea Four, installation techniques and engineering designs/modifications) as part of their pre-application phase, to eliminate and/or reduce the likely significant effect (LSE) arising from a number of impacts (as far as possible). These are outlined in **Volume A4, Annex 5.2 Commitments Register**. Further commitments (adoption of best practice guidance), referred to as tertiary commitments are embedded as an inherent aspect of the EIA process. Secondary commitments are incorporated to reduce LSE to environmentally acceptable levels following initial assessment, i.e. so that residual effects are reduced to environmentally acceptable levels.

1.8.3.2 The commitments adopted by Hornsea Four in relation to marine processes are presented in **Table 1.12**. The full list of Commitments can be found in **Volume A4, Annex 5.2: Commitments Register**.

Table 1.12: Relevant marine processes commitments.

Commitment ID	Measure Proposed	How the measure will be secured
Co2	Primary: A range of sensitive historical, cultural and ecological conservation areas (including statutory and non-statutory designations) have been directly avoided by the permanent Hornsea Four footprint, at the point of Development Consent Order Submission (DCO). These include, but are not restricted to: Listed Buildings (564 sites); Scheduled Monuments (30 sites); Registered Parks and Gardens (Thwaite Hall and Risby Hall); Onshore Conservation Areas (18 sites); Onshore National Site Network (one site); Offshore National Site Network (three sites); Offshore Marine Conservation Zones (two sites); Sites of Special Scientific Interest (two sites); Local Nature Reserves (none have been identified); Local Wildlife sites (33 sites); Yorkshire Wildlife Trust Reserves (none have been identified); Royal Society for the Protection of Birds (RSPB) Reserves (none have been identified); Heritage Coast; National Trust land; Ancient Woodland (10 sites and known Tree Preservation Orders (TPOs)); non-designated built heritage assets (334 sites); and historic landfill (none have been identified). Where possible, unprotected areas of woodland, mature and protected trees (i.e. veteran trees) have and will also be avoided.	DCO Works Plan - Onshore; and DCO Works Plan - Offshore
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 Works Plan – Offshore (**Volume D1, Annex 4.1: Works Plan – Offshore**)
Co45	Primary: The Holderness Offshore MCZ will not be crossed by the offshore export cable corridor including the associated temporary works area.	DCO Works Plan – Offshore (**Volume D1, Annex 4.1: Works Plan – Offshore**)
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 13(1)(e) and; DCO Schedule 12, Part 2 - Condition 13(1)(e)

Commitment ID	Measure Proposed	How the measure will be secured
		(Scour Protection Management Plan)
Co83	Primary: Where possible, cable burial will be the preferred option for cable protection.	DCO Schedule 11, Part 2 - Condition 13(1)(h) and; DCO Schedule 12, Part 2 - Condition 13(1)(h) (Cable Specification and Installation Plan)
Co181	Tertiary: An Offshore Decommissioning Plan will be developed prior to decommissioning.	DCO Schedule 11, Part 1(6) and; DCO Schedule 12, Part 1(6) (General Provisions)
Co187	Secondary: The installation of the offshore export cables at landfall will be undertaken by Horizontal Directional Drilling (HDD) or other trenchless methods.	DCO Requirement 17 (Code of Construction Practice)
Co188	Secondary: No cable protection will be employed within 350 m seaward of mean low water springs (MLWS).	DCO Schedule 11, Part 2 - Condition 13(1)(h) and; DCO Schedule 12, Part 2 - Condition 13(1)(h) (Cable Specification and Installation Plan)
Co189	Secondary: The Dogger Bank cable crossing will be positioned east of Smithic Bank (as identified at https://data.gov.uk/dataset/d19f631c-27c0-4c74-804f-d76a4632b702/annex-i-sandbanks-in-the-uk-v2-public) and seaward of 20 m depth contour.	DCO Schedule 11, Part 2 - Condition 13(1)(h) and; DCO Schedule 12, Part 2 - Condition 13(1)(h) (Cable Specification and Installation Plan)
Co201	Gravity Base Structure (GBS) foundations will be utilised at a maximum of 110 foundation locations. The location of GBS foundations will be confirmed through a construction method statement which will include details of foundation installation methodology.	DCO Schedule 11, Part 2 - Condition 13(1(c) (Construction Method Statement)

1.9 Maximum Design Scenario (MDS)

1.9.1.1 This section describes the MDS parameters on which the marine processes assessment has been based. These are the parameters which are judged to give rise to the maximum levels of effect for the assessment undertaken, as set out in **Volume A1, Chapter 4: Project Description**. Should Hornsea Four be constructed to different parameters within the design envelope, then impacts would not be any greater than those set out in this ES using the MDS presented in **Table 1.13**.

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 (risk of increased turbidity) and subsequent deposition (smothering risk on seabed receptors). These activities include:

- Seabed levelling for foundations;
- Sandwave clearance for cable installation;
- Cable installation, including jointing pits;
- Inshore HDD exit pits, with the potential use of cofferdams and possibility of bentonite spills;
- Drilling for foundation piles; and
- Spoil disposal.

In addition, the construction phase also includes a temporary beach access ramp to cross from the top of the cliff onto the beach. The main consideration related to this activity is the potential risk to the stability of the cliff edge, noting the Holderness cliffs are relatively soft and easily eroded. The likely arrangement for the beach access ramp is a relatively narrow, single track, device which is only in place for a short period during the construction of HDD exit pits (around 36 months). Sandbags placed onto the beach would take the weight of vehicles rather than the cliff edge. The toe of the ramp is expected to remain above mean high water and not interfere with any beach processes. When removed there is not expected to be any lasting damage to the cliff. Further details about the arrangement of the beach access ramp are provided in Section 4.9 of **Volume A1, Chapter 4: Project Description**. No further impact assessment is considered necessary.

1.9.3 MDS for Operation Phase

1.9.3.1 During operation of the wind farm (the longest phase of the development, expected to be around 35 years) the main consideration for marine processes is persistent 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 foundations).

1.9.3.2 Blockage effects formed by individual structures can manifest as local-scale flow and wave related wakes (retardation of flows with increased turbulence, 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 drift.

1.9.3.3 The MDS for any array-scale 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, such as cable repairs and re-burial requirements, which have the potential to create short-term

[2] **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).

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 1.13 provides details of the MDS options for marine processes.

Table 1.13: MDS for impacts on marine processes.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
Construction			
Seabed preparation activities (MP-C-1) Seabed preparation activities (levelling, sandwave clearance, cable jointing pits, etc.) which may lead to a requirement for spoil disposal elsewhere creating elevated suspended sediment and potential smothering by deposition.	**Primary:** Co44 Co45 **Secondary:** Co188 Co189	**Landfall area** Up to eight offshore HDD exit pits (noting up to three will be open at any time for up to three months), each requiring excavation of 2,500 m^3 which will be side-cast onto the adjacent seabed. Backfilling of exit pits will recover a similar amount of material 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 for six export cables. **Cable jointing pits** – Up to four joints per export cable (maximum of 24 jointing pits for six export cables), each pit excavated to 5 m over an area of 3,500 m^2 and producing 17,500 m^3 of sediment for removal, a total of 420,000 m^3 for all pits, with a provision for 50 % of losses to be made up **HVAC booster station foundations -** Seabed preparation for three six-legged Suction Bucket Jacket foundations requires removal of 171,735 m^3 for three HVAC booster station foundations. **Total spoil in offshore ECC area = 1,348,735 m^3** **Offshore array area** **Sandwave clearance** –Total sandwave clearance of 961,000 m^3 which includes 77,000 m^3 10 km of export cable within the offshore array area. **180 WTG foundations -** Seabed preparation for WTG foundations requires removal of 1,045,221 m^3. **Nine Offshore Substation (OSS) foundations -** Seabed preparation for six Suction Bucket Jacket (Small OSS) & three GBS (Large OSS) requires removal of 737,130 m^3 of spoil for nine OSS foundations.	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. There may be up to two TSHD operating on site at any time. It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however, in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three,

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		Offshore accommodation platform foundation - Seabed preparation for Suction Bucket Jacket (Small OSS) requires removal of 57,245 m^3 of spoil for a single offshore accommodation platform foundation. **Total spoil in offshore array area = 2,800,596 m^3**	respectively). As a result, the outcome of the assessment is therefore inherently conservative and precautionary.
Seabed installation activities (MP-C-2) All direct sediment disturbance activities that may lead to locally raised suspended sediment concentrations at source (e.g. drilling, cable trenching, etc).	**Primary:** Co44 Co45 **Secondary:** Co187 Co188	**Landfall area** Depending on the configuration of the HDD Exit Pits, the use of cofferdams and the design of a drilling fluid management system there remains a residual risk for drilling muds (e.g. bentonite) to be discharged into the marine environment at break-out. The maximum estimated spill volume is 265 m^3 per HDD Exit Pit and a total of 2,120 m^3 (eight pits). **Offshore ECC** **Cable trenching** – Cable installation along a length of 109 km for up to six cables releasing 3,903,000 m^3 into suspension by a Controlled Flow Excavator (CFE). 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 station foundations** – Drilling for Piled Jacket (Small OSS) foundation option, releasing 4,618 m^3 for three foundations, representing 10 % (of depth). **Offshore array area** **Cable trenching** - Cable installation along a length of 600 km for array and interconnector cables and 90 km for interconnector cables releasing 4,140,000 m^3 into suspension by CFE. Fastest excavation rate of 300 m/hr in soft soils. Single trenching vessel assumed for a sequential activity. **Drilling of WTG foundations** – Drilling for monopile foundation option, 127,234 m^3 for 18 foundations, representing 10 % (of all WTGs). **Drilling of nine OSS foundations** – Drilling for six Piled Jacket (Small OSS) & three Piled Jacket (Large OSS), 13,854 m^3 for nine foundations, representing 10% (of depth).	All direct sediment disturbance activities that may lead to locally raised suspended 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. CFE 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. It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including**

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		Drilling of offshore accommodation platform foundation - Drilling for Piled Jacket (Small OSS), 1,540 m^3 for one foundation, representing 10% (of depth). **Total drill arisings in offshore array area = 142,629 m^3** Up to two drilling rigs will be available meaning any drilling activities across the offshore array area can be active at two sites at the same time.	**Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently conservative and precautionary.
Scouring around foundations (MP-C-3)	**Tertiary:** Co82	**Offshore ECC** **HVAC booster station foundations** – Risk for scouring in pre-scour protection period around three 75 m wide GBS (Box-type) foundations. A minimum separation distance between foundations of 100 m may lead to group scour between adjacent structures for any areas without scour protection. **Offshore array area** **180 WTG foundations** – up to 110 GBS plus 70 monopile foundations (based on the second largest provisions for scour protection). **Nine OSS foundations** – Three 150 m wide GBS (Large OSS) and six 75 m wide GBS (Box-type). **Offshore accommodation platform foundation** – 75 m wide GBS (Box-type).	Installed foundations may lead to local scouring around their base if scour protection has not already pre-armoured the seabed. Depending on the 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 is expected to develop the most amount of scour, rather than the greatest depth of scour. To note, three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
			single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently precautionary.
Turbulent wakes around scouring around cofferdams (MP-C-4)	**Secondary:** Co187	**Landfall** Inshore temporary cofferdams 18 m wide (long-shore) and 50 m long (cross-shore) to enclose HDD exit pits (up to 900 m^2), separated by a minimum of 50 m in a shore parallel configuration. Up to three cofferdams in place at any time for up to three months for up to eight cofferdams in total (HVDC option). Groups of up to three cofferdams have the potential to form wakes in their lee over the period of installation.	Temporary cofferdams may lead to local blockage effects in the landfall area, interrupting local flows and waves which may also lead to local scouring around their base, subject to the erodibility of the seabed. Closely spaced cofferdams may also lead to interaction of wakes and develop group scour.
Operation			
Scouring around cable protection (MP-O-1)	**Secondary:** Co188 Co189 **Tertiary:** Co82	**Offshore ECC** **Rock berms at nearshore cable crossing** – Up to six export cables (HVAC option) from Hornsea Four will cross the export cables (up to two pairs of cables) of Dogger Bank A and B (12 crossings) at a location seaward of Smithic Bank to form the largest overall crossing. **Rock berms at offshore cable crossings along ECC** – seven additional locations with up to 42 crossings (excluding locations within offshore array area).	Sub-sea structures which have a profile proud of the seabed (e.g. rock berms), may lead to local scouring around their base. Depending on the seabed material, the scouring process may erode material into bedload and/or suspended load transport until an equilibrium condition is reached.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		Total of 54 crossing at eight locations along ECC (excluding locations within offshore array area) with rock berm volume of 372,000 m^3. **<u>Offshore array area</u>** **Rock berms at cable crossings** – up to 32 array cable crossings (total rock berm volume of 221,000 m^3) plus two further locations for sections of offshore ECC within the offshore array area All cable crossings up to 3 m in height (0.3 m pre-lay plus 2.7 m rock berm) where protection is required from anchors using rock up to 0.5 m in diameter. **Total volume for all rock berms 593,000 m^3** (with provisions for 25 % replenishment during operation period, if required). **<u>Cable protection</u>** A provision to use cable protection for up to 10 % of the length of all cables for locations which do not achieve full burial depths (excluding inshore area).. Offshore ECC: 849,000 m^3 Offshore Array: 600,000 m^3 **Total volume: 1,449,000 m^3**	Rock berms target known locations which require a cable crossing whereas general cable protection is a provision to manage any locations where cable burial depths are not achieved or where cable repairs need additional protection.
Turbulent wakes from foundations interfering with remote receptors, e.g. Flamborough Front (MP-O-2)	N/A	**<u>Offshore ECC</u>** **HVAC booster station foundations** – Largest solid structure in the vertical plane (for blockage type effects) 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 all three structures. A minimum separation distance of 100 m between foundations is likely to result in wake-wake interactions and a larger cumulative effect between all three structures. **Rock berms** – Minimal vertical profile with all in water depths between 40 to 50 m below LAT. 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). Rock berms in deeper water are unlikely to have sufficient vertical profile to develop wakes, however, if

