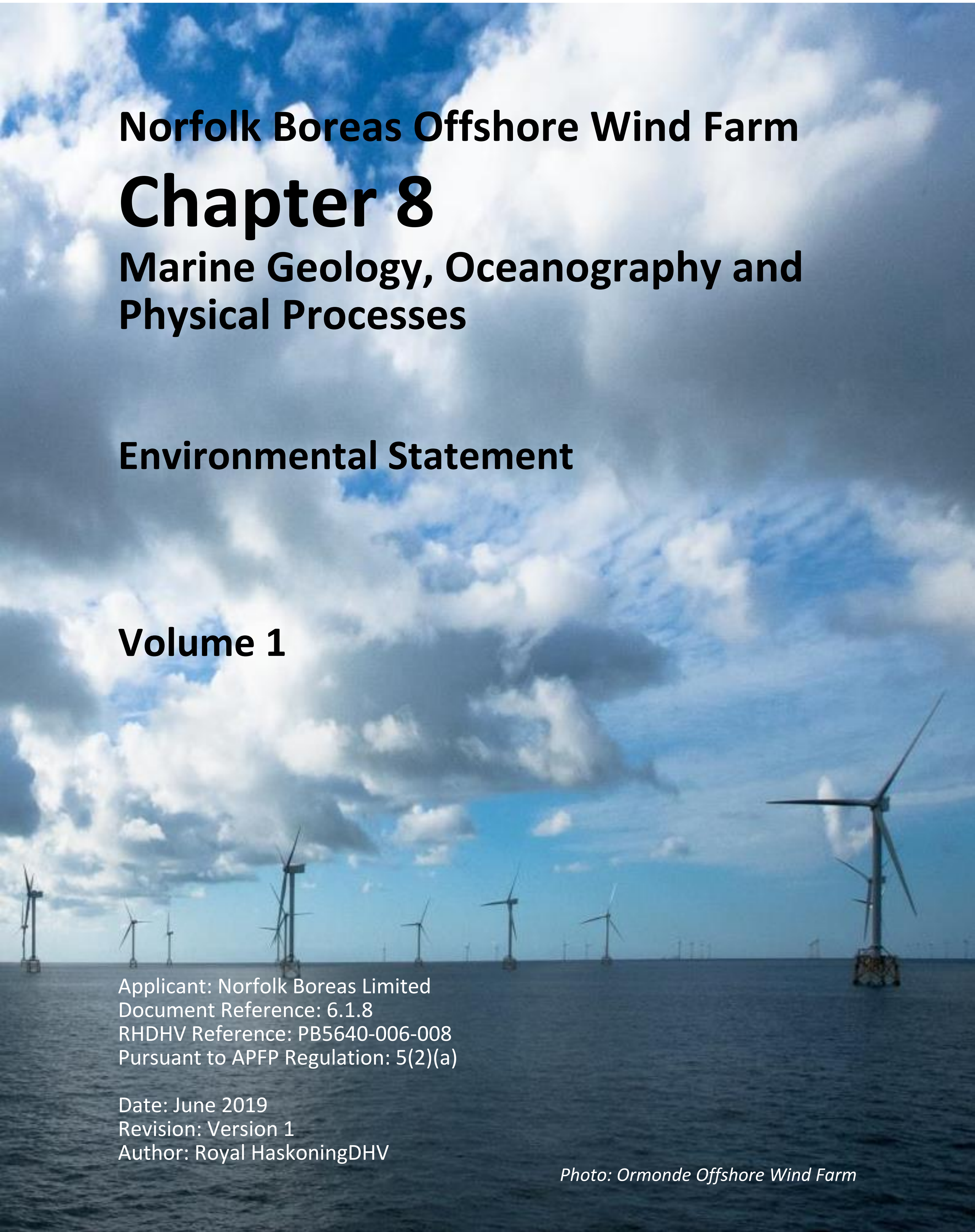

Norfolk Boreas Offshore Wind Farm

Chapter 8

Marine Geology, Oceanography and Physical Processes

Environmental Statement

Volume 1

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Appendix 8.1 Particle size characteristics

Glossary of Acronyms

3D	Three Dimensional
ADCP	Acoustic Doppler Current Profiler
AWAC	Acoustic Wave and Current Meter
BGS	British Geological Society
CD	Chart Datum
CIA	Cumulative Impact Assessment
DCO	Development Consent Order
EIA	Environmental Impact Assessment
EPP	Evidence Plan Process
ES	Environmental Statement
ETG	Expert Topic Group
EU	European Union
FTU	Formazin Turbidity Unit
GBS	Gravity Base Structure
HAT	Highest Astronomical Tide
HDD	Horizontal Directional Drilling
km	Kilometre
km^2	Kilometre Squared
LAT	Lowest Astronomical Tide (CD)
m	Metre
m^2	Metre Squared
m^3	Metre Cubed
m/s	Metres Per Second
MCZ	Marine Conservation Zone
MESL	Marine Ecological Surveys Limited
mg/l	Milligrams Per Litre
MHWS	Mean High Water Spring
mm	Millimetre
MW	Megawatt
NPS	National Policy Statements
NSIP	Nationally Significant Infrastructure Projects
NV	Norfolk Vanguard offshore windfarm which is comprised of NV East (the Eastern offshore array area) and NV West (the western offshore array area)
OD	Ordnance Datum
OWF	Offshore Wind Farm
PEIR	Preliminary Environmental Information Report
RCP	Representative Concentration Pathways
s	Second (unit of time)
SMP	Shoreline Management Plan
SAC	Special Area of Conservation
SNCB	Statutory Nature Conservation body
SPA	Special Protection Area
SPM	Suspended Particulate Matter
S-P-R	Source-Pathway-Receptor conceptual model

SSC	Suspended Sediment Concentration
SSSI	Site of Special Scientific Interest
UK	United Kingdom of Great Britain and Northern Ireland
UKCP18	United Kingdom Climate Projections 2018
ZEA	Zone Environmental Appraisal

Glossary of Terminology

Accretion	The addition of newly deposited sediment vertically and/or horizontally
Amphidromic point	The centre of an amphidromic system; a nodal point around which a standing-wave crest rotates once each tidal period
Array cables	Cables which link wind turbine to wind turbine and wind turbine to offshore electrical platform.
Astronomical tide	The predicted tide levels and character that would result from the gravitational effects of the earth, sun and moon without any atmospheric influences
Bathymetry	Topography of the seabed
Beach	A deposit of non-cohesive sediment (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively ‘worked’ by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds
Bedforms	Features on the seabed (e.g. sand waves, ripples) resulting from the movement of sediment over it
Bedload	Sediment particles that travel near or on the bed
Clay	Fine-grained sediment with a typical particle size of less than 0.002 mm
Climate change	A change in global or regional climate patterns. Within this chapter this usually relates to any long-term trend in mean sea level, wave height, wind speed etc, due to climate change
Closure depth	The depth that represents the ‘seaward limit of significant depth change’, but is not an absolute boundary across which there is no cross-shore sediment transport
Coastal processes	Collective term covering the action of natural forces on the shoreline and nearshore seabed
Cohesive sediment	Sediment containing a significant proportion of clays, the electromagnetic properties of which causes the particles to bind together
Crest	Highest point on a bedform or wave
Cross-shore	Perpendicular to the shoreline. Also referred to as shore normal
Current	Flow of water generated by a variety of forcing mechanisms (e.g. waves, tides, wind)
Ebb tide	The falling tide, immediately following the period of high water and preceding the period of low water
Episodic	Composed of a series of discrete events rather than as a continual process
Erosion	Wearing away of the land or seabed by natural forces (e.g. wind, waves, currents, chemical weathering)
Evidence Plan Process	A voluntary consultation process with specialist stakeholders to agree the approach to the EIA and information to support the HRA.
Export cables	Cables that transmit electricity from the offshore electrical platform to the onshore project substation.
Flood tide	The rising tide, immediately following the period of low water and preceding the period of high water

Foreshore	A morphological term for the lower shore zone/area on the beach that lies between mean low and high water
Glacial till	Poorly-sorted, non-stratified and unconsolidated sediment carried or deposited by a glacier
Gravel	Loose, rounded fragments of rock larger than sand but smaller than cobbles. Sediment larger than 2mm (as classified by the Wentworth scale used in sedimentology)
Habitat	The environment of an organism and the place where it is usually found
High water	Maximum level reached by the rising tide
Holocene	The last 10,000 years of earth history
Hydrodynamic	The process and science associated with the flow and motion in water produced by applied forces
Interconnector cables	Offshore cables which link offshore electrical platforms within the Norfolk Boreas site.
Intertidal	Area on a shore that lies between Lowest Astronomical Tide (LAT) and Highest Astronomical Tide (HAT)
Landfall	Where the offshore cables come ashore at Happisburgh South
Lithology	The description of the macro features of a rock or rock-type
Longshore transport rate	Rate of transport of sediment parallel to the shore. Usually expressed in cubic metres per year
Long-term	Refers to a time period of decades to centuries
Low water	The minimum height reached by the falling tide
Mean sea level	The average level of the sea surface over a defined period (usually a year or longer), taking account of all tidal effects and surge events
Megaripples	Bedforms with a wavelength of 0.6 to 10.0m and a height of 0.1 to 1.0m. These features are smaller than sand waves but larger than ripples
Neap tide	A tide that occurs when the tide-generating forces of the sun and moon are acting at right angles to each other, so the tidal range is lower than average
Nearshore	The zone which extends from the swash zone to the position marking the start of the offshore zone (~20m)
Norfolk Boreas site	The Norfolk Boreas wind farm boundary. Located offshore, this will contain the windfarm array.
Norfolk Vanguard	Norfolk Vanguard offshore wind farm, sister project of Norfolk Boreas.
The Norfolk Vanguard OWF sites	Term used exclusively to refer to the two-distinct offshore wind farm areas, Norfolk Vanguard East and Norfolk Vanguard West (also termed NV East and NV West).
Numerical modelling	Refers to the analysis of coastal processes using computational models
Offshore	Area to seaward of nearshore in which the transport of sediment is not caused by wave activity
Offshore cable corridor	The corridor of seabed from the Norfolk Boreas site to the landfall site within which the offshore export cables will be located.
Offshore electrical platform	A fixed structure located within the wind farm area, containing electrical equipment to aggregate the power from the wind turbine generators and convert it into a more suitable form for export to shore
Offshore export cables	The cables which transmit power from the offshore electrical platform to the landfall.
Offshore project area	The area including the Norfolk Boreas site, project interconnector search area and offshore cable corridor.

Offshore service platform	A platform to house workers offshore and/or provide helicopter refuelling facilities. An accommodation vessel may be used as an alternative for housing workers.
Project interconnector cable	Offshore cables which would link either turbines or an offshore electrical platform in the Norfolk Boreas site with an offshore electrical platform in one of the Norfolk Vanguard sites.
Project interconnector search area	The area within which the project interconnector cable would be installed.
Pleistocene	An epoch of the Quaternary Period (between about 2 million and 10,000 years ago) characterised by several glacial ages
Quaternary Period	The last 2 million years of earth history incorporating the Pleistocene ice ages and the post-glacial (Holocene) Period
Safety zone	An area around a vessel or structure which should be avoided during offshore construction.
Sand	Sediment particles, mainly of quartz with a diameter of between 0.063mm and 2mm. Sand is generally classified as fine, medium or coarse
Sand wave	Bedforms with wavelengths of 10 to 100m, with amplitudes of 1 to 10m
Scour protection	Protective materials to avoid sediment being eroded away from the base of the foundations as a result of the flow of water.
Sea level	Generally refers to 'still water level' (excluding wave influences) averaged over a period of time such that periodic changes in level (e.g. due to the tides) are averaged out
Sea-level rise	The general term given to the upward trend in mean sea level resulting from a combination of local or regional geological movements and global climate change
Sediment	Particulate matter derived from rock, minerals or bioclastic matter
Sediment transport	The movement of a mass of sediment by the forces of currents and waves
Shallow water	Commonly, water of such depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than half the surface wave length as shallow water
Shore platform	A platform of exposed rock or cohesive sediment exposed within the intertidal and subtidal zones
Short-term	Refers to a time period of months to years
Significant wave height	The average height of the highest of one third of the waves in a given sea state
Silt	Sediment particles with a grain size between 0.002mm and 0.063mm, i.e. coarser than clay but finer than sand
Spring tide	A tide that occurs when the tide-generating forces of the sun and moon are acting in the same directions, so the tidal range is higher than average
Storm surge	A rise in water level on the open coast due to the action of wind stress as well as atmospheric pressure on the sea surface
Surge	Changes in water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and the astronomical tide predicted using harmonic analysis
Suspended sediment	The sediment moving in suspension in a fluid kept up by the upward components of the turbulent currents or by the colloidal suspension
Swell waves	Wind-generated waves that have travelled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter crests than waves within their fetch
The Applicant	Norfolk Boreas Limited
The project	Norfolk Boreas Wind Farm including the onshore and offshore infrastructure.

Tidal current	The alternating horizontal movement of water associated with the rise and fall of the tide
Tidal range	Difference in height between high and low water levels at a point
Tide	The periodic rise and fall of the water that results from the gravitational attraction of the moon and sun acting upon the rotating earth
Wave climate	Average condition of the waves at a given place over a period of years, as shown by height, period, direction etc.
Wave height	The vertical distance between the crest and the trough
Wavelength	The horizontal distance between consecutive bedform crests

8 MARINE GEOLOGY, OCEANOGRAPHY AND PHYSICAL PROCESSES

8.1 Introduction

1. This chapter of the Environmental Statement (ES) describes the marine physical environment of the Norfolk Boreas Offshore Wind Farm (herein 'the project' or 'Norfolk Boreas').

2. Norfolk Boreas comprises the main Norfolk Boreas site (where the wind farm array is located), the offshore cable corridor from the site to the landfall at Happisburgh South and the project interconnector search area within which cables would be installed to connect Norfolk Boreas to the Norfolk Vanguard offshore wind farm.

3. This chapter provides a summary description of key aspects relating to existing marine physical processes followed by an assessment of the magnitude and significance of the effects upon the baseline conditions resulting from the construction, operation and decommissioning of the project, as well as those effects resulting from cumulative interactions with other existing or planned projects.

4. This chapter of the ES was written by Royal HaskoningDHV marine physical processes specialists, and incorporates interpretation of geophysical, geotechnical and benthic survey data collected by Fugro (2017a; 2018) and metocean data collected by Cefas between May 2018 to January 2019. In addition, ABPmer (2018) has undertaken a sand wave study (Appendix 7.1 of the Information to Support HRA, document reference 5.3) in relation to cable installation activities in the Haisborough, Hammond and Winterton SAC which has informed the impact assessments in this chapter.

5. Vattenfall Wind Power Limited (VWPL) (the parent company of Norfolk Boreas Limited) is also developing Norfolk Vanguard, a 'sister project' to Norfolk Boreas. Norfolk Vanguard's development schedule is approximately one year ahead of Norfolk Boreas and as such the Development Consent Order (DCO) application was submitted in June 2018.

6. Norfolk Vanguard may undertake some enabling works for Norfolk Boreas, but these are only relevant to the assessment of impacts onshore. This assessment does however include interconnector cables between the Norfolk Boreas and Norfolk Vanguard projects (herein, 'project interconnector cables'). If Norfolk Vanguard does not proceed then project interconnector cables would not be required.

7. This assessment process has been informed by the following, as explained in more detail throughout the chapter:

   - Interpretation of survey data specifically collected for the project including bathymetry, geophysical, geotechnical, environmental and metocean data;

- The existing evidence base regarding the effects of offshore wind farm developments on the physical environment;
- Appendix 7.1 of the Information to Support HRA (document reference 5.3) which provides a sand wave study by ABPmer (2018), assessing potential impacts of cable installation activities on the Annex I Sandbanks features of the Haisborough, Hammond and Winterton Special Area of Conservation (SAC);
- Detailed numerical modelling studies undertaken for both the East Anglia Zone Environmental Appraisal (ZEA) and the ES for East Anglia ONE;
- Desk-based assessments undertaken for the ES for East Anglia THREE and the ES for Norfolk Vanguard;
- Discussion and agreement with key stakeholders; and
- Application of expert-based assessment and judgement by Royal HaskoningDHV.

8. The potential effects on marine physical processes have been assessed conservatively using realistic worst-case scenarios for the project.

9. All figures referred to in this chapter are provided in Volume 2 of the ES.

8.2 Legislation, Guidance and Policy

10. The assessment of potential effects has been made with specific reference to the relevant National Policy Statements (NPS) (discussed further in Chapter 3, Policy and Legislative Context). These are the principal decision-making documents for Nationally Significant Infrastructure Projects (NSIP). Those relevant to marine physical processes are:

- Overarching NPS for Energy (EN-1) (July 2011); and
- NPS for Renewable Energy Infrastructure (EN-3) (July 2011).

11. Relevant aspects of EN-1 and EN-3 are presented below in Table 8.1. This chapter of the ES either directly addresses these issues or provides information which enables these issues to be directly addressed in other, more relevant chapters, most notably Chapter 9 Marine Water and Sediment Quality, Chapter 10 Benthic and Intertidal Ecology, Chapter 11 Fish and Shellfish Ecology, Chapter 14 Commercial Fisheries, and Chapter 17 Offshore and Intertidal Archaeology and Cultural Heritage.

Table 8.1 NPS assessment requirements

NPS Requirement	NPS Reference	ES Reference
EN-1 NPS for Energy (EN-1)		
'where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures'	Section 5.5, paragraph 5.5.6	The approach adopted in this ES is a conceptual model based on expert judgement. This was agreed in general terms through the Norfolk Boreas Physical Processes (Expert Topic Group) ETG.

NPS Requirement	NPS Reference	ES Reference
'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) and any relevant Marine Plans (Objective 10 of the East Inshore and East Offshore Marine Plans is "To ensure integration with other plans, and in the regulation and management of key activities and issues, in the East Marine Plans, and adjacent areas" this therefore refers back to the objectives of the SMPs)… 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. • The vulnerability of the proposed development to coastal change, taking account of climate change, during the project's operational life and any decommissioning period.'	Section 5.5, paragraph 5.5.7	The assessment of potential construction and operation and maintenance impacts are described in sections 8.7.6.5 and 8.7.7.6, respectively. The project will not affect the Shoreline Management Plan and allowance has been made for predicated erosion rates during the project design (further detail is provided in Chapter 4 Site Selection and Assessment of alternatives and Appendix 4.3). Embedded mitigation to minimise potential impacts at the coast of cable installation and operation are described in section 8.7.4. Effects on marine ecology biodiversity and protected sites are assessed in Chapter 10 Benthic Ecology, Chapter 11 Fish and Shellfish Ecology, Chapter 12 Marine mammal ecology and chapter 13 Offshore Ornithology Effects on recreation are assessed in Chapter 30 Tourism and Recreation. As described above the project has been designed so that it is not vulnerable to coastal change or climate change.
'the applicant should be particularly careful to identify any effects of physical changes on the integrity and special features of Marine Conservation Zones, candidate marine Special Areas of Conservation (SACs), coastal SACs and candidate coastal SACs, coastal Special Protection Areas (SPAs) and potential SCIs and Sites of Special Scientific Interest (SSSI).'	Section 5.5, paragraph 5.5.9	The potential receptors to morphological change are Haisborough, Hammond and Winterton SAC, North Norfolk Sandbanks and Saturn Reef SAC, Cromer Shoal Chalk Beds MCZ and the East Anglian coast. The potential to affect their integrity is assessed with respect to changes in seabed level caused by foundation and cable installation (sections 8.7.6.3, 8.7.6.4, 8.7.6.6 and 8.7.6.10) and interruption to bedload sediment transport by sand wave levelling for cable installation (section 8.7.6.8).

NPS Requirement	NPS Reference	ES Reference
NPS for Renewable Energy Infrastructure (EN-3)		
'The assessment should include predictions of 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.'	Section 2.6, paragraph 2.6.193 and 2.6.194	Each of the impacts in sections 8.7.6 and 8.7.7 cover the potential magnitude and significance of the physical (waves, tides and sediments) effects upon the baseline conditions resulting from the construction and operation of Norfolk Boreas. Scour resulting from the proposed development is not assessed because scour protection will be used wherever scour will occur, reducing sediment release to negligible quantities.
'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. • Habitat disturbance from construction vessels extendible legs and anchors. • Increased suspended sediment loads during construction. • Predicted rates at which the subtidal zone might recover from temporary effects.'	Section 2.6, paragraph 2.6.113	See above for scour. The quantification and potential impact of seabed loss due to the footprints of the project infrastructure is covered in section 8.7.7.4. A worst-case scenario of all foundations having scour protection is considered to provide a conservative assessment. The worst-case scenario cable-laying technique is jetting and is considered as such in all the cable construction assessments. The disturbance to the subtidal seabed caused by indentations due to installation vessels is assessed in section 8.7.6.11. The potential increase in suspended sediment concentrations and change in seabed level is assessed in sections 8.7.6.2 to 8.7.6.6 and 8.7.6.9 to 8.7.6.10. The recoverability of receptors is assessed for all the relevant impacts, particularly those related to changes in seabed level due to export cable installation (sections 8.7.6.6 and 8.7.6.7), interruptions to bedload sediment transport due to sand wave levelling in the offshore cable corridor (section 8.7.6.8) and morphological and sediment transport effects due to cable protection measures for export cables (section 8.7.7.6).

NPS Requirement	NPS Reference	ES Reference
‘an assessment of the effects of installing cable across the intertidal zone should include information, where relevant, about: • Any alternative landfall sites that have been considered by the applicant during the design phase and an explanation of the final choice. • Any alternative cable installation methods that have been considered by the applicant during the design phase and an explanation of the final choice. • Potential loss of habitat. • Disturbance during cable installation and removal (decommissioning). • Increased suspended sediment loads in the intertidal zone during installation. • Predicted rates at which the intertidal zone might recover from temporary effects.’	Section 2.6, paragraph 2.6.81	Landfall Site Selection and Assessment of Alternatives are provided in Chapter 4. A range of cable installation methods are required and these are detailed in Chapter 5 Project Description. The worst-case scenario for marine physical processes is provided in section 8.7.5.4. Potential habitat loss in the intertidal zone is covered in Chapter 10 Benthic and Intertidal Ecology. Assessment of the potential disturbance and increased suspended sediment concentrations in the nearshore (including the intertidal zone) due to cable installation is provided in section 8.7.6.5. The recoverability of the coastal receptor (East Anglia coastline) is assessed for morphological and sediment transport effects due to cable protection measures at the coast (section 8.7.7.6).

12. The Marine Policy Statement (MPS, HM Government, 2011; discussed further in Chapter 3, Policy and Legislative Context) provides the high-level approach to marine planning and general principles for decision making that contribute to achieving this vision. It also sets out the framework for environmental, social and economic considerations that need to be considered in marine planning. Regarding the topics covered by this chapter the key reference is in section 2.6.8.6 of the MPS which states:

    - “…Marine plan authorities should not consider development which may affect areas at high risk and probability of coastal change unless the impacts upon it can be managed. Marine plan authorities should seek to minimise and mitigate any geomorphological changes that an activity or development will have on coastal processes, including sediment movement.”

13. The MPS is also the framework for preparing individual Marine Plans and taking decisions affecting the marine environment. The Marine Plans relevant to Norfolk Boreas are the East Inshore and the East Offshore Marine Plans (HM Government, 2014; discussed further in Chapter 3, Policy and Legislative Context). Objective 6 “*To*

have a healthy, resilient and adaptable marine ecosystem in the East Marine Plan areas" is of relevance to this Chapter as this covers policies and commitments on the wider ecosystem, set out in the MPS including those to do with the Marine Strategy Framework Directive and the Water Framework Directive (see Chapter 3 Policy and Legislative Context), as well as other environmental, social and economic considerations. Elements of the ecosystem considered by this objective include: "*coastal processes and the hydrological and geomorphological processes in water bodies and how these support ecological features".*

14. In addition to NPS, MPS and East Inshore and East Offshore Marine Plans, guidance on the generic requirements, including spatial and temporal scales, for marine physical processes studies associated with offshore wind farm developments is provided in seven main documents:

- 'Offshore wind farms: guidance note for Environmental Impact Assessment in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) requirements: Version 2' (Cefas, 2004).
- 'Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment' (Lambkin et al., 2009).
- 'Review of Cabling Techniques and Environmental Effects applicable to the Offshore Wind Farm Industry' (BERR, 2008).
- 'General advice on assessing potential impacts of and mitigation for human activities on Marine Conservation Zone (MCZ) features, using existing regulation and legislation' (JNCC and Natural England, 2011).
- 'Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects' (Cefas, 2011).
- 'East Inshore and East Offshore Marine Plan Areas: Evidence and Issues' (MMO, 2012).

8.3 Consultation

15. Consultation is a key part of the Development Consent Order (DCO) application process. To date, consultation regarding marine physical processes has been conducted through:

- The Physical Processes Expert Topic Group (ETG) which includes Natural England, the Marine Management Organisation (MMO), the Environment Agency and North Norfolk District Council. Meetings have been held as part of the Evidence Plan Process (an explanation of the Evidence Plan Process is provided in Chapter 7 Technical Consultation);
- The Norfolk Boreas Offshore wind farm Scoping Report (Royal HaskoningDHV, 2017);

- Consultation on the Norfolk Boreas Marine physical processes Method Statement (Appendix 9.16 of the Consultation Report (document reference 5.1), submitted to the ETG in February 2018 as part of the Evidence Plan Process. This document provided data requirements and a method for the assessment of potential effects on the baseline marine physical processes due to the proposed project;
- Section 42 consultation on the Preliminary Environmental Information Report (PEIR) (Norfolk Boreas Limited, 2018). The consultation was undertaken between 31st October and 11th December 2018 on a draft ES; and
- An ETG meeting held on the 21st February 2019.

16. Full details of the project consultation process are presented within Chapter 7 Technical Consultation.

17. The comments received during the different stages of consultation are summarised in Table 8.2 a response or reference to where the comment has been addressed is also provided.

18. In addition to the responses specific to Norfolk Boreas (Table 8.2) consultation has also been carried out for the Norfolk Vanguard project, and many of the responses received as part of those consultations (both with the community and through the Vanguard EPP) have influenced the Norfolk Boreas assessment. Further to this, information submitted as part of the Norfolk Vanguard Examination (currently ongoing), up to Deadline 5 (20th March 2019), has also been considered where possible (see section 7.1 and section 7.3.2 of Chapter 7 Technical Consultation for further detail). The key responses and information provided to Norfolk Vanguard which have been used to inform this assessment are presented in Table 8.3.

Table 8.2 Consultation Responses for Norfolk Boreas

Consultee	Document & Date	Comment	Response / where addressed in the ES
Secretary of State	Scoping Opinion June 2017	The extent of the study areas should be on the basis of recognised professional guidance, whenever such guidance is available. The physical scope of the study areas should be identified under all the environmental topics and should be sufficiently robust in order to undertake the assessment. The scope should also cover the breadth of the topic area and the temporal scope, and these aspects should be described and justified.	The extent of the study area, which has been determined, using expert judgement by the chapter author, is described in section 8.6 (existing environment). The marine physical processes topic areas that are assessed (waves, tidal currents, sediment transport) are also described in section 8.6, and impacts on those parameters in sections 8.7.6 (construction) and 8.7.7 (operation and maintenance)
Secretary of State	Scoping Opinion June 2017	The technical chapters of the Scoping Report provide a thorough overview of the existing baseline environment and there is a large amount of existing survey data to draw upon, a lot of which comes from East Anglia THREE and East Anglia FOUR surveys. Where existing survey data is relied upon, their suitability for Norfolk Boreas should be agreed with relevant consultees; in particular the spatial and temporal scope of the surveys should be considered. The SoS expects and recognises that this is likely to be a key objective of the Evidence Plan Process.	The use of existing survey data from East Anglia THREE and East Anglia FOUR to support the baseline and assessment of Norfolk Boreas has been discussed with stakeholders during the Evidence Plan Process (EPP). Agreement was reached that the data was of appropriate quality and could be used in this ES. More pertinent to the assessment of Norfolk Boreas is that data collected for Norfolk Vanguard which has also been agreed for use through the EPP. Section 8.6 provides details of the data used in this assessment.
Secretary of State	Scoping Opinion June 2017	The SoS considers that the environmental baseline should be established having regard to conditions present at the time of surveys and that Norfolk Vanguard should be considered within the cumulative impact assessment(s) (CIA).	Surveys completed for Norfolk Boreas are summarised in section 8.5.2 and detailed in the baseline environment (section 8.6). Norfolk Vanguard is considered in the Cumulative Impact Assessment (CIA) (section 8.8)
Secretary of State	Scoping Opinion June 2017	Where the matrix-based approach is not used to determine significance, and instead expert / professional judgement is applied, this should be explained and fully justified.	Justification for the use of expert-based assessment and judgement is discussed in the appropriate sections in this ES including section 8.7.
Secretary of State	Scoping Opinion June 2017	The ES should report on any data limitations encountered in establishing the baseline environment.	Data assumptions and limitations are discussed in section 8.5.3

Consultee	Document & Date	Comment	Response / where addressed in the ES
Secretary of State	Scoping Opinion June 2017	The SoS welcomes the proposal to consider interrelationships, The SoS has noted some discrepancies in these tables. For example it is stated in Table 2.32 that some topics (e.g. Marine, Geology, Oceanography and Physical Processes) would affect another topic (e.g. Fish and Shellfish Ecology); yet the latter is not stated to be affected by the former. The Applicant is encouraged to cross check any similar tables within the ES to ensure consistency.	Section 8.9 describes inter-relationships of marine physical processes with other receptors. The reciprocal inter-relationships have been cross-checked and are highlighted in the appropriate sections of the other receptors.
Secretary of State	Scoping Opinion June 2017	The Applicant should ensure that all projects that have the potential to interact with the Proposed Development are considered and should demonstrate that they have not focussed solely on offshore wind farms, for example by determining whether there are any other developments in the marine area with potential for cumulative impacts.	Projects other than offshore wind farms are considered in the CIA (section 8.8).
Secretary of State	Scoping Opinion June 2017	The ES will also need to address interrelationships in each topic area and summarise the position on trans-boundary effects of the Proposed Development, taking into account inter-relationships between any impacts in each topic area.	Section 8.9 describes inter-relationships of marine physical processes with other receptors. Transboundary impacts are unlikely to occur and are scoped out of this chapter. This approach was confirmed during the Evidence Plan Process.
Natural England	Scoping Opinion June 2017	We advise that the ES should include a clear description of how each of the categories for extent, duration and frequency are defined and similarly for the sensitivity categories of vulnerability, recoverability and value. The ES should also include a description of how the various combinations of frequency, duration, extent and reversibility of effects have been combined to reach the final prediction of effect magnitude. Similarly, a discussion should be included as to how the various combinations of receptor sensitivity, probability of interaction and magnitude of effect have been combined to reach the final determination of impact significance.	The impact assessment methodology including definitions of the effect/impact terminology is provided in section 8.4.1. The application of each level of significance and their combinations, related to the impact topics (waves, tidal currents and sediment transport) is discussed in individual sections of the assessments, where appropriate.