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 53 m diameter base conical shaped GBS (WTG-type), limit of up to 110 units. The next largest MDS foundation for blockage is the mono-suction bucket which has a base diameter of up to 40 m with a height of up to 10 m above the seabed (70 units or more). **Nine OSS foundations** – For the six small OSS, the 75 m GBS (Box-type) foundation has the greatest blockage effect. For the three large OSS foundations, the large 150 m GBS (Box -type) foundation has the largest blockage. **Offshore accommodation platform foundation** – 75 m GBS (Box-type) foundation has the greatest blockage effect. The total blockage effect for the whole offshore array is also a function of the spacing and layout of all 190 foundations. The principles for the array layout are based on a minimum WTG separation of 810 m from foundation centres.	there were equivalent structures in shallower water, they may have a proportionally larger influence and develop partial wakes. It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently precautionary.
Changes to waves affecting coastal morphology (MP-O-3)	**Secondary:** Co188 Co189	**<u>Offshore ECC</u>** **Rock berms at nearshore cable crossing** – Dogger Bank A and B cable crossing at a location > 20 m below LAT with a berm height of up to 3 m. **HVAC booster station foundations** – 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 some wave interactions and a larger cumulative effect between structures.	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
		Rock berms at offshore cable crossings – Seven crossings further offshore in water depths between 40 to 50 m below LAT. **<u>Offshore array area</u>** **180 WTG foundations** – The foundation considered to have the greatest blockage effect for MDS is the 53 m diameter base conical shaped GBS (WTG-type), limit of up to 110 units. The next largest MDS foundation for blockage is the mono-suction bucket which has a base diameter of up to 40 m with a height of up to 10 m above the seabed (70 units or more). **Nine OSS foundations** –For the six small OSS, the 75 m GBS (Box-type) foundation has the greatest blockage effect. For the three large OSS foundations, the large 150 m wide GBS (Box -type) foundation has the largest blockage effect. **Offshore accommodation platform foundation** –75 m wide GBS (Box-type) foundation has the greatest blockage effect.	It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently precautionary.
Changes to nearshore sediment pathways (MP-O-4)	**Secondary:** Co188 Co189	**Rock berms at cable crossings** – Hornsea Four will cross the Dogger Bank A and B export cables seaward of Smithic Bank. Maximum berm height of 2.7 m, plus a pre-lay berm of 0.3 m (total height of up to 3 m), placed seaward of 20 m below LAT isobath. Remedial rock protection also assumed for 10% of offshore ECC cable length in addition to any cable crossings. **HVAC booster station foundations** – Three GBS |(Box-type) foundations closely spaced at 100 m may moderate nearshore waves and longshore sediment transport.	This issue relates to the consequence of changes to nearshore flows and waves that drive nearshore sediment pathways
Cable re-burial and repair (MP-O-5)	**Primary:** Co44 Co45	**<u>Export Cable Activities:</u>** Re-burial of up to 2 km in length for any single event (equivalent to 12,000 m^3 of disturbed sediment for a seabed release by CFE) to a total of 14 km over	Largest disturbed volume and highest trenching rate per event by CFE produces the greatest rate of sediment

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
	Secondary: Co188	the lifetime of the project (equivalent to a total volume of 84,000 m^3 of disturbed sediment). For cable repairs, the MDS option is based on full de-burial and re-burial of the relevant section of cable using jetting equipment (i.e. CFE or similar) with a provision for up to 23 repairs over the operational phase. **Array Cable Activities:** Re-burial of up to 2 km in length for any single event (equivalent to 12,000 m^3 of disturbed sediment for a seabed release by CFE) to a total of 42 km over the lifetime of the project (equivalent to a total volume of 252,000 m^3 of disturbed sediment). For cable repairs, the MDS option is based on full de-burial and re-burial of the relevant section of cable using jetting equipment (i.e. CFE or similar) with a provision for up to 10 repairs over the operational phase. **Interconnector Cable Activities:** Re-burial of up to 2 km in length for any single event (equivalent to 12,000 m^3 of disturbed sediment for a seabed release by CFE) to a total of 7 km over the lifetime of the project (equivalent to a total volume of 42,000 m^3 of disturbed sediment). For cable repairs, the MDS option is based on full de-burial and re-burial of the relevant section of cable using jetting equipment (i.e. CFE or similar) with a provision for up to three repairs over the operational phase.	release at source. These effects are considered to be comparable to cable installation (MP-C-2) but are moderated by the limits on the maximum amount of cable per event. (MP-O-1 refers to the presence of the structure whereas MP-O-5 refers to the excavation activities disturbing sediments).
Decommissioning			
Sediment disturbance - all direct sediment disturbance activities during	N/A	The assumption is for comparable (or lesser) rates of sediment disturbance to those described for installation of foundations. Inter-array and export cables are expected to remain *in situ*.	Foundation removal is likely to involve cutting off any piles and lift of the main structure and would involve a smaller

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
decommissioning that may lead to locally raised suspended sediment concentration SSC at source (MP-D-1)		Scour protection and rock berms at cable crossings are planned to remain *in situ*.	footprint than any seabed preparation activity.
Changes to tidal and wave regimes associated with the removal of foundations (MP-D-2)	N/A	Removal of the following foundations and cessation of associated blockage effects: **<u>Offshore ECC</u>** **HVAC booster station foundations** – largest solid structure in the vertical plane is the 75 m width GBS (Box-type). **<u>Offshore array area</u>** **180 WTG foundations** – The reversal of MP-O-2 and MP-O-3 foundation options. **Nine OSS foundations** – For the six small OSS, the 75 m GBS (Box-type) foundation has the greatest blockage effect. For the three large OSS foundations, the large 150 m GBS (Box -type) foundation has the largest blockage effect. **Offshore accommodation platform foundation** – 75 m GBS (Box-type) foundation has the greatest blockage effect. The total blockage effect for the whole offshore array is also a function of the spacing and layout of all 190 foundations. The principles for the array layout are based on a minimum WTG separation of 810 m from centres.	Removal of the greatest number of turbines with the closest spacing, mounted on the largest foundation options represents the MDS for cessation of blockage effects on wave and tidal regimes. It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently precautionary.

1.10 Assessment methodology

1.10.1.1 The assessment of sources, pathways and receptors is delivered with an evidence-based approach drawn from comparable developments in comparable settings, notably Hornsea Project One and Hornsea Project Two.

1.10.1.2 The evidence-based approach is consistent with present best practice for conducting coastal process studies (ABPmer and HR Wallingford 2009). This approach is described in Orsted (2018b) which was presented at the first meeting of the Marine Ecology & Processes Evidence Plan Technical Panel on 12th September 2018. The approach is consistent with **Volume A1, Chapter 5: Environmental Impact Assessment Methodology**.

1.10.1.3 Additional modelling of specific features of interest also forms part of the assessment methodology. This modelling is described in Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

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 A1, Chapter 5: Environmental Impact Assessment Methodology**.

1.10.2.2 The criteria for defining sensitivity for marine process receptors are provided in **Table 1.14**.

Table 1.14: Definition of terms relating to receptor sensitivity.

Sensitivity	Definition used in this chapter
Very High	Receptor is very 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 high 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 medium 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 1.15**.

Table 1.15: 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 1.16**. Where a range of significance of effect is presented in **Table 1.16**, 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 slight or less have been concluded to be not significant in terms of the EIA Regulations.

Table 1.16: Matrix used for the assessment of the significance of the effect.

		Magnitude of impact (degree of change)			
		Negligible	*Minor*	*Moderate*	*Major*
Environmental value (sensitivity)	*Low*	Neutral or Slight (Not Significant)	Neutral or Slight (Not Significant)	Slight (Not Significant)	Slight (Not Significant) or Moderate (Significant)
	Medium	Neutral or Slight (Not Significant)	Slight (Not Significant) or Moderate (Significant)	Moderate or Large (Significant)	Moderate or Large (Significant)
	High	Slight (Not Significant)	Slight (Not Significant) or Moderate (Significant)	Moderate or Large (Significant)	Large or Very Large (Significant)
	Very High	Slight (Not Significant)	Moderate or Large (Significant)	Large or Very Large (Significant)	Very Large (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 ES, namely; **Chapter 2: Benthic and Intertidal Ecology**, **Chapter 3: Fish and Shellfish Ecology**, **Chapter 4: Marine Mammals**, **Chapter 9: Marine Archaeology**, and **Chapter 11: Infrastructure and Other Users**.

1.11 Impact assessment

1.11.1 Construction Phase

1.11.1.1 The environmental impacts arising from the construction of Hornsea Four are listed in **Table 1.13** 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 sediment plumes with 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 are outlined in **Section 1.9.2** with Section 4.3 of the **Volume 5, Annex 1.1: Marine Processes Technical Report** providing further supporting information.

Representation of sediment plumes in coastal process models

1.11.1.5 Coastal process modelling is applied to help examine the far-field reach of effects, such as sediment plumes.

1.11.1.6 In the near-field, there are sediment releases from either near-surface or near-bed and at these locations the sediment concentrations will be highest but also present over the smallest volume of water. In addition, these concentrations only last as long as the source of such effect continues. The modelling report (**paragraph 5.5.2.6** of **Appendix C, Volume 5, Annex 1.1: Marine Processes Technical Report**) states that; "*within 5 m of the activity, SSC might be millions of mg/l or more locally, i.e. more sediment than water in parts of the local plume. The effect is very localised and would last only while the CFE is active over that section of the trench. As sediment in the plume is redeposited and dispersed both vertically and horizontally with distance and time downstream, SSC is expected to reduce to thousands or high hundreds of mg/l within tens to low hundreds of metres. These detailed near-field processes are only relatively coarsely resolved in the model (at a resolution of 50 - 100 m)*".

1.11.1.7 From the near-field to the far-field (i.e. distances > 100 m, the scale of a grid cell), then SSC will start to advect with the tide and be carried away from the source as a sediment plume to mix (through dispersion) with a larger volume of water which then reduces SSC. The modelling report (**paragraph 5.5.2.8** of **Appendix C, Volume 5, Annex 1.1: Marine Processes Technical Report**) states that; "*the width of the plume of finer material (silt) is initially in the order of 10 to 50 m (within 10 to 20 minutes of release, up to 500 to 1,000 m downstream). The SSC in this section of plume is relatively high (up to 1,000 mg/l for all sediment types and up to 100 mg/l for silts alone)*".

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

1.11.1.8 The MDS sediment volume for excavation of up to eight HDD exit pits in the landfall area is a total of 20,000 m^3. This equates to an average excavation volume of up to 2,500 m^3 per pit and to a maximum depth of 5 m.

1.11.1.9 The excavation of each pit is likely to be sequential with up to three exits pits open at any given time, limiting the chance for one large spill event.

1.11.1.10 The preferred option is to side-cast the excavated material onto the adjacent seabed as a temporary spoil mound for later backfilling. Alternatives include removing the material elsewhere to a temporary storage area prior to use for backfilling.

1.11.1.11 In the three month period between excavation and backfilling 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 across the surface of the spoil mound will be susceptible to erosion to become assimilated into the general nearshore transport process. Any coarse gravels and clumps of consolidated clay till are likely to be less affected and will be expected to remain in place.

1.11.1.12 Backfilling will create a further period of sediment spill causing further temporary and locally elevated suspended sediment concentrations. Some additional material (e.g. rocks) may be required to make up for any loss in sediment volume.

Environmental value

1.11.1.13 The relevant receptors to the excavation of the exit pits for any sediment plumes are Bridlington Harbour, LSOs and the spoil ground HU015. All these receptors are to the north and relatively distant (> 4 km) from the excavation (**Figure 1.2**). Any fine material being dispersed from the exit pits during excavation is likely to be widely dispersed and quickly form part of the background concentration of SPM along the nearshore. Only Bridlington Harbour would have the potential for any settlement of fine sediment and then limited to periods when the ebb tide advects any plume to the north. There is expected to be a **low** sensitivity of the receptor to the excavation activity due to remoteness from the source and small sediment volumes involved.

Magnitude of impact

1.11.1.14 The excavation and backfilling of exit pits is a small-scale, highly localised and intermittent activity limited to the short-term which has the capacity to generate a low sediment volume. The magnitude of impact resulting from temporarily elevated levels of siltation in the vicinity of the landfall area would be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Table 1.16**) and is therefore not considered further in this assessment.

Further mitigation

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

Seabed preparation activities – Sandwave clearance (MP-C-1)

1.11.1.16 Sandwave clearance is considered in further detail in Section 4.3.3 of **Volume A5, Annex 1.1: Marine Processes Technical Report**.

1.11.1.17 The MDS provision for sandwave clearance along the offshore ECC is a total of up to 757,000 m^3 across six export cables and sweeping a width of 40 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 as well as inter-array cables. The assumption is this activity would be achieved with a TSHD which would initially lead to overspill along the areas being cleared of sandwaves and then spoil disposal at a site elsewhere associated with a higher discharge volume as the hopper is emptied.

1.11.1.18 Overspill losses depend on many issues, not least hopper capacity, filling rates and sediment types. For sandwave sediments (demonstrated to be mainly medium sand in the offshore array from relevant grab samples) the overspill losses are likely to be relatively low and limited to marginal amounts (around 5 % of content) of finer grained sands and silts present in the sediment.

1.11.1.19 A sediment plume will form from the marginal amount of fine sediments present in the overspill. 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.

1.11.1.20 For the volume of sediment involved, and accounting for bulking factors and overspill, sandwave clearance within the offshore array area is estimated to require up to 78 hopper loads along the offshore ECC and 100 hopper loads within the offshore array area.

1.11.1.21 The pathway for any sediment plume will be governed by tidal advection (flood to the south-east and ebb to the north-west) 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.

1.11.1.22 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 (estimated to be around 5 % of total content for sandwave areas) may remain in suspension for relatively long periods due to relatively slow settling rates. This material is likely to become undiscernible from the background sediment load within a few tidal cycles. The period between loading and dumping is expected to be sufficient for each sediment plume to be a separate event.

1.11.1.23 Modelling of spoil disposal for a nearshore location seaward of Smithic Bank (**Appendix C** of **Volume A5, Annex 1.1: Marine Processes Technical Report)** demonstrates the scale of tidal advection where the silt fraction determines the material held in suspension to form a sediment plume. The scale of tidal advection is around 10 km with concentrations generally < 10 mg/l away from the point of release.

1.11.1.24 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 localised depth of accumulation at the seabed).

1.11.1.25 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 and up to 1.5 m. For Hornsea Four, spoil mounds are estimated in the range 10,000 to 152,100 m^2 with an associated maximum height in the range 0.99 to 0.07 m.

1.11.1.26 Once deposited the sand removed from sandwaves is likely to re-join the same bedload 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 peak flows of spring tides, a restriction which may lead to a slower winnowing process. For spoil deposition in the shallower nearshore environment, where flows are typically stronger and waves begin to interact with the seabed, the mobility of sediments can be expected to be higher and the spoil is likely to disperse at a faster rate.

1.11.1.27 Uncertainties in the assessment relate mainly to partial mapping of sandwave areas from the geophysical survey which is offer less than 100% coverage. Whilst sandwaves appear most abundant in the northern part of the offshore array area they are not identified along the offshore ECC apart from a very few locations, such as the southern part of the fan area connecting with the offshore array area.

Environmental value

1.11.1.28 In most cases the 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. Only relevant nearshore receptors identified in **Table 1.6** are considered here.

1.11.1.29 The relevant nearshore receptors related to sandwave clearance for any sediment plumes are Bridlington Harbour, LSOs and spoil ground HU015 due to their interactions with suspended sediment and settling. All these receptors are to the north of the nearshore section of the offshore ECC and relatively distant (> 4 km) from the excavation (**Figure 1.2**). Any fine material being dispersed by overspill or spoil disposal is likely to be widely dispersed and quickly form part of the background concentration of SPM along the nearshore. Only Bridlington Harbour would have the potential for any settlement of fine sediment and then limited to periods when the ebb tide advects any plume to the north. There is expected to be a **low** sensitivity of these receptors to sandwave clearance, not least because of the expected absence of such features in this area.

Magnitude of impact

1.11.1.30 The excavation of exit pits is a small-scale, highly localised and intermittent activity limited to the short-term which has the capacity to generate a low sediment volume. The magnitude of impact resulting from temporarily elevated levels of siltation in the vicinity of the landfall area would be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Table 1.16**) and is therefore not considered further in this assessment.

Further mitigation

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

Seabed preparation activities: Seabed levelling – HVAC Booster Search Area (MP-C-1)

1.11.1.32 The MDS volume for seabed levelling within the HVAC Booster Station Search Area is up to 171,735 m^3 for three six-legged Suction Bucket Jacket (Small OSS) foundation option. The sediment volume represents an area of 111 m by 111 m and around 4.6 m deep for each foundation. During excavation overspill is expected when the dredger is filling, followed by a period of spoil disposal nearby.

1.11.1.33 The geophysical survey describes this area as a relatively flat and featureless seabed (i.e. no large mobile bedforms) with a lithology formed of gravelly sands. The exceptions are several discrete seafloor contacts (e.g. boulders) with heights generally < 0.5 m and the very eastern boundary which overlaps with a sandy area of low profile megaripples (heights < 0.5 m, and typically less than 0.1 m).

1.11.1.34 SBP interpretations suggest the surficial sediments are generally a thin layer (0 to 2 m) over the Bolders Bank formation.

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. For the volume of sediment involved, and accounting for bulking factors and overspill, the seabed levelling for foundations within the HVAC Booster Search Area is estimated to require up to 19 hopper loads.

1.11.1.36 The pathway for any sediment plume will be governed by tidal advection (flood tide taking the plume to the south-east and ebb to the north-west) 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.

1.11.1.37 Modelling of spoil disposal for the HVAC Booster Station Search Area (Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report)** demonstrates the scale of tidal advection where the silt fraction determines the material held in suspension to form a sediment plume. The scale of tidal advection is around 6 km with concentrations generally < 10 mg/l away from the point of release.

1.11.1.38 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 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 (within a few minutes, and less than one hour, to fall around 51 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.

1.11.1.39 The deposition depth 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. Spoil mounds at this location are estimated to cover between 10,000 to 717,409 m^2 with an associated maximum height in the range 0.99 to 0.01 m.

1.11.1.40 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 then for material that is not covered and armoured by the relatively immobile coarser sediment sizes.

1.11.1.41 Overspill and spoil disposal from seabed levelling in the HVAC Booster Station Search 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.

1.11.1.42 Uncertainties in the assessment relate mainly to potential variability in sediment composition over the depth of seabed levelling.

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

1.11.1.43 The MDS volume for seabed levelling within the offshore array area is up to 1,045,221 m^3 for 180 WTG foundations (comprising 110 GBS foundations at 6,234 m^3 per foundation plus 70 suction bucket jacket at 5,135 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 Bucket 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 1,839,596 m^3 of sediment removal.

1.11.1.44 The geophysical survey (Gardline 2019) identifies surficial sediment types in the offshore array area as 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 exposed 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, however, for an area with a cover of mobile sands and bedform features, the turnover of sediments through bedload transport is likely to maintain a relatively homogeneous top layer of sediments.

1.11.1.45 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 four hours is assumed to fill a 11,000 m^3 hopper. For the volume of sediment involved, and accounting for bulking factors and overspill, the seabed levelling for foundations within the offshore array area is estimated to require up to 190 hopper loads.

1.11.1.46 The pathway for any sediment plume will be governed by tidal advection (flood tide to the south-east and ebb to the north-west) 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 (4 to 4.3 km) than a spring tide (8 to 8.5 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.

1.11.1.47 Modelling of spoil disposal in the offshore array area (Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report)** demonstrates the scale of tidal advection where the silt fraction determines the material held in suspension to form a sediment plume. The scale of tidal advection is around 6 km with concentrations generally < 2 mg/l away from the point of release.

1.11.1.48 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.

1.11.1.49 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 <1 m and up to 1.5 m. For Hornsea Four, the area of deposition for each spoil mound is estimated to be in the range 10,000 to 476,100 m^2 with a corresponding maximum height of the spoil mound likely to be in the range 0.99 to 0.02 m.

1.11.1.50 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.

1.11.1.51 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.

1.11.1.52 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)

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

1.11.1.54 Seabed installation activities planned for the construction phase include:

- Depending on the configuration of the HDD Exit Pits, the use of cofferdams and the design of a drilling fluid management system there remains a residual risk for drilling muds (e.g. bentonite) to be discharged into the marine environment (landfall area) at break-out.
- Cable trenching along offshore ECC (for export cables) and through offshore array area (for array and interconnector cables); and

- Drilling for foundation options requiring piles to be inserted into the seabed in the HVAC Booster Station Search Area (up to three foundations) and offshore array area (up to 190 foundations).

1.11.1.55 Section 4.4 of the **Volume A5, Annex 1.1: Marine Processes Technical Report** provides further details of the assessment of seabed installation activities.

Landfall – bentonite release (MP-C-2)

1.11.1.56 When used as a drilling mud, bentonite can be considered as a non-toxic solute of clay sized particles. Any accidental release into the marine environment would be relatively short-lived and of low volume (unmitigated estimated to be up to 265 m^3 per event for up to eight events), and quickly disperse into the background nearshore suspended sediments. The effects are considered to be less than the excavation of exit pits at the same location (**paragraph 1.11.1.8** to **1.11.1.15**).

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

1.11.1.57 Cable trenching will occur after sandwave clearance is completed. MDS provision are for six export cables (HVAC option) laid along the 109 km offshore ECC (N.B. includes a 10 km section within the offshore array area).

1.11.1.58 The final cable 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 a CFE) with a maximum installation width of disturbance of 15 m (i.e. within the 40 m sandwave and boulder clearance corridor). The actual width of the trench depends on the cross-section profile which would be between 6 m for a triangular cross-section to 3 m for a box cross-section.

1.11.1.59 The optimal method to achieve trenching generally corresponds to soil strength and may require fluidising or mechanically removing the sediment from the trench. Fluidising options are based on either jetting or CFE, both options use hydraulic forces to fluidise unconsolidated sediments allowing a heavier cable to fall to the base of the trench prior to any settlement of sediment. CFE is considered as the conservative / worst-case installation option because of the greater volume of sediments likely to be disturbed and the type of disturbance which has the potential to mobilise fine sediment from the trench into suspension (leading to the possibility of sediment plumes) in comparison to ploughing which will simply cast material to the side.

1.11.1.60 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 offered:

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

1.11.1.61 Up to three cable laying vessels may be used along the offshore ECC creating the potential for these vessels to be operating in a similar area although the likelihood of this occurring is considered to be limited by logistical and safety considerations. Initial near-field sources of sediment disturbance will remain separate with only the lower concentrations of suspended sediments in far-field sediment plumes having the potential to overlap when vessels are operating on the alignment of tidal flows.

1.11.1.62 The maximum sediment volume expected to be displaced by CFE 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. In addition, provisions include for up to four cable joints per cable, each requiring a jointing pit which is up to 5 m deep and excavating a sediment volume of 17,500 m^3, a total of 420,000 m^3 for a maximum of 24 pits.

1.11.1.63 The majority of the excavated material is expected to be coarse sediments (sands and gravels) which will mostly drop back into the trench 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 suspended sediment 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 %).