Consultee	Document & Date	Comment	Response / where addressed in the ES
Natural England	Scoping Opinion June 2017	The magnitude and sensitivity scores which contribute to the final impact assessment should be presented for each of the receptors included in the assessment. This should be supported by appropriate references to scientific literature. Where conclusions are based on expert judgements this should be clearly described and discussed in the text. This would add confidence in the validity of the determinations and any subjective decisions or professional judgements based on experience that are made by the applicant are transparent and clear.	The magnitude and sensitivity of an effect/impact are discussed in the appropriate sections in this ES. The application of expert-based assessment and judgement are also fully described in the appropriate sections in this ES. The justification for using the results of East Anglia ONE modelling as part of the expert assessments is described in section 8.7.3.
Natural England	Scoping Opinion June 2017	Furthermore, we highlight the importance and difficulty of establishing the uncertainty associated with data. The level of uncertainty/confidence associated with each significance assessment should be discussed based on the nature of evidence used and how this evidence was used to determine impact significance.	Data assumptions and limitations are discussed in section 8.5.3.
The MMO	ETG meeting February 2018	An unrealistic worst-case scenario (w-cs) should only be used when it demonstrates no possible impact. If an unrealistic w-cs is found to exceed impact criteria, a more reasonable and realistic scenario should be adopted and this used as evidence instead.	Section 8.7.5 details what is predicted to be a realistic but precautionary worst case scenario. There is ongoing work to refine and potentially reduce this where possible.
The MMO	ETG meeting February 2018	The list [of projects included for CIA] appears to be relevant and the MMO do not know of any other projects which should be included or considered at this time.	The list of projects proposed for inclusion in the CIA (section 8.8) was informed by the list proposed in the Method Statement.
Natural England	ETG meeting February 2018	As highlighted at the meeting with Vanguard OWF on 31st January, wider impacts throughout the Southern North Sea have been witnessed in recent years and with our concerns regarding impacts to the recovery of the sandbank systems of the HHW SAC (see attached response to Norfolk Vanguard sent on 22nd Feb 2018) we would require reassurance in the ES and Application in order to agree that no further modelling is required.	Justification as to why a conceptual approach has been used is shown in section 8.7.3.
Secretary of State	Scoping Opinion June 2017	The Scoping Report states that "Modelling of sediment plumes completed as part of the East Anglia ONE EIA (EAOL, 2012) showed that coarser material is likely to settle out within a short distance	This is clarified in sections 9.7.3.3 and 9.7.3.5 of Chapter 9 Marine Water and Sediment quality.

Consultee	Document & Date	Comment	Response / where addressed in the ES
		(between a few hundred meters and 1km) of the activity and limit the overall footprint of the affected area". However, no reference has been made to the distance which finer material may settle. As such, the assertion that designated bathing waters (3.1km and 3.9km from the landfall search area) are unlikely to be affected has not been fully justified. Any such statements should be clarified within the ES, with reference to guidance or studies from which the conclusions have been drawn."	
Natural England	PEIR Section 42 Response November 2018	Other outstanding matters [For Norfolk Vanguard] requiring attention: Coastal Processes: Cliff recession prediction Cable burial depth below beach	Coastal processes are described in section 8.6.11. The predicted rates of cliff recession are provided in Appendix 4.5. Cable burial embedded mitigation is detailed in section 8.7.4. Under the Norfolk Vanguard Examination these matters are resolved and agreement has been reached through the Statement of Common Ground between Norfolk Vanguard and Natural England (Norfolk Vanguard Limited and Natural England, 2019).
Norfolk County Council	PEIR Section 42 Response November 2018	The local member for North Walsham East division has made the following comments: Reiterate the comments made to North Norfolk District Council for the PEIR in relation to Vattenfall's Norfolk Vanguard proposal. Whilst accepting that there is no need to refer to relay stations (no longer a proposal) or concerns about one of the drilling options at the landfall site in Happisburgh as it is now "deep drill". Concerns about cliff erosion at the landfall site still of course remain.	Details regarding coastal erosion at the landfall can be found in section 8.7.4. Section 8.7.7.6 describes potential impacts of the landfall on coastal erosion.
The MMO	PEIR Section 42 Response December 2018	The Marine Process reports reviewed state on multiple occasions that waves are generally unimportant except under major storm conditions. However, Table 7 of the sand wave clearance shows that the seabed sediment threshold for movement is exceeded by the combined wave and tidal flow bed shear stress 80% or more of the time. The MMO considers that this could indicate that minor changes to the wave field could have consequences for the transport of sediment. Therefore, the wording in the EIA should reflect this.	A paragraph has been added to section 8.6.8 to reflect the results described in the study. Possible changes in wave heights due to the presence of foundations and the consequential effects on sediment transport has been assessed as sections 8.7.7.2 and 8.7.7.3. Sections 8.8.3.2 and 8.8.3.3 assess the potential cumulative effects of Norfolk Boreas and other projects on the wave climate and the resultant effects on sediment transport.

Consultee	Document & Date	Comment	Response / where addressed in the ES
The MMO	PEIR Section 42 Response December 2018	In comparison to the rest of the PEIR, the presentation of the cumulative assessment for coastal processes appears relatively simplistic. In particular, figures 8.15 and 8.16 show large areas of overlap for the effects in wave and tidal currents due to the several adjacent OWFs. The cumulative assessment within the PEIR describes this as simply an extension of the area of impact, applying the negligible impact assessment for each area individually to the whole. However, the Norfolk Boreas OWF contains the overlapping zones of influence of two other windfarms along the south-south east / north-north west wave propagation axis, suggesting that magnitude of effects may be increased in this area. The MMO requests the EIA acknowledges this and further justification is provided to demonstrate why this is of no concern to the maintenance of marine processes in the southern North Sea. This should acknowledge (i) the observation that the majority of sediments are potentially mobilised 60-80% of the time under measured wave and current conditions (Table 7, sand wave clearance report) and (ii) that the dynamics of sandbank systems are poorly understood and the complex sediment transport patterns could mean that apparently slight changes in some areas could contribute to unexpected wider consequences.	The cumulative impacts assessment has been expanded from that presented within the PEIR (section 8.8). This section of the ES includes a cumulative assessment of effects on the tidal and wave climates and their combined effects on sediment transport (section 8.8.3) and a cumulative assessment of changes to seabed level as a result of multiple projects being present (section 8.8.3.3).
The MMO	PEIR Section 42 Response December 2018	The MMO notes the uncertainty due to the absence of strong evidence for the scale of impacts, and the low certainty around the seabed recovery post-installation. Assessment methods are principally based on the expected outcomes following expert assessment of generic evidence and verification via monitoring is a necessary means of validating the assumptions made. PEIR section 5.4.18.3 Paragraph 260 notes that the assessments are 'deemed' conservative. The MMO would welcome further discussion on any monitoring to be included in the DML to validate the predictions made within the EIA.	Details of monitoring to validate the predictions made in this ES are explained in the Offshore In Principle Monitoring Plan (document reference 8.12). At a minimum a pre and post construction bathymetric survey is proposed and further survey requirements would be agree with regulators following results of the initial post construction survey.

Consultee	Document & Date	Comment	Response / where addressed in the ES
The MMO	PEIR Section 42 Response December 2018	Repeated works in the same seabed area and cable protection requirements should be monitored against the projections, as prevention of repeated disturbance is a principal means of mitigating the impacts of disruption to the designated environment. This may require a prior agreement as to the acceptable duration of environmental perturbation e.g., based on anticipated sand wave recovery rates.	Norfolk Boreas Limited are advocating that seabed levelling to the "bed reference level" occurs prior to cable installation to minimise the possibility of any cables becoming exposed and therefore the need for repeated work. Further detail is provided in Appendix 5.2 and the worst case parameters for achieving this have been assessed within the ES (8.7.6.5 and 8.7.6.6). Appendix 7.1 of the Information to Support HRA (document reference 5.3) assesses the impacts of multiple cable installations on sand waves and predicts their recovery rates. An estimation of the frequency of cable reburial and repair has been made (sections 8.7.5.7.2 and 8.7.5.7.3) and assessed in section 8.7.7.7. Details of proposed monitoring to validate the predictions made in this ES are explained in the Offshore In Principle Monitoring Plan (document reference 8.12)
The MMO	PEIR Section 42 Response December 2018	Available sediment transport data (section 8.6.8, Figure 8.10) indicates complex patterns over the SAC sandbanks and Norfolk banks in general, but is sparse over the OWF itself. In the area over the OWF, transport is generally assumed to be aligned North-South with the tidal flow, based on broad observations of the bedforms. Further information on sediment transport within the red line boundary should be provided in the EIA	Norfolk Boreas limited are in the process of undertaking seabed mobility studies within the Norfolk Boreas site. The preliminary findings from these studies are provided in section 8.6.8.
The MMO	PEIR Section 42 Response December 2018	The MMO notes that Chapter 8 considered the effect of deposition to be insignificant. However, this should be considered 'in-combination' with the repeated clearance campaigns under the worst-case, multi-phase development scenario. As noted in the sand wave clearance report, this would result in repeated disturbance of potentially incomplete sand wave recovery, delaying the eventual re-establishment of the bed and possibly leading to a period of dis-equilibrium in the local sediment transport. This should be assessed in the EIA.	Section 8.8.1.3 contains an assessment of the impacts from multiple phases of seabed clearance.

Consultee	Document & Date	Comment	Response / where addressed in the ES
The MMO	PEIR Section 42 Response December 2018	Appendix 8.1, Section 2.4.3 states that surge (adding up to 0.4m/s to flows and 2.5m of water depth) is relatively important for sediment transport. This information should also be highlighted in Chapter 8, Section 8.6.10, where detail on sandbank change and divergent sand wave migration directions in the cable corridor are considered.	This information has now been included within section 8.6.4. which discusses tidal flows.
The MMO	PEIR Section 42 Response December 2018	In Section 8.6.9 of the PEIR, the figures relating to suspended sediment appear contradictory. Paragraph 114 states "Suspended sediment concentrations across the Norfolk Boreas site could range from 1 to 35mg/l. During the Land Ocean Interaction Study (NERC, 2016), measurements near to Norfolk Boreas recorded a maximum concentration of 83mg/l ..." However higher readings are also stated throughout the section. The MMO seeks clarification on the correct suspended sediment concentrations.	The older values for suspended sediment concentrations in section 8.6.9 have been superseded by bespoke measurements recorded from the adjacent Norfolk Vanguard OWF site. The older values have been removed from this ES chapter. Turbidity measurements have been completed in the Norfolk Boreas site but a reliable conversion from Formazin Turbidity Unit (FTU) to mg/l (suspended sediment concentration) is not available currently. The FTU values from the Norfolk Boreas site have been reported here however the due to availability of a reliable conversion factor for the Norfolk Vanguard, date collected at that site has been used in the assessment.
The MMO	PEIR Section 42 Response December 2018	In PEIR Chapter 8, reference is made to an average sediment depth for sand wave clearance of 3m, however, paragraph 324 says 'up to 3m' and paragraph 400 refers to 9m. The MMO seeks clarity on the correct sediment depths.	Reference to "up to 3m" has been removed from this Chapter and only the average depth is used.
North Norfolk District Council	PEIR Section 42 Response December 2018	This area of North Norfolk in particular has seen significant loss of cliff in recent years due to the effect of coastal processes with an increased risk to life and property including numerous buildings of heritage interest. It will therefore be important for Development Consent Order to give appropriate consideration to the potential for the project to be affected by and/or contribute to coastal change and to consider any public benefits that can be derived either as part of formal mitigation or as part of any wider community benefits to manage those adverse impacts in accordance with the adopted Shoreline Management Plan (SMP 6).	Information regarding the predicted rates of coastal erosion at the landfall can be found in section and Appendix 4.5. Section 8.7.7.6 describes potential impacts of the landfall on coastal erosion.

Consultee	Document & Date	Comment	Response / where addressed in the ES
Geraldine Watson – Local Resident	PEIR Section 42 Response December 2018	As, I hope, you are aware this part of the coast is experiencing increasing erosion, and recently there have been devastating cliff falls and loss of land. If, as locals expect, the rate of loss continues and accelerates then your estimate of 25 years of life for your pits where the cable comes above ground onshore, will be very optimistic. I am not a geologist but noticed until last year there seemed to be a thick band of clay which was resistant to the waves, now that has been eroded, there is only soft sand which disappears at every high tide.	Details regarding coastal erosion at the landfall can be found in section 8.7.4. Section 8.7.7.6 describes potential impacts of the landfall on coastal erosion.
MMO	ETG meeting 21st February 2019	We understand that some preliminary results from the seabed mobility study will be included in the ES chapter. We would recommend that a description of how this work has been undertaken should be also been included.	Section 8.5.2 provides a summary of how this work has been undertaken to date. The results which are relevant to establishing the baseline for this chapter are focused around understand sand wave migration rates and directions across the site. As discussed at the ETG meeting what is presented within this chapter are preliminary findings only which have not yet been published.
MMO	ETG meeting 21st February 2019	Further detail of how the ZOIs for wave and tidal effects have been created would be helpful, the comments [provided at PEIR] were about the interaction of tidal and wave effects, which can be non linear if they interact together, currently the chapter relies on directionality of waves and ZOI not interacting with the receptors (combined influence of waves and tide rather than one or the other). ABPmer sand wave study said combined wave and tide have mobile sediments for 80% of the time.	Additional detail regarding the methods adopted to create the cumulative zones of influence is provided in sections 8.8.3.1 and 8.8.3.2. A new section (8.8.3.3) has been added to cover cumulative impacts of combined wave and tidal current effects.

Table 8.3 Responses for Norfolk Vanguard that are relevant to Norfolk Boreas

Consultee	Document & Date	Comment	Response / where addressed in this ES
Stiffkey Parish Council	Scoping Opinion November 2016	Will coastal process modelling be used and made available to the public for the proposed wind farm development?	The approach adopted in this ES, which has been made available to the public, is expert-based assessment and judgement by Royal HaskoningDHV including use of the results of previous numerical modelling for East Anglia ONE. Only conceptual modelling is being undertaken for Norfolk Boreas.
Stiffkey Parish Council	Scoping Opinion November 2016	Impact of onshore locations and routes both during construction and then operation and how these impacts will be addressed / mitigated on the following: Compatibility with the Shoreline Management Plan (SMP) and the position that the area around Mundesley/Bacton will be a managed retreat.	The project is compatible with the SMP as there will be no impact on existing or planned coastal defences.
Secretary of State	Scoping Opinion November 2016	Paragraph 304 of the [Norfolk Vanguard] Scoping Report notes that there is rapid cliff erosion on the coast of north-east Norfolk. The ES should explain how erosion rates have been taken into account in determining the depth of cable burial at the landfall, the depths of transition pits and the set-back distance of the cable relay station from the coastline.	A coastal erosion study (Appendix 4.5) informed the landfall site selection and design of the horizontal directional drilling (HDD) works. This work supports identification of where the landfall infrastructure would need to be located, considering estimates of natural erosion rates in this area.
Secretary of State	Scoping Opinion November 2016	The [Norfolk Vanguard] Scoping Report makes numerous references to the use of modelling (both conceptual and empirical) to undertake the assessments; however, has not provided details of these therefore, the Secretary of State cannot provide any meaningful comments at this time. The ES should provide details of all models used including any assumptions and limitations and how these have been factored in to the assessment.	The detailed methodology has been discussed with stakeholders during the Evidence Plan Process and is outlined in sections 8.4.1 and 8.7.3.
Secretary of State	Scoping Opinion November 2016	The Secretary of State welcomes the consideration of the potential effects of sedimentary processes on Haisborough, Hammond and Winterton SCI.	Noted, these are assessed in section 8.7.

Consultee	Document & Date	Comment	Response / where addressed in this ES
Secretary of State	Scoping Opinion November 2016	Paragraph 304 of the [Norfolk Vanguard] Scoping Report notes there is rapid cliff erosion on the coast of north-east Norfolk. The potential impacts of landfall works on coastal processes, including erosion and deposition, should be addressed with appropriate cross reference to other technical reports including landscape and visual impacts. Reference should be made to the Kelling to Lowestoft Ness Shoreline Management Plan, where appropriate.	A coastal erosion study (Appendix 4.5) informed the assessment of the potential impacts at the landfall. Section 8.7.7 discusses this element of the assessment.
Cefas	EPP Meeting 16th February 2017	Cefas require more justification on how similar the sites are to be able to use analogous studies from other sites.	Section 8.7.3 of this ES chapter discusses in detail the justification for using the modelling results of East Anglia ONE as analogies for the potential effects/impacts of Norfolk Boreas.
Cefas	Written feedback (provided 6th July 2017) in response to an early draft of the PEIR	Draft section 8.7.5.10 notes that suspended sediments may exceed prevailing levels but remain within background levels range – this should be supported by justified quantitative estimates.	Reliable quantitative assessments of suspended sediment concentrations close to the coast are difficult to obtain and so a qualitative conceptual approach has been adopted in section 8.7.6.5.
Cefas	Written feedback dated 1st July 2017 (provided 6th July 2017) in response to an early draft of the PEIR chapter dated 21st June 2017	A regional sediment transport map should be provided (to accompany sections 8.6.8 and 8.6.9). Not only would this be useful in respect of statements made later in the report (e.g., that there is no pathway for changes offshore to affect the shoreline), but it would be a major piece of evidence in support of the assumption that the physical contexts of the East Anglia OWF are sufficiently similar to Norfolk Vanguard to justify their use as primary evidence for impact assessment of the latter. It would also clarify the step to section 8.6.11 (coastal process at the landfall / shoreline), and thence to the impact receptors defined in 8.7.	Figure 8.10 and explanation added to section 8.6.8. Plate 8.7 provides an illustration of preliminary findings of seabed mobility studies within the Norfolk Boreas site.

Consultee	Document & Date	Comment	Response / where addressed in this ES
Numerous consultees including: Happisburgh Parish Council, North Norfolk District Council and Environment Agency	PEIR Responses September 2017	Raised concerns about the impact that a short HDD at the cable landfall could have on coastal erosion and the beach at Happisburgh.	A decision has been made, based on consultation feedback, to use long HDD at the landfall with an exit point in the subtidal zone beyond -5.5m LAT (approximately 1km from the onshore drilling location). Therefore, these concerns have been addressed, as potential intertidal impacts would be avoided.
MMO	PEIR Responses 11th December 2017	This study does show considerable overlap between the envelope of effects on hydrodynamics (in terms of wave height) for an adjacent development (East Anglia Three) and Norfolk Vanguard East. The assessment essentially concludes that effects of each individual development are negligible, and that the cumulative impacts are negligible also. However, the method used (simple extension of modelling results for a third individual development) does not convincingly support this conclusion since the original results did not assess in-combination effects.	The approach to cumulative operational effects on waves was based on expert assessment (overlapping of zones of potential influence) as described in section 8.8.3. The modelling results of East Anglia ONE were used in the expert assessment merely to show that changes to waves due to the presence of foundation structures would be small in magnitude and localised in spatial extent (i.e. restricted to the vicinity of each foundation), and that this applies to cumulative layouts as well as for individual wind farm layouts.
Natural England	Relevant Representation 31st August 2018	Any sand wave levelling within the SAC (if agreed) must have detailed monitoring before and after the activity, with method and frequency to be agreed with Natural England in order to monitor impact and recovery, as there is currently an evidence gap in this area. This needs documenting for the record and implementing as a specific license condition.	Details of monitoring to assess impact and recovery of sand waves are explained in the Offshore In Principle Monitoring Plan (document reference 8.12).

Consultee	Document & Date	Comment	Response / where addressed in this ES
Natural England	Relevant Representation 31st August 2018	As mentioned previously there is currently no evidence for timescales for recovery of sand waves from sand wave clearance, or that the sandbank system will remain undisturbed. Initial monitoring from Race Bank showed that some dredged areas showed some signs of infill within a few months of dredging and other areas did not. Whilst we agree that theoretically larger morphological processes should enable the sandbank to recover, the impact is none the less significant and timescales for recovery are unclear. If permitted monitoring will be required to demonstrate that recovery does occur within a year and should be a license condition.	Details of monitoring to assess impact and recovery of sand waves are explained in the Offshore In Principle Monitoring Plan (document reference 8.12).

8.4 Assessment Methodology

19. To meet the requirements of the guidance documents described in section 8.2, the assessment approach has adopted the following stages:

- Review of existing relevant data;
- Acquisition of additional project-specific data to fill any gaps;
- Formulation of a conceptual understanding of baseline conditions;
- Consultation and agreement with the regulators regarding proposed assessment approaches;
- Determination of the worst-case scenarios;
- Consideration of embedded mitigation measures; and
- Assessment of effects using analytical tools, empirical methods, results from previous numerical modelling (East Anglia ZEA and East Anglia ONE) and expert-based judgements by Royal HaskoningDHV.

8.4.1 Impact Assessment Methodology

20. The assessment of effects on marine physical processes is predicated on a Source-Pathway-Receptor (S-P-R) conceptual model, whereby the source is the initiator event, the pathway is the link between the source and the receptor impacted by the effect, and the receptor is the receiving entity.

21. An example of the S-P-R conceptual model is provided by cable installation which disturbs sediment on the seabed (source). This sediment is then transported by tidal currents until it settles back to the seabed (pathway). The deposited sediment could change the composition and elevation of the seabed (receptor).

22. Consideration of the potential effects of Norfolk Boreas on the marine physical processes is carried out over the following spatial scales:

- Near-field: the area within the immediate vicinity (tens or hundreds of metres) of the project infrastructure; and
- Far-field: the wider area that might also be affected indirectly by the project (e.g. due to disruption of waves, tidal currents or sediment pathways).

23. Three main phases of development are considered, in conjunction with the present-day baseline, over the life cycle of the project. These are:

- Construction phase;
- Operation and maintenance phase; and
- Decommissioning phase.

24. For the effects on marine physical processes, the assessment follows two approaches. The first type of assessment is impacts on marine physical processes

whereby a number of discrete direct receptors are identified. These include certain morphological features with inherent value, such as:

- Offshore sandbanks – these morphological features play an important role in influencing the baseline tidal, wave and sediment transport regimes; and
- Beaches and sea cliffs - these morphological features play an important natural coastal defence role at the coast.

25. The impact assessment incorporates a combination of the sensitivity of the receptor, its value (if applicable) and the magnitude of the change to determine a significance of impact. Chapter 6 EIA Methodology provides an overview of this approach to the assessment of impacts.

26. In addition to identifiable receptors, the second type of assessment covers changes to marine physical processes which in themselves are not necessarily impacts to which significance can be ascribed. Rather, these changes (such as a change in the wave climate, a change in the tidal regime or a change in suspended sediment concentrations) represent effects which may manifest themselves as impacts upon other receptors, most notably marine water and sediment quality, benthic ecology, and fish and shellfish ecology (e.g. in terms of increased suspended sediment concentrations, or erosion, or smothering of habitats on the seabed).

27. Hence, the two approaches to the assessment of marine physical processes are:

- Situations where potential impacts can be defined as directly affecting receptors which possess their own intrinsic morphological value. In this case, the significance of the impact is based on an assessment of the sensitivity of the receptor and magnitude of effect by means of an impact significance matrix (section 8.4.1.2).
- Situations where effects (or changes) in the baseline marine physical processes may occur which could manifest as impacts upon receptors other than marine physical processes. In this case, the magnitude of effect is determined in a similar manner to the first assessment method but the significance of impacts on other receptors is made within the relevant chapters of the ES pertaining to those receptors.

28. Impacts associated with installation of the project interconnector (between the Norfolk Boreas and Norfolk Vanguard project) cables, array cables and interconnector (within the Norfolk Boreas site) cables are assessed together, where it is appropriate to do so. This is justified because the landscape-scale waves and tides that affect the Norfolk Boreas site and the project interconnector search area are similar and the seabed conditions are homogenous. Hence, the potential effects on the project interconnector cable and the array and interconnector cables are analogous.

8.4.1.1 Sensitivity, value and magnitude

29. The sensitivity and value of discrete morphological receptors and the magnitude of effect are assessed using expert judgement and described with a standard semantic scale. These expert judgements of receptor sensitivity, value and magnitude of effect are guided by the conceptual understanding of baseline conditions.

30. The sensitivity of a receptor (Table 8.4) is dependent upon its:

- *Tolerance*: the extent to which the receptor is adversely affected by an effect);
- *Adaptability*: the ability of the receptor to avoid adverse impacts that would otherwise arise from an effect; and
- *Recoverability*: a measure of a receptor's ability to return to a state at, or close to, that which existed before the effect caused a change.

Table 8.4 Definitions of sensitivity levels for a morphological receptor

Sensitivity	Definition
High	Tolerance: Receptor has very limited tolerance of effect Adaptability: Receptor unable to adapt to effect Recoverability: Receptor unable to recover resulting in permanent or long-term (greater than ten years) change
Medium	Tolerance: Receptor has limited tolerance of effect Adaptability: Receptor has limited ability to adapt to effect Recoverability: Receptor able to recover to an acceptable status over the medium term (5-10 years)
Low	Tolerance: Receptor has some tolerance of effect Adaptability: Receptor has some ability to adapt to effect Recoverability: Receptor able to recover to an acceptable status over the short term (1-5 years)
Negligible	Tolerance: Receptor generally tolerant of effect Adaptability: Receptor can completely adapt to effect with no detectable changes Recoverability: Receptor able to recover to an acceptable status near instantaneously (less than one year)

31. In addition, a value component may also be considered when assessing a receptor (Table 8.5). This ascribes whether the receptor is rare, protected or threatened.

Table 8.5 Definitions of the different value levels for a morphological receptor

Value	Definition
High	Value: Receptor is designated and/or of national or international importance for marine physical processes. Likely to be rare with minimal potential for substitution. May also be of significant wider-scale, functional or strategic importance
Medium	Value: Receptor is not designated but is of local to regional importance for marine physical processes
Low	Value: Receptor is not designated but is of local importance for marine physical processes

Value	Definition
Negligible	Value: Receptor is not designated and is not deemed of importance for marine physical processes

32. The magnitude of an effect (Table 8.6) is dependent upon its:

- Scale (i.e. size, extent or intensity);
- Duration;
- Frequency of occurrence; and
- Reversibility (i.e. the capability of the environment to return to a condition equivalent to the baseline after the effect ceases).

Table 8.6 Definitions of magnitude of effect levels for marine physical processes

Magnitude	Definition
High	Scale: A change which would extend beyond the natural variations in background conditions Duration: Change persists for more than ten years Frequency: The effect would always occur Reversibility: The effect is irreversible
Medium	Scale: A change which would be noticeable from monitoring but remains within the range of natural variations in background conditions Duration: Change persists for 5-10 years Frequency: The effect would occur regularly but not all the time Reversibility: The effect is very slowly reversible (5-10 years)
Low	Scale: A change which would barely be noticeable from monitoring and is small compared to natural variations in background conditions Duration: Change persists for 1-5 years Frequency: The effect would occur occasionally but not all the time Reversibility: The effect is slowly reversible (1-5 years)
Negligible	Scale: A change which would not be noticeable from monitoring and is extremely small compared to natural variations in background conditions Duration: Change persists for less than one year Frequency: The effect would occur highly infrequently Reversibility: The effect is quickly reversible (less than one year)

8.4.1.2 Impact significance

33. Following the identification of receptor sensitivity and value, and magnitude of effect, it is possible to determine the significance of the impact. A matrix is presented in Table 8.7 as a framework to guide how a judgement of the significance is determined.

Table 8.7 Impact significance matrix

		Negative Magnitude				Beneficial Magnitude			
		High	**Medium**	**Low**	**Negligible**	**Negligible**	**Low**	**Medium**	**High**
Sensitivity	**High**	*Major*	*Major*	*Moderate*	*Minor*	*Minor*	*Moderate*	*Major*	*Major*
	Medium	*Major*	*Moderate*	*Minor*	*Minor*	*Minor*	*Minor*	*Moderate*	*Major*
	Low	*Moderate*	*Minor*	*Minor*	*Negligible*	*Negligible*	*Minor*	*Minor*	*Moderate*
	Negligible	*Minor*	*Negligible*	*Negligible*	*Negligible*	*Negligible*	*Negligible*	*Negligible*	*Minor*

34. Through use of the matrix shown in Table 8.7, an assessment of the significance of an impact can be made in accordance with the definitions in Table 8.8.

Table 8.8 Impact significance definitions

Impact Significance	Definition
Major	Very large or large change in receptor condition, both adverse or beneficial, which are likely to be important considerations at a regional or district level because they contribute to achieving national, regional or local objectives, or, could result in exceedance of statutory objectives and / or breaches of legislation
Moderate	Intermediate change in receptor condition, which is likely to be an important consideration at a local level
Minor	Small change in receptor condition, which may be raised as a local issue but is unlikely to be important in the decision-making process
Negligible	No discernible change in receptor condition

35. For the purposes of this ES, ‘major’ and ‘moderate’ impacts are deemed to be significant (in EIA terms). In addition, whilst ‘minor’ impacts may not be significant, it is important to distinguish these from other non-significant (negligible) impacts as they may contribute to significant impacts cumulatively.