1.11.1.64 Modelling of cable trenching at three representative locations (along ebb channel inshore of Smithic Bank, Dogger Bank A and B crossing, and HVAC Booster Station Search Area) along the offshore ECC (**Appendix C** of **Volume A5, Annex 1.1: Marine Processes Technical Report**) demonstrates the scale of tidal advection where the silt fraction determines the material held in suspension to form a sediment plume. Close to the trench concentrations of suspended sediment can reach 300 mg/l in the deeper water of the HVAC Booster Station Search Area and 10,000 mg/l at the shallower inshore site and Dogger Bank A and B cable crossing with only the silt fraction dispersing away from the trench with plume concentrations typically dropping to < 100 mg/l around 2 km from the trench.

1.11.1.65 During the ebb phase of both a mean spring and neap tide, modelling results indicate that the sediment plume formed during inshore trenching across the ebb channel advects in front of Bridlington Harbour (and across the LSOs) whilst still maintaining some distance away from the coastline (N.B. Co187 ensures that trenching is seaward of the landfall area and not up to the coast). On springs tides only, this plume advects a greater distance to reach disposal site HU015 and Flamborough Head SAC with SSC < 25 mg/l.

1.11.1.66 The conditions at LSOs, HU015 and the SAC are highly dispersive for muds and silts, so there is limited opportunity for fine sediments to permanently settle in these locations. Modelling results show small amounts of (temporary) deposition (around 0.1 mm of fine sediment) is possible in these locations during a spring tide, noting re-erosion is deliberately inhibited in the model setup to help identify this initial deposition process. Areas within the harbour offer calmer conditions conducive to more permanent settling for any fine sediments which area able to reach this location (e.g. for periods when strong easterly winds may cause the sediment plume to move towards the coast). The harbour already has an existing exposure to siltation from nearshore marine sources.

1.11.1.67 Present uncertainties in the assessment relate mainly to the assumptions in sediment composition over the depth of trenching along the offshore ECC, trenching rates and the logistics of multiple vessels operating in the nearshore.

Environmental value

1.11.1.68 The relevant nearshore receptors to cable trenching and sediment plumes are Bridlington Harbour, LSOs, spoil ground HU015 and Flamborough SAC. All these receptors are to the north of the nearshore section of the offshore ECC and relatively distant (> 4 km) from the excavation (**Figure 1.2**). Any fine material being brought into suspension is likely to be widely dispersed and quickly form part of the background concentration of SPM along the nearshore. Only Bridlington Harbour would have the potential for any settlement of fine sediment and then limited to periods when the ebb tide advects any plume to the north and when easterly winds are able to divert the strong tidal flows towards the coast. There is expected to be a **medium** sensitivity of Bridlington Harbour to the cable installation process for nearshore sections.

Magnitude of impact

1.11.1.69 The nearshore section of the offshore ECC 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 affecting Bridlington Harbour would be **negligible**. The significance of the impact is considered to be **slight (not significant)** as defined in the assessment of significance matrix (**Table 1.16**) and is therefore not considered further in this assessment.

Further mitigation

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

<u>*Cable trenching – offshore array area (MP-C-2)*</u>

1.11.1.71 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.

1.11.1.72 Similar assumptions are made for burial depth, trench size and excavation tool options as for the offshore ECC cable trenching. The MDS option is CFE to develop a trench of 2 m depth.

1.11.1.73 The geophysical survey (Gardline 2019) resolves a relatively thin surface layer of Holocene sand (depths generally < 1 m) for the majority of the offshore array (**Figure 1.13**). Sediments are deeper (> 2 m, equivalent to depth of trench) mainly along the western, northern and southern boundaries. Below the Holocene sands there is expected to be stiff clays of the Bolders Bank formation. Two sediment samples taken towards the eastern boundary coincide with an area where the depth of the Holocene sands is effectively nil. These sites are likely to be indicative of wider locations where trenching reaches the underlying soils and suggests increased contents of silts up to 15.3 %, with remaining fractions of 61 % sands and 23.8 % gravels.

1.11.1.74 The maximum sediment volume expected to be displaced by CFE across the offshore array is up to 4,140,000 m^3 or 6 m^3 per metre of trench, on average (N.B. this volume excludes a 10 km section of export cables which overlap with the offshore array area which is expected to displace up to 358,073 m^3 (N.B. This section of cable is accounted for within **paragraph 1.11.1.62**).

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

1.11.1.76 The pathway for any sediment plume of fine sediments will be governed by tidal advection (flood tide to the south-east and ebb to the north-west) with lower concentrations spreading around this axis due to dispersion and diffusion mixing processes. Plume concentrations will reduce with distance from source 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 advect further and have proportionally lower concentrations, i.e. become more dilute over a wider area.

1.11.1.77 Modelling of cable trenching in the offshore array area (**Appendix C** of **Volume A5, Annex 1.1: Marine Processes Technical Report**) demonstrates the scale of tidal advection where the silt fraction determines the material held in suspension to form a sediment plume. Concentrations of suspended sediment reach 1,000 mg/l in the vicinity of the trenching with only the silt fraction dispersing away from the trench with plume concentrations of around 100 mg/l up to 2 km.

1.11.1.78 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 sediments (silts and muds) within the offshore array due to persistent influence of tidal mixing.

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

1.11.1.80 Uncertainties in the assessment relate mainly to the assumptions in sediment composition over the depth of trenching and trenching rates

Foundation installation: drilling at HVAC Booster Station Search Area (MP-C-2)

1.11.1.81 Drilling may be required for HVAC Booster Station 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 all pile installations (or up to 10 % of the depth across all installations).

1.11.1.82 Drilling produces drill arisings (drill arisings are the entire product of the drilling process (liquids and solids) with drill cuttings considered to be the larger sized fragments that fall to the seabed to form a cuttings pile) that will be brought back to the drilling rig 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 aligned to the direction of tidal excursion, then there is the potential for sediment plumes to disperse together and lead to higher overall increases in SPM, i.e. overlapping plumes.

1.11.1.83 The composition 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 2008b).

1.11.1.84 The MDS foundation option related to drill arisings in the HVAC Booster Station Search Area is the Piled Jacket (Small OSS) with 16 pin piles with a 3.5 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. The conservative assumption is drilling would produce similar (but lesser) sediment plumes in comparison to the seabed levelling activity in this area.

1.11.1.85 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.

1.11.1.86 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)

1.11.1.87 The MDS considerations for drilling in the offshore array area are based on the information presented in **Table 1.17** based on a provision of 10 % of total pile volumes. In comparative terms, these quantities of drill arisings are lower than the overall volume requirements for seabed levelling at the same locations.

Table 1.17: 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	127,234	Either 707 for each foundation or 7,069 for 18 foundations
OSS	Piled jacket (Small OSS)	9	13,854	1,540
Offshore Accommodation Platform	Piled jacket (Small OSS	1	1,540	1,540
	Total	**190**	**142,628**	

1.11.1.88 The geophysical survey has resolved stratigraphy across the offshore array area to around 150 m below seabed (GeoSurveys 2019). Nine seismic units have been described, including the surface layer of Holocene Sands to the base unit represented by Pre-Chalk Mesozoic sediments (medium to coarse-grained sands). Where the base unit is absent the next seismic unit is described as fine-grained limestones, with coccolith bioclasts in a matrix of coarser calcite components which correspond to the Chalk Formation (Upper Cretaceous). **Figure 1.14** indicates the depth below seabed for this chalk layer and attributed to the depth of different piled foundations.

1.11.1.89 The requirement to drill into chalk depends on the hardness of the substrate which is presently unknown. Notably, Sheringham Shoal, 90 km to the south of Hornsea Four, encountered Cretaceous Chalk but was still able to drive all piles into the seabed without the need of drilling (Carotenuto et al. 2018).

1.11.1.90 At Lynn & Inner Dowsing Offshore Wind Farms, sites even further to the south, drilling was required through patches of hard chalk at six of 54 monopile installations. A licence was required to dispose of the drill cuttings which included conditions to monitor sediment plumes and drill cuttings mounds. The monitoring found no significant increase in SPM above background levels but larger than expected drill cuttings mounds that persisted (albeit slightly diminishing to a stable level with a maximum height of around 1 m above seabed) over the four-year monitoring period. These findings were contrary to model predictions which had assumed smaller particle sizes (3.2 to 15 mm for the cuttings mound) which would have potentially been more easily dispersed. Drill cuttings samples observed on the spoil mound were typically in the range 50 to 100 mm (BOEM 2017).

1.11.1.91 If drilling is required, the drilling rate is expected to be between 0.5 to 1.0 m/hr, this equates to a production rate of drill arisings of between 88 to 177 m^3/hr for WTG foundations. For comparison, Hornsea Three assumed a production rate of 88 m^3/hr and Hornsea Project One and Two a rate of 235 m^3/hr for 10 m and 15 m diameter monopiles.

1.11.1.92 The (particle) density of drill cuttings for silica type rock is typically around 2.65 kg/m^3, however, if the drill cuttings are derived from chalk rock then a slightly lower (particle) density would be expected at around 2.50 kg/m^3 (composite chalk rock prior to fractionating into particles would expect to have a lower bulk dry density). The implication for any chalk cuttings of fine particle size (e.g. silt sized at < 0.063 mm) which are capable of forming a sediment plume is a slight reduction in the theoretical settling velocity compared to silica based particles (0.0021 m/s compared to 0.0023 m/s for the same set of ambient seawater conditions), a very small reduction which is unlikely to be significant.

1.11.1.93 Presently available details would suggest comparable sediment plumes and deposition effects to seabed levelling at foundations. Any sediment plumes and drill cuttings mounds 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.

1.11.1.94 Uncertainties in the assessment relate mainly to the assumptions for any locations requiring drilling and the consequential size and density of any drill arisings being produced.

Scouring around foundations (MP-C-3) – Overview

Overview

1.11.1.95 One design option may place scour protection (or a pre-lay filter layer) on the seabed prior to foundation installation. In this case scouring is likely to be mitigated. The alternative option is to install the foundations first and then add scour protection later. In this case, the period between foundation installation and placement of scour protection leaves the structure prone to some local scouring. This option becomes the MDS with the amount of scour that may take place in this period depending on many factors, including; the prevailing flow environment, structure size and shape, the depth of mobile sediments and any less erodible sub-surface layer of sediment.

1.11.1.96 The potential for any environmental impact across the offshore array area related to foundation related scouring is likely to be minimal when the scale of effect is localised to each foundation and with seabed preparation already removing the upper layer of mobile sediment. The separation between adjacent foundations is also sufficient to mitigate the risk of group scour occurring over the scale of the offshore array area which has the potential to destabilise a larger morphological feature, such as a sand ridge, etc..

1.11.1.97 The main environmental change is likely to be related to the introduction of rock armour as scour protection (maximum rock size up to 1 m and up to 2 m thickness of scour protection layer) 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.

Scouring around foundations – HVAC Booster Station Search Area (MP-C-3)

1.11.1.98 The MDS option for the HVAC booster Station Search Area is based on three 75 m wide GBS (Box-type) foundations in an area of 24 km^2 located around 35 to 41 km offshore and within the offshore ECC (**Figure 1.4**). The precise location of each foundation is yet to be determined and their orientation with respect to incident flows and waves also remains unknown. If flows are at 45° to the structure then the effective width of this type of foundation increases to 106 m. This scale of structure in a water depth of around 51 m below LAT is likely to lead to edge scour rather than scour around the full perimeter.

1.11.1.99 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. The equivalent width of scour protection around the base of the square box-shaped foundation would be 50 m. 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 in any unprotected mobile layer of sediment.

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

1.11.1.101 Deeper scour could be limited by the underlying immobile sediment layers. The depth of these layers and type of sub-surface sediments remain unknown at this time.

1.11.1.102 There are no marine process receptors in the vicinity of the HVAC Booster Station Search Area. Any 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.

1.11.1.103 Uncertainties in the assessment relate mainly to the location and the final arrangement of foundations.

Scouring around foundations – offshore array area (MP-C-3)

1.11.1.104 The MDS foundation 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 the largest scales of local scouring of mobile sediment around the base of any unprotected foundation. Relative scales of blockage for each foundation option have been assessed using indicative solidity ratios applicable across the vertical face of the foundation presented to incident flows.

1.11.1.105 The MDS array-scale option is based on the combination of relevant foundation types which have the largest requirement for scour protection. This is made up of a 110 GBS WTG-type and 70 monopile WTG-type for sites where GBS foundations cannot be used, plus box-type GBS for the OSS foundations and offshore accommodation platform.