36. As described in Chapter 6 EIA Methodology a confidence value has been assigned to each impact assessment to assist in the understanding of the judgement. This is undertaken on a simple scale of high-medium-low.

8.4.2 Cumulative Impact Assessment

37. Cumulative impacts are assessed through consideration of the extent of influence of changes to marine physical processes arising from the project alone and those arising from the project cumulatively or in combination with other offshore wind farm developments (particularly Norfolk Vanguard and East Anglia THREE) but also considering any other nearby seabed activities, including marine aggregate extraction and marine disposal.

38. The Cumulative Impact Assessment (CIA) draws from findings of earlier studies undertaken to inform the East Anglia ZEA (ABPmer, 2012a) which considered cumulative effects arising from development of the whole of the former East Anglia zone, the ES for East Anglia THREE (EATL, 2015), ES for East Anglia ONE (EAOW, 2012b) and ES for Norfolk Vanguard (Norfolk Vanguard Limited, 2018) which considered cumulative effects from those projects and other nearby project activities.

8.4.3 Transboundary Impact Assessment

39. Transboundary impacts are assessed through consideration of the extent of influence of changes or effects and their potential to impact upon marine physical processes receptor groups that are located within other European Union (EU) member states.

40. Transboundary impacts were considered in the Scoping Report for this topic and it was concluded that "transboundary impacts are unlikely to occur or would be insignificant." (Royal HaskoningDHV, 2017). This statement is supported by the assessments that have been completed for the East Anglia ZEA (ABPmer, 2012a), the ES of Norfolk Vanguard (Norfolk Vanguard Limited, 2018), the ES of East Anglia THREE (EATL, 2015), and the ES of East Anglia ONE (EAOW, 2012b), as well as this document. Therefore, transboundary impacts are scoped out and will not be considered further in this chapter. This approach was confirmed during the scoping process (Royal HaskoningDHV, 2017; Planning Inspectorate, 2017) and Evidence Plan Process.

8.5 Scope

8.5.1 Study Area

41. The Norfolk Boreas site is located in the southern North Sea, encompassing a seabed area of approximately 725km^2. It is located approximately 73km from the nearest point on the coast of Norfolk. An offshore cable corridor joins the Norfolk Boreas site to the landfall at Happisburgh South. In addition, a project interconnector search area has been defined as there may a requirement to install cables which link the Norfolk Boreas site with the Norfolk Vanguard site. The offshore infrastructure required for Norfolk Boreas is outlined in section 8.7.5.

42. Norfolk Boreas Limited has committed to using Horizontal Directional Drilling (HDD) from an onshore location to the subtidal zone (at least -5.5m LAT). Therefore, there will be no impacts on the intertidal zone, and so impacts in this area are not considered further.

8.5.2 Data Sources

43. Information to support this ES has come from a series of previous surveys and studies, including numerical modelling studies, which were undertaken to inform the ZEA for the former East Anglia Zone (EAOW, 2012a) as well as the ES for Norfolk Vanguard (Norfolk Vanguard Limited, 2018), the ES for East Anglia THREE (EATL, 2015) and the ES for East Anglia ONE (EAOW, 2012b) (Table 8.9).

44. Appendix 7.1 of the Information to Support HRA (document reference 5.3) contains a sand wave study (ABPmer, 2018) which has informed the assessment of potential impacts from cable installation activities on the Annex I Sandbanks features of the Haisborough, Hammond and Winterton SAC.

45. Geophysical and grab sample surveys were undertaken across the former East Anglia Zone in 2010 (Table 8.9) by Marine Ecological Surveys Limited (MESL). These surveys are herein referred to as the "ZEA surveys".

46. A geophysical (bathymetry sub-bottom profiling, sidescan sonar, magnetometer and ultra-high resolution seismic) survey of the Norfolk Boreas site was completed between 14th May and 30th August 2017 (Fugro, 2017a) and a geotechnical (vibrocores and cone penetration tests) survey was completed between 7th September and 25th October 2017. Bathymetry and sub-bottom profiling were used to characterise the existing environment in this chapter. A benthic survey of Norfolk Boreas was completed between 11th and 16th August 2017 (Appendix 10.1). These surveys are herein referred to as the "Norfolk Boreas site surveys".

47. Norfolk Boreas limited are currently undertaking a seabed mobility study to map the direction and migration rate of selected sand waves across the Norfolk Boreas site. The study, which is ongoing, compares bathymetric data collect from the site at different across different years to assess the rate and direction of sandwave migration. At the time of writing however only preliminary findings which compare data collected by Gardline in 2010 and the Fugro surveys discussed above) are available, further surveys that cover smaller areas (2016 to 2020) have been commissioned which will be used to update and validate the initial findings.

48. Norfolk Boreas and Norfolk Vanguard have a shared offshore cable corridor. Therefore, the geophysical survey completed as part of the Norfolk Vanguard campaign between 1st September and 15th November 2016 (Fugro, 2017b) also encompassed all areas relevant to the Norfolk Boreas offshore cable corridor (Table 8.9). The resulting data has therefore been used to establish the baseline for Norfolk Boreas. This approach was agreed with the Marine Physical Processes ETG during a meeting on the 21st March 2016 as part of the Norfolk Vanguard Evidence Plan

Process. These surveys are herein referred to as the "offshore cable corridor surveys".

49. The project interconnector search area is within the southern half of Norfolk Vanguard West and the north-west part of Norfolk Vanguard East as well as the offshore cable corridor (Figure 8.2). The geophysical and benthic survey data collected for Norfolk Vanguard between September and November 2016 is therefore used to characterise the project interconnector search area bathymetry and seabed sediments (Fugro Survey B.V., 2016).

50. In addition, a range of information sources is available, many of which were collated for the ZEA, including:

- Marine Renewable Atlas (BERR, 2008);
- Wavenet (Cefas);
- National Tide and Sea Level Forecasting Service;
- Extreme sea levels database (Environment Agency, 2011);
- UK Hydrographic Office (UKHO) tidal diamonds;
- British Oceanographic Data Centre;
- National Oceanographic Laboratory Class A tide gauges;
- Baseline numerical model runs (ABPmer, 2012a, 2012b);
- Numerical metocean studies (Deltares, 2012, 2015a, 2015b);
- UK Climate Projections '18 (UKCP19) (Met Office, 2018);
- British Geological Survey 1:250,000 seabed sediment mapping;
- British Geological Survey bathymetric contours and paper maps; and
- Admiralty Charts and UK Hydrographic Office survey data.

Table 8.9 Data sources

Data	Date	Coverage	Confidence	Notes
ZEA Geophysical Survey	April - Aug 2010	Former East Anglia Zone (partial coverage)	High	High-resolution swath bathymetric survey
ZEA grab sample surveys	Mar- Sept 2010	Former East Anglia Zone	High	Grab samples at selected locations 105 of which are now within the Norfolk Boreas site, 43 within the offshore cable corridor and 44 within the project interconnector search area
Norfolk Boreas site Geophysical Survey	May – Aug 2017	Norfolk Boreas site	High	Seabed bathymetry, seabed texture and morphological features, and shallow geology using multibeam echosounder, side-scan sonar, pinger, sparker, and magnetometer

Data	Date	Coverage	Confidence	Notes
Offshore cable corridor Geophysical Survey	Sept - Nov 2016	Norfolk Boreas offshore cable corridor	High	High-resolution seabed bathymetry, seabed texture and morphological features, and shallow geology using multibeam echo sounder, side-scan sonar, magnetometer and pinger
Norfolk Vanguard Geophysical Survey	Sept - Nov 2016	Project Interconnector search area	High	High-resolution seabed bathymetry, seabed texture and morphological features, and shallow geology using multibeam echo sounder, side-scan sonar and sparker and pinger
East Anglia Four Geophysical Survey	June - Sept 2012	Former East Anglia FOUR* site (project interconnector search area within NV East)	High	High-resolution seabed bathymetry, seabed texture and morphological features, and shallow geology using multibeam echo sounder, side-scan sonar and sparker and pinger
ZEA Grab Sample Survey	Sept 2010 - Jan 2011	East Anglia Zone	High	Grab samples at selected sites (101 within Norfolk Boreas, 14 within the offshore cable corridor and 31 in the project interconnector search area)
Norfolk Boreas site Grab Sample Survey	Sept - Oct 2017	Norfolk Boreas site	High	35 grab samples at selected sites
Offshore cable corridor Grab sample surveys	Oct - Nov 2016	Norfolk Boreas offshore cable corridor	High	33 grab samples at selected sites
Norfolk Vanguard Grab Sample Survey	Oct - Nov 2016	Project Interconnector search area	High	5 grab samples at selected sites
Drop-down Video Survey	Sept – Oct 2017	Norfolk Boreas site	High	35 videos of the seabed at the locations of the grab samples
Norfolk Boreas site Geotechnical Survey	Sept - Oct 2017	Norfolk Boreas site	High	Vibrocores and cone penetration testing at selected sites
Metocean Survey	Dec 2012 – November 2018	Norfolk Vanguard OWF sites	High	AWAC and directional waverider buoy. Data collection is ongoing at time or writing

Data	Date	Coverage	Confidence	Notes
Metocean Survey	May 2018 to January 2019	Norfolk Boreas site	High	One directional waverider buoy, and one AWAC to be deployed for one year. Data collection is ongoing at time or writing
Satellite Suspended Particulate Material (SPM), covering UK waters and UK Continental Shelf	1998 - 2015	The offshore project area	Medium	Data inferred from measurements undertaken by satellites therefore. Not site specific or ground truthed

* The former East Anglia FOUR site is now occupied by Norfolk Vanguard East

8.5.3 Assumptions and Limitations

51. Due to the large amount of data that has been collected during the ZEA and site-specific surveys, as well as other available data (Table 8.9), there is a good understanding of the existing marine physical processes environment at Norfolk Boreas and its adjacent areas.

52. Although the ZEA and Norfolk Boreas site surveys were seven years apart, the data is still compatible and comparable because conditions at the offshore seabed at a regional scale will not have changed significantly over this time period and indeed the data indicates this as it is very similar. Local changes may have taken place (due to migration of bedforms) but these will not be significant for the purposes of site characterisation.

53. Similarly, regional metocean conditions have been measured over different time periods and different lengths of time and there may be some site-specific bias towards more energetic or less energetic conditions depending on the season in which they were collected. However, given the large geographical spread of the deployments, it is likely that the potential site-specific differences will be accounted for at a regional level. Seasonal and site-specific bias is removed by using hydrodynamic models which cover multiple years.

54. Data for the ambient suspended sediment concentrations along the Happisburgh coast are not available, and this assessment is solely based on expert geomorphological assessment of the likely magnitudes at the coast, based on the perceived energy conditions. Regional suspended sediment data was available from the southern North Sea Sediment Transport Study (HR Wallingford et al., 2002), but estimates at the coast are extrapolated from two locations further offshore, which were the closest data points to the cable corridor (near shore section) and landfall.

Hence, there is uncertainty as to the validity of this extrapolation inshore where physical conditions are different (e.g. more energetic).

8.6 Existing Environment

8.6.1 Bathymetry

8.6.1.1 The Norfolk Boreas site

55. Water depths across the Norfolk Boreas site vary between approximately 20 and 43m below LAT. The minimum water depth is along the crest of sandbank 4 in the south-east part of the site and the maximum water depth is between sandbank 3 and sandbank 4, also in the south-east (Figure 8.1).

56. The primary bathymetric features are five elongate sandbanks (numbered 1 to 5 on Figure 8.1) which trend north-south through the site. These are generally of heights ranging from 9 to 14m above the surrounding seabed. However, Sandbank 4 is locally higher (up to 19m, measured from the trough between sandbanks 3 and 4). The sandbanks are spaced 4.5 to 5.5km apart and represent the south-east limit of the Norfolk Bank System.

57. At a more local scale the seabed is uneven due to the presence of bedforms of various sizes. Sand waves within Norfolk Boreas are up to 4.5m high with up to 700m wavelengths with crests oriented between west-south-west to east-north-east and west-north-west to east-south-east, indicative of north-south tidal currents. The sand waves are asymmetric with their steeper sides facing north, indicating migration towards the north.

58. The site also includes smaller megaripples with heights of between 0.1 and 0.5m and wavelengths of 5 to 12m, which blanket large areas of the site. However, sand at the seabed is locally absent within the trough between sandbanks 3 and 4. As a result no bedforms have formed in this area, and the underlying Brown Bank Formation (section 8.6.2) lies just underneath the seabed surface.

59. The Norfolk Boreas site also contains a relict channel and levee system within the bathymetric low between sandbanks 1 and 2 (Figure 8.1). The channel is 30 to 70m wide with levees which are approximately 1m above the surrounding seabed. Fugro (2017a) interpreted the positive relief exhibited by this feature as a result of differences in soil strength (associated with channel sediments), which in turn has resulted in differences in the magnitude of erosion. Remnants of other raised leveed channels are also present on the western flank of sandbank 4. The features are probably part of the Brown Bank Formation, deposited in a tidal channel environment (Fugro, 2017a).

60. Two areas on the western flank of sandbank 4 contain parallel seabed furrows (Figure 8.1). They were formed by bottom currents, with the orientation of the furrows parallel to the dominant current direction (Fugro, 2017a).

61. To the north of the Norfolk Boreas site are a series of sandbanks collectively called the Norfolk Bank System (Figure 8.2). They represent the most extensive example of offshore linear ridge type sandbanks in UK waters. The proposed offshore cable corridor has a route through the banks within the south-west part of the system.

8.6.1.2 Offshore cable corridor

62. Water depths within the offshore portion of the cable corridor, in the region of the Norfolk Boreas site, are typically 40 to 50m below LAT (Figure 8.3). Progressing towards the coast, water depths decrease progressively from around 50m below LAT to 10m below LAT about 500 to 1000m from the coast. The 2m below LAT contour is typically 200m to 30m from the coast.

63. Superimposed on the general reduction in water depth shoreward are a series of broad, elongate, north-south aligned sandbanks and shoals which cross or extend into the offshore cable corridor. The sandbank furthest offshore is the southern limit of Smith’s Knoll with a minimum water depth of approximately 25m below LAT. Subsequent sandbanks progressing towards the coast, such as Hearty Knoll and Newarp Banks, have minimum water depths of approximately 15m below LAT.

64. Secondary bedforms within the offshore cable corridor include sand waves, megaripples and sand ridges. The sand waves are up to 9m high with crests typically oriented west-east to south-west to north-east, perpendicular to the tidal currents. They have symmetric or asymmetric profiles, the latter implying net migration towards either the north or south.

65. Megaripples cover the sand waves, and blanket the seabed where sand waves are absent and the seabed is mobile. They are 5 to 10m in wavelength, 0.2 to 0.6m high, and can be symmetric or asymmetric.

66. Low continuous sand ridges (typically 0.5 to 1m high and spaced 100 to 200m apart) formed parallel to tidal current flows occur in the eastern part of the offshore cable corridor.

8.6.1.2.1 Haisborough, Hammond and Winterton SAC

67. The offshore cable corridor passes through the southern end of the Annex I Sandbanks system located within the Haisborough, Hammond and Winterton SAC.

68. The Haisborough sandbank system comprises of a series of north-west to south-east oriented en-echelon (approximately parallel to the coast) alternating ridge headland associated sandbanks, which have evolved over the last 5,000 years in response to

shoreline recession and sea-level rise (Cooper et al., 2007). The sandbank system consists of Haisborough Sand, Haisborough Tail, Hammond Knoll, Winterton Ridge and Hearty Knoll (Figure 8.2).

69. Water depths within the sandbank system range from approximately 12 to 52m below LAT. Approximately two thirds of the sandbank habitat occurs in depths greater than 20m below LAT. The crests of the sandbanks are in water shallower than 20m below LAT with their flanks extending into water depths up to 40m below LAT (ABPmer, 2018). Although the Annex I qualifying habitat is Sandbanks which are ‘slightly’ covered by seawater all the time, indicating shallow sandbanks only, those sandbanks in water depths greater than 20m are also considered to fall within the Annex I criteria of the Haisborough, Hammond and Winterton SAC.

8.6.1.3 Project interconnector search area

70. The project interconnector search area, which would only be required if Norfolk Vanguard is constructed, occupies the southern half of Norfolk Vanguard West (and its connection to the cable corridor) and the north-west portion of Norfolk Vanguard East including a section between Norfolk Boreas and Norfolk Vanguard East (Figure 8.4).

71. Water depths across the project interconnector search area in the southern part of Norfolk Vanguard West vary between approximately 32.5 and 47m below LAT (Figure 8.4). The area includes the southern tails of sandbanks to the north with local occurrence of northerly migrating sand waves and megaripples (Norfolk Vanguard Limited, 2018).

72. The bathymetry within the project interconnector search area in the north-west part of Norfolk Vanguard East varies from a maximum depth of 40m below LAT to a minimum depth of 25m below LAT (Figure 8.4). The bathymetry is dominated by two north-south oriented sandbanks with widths of 2.3 to 3.1km and heights up to 10m above the surrounding seabed. The sand banks are occupied by sand waves which are oriented mainly west to east and are asymmetric with their steeper side facing north. They have wavelengths of approximately 50m to 200m and heights of up to 4m.

73. Following the consultation on the PEIR the project interconnector search area has been extended to allow for cables to be installed across the gap between the Norfolk Boreas site and Norfolk Vanguard East. The extended area has not been subject to dedicated bathymetric surveys. However, data to cover the majority of this area is available from the Norfolk Boreas geophysical site survey and the East Anglia FOUR geophysical surveys (Table 8.9). Together, these survey data cover approximately 80% of the extended area (Figure 8.4) and show that large and medium sized

features such as sand banks, troughs and sand waves appear to be continuous across the extended area (Figure 8.4).

74. Pre and post construction surveys will be used to provide additional bathymetric information where data is currently not available. Further details are provided in the Offshore In Principle Monitoring Plan (document reference 8.12).

8.6.2 Geology

8.6.2.1 The Norfolk Boreas site

75. Fugro (2017a) described eight geological formations under the Norfolk Boreas site (Table 8.10). The sequence between the Smith's Knoll Formation and the Twente Formation is Pleistocene in age, whereas the Elbow Formation and Bligh Bank Formation are Holocene.

Table 8.10 Geological formations present under the Norfolk Boreas site and the project interconnector search area in the southern half of NV West* (Fugro, 2016; Fugro, 2017a).

Formation	Norfolk Boreas	Project interconnector search area in Norfolk Vanguard West	Lithology (BGS Lexicon http://www.bgs.ac.uk/lexicon)
Bligh Bank	Present	Present	Marine, medium- or fine- to medium-grained, clean, yellow-brown sands
Elbow	Present	Present	Brackish-marine, fine-grained sands and clays with discontinuous basal peat bed
Twente	Present	Present	Fine-grained, well-sorted, wind-blown periglacial sands
Brown Bank	Present	Present	Brackish-marine, grey-brown silty clays. Pass upwards into lacustrine clays in the east, include interbeds gravelly sand towards base in west
Swarte Bank	Present	Present	Infilled glacial tunnel valleys
Yarmouth Roads	Present	Present	Mainly riverine, fine or medium-grained grey-green sands, typically non-calcareous, with variable clay lamination and local intercalations of reworked peat
Winterton Shoal	Present	Present	Fine- or medium-grained sands with minor clay laminations
Smith's Knoll	Thought to be present but not resolved in the Norfolk Boreas site surveys	Present	Fine to medium-grained, muddy marine sands, with clay intercalations in the east
Westkapelle Ground	Not reached or absent	Present	Marine clays with thin sandy laminae passing gradationally upwards to sand with thin clay laminae

*Only the Yarmouth Roads, Brown Bank and Bligh Bank Formations were identified from the data set acquired (Fugro EMU, 2013) within the project interconnector search area in the northern part of NV East.

76. The geology of the Norfolk Boreas site generally consists of Holocene sand deposits overlying a series of Pleistocene sands and clays. The Bligh Bank Formation blankets most of the site with variable thickness. It is thickest beneath the sandbanks (up to

11m) and is a thin seabed veneer (less than 1m) in the bathymetric lows. It represents the sediment currently being reworked into sandbanks, sand waves and megaripples (Plate 8.1).

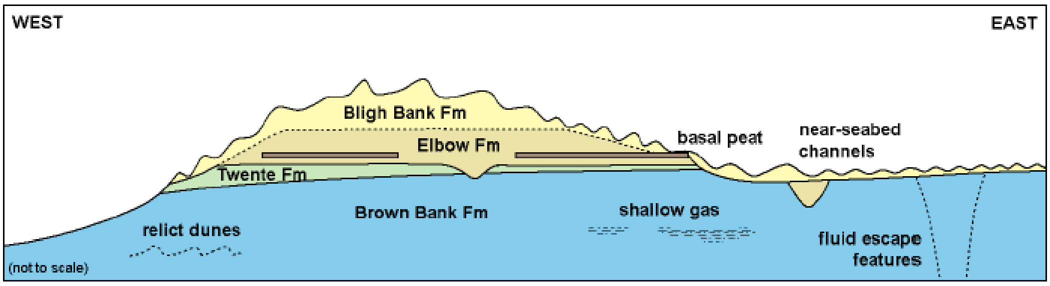

Plate 8.1 Schematic representation of the shallow geology of Norfolk Boreas (Fugro, 2017a)

8.6.2.2 Offshore cable corridor

77. Fugro (2017b) completed the offshore cable corridor geophysical survey in 2016 (Table 8.9) using three different survey vessels. This was due to vessel operation limitations with regards to minimum water depths, and so the route was split into three sub-sections (west, central and east). The sub-sections were surveyed using a pinger sub-bottom profiler, achieving a typical penetration of about 15m below seabed in the eastern sub-section, whereas the western and central sub-sections achieved 5m penetration. Differences in ground conditions along each section resulted in different attenuations of the seismic signal using the same pinger.

78. Pinger sub-bottom profiler penetration can be limited by subsurface sediment type and structure. Also, if the geological units are homogenous, or have little structure, the pinger will be unable to resolve different formations. Hence, within the western and central sub-sections (5m penetration), the shallow geological sequence is only divided into Holocene sands and the underlying undifferentiated Pleistocene sediments. Along the eastern sub-section, Fugro (2017b) described the Pleistocene Yarmouth Roads Formation overlain in sequence by the Pleistocene Eem Formation (fine- to medium-grained shelly marine sands and not present beneath the Norfolk Boreas site), Brown Bank Formation and Twente Formation, and then Holocene formations to the seabed (Plate 8.2).

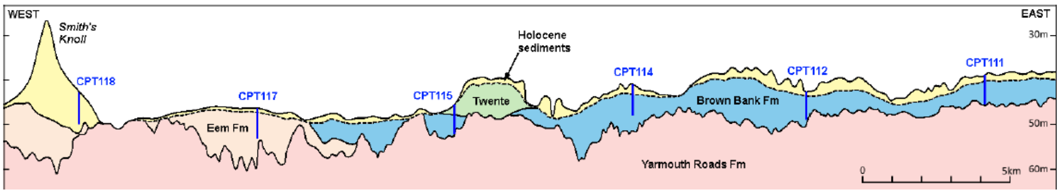

Plate 8.2 Shallow geology of the eastern sub-section of the offshore cable corridor (Fugro, 2017b)

8.6.2.3 Project interconnector search area

79. The project interconnector search area occupies the southern half of Norfolk Vanguard West (and its connection to the cable corridor) and the north-west portion of Norfolk Vanguard East with a section linking the Norfolk Boreas site with Norfolk Vanguard East.

80. The Norfolk Vanguard survey (Fugro, 2016) described nine geological formations that are beneath the project interconnector search area in the southern half of Norfolk Vanguard West (the same as Norfolk Boreas but including the older Westkapelle Formation (Table 8.10). The Bligh Bank Formation is present across most of the project interconnector search area.

81. Fugro EMU (2013) described three geological formations that are within the project interconnector search area in the north-west part of Norfolk Vanguard East. In ascending order, these are the Pleistocene Yarmouth Roads Formation comprising 0 to 100m of sands and channel infills, overlain by the Pleistocene Brown Bank Formation comprising 5 to 10m of silty clay, capped by 0 to 20m of Bligh Bank Formation (Holocene sand). The Holocene sand varies in thickness from several metres beneath sandbanks and sand waves to a thinner veneer in deeper areas.

82. The base of the Yarmouth Roads Formation was not imaged by the sub-bottom profiler, and so the older formations described at the project interconnector search area in the southern half of Norfolk Vanguard West (Fugro Survey B.V., 2016) were not delineated across the project interconnector search area in the north-west part of Norfolk Vanguard East.

8.6.3 Water Levels

83. The Norfolk Boreas site is located within an area of seabed that is subject to a micro-tidal regime, with a mean spring tidal range (difference in water levels between mean high water spring and mean low water spring) from 1.0m at its southern boundary to 1.5m at its northern boundary. This low tidal range is due to the proximity of an amphidromic point that is positioned to the south of Norfolk Boreas (Figure 8.5). At the amphidromic point, the tidal range is near zero. Tidal range then increases with radial distance from this point. The crest of the tidal wave at high water circulates anticlockwise around this point once during each tidal period.

84. Due to the regional tidal regime being influenced by the amphidromic point in the southern North Sea, the tidal range increases with progression west along the offshore cable corridor. At the Happisburgh South landfall, the tidal range is approximately 2.6m on mean spring tides.

8.6.3.1 Storm surge

85. The North Sea is particularly susceptible to storm surges and water levels at Norfolk Boreas could become elevated to between 1.5 and 1.6m above mean sea level during a 1 in 1-year return period surge event and between 2.3 and 2.4m above mean sea level during a 1 in 100-year return period surge event (Deltares, 2015b).

86. The coast can also be subject to significant surge activity which may raise water levels above those of the predicted tide. Predicted extreme water levels can exceed predicted mean high-water spring levels by more than 1m. The Environment Agency (2011) calculated 1 in 1-year water levels of 1.1m above mean high water spring (MHWS) at Lowestoft and 1.16m above MHWS at Cromer. The 1 in 50-year water levels are predicted to be 1.98m above MHWS at Lowestoft and 1.67m above MHWS at Cromer.

8.6.4 Tidal Currents

87. Regional tidal current velocity and direction are influenced by the presence of the amphidromic point and the anti-clockwise circulation around it. Figure 8.6 shows current roses from previous observations (ABPmer, 2012a) and shows that immediately north of Norfolk Boreas, currents are generally aligned along a north to south axis. Further to the south, a stronger north-north-east to south-south-west axis is evident. Tidal currents generally flow north to south on the flooding tide and south to north on the ebbing tide. This orientation is relatively uniform throughout most of the offshore project area, with some small, localised variations caused by flow around sandbanks (ABPmer, 2018). The highest current velocities occur during spring tides.

88. Immediately inside the northern boundary, the Norfolk Boreas site experiences a maximum 1 in 1 year predicted depth-averaged tidal current velocity of 0.95m/s (metocean output location A17, Deltares, 2015a). The maximum extreme 1 in 50 year current velocity is predicted to be 1.0m/s, at the same location. At metocean output location H (central to Norfolk Boreas), the predicted maximum 1 in 1 year and 1 in 50 year depth-averaged tidal current velocities are 1.0m/s and 1.1m/s, respectively (Deltares, 2015b). Despite the low tidal range, the regional tidal currents remain strong due to the rapid, anti-clockwise circulation of the tide around the amphidromic point. ABPmer (2018) suggested that short-duration storm surges with a 50-year frequency could add up to a further 0.4m/s to flows (and 2.5m of water depth).

89. Tidal current measurements are currently available for the Norfolk Boreas site (at the metocean output location A17, Deltares, 2015a) between May 2018 and November 2018. Here, current velocity and direction data were recorded by an Acoustic Wave and Current Meter (AWAC) located in 25m water depth. Plate 8.3

shows a time series of tidal current velocities and Plate 8.4 shows a current rose for the sea surface (where the currents are greatest). Most of the currents flow along a north-south aligned axis, with velocities up to about 1m/s during spring tides and up to 0.6m/s during neap tides.

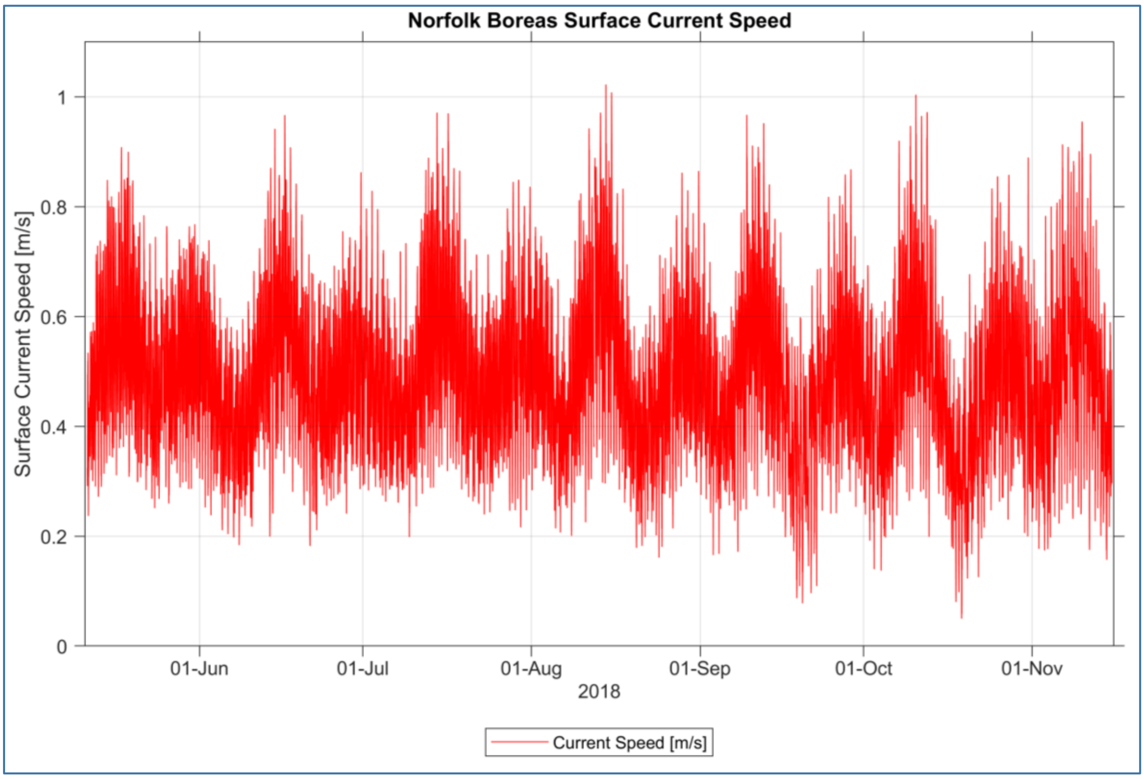

Plate 8.3 Time series of current velocity measured by the AWAC in Norfolk Boreas between May 2018 and November 2018

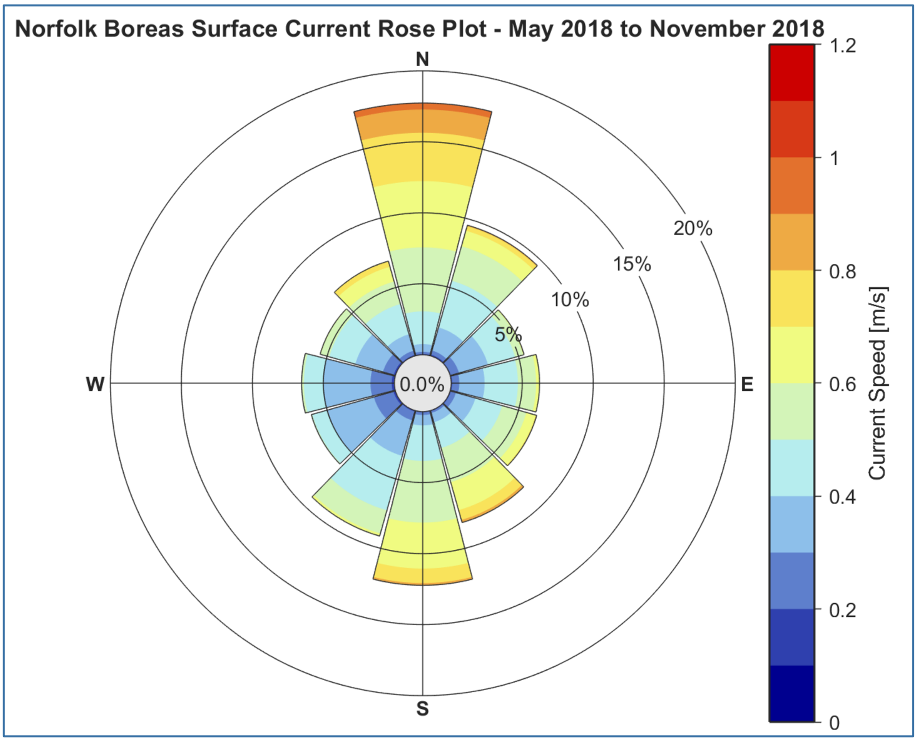

Plate 8.4 Near sea surface current rose measured in Norfolk Boreas between May 2018 and November 2018

90. Figure 8.6 shows that tidal currents across the region. Data collected in 2015 and 2016 from locations within and just to the south of the project interconnector search area are aligned north-south and north southwest with velocities of up to 1.2m/s associated with the ebb tide (Deltares, 2015a, 2015b).

91. Tidal currents increase in the shallower waters nearer to the coast, especially across the offshore cable corridor as it approaches north-east Norfolk. Current velocities here can exceed 1.5m/s.

8.6.5 Waves

92. The regional wave climate is composed of a combination of swell waves generated offshore and locally-generated wind-waves. Data from observation campaigns shows that the predominant waves close to Norfolk Boreas arrive from the south-south-west with subordinate waves from the north and north-north-west (ABPmer, 2012a) (Figure 8.7).

93. The maximum 1 in 1-year return period significant wave height, immediately inside the northern boundary of Norfolk Boreas, is predicted to be 5.2m (metocean output location A17, Deltares, 2012). The predicted maximum 1 in 50-year significant wave height at the same location is 9.2m. At metocean output location A22 (central to Norfolk Boreas), the predicted 1 in 1 year and 1 in 50-year maximum significant wave heights are 5.1m and 9.0m, respectively.

94. Across the majority of Norfolk Boreas, water depths are likely to be sufficient to limit the effect of wave action on seabed sediments, apart from during exceptionally stormy seas or over shallower areas.

95. Wave measurements from the AWAC and directional waverider buoy (at the metocean output location A17, Deltares, 2015a) were recorded between May 2018 and January 2019. Plate 8.5 shows the wave rose derived from the data. The waves mimic, to some extent, the dominant regional wave climate (ABPmer, 2012a), with most waves arriving from the south and south-south-west and the north and north-north-west. Waves can, however, approach from all directions and there is a small, but notable, proportion also arriving from the north-north-east.

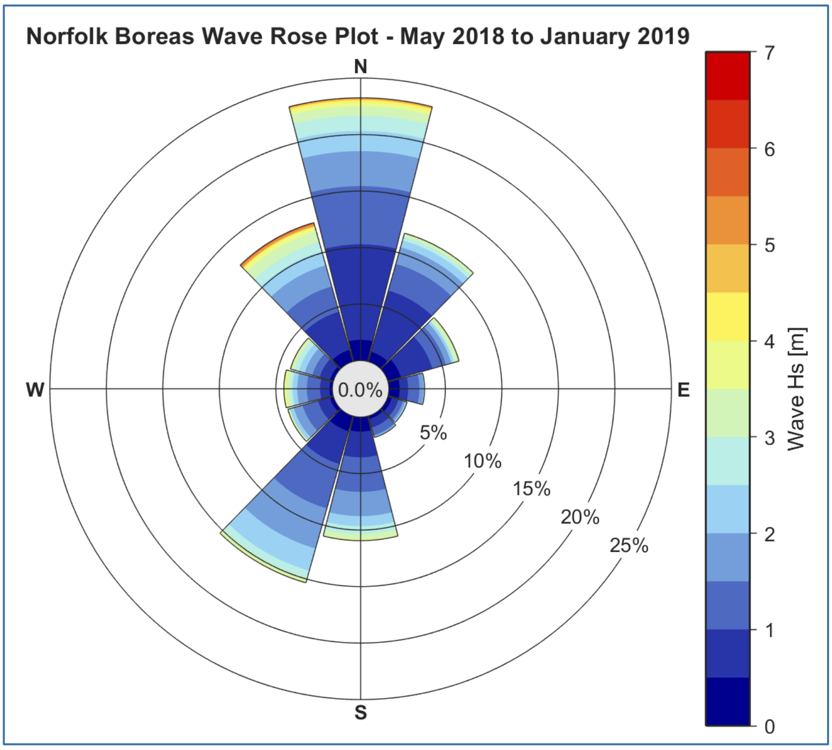

Plate 8.5 Wave rose measured in Norfolk Boreas between May 2018 and January 2019

96. Plate 8.6 shows a time series of significant wave heights recorded by the AWAC and waverider buoy in Norfolk Boreas. The minimum significant wave height recorded during this period was less than 0.2m, with a maximum value of approximately 7m.

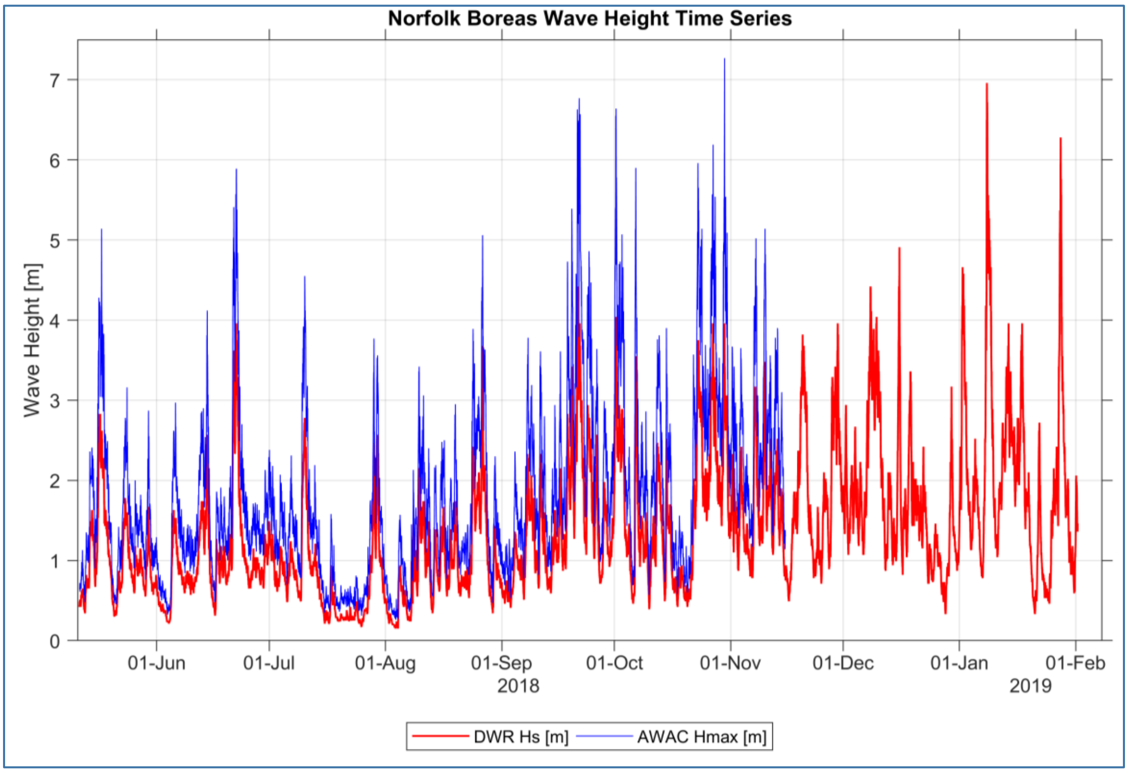

Plate 8.6 Time series of wave heights measured by the waverider buoy and AWAC in Norfolk Boreas between May 2018 and January 2019

97. Figure 8.7 shows wave data from across the region. This indicates that waves within the project interconnector search area (data collected from A11, a location within Norfolk Vanguard East) arrive from the south and south-south-west. The maximum 1 in 1-year return period significant wave height is 4.9m (Deltares, 2012).

98. Closer to the coast, water depths reduce and wave effects become more important in governing sediment transport. At shallow water locations off the north-east Norfolk coast, waves are dominated by short-period wind-generated waves and generally reveal a predominant wave direction from the north-east. Along the coast itself the wave energy varies significantly and in places is heavily influenced by the sheltering effect of nearshore banks.

8.6.6 Climate Change

99. Historical data show that the global temperature has risen significantly due to anthropogenic influences since the beginning of the 20th century, and predictions are for an accelerated rise, the magnitude of which is dependent on the magnitude of future emissions of greenhouse gases and aerosols.

100. According UKCP18 which draws on the IPCC’s Fifth Assessment of Climate Change (Church et al., 2013), it is likely (IPCC terminology meaning greater than 66% probability) that the rate of global sea-level rise has increased since the early 20th century. It is very likely (IPCC terminology meaning greater than 90% probability) that the global mean rate was 1.7mm/year (1.5 to 1.9mm/year) between 1901 and 2010 for a total sea-level rise of 0.19m (0.17 to 0.21m). The average long-term trend for the UK is estimated as 1.4mm/year which is slightly lower than the global 1.7mm/year. Between 1993 and 2010, the rate was very likely (IPCC terminology) higher at 3.2 mm/year (2.8 to 3.6mm/year), and this is the historic rate used in this analysis.

101. The rate of global mean sea-level rise during the 21st century is likely to exceed the rate observed between 1993 and 2010. Church et al. (2013) developed projections of global sea-level rise for four emissions scenarios of future climate change, called the Representative Concentration Pathways (RCP). In this analysis, the median projection of the worst-case emissions scenario (RCP8.5) is used. For RCP8.5, the rise by 2100 is 0.74m (range 0.52 to 0.98m) with a predicted sea-level rise rate during 2081–2100 of 8 to 16mm/year.

102. As the indicative design life of the project is 30 years, and both onshore and offshore infrastructure is set far enough from the coast, this rise in sea level will not change significantly through the design life of the project.

103. With respect to waves, climate projections indicate that wave heights in the southern North Sea will only increase by between 0 and 0.05m by 2100 and there is

predicted to be an insignificant effect on storm surges over the lifetime of Norfolk Boreas (Lowe et al., 2009).

104. One of the most important long-term implications of climate change is the physical response of the shoreline to future sea-level rise. Predicting shoreline erosion rates is critical to forecasting future problem areas. It is likely that the future erosion rate of the cliffs at Happisburgh South will be affected by the higher rates of sea-level rise than historically. Higher baseline water levels would result in a greater occurrence of waves impacting the toes of the cliffs, increasing their susceptibility to erosion.

8.6.7 Seabed Sediment Distribution

105. A regional seabed sediment grab sampling campaign was completed between September 2010 and January 2011, recovering 101 samples from what is now the Norfolk Boreas site (Figure 8.8) (MESL, 2011). A total of 14 samples also fell within the bounds of the offshore cable corridor (Figure 8.9). The offshore cable corridor surveys included 33 grab samples (Figure 8.9). Also, 35 grab samples were collected during the Norfolk Boreas site surveys (Table 8.9).

8.6.7.1 The Norfolk Boreas site

106. The particle size characteristics of all the seabed sediment samples collected in the Norfolk Boreas site (a total of 136) are presented in Appendix 8.1. The dominant sediment type is sand (65-100% content in all samples) with median particle sizes mainly between 0.17 and 0.33mm (fine to medium sand). The mud content is less than 5% in 80% of the samples and less than 10% in 90%. However, 10% of the samples contain greater than 10% mud, ranging from 10% to 31%. The gravel content is less than 5% in 90% of the samples.

8.6.7.2 Offshore Cable Corridor

107. The particle size characteristics of all the seabed samples collected along the offshore cable corridor (a total of 47) are presented in Appendix 8.1. Sediment distribution is variable depending on location. However, the dominant sediment size is sand. Higher proportions of mud (greater than 10%) were found in 25% of samples with two samples containing greater than 60% mud. Many samples closer to the coast contained greater than 50% gravel.

8.6.7.1 Project Interconnector Search Area

108. The project interconnector search area occupies the southern half of Norfolk Vanguard West (and its connection to the cable corridor) and the north-west portion of Norfolk Vanguard East. A total of 36 seabed samples fall within the boundary of the project interconnector search area (Figure 8.8).

109. The particle size characteristics of all the seabed sediment samples collected in the project interconnector search area in the southern half of Norfolk Vanguard West (a

total of 18) are presented in Appendix 8.1. The dominant sediment type is medium-grained sand with median particle sizes mainly between 0.25 and 0.40mm. The mud content is less than 5% in 83% of the samples. However, 17% of the samples contain greater than 15% mud, ranging from 15% to 45%. The gravel content varies from zero to 9% in all the samples.

110. The particle size characteristics of all the seabed sediment samples collected in in the project interconnector search area in the north-west part of Norfolk Vanguard East (a total of 18) are presented in Appendix 8.1. The dominant sediment type is medium-grained sand (82-100% sand) with median particle sizes between 0.20mm and 0.37mm, with most samples (90%) containing less than 5% mud. The gravel content varies from zero to 7% in all the samples.

8.6.8 Bedload Sediment Transport

111. Regional bedload sediment transport pathways in the southern North Sea have been investigated by Kenyon and Cooper (2005) (Figure 8.10). They analysed the results of modelling studies and bedform indicators and showed that tidal currents are the dominant mechanism responsible for bedload transport. The dominant transport vectors are to the north across the Norfolk Boreas site and the project interconnector search area and to the south and north closer to the coast. There are very few transport vectors directed to the west or the east either near Norfolk Boreas, the project interconnector search area, or between the project and the coast.

112. ABPmer (2018) (Appendix 7.1 of the Information to Support HRA (document reference 5.3)) demonstrated that medium sand on the sand wave crests (-13m CD) would be mobilised by tidal currents alone 74% of the time and by waves alone 52% of the time, and by combined tidal currents and waves, 91% of the time. The proportion of time for movement on the sand wave flanks (-28m CD) is similar for tidal currents alone (71%) and reduces significantly to 5% for waves alone, although a combination of tidal currents and waves still moves medium sand 85% of the time. This information indicates that tidal currents are the dominant driver of sediment transport with secondary influence from waves.

113. Sediment transport pathways within the Norfolk Boreas site and the project interconnector search area have been analysed using the orientation of bedforms. Sand waves are present across parts of the site and exhibit a consistent asymmetry that indicates a net direction of transport to the north. Tidal currents are the main driving force of sediment transport and, due to the tidal asymmetry, move sediments in a northerly direction.

114. The preliminary results from the seabed mobility study compare bathymetries from 2010 (ZEA geophysical survey and 2017 (Fugro, 2017a) to determine historic migration rates and directions of the sand waves within the Norfolk Boreas site. The results show that most of the sand waves are migrating north and just west of north at rates between 2m/year and 5m/year (Plate 8.7).

115. More complex patterns of sediment transport occur around the Haisborough sandbank system along the offshore cable corridor to the west of Norfolk Boreas and these are described in section 8.6.10.

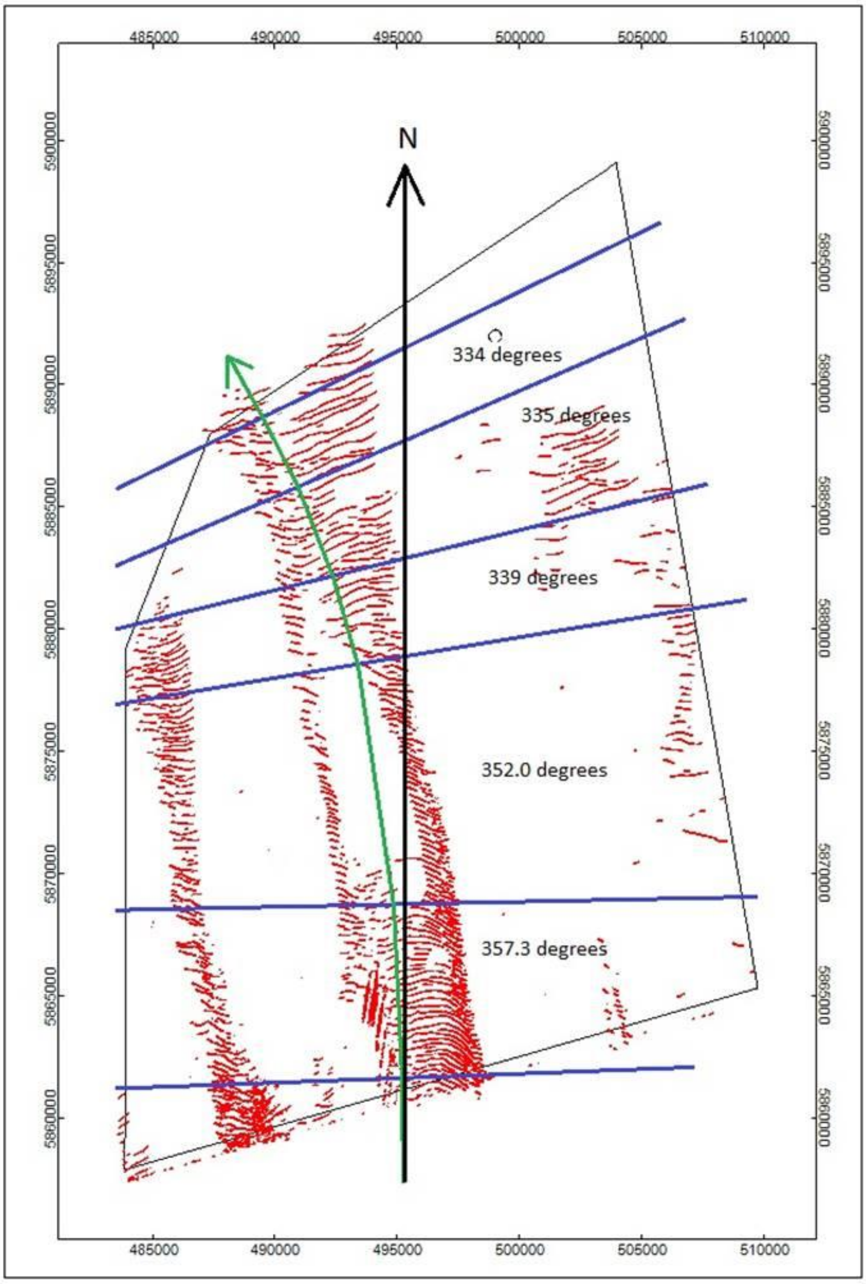

Plate 8.7 General direction of migration (green arrow). Preliminary results from the Norfolk Boreas seabed mobility studies

8.6.9 Suspended Sediment Transport

116. Turbidity measurements from the AWAC are available for Norfolk Boreas (at the metocean output location A17, Deltares, 2015a) between May 2018 and November 2018. Turbidity of up to 120 FTU were measured (Plate 8.5), but a reliable conversion to suspended sediment concentrations is not available at time of writing.

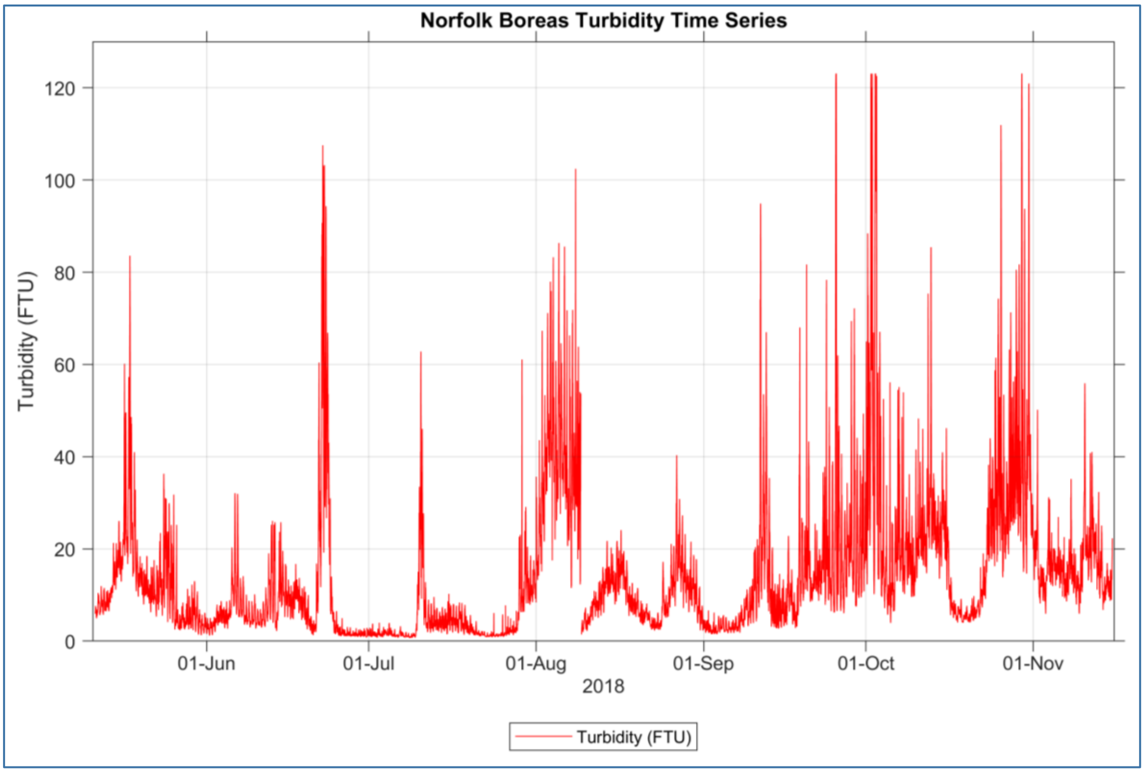

Plate 8.8 Time series of turbidity at the AWAC station in Norfolk Boreas between May 2018 and November 2018

117. Measurements of turbidity converted to suspended sediment concentrations were also carried out at the AWAC station in Norfolk Vanguard East (immediately to the south of Norfolk Boreas) between December 2012 and December 2013 (Plate 8.9). These data provide the baseline suspended sediment concentrations for the project interconnector search area in the north-west part of Norfolk Vanguard East.

118. Overall, suspended sediment concentrations in Norfolk Vanguard East were between 0.3 and 108mg/l throughout that year. Concentrations were less than 30mg/l for 95% of the time and less than 10mg/l for 70% of the time. Given the proximity of Norfolk Boreas to Norfolk Vanguard East and the similar physical and seabed sediment conditions, these measurements are used as an analogy for Norfolk Boreas. Hence, the baseline suspended sediment concentrations across Norfolk Boreas are estimated to vary from 0 to 100mg/l, and are less than 30mg/l most of the time.

119. For context turbidity at the East Anglia THREE offshore windfarm which is located approximal 10km to the south of Norfolk Boreas was found to be fairly similar (generally between 5 and 10mg/l in winter and below 5mg/l in summer (East Anglia THREE limited, 2015) and turbidity at the Hornsea 3 offshore windfarm project located approximately 53km north of Norfolk Boreas was typically found to be in the range 10 to 30 mg/l (Ørsted, 2018).

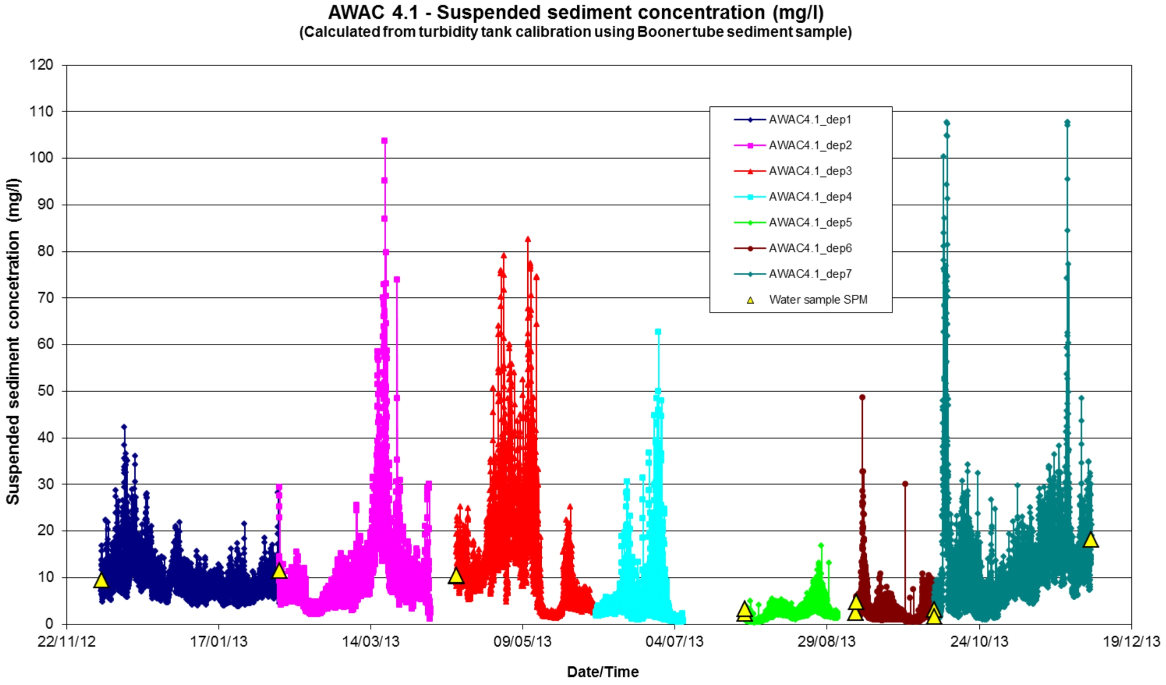

Plate 8.9 Time series of suspended sediment concentrations measured at the AWAC station in Norfolk Vanguard East between December 2012 and December 2013

120. A study using remote sensing (satellite imagery) of suspended particulate matter (SPM) in UK waters covering 18 years of data is provided in Cefas (2016). Maps of monthly climatologies and yearly anomalies show that the southern North Sea, and in particular the sea off East Anglia, has regularly experienced relatively high levels of suspended particulate matter.

8.6.10 Morphological Change of the Haisborough Sandbank System

121. The key driving mechanisms for the formation and maintenance of the sandbanks in the Haisborough, Hammond and Winterton SAC include tidal currents, waves and sea-level change, whilst sediment transport (supply to/loss from) is also important in enabling growth or decay. The offshore cable corridor for Norfolk Boreas passes through the southern end of this sandbank system.

122. The seabed within the Haisborough, Hammond and Winterton SAC can be broadly characterised as sand, with small areas of slightly gravelly sand and gravelly sand (ABPmer, 2018).

123. Morphological change of the Haisborough sandbank system and their interconnecting seabed was analysed by Burningham and French (2016) using historical charts from six distinct time periods; 1840s, 1880s, 1910s, 1930s, 1950s and 1990s. The results show that the gross morphology of the banks has remained relatively consistent over the 160-year period. However, net change of seabed bathymetry describes erosion and accretion around the banks with a dominance of erosion over the wider seabed.