1.11.1.106 **Table 1.18** summarises the MDS requirements for scour protection. The dimensions of a pre-lay filter layer are typically 8 m wider than the base of any foundation which would subsequently be installed afterwards. The dimensions for scour protection assume the rock armour material is placed around the periphery of each foundation which is intended to be more extensive than the effect of any local scouring.

Table 1.18: Summary of MDS foundation options for scour protection in offshore array area.

Unit	Foundation type	Number	Base width (m)	Scour protection width around foundation base (m)	Scour protection area (m^2)
WTG	GBS (WTG-type)	110	53	20	504,540
WTG	Monopile	70	15	30	296,881
OSS large	GBS (Large OSS)	3	150	50	120,000
OSS small	GBS (Box-type)	6	75	50	150,000
Accommodation platform	GBS (Box-type)	1	75	50	25,000
Totals		**190**			**1,096,421**

1.11.1.107 The likely vertical cross-section for the GBS (WTG-type) foundation is conical shaped with a base diameter of 53 m, comparable to the MDS case for Hornsea Three. The top section reduces to a 15 m diameter pile. The width of scour protection around the foundation base is up to 20 m which leads to a total diameter of 93 m.

1.11.1.108 The effective base width for 75 and 150 m box-type GBS increases when the incident wave or flow is at 45°, this leads to potential maximum effective widths of 106 and 212 m, respectively. Scour protection is planned around the base of these foundations with a width of up to 50 m.

1.11.1.109 All foundations are considered to be sufficiently separated to mitigate the chance of group scour between foundations.

1.11.1.110 If there was no pre-armouring of the seabed with a pre-lay filter layer, and prior to any scour protection being installed, then 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 (**paragraph 1.11.1.43**). In any case, seabed levelling would also remove the top layer of mobile sediment which would be the material most likely to be prone to scouring. Once any scouring has removed the surface layer of mobile sands (generally < 1 m thick), deeper scour is likely to be moderated by the underlying till which is expected to have a much slower rate of scouring.

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

1.11.1.112 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.

1.11.1.113 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.

Turbulent wakes and scour around temporary cofferdams (MP-C-4)

1.11.1.114 Temporary cofferdams are an option to enable drilling fluids (e.g. bentonite) to be manged within HDD exit pits and prevent any spills into the marine environment during punch out. There is a provision for up to eight HDD exit pits (HVDC option) with up to three pits open at any time for up to three months. A cofferdam would expect to surround each HDD pit in a configuration which is likely to be up to 50 m long (cross-shore direction) and 18 m wide (longshore direction). The minimum separation between cofferdams would be around 50 m (see Section 4.5.2 and 4.7.2 of **Volume A5, Annex 1.1: Marine Processes Technical Report**).

1.11.1.115 Over the period of placement of cofferdams shore parallel blockage induced local flow accelerations would be expected around the edge of each cofferdam and turbulent flow and wave wakes forming in their lee. These processes may induce local scouring of any mobile sediments, noting the geophysical evidence suggests sand cover is typically thin, or absent, with underlayer bolder clay which is expected to be relatively immobile. The potential for local scouring is therefore expected to be limited by both the short period of placement as well as by the underlying sediment.

1.11.1.116 Waves which drive longshore transport may break against the cofferdams, dissipating energy before reaching the shoreline. A shore parallel) arrangement of cofferdams, with a minimum spacing of 50 m, would extend up to 154 m. The likelihood is this configuration would not significantly interfere with longshore transport and with no greater effects than those from existing WWII tank traps already present along the foreshore.

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

Environmental value

1.11.1.118 The potential sensitive receptor related to nearshore blockage of waves and flows would be a small section of Fraisthorpe Sands (and cliffs) and due to potential temporary modifications to the balance in longshore drift (and potential reduction of cliff erosion rates at times of high waves). The sensitivity of this receptor to changes in waves over the duration of the three-month period when the cofferdams are in place is considered **low** due to the short-term period and expected high recoverability of the beach thereafter.

Magnitude of impact

1.11.1.119 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 subtidal areas are expected to recover relatively quickly. Accordingly, the magnitude of any impact is considered **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Table 1.16**) and is therefore not considered further in this assessment.

Further mitigation

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

1.11.2 Operation and Maintenance

1.11.2.1 The environmental impacts arising from the operation and maintenance of Hornsea Four relate to effects that are lasting during this period due to structures installed on the seabed as well as remedial works to maintain the wind farm. These impacts are identified in **Table 1.13**, along with their associated MDS, and include for;

- Scouring around cable protection (MP-O-1);
- Turbulent wakes from foundations interfering with remote receptors (MP-O-2);
- Changes to waves affecting coastal morphology (MP-O-3);
- Changes to nearshore sediment pathways (MP-O-4); and
- Cable re-burial and repair (MP-O-5).

Cable protection

1.11.2.2 Rock armour is the MDS option for cable protection where this results in a change in profile of the seabed due to a rock berm (shallowing) and / or a change in substrate type (coarsening) with potential effects which may last over the operation period. Co188 ensures that no cable protection will be deployed within 350 m seaward of MLWS.

1.11.2.3 Rock armour grading will generally be in the range 90 to 125 mm and a maximum rock size up to 250 mm, although larger rocks (up to 500 mm in shipping corridors) may be necessary if protection from anchors is required.

1.11.2.4 Provisions for cable protection include:

During construction:

- Cable crossings of existing pipelines or cables (known locations, see **Table 1.7**); and
- Provisions for cable protection for up to 10 % of the total amount of cables where cable burial depths during construction are not achieved (unknown locations).

During operation:

- Replenishment of rock protection (up to 25 % of original volume installed during construction at known locations); and
- Locations where cables become exposed and need to be reburied (unknown locations).

1.11.2.5 A CBRA would expect to identify both vulnerable sites based on a high likelihood of sediment mobility as well as ground conditions where full burial may be problematic. Reburial requirements may also arise from other causes or events such as anchor drags.

1.11.2.6 The potential concerns 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 cable protection may have to develop local scour around the margins (MP-O-1), modify wave propagation (MP-O-3), flows and the associated potential to locally interrupt sediment pathways, notably bedload transport (MP-O-4).

Scouring around cable protection (MP-O-1) – Overview

1.11.2.7 Whilst local scour around the base of foundations (MP-C-3) is likely to occur in areas with mobile sediment during the construction phase, until scour protection is fully installed, the potential for edge scour around the periphery of any areas with cable protection (e.g. at rock berms for cable crossings) is considered to be a longer-lasting process (to achieve equilibrium conditions) that continues through the operational phase. The development of edge scour is only likely where the seabed has a mobile layer of sediment and where the periphery of the cable protection creates a discontinuity in near-bed flows which elevates local bed shear stress leading to erosion and scouring of the mobile sediment.

Cable crossings – offshore ECC (MP-O-1)

1.11.2.8 The Project Description for Hornsea Four provides an indicative example of a rock berm for a cable crossing of an existing pipeline or cable (Figure 4.11 of **Volume A1, Chapter 4: Project Description**). The existing cable or pipeline will first be covered with a pre-lay rock berm of a typical length of around 25.3 m in length and 12.4 m in width and to a thickness 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.

1.11.2.9 The final cross-section profile of the rock berm will be a trapezium shape with a 3:1 gradient, up to approximately a height of 1.5 m over the pre-lay berm (total height of 1.8 m plus 0.3 m for pre-lay rock armour). This rock grading has a typical rock size in the range of 90 to 125 mm, up to maximum rock size up to 250 mm. If additional protection is required from large anchors then rock sizes may be up to 500 mm and a higher berm of 3.0 m (including 0.3 m pre-lay rock).

1.11.2.10 Cable crossings are identified over existing assets as well as proposed assets in both the offshore ECC and offshore array area, as detailed within **Volume A4, Annex 4.1 – Offshore Crossing Schedule**.

1.11.2.11 There are seven anticipated locations along the offshore ECC which require cable crossings (**Table 1.7**), excluding two locations within the offshore array. Apart from the nearshore crossing with Dogger Bank A and B export cables, all remaining sites are distant from the coastline (> 37 km) and in relatively deep water (> 40 m depth). These offshore locations are too deep to interfere with wave energy transformation onto the coast. Some local scouring may occur around the perimeter of rock berms due to increased turbulence in the local flow, especially where there are mobile bedforms, such as the areas with megaripples east of the HVAC Booster Station Search Area.

1.11.2.12 The nearshore crossing with the Dogger Bank A and B export cables is at a planned location just seaward of Smithic Bank in a water depth > 20 m. Up to six export cables from Hornsea Four and two pairs of export cables from Dogger Bank A and B could potentially lead to a MDS of up to 12 crossings all relatively close together. The local seabed is described as mainly sandy gravel suggesting a limited capacity for scouring. Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides details of modelling of a MDS case for the combined rock berm occupying an area of 500 m by 1,000 m and up to 3 m high, along with increased roughness. Flow acceleration was predicted around the edges of the berm which may lead to local scouring of mobile sediments. The extent of the scouring would be limited to these areas and remain distant from other features, such as Smithic Bank.

1.11.2.13 Any scouring around cable crossings along the offshore ECC is considered to have a **negligible** magnitude of impact on the seabed and would not have far reaching effects. Consequently, no further impact assessment is offered here for marine processes. The potential for the nearshore crossing with Dogger Bank A and B to interrupt sediment pathways is considered separately in **paragraph 1.11.2.46**.

1.11.2.14 Uncertainties in the assessment relate mainly to depth of mobile sediments which may impede full equilibrium scour depths.

Cable crossings – offshore array area (MP-O-1)

1.11.2.15 Provisions for cable crossings are also required within the offshore array area. Due to the need to account for two proposed pipelines the total number of crossings required may be up to 32, along with two cable crossings for the ECC which occur within the offshore array area. Further details on these crossings are presented in **Volume A4, Annex 4.1: Offshore Crossing Schedule**.

1.11.2.16 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 further impact assessment is offered here for marine processes.

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

Turbulent wakes from foundations interfering with remote receptors (MP-O-2) – Overview

1.11.2.18 Turbulent wakes are an extension of the near-field scour related blockage effects on flows. Flow wakes will occur on the leeward side of each foundation and are generally represented in models as a local reduction in the time-averaged flow speed. The intensity of turbulence within the wake is higher than the baseline which can also lead to faster rates of dispersion and mixing. In some situations this can lead to increased turbidity within the wake due to vertical mixing of near-bed layers of suspended sediments, which are then visible as a plume e.g. Thanet Offshore Wind Farm (The Crown Estate 2018).

1.11.2.19 Individual wakes will quickly dissipate away from each foundation and typically over a shorter distance than any separation between adjacent foundations. This distance tends to mitigate the potential for wake to wake interactions. Nevertheless, multiple individual wakes across the array also have the potential to lead to an array scale affect with the potential to influence the far-field with higher levels of turbulence. This array scale effect is likely to be relevant only to the foundation option with the largest blockage effect (WTG-GBS) rather than all foundation types. The main consideration for turbulent wakes is in regard to the potential disruption to the Flamborough Front due to wakes forming across the offshore array area.

Turbulent wakes: HVAC Booster Station Search Area (MP-O-2)

1.11.2.20 Flow and wave related wakes will form locally in the lee of the three 75 m wide box-type GBS foundations.

1.11.2.21 Due to the scale of these 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.

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

1.11.2.23 There are no marine process receptors identified in the vicinity of the HVAC Booster Station Search Area. Consequently, no further impact assessment is offered here for marine processes.

Turbulent wakes: offshore array area (MP-O-2)

1.11.2.24 Section 4.7.4 of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a detailed review of turbulent wakes which will form locally around the 190 foundations (180 WTG locations and 10 OSS and accommodation platforms) in the offshore array area.

1.11.2.25 There could be up to four types of foundations in the offshore array area (representing the MDS option) 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):

- Up to 110 GBS (WTG-type) with 53 m diameter, conical base, narrowing to 15 m diameter column;

- 70 mono-suction bucket (WTG type), 40 m diameter bucket with up to 10 m above seabed with 15 m diameter upper section;
- Three large OSS GBS box-type with 150 m width base; and
- Seven small OSS GBS box-type with 75 m width base (six small OSS plus one accommodation platform).

1.11.2.26 The distribution of the various foundation type across the indicative array layout (**Figure 1.11**) is currently unknown, neither is the orientation nor spacing between any of the box-type GBS foundations. The minimum spacing between the centres of all infrastructure will not be less than 810 m. The measurable distance of any wake is likely to be less than this distance.

1.11.2.27 A layout comprising of only WTG-type 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, however, this effect is expected to be largely mitigated by the separation distance. The inclusion of ten GBS box-type foundations with greater widths (75 m 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 also be limited.

1.11.2.28 The main environmental receptor which could be susceptible to turbulent wakes across the offshore array area is the Flamborough Front which develops during the summer month as the interface between thermally stratified water in the northern North Sea and well-mixed water in the southern North Sea. Available evidence to help map the location of the front (from modelling and satellites) suggests the location of this feature is typically further to the south of Hornsea Four by around 11 km (at the closest point in the direction of the flood tide). During the flood tide, turbulent wakes would extend to the south-east from foundations located along the southern boundary of the array, however, at the same time the front would advect over the same scales and the two features would not interact. During the ebb tide, the front would advect in a north-westerly direction towards Hornsea Four, however, the scale of advection even during spring tides is considered insufficient to lead to the front passing into the southern margins of the offshore array area which means turbulent wakes would not expect to interact with the front.

1.11.2.29 Increased seasonal mixing from autumn to winter due to stronger winds and increased wave stirring effects, as well as surge related currents, act together to increased vertical mixing and de-stabilises the stratification with the front dissipating at these times.

Environmental value

1.11.2.30 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** due to the relationship of the front giving rise to nutrient-rich water, increased primary production and fisheries providing a feeding ground for birds (English Nature 2004).

Magnitude of impact

1.11.2.31 The magnitude of any impact on the Flamborough Front is considered to be **negligible** because the influence from any turbulent flow wakes is likely to remain spatially distant.

Significance of the effect

1.11.2.32 The likely effect is **neutral** (not significant).

Further mitigation

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

Changes to waves affecting coastal morphology (MP-O-3)

1.11.2.34 Section 4.8 of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a detailed review of potential changes to waves affecting coastal morphology.

1.11.2.35 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 along the shoreline determines if longshore drift 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 Bank. In turn, the profile of this sandbank also acts to dissipate wave energy from large storms due to shoaling effects. Substantial modification to waves arriving at the coastline has the potential to affect the balance in these nearshore processes.

1.11.2.36 There will always be some natural 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 how these changes might be manifested.

1.11.2.37 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 of foundations 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, with large obstacles creating the most diffraction. The interactions between an incident wave and a structure are regarded as blocking type effects with a leeward change possible in wave height, period and direction.

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

1.11.2.39 An assessment of the potential effect of Hornsea Four on blocking wave energy transmission towards the Holderness Coast is investigated using wave modelling (Appendix C of **Volume A5, Annex 1.1: Marine Processes Technical Report**). The configuration of the wave model accounts for the influence of foundations in the HVAC Booster Station Search Area and the offshore array area, together with the raised profile of the nearshore rock berm which crosses Dogger Bank A and B export cables. The maximum number of GBS-WTG foundations in the offshore array area will not exceed 110 locations (of 180 WTG), with the MDS case for the remaining 70 WTG foundations becoming the mono-suction bucket option. Since the final layout and distribution of WTG foundations remains unknown at this time then a conservative assumption has been adopted applying the GBS foundation option to all 180 WTG sites, despite this being limited to 110 locations. The modelling also accounts for the final layout and foundation types for Hornsea Project One and Hornsea Project Two, along with MDS case for Hornsea Three as the maximum potential blockage representing an in-combination scenario across the former Hornsea Zone.

1.11.2.40 Modelling scenarios have considered representative wave directions and return period events that affect the Holderness Coast. The easterly directional sector demonstrated the most change in waves towards the coastline compared with other wave directions as this sector also represents the alignment between the offshore array, the HVAC Booster Station foundations and the nearshore berm. However, all scenarios still showed full dissipation of wave energy (represented as a reduction in wave height in this case) well away from the coastline. Figure 1.18 compares between the baseline case and the MDS configuration for easterly waves arriving along the coastline which demonstrates no discernible change in wave conditions.

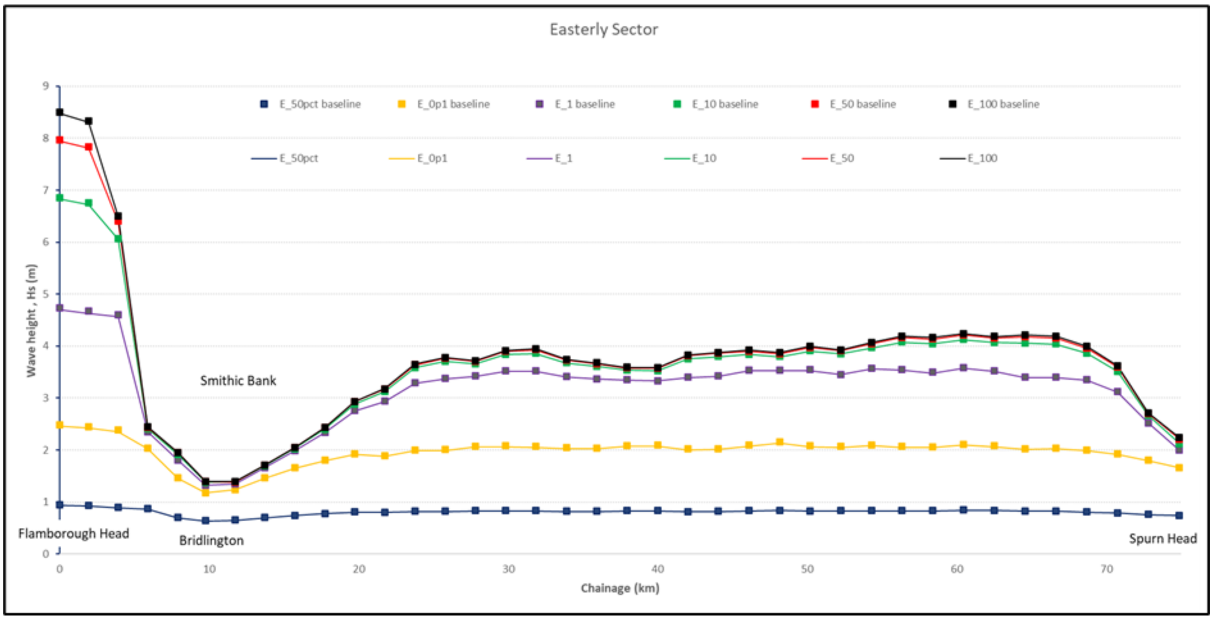


Figure 1.18: Nearshore wave conditions for easterly sector scenarios (derived from wave modelling).

Environmental value

1.11.2.41 The rates of cliff erosion and patterns of longshore drift along the Holderness Coast are the primary environmental interest sensitive to potential changes in wave energy transmission due to Hornsea Four. This receptor has a **high** environmental value for sediment transfer to the south to the Humber, the Lincolnshire coast and The Wash

(Natural England 2015).

1.11.2.42 The morphology of Smithic Bank is a further environmental receptor sensitive to changes in waves. This feature is considered to have a **medium** environmental value due to the more localised influence.

Magnitude of impact

1.11.2.43 There is no measurable change in wave conditions predicted to reach Smithic Bank or the Holderness Coast which implies there will be no impact to cliff erosion rates or changes to longshore drift due to wave blockage effects from Hornsea Four.

1.11.2.44 The magnitude of impact is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Table 1.16**) and is therefore not considered further in this assessment.

Further mitigation

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

Changes to nearshore sediment pathways (MP-O-4)

1.11.2.46 Section 4.9 of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a detailed review of potential changes to nearshore sediment pathways with Section 4.6.5 considering implications of cable protection measure being placed on Smithic Bank.

1.11.2.47 The nearshore is considered here as the shallowing area within the shelter of Flamborough Head up to the coast, including Smithic Bank. The 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 further pathway for sands onto Smithic Bank. Waves help to limit the profile of the bank with larger waves dissipating some of their energy onto the bank creating a southern section which is wide and smooth. In contrast, the more wave sheltered northern part of the bank is prone to faster tidal flows accelerating around the headland which act to develop distinct sandwaves.

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

- Wave blockage effects from the offshore which propagate to the nearshore;
- Rock berms to manage cable crossings with Dogger Bank A and B export cables;
- Provisions for rock protection across Smithic Bank; and
- Requirements for remedial measures to rebury exposed cables.

1.11.2.49 Wave blockage effects have been discussed in **paragraph 1.11.2.43** with no measurable effects reaching the nearshore.

1.11.2.50 The cable crossing with Dogger Bank A & B export cables has been discussed in **paragraph 1.11.2.10** in relation to changes in flows and the implication for local scour. Any sediment pathways passing this feature are expected to reform in the lee of the structure. In addition, this feature is located seaward of the depth of closure (for waves) and would not interfere with any wave driven nearshore pathways.

1.11.2.51 The potential remains for cables to become unburied at any location during the operational period, including across the nearshore and Smithic Bank. This may happen due to anchor dragging or a dramatic change in seabed levels, for example. Any rock armour protection required for re-burial will follow the alignment of the cable with a profile which may also be locally higher than the adjacent seabed. The rock armour may then initially act as a partial (low profile) barrier to bedload sediment transport along the length of the rock berm. Material in suspension is not expected to be affected. Depending on the situation, coarser grained mobile sediments moving as bedload may initially build up against this partial barrier where flows are weakened, as well as bypass around the ends of any rock berm where flows may accelerate.

1.11.2.52 Uncertainties in the assessment relate mainly to the likelihood for cable protection being required across Smithic Bank at some stage, noting this is considered unlikely due to any difficulties in achieving target cable burial depths (during the construction period) or cable exposure due to seabed mobility (during the operation period), with the only potential requirement for remedial protection from anchor drags (also a low likelihood).

Environmental value

1.11.2.53 Nearshore pathways are relevant to both the Holderness Coast and Smithic Bank. In the context of nearshore pathways, both these features are considered to have a **medium** environmental value due to the more localised influence.

Magnitude of impact

1.11.2.54 In some situations (such as cable protection across Smithic Bank) there is a potential for small changes in nearshore pathways which are expected to remain localised to any infrastructure. The magnitude of impact is therefore considered to be **negligible** to **minor**.

Significance of the effect

1.11.2.55 The likely effect of changes in nearshore pathways to both Smithic Bank and the Holderness Coast is considered to be **slight** (not significant) adverse significance. The judgement for this outcome over a **moderate** (significant) adverse effect is partially due to a magnitude of effect between negligible to minor and partially due to more pathways remaining available to feed Smithic Bank than those which would be partially affected by the crossing, so the overall significance is given as **slight** (not significant).

Further mitigation

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

Cable re-burial and repair (MP-O-5)

1.11.2.57 Section 4.6.4 of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a detailed review of cable burial and repairs.

1.11.2.58 During the operation phase (expected to be around 35 years) provisions exist for cable re-burial and repair for sections of the export, array and interconnector cables, should the need arise. Jetting tools (i.e. CFE or similar) are likely to be used to help achieve desired cable burial depths. During this activity seabed sediments will become fluidised within a trench with any (remaining) fines likely to locally increase suspended sediment concentrations in a similar manner described for cable installation (MP-C-2), albeit for smaller discrete sections of cables (up to 2 km sections for cable re-burial).

1.11.2.59 The magnitude of impact and significance of effect are considered to be similar in behaviour but lesser in volume than those previously indicated in **Section 1.11.1** for seabed installation activities related to cable trenching (i.e. **negligible** magnitude and **not significant**).

1.11.3 Decommissioning

1.11.3.1 The impacts of 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 1.13** along with the MDS option.

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

Sediment disturbance – all direct activities during decommissioning that may lead to locally raised SSC at source (MP-D-1)

1.11.3.3 Sediment disturbance from decommissioning foundations is limited to the HVAC Booster Station Search 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 considered not significant). 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.

Changes to tidal and wave regimes associated with the removal of foundations (MP-D-2)

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 situation that represents a future baseline. Most blockage effects from the array and HVAC Booster Station Search Area are remote from any receptors, so a cessation of blockage related effects is not expected to lead to any concern.

Environmental value

1.11.3.7 The rates of cliff erosion and patterns of longshore drift along the Holderness Coast are the primary environmental interest sensitive to potential changes in waves due to Hornsea Four. This receptor has a **high** environmental value for sediment transfer to the south to the Humber, the Lincolnshire coast and The Wash (Natural England 2015).

1.11.3.8 The morphology of Smithic Bank is a further environmental receptor sensitive to changes in waves. This feature is considered to have a **medium** environmental value due to the more localised influence.