124. The patterns of erosion and accretion around Haisborough Sand describe a small clockwise rotation (accretion at its north-east and south-west ends with associated erosion on the opposite sides of the bank from the accretion) of its along-bank orientation. The southern part of the bank has moved shoreward and the northern part has moved seaward by similar average rates of 9m/year over 160 years (Burningham and French, 2016).

125. Volumetric analysis of Haisborough Sand showed that the volume of the sandbank (1990s) above the -16m, -17m, -18m, -19m and -20m Ordnance Datum (OD) contours was $227 \times 10^6 m^3$, $259 \times 10^6 m^3$, $294 \times 10^6 m^3$, $330 \times 10^6 m^3$ and $369 \times 10^6 m^3$, respectively. Using an 'optimal' -18m OD bounding contour, the volume of Haisborough Sand increased to a peak in the 1930s before losing volume (about 24%) up to the 1990s (Burningham and French, 2016).

126. The analysis of Burningham and French (2016) shows that Haisborough Sand is an active and very dynamic feature, with historic large-scale natural changes having occurred over decadal periods.

127. The area within which the offshore cable corridor sits is an active and highly dynamic environment with development and maintenance of sand waves. Individual sand wave migration rates vary between 5 and 30m/year with both northerly and southerly migrating sand waves present within the cable corridor (ABPmer, 2018).

8.6.11 Coastal Processes at the Landfall

128. The coast of north-east Norfolk is an almost continuous line of cliffs composed of glacial sediments. The coast is exposed and rapid cliff erosion is occurring in places including at Happisburgh South. Severe storm events can rapidly change beach levels and the degree of exposure of the natural or defended coast.

129. Along the north-east Norfolk coast, net sediment transport is to the south-east and the potential for transport increases with distance south as the coast curves from a west to east alignment to a north to south alignment (AECOM, 2012). During storm surges, large waves predominantly approach from the north and north-east, and combined with strong nearshore currents, transport sediment offshore and alongshore.

130. At Happisburgh, more sediment is leaving from the south than is entering from the north-west, due in part to the updrift coastal defences and the change in orientation of the coast. The cliffs between Walcott and Happisburgh consist of fine sediment, containing a mixture of silt/clay and fine sand, and therefore contribute only small volumes of sediment to the beach system. The foreshore along this stretch of coast primarily relies on supply of sediment from the north-west.

131. The cliffs at the Happisburgh South landfall are eroding (see Appendix 4.5). The shoreline has shown a history of net retreat and pre-defence maps (1900 – 1937) show the average erosion rate was between 0.4 and 2.1m/year. In 1959 and 1960 groynes were constructed at Happisburgh to increase the thickness of the beach. At the same time revetments were installed to protect the upper foreshore and lower cliff. An analysis of post-defence erosion rates (1937 – 1999) concluded that erosion rates varied between 0.4 (north of the landfall site) and 0.8m/year.

132. Due to undermining and deterioration, some of these structures failed in 1991 and 1996. The initial erosion was remarkably rapid and has resulted in the formation of a bay (between defences to its north and south), which is located at the position of the landfall site. Between 1994 and 2003, the average retreat rate at the widest part of the bay was around 9m/year. However, subsequently, the cliff and shore platform profiles have developed a near–equilibrium with the physical processes drivers and cliff-top analysis in 2017 showed negligible retreat. The shore platform is lithologically and geotechnically closely related to the lower layers of the cliff. There is a dynamic relationship between cliff erosion and shore platform lowering.

133. The shoreline management plan (AECOM, 2012) states that the intended management at Happisburgh South is Managed Realignment over the next 100 years, meaning that beach and cliff erosion will be allowed to occur but in a controlled manner (i.e. minimising the rate of coastal erosion in the short term using appropriate temporary measures with a view to allowing time for measures to be introduced to allow people to adapt to the changes in the medium and long term).

134. Any impacts of climate change on coastal erosion (including those to be managed as part of the managed realignment) have been considered in the selection and design of the long HDD, cable burial depth and position of the onshore transition pit, which will avoid works on the eroding cliffs. The onshore landfall works will be positioned far enough back from the cliffs, and offshore works will be below -5.5m LAT, to not interact with the coast.

8.6.12 Anticipated Trends in Baseline Conditions

135. The baseline conditions for marine physical processes will continue to be controlled by waves and tidal currents driving changes in sediment transport and then seabed

morphology. However, the long-term established performance of these drivers may be affected by environmental changes including climate change driven sea-level rise. This will have the greatest impact at the coast where more waves will impinge on the cliffs, potentially increasing their rate of erosion. Climate change will have little effect offshore where landscape-scale changes in water levels (water depths) far outweigh the effect of minor changes due to sea-level rise.

8.7 Potential Impacts and Effects

8.7.1 Impact Receptors

136. The principal receptors with respect to marine physical processes are those features with an inherent geological or geomorphological value or function which may potentially be affected by the project. For individual projects, the East Anglia ZEA recommended that the potential impacts on marine physical processes should be considered for four receptor groupings, two of which are relevant to Norfolk Boreas; the sensitive 'East Anglia' coastline and the 'Norfolk' Natura 2000 site. These receptor groups have been retained for Norfolk Boreas to allow comparability with previous work and CIA. The other two receptors mentioned in the East Anglia ZEA ('Suffolk' Natura 2000 site and 'non-designated sandbanks') are too distant from the project to be influenced. The specific features defined within these two receptor groupings as requiring assessment are listed in Table 8.11 and shown in Figures 8.12 and 8.13.

Table 8.11 Marine physical processes receptors relevant to Norfolk Boreas

Receptor group (Figure 8.11)	Extent of coverage	Description of features	Distance from Norfolk Boreas
East Anglian coast (waves and sediment transport)	King's Lynn to Felixstowe	Sand and gravel beaches, dunes and cliffs	73km from the nearest point of Norfolk Boreas with the export cable making landfall on the East Anglian coast (at Happisburgh South)
Norfolk designated sites (waves, currents and sediment transport)	Haisborough, Hammond and Winterton SAC	Offshore sandbanks	Offshore cable corridor passes through the SAC. The Norfolk Boreas site is 34.1km from the SAC at the closest point.
	Cromer Shoal Chalk Beds MCZ	Chalk reef	The offshore cable corridor is approximately 60m from the southern boundary of the MCZ.
	North Norfolk Sandbanks and Saturn Reef SACI	Offshore sandbanks and reef	The SAC is 22.9km to the west of Norfolk Boreas

137. This section assesses the significance of potential impacts on the wave and/or current and/or sediment transport regimes on the receptor groups of the sensitive 'East Anglia' coastline and the 'Norfolk' Natura 2000 site.

8.7.1.1 Haisborough, Hammond and Winterton SAC

138. The Haisborough, Hammond and Winterton SAC is highly dependent upon the prevailing marine physical processes. This SAC is located off the north-east coast of Norfolk and presents marine features which meet the descriptions for the two Annex I habitats 'Sandbanks slightly covered by sea water all the time' and 'Reefs' formed by *Sabellaria spinulosa*. The Conservation Objectives for this SAC are:

- Maintain the Annex I Sandbanks in Favourable Condition, implying that existing evidence suggests the feature to be in favourable condition; and
- Maintain or restore the Annex I reefs in Favourable Condition, implying that the feature is degraded to some degree.

139. In 2010, Annex I sandbank habitat occupied a maximum area of 66,900ha (6.69km^2) of the Haisborough, Hammond and Winterton SAC. This is equivalent to 0.84% of the UK total Annex I sandbank resource (Natura 2000, 2015).

8.7.1.2 North Norfolk Sandbanks and Saturn Reef SAC

140. North Norfolk Sandbanks and Saturn Reef SAC is located off the north-east coast of Norfolk approximately 23.9km west of the Norfolk Boreas site. The marine features and conservation objectives are the same as those for the Haisborough, Hammond and Winterton SAC above.

8.7.1.3 Cromer Shoal Chalk Beds MCZ

141. Closer to the coast, is the Cromer Shoal Chalk Beds MCZ. The site was designated as a MCZ in January 2016. It is located up to 200m off the north-east Norfolk coast, covering an area of 321km^2, with a maximum depth of 20m.

142. The Conservation Objectives for this MCZ are:

- Maintain favourable conditions for moderate energy infralittoral rock, high energy infralittoral rock, moderate energy circalittoral rock, high energy circalittoral rock, subtidal chalk, subtidal coarse sediment, subtidal mixed sediments, subtidal sand, peat and clay exposures and north Norfolk coast (subtidal geological feature).

143. The offshore cable corridor is routed to the south of this MCZ to avoid potential impacts on the MCZ.

8.7.2 Effects

144. In addition to the receptor groups listed in Table 8.11, there are other potential changes (effects) to marine physical processes associated with Norfolk Boreas which may manifest themselves as impacts upon a wider grouping of receptors. These include marine water and sediment quality, benthic and intertidal ecology, fish and shellfish ecology, commercial fisheries, and offshore and intertidal archaeology and cultural heritage.

145. In respect of these effects, the marine physical processes assessment only defines the magnitude of change. The assessments of the significance of impacts arising from these effects or changes on other receptors are made within the relevant chapters of this ES pertaining directly to those receptor types.

8.7.3 Justification for why a conceptual approach is appropriate for Norfolk Boreas

146. A considerable amount of previous numerical modelling work has been undertaken specifically for the East Anglia ONE project located about 60km to the south of Norfolk Boreas to assess the potential effects of the offshore wind farm on the marine physical environment. The results of the modelling from East Anglia ONE (within the former East Anglia Zone) are used as part of the expert-based assessment and judgement of potential construction and operation and maintenance effects or impacts of Norfolk Boreas described later in this ES chapter. The physical basis for using the modelling results is that the East Anglia ONE wind farm design and marine physical processes operating at the site are like Norfolk Boreas and therefore provide suitable evidence (and is a suitable analogue) to support the assessment of effects/impacts at Norfolk Boreas.

147. Justification for using the modelling results from East Anglia ONE as the principal evidence of potential effects or impacts at Norfolk Boreas is provided in Table 8.12, which describes the designs and the existing physical and sedimentary conditions (water depths, tidal currents, waves, seabed sediments, sediment transport, bedforms and suspended sediment concentrations) at each of the sites.

148. A comparison of the characteristics of each site are given below:

- Water depths at East Anglia ONE (30-53m CD) are slightly deeper than those at Norfolk Boreas (20m to 43m LAT), but are predominantly comparable;
- Tidal currents demonstrate similar directions on the flood tide (to the south or south-south-west) and ebb tide (to the north or north-north-east);
- Tidal currents have similar asymmetries with stronger ebb flows than flood flows;
- Peak spring tidal current velocities are about 1.2m/s at East Anglia ONE, and 1m/s at Norfolk Boreas;

- Predominant waves approach both sites from similar directions (from the south-south-west in East Anglia ONE and from the south-south-west and north-north-west in Norfolk Boreas);
- 1 in 1-year return period significant wave heights of about 4.8m and 5.2m are experienced at East Anglia ONE and Norfolk Boreas, respectively; and
- Seabed sediments at both sites are predominantly medium-grained sand with mud comprising less than 5%.

149. As a result of the above characteristics, the following marine physical processes are similar at each site:

- Tidal currents are the main driver of sediment transport and water depths are large enough to limit the effect of wave action on seabed sediments;
- Net sediment transport is towards the north as a result of the asymmetry in tidal currents;
- Sand waves of similar dimensions (6-8m high and wavelengths of 200-500m) occur across both sites with crests oriented perpendicular to the predominant current direction;
- Most of the sand waves are asymmetric with their steeper sides predominantly facing north, indicating migration towards the north; and
- Baseline suspended sediment concentrations are typically in the range 0 to 40mg/l.

150. Whilst it is recognised that there are small differences in conditions and project parameters between the East Anglia ONE and Norfolk Boreas project sites, the highly conservative nature of the numerical modelling conducted for East Anglia ONE (discussed further throughout the impact assessments) allow for these differences in the effect that may arise due to these factors.

151. In addition, East Anglia ONE is more likely to have an impact at the coast compared to Norfolk Boreas because it is much closer. However, the modelling of East Anglia ONE predicts no marine physical processes impacts at the coast, because the zones of influence for waves, tidal currents and sediment transport do not impinge on the coast. Hence, given the similarities between the two wind farms, their respective distances from the coast and the smaller number of turbines in Norfolk Boreas, means that marine physical processes impacts at the coast from Norfolk Boreas are extremely unlikely. Numerical modelling of marine physical processes effects of Norfolk Boreas would be disproportionate to the potential impact and an expert-based assessment is appropriate.

Table 8.12 Comparison of design and marine physical processes parameters at East Anglia ONE and Norfolk Boreas

Parameter	East Anglia ONE	Norfolk Boreas
Area	300km^2	725km^2
Distance from shore	43.4km at closest point	73km at closest point
Indicative capacity	Up to 1,200MW	Up to 1,800MW
Maximum number of largest turbine foundations	150 (8MW)	90 (20MW)
Maximum number of smallest turbine foundations	325 (3MW)	180 (10MW)
Maximum GBS foundation diameter	50m (240 turbines with 50m diameter GBS foundations were modelled)	50m
Offshore cable corridor length	73km	100km
Cable landfall	Bawdsey	Happisburgh South
Minimum water depth (LAT)	30.5m	20m
Maximum water depth (LAT)	53.4m	43m
Current regime	The flood tide is to the south to south-south-west and the ebb tide is to the north to north-north-east. Peak spring depth-averaged tidal current velocities are around 1.15 to 1.25m/s, with the fastest velocities recorded in the north of the site. Mean neap values are approximately half of that recorded during spring tides.	The flood tide is to the south or south-south-east and the ebb tide is to the north or north-north-west. Measured tidal current velocities are up to about 1m/s during spring tides and up to 0.6m/s during neap tides.
Wave regime	Waves propagate in general through the East Anglia ONE site from the north to north-north-east and from the south-south-west. Maximum significant wave heights of approximately 5.45m have been recorded over a years' survey period (December 2012 to December 2013). The mean significant wave height was 1.26m.	Waves propagate in general through the Norfolk Boreas site from the north to north-north-east and from the south-south-west. Predicted 1 in 1-year significant wave height is 5.2m. Waves measured within the Norfolk Vanguard East (immediately south of Norfolk Boreas) site over a period of a year (December 2012 to December 2013) show a maximum significant wave height of 5.94m. The mean significant wave height was 1.41m. The maximum significant wave height recorded in Norfolk Boreas

Parameter	East Anglia ONE	Norfolk Boreas
		between May 2018 and Jan 2019 (as part of the one-year long survey) was 7.0m. The mean significant wave height was 1.32m, but this does not reflect a full year of data.
Seabed sediment	Seabed sediments across the East Anglia ONE site generally consist of slightly gravelly sand with some sand and sandy gravel. Fine (silt and clay sized) particles are largely absent (less than 2%). On average all grab samples comprise approximately 75% medium sand (in the range 0.25 to 0.5mm).	Seabed sediments across the Norfolk Boreas site generally consist of sand and slightly gravelly sand with some gravelly sand. Fine (silt and clay sized) particles are absent in 54% of the samples, with less than 10% mud in 84%. The dominant sediment type is sand (73-100% content in all samples) with median particle sizes mainly between 0.21 and 0.39mm (fine to medium sand).
Bedload sediment transport	Within the East Anglia ONE site, sediment transport is predominantly under the control of tidal forcing and because water depths are generally between 30 and 50m LAT, only large, infrequently occurring storm waves are likely to have any significant influence on sediment transport at the bed. Across most of the East Anglia ONE site, net sediment transport is towards the north as a result of the asymmetry in tidal currents.	Within the Norfolk Boreas site, sediment transport is predominantly under the control of tidal forcing and because water depths are generally between 20 and 43m LAT, only large, infrequently occurring storm waves are likely to have any significant influence on sediment transport at the bed. Across most of the Norfolk Boreas site, net sediment transport is towards the north as a result of the asymmetry in tidal currents.
Bedforms	Dense fields of active migrating sand waves are extensive in the southern third of the East Anglia ONE site, as well as in the east and the northern corner of the site. These sand waves can have heights of over 8m and wavelengths of up to 500m, whilst many of the sand waves show some degree of asymmetry.	Sand waves within Norfolk Boreas are up to 4.5m high with crests oriented between west-south-west to east-north-east and west-north-west to east-south-east, indicative of north-south tidal currents. The sand waves are asymmetric with their steeper sides facing north, indicating migration towards the north.
Suspended sediment concentrations	Late winter and spring (near-bed) suspended sediment concentration values are typically in the range 0 to 40mg/l and finer sediment held in suspension will generally be transported in a northerly direction across the East Anglia ONE site.	Measurements of suspended sediment concentrations in Norfolk Vanguard East over a period of a year recorded values between 0.3 and 108mg/l throughout that year. Concentrations were less than 30mg/l for 95% of the time and less than 10mg/l for 70% of the time.

8.7.4 Embedded Mitigation

152. Norfolk Boreas Limited has committed to several techniques and engineering designs/modifications as part of the project, during the pre-application phase, to avoid a number of impacts or reduce impacts as far as possible. Embedding mitigation into the project design is a type of primary mitigation and is an inherent aspect of the EIA process.

153. A range of different information sources has been considered as part of embedding mitigation into the design of the project (for further details see Chapter 5 Project Description, Chapter 4 Site Selection and Assessment of Alternatives) including engineering preference, ongoing discussions with stakeholders and regulators, commercial considerations and environmental best practice.

8.7.4.1 Embedded Mitigation Relevant to Marine Physical Processes

154. A minimum separation of 720m has been defined between adjacent wind turbines (i.e. four times the rotor diameter of the smallest 10MW turbines which is 180m) within each row and between rows in order that the potential for marine physical process interactions between adjacent wind turbines is minimised.

155. The selection of appropriate foundation designs and sizes at each wind turbine location would be made following pre-construction surveys within the offshore project area.

156. For piled foundation types, such as monopiles and jackets with pin piles, pile-driving would be used in preference to drilling where it is practicable to do so (i.e. where ground conditions allow). This would minimise the quantity of sub-surface sediment that is released into the water column from the installation process. For the purposes of this assessment it has been assumed that drilling could be required at 50% of the locations. This provides an extremely conservative assessment as a review of geophysical and geotechnical data indicates that piling would be possible across the majority of the site.

157. Micro-siting would be used where possible to minimise the requirements for seabed preparation prior to foundation installation.

158. Norfolk Boreas Limited has made the decision to use an HVDC solution rather than a HVAC solution to reduce the number of export cables and volume of cable protection (as advised in Natural England’s recommendations document (Natural England, 2018). This results in the following mitigating features:

- There would be two export cable trenches instead of six;
- The volume of sediment arising from pre-sweeping and cable installation works would be reduced;

- The area of disturbance for pre-sweeping and cable installation is reduced;
- The space required for cable installation is reduced, increasing the space available within the cable corridor for micrositing to avoid sensitive features including designated features within the Haisborough Hammond and Winterton SAC;
- The potential requirement for cable protection in the unlikely event that cables cannot be buried is reduced; and
- The number of existing cable and pipeline crossings and associated cable protection is reduced due to the reduction on number of export cables.

159. Cables would be buried where possible, minimising the requirement for cable protection measures and thus effects on sediment transport. Cable protection would be minimised in the nearshore zone (within the 10m depth contour), and is expected to be used only at the HDD exit point.

160. A long HDD will be used to install the cables at the landfall, exiting in water deeper than -5.5m LAT. Cables would be buried at sufficient depth below the coastal shore platform and cliff base to have no effect on coastal erosion. Erosion would continue as a natural phenomenon driven by waves and subaerial processes, which would not be affected by Norfolk Boreas. Natural coastal erosion throughout the lifetime of the project has been taken into account within the project design by ensuring appropriate set back distances from the coast for the HDD entry point.

161. Norfolk Boreas Limited has located the offshore cable corridor to the south of the Cromer Shoal Chalk Beds MCZ to avoid potential impacts on the MCZ. Norfolk Boreas export cables are also likely to be located to the south of the Norfolk Vanguard cables and therefore would be further away from the MCZ.

162. All seabed sediment arising from cable installation activities in the Haisborough, Hammond and Winterton SAC would be placed back into the SAC using an approach, to be agreed with Natural England and the MMO, which would ensure that the sediment is available to replenish the sandbank features and remain within the SAC.

8.7.4.2 Monitoring

163. It is recognised that monitoring is an important element in the management and verification of the actual project impacts. The requirement for appropriate design and scope of monitoring will be agreed with the appropriate regulators and discussed with stakeholders prior to construction works commencing. The following documents will be submitted as part of the DCO application (anticipated to be in June 2019):

- Offshore In Principle Monitoring Plan (document reference 8.12);
- Project Environmental Management Plan (PEMP) (document reference 8.14)

164. Through these documents the requirement for and extent of monitoring will be agreed and secured within the DCO.

8.7.5 Worst-Case Scenarios

165. A single worst case project envelope is considered below. A summary of the worst case scenario is provided in Table 8.16.

166. The offshore project area consists of:

- The offshore cable corridor with landfall at Happisburgh South;
- The project interconnector search area; and
- The Norfolk Boreas site.

167. The detailed design of the Norfolk Boreas project (including numbers of wind turbines, layout configuration, requirement for scour protection etc.) has not yet been determined, and may not be known until sometime after any DCO has been granted. Therefore, realistic worst-case scenarios in terms of potential impacts/effects on marine physical processes are adopted to undertake a precautionary and robust impact assessment.

168. The project design envelope on which the ES is based was “frozen” in January 2019 to allow the DCO to be completed and submitted in June 2019.

8.7.5.1 Foundations

169. Within the Norfolk Boreas site, different sizes of wind turbine are being considered within a range between 10MW and 20MW. To achieve the maximum 1,800MW capacity, there would be between 90 and 180 wind turbines.

170. In addition, up to two offshore electrical platforms, one offshore service platform, two meteorological (met) masts, two LiDAR platforms and two wave buoys, plus offshore cables are considered as part of the worst-case scenario.

171. A range of foundation options for the above-sea structures are currently being considered, these include:

- Wind turbines - jacket, GBS, suction caisson, monopile and TetraBase;
- Offshore electrical platforms – jackets with pin-pile or suction caissons, or multi-legged gravity base;
- Offshore service platform – jackets with pin-pile or suction caissons, or multi-legged gravity base;
- meteorological masts - GBS, monopile or jackets with pin-pile;
- LiDAR - floating with anchors or monopile; and
- Wave buoys – floating with anchors.

172. The largest disturbance areas are associated with GBS foundations.

8.7.5.2 Layout

173. The layout of the wind turbines will be defined post consent. However, the spacing would be between four and seven turbine diameters and the between row spacing will be between four and 20 turbine diameters.

8.7.5.3 Construction programme

174. Norfolk Boreas Limited is currently considering constructing the project in one of the two following phase options:

- A single phase of up to 1,800MW; or
- Two phases of up to a combined 1,800MW capacity.

175. The indicative offshore construction window is anticipated to be up to approximately three years for the full 1,800MW capacity. Table 8.13 and Table 8.14 provide indicative construction programmes for the single phase and two-phase options, respectively. For the purposes of this assessment it is assumed that these programmes may move up to 12 months either forward or backwards in time. This would allow, for example, Norfolk Boreas to be bought forward 12 months under a scenario whereby Norfolk Vanguard does not proceed to construction (see chapter 5 Project description for further detail), or to be put back should there be any delays to the programme.

Table 8.13 Indicative Norfolk Boreas construction programme – single phase

		2024				2025				2026				2027				2028			
Indicative Programme	**Approximate duration**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Pre-construction survey	12 months			■	■	■	■														
UXO survey and licensing	12 months			■	■	■	■														
UXO clearance following licencing	9 months							■	■	■											
Foundation seabed preparation	3 months									■											
Foundation installation	18 months										■	■	■	■	■	■					
Scour protection installation	12 months									■	■	■	■								
Offshore electrical platform installation works	12 months										■	■	■	■							
Array & interconnector (or project interconnector) cable seabed preparation	6 months									■	■										
Array & interconnector (or project interconnector) cable installation	18 months										■	■	■	■	■	■					
Export cable installation seabed preparation	6 months								■	■											
Export cable installation	18 months									■	■	■	■	■	■						
Cable protection installation	18 months										■	■	■	■	■	■					
Wind turbine installation	18 months														■	■	■	■	■	■	
Total construction works	36 months								■	■	■	■	■	■	■	■	■	■	■	■	

Table 8.14 Indicative Norfolk Boreas construction programme – two phases

		2024				2025				2026				2027				2028			
Indicative Programme	**Approximate duration**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Pre-construction survey	12 months			■	■	■	■														
UXO survey and licensing	12 months			■	■	■	■														
UXO clearance following licencing	9 months							■	■	■											
Foundation seabed preparation	3 months									■											
Foundation installation	2 x 9 months										■	■	■		■	■	■				
Scour protection installation	2 x 6 months									■	■			■	■						
Offshore electrical platform installation works	2 x 6 months										■	■			■	■					
Array & interconnector (or project interconnector) cable seabed preparation	2 x 3 months									■				■							
Array & interconnector (or project interconnector) cable installation	2 x 9 months										■	■	■		■	■	■				
Export cable installation seabed preparation	2 x 3 months								■				■								
Export cable installation	2 x 9 months									■	■	■		■	■	■					
Cable protection installation	2 x 9 months										■	■	■		■	■	■				
Wind turbine installation	2 x 9 months														■	■	■		■	■	■
Total construction works	39 months								■	■	■	■	■	■	■	■	■	■	■	■	■

8.7.5.4 Cable installation

176. Under the worst case scenario the cables that could be installed within the offshore project area are as follows:

- Array cables - cables that connect wind turbine to wind turbine and connect wind turbine to offshore electrical platform;
- Interconnector cables - one pair of HVDC cables and a single AC cable that connect two offshore electrical platforms within the Norfolk Boreas site; or
- Project interconnector cables – HVDC and HVAC cables which connect an offshore electrical platform or wind turbines within the Norfolk Boreas site to an offshore electrical platform within the Norfolk Vanguard OWF sites. These cables would be located within the project interconnector search area (Figure 8.4); and
- Export cables - cables that connect an offshore electrical platform within the Norfolk Boreas site with the landfall.

177. As discussed in section 8.4, the effects of the project interconnector cable are assessed in conjunction with the effects of the array and interconnector cables. There would only be a requirement for either the interconnector cables or the project interconnector cables but never both. The need for the project interconnector cables could only occur if Norfolk Vanguard proceeds to construction, and even then, it would depend on the final electrical solution. Section 5.4.12 of Chapter 5 Project Description describes in further detail the three electrical solutions currently being considered.

178. When assessing the impacts associated with installation, operation and maintenance of the project interconnector cables it is only the parts of these cables that are located within the project interconnector search area that are considered, and not the parts within the Norfolk Boreas site. This is because the worst case scenario for impacts within the Norfolk Boreas site assess 90km (installed within 60km of cable trench) of interconnector cables and 600km of array cables. No matter which of the electrical solutions is eventually chosen, cable installation within the Norfolk Boreas site will not exceed these distances.

8.7.5.4.1 Pre-installation works

Pre-lay grapnel run

179. A pre-lay grapnel run would be undertaken to clear any debris in advance of any cable installation. The maximum width of seabed disturbance along the pre-grapnel run would be 20m. This is encompassed by the maximum footprint of cable installation works associated with ploughing (30m disturbance width).

Pre-sweeping

180. The potential for sand wave levelling (pre-sweeping) has been assessed as a possible strategy for cable installation to ensure the cables are installed at a depth below the seabed surface that will mitigate against re-exposure and reduce the requirement for reburial throughout the life of the project. Sand wave levelling may also be required to create a suitable surface for foundation installation. A final decision on the requirement would be made post consent, in the Cable Specification, Installation and Monitoring Plan (required under Condition 14(1)(g) of DCO Schedules 9 and 10, Condition 9(1)(g) of DCO Schedules 11 and 12 and Condition 7(1)(f) in DCO Schedule 13) following pre-construction surveys.

181. Indicative pre-sweeping volumes and area impacted as provided by CWind (Appendix 5.2) are outlined in Figure 8.12 and Table 8.15. The sediment released at any one time would depend on the capacity of the dredger. The maximum width of pre-sweeping in the offshore cable corridor would be approximately 37m depending on the depth of sand waves. The 37m pre-sweeping width is based on sand wave depth of approximately 5m with a slope gradient of 1 in 3 and a width of 7m at the base of the dredged area. This would be in discrete areas and not along the full length of the corridor.

Table 8.15 Parameters for pre-sweeping activity in the section of the offshore cable corridor that is within the Haisborough, Hammond and Winterton SAC (Appendix 5.2) in the context of totals for the entire export cable (including within the Norfolk Boreas site)

Parameter	Maximum pre-sweeing volume for the section of export cables within the Haisborough, Hammond and Winterton SAC (m^3)	Maximum pre-sweeping volume for the entire export cables (including the SAC and Norfolk Boreas site volume and area) (m^3)
Per trench (pair of export cables)	250,000	1,800,000
Total for two trenches	500,000	3,600,000

182. Sediment arising from pre-sweeping in the Haisborough, Hammond and Winterton SAC would be disposed of within the section of the offshore cable corridor overlapping the SAC. The exact location(s) for disposal of sediment would be determined in consultation with the relevant SNCBs following the pre-construction surveys. The area over which sediment may be deposited is therefore not known at this stage, but an indicative disposal site has been identified which is approximately 3.6km^2 in size.

Removal of existing disused cables

183. There are up to seven out-of-service cables in the offshore cable corridor. Four are suspected of being intact and span the offshore cable corridor; it is assumed that these will be crossed subject to agreement with the cable owners. Two appear to have been cut previously and stop within the offshore cable corridor; it is proposed that these will be further cut subject to agreement with the cable owners and clump

weights will be placed on the cut ends. Finally, one enters and exits the southern edge of the cable corridor which would be avoided, where possible. However, as described in section 5.4.14.3 of Chapter 5 Project description and in Chapter 18 Infrastructure and other users, some of these cables may no longer be present.