Magnitude of impact

1.11.3.9 Since there is no measurable change in wave conditions predicted to reach Smithic Bank or the Holderness Coast when the foundations are in place then when they are removed there is also not expected to be any measurable change which would impact on cliff erosion rates or patterns of longshore drift. The magnitude of impact is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact is **not significant** as defined in the assessment of significance matrix (**Table 1.16**) and is therefore not considered further in this assessment.

Further mitigation

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

1.12 Cumulative Effect Assessment (CEA)

1.12.1 CEA Methodology

1.12.1.1 Section 4.11 of **Volume A5, Annex 1.1: Marine Processes Technical Report** provides a detailed review of cumulative effects.

1.12.1.2 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

1.12.1.3 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 A4, Annex 5.3: Offshore Cumulative Effects** and **Volume A4, Annex 5.4 Location of Offshore Cumulative Schemes** and are presented in a series of maps within the same documents.

1.12.1.4 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 tier structure aims to provide a clear understanding of the level of confidence in the cumulative assessments. An explanation of each tier is provided in **Table 1.19**.

Table 1.19: 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.

1.12.1.5 The plans and projects selected as relevant to the CEA of impacts to marine processes are based on an initial screening exercise undertaken on a long list (see **Volume A4, Annex 5.3: Offshore Cumulative Effects** and **Volume A4, 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.

1.12.1.6 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 equates 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 potentially encounter successive modifications.

1.12.1.7 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 1.20**. The operational projects within the table are included due to their completion / commissioning subsequent to the data collection process for Hornsea Four and as such are not included within the baseline characterisation. 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 A4, Annex 5.3: Offshore Cumulative Effects** and **Volume A4, Annex 5.4 Location of Offshore Cumulative Schemes**.

Table 1.20: Projects screened into the marine processes cumulative assessment.

Tier	Project / plan	Details / relevant dates	Distance to Hornsea Four Array (km)	Distance to Hornsea Four ECC (km)	Distance to Hornsea Four HVAC Booster Station Search Area (km)	Reason for inclusion in CEA
1	Spoil disposal at HU015	Active	n/a	2.5	n/a	Potential overlap in sediment plumes between spoil disposal at HU015 and cable trenching within nearshore area.
1	Dogger Bank A and B export cable	Planned	n/a	1.3	n/a	Comparable adjacent works to landfall area. Crossing required seaward of Smithic Bank.
1	Hornsea Project One	Constructed	16.8	n/a	83.6	Potential for interaction of array scale blockage effects on wave energy transmission towards the coast.
1	Hornsea Project Two	Constructed (foundations)	3.4	n/a	67.3	
1	Hornsea Three	Planned	46.5	n/a	117.1	
1	Johnston	Planned decommissioning	Within array boundary	n/a	n/a	Wellhead Protection Structure (WHPS) and manifold / template due for decommissioning from 2022. Possible sediment disturbance events.
1	Tolmount Platform	Installed	n/a	1	n/a	Potential for drill arisings from production wells during operation interacting with sediment plumes during cable installation activities.

Tier	Project / plan	Details / relevant dates	Distance to Hornsea Four Array (km)	Distance to Hornsea Four ECC (km)	Distance to Hornsea Four HVAC Booster Station Search Area (km)	Reason for inclusion in CEA
3	Endurance	Proposed	Potential for some overlap	Potential for pipeline crossing	n/a	Possible co-location for some offshore assets. Cable crossing with pipeline to Easington.
3	Scotland England Green Link 2 (SEGL2)	Pre-planning application	TBC	TBC	TBC	Adjacent to landfall area, crossing Smithic Bank.

1.12.1.8 The proposed Platypus pipeline is already considered as a potential impact with Hornsea Four in relation to the requirement for an additional cable crossing along the offshore ECC (**Table 1.7**). The Platypus platform is located around 9 km south of the offshore ECC.

1.12.1.9 Given the likely reach of effects assessed for the MDS case, there is no basis for the list of projects screened into the cumulative assessment to extend north of Flamborough Head or include the Humber Estuary, or activities further south.

1.12.1.10 The cumulative MDS cases outlined in **Table 1.20** have the potential to result in the greatest cumulative effect (i.e. increased sources and pathways) on various receptor groups. The cumulative effects assessed in this section have been selected from the details provided in the project description for Hornsea Four (summarised in **Table 1.13**), as well as the information available on other projects and plans 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. Spoil disposal is believed to occur on ebb tides to ensure sediment plumes disperse away from the coast to the east. The use of the spoil site by the harbour is expected to be relatively infrequent and on demand (Hornsea Four is not proposing to use HU015 for any disposal activities).

1.12.2.2 Hornsea Four has the potential to create elevated levels of suspended sediments in the nearshore during excavation of HDD exit pits and cable trenching using CFE. If these activities occur on the ebb tide then sediment plumes could be advected towards the spoil site and potentially combine with any spoil disposal occurring at HU015 at the same time. Given the distance involved the concentrations of any sediment plumes related to Hornsea Four are likely to become proportional to background concentrations and be short-lived as the area is highly dispersive for fine sediments. The cumulative effect of combined sources and pathways is considered to be negligible due to the low likelihood of occurrence and relatively short-term of the activities.

1.12.3 Dogger Bank A and B export cable landfall works

1.12.3.1 The assumption is that all landfall works for Dogger Bank A and B export cables 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 cumulative effects on the integrity of the local beach.

1.12.3.2 The Hornsea Four ECC plans to cross the export cables from Dogger Bank A and B at a location seaward of Smithic Bank. This issue is considered in **paragraph 1.11.2.12** *et seq*.

1.12.4 Hornsea Project One and Hornsea Project Two and Hornsea Three

1.12.4.1 **Paragraph 1.11.2.34** discusses the potential changes to waves affecting coastal morphology on the basis of Hornsea Project One and Two and Hornsea Three all being present along with Hornsea Four. The conclusion of the assessment, supported by wave modelling, was a **not significant** adverse impact on either the Holderness Coast or Smithic Bank.

1.12.4.2 Hornsea Project One and Hornsea Project Two are relatively close to Hornsea Four (around 3.3 km to the southeast at the closest point). The consented layouts and foundation types for these two projects assumed a MDS case with wide based GBS foundations that would have had the potential for array-scale blockage effects on waves and flows which could have acted cumulatively with Hornsea Four for waves passing between these projects (i.e. from north-westerly or south-easterly wave directions). The moderation of this potential interaction now exists because both Hornsea Project One and Hornsea Project Two have been developed with an alternative layout with a fewer number of smaller diameter monopile type foundations which dramatically reduces the effective scale of blockage for both an individual foundation and for all foundations at the array scales.

1.12.4.3 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 Orsted (2020a). This review concluded no discernible changes in wave heights due to the presence of the monopile foundations of Hornsea Project One. As the installation of foundations at Hornsea Project One is now complete, the effect of these structures becomes part of the present baseline.

1.12.4.4 Hornsea Three is located approximately 46.5 km (at the closest point) to the east of Hornsea Four (**Figure 1.11**). The original application to develop this project was submitted to the Planning Inspectorate with a MDS for effects on waves based on 319 m * 53 m diameter GBS WTG-type foundations. The application has subsequently been revised with a maximum of 231 WTG-type foundations, plus 19 associated structures (a total of 250 foundations) (Orsted 2020b). The moderation of possible cumulative effects on wave energy reduction towards the coast with Hornsea Three is largely based on the distance apart and the limited occasions when waves can pass from one project to another to create a cumulative interaction.

1.12.5 Johnston WHPS and manifold / template

1.12.5.1 The Johnston WHPS and manifold / template are both located within the offshore array along with a section of pipeline which requires cable crossings. There are plans to decommission these subsea structures from 2022, or later. Short-term periods of seabed disturbance could occur during decommissioning activity, depending on the methods used. The potential for any cumulative impact depends on the timing of any adjacent activities related to the construction period for Hornsea Four which may also generate sediment plumes (e.g. from cable trenching) that have a potential to overlap and develop a greater stress level on relevant environmental receptors. Health and Safety provision will likely maintain safe working areas for both projects which will mitigate any larger effect. In any case the main sediment types involved are sandy sediments that would fall out of suspension relatively quickly.

1.12.5.2 Based on present information, the case for any cumulative effect of combined sources and pathways is considered to have a low likelihood of occurrence and is not considered further.

1.12.6 Tolmount Platform

1.12.6.1 Tolmount is a drilling platform mounted on a jacket structure at a location around 1 km to the south of the offshore ECC, a site in relative close proximity to the HVAC Booster Search Area (around 2.4 km to the south-east, at the closest point). The development also includes a new pipeline to connect with the Easington Gas Terminal. The offshore ECC does not require any crossings of this new pipeline. The potential cumulative impact would be short-term during the drilling activities of four wells to reach the gas reserve with drilling muds and finer drill cuttings potentially forming a sediment plume that could advect across the offshore ECC. If trenching operations for the offshore ECC occurred at the same time, in this general area, then there may be a potential for overlapping sediment plumes and wider smothering effects of benthic receptors. The main areas with accumulations of drilling muds and cuttings was assessed to be within a 150 m radius of the Tolmount Platform (Premier Oil 2017). Since the installation of the platform was completed in October 2020 the likelihood for any overlapping sediment plumes with the construction phase of Hornsea Four is considered minimal to nil.

1.12.6.2 Based on present information, the case for any cumulative impacts is considered to have a low likelihood of occurrence and is not considered further.

1.12.7 Endurance

1.12.7.1 Endurance is a proposed CO_2 storage facility targeting a marine geological reservoir that overlaps with the northern part of the Hornsea Four array area, albeit using a large scale saline aquifer at a depth below seabed of over 1,000 m. Based on the limited information available at this time (Tier 3 activity), the scheme appears to require around 30 wells to be drilled, install flow lines and subsea manifolds to link the wells and pipelines to bring in CO_2 from Teesside and Easington. There will also be a number of Brine Production Platforms which may target sites both within the array area as well as slightly to the north. The final siting of all structures remains dependent on completing site surveys and front-end engineering design.

1.12.7.2 Drilling for of the wells has the potential to created drill arisings, sediment plumes and cuttings mounds. The timing of this activity is most likely to be before the construction phase of Hornsea Four and safety restrictions would necessarily limit both activities from occurring at the same time, however, during the operation phase of Hornsea Four the chance remains that some cable re-burial or repairs might occur within the southern part of the array area to leading to seabed disturbance and sediment plumes that might overlap with and drilling related sediment plumes.

1.12.7.3 Flow lines from Endurance that overlap with the array area will most likely require rock berms with any array or interconnector cables. The pipeline to Easington will also need to be crossed by the offshore ECC with additional requirements for rock berms (see **Table 1.7**). The direct line for this pipeline is planned to pass to the west of the HVAC Booster Search Area. The effects of rock berms for both areas are considered from **paragraph 1.11.2.8** to **1.11.2.15**.

1.12.7.4 If any Brine Production Platforms are placed within the Hornsea Four offshore array area then the potential exists for additional wake related effects to be present, similar to foundation related effects from Hornsea Four. At the present time, there are no specific details about the location, scale and type of the Brine Production Platforms foundations within the offshore array area, however, the number is expected to be minimal and the type of structure is also likely to have a low solidity factor (multi-leg). Wake related effects for the offshore array area are considered in **paragraph 1.11.2.24**.

1.12.8 Scotland England Green Link 2 (SEGL2)

1.12.8.1 The SEGL2 is a proposed interconnector being developed by National Grid Electricity Transmission (NGET), with a landfall site which may be just to the north of the Hornsea Four landfall with a cable which would also pass across Smithic Bank to the north of the offshore ECC but without any requirement for a cable crossing. The potential cumulative effects with Hornsea Four relate to construction related sediment plumes should both projects be installing cables around the same period and also the potential for cable protection requirements across Smithic Bank, although the likelihood of this requirements is considered to be low based on presently available evidence.

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** (Orsted 2018a)) which concluded that impacts on marine processes would be limited to the UK Exclusive Economic Zone (EEZ). Based on present understanding of the baseline environment, along with modelling work carried out for Hornsea Project One, Hornsea Project Two and Hornsea Three (which are all located closer to the boundaries of other European Economic Area (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 sediment 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 A marine processes assessment is provided for Hornsea Four based on MDS considerations (for conservatism of the likely scale of effects) and acknowledging in-built project commitments. An evidence-based approach underpins the methodology for the assessment which is also supported by modelling of specific features of interest.

1.15.1.2 The final layouts and installed foundation for Hornsea Project One and Hornsea Project Two provide important moderations to potential blockage effects on waves in comparison to their respective EIA cases which were based on conservative assumptions. The review of operational wave monitoring evidence from Hornsea Project One provides important evidence to underpin the minimal scale of influence on waves now passing through this array (Orsted 2020a). Consequently, the cumulative assessment for Hornsea Four with these projects, as well as Hornsea Three, demonstrates no measurable effect on waves arriving at the coast and therefore no associated impact on longshore drift along the Holderness Coast.

1.15.1.3 **Table 1.21** presents a summary of the potential impacts assessed within this chapter. All impacts which have been assessed are listed for completeness, however, some remain as pathways for consideration in related EIA chapters.

Table 1.21: Summary of potential impacts assessed for marine processes.

Impact and Phase	Receptor and value/sensitivity	Magnitude and significance	Mitigation	Residual impact
Construction				
Seabed preparation activities in landfall area (MP-C-1)	Bridlington Harbour LSO Spoil site HU015 Low	Negligible adverse Not significant	None	Not significant
Seabed preparation activities - sandwave clearance (MP-C-1)	Pathway for other receptors n/a	n/a	n/a	n/a
	Nearshore: Bridlington Harbour LSO Spoil site HU015 Low	Negligible adverse Not significant	None	Not significant
Seabed preparation activities: Seabed levelling – HVAC Booster Station Search Area (MP-C-1)	Pathway for other receptors n/a	n/a	n/a	n/a
Seabed preparation activities: Seabed levelling – offshore array area (MP-C-1)	Pathway for other receptors n/a	n/a	n/a	n/a
Seabed installation activities: Cable trenching – offshore ECC (nearshore section) (MP-C-2)	Bridlington Harbour Medium	Minor Slight (Not significant)	None	Not significant
Seabed installation activities: Cable trenching – offshore array area (MP-C-2)	Pathway for other receptors n/a	n/a	n/a	n/a
Seabed installation activities: Foundation installation: drilling at HVAC Booster Search Area (MP-C-2)	Pathway for other receptors n/a	n/a	n/a	n/a

Impact and Phase	Receptor and value/sensitivity	Magnitude and significance	Mitigation	Residual impact
Seabed installation activities: Foundation installation: drilling at offshore array area (MP-C-2)	Pathway for other receptors n/a	n/a	n/a	n/a
Scouring around foundations – HVAC Booster Station Search Area (MP-C-3)	Pathway for other receptors n/a	n/a	n/a	n/a
Scouring around foundations – offshore array area (MP-C-3)	Pathway for other receptors n/a	n/a	n/a	n/a
Turbulent wakes around temporary cofferdams (MP-C-4)	Holderness Coast (Fraisthorpe Sands) Low	Negligible adverse Not significant	None	Not significant
Operation and Maintenance				
Scouring around rock berms: Cable crossings – offshore ECC (MP-O-1)	Pathway for other receptors n/a	n/a	n/a	n/a
Scouring around rock berms: Cable crossings – offshore array area (MP-O-1)	Pathway for other receptors n/a	n/a	n/a	n/a
Turbulent wakes from foundations interfering with remote receptors, e.g. Flamborough Front: HVAC Booster Search Area (MP-O-2)	Pathway for other receptors n/a	n/a	n/a	n/a
Turbulent wakes from foundations interfering with remote receptors, e.g. Flamborough Front: offshore array area (MP-O-2)	Flamborough Front Medium	Negligible Neutral	None	Neutral
Changes to waves affecting coastal morphology (MP-O-3)	Holderness Coast and cliffs, Smithic Bank High Medium	Negligible adverse Not significant	None proposed beyond existing commitments	Not significant

Impact and Phase	Receptor and value/sensitivity	Magnitude and significance	Mitigation	Residual impact
Changes to nearshore sediment pathways (MP-O-4)	Holderness Coast, Smithic Bank Medium	Negligible to minor adverse Slight (not significant)	None proposed beyond existing commitments	Slight (not significant)
Decommissioning				
Sediment disturbance – all direct sediment disturbance activities during decommissioning that may lead to locally raised SSC at source (MP-D-1)	Pathway for other receptors n/a	n/a	n/a	n/a
Changes to tidal and wave regimes associated with the removal of foundations (MP-D-2)	Holderness Coast and cliffs, Smithic Bank High Medium	Negligible positive Not significant	None	Not significant

1.16 References

ABPmer and HR Wallingford. (2009). Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide. for COWRIE.

Bibby HydroMap. (2019). Hornsea 4 Offshore Wind Farm. Lot 7 GP1a Export Cable Corridor. Volume 3: Results Report. Bibby HydroMap Project No. 2019-023A.

BOEM. (2017). Improving Efficiencies of National Environmental Policy Act Documentation for Offshore Wind Facilities - Case Studies Report. OCS Study. BOEM 2017-16.

Bradley, S. L., Milne, G. A., Shennan, I., & Edwards, R. J. (2011). An improved glacial isostatic adjustment model for the British Isles. Journal of Quaternary Science, 26, 541-52. doi:https://doi.org/10.1111/j.1365-246X.2008.04033.x

Carotenuto, P., Meyer, P. J., Strøm, P. J., Cabarkapa, Z., St John, H., Jardine, R., Buckley, R. (2018). Installation and axial capacity of the Sheringham Shoal offshore wind farm monopiles – a case history. Engineering in Chalk: Proceedings of the Chalk 2018 Conference. doi:https://doi.org/10.1680/eiccf.64072.117

CCO. (2014). Seabed Mapping: Flamborough Head to Spurn Point. TR47. East Riding Coastal Monitoring Programme.

Cefas. (2010). SLAB5 Monitoring at Bridlington dredged material disposal site (HU015): implications for the integrity of the Flamborough Head SAC.

Cefas. (2016). Suspended Sediment Climatologies around the UK. Report for the UK Department for Business, Energy & Industrial Strategy offshore energy Strategic Environmental Assessment programme.

CIRIA. (2000). Scoping the assessment of sediment plumes arising from dredging. Report CIRIA C547.

DECC. (2008a). Atlas of UK Marine Renewable Energy Resources. Technical Report. For BERR. R.1432.

DECC. (2008b). Review of Round 1 sediment process monitoring data – lessons learnt. A report for the Research Advisory Group. Final Report.

DECC (2011a). Overarching National Policy Statement for Energy (EN-1). Presented to Parliament pursuant to Section 5(9) of the Planning Act 2008. London: The Stationery Office.

DECC. (2011b). National Policy Statement for Renewable Energy Infrastructure (EN-3). Presented to Parliament pursuant to section 5(9) of the Planning Act 2008. London: The Stationery Office.

DECC (2016). OESEA3 Environmental Report. Future Leasing/Licensing for Offshore Renewable Energy, Offshore Oil & Gas, Hydrocarbon Gas and Carbon Dioxide Storage and Associated Infrastructure.

EMU (2013). Subzone Assessment (Phase 1&2): Final Technical Report – MetOcean: Data. Data Collection Campaign. June 2010 - July 2012. Report No: 11/J/1/1563/1264. Issue 2.

English Nature (2004). The Southern North Sea Marine Natural Area. A contribution to regional planning and management of the seas around England.

Environment Agency (2020). National Coastal Erosion Risk Mapping (NCERM) - National (2018 - 2021). Retrieved from data.gov.uk: https://data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021

EU (2008). DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Union.

ForeWind. (2013). Dogger Bank – Creyke Beck. Continuation from Part 1: ES Chapter 12 Appendix C - Gardline Cable Corridor Inshore Survey Report. Application Reference: 6.12.3.

Gardline. (2019). Hornsea 4 Offshore Wind Farm GP1A Survey. Processing and Interpretation Report. Survey Date: August - September 2018. Report Number: 11210.2. Rev 0.

GeoSurveys. (2019). 2D UHRS Hornsea 04 Windfarm Geophysical Survey. Interpretative Report. Document No.: REP83148. 8 March 2019.

Hallermeier, R. J. (1983). Sand Transport Limits in Coastal Structure Design. Coastal Structures '83 (pp. 703-716). American Society of Civil Engineers.

HM Government. (2011). UK Marine Policy Statement. HM Government, Northern Ireland Executive, Scottish Government and Welsh Assembly Government.

HR Wallingford. (1993). Coastal Management. Mapping of littoral cells. Report SR 328.

HR Wallingford. (2005). Bridlington Harbour half–tide basin. Wave disturbance modelling. EX5205.

HR Wallingford, Cefas/UEA, Posford Haskoning, and Brian D'Olier. (2002). Southern North Sea Sediment Transport Study, Phase 2. Report EX 4526.

IECS. (2016). The East Riding Coastline: Past, Present and Future. Institute of Estuarine and Coastal Studies (IECS). The University of Hull.

IECS. (2019). Hornsea Four Foreshore Survey 2019: Intertidal Benthic Community Characterisation.

JNCC. (2007). Geological Conservation Review. Volume 28: Coastal Geomorphology of Great Britain. Chapter 4: Soft-rock cliffs – GCR site reports. Site: HOLDERNESS (GCR ID: 9102).

JNCC. (2016). UK0013036. Retrieved from https://sac.jncc.gov.uk: https://sac.jncc.gov.uk/site/UK0013036

JNCC. (2017). Method for creating version 2 of the UK Composite Map of Annex I Sandbanks slightly covered by seawater all of the time.

Kenyon, N. H., & Cooper, B. (2005). Sand banks, sand transport and offshore wind farms.

MMO. (2015). https://www.gov.uk/government/publications/. Retrieved July 2019, from east-inshore-and-east-offshore-marine-plans: https://www.gov.uk/government/publications/east-inshore-and-east-offshore-marine-plans

Natural England. (2015). National Character Area profile: 40. Holderness.

Orsted. (2018a). Hornsea Four Environmental Impact Assessment: Scoping Report.

Orsted. (2018b). Hornsea Project Four Offshore Wind Farm – Evidence Plan. Marine Ecology & Processes Technical Panel. Marine Geology, Oceanography and Physical Processes Evidence Based Approach Position Paper – Meeting 1. 12th September 2018.

Orsted. (2020a). Hornsea Project Four Offshore Wind Farm - Evidence Plan. Marine Ecology & Processes Technical Panel. Technical Note - Marine Processes: Operational Wave Monitoring Assessment. Doc. no. 01493919. Version B

Orsted. (2020b). Hornsea Project Three Offshore Wind Farm. Response to the Secretary of State's Consultation. Appendix 11: Draft Development Consent Order Schedule of Changes. February 2020.

Palmer, Matthew; Howard, Tom; Tinker, Jonathan; Lowe, Jason; Bricheno, Lucy ; Calvert, Daley; Edwards, Tamsin; Gregory, Jonathan; Harris, Glen; Krijnen, Justin; Pickering, Mark; Roberts, Chris; Wolf, Judith . 2018 UKCP18 marine report. Met Office Hadley Centre, 133pp.

Premier Oil. (2017). Tolmount Area Development Offshore Environmental Statement.

Pye, K., & Blott, S. J. (2015). Spatial and temporal variations in soft-cliff erosion along the Holderness coast, East Riding of Yorkshire, UK. Journal of Coastal Conservation, Planning and Management, 19(6), 785 - 808. doi:10.1007/s11852-015-0378-8

Scott Wilson. (2010). Humber Estuary Coastal Authorities Group. Flamborough Head to Gibraltar Point Shoreline Management Plan. Appendix C – Assessment of Coastal Behaviour and Baseline Scenarios. Final. December.

Sistermans, P., & Nieuwenhuis, O. (2003). Holderness Coast (United Kingdom). Eurosion Case Study.

SMart Wind. (2013). Hornsea Offshore Wind Farm. Project One. Environmental Statement. Volume 2 - Offshore. Chapter 1 - Marine Processes. PINS Document Reference: 7.2.1.

SMart Wind. (2015). Hornsea Offshore Wind Farm. Project Two. Environmental Statement. Volume 2 - Offshore. Chapter 1 - Marine Processes. PINS Document Reference: 7.2.1.

Soulsby, R. (1997). Dynamics of marine sands. A manual for practical applications. Thomas Telford.

The Crown Estate, 2018. The effect of monopile-induced turbulence on local suspended sediment patterns around UK wind farms: field survey report. Prepared for The Crown Estate by IECS. IECS-YBB313-2017.

The Planning Inspectorate. (2018). Scoping Opinion: Proposed Hornsea Four Wind Farm. Case Reference: EN010098.