8.7.5.4.2 Cable burial

184. Following the pre-installation works described above, the cables would be installed and buried where possible. The following methods may be used for cable burial and would be dependent on the results of the pre-construction survey and post consent procurement of the cable installation contractor:

- Ploughing (worst-case scenario with a trench width of 10m and disturbance width of 30m);
- Trenching or cutting; or
- Jetting.

185. The maximum length of a single export cable pair would be 125km. Therefore, with a worst case of two cable pairs, up to 250km of cable trench would be required. 200km of which would be located within the offshore cable corridor and 50km of which would be located within the Norfolk Boreas site.

186. The length of the offshore cable corridor within the SAC is approximately 40km and therefore the total length of trenches would be 80km in the SAC.

8.7.5.4.3 Landfall

187. As previously discussed, the export cable would make landfall at Happisburgh South using long HDD and duct installation, with cable burial on the seaward side of the drilling exit point. The landfall ducts would exit in the subtidal zone beyond -5.5m LAT but within 1km of the onshore drilling location.

8.7.5.4.4 Cable protection

Unburied cable

188. Cable burial is expected to be possible throughout the offshore cable corridor, except for cable crossing locations. To provide a conservative impact assessment, a contingency estimate is included, should cable burial not be possible due to unexpected hard substrate. Up to 10km of seabed protection per cable pair (20km in total) for the whole offshore cable corridor, of which, 4km per pair (8km in total) could be within the SAC has been assessed. The maximum width and height of cable protection for unburied cable (per pair of cables) would be 5m and 0.5m, respectively.

Cable crossings

189. In total, there may be up to eleven existing cables (seven of which are out of service (see section 8.7.5.4.1) and two pipelines which the Norfolk Boreas export cables would need to cross (up to five cables and one pipeline within the SAC). Each crossing would require a carefully agreed procedure between the respective cable/pipeline owners.

190. At each crossing, protection would be installed to protect the existing pipeline or cable being crossed. Each Norfolk Boreas cable pair would then be placed on top of the layer of protection with a further layer of cable protection placed on top.

191. The maximum width and length of cable protection for cable crossings would be 10m and 100m, respectively. The maximum height of cable crossings would be 0.9m.

Types of cable protection

192. The following cable protection options may be used which would be determined during the final design of the project:

- Rock placement - the laying of rocks on top of the cable;
- Concrete mattresses - prefabricated flexible concrete coverings that are laid on top of the cable. The placement of mattresses is slow and as such is only used for short sections of cable;
- Grout or sand bags - bags filled with grout or sand could be placed over the cable. This method is also generally applied on smaller scale applications;
- Frond mattresses - used to provide protection by stimulating the settlement of sediment over the cable. This method develops a sandbank over time protecting the cable but is only suitable in certain water conditions. This method may be used in close proximity to offshore structures; and
- Uraduct or similar - a protective shell which can be fixed around the cable to provide mechanical protection. Uraduct is generally used for short spans at crossings or near offshore structures where there is a high risk from falling objects. Uraduct does not provide protection from damage due to fishing trawls or anchor drags.

8.7.5.5 Sediment disposal

193. The worst-case scenario for the volume of sediment arising from seabed preparation in the Norfolk Boreas site would be associated with levelling the seabed for GBS foundations (180 foundations, levelling an area 50m in diameter) resulting in a total footprint of disturbance of 353,429m^2 (1,963m^2 per foundation) and a potential sediment volume disturbance of 1,767,146m^3 (based on a maximum thickness of 5m of sediment levelled). In addition, levelling of 7,500m^2 per electrical platform and offshore service platform and 1,257m^2 per meteorological masts may be required resulting in a footprint of 25,014m^2 and sediment volume of 125,070m^3.

194. Sediment arising from construction activities in the Norfolk Boreas site and the offshore corridor would be deposited within the proposed disposal area (Figure 5.2). Sediment arising from within the SAC would be deposited back into the SAC in locations to be agreed with Natural England and the MMO based on the preconstruction survey.

8.7.5.6 Vessel footprints

195. Anchor placement may be required during jointing of the export cable and during foundation installation. As a worst-case scenario it is estimated that there may be two joints per export cable pair (one of which may be in the SAC). An average of one vessel placing anchor at each wind turbine has also been assessed. The seabed footprint associated with anchor placement would be approximately 150m^2 (based on six anchors per vessel).

196. In addition, jack-up vessels may be used during foundation installation and an estimate of two jack-up placements per turbine during construction has been assessed. A jack-up footprint of 792m^2 has been assessed based on a six-legged vessel.

8.7.5.7 Maintenance

8.7.5.7.1 Turbines

197. Regular maintenance of the wind turbines would be required during operation. These works would have minimal impact on marine physical processes. However, the placement of anchors or jack-up vessels during maintenance activity has been considered to provide a comprehensive assessment. A maximum average of two turbine locations per day, visited by a jack-up vessel has been assessed.

8.7.5.7.2 Cable repairs

198. During the life of the project, there should be no need for scheduled repair or replacement of the subsea cables. However, periodic inspection would be required and where necessary, reactive repairs and reburial would be undertaken.

199. While it is not possible to determine the number and location of repair works that may be required during the life of the project, an estimate of one export cable repair every year, based on length of cable (one repair every five years within the SAC), is included in the assessment. In addition, one interconnector cable or project interconnector repair and two array cable repairs every five years have been assessed.

200. In most cases a failure would lead to the following operation:

- Vessel anchor placement (150m^2 footprint);
- Exposing/unburying the damaged part of the cable using jetting (3m disturbance width);
- Cutting the cable, assumed to be approximately 300m of export cable or interconnector cable subject to the nature of the repair, or the whole length of an array cable (approximately 2km);
- Lifting the cable ends to the repair vessel;
- Jointing a new segment of cable to the old cable;
- Lowering the cable (and joints) back to the seabed; and
- Cable burial, where possible.

8.7.5.7.3 Cable reburial

201. Cables, including the interconnector or project interconnector, could become exposed due to migrating sand waves. During the life of the project, periodic surveys would be required to ensure the cables remain buried and if they do become exposed, reburial works would be undertaken.

202. For the export cables, the aim would be to avoid requirement for reburial by using pre-sweeping, to ensure the cables are buried in more stable sediment. However, a worst-case scenario of reburial of up to 20km per export cable pair at approximately five-year intervals is assumed to provide a conservative assessment. Of this 20km, reburial of up to 10km per cable within the SAC at five-year intervals has been estimated based on the worst-case scenario that no pre-sweeping is undertaken.

203. Given the small scale of the repairs, the changes to suspended sediment concentrations and seabed level would be negligible in magnitude and short-lived, with no potential significant impact and therefore this is not assessed further.

Table 8.16 Summary of worst-case scenarios for Norfolk Boreas

Impact	Parameter	Worst Case	Rationale
Construction			
Impact 1: Changes in suspended sediment concentrations due to foundation installation in the Norfolk Boreas site	1A. Sediment plume created by seabed preparation	Worst-case scenario for a single wind turbine foundation would be a GBS foundation for a 20MW turbine due to this having the largest single footprint. Seabed preparation may be required up to a sediment depth of 5m. The preparation volume for a single 20MW GBS foundation is 14,137m^3 (based on a 60m diameter preparation area to a depth of 5m). Total maximum seabed preparation volumes for 1,800MW capacity: • 180 GBS foundations for 10MW turbines (requiring preparation area 50m in diameter and 5m preparation depth) = 1,767,146m^3 • 2 electrical platforms (7,500m^2 x 5m depth) = 75,000m^3 • 2 meteorological masts (1,257m^2, 5m depth) = 12,570m^3 • 1 offshore service platform (7,500m^2 x 5m depth) = 37,500m^3 Total worst-case seabed preparation volume for foundations is **1,892,212m^3.**	Seabed preparation (dredging using a trailer suction hopper dredger and installation of a bedding and levelling layer) may be required up to a sediment depth of 5m. The worst-case scenario considers the maximum volumes for the project and assumes that sediment would be dredged and returned to the water column at the sea surface during disposal from the dredger vessel.
	1B. Sediment plume created by drill arisings	The worst-case scenario for a single turbine would be a 20MW monopile foundation, with a maximum drill arisings volume of 8,836m^3 per turbine (based on penetration of 50m and 15m drill diameter). The worst-case scenario for the whole project is an array of 180 monopile foundations, two meteorological masts on pin-pile quadropods, an offshore service platform and two offshore electrical platforms on six-legged pin-piles (18 piles in total) and two LiDAR platforms on monopiles. As a worst case, 50% of the turbines may need to be drilled. For the project as a whole; the maximum amount of drill arisings per monopile for each of the largest wind turbine is 8,836m^3 (based on a drill diameter of 15m per pile and an average drill penetration of 50m). Therefore, the drill arisings would be as follows: • 45 x largest quadropod foundations is 397,608m^3. • Meteorological masts - 2 x pin-pile quadropod = 1,131m^3	Up to 50% of the turbines and platform foundations may need to be drilled (if piled foundations with drilling are used, the level of seabed preparation described above for gravity anchor foundations would not be required).

Impact	Parameter	Worst Case	Rationale
		- Offshore electrical platform - 2 x six-legged with 18 pin-pile = 14,137m^3 - Offshore service platform - 1 x six-legged pin-pile = 848m^3 - Lidar - 2 x monopiles = 189m^3 Total drill arisings volume for foundations in the Norfolk Boreas site is **413,913m^3**.	
Impact 2: Changes in seabed level (morphology) due to foundation installation in the offshore wind farm	2A. Sediment deposited from plume created by seabed preparation	As Impact 1A.	As Impact 1A.
	2B. Sediment deposited from plume created by drill arisings and fate of aggregated drill arisings that are not suspended during foundation installation	As Impact 1B for deposition from the plume. For non-suspended sediment, the worst case assumes that the sediment that is released from drilling is wholly in the form of aggregated 'clasts' of finer sediment that remain on the seabed (at least initially) in the form of a mound, rather than being disaggregated into individual fine sediment components immediately upon release. Footprint of an individual mound arising from the largest quadropod foundation would be 8,836m^2 (or **441,800m^2** total for the whole site including 50% of the largest wind turbines plus one offshore service platform, two meteorological masts and two offshore electrical platform foundations).	Up to 50% of the turbines may need to be drilled (if piled foundations with drilling are used, the level of seabed preparation described above would not be required).
Impact 3: Changes in suspended sediment concentrations during cable installation within the offshore cable corridor (including nearshore)	3. Sediment plume created by export cable installation	Pre-sweeping (dredging) of the export cable route may be required as follows: - Up to 500,000m^3 pre-sweeping within the Haisborough, Hammond and Winterton SAC which would be disposed of within the SAC; and - Up to 100,000m^3 for the rest of the offshore cable corridor based on calculations by CWind (Appendix 5.2). This would lead to a total of **600,000m^3** of disturbed material Following pre-sweeping, trenching (e.g. by jetting or ploughing) would be required to bury the cables. Trenches would have a 'V'-shaped profile with a top width of 10m. The worst case average burial depth for the export cables would be 3m and therefore **3,000,000m^3** of sediment would be disturbed. The export cables would make landfall at Happisburgh South. Cable ducts would be installed at the landfall so that the ends of the export cables can be pulled through from the landward side. The HDD will exit an offshore location, away from	Maximum export cable trench length within the offshore cable corridor is 200km based on four HVDC cables in 2 trenches and 100% burial. 80km of this will be within the Haisborough, Hammond and Winterton SAC (based on 40km x 2 trenches).

Impact	Parameter	Worst Case	Rationale
		the beach (up to 1,000m in drill length from the onshore HDD location). Cable burial will be undertaken from the HDD exit point. ***Disturbance volumes within the Haisborough, Hammond and Winterton SAC. Note these areas are included in the calculations above*** The sediment released due to disposal of pre-swept sediment in the SAC would equate to approximately 500,000m^3. The sediment released at any one time would be subject to the capacity of the dredger. Disposal would be at least 50m from *Sabellaria spinulosa* reef identified during pre-construction surveys. The sediment disturbed or released due to trenching for the export cables would equate to approximately 1,200,000m^3 within the SAC (based on 10m trench width with a V shaped profile x 3m maximum average depth x 2 trenches x 40km length in the SAC). This would be back filled naturally or manually.	
Impact 4: Changes in seabed level due to cable installation within the offshore cable corridor	4A. Changes in seabed level due to deposition from the suspended sediment plume during export cable installation	As Impact 3.	
	4B. Changes in seabed level due to disposal of sediment from sand wave levelling	As Impact 3.	
	4C. Interruptions to bedload transport caused by sand wave levelling	The disposal of any sediment that would be disturbed or removed during sand wave levelling would occur within the Norfolk Boreas offshore cable corridor. Sediment from the Haisborough, Hammond and Winterton SAC would be deposited back within the SAC.	

Impact	Parameter	Worst Case	Rationale
Impact 5: Changes in suspended sediment concentrations during cable installation within the Norfolk Boreas site and Project Interconnector search area	5A. Sediment plume created by array, interconnector and export cable installation within the Norfolk Boreas site	Worst-case scenario is 600km of array cables, 60km of interconnector and 50km of export cable with 100% burial. Potential for pre-sweeping a 20m wide corridor to clear debris or level sand waves prior to excavation of trenches. Therefore, the volumes would be as follows: • Up to 36,000,000m^3 based on 600km of array cable length in the Norfolk Boreas site that may require pre-sweeping (assuming a width of 20m and average depth of 3m). • Up to 3,000,000m^3 based on 50km export cable length in the Norfolk Boreas site that may require pre-sweeping (assuming an average width of 20m and average depth of 3m). • Up to 3,600,000m^3 based on 60km interconnector cable length in the Norfolk Boreas site that may require pre-sweeping (assuming an average width of 20m and average depth of 3m). Total pre-sweeping volume = **42,600,000m^3**	
	5B Sediment plume created by project interconnector cable installation within the Project Interconnector search area.	Maximum parameters for project interconnector cables: • 92km trench length based on up to 10 trenches with 100% burial. • Average burial depth of 3m. • Potential for pre-sweeping a 20m wide corridor to clear debris or level sand waves prior to excavation of trenches. Total pre-sweeping volume = **5,520,000m^3**	Assessment of impacts from any parts of the project interconnector cables located within the Norfolk Boreas site would be included within impact 5A under impacts caused by the interconnector.
Impact 6: Changes in seabed level due to cable installation within the Norfolk Boreas site and Project Interconnector search area	6A. Sediment deposited from plume created by array cable installation	As Impact 5A.	As Impact 5A.
	6B. Sediment deposited from plume created by project interconnector cable installation	As Impact 5B.	Assessment of impacts of any parts of the project interconnector cables located within the Norfolk Boreas site would be included within impacts 6A.

Impact	Parameter	Worst Case	Rationale
Impact 7: Indentations on the seabed due to installation vessels	7A. Jack-up footprints	Total footprint is **294,624m^2** (based on two jacking operations per platform (4 in total) and two per wind turbine for 180 turbines).	Worst-case scenario is jack-up barges with six legs per barge (with a combined leg area of 792m^2).
	7B. Anchor footprints	Total impacted area of **82,800m^2** (1,800m^2 of which is within the offshore cable corridor).	Worst-case scenario is six anchors each with a footprint of 25m^2 equating to a total footprint of 150m^2 per installation. With 552 anchor placements being made
Operation and Maintenance			
Impact 1: Changes to the Tidal Regime due to the Presence of Structures in the Norfolk Boreas site (wind turbines and platforms)	1. Changes to tidal currents created by presence of wind turbines	A larger number of GBS with minimum wind turbine spacing is the worst case (1,800MW in one site). This equates to a worst-case scenario of 180 smaller GBS wind turbine foundations (based on a 40m base diameter) (226,195m^2), two meteorological masts on GBS (628m^2), an offshore service platform (7,500m^2) and two electrical platforms on GBS (15,000m^2), totalling **249,329m^2** of obstructions with a foundation height of 12m and minimum spacing of 720m.	GBS are the worst-case foundation types for effects on tidal currents. This is based on GBS having the greatest cross-sectional area within the water column (compared to other foundation types) representing the greatest physical blockage to tidal currents. The worst-case scenario for changes to the tidal regime does not include effects caused by cable protection. This is because, although flows would tend to accelerate over the protection and then decelerate on the ‘down-flow’ side, they would return to baseline values a very short distance from the structure. Hence, the effect on

Impact	Parameter	Worst Case	Rationale
			tidal currents would be very small.
Impact 2: Changes to the Wave Regime due to the Presence of Structures in the Norfolk Boreas site	2. Changes to waves created by presence of wind turbines	For the entire array, a larger number of GBS with minimum wind turbine spacing is the worst case (720m). As Impact 1.	GBS are the worst-case foundation types for effects on waves due to the height of the foundation above the seabed.
Impact 3: Changes to the Sediment Transport Regime due to the Presence of Structures in the Norfolk Boreas site	3. Sediment plume and changes to bedload sediment transport created by presence of wind turbines	For the entire array, a larger number of GBS with minimum wind turbine spacing is the worst case. As Impacts 1 and 2.	GBS are the worst-case foundation types for effects on waves due to the height of the foundation above the seabed.
Impact 4: Loss of Seabed Morphology due to the Footprint of Wind Turbine Foundation Structures	4. Seabed morphology	Seabed morphology directly impacted by the footprint of each foundation structure on the seabed within the site, constituting a loss in natural seabed area during the operational life. The largest combined footprint of foundations and scour protection would be GBS foundations supporting 10MW turbines which would occupy a maximum area of 200m in diameter (i.e. 31,416m^2 per foundation). The total worst case for 1,800MW capacity would be 180 of the 10MW GBS foundations which would equate to and area 5,654,867m^2 Footprints of platforms and other infrastructure: • Two electrical platforms with scour protection 35,000m^2 • One offshore service platform with scour protection 17,500m^2 • Two meteorological masts with scour protection 15,708m^2 • Two wave buoys 300m^2 • Two LiDAR monopiles with scour protection 157m^2 Total footprint due to foundations: **5,725,532m^2 (5.73km^2)**.	

Impact	Parameter	Worst Case	Rationale
Impact 5: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Norfolk Boreas site and Project Interconnector search area.	5A. Seabed morphology and sediment transport within the Norfolk Boreas site	The worst case scenario for array cables is as follows: Up to 60km of array cable protection may be required in the unlikely event the cables cannot be buried (based on 10% of the total length) resulting in a footprint of 300,000m^2 and volume 150,000m^3 (based on height of 0.5m). Array cable protection at turbines 100m cable length x 5m width x 180 turbines = 90,000m^2 (45,000m^3) Array cable crossings protection: 10 crossings x 100m x 10m = 10,000m^2. Total volume of rock berm cable protection will be 9,000m^3 (based on 0.9m height). The total footprint of array cables would therefore be **400,000m^2** with a volume of **204,000m^3**. Up to 6km of interconnector cable protection could be required in the unlikely event the cables could not be buried (based on 10% of the total length) resulting in a footprint of 30,000m^2 = 5m width x 6,000m (10% of the length) and a volume 15,000m^3 (based on 0.5m height). Interconnector cable protection approaching platforms would be 100m per cable (x2) length x 10m width x two platforms = 4,000m^2 footprint, with a volume of 2000m^3 (based on 0.5m height). Interconnector cable crossings protection is captured within export array cable crossing total shown above. The total footprint of interconnector cables would therefore be **34,000m^2** with a volume of **17,000m^3**. Up to 5km of export cable protection could be required in the unlikely event the cables within the Norfolk Boreas site could not be buried (based on 10% of the length) resulting in a footprint of 5m width x 5,000m (10% of the length) = 25,000m^2 and a volume 12,500m^3 (based on 0.5m height). Export cable protection approaching platforms would be 100m cable length x 10m width x one platform each = 1000m^2 footprint, with a volume of 500m^3 (based on	Cable protection for unburied cables will be up to 0.5m in height and 5m wide

Impact	Parameter	Worst Case	Rationale
		0.5m height). Export cable crossings within the Norfolk Boreas site are captured within the array cable crossing total shown above. The total footprint of the export cables within the Norfolk Boreas site would therefore be **26,000m^2** with a volume of **13,000m^3**.	
	5B. Seabed morphology and sediment transport within the Project Interconnector search area	Up to 9.2km of cable protection may be required in the unlikely event that project interconnector cables cannot be buried (based on 10% of the length) resulting in footprint of 5m width x 9,200m (10% of the length) = 46,000m^2 and a volume of 23,000m^3 (based on 0.5m height). Project Interconnector cable protection approaching platforms would be 100m cable length x 10m width x 10 approaches to platforms = 10,000m^2 footprint, with volume 5,000m^3 (based on 0.5m height). Project Interconnector pipeline crossings protection: 10 crossings x 100m x 10m = 10,000m^2. Total volume of rock berm cable protection will be 9,000m^3 (based on 0.9m height). The total footprint would therefore be **66,000m^2** with a volume of **37,000m^3**.	Assessment of impacts of any parts of project interconnector cables located within the Norfolk Boreas site would be included within impacts 5A. Cable protection for unburied cables would be up to 0.5m in height and 5m wide. The volumes provided here are conservative as the protection would be placed in a trapezoid shape rather than the cuboid shape used in the calculations.
Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures within the offshore cable corridor	6. Seabed morphology and sediment transport along export cables	Cable protection would be required at locations where the export cables cross other cables or pipelines; at the landfall HDD exit points; in the unlikely event that cable burial is not possible; and/or during the operation and maintenance phase should cables become unburied. • Crossings A total of thirteen crossings are required for each cable pair (up to 26 crossings in total) resulting in a total footprint of **26,000m^2** (based on a width of 10m and length of 100m of cable protection per crossing). The volume of cable protection would be **23,400m^3** (based on a height of 0.9m) • Nearshore (within 10m depth contour) Cable protection may be required at each of the landfall HDD exit points. This would entail one mattress (6m length x 3m width x 0.3m height) plus rock dumping (5m length x 5m width x 0.5m height) at each exit point (up to two cable pairs) resulting in a footprint of **36m^2** and volume of **18m^3**.	

Impact	Parameter	Worst Case	Rationale
		• Unburied cables In the unlikely event that cable burial is not possible due to hard substrate being encountered, up to 16km per cable pair outside the SAC and 4km inside the SAC per cable pair (8km in total within the SAC and 40km within the offshore cable corridor) could require additional protection resulting in a footprint of 200,000m^2 and volume of 100,000m^3.	
Impact 7: Cable repairs/reburial and maintenance vessel footprints	7A. Repairs/Reburial	Unplanned repairs and reburial of cables may be required during operations and maintenance: • Reburial of all sections of array cable is estimated once every 5 years – 3m disturbance width x 600km = 1,800,000m^2. • Two array cable repairs per year are estimated. An array cable may be up to 6km (based on turbine spacing) – 3m disturbance width x 6,000m x 2 = 36,000m^2. • One interconnector repair per year is estimated – 10m disturbance width x 300m repair length = 3,000m^2; or • One project interconnector cable repair per year is estimated – 10m disturbance width x 300m repair length = 3,000m^2. • One export cable repair per year with 300m sections removed and replaced. Disturbance width of 3m = 900m^2 per year. • Reburial of up to 20km length per export cable (10km in the Haisborough, Hammond and Winterton SAC and 10km outside the SAC) = 120,000m^2 based on two cables and a disturbance width of 3m = 1,200,000m^2 (1.2km^2) **In Haisborough, Hammond and Winterton SAC (encompassed within the above parameters):** • One export cable repair every 5 years is estimated within the SAC. • It is estimated that 300m sections would be removed and replaced per repair. • Disturbance width of 3m = 900m^2 every 5 years • Anchor placement associated with repair works – 150m^2 based on six anchors per vessel • Reburial of up to up to 10% of the cable length (4km per pair) every 5 years	Either an interconnector cable repair or a project interconnector cable repair are anticipated each year but never both as only one of these options would have been installed

Impact	Parameter	Worst Case	Rationale
		may be required should pre-sweeping not be undertaken. The disturbance width would be approximately 10m and therefore the total disturbance would be 0.08km^2 every 5 years. If reburial is required, it is likely that this would be in relatively short sections (e.g. 1km) at any one time.	
	7B. Jack-up footprints	Maintenance of wind turbine generators will be required during O&M. An estimate of up to two locations visited per day during O&M using a jack up vessel with a footprint of 792m^2 which would lead to a total area of up to 0.58km^2 per year (assumes large jack up with six legs each).	
	7C. Anchor footprints	Anchored vessels placed temporarily on site to maintain the wind turbines. Worst-case scenario is six anchors each with a footprint of 25m^2 equating to a maximum total footprint of 150m^2 per installation (450m^3 footprint volume based on an indicative anchor penetration depth of 3m).	
Decommissioning			
Impact 1: Changes in Suspended Sediment Concentrations due to Wind Turbine Foundation Removal	1. Suspended sediment concentrations	Removal of foundations is likely to be limited to parts that are above the seabed. Impacts will be less than during the construction phase. Scour protection would likely be left in-situ.	
Impact 2: Changes in Seabed Level due to Wind Turbine Foundation Removal	2. Seabed morphology	Removal of foundations is likely to be limited to parts that are above the seabed. Impacts will be less than during the construction phase. Scour protection would likely be left in-situ.	
Impact 3: Changes in Suspended Sediment Concentrations during Removal of parts of the Array, Interconnector and Project Interconnector Cables	3. Suspended sediment concentrations	Removal of some or all the array cables, interconnector and project interconnector cables. Cable protection would likely be left in-situ.	

Impact	Parameter	Worst Case	Rationale
Impact 4: Changes in Seabed Level due to Removal of parts of the Array, Interconnector and Project Interconnector Cables	4. Seabed morphology	Removal of some or all the array cables, interconnector and project interconnector cables. Cable protection would likely be left in-situ.	
Impact 5: Changes in Suspended Sediment Concentrations during Export Cable Removal (including nearshore and at the coastal landfall)	5. Suspended sediment concentrations	Removal of some or all the export cables. Cable protection would likely be left in-situ.	
Impact 6: Indentations on the Seabed due to Decommissioning Vessels	6. Seabed morphology	As with construction the, worst-case scenario is jack-up barges with four legs per barge (based on a combined leg footprint of 792m^2). Total footprint is 294,624m^2 (based on two jacking operations per wind turbine and per platform for 180 x smallest turbines). Worst-case scenario for vessel anchors is six anchors at each with a footprint of 25m^2 equating to a total footprint of 150m^2 per installation.	

8.7.6 Potential Impacts during Construction

204. During the construction phase of Norfolk Boreas, there is the potential for foundations and cable installation activities to disturb sediment, potentially resulting in changes in suspended sediment concentrations and/or seabed levels or, in the case of nearshore cable installation, shoreline morphology due to deposition or erosion.

205. The worst-case layout scenario (discussed in section 8.7.5) is assessed with construction carried out in either one or two phases. A detailed assessment of the single-phase approach is presented and then highlights are given of any pertinent differences associated with the two-phase approach.

8.7.6.1 Impact 1A: Changes in suspended sediment concentrations due to seabed preparation for foundation installation

206. Seabed sediments and shallow near-bed sediments within Norfolk Boreas would be disturbed during any levelling or dredging activities to create a suitable base prior to foundation installation. The worst-case scenario assumes that sediment would be dredged and returned to the water column at the sea surface as overflow from a dredger vessel. This process would cause localised and short-term increases in suspended sediment concentrations both at the point of dredging at the seabed and, more importantly, at the point of its discharge back into the water column. The disposal of any sediment that would be disturbed or removed during foundation installation would occur within the Norfolk Boreas site.

207. Mobilised sediment from these activities may be transported by wave and tidal action in suspension in the water column. The disturbance effects at each wind turbine location are likely to last for no more than a few days, within an overall single-phase foundation installation programme of approximately 20 months.

208. The median particle sizes of seabed sediments across Norfolk Boreas are predominantly 0.17 to 0.33mm (fine to medium-grained sand). Most seabed samples contained less than 10% mud and less than 5% gravel. Baseline suspended sediment concentrations in Norfolk Boreas are typically between 0.3 and 108mg/l throughout a year. Concentrations are less than 30mg/l for 95% of the time and less than 10mg/l for 70% of the time.

209. For a sediment release from an individual wind turbine foundation, the worst-case scenario is associated with the dredging volume for each 20MW GBS foundation, with a maximum preparation area of 2,827m^2. This yields a worst-case dredging volume of 14,137m^3 per foundation based on levelling up to 5m of sediment.

210. For the total volume released during the construction phase, the worst-case scenario is associated with the maximum number (180) of 10MW GBS foundations with a

maximum preparation area of 1,963m^2. This yields a total dredging volume of 1,767,146m^3. Also, using a worst-case approach the following platforms would be installed:

- Up to two meteorological masts yielding a dredging volume of 12,570m^3;
- Up to two offshore electrical platforms yielding a dredging volume of 75,000m^3; and
- Up to one offshore service platform yielding a dredging volume of 37,500m^3.

211. Therefore, the total maximum seabed preparation volume under the single-phase approach would be 1,892,212m^3 of excavated sediment.

212. Expert-based assessment suggests that, due to the predominance of medium-grained sand across the Norfolk Boreas site, the sediment disturbed by the drag head of the dredger at the seabed would remain close to the bed and settle back to the bed rapidly. Most of the sediment released at the water surface from the dredger vessel would fall rapidly (minutes or tens of minutes) to the seabed as a highly turbid dynamic plume immediately upon its discharge (within a few tens of metres along the axis of tidal flow).

213. Some of the finer sand fraction from this release and the very small proportion of mud that is present are likely to stay in suspension for longer and form a passive plume which would become advected by tidal currents. Due to the sediment sizes present, this is likely to exist as a measurable but modest concentration plume (tens of mg/l) for around half a tidal cycle (up to six hours). Sediment would eventually settle to the seabed in proximity to its release (within a few hundred metres up to around a kilometre along the axis of tidal flow) within a short period of time (hours). Whilst lower suspended sediment concentrations would extend further from the dredged area, along the axis of predominant tidal flows, the magnitudes would be indistinguishable from background levels.

214. This expert-based assessment is supported by the findings of a review of the evidence base into the physical impacts of marine aggregate dredging on sediment plumes and seabed deposits (Whiteside et al., 1995; John et al., 2000; Hiscock and Bell, 2004; Newell et al., 2004; Tillin et al., 2011; Cooper and Brew, 2013).

215. Modelling simulations undertaken for the East Anglia ONE site using the Delft3D plume model (ABPmer, 2012b) were used as part of the expert-based assessment of suspended sediment concentrations arising from seabed preparation. The sediment types across East Anglia ONE (5% gravel, 93% sand and 2% mud) are like those across Norfolk Boreas (5% gravel, 65-100% sand and 10% mud).

216. Also, Norfolk Boreas and East Anglia ONE are similar distances from the amphidromic point, and therefore the tidal currents and hence sediment dispersion

patterns would be similar. Given these similarities, the earlier modelling studies for East Anglia ONE are considered to represent a suitable analogue for verifying the conclusions of the more qualitative expert-based assessment described in this ES.

217. In the East Anglia ONE modelling studies (ABPmer, 2012b), consecutive daily releases of 22,500m^3 of sediment (mostly medium-grained sand, but also with small proportions of gravel, other sand fractions and mud) were simulated at the water surface at 15 wind turbine locations. The value used in the modelling for sediment release is just over double the release volume predicted for each of the Norfolk Boreas 10MW wind turbine foundations (9,817m^3), and so can be used as a conservative analogue to establish the magnitude of effect.

218. The ABPmer (2012b) model predicted that close to the release locations, suspended sediment concentrations would be very high (orders of magnitude greater than natural background levels), but of very short duration (seconds to minutes) as the dynamic plume falls to the seabed. Within the passive plume, suspended sediment concentrations above background levels were low (less than 10mg/l) and within the range of natural variability. Net movement of fine-grained sediment retained within the passive plume was to the north, in accordance with the direction of residual tidal flow. Suspended sediment concentrations rapidly returned to background levels after cessation of the release into the water column.

219. Given this finding from the modelled consecutive installation of 15 wind turbine foundations (ABPmer, 2012b), it is expected that effects from installation of 180 foundations across the whole of Norfolk Boreas would be less. Given that the maximum sediment volume released through seabed preparation at Norfolk Boreas would be less than the modelled release at East Anglia ONE; the worst case suspended sediment concentrations will also be less (given similar hydrodynamic conditions). Hence, it is anticipated that the worst case suspended sediment concentrations at Norfolk Boreas would not likely exceed a maximum of 20mg/l within the passive plume, with northward movement and reduced concentrations within a dynamic plume and rapid dissipation to background levels after release into the water column has stopped.

220. The point of release would move across the site with progression of the construction sequence. There would be little additional effect of scaling-up from the modelled 15 foundations to the 180 foundations proposed across Norfolk Boreas. This is because the modelled results show that after completion of installation of a foundation, the suspended sediment concentrations do not persist but rapidly (minutes to hours) return to background levels. Hence, the release of sediment from one foundation installation would not last for a long enough time to interact with the next installation. This would be the case regardless of the number of foundations that

were installed and so the cumulative effects of 15 and 180 installations would be similarly small.

8.7.6.1.1 *Assessment of effect magnitude and/or impact significance for a single-phase construction*

221. The expert-based assessment of the dynamic and passive plume effects on suspended sediment concentrations for Norfolk Boreas are consistent with the findings of the earlier modelling studies for the East Anglia ONE project. This means there is high confidence in the assessment of effects.

222. The worst-case changes in suspended sediment concentrations due to seabed preparation for GBS foundation installation are likely to have the magnitudes of effect shown in Table 8.17.

Table 8.17 Magnitude of effect on suspended sediment concentrations under the worst-case scenario for GBS foundation installation

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	High	Negligible	Negligible	Negligible	Medium
Far-field	Low	Negligible	Negligible	Negligible	Low

*The near-field effects are confined to a small area, likely to be several hundred metres up to a kilometre from each foundation location.

223. The effects on suspended sediment concentrations due to foundation installation for Norfolk Boreas do not directly impact upon the identified receptor groups for marine physical processes (i.e. the offshore SAC, SAC and East Anglia coast). This is because the designated features of North Norfolk Sandbanks and Saturn Reef SAC (23.9km west of Norfolk Boreas) and the Haisborough, Hammond and Winterton SAC (34.1km west of Norfolk Boreas) are related to processes operating on the seabed and not in the water column. Also, regional sediment transport directions are directed along a north-south axis with no east to west component, and so there is no pathway for suspended sediment to reach the East Anglian coast. Hence, there is **no impact** on the identified receptors groups associated with the suspended sediment generated by the project. However, the effects have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.1.2 *Assessment of effect magnitude and/or impact significance for a two-phase construction*

224. The worst-case release of sediments through seabed preparation would occur over two distinct phases, each lasting up to eight months (rather than a single 20-month period), for the installation of the foundations. Whilst this scenario would mean that the effects are caused in two separate periods, with a longer additive duration of

disturbance, this would not materially change the assessment of significance compared with a single-phase approach. Any potential implications for receptors will be considered in the relevant chapters.

8.7.6.2 Impact 1B: Changes in suspended sediment concentrations due to drill arisings for installation of piled foundations for wind turbines

225. Sub-seabed sediments within Norfolk Boreas would become disturbed during any drilling activities that may be required at the location of piled foundations. The disposal of any sediment that would be disturbed or removed during foundation installation would occur within the Norfolk Boreas site. The worst-case scenario for a release from an individual wind turbine assumes a monopile foundation for the largest 20MW wind turbine. In this case, a 15m drill diameter would be used from the seabed to a depth of 50m, releasing a maximum of 8,836m^3 of sediment into the water column.

226. Norfolk Boreas Limited estimates that the maximum number of foundations that would require drilling would be 50%. Given the seabed conditions and underlying geology, this is likely to be an over estimate and it is possible that no monopile or pin pile foundations (if chosen) would require drilling. Hence, for the total volume released during the construction phase, the worst-case scenario for drilling is associated with the maximum number of 20MW monopiles. This yields a total sediment volume of 397,608m^3 (45 x 20MW).

227. Also, pin-pile quadropod foundations with diameters of 3m would represent the worst-case scenario for the two meteorological masts, yielding up to 1,131m^3 of sediment. As a worst case, the two offshore electrical platforms, both on six-legs with 18 pin piles, would yield up to 14,137m^3 of sediment in total and the offshore service platform with six pin piled legs would yield 848m^3. Two LiDAR monopiles may also be required, yielding up to 189m^3 of sediment.

228. The total volume of drill arisings under the single-phase approach would therefore be 413,913m^3.

229. The drilling process would cause localised and short-term increases in suspended sediment concentrations at the point of discharge of the drill arisings. Released sediment may then be transported by tidal currents in suspension in the water column. Due to the small quantities of fine-sediment released (most of the sediment will be sand or aggregated clasts), the fine-sediment is likely to be widely and rapidly dispersed. This would result in only low suspended sediment concentrations and low changes in seabed level when the sediments ultimately come to deposit. The disturbance effects at each wind turbine location are only likely to last for a few days of construction activity within the overall construction programme lasting up to 20 months for foundation installation (single phase).

230. In the East Anglia ONE modelling studies (ABPmer, 2012b), 982m^3 of variably graded fine sediment (sand, clay and silt), released into the water column once every two days was assessed to simulate the construction of eight consecutively drilled foundations over a 15-day simulation period. The release volume is approximately nine times less than that of the individual worst case scenario for the largest monopile foundations being considered for Norfolk Boreas (8,836m^3).

231. The larger release volumes associated with the worst-case scenario for Norfolk Boreas and similar tidal currents compared to East Anglia ONE may combine to result in larger concentrations above background levels than previously modelled. However, these are likely to still be modest (tens of mg/l) due to the low volumes of disaggregated fine-grained sediment in the drill arisings. Hence, the principle of wide dispersion in relatively low concentrations remains valid. Also, a conservative assumption was made in the modelling that all drilled sediment would disperse. However, in reality some of the drill arisings would arrive at the sea surface as larger aggregated clasts which would settle rapidly (see construction impact 2B, section 8.7.6.4).

232. The previous modelling results support the general principles of the expert-based assessment in that, away from the immediate release locations, elevations in suspended sediment concentration above background levels were low (less than 10mg/l) and within the range of natural variability. Indeed, modelling indicated that concentrations would generally be no greater than 5mg/l above background levels at 5km from the release location, indicating wide dispersion in low concentrations. Net movement of fine-grained sediment retained within a plume was to the north, in accordance with the direction of residual tidal flow, although gross movement to both the north and south was possible depending on timing of release. Sediment concentrations arising from one foundation installation were deemed unlikely to persist sufficiently long for them to interact with subsequent operations, and therefore no cumulative effect was anticipated from multiple installations.

233. The changes in suspended sediment concentrations (magnitudes, geographical extents and durations of effect) that are anticipated at Norfolk Boreas would move across the site with progression of the construction sequence as the point of sediment release (and hence geographic location of the zone of effect) changes with the installation of foundations at different wind turbine locations.

8.7.6.2.1 Assessment of effect magnitude and/or impact significance for a single-phase construction

234. The worst case changes in suspended sediment concentrations due to dispersal of drill arisings for foundation installation would have the same magnitudes of effect as those for seabed preparation (see Impact 1A, section 8.7.6.1), and are shown in Table 8.18.

Table 8.18 Magnitude of effect on suspended sediment concentrations under the worst-case scenario for piled foundation installation

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	High	Negligible	Negligible	Negligible	Medium
Far-field	Low	Negligible	Negligible	Negligible	Low

*The near-field effects are confined to a small area, likely to be several hundred metres up to a kilometre from each foundation location.

235. In a similar way to seabed preparation (section 8.7.6.1) there is **no impact** on the identified receptors groups associated with the suspended sediment generated by the project. However, the effects have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.2.2 Assessment of effect magnitude and/or impact significance for a two-phase construction

236. The worst-case release of sediments through drilling would occur as the favoured method of installing monopiles foundations. Under the indicative two phased approach impacts would occur over two distinct phases, each lasting up to nine months (rather than a single 18-month period) with approximately a three month gap. Whilst these scenarios would mean that the effects are caused in two separate periods, with a longer additive duration of disturbance, this would not materially change the assessment of significance compared with a single-phase approach.

8.7.6.3 Impact 2A: Changes in seabed level due to seabed preparation for foundation installation

237. The increased suspended sediment concentrations associated with construction impact 1A (section 8.7.6.1) have the potential to deposit sediment and raise the seabed elevation slightly.

238. Expert-based assessment suggests that coarser sediment disturbed during seabed preparation would fall rapidly to the seabed (minutes or tens of minutes) as a highly turbid dynamic plume immediately after it is discharged. Deposition of this sediment would form a ‘mound’ local to the point of release. Due to the coarser sediment particle sizes observed across the site (predominantly medium-grained sand), a large proportion of the disturbed sediment would behave in this manner.

239. The resulting mound would be a measurable protrusion above the existing seabed (likely to be tens of centimetres to a few metres high) but would remain local to the release point. The geometry of each of these produced mounds would vary across Norfolk Boreas, depending on the prevailing physical conditions, but in all cases the sediment within the mound would be like the surrounding seabed. This would mean

that there would be no significant change in seabed sediment type. Also, the overall change in elevation of the seabed is small compared to the absolute depth of water (greater than 20m). The change in seabed elevation is within the natural change to the bed caused by sand waves and sand ridges and hence the blockage effect on physical processes would be negligible.

240. The mound will be mobile and be driven by the physical processes, rather than the physical processes being driven by it. This means that over time the sediment comprising the mound will gradually be re-distributed by the prevailing waves and tidal currents.

241. In addition to localised mounds, the very small proportion of mud would form a passive plume and become more widely dispersed before settling on the seabed. The East Anglia ONE modelling (ABPmer, 2012b) considered seabed level changes resulting from deposition of sediments from the passive plume due to seabed preparation for 15 foundations. This involved a worst-case sediment release of 22,500m^3 per foundation (i.e. around twice the volume considered as the worst case for an individual wind turbine foundation in Norfolk Boreas). For the most part, the deposited sediment layer across the wider seabed was found to be less than 0.2mm thick and did not exceed 2mm anywhere. The area of seabed upon which deposition occurred (at these low values) extended a considerable distance from the site boundary (around 50km), but in doing so only covered a very narrow width of seabed (a few hundred metres). This is because the dispersion of the plume followed the axis of tidal flow. The previous assessment also concluded that this deposited sediment has the potential to become re-mobilised and therefore would rapidly become incorporated into the mobile seabed sediment layer, thus further reducing any potential effect.

242. Using the plume modelling studies for East Anglia ONE as part of the expert-based assessment suggests that deposition of sediment from the Norfolk Boreas plume would occur across a wide area of seabed and would be very thin (millimetres). Given that the maximum sediment volume released through seabed preparation at Norfolk Boreas would be less than the modelled release at East Anglia ONE; the worst-case thickness of sediment deposited from the plume will also be less (given similar hydrodynamic conditions). Hence, it is anticipated that the worst-case sediment thicknesses at Norfolk Boreas would not likely exceed a maximum of 1mm and be less than 0.1mm over larger areas of the seabed.

243. This expert-based assessment is supported by an evidence-base obtained from research into the physical impacts of marine aggregate dredging on sediment plumes and seabed deposits (Whiteside et al., 1995; John et al., 2000; Hiscock and Bell, 2004; Newell et al., 2004; Tillin et al., 2011; Cooper and Brew, 2013).

8.7.6.3.1 Assessment of effect magnitude and/or impact significance for a single-phase construction

244. The expert-based assessment of seabed level changes associated with foundation installation for Norfolk Boreas are consistent with the findings of the earlier modelling studies for East Anglia ONE. The models of East Anglia ONE were successfully calibrated and verified with existing data, and so there is high confidence in the assessment of effects, including their scaling up from modelling results of a sub-set of wind turbines to the whole project area.

245. The changes in seabed levels due to foundation installation under the worst-case sediment dispersal scenario are likely to have the magnitudes of effect shown in Table 8.19.

Table 8.19 Magnitude of effects on seabed level changes due to deposition under the worst-case scenario for sediment dispersal following GBS foundation installation

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Medium	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area of seabed (likely to be several hundred metres up to a kilometre from each foundation location) and would not cover the whole of Norfolk Boreas.

246. The overall impact of foundation installation activities for the project under a worst-case scenario on seabed level changes for identified morphological receptor groups (North Norfolk Sandbanks and Saturn Reef SAC 22.9km west of the Norfolk Boreas site, and the Haisborough, Hammond and Winterton SAC 34.1km west of the Norfolk Boreas site) is considered to be **negligible impact**. This is because the predicted thickness of sediment resting on the seabed would only amount to a maximum of 1mm. After this initial deposition, this sediment will be continually re-suspended to reduce the thickness even further to a point where it will be effectively zero. This will be the longer-term outcome, once the sediment supply from foundation installation has ceased.

247. The worst-case scenario assumes that seabed preparation activities would be the maximum for the given water depth. In practice, the volumes of sediment released would be lower than the worst case at many wind turbine locations because the detailed design process would optimise the foundation type and installation method to the site conditions.

248. The effects on seabed level have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.3.2 Assessment of effect magnitude and/or impact significance for a two-phase construction

249. Under a two-phase construction approach, the principal differences compared to the single-phase assessment are those described previously for construction impact 1A (i.e. the effect of distinct construction periods). Consequently, there would be no material change to the assessment of significance for construction impact 2A for two phases compared with that for a single phase.

8.7.6.4 Impact 2B: Changes in seabed level due to drill arisings for installation of piled foundations

250. The increased suspended sediment concentrations associated with construction impact 1B (section 8.7.6.2) have the potential to deposit sediment and raise the seabed elevation slightly.

251. Drilling of piled foundations could potentially occur through two different geological units; sand similar to that at the seabed and the underlying mud deposits of the Brown Bank Formation. Expert-based assessment suggests that the coarser sediment fractions (medium and coarse sands and gravels) and aggregated 'clasts' of mud of the Brown Bank Formation would settle out of suspension in proximity to each foundation location.

252. If drilling takes place through 100% sand, expert-based assessment suggests that the coarser sediment from the drilling process would fall rapidly (within minutes or tens of minutes) to the seabed to form a 'mound' in a similar way to the disturbed sediment during seabed preparation. The very small proportion of mud within the predominantly sand deposit would be released into the water column and dispersed before settling on the seabed.

253. The plume modelling studies for East Anglia ONE (ABPmer, 2012b) considered the seabed level changes resulting from deposition of sediments from drilling eight piled quadropod foundations. The coarser sediment was deposited near to the point of release up to thicknesses of a few centimetres and over a seabed area local to each foundation (within a few hundred metres). For the most part, the deposited sediment layer across the wider seabed area was less than 0.025mm thick.

254. Although the modelling used a smaller volume of sediment (982m^3) than the worst case for Norfolk Boreas (8,836m^3 for an individual turbine) it does support the principles of the expert-based assessment that the envisaged scale of seabed level change would be small. Using the assumption that an increase in sediment release would lead to a proportional increase of the sediment thickness, then the worst case thicknesses for Norfolk Vanguard near each foundation would be a few 10's of centimetres with thickness up to 0.23mm across the wider seabed.

255. The seabed level changes that are anticipated would move across Norfolk Boreas with progression of the construction sequence as the point of sediment release (and hence geographic location of the zone of effect) changes with the installation of foundations at different wind turbine locations.

256. If the drilling reaches depths where it penetrates the underlying mud deposits (Brown Bank Formation), then a worst-case scenario is considered whereby the sediment released from the drilling is assumed to be wholly in the form of aggregated 'clasts'. These clasts would remain on the seabed (at least initially), rather than being disaggregated into individual fine-grained sediment components immediately upon release. Under this scenario, the worst-case scenario assumes that a 'mound' would reside on the seabed near the site of its release.

257. For an individual wind turbine, the worst case is associated with a 15m diameter monopile and assumes that each mound would contain a maximum volume of 8,836m^3 of sediment (assumes that all the drill arisings are in the form of aggregated clasts).

258. For drill arisings from the project as a whole, the worst case is for 45 quadropods for the largest turbine foundations (i.e. 50% of turbine locations) along with two meteorological masts, one offshore service platform and two offshore electrical platforms, amounting to total volume of 441,800m^3 of sediment. These mounds would be composed of sediment with a different particle size and would behave differently (they would be cohesive) to the surrounding sandy seabed, and therefore represent the worst-case scenario for mound formation during construction.

259. The method for calculating the footprint of each mound follows that which was developed and agreed with Natural England for earlier major offshore wind projects at Dogger Bank Creyke Beck (Forewind, 2013), Dogger Bank Teesside (Forewind, 2014) and East Anglia THREE (EATL, 2015). The methodology involves the following stages:

- Calculate the maximum potential width of a mound (for the given volume) based on the diameter of an assumed idealised cone on the seabed. This was based on simple geometric relationships between volume, height, radius and side-slope angle of a cone. The latter parameter was taken as 30°, which is a suitable representation for an angle of friction of clasts of sediment.
- Calculating the maximum potential length of the mound (for the given volume and maximum potential width). The assumed height of the mound was 'fixed' in the calculation as being equivalent to the average height of the naturally occurring sand waves on the seabed within the site. This calculation was based on simple geometric relationships between volume, height, width and length and assumed that, when viewed in side elevation, the mound would be

triangular in profile but that its length is greater than its width, thus forming a 'ramp' shape.

- Based on the newly-calculated width and length of the mound, a footprint area on the seabed could then be calculated.

260. Based on this approach, the footprint of an individual 2m-high mound arising from the 15m diameter drill used for 20MW wind turbine monopiles would be 8,836m^2 (or 441,800m^2 for the whole of Norfolk Boreas under the single-phase approach, assuming a worst-case scenario of 45 wind turbines, three platforms and two metmasts are drilled). When compared to the total area of Norfolk Boreas (725km^2), the worst-case mound footprint is only 0.06% of the seabed within the wind farm area.

8.7.6.4.1 Assessment of effect magnitude and/or impact significance for a single-phase construction

261. The assessment of seabed level changes associated with foundation installation for Norfolk Boreas are consistent with the findings of the earlier modelling studies for East Anglia ONE. The models that were used for East Anglia ONE had been successfully calibrated and verified with existing data, and so there is high confidence in the assessment of effects, including their scaling up from modelling results of a sub-set of wind turbines to the whole project area.

262. The changes in seabed levels due to foundation installation under the worst-case sediment dispersal scenario and sediment mound scenario are likely to have the magnitudes of effect shown in Table 8.20 and Table 8.21, respectively.

Table 8.20 Magnitude of effects on seabed level changes due to deposition under the worst-case scenario for sediment dispersal following piled foundation installation

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Medium	Medium-High	High	Medium	Medium-High
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area of seabed (likely to be several hundred metres up to a kilometre from each foundation location) and would not cover the whole of Norfolk Boreas.

Table 8.21 Magnitude of effects on seabed level changes due to deposition under the worst-case scenario for sediment mound creation following piled foundation installation

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field$^+$	Medium	Medium-High	High	Medium	Medium-High
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

+The near-field effects are confined to a small area of seabed (likely to be immediately adjacent to each wind turbine location), and would not cover the whole of Norfolk Boreas.

263. As the impacts are restricted to the near-field impacts of the mounds, the overall impact of foundation installation activities for the project under a worst-case scenario is considered to be **no impact** on seabed level changes for identified morphological receptor groups (the cSCI/SAC, SAC and coastal environment). This is because there is a separation distance of at least 22.9km between the nearest sediment mound and the offshore designated sites or the East Anglian coast. Transport of the aggregated clasts would be limited, and so there would be no pathway between the source (mounds) and the receptors (SAC, SAC and coast).

264. The worst-case scenario assumes that piles would be drilled to their full depth for the given water depth. In practice, the volumes of sediment released would be lower than the worst case at many wind turbine locations because the detailed design process would optimise the foundation type and installation method to the site conditions, and the worst case scenario of 50% drilling is deemed to be conservative.

265. The effects on seabed level have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.4.2 Assessment of effect magnitude and/or impact significance for a two-phase construction

266. Under the two-phase approach, the principal differences compared to the single-phase assessment are those described previously for construction impact 1B (i.e. the effect of distinct construction periods). Consequently, there would be no material change to the assessment of significance for construction impact 2B for two phases compared with that for a single phase.

8.7.6.5 Impact 3: Changes in suspended sediment concentrations due to cable installation within the offshore cable corridor

267. The details of how the export cable would be installed depend on the final project design and are discussed in Chapter 5 Project Description. The total maximum length of export cable trenches within the offshore cable corridor would be 200km.

268. The installation of the export cables has the potential to disturb the seabed sediment to an average depth of 3m, either directly through the installation method chosen, or through seabed levelling of any large sand waves that may be present along the cable corridor prior to cable installation. The worst-case scenario cable-laying technique is considered to be jetting. At the Happisburgh South landfall, cables would be installed via long HDD. The potential release of suspended sediment from these construction phase activities, with the release points along different parts of the offshore cable corridor, is considered here.

269. The types and magnitudes of effects that could be caused have previously been assessed within an industry best-practice document on cabling techniques (BERR, 2008). This document has been used alongside expert-based judgement and analysis of site conditions to inform the assessments presented below.

8.7.6.5.1 Cable installation (trenching and sand wave levelling)

270. The sediment released due to pre-sweeping for the export cables within the offshore cable corridor would equate to up to 600,000m^3 of sediment. Approximately 500,000m^3 would be within the Haisborough, Hammond and Winterton SAC; 100,000m^3 within the rest of the offshore cable corridor (excluding the nearshore (10m water depth contour) where no pre-sweeping is proposed).

271. Following pre-sweeping, the sediment disturbed due to trenching for the export cables would equate to a maximum of 3,000,000m^3 of sediment. Approximately 1,200,000m^3 would be within the Haisborough, Hammond and Winterton SAC, and the remainder from the rest of the offshore cable corridor. Ploughing would create temporary mounds either side of the trench and therefore it is expected that only a small proportion of the 3,000,000m^3 would result in sediment plumes during cable installation.

272. There are similarities in water depth, sediment types and metocean conditions between the offshore cable corridor for East Anglia ONE and Norfolk Boreas. Hence, the earlier modelling studies provide a suitable analogue for the present assessments. Plume modelling simulations undertaken for East Anglia ONE (ABPmer, 2012b) were used in the above expert-based assessments and provided the following quantification of magnitude of change of suspended sediment concentrations:

a. In water depths greater than -20m LAT, peak suspended sediment concentrations would be typically less than 100mg/l, except in the immediate vicinity (a few tens of metres) of the release location.

b. In shallow water depths nearer to shore (less than -5m LAT) the potential for dispersion is more limited and therefore the concentrations are likely to be greater, approaching 400mg/l at their peak. However, these plumes would be localised to within less than 1km of the location of installation and would persist for no longer than a few hours.

c. Following cessation of installation activities, any plume would have been fully dispersed because of advection and diffusion. Sediments arising from the offshore cable corridor would tend to be advected to the north and potentially across Haisborough, Hammond and Winterton SAC for some parts of the offshore cable corridor.

d. The residual plume concentrations resulting from the East Anglia ONE model (and hence as an analogue for Norfolk Boreas) are likely to be overly conservative. This is because the plume dispersion model takes into consideration the potential for re-mobilisation of the dispersed sediment once it has settled to the bed.

273. This assessment is based on the overall sediment release volumes being low and confined to near the seabed (rather than higher in the water column) along the alignment of the offshore cable corridor, and the rate at which the sediment is released into the water column from the jetting process would be relatively slow.

274. The results show that concentrations would be enhanced by the greatest amount in the shallowest sections of the offshore cable corridor. However, in these locations the background concentrations are also greater than in deeper waters.

8.7.6.5.2 Landfall construction activities

275. At the Happisburgh South landfall, cables would be installed via long HDD. The key components of the construction methodologies for the export cables close to shore with the potential to affect coastal processes are:

- The connection of the landfall to the nearshore portion of the export cables;
- The placement of structures on the shore to achieve the connection; and
- The sequencing of activities.

276. The HDD exit point will be in the subtidal zone, seaward of the low water mark and at least -5.5m LAT. The exit point would require excavation of a trench to bury the nearshore portions of the export cables on the seaward side of the landfall HDD. This excavation has the potential to increase suspended sediment concentrations close to shore.

277. As discussed in section 8.6.9, nearshore ambient suspended sediment data is limited. During the landfall excavation process the suspended sediment concentrations will be elevated above prevailing conditions, but are likely to remain within the range of background nearshore levels (which will be high close to the coast because of increased wave activity) and lower than those concentrations that would develop during storm conditions. Also, once trenching is completed, the high energy nearshore zone is likely to rapidly disperse the suspended sediment (i.e. over a period of a few hours) in the absence of any further sediment input.

278. Excavated sediment would be backfilled into the trench by mechanical means (within a few days of excavation) and re-instated close to its original morphology. This activity would result in some localised and short-term disturbance, but there would be no long-term effect on sediment transport processes.

8.7.6.5.3 Assessment of effect magnitude and/or impact significance for a single-phase installation

279. The worst-case changes in suspended sediment concentrations due to export cable installation within the offshore cable corridor are likely to have the magnitudes of effect shown in Table 8.22.

Table 8.22 Magnitude of effects on suspended sediment concentrations under the worst-case scenario for export cable installation (including any sand wave levelling and landfall construction activities) within the offshore cable corridor

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field* (nearshore and landfall)	Low	Negligible	Negligible	Negligible	Low
Near-field* (offshore)	High	Negligible	Negligible	Negligible	Medium
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area (likely to be of the order of several hundred metres up to a kilometre from the offshore cable corridor), and would not cover the whole offshore cable corridor

280. These effects on suspended sediment concentrations due to export cable installation (including that from any sand wave levelling) within the offshore cable corridor would have **no impact** upon the identified receptors groups for marine physical processes. This is because the receptors are dominated by processes that are active along the seabed and are not affected by sediment suspended in the water column. However, there may be impacts arising from subsequent deposition of the suspended sediment on the seabed and these are discussed under construction impact 4A (section 8.7.6.6).

281. The effects do have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.5.4 Assessment of effect magnitude and/or impact significance for a two-phase installation

282. Under the two-phase approach, the principal difference compared to the single-phase assessment is associated with the installation programme. There is no difference in the worst-case length of cable to be installed.

283. For the two-phase approach, the worst-case installation period for the export cables within the offshore cable corridor would be installation in parallel with other elements of the offshore wind farm. Installation of the cables would occur over two distinct phases, each lasting up to nine months (rather than a single eighteen-month period). However, due to the remaining low near-field and negligible far-field magnitude of effect, the overall assessment of significance remains in keeping with that for a single phase.

284. At the landfall, the only difference would be that the landfall operations would be undertaken as two discrete events rather than a single event. Whilst this would increase the occurrence of disturbance events, there would be less volume disturbed during each event compared to the single-phase approach.

8.7.6.6 Impact 4A: Changes in seabed level due to deposition from the suspended sediment plume during export cable installation within the offshore cable corridor

285. The increases in suspended sediment concentrations associated with export cable installation within the offshore cable corridor have the potential to result in changes in seabed levels as the suspended sediment deposits. Ploughing represents the worst-case burial method due to having the greatest disturbance volume. Should a project interconnector cable be installed it would not be installed at the same time as the export cable and therefore a cumulative effect of the two would not occur. Impacts as a result of the project interconnector are assessed in Impact 5 (section 8.7.6.9).

286. Based on a maximum potential disturbance width of 10m (for ploughing) along the 200km length of the export cable within the offshore cable corridor, the area of disturbance would be up to 2.0km^2. Up to 40km of these cable trenches would be within the SAC and this would represent a footprint of 0.8km^2. The maximum volume associated with trenching for the export cables would be 3,000,000m^3 (up to 1,200,000m^3 of which could be within the SAC, based on 10m trench width with a V shaped profile x 3m average depth x 2 trenches x 100km trench length or 40km length in the SAC). This would be back filled naturally or manually. As previously discussed, the plough would create temporary mounds either side of the trench and so only a small proportion of the 3,000,000m^3 would result in sediment plumes.

287. The East Anglia ONE plume modelling simulations (ABPmer, 2012b) suggest that any suspended sand-sized sediment (which represents most of the potentially disturbed sediment) would settle out of suspension within less than 1km from the point of installation within the offshore cable corridor and persist in the water column for less than a few tens of minutes. Due to the coarser sediment particle sizes observed across the site (predominantly medium-grained sand), a large proportion of the disturbed sediment would behave in this manner.

288. Mud-sized sediment (which represents only a very small proportion of the disturbed sediment) would be advected a greater distance and persist in the water column for hours to days. According to the East Anglia ONE modelling, following completion of the cable installation activity, theoretical bed level changes greater than 0.2mm (and up to 0.8mm) are predicted at approximately 20km from the cable trench and changes of up to 2mm within a few hundred metres of the inshore release locations. However, it is anticipated that under the prevailing hydrodynamic conditions, this sediment would be readily re-mobilised, especially in the shallow inshore area where

waves would regularly agitate the bed. Accordingly, outside the immediate vicinity of the export cable trench, bed level changes and any changes to seabed character are expected to be not measurable in practice.

8.7.6.6.1 Assessment of effect magnitude and/or impact significance for a single-phase installation

289. The worst-case changes in seabed levels due to export cable installation within the offshore cable corridor are likely to have the magnitudes of effect described in Table 8.23.

Table 8.23 Magnitude of effects on seabed level changes due to export cable installation within the offshore cable corridor under the worst-case scenario for suspended sediment concentrations

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Medium	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area of seabed (likely to be of the order of several hundred metres up to a kilometre from the offshore cable corridor), and would not cover the whole offshore cable corridor.

290. Importantly, the offshore cable corridor crosses through the southern part of the Haisborough, Hammond and Winterton SAC and its western end is approximately 60m from the Cromer Shoal Chalk Beds MCZ (at the nearest point). The sensitivity and value of the SAC and MCZ are presented in Table 8.24.

Table 8.24 Sensitivity and value assessment of Haisborough, Hammond and Winterton SAC and Cromer Shoal Chalk Beds MCZ

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
Haisborough, Hammond and Winterton SAC	Negligible	Negligible	Negligible	High	Negligible
Cromer Shoal Chalk Beds MCZ	Negligible	Negligible	Negligible	High	Negligible

291. As the North Norfolk Sandbanks and Saturn Reef SAC is approximately 23.9km from the offshore cable corridor, there would be no discernible impact associated with deposition of suspended sediment because of cable installation.

292. Based on the East Anglia ONE plume modelling simulations discussed above, expert-based assessment of deposition from the plume generated from cable installation within the offshore cable corridor indicates that the changes in seabed elevation are effectively immeasurable within the accuracy of any numerical model or bathymetric survey. This means that given these very small magnitude changes in seabed level arising from export cable installation the impacts on the Haisborough, Hammond

and Winterton SAC and Cromer Shoal Chalk Beds MCZ receptors would not be significant.

293. The overall impact of export cable installation activities within the offshore cable corridor under a worst-case scenario on bed level changes due to deposition from the suspended sediment plume for the identified morphological receptor groups is considered to be **no impact** for North Norfolk Sandbanks and Saturn Reef SAC and **negligible impact** for Haisborough, Hammond and Winterton SAC and Cromer Shoal Chalk Beds MCZ.

294. The effects on seabed level have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within relevant chapters of this ES.

8.7.6.6.2 Assessment of effect magnitude and/or impact significance for a two-phase installation

295. Under the two-phase approach, the principal difference compared to the single-phase assessment is that described previously for construction impact 3. Consequently, there would be no material change to the assessment of significance for construction impact 4C compared to a single-phase approach.

8.7.6.7 Impact 4B: Changes in seabed level due to disposal of sediment from sand wave levelling for export cable installation within the offshore cable corridor

296. There is potential for temporary physical disturbance to Annex I Sandbanks in the offshore cable corridor due to disposal of dredged sediment from sand wave levelling for cable laying.

297. The maximum volume of sediment arising because of pre-sweeping for the export cable within the offshore cable corridor would equate to approximately 600,000m^3 (500,000m^3 of which would be within the Haisborough, Hammond and Winterton SAC). As mitigation, all sediment arising from the SAC during cable installation would be placed back into the SAC, ensuring that the sediment is not lost from the system.

298. The thickness of the disposed sediment would depend on the volume deposited at any one time, the disposal method, footprint of the placement and the ambient environmental conditions at the time of the event. ABPmer (Appendix 7.1 of the Information to Support HRA (document reference 5.3)) used a given volume of sediment to calculate a range of potential alternative combinations of extent, thickness and shape. These included:

- localised deposition that is assumed to form naturally into a cone shape;
- uniformly distributed thicknesses of 0.5m, 0.25m and 0.05m (making no assumptions about the shape of the area); and

- deposition thickness associated with a uniform disposal across the whole indicative disposal site.

299. With respect to local deposition, a steeper-sided cone would have a greater thickness and a smaller area of change than a less steep sided cone.

300. For the proposed disposal, a range of deposition scenarios were assessed, which included:

- The maximum possible thickness, associated with the smallest footprint or extent of impact;
- The different thicknesses and footprints associated with varying disposal ‘cones’;
- The maximum thickness from a single disposal from the hopper compared with the cumulative thickness associated with multiple disposal events; and
- The most extensive accumulation over the entire indicative disposal site and the resulting thickness.

301. On initial release from the dredger, ABPmer (2018) assumed that around 90% of the sediment released will fall directly to the seabed as a single mass.

302. The results show that if the total volume of sediment (500,000m^3) is released and 450,000m^3 (90%) returned to the seabed with an average uniform thickness of 0.5m, an area of about 900,000m^2 would be covered.

303. A disposal event, could theoretically range from 4.2m to 0.25m depending on the environmental conditions and nature of disposal (Table 8 of Appendix 7.1 of the Information to Support HRA (document reference 5.3)). However, as described in Appendix 7.1 of the Information to support HRA (document reference 5.3), the actual thickness of the deposited layer is more likely to range between 0.3m and 0.02m based on typical conditions for the site including water depth of 31m (the depth within an indicative disposal location), a current speed of 0.5m/s and particle size of 0.35mm (which would be expected to have a settling rate of 0.05m/s).

304. The absolute width, length, shape and thickness of sediment deposition as a result of individual and all (combined) disposal events cannot be predicted with certainty. Irrespective of the deposition scenario, the sand waves within the indicative disposal site typically have amplitudes of over 3m and wavelengths of about 100m. Therefore, there is already some variation in bathymetry within the site and depending on the deposition characteristics (i.e. location, thickness and extent) the result would potentially be within the bathymetric range already encountered. It is considered that if sediment mounds (cones) are formed during disposal, they would be quickly (within a matter of days to a year) winnowed down to levels resembling the nearby bedforms.

8.7.6.7.1 Assessment of effect magnitude and/or impact significance for a single-phase installation

305. The worst-case changes in seabed levels due to disposed sediment from sand wave levelling within the offshore cable corridor are likely to have the magnitudes of effect described in Table 8.25.

Table 8.25 Magnitude of effects on seabed level changes under the worst-case scenario for disposal of sediments from sand wave levelling within the offshore cable corridor

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Low	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to the disposal site and a small area of seabed outside the disposal site (likely to be of the order of several hundred metres up to a kilometre outside).

306. The main area of sand wave levelling for the offshore cable corridor would be within the southern part of the Haisborough, Hammond and Winterton SAC. The sensitivity and value of the SAC is presented in Table 8.26.

307. No sand wave levelling is expected along the western end of the cable corridor and any sediment arising from the offshore cable corridor outside the SAC would be deposited in the Norfolk Boreas site. Therefore, there would be no impact on the nearshore Cromer Shoal Chalk Beds MCZ as a result of disposal of sediment from sand wave levelling.

Table 8.26 Sensitivity and value assessment of Haisborough, Hammond and Winterton SAC

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
Haisborough, Hammond and Winterton SAC	Negligible	Negligible	Negligible	High	Negligible

308. The overall impact of sand wave levelling activities within the offshore cable corridor under a worst-case scenario on bed level changes due to sediment disposal for the identified morphological receptor groups is considered to be **negligible impact** for Haisborough, Hammond and Winterton SAC.

309. The effects on seabed level also have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within relevant chapters of this ES.

8.7.6.7.2 Assessment of effect magnitude and/or impact significance for a two-phase installation

310. Phasing the disposal would increase the likelihood that the initial disposed sediment would be incorporated back into the natural system within the Haisborough, Hammond and Winterton SAC before the sediment from the next phase of

installation is deposited. Whilst this would increase the occurrence of disturbance events, there would be less volume disturbed during each event compared to the single-phase approach.

311. Consequently, there would be no material change to the assessment of significance for construction impact 4A for two phases compared to a single-phase approach.

8.7.6.8 Impact 4C: Interruptions to bedload sediment transport due to sand wave levelling for the export cable within the offshore cable corridor

312. The removal of sand waves could potentially interfere with sediment transport pathways that supply sediment to the sandbank system. Within the offshore cable corridor, sand wave levelling is estimated to require excavation of sediment across an area of 360,000m^2 (volume of 600,000m^3), of which up to 250,000m^2 (500,000m^3) would be within the Haisborough Hammond and Winterton SAC.

313. As previously discussed the 500,000m^3 of sediment arising from the SAC would be disposed back into the SAC; the 100,000m^3 of sediment arising from the rest of the offshore cable corridor would be deposited in the corridor or within the Norfolk Boreas site.

314. As the sediment excavated from within the SAC would be disposed of within the SAC there would be no net loss of sediment within the designated site.

315. The total area of sandbanks within the SAC is 678km^2 and the area of the SAC is 1,468km^2, so the area of sand wave levelling in the SAC equates to 0.04% of the sandbanks and 0.02% of the total area of the SAC. Hence, the effects on the surrounding environment are anticipated to be small because it is likely that the natural changes to the sand waves, through the active physical processes, are far greater than the quantities of sand that would be extracted.

316. ABPmer (2018) (Appendix 7.1 of the HRA (document Reference 5.3)) also concluded that in most cases, the cable corridor is oriented transverse to the sand wave crests which require levelling. Therefore, only a small width (up to approximately 37m) of each sand wave is disturbed and it can continue to evolve and migrate along most of its length. As a result, the overall form and functioning of any sand wave, or the SAC sandbank system, is not disrupted.

317. Where sand wave crests occur that run roughly parallel to the cable corridor, broader sections of the longitudinal form of individual sand waves would require levelling. However, the area and volume of sediment affected would be minimal in the context of the sandbank system of the SAC. In addition, the cable corridor is in an active and highly dynamic environment governed by current flow speeds, water depth and sediment supply, all of which are conducive to the development and maintenance of sandbanks. Therefore, despite the disturbance to sand waves

intersecting the cable corridor, the Haisborough, Hammond and Winterton SAC sandbank system will remain undisturbed as new sand waves will continue to be formed.

318. The analysis of Burningham and French (2016) (see section 8.7.6) shows that Haisborough Sand is an active and very dynamic feature, with historic large-scale natural changes having occurred over decadal periods. Given this dynamism, it is likely that the volumetric changes to the bank system that would occur due to installation of the export cables will be significantly smaller in magnitude than the natural changes. Hence, the potential for recovery of the bank after the physical changes due to construction would be high.

8.7.6.8.1 Assessment of effect magnitude and/or impact significance for a single-phase installation

319. The worst-case changes in bedload sediment transport due to sand wave levelling within the offshore cable corridor are likely to have the magnitudes of effect described in Table 8.27.

Table 8.27 Magnitude of effects on bedload sediment transport under the worst-case scenario for sand wave levelling within the offshore cable corridor

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Medium	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area (likely to be of the order of several hundred metres up to a kilometre from the offshore cable corridor), and would not cover the whole offshore cable corridor

320. Importantly, the offshore cable corridor crosses through the southern part of the Haisborough, Hammond and Winterton SAC. The sensitivity and value of the SAC are presented in Table 8.28.

Table 8.28 Sensitivity and value assessment of Haisborough, Hammond and Winterton SAC

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
Haisborough, Hammond and Winterton SAC	Negligible	Negligible	Negligible	High	Negligible

321. Keeping the dredged sand within the sandbank system enables the sand to become re-established within the local sediment transport system by natural processes and encourages the re-establishment of the SAC bedform features. ABPmer (2018) estimated potential transport rates for sand (median 0.25-0.5mm) within the SAC of between 0.01 and 3.4m^3/m/ hr (using representative annual average waves combined with current speeds ranging from 0.5 to 1.29m/s), which are also within the range modelled for the wider region of the southern North Sea (HR Wallingford et al., 2002).

322. ABPmer (2018) (Appendix 7.1 of the Information to Support HRA (document reference 5.3)) also found that given the local favourable conditions that enable sand wave development, the sediment would be naturally transported back into the dredged area within a short period of time. The dredged area will naturally act as a sink for sediment in transport and will be replenished in the order of a few days to a year.

323. The offshore cable corridor is in an active and highly dynamic seabed environment, governed by current flow speeds, water depth and sediment supply. These governing processes within the SAC occur at a much larger scale than the temporary physical disturbance which would occur because of cable installation. The sediment volume that would be affected is small in comparison to the volume of sediment within the local sandbank systems (i.e. the Newarp Banks system) and the SAC. As all the sediment will remain within the boundaries of the SAC, presenting minimal impacts on local sediment availability, there will be no significant change to sandbank extent, topography and sediment composition.

324. Hence, the overall impact of sand wave levelling activities within the offshore cable corridor under a worst-case scenario for the identified morphological receptor groups is **no impact**, except for Haisborough, Hammond and Winterton SAC which is assessed as **negligible impact**.

325. The effects on bedload sediment transport also have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within relevant chapters of this ES.

8.7.6.8.2 Assessment of effect magnitude and/or impact significance for a two-phase installation

326. Under the two-phase approach, the principal difference compared to the single-phase assessment is that described previously for construction impact 4A and consequently there would be no material change to the assessment of significance for construction impact 4B for two phases compared to a single-phase approach.

8.7.6.9 Impact 5: Changes in suspended sediment concentrations during cable installation within the Norfolk Boreas site and Project Interconnector Search Area

327. The details of the array, interconnector, project interconnector and export cabling are dependent upon the final project design, but present estimates for a single-phase approach are:

- Maximum length of the array cables trenches would be up to 600km;
- Maximum length of the interconnector cable trenches would be up to 60km;

- Maximum length of project interconnector cable trenches[1] would be up to 92km within the project interconnector search area. Of this total, depending on which electrical solution is chosen either a maximum of 60km would be located in the overlap with the offshore cable corridor and 20km would be within the overlap with Norfolk Vanguard West (Electrical solution c) described in section 5.4.12.3 of Chapter 5 Project description), or all 92km would be within the overlap with the Norfolk Vanguard East (Electrical solution b) described in section 5.4.12.3 of Chapter 5 Project description); and
- Maximum length of the export cable trenches within the Norfolk Boreas site would be up to 50km.

328. In a similar way to the export cables within the offshore cable corridor, the installation of the array, interconnector or project interconnector and export cables would disturb seabed sediment within the Norfolk Boreas site and project interconnector search area. Disturbance could be through levelling of sand waves that may be present along the cables prior to installation or directly through installation of the cable (worst-case scenario is jetting).

8.7.6.9.1 Sand wave levelling

329. For the worst-case scenario, it is assumed that sand wave levelling may be required for 100% of the array cables, interconnector cables, project interconnector cables or export cables to an average depth of 3m and with an average width of 20m. This equates to a total of 802km of cable, 16km^2 of seabed or excavation of 48,120,000m^3 of sediment.

330. The direct impact of change to the substrate elevation is about 2% of the Norfolk Boreas site. In addition, the dynamic nature of the sand waves in this area means that any direct changes to the seabed associated with sand wave levelling are likely to recover over a short period of time due to natural sand transport pathways.

331. The excavated sediment due to sand wave levelling for the array and interconnector cables would be disposed of within the Norfolk Boreas site, and any sediment due to sand wave levelling for the project interconnector and export cables would be disposed of within the project interconnector search area. This means there will be no net loss of sand from either the site or the project interconnector search area. It is likely that some of this sand could be disposed on the upstream side of any cable where tidal currents would, over time, re-distribute the sand back over the levelled area (as re-formed sand waves). The overall effect of changes to the seabed would therefore be minimal.

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[1] It should be noted that there would only be a requirement for either the interconnector cables or the project interconnector cables but never both.

332. Also, in many parts of Norfolk Boreas there would not be the need for release of sediment volumes as considered under this worst-case scenario and optimisation of array cable and interconnector cable alignment, depth and installation methods during detailed design would ensure that effects are minimised.

8.7.6.9.2 Installation of the cables

333. The worst-case scenario cable-laying technique is considered to be jetting. The plume modelling simulations undertaken for East Anglia ONE (ABPmer, 2012b) described in section 8.7.6.5 are used as a basis for the expert-based assessment described here. It is anticipated that the changes in suspended sediment concentration due to array, interconnector, project interconnector and export cable installation (including any sand wave levelling) within the Norfolk Boreas site and project interconnector search area would be minimal. This assessment is based on the overall sediment release volumes from the jetting process being low and confined to near the seabed (rather than higher in the water column) along the alignments of the cables, and the rate at which the sediment is released into the water column would be relatively low.

334. The predominance of medium-grained sand (which represents most of the disturbed sediment) means that most of the sediment would settle out of suspension within a few tens of metres along the axis of tidal flow from the point of installation along the cable and persist in the water column for less than a few tens of minutes.

335. Mud-sized sediment (which represents only a very small proportion of the disturbed sediment) would be advected a greater distance and persist in the water column for longer and form a passive plume which would become advected by tidal currents. Due to the sediment sizes present, this is likely to exist as a measurable but modest concentration plume (tens of mg/l) for around half a tidal cycle. Sediment would eventually settle to the seabed in proximity to its release (within a few hundred metres up to around a kilometre along the axis of tidal flow) within a short period of time (hours). Whilst lower suspended sediment concentrations would extend further from the cable, along the axis of predominant tidal flows, the magnitudes would be indistinguishable from background levels.

8.7.6.9.3 Assessment of effect magnitude and/or impact significance for a single-phase installation

336. The worst-case changes in suspended sediment concentrations due to array, interconnector, project interconnector and export cable installation (including any necessary sand wave levelling) within the Norfolk Boreas site and project interconnector search area are likely to have the magnitudes of effect described in Table 8.29.

Table 8.29 Magnitude of effects on suspended sediment concentrations under the worst-case scenario for array, interconnector, project interconnector and export cable installation (including sand wave levelling) within the Norfolk Boreas site and Project Interconnector Search Area

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Low	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area of seabed (likely to be of the order of several hundred metres up to a kilometre from the cables), and would not cover the entirety of the seabed area within Norfolk Boreas site or the entirety of the Project interconnector search area.

337. These effects on suspended sediment concentrations do not directly impact upon the identified receptor groups for marine physical processes (i.e. the offshore SAC or SAC). This is because the designated features of North Norfolk Sandbanks and Saturn Reef SAC (22.9km west of Norfolk Boreas site and 9.7km north of the project interconnector search area) and the Haisborough, Hammond and Winterton SAC (34.1km west of the Norfolk Boreas site and 9.8km west of the project interconnector search area) are related to processes operating on the seabed and not in the water column. Also, regional sediment transport directions are directed along a north-south axis with no east to west component, and so there is no pathway for suspended sediment to reach the East Anglian coast. Hence, there is **no impact** on the identified receptors groups associated with the suspended sediment generated by the project.

338. The effects do have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.9.4 Assessment of effect magnitude and/or impact significance for a two-phase installation

339. Under the two-phase approach, the principal difference compared to the single-phase assessment is that installation of the cables would occur over two distinct phases, each lasting up to 12 months (rather than a single, up to 24 month period). However, due to the remaining low near-field and negligible far-field magnitude of effect, this would not materially change the assessment of significance compared with a single-phase approach.

8.7.6.10 Impact 6: Changes in seabed level due to cable installation within the Norfolk Boreas site and Project Interconnector Search area

340. The increases in suspended sediment concentrations associated with construction impact 5 have the potential to result in changes in seabed levels as the suspended sediment deposits.

341. Expert-based assessment suggests that coarser sediment disturbed during cable installation (including pre-sweeping) would fall rapidly to the seabed (minutes or tens of minutes) as a highly turbid dynamic plume immediately after it is discharged. Deposition of this sediment would form a linear mound (likely to be tens of centimetres high) parallel to the cable as the point of release moves along the excavation. Due to the coarser sediment particle sizes observed across the site (predominantly medium-grained sand), a large proportion of the disturbed sediment would behave in this manner and be similar in composition to the surrounding seabed. This would mean that there would be no significant change in seabed sediment type.

342. A very small proportion of mud would also be released to form a passive plume and become more widely dispersed before settling on the seabed. Expert-based assessment suggests that due to the dispersion by tidal currents, and subsequent deposition and re-suspension, the deposits across the wider seabed would be very thin (millimetres).

8.7.6.10.1 Assessment of effect magnitude and/or impact significance for a single-phase installation

343. Expert-based assessment indicates that changes in suspended sediment concentration due to array, interconnector, project interconnector and export cable installation (including any necessary sand wave levelling) within the Norfolk Boreas site and project interconnector search area would be minor and are likely to have the magnitudes of effect shown in Table 8.30.

Table 8.30 Magnitude of effects on seabed level changes due to deposition under the worst-case scenario for sediment dispersal following array, interconnector, project interconnector and export cable installation (including sand wave levelling) within the Norfolk Boreas site and project interconnector search area

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Low	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area of seabed (likely to be of the order of several hundred metres up to a kilometre from the cable), and would not cover the whole of the Norfolk Boreas site or the entirety of the project interconnector search area.

344. These effects on seabed level are considered highly unlikely to have the potential to impact directly upon the identified receptor groups for marine physical processes. Any impacts will be of a significantly lower magnitude than those seabed level impacts already considered for the installation of foundations. Consequently, the overall impact of array, interconnector, project interconnector and export cable installation activities within the Norfolk Boreas site and project interconnector

search area under a worst-case scenario on seabed level changes for identified morphological receptor groups is therefore considered to be **negligible impact**.

345. The effects on seabed level also have the potential to impact upon other receptors and the assessment of impact significance is addressed within the relevant chapters of this ES.

8.7.6.10.2 Assessment of effect magnitude and/or impact significance for a two-phase installation

346. Under the two-phase approach, the principal differences compared to the single-phase assessment are those described previously for construction impact 5. Consequently, there would be no material change to the assessment of significance for construction impact 6 compared with that for a single-phase approach.

8.7.6.11 Impact 7: Indentations on the seabed due to installation vessels

347. There is potential for certain vessels used during the installation of Norfolk Boreas to directly impact the seabed. This applies for those vessels that utilise jack-up legs or several anchors to hold station and to provide stability for a working platform. Where legs or anchors (and associated chains) have been inserted into the seabed and then removed, there is potential for an indentation to remain, proportional in size to the dimensions of the object. The worst-case scenario is considered to correspond to the use of jack-up vessels, since the depressions would be greater than the anchor scars.

348. As the leg is inserted, the seabed sediments would primarily be compressed vertically downwards and displaced laterally. This may cause the seabed around the inserted leg to be raised in a series of concentric pressure ridges. As the leg is retracted, some of the sediment would return to the hole via mass slumping under gravity until a stable slope angle is achieved. Over the longer term, the hole would become shallower and less distinct due to infilling with mobile seabed sediments.

349. A six legged jack-up barge would have a footprint of 792m^2. Each leg could penetrate 5 to 15m into the seabed and may be cylindrical, triangular, truss leg or lattice.

350. The worst-case scenario assumes that legs could be deployed on up to two different occasions around a single foundation as the jack-up barge manoeuvres into different positions.

8.7.6.11.1 Assessment of effect magnitude and/or impact significance for a single-phase installation

351. The worst-case changes in terms of indentations on the seabed due to installation vessels are likely to have the magnitudes of effect described in Table 8.31.

Table 8.31 Magnitude of effect on seabed level changes under the worst-case scenario for installation vessels

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field (immediate vicinity of leg)	High	Negligible	Negligible	Medium	Medium
Near-field (beyond immediate vicinity of leg)	No change	-	-	-	No change
Far-field	No change	-	-	-	No change

352. There is **no impact** under a worst-case scenario on the identified morphological receptor groups since they are remote from the immediate vicinity of each leg.

353. The impact significance of these effects on other receptors is addressed within the relevant chapters of this ES.

8.7.6.11.2 Assessment of effect magnitude and/or impact significance for a two-phase installation

354. Under the two-phased approach, the construction phase would occur over two distinct periods, totalling longer overall durations. In the context of this impact, the phasing and duration of construction does not materially change the assessment of significance previously made for the single-phase approach.

8.7.7 Potential Impacts during Operation

355. During the operational phase of Norfolk Boreas, there is potential for the presence of the foundations to cause changes to the tidal and wave regimes due to physical blockage effects. These changes could potentially affect the sediment regime and/or seabed morphology. These potential effects are considered as operational impacts 1 to 6. In addition, there is potential for the temporary presence of engineering equipment, such as jack-up barges or anchored vessels, to have local effects on the hydrodynamic and sediment regimes during maintenance activities. These potential effects are considered as operational impact 7.

356. Note that the qualitative consideration of impacts will not be affected by the number of phases that are taken to construct Norfolk Boreas, and hence the effects of one-phase and two-phase approaches are the same.

8.7.7.1 Impact 1: Changes to the tidal regime due to the presence of wind turbine structures and platforms

357. The presence of foundation structures and platforms within Norfolk Boreas has the potential to alter the baseline tidal regime, particularly tidal currents. Any changes in the tidal regime may have the potential to contribute to changes in seabed morphology due to alteration of sediment transport patterns (see operational impact 3, section 8.7.7.3).

358. There is a pre-existing scientific evidence base which demonstrates that changes in the tidal regime due to the presence of foundation structures are both small in magnitude and localised in spatial extent. This is confirmed by existing guidance documents (ETSU, 2000; ETSU, 2002; Lambkin et al., 2009) and numerous Environmental Statements for offshore wind farms (e.g. Dogger Bank Creyke Beck; Forewind, 2013).

359. Numerical modelling of changes in hydrodynamics associated with the East Anglia ONE project (ABPmer, 2012b) also describe small magnitude and localised changes in tidal currents. This modelling was based on a worst case of 240 GBS (50m base diameter and height up to 10m off the seabed) and predicted maximum reductions in peak flow speeds of 0.05 to 0.1m/s and maximum increases in peak flow speeds of 0.05m/s, from peak baseline values of around 1m/s. The geographical extent of these maximum changes was largely confined to the near-field environment (a wake zone local to each wind turbine foundation).

360. The application of the East Anglia ONE results and other pre-existing evidence in expert-based assessment suggests that each foundation would present an obstacle to the passage of currents locally, causing a wake in the current flow. Flow would be decelerated immediately upstream and downstream of each foundation and accelerated around their sides. Current speeds return to baseline conditions with progression downstream of each foundation and generally do not interact with wakes from adjacent foundations due to the large separation distances.

8.7.7.1.1 Assessment of effect magnitude and/or impact significance

361. The expert-based assessments of the changes in tidal currents associated with the presence of foundation structures for Norfolk Boreas are consistent with the findings of the earlier modelling studies for the East Anglia ONE project. The models used in East Anglia ONE had been successfully calibrated and verified with existing data, and so there is high confidence in the assessment of effects.

362. The worst-case changes to tidal currents due to the presence of GBS foundations are likely to have the magnitudes of effect described in Table 8.32.

Table 8.32 Magnitude of effect on tidal currents under the worst-case scenario for the presence of GBS foundations

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field	Low	High	Medium	Negligible	Low
Far-field	Negligible	High	Medium	Negligible	Negligible

363. These effects on the tidal regime have been translated into a ‘zone of potential influence’ based on an understanding of the tidal ellipses. It is expected that changes to the tidal regime would have returned to background levels well within the

excursion of one tidal ellipse, and this threshold has been used to produce the maximum ‘zone of potential influence’ on the tidal regime, as presented in Figure 8.13.

364. All the identified receptor groups for marine physical processes are remote from the ‘zone of potential influence’ on the tidal regime. Due to this, no pathway exists between the source and the receptor in these areas, and so in terms of impacts on these receptor groups there is **no impact** associated with the project.

8.7.7.2 Impact 2: Changes to the wave regime due to the presence of structures in the Norfolk Boreas site

365. The presence of foundation structures and platforms within the Norfolk Boreas site has the potential to alter the baseline wave regime, particularly in respect of wave heights and directions. Any changes in the wave regime may have the potential to contribute to changes in the seabed morphology due to alteration of sediment transport patterns. This issue has been raised by the MMO (Table 8.2) and discussed through the ETG meeting held on the 21st February 2019 (section 8.3). This is addressed in operational impact 3 (section 8.7.7.3).

366. Expert-based assessment suggests that each foundation would present an obstacle to the passage of waves locally, causing a small modification to the height and/or direction of the waves as they pass. Generally, this causes a small wave shadow effect to be created by each foundation. Wave heights return to baseline conditions with progression downstream of each foundation and generally do not interact with effects from adjacent foundations due to the separation distances.

367. There is a strong evidence base which demonstrates that the changes in the wave regime due to the presence of foundation structures, even under a worst-case scenario of the largest diameter GBS, are relatively small in magnitude. Changes are typically less than 10% of baseline wave heights near each wind turbine, reducing with greater distance from each wind turbine. Effects are relatively localised in spatial extent, extending as a shadow zone typically up to several tens of kilometres from the site along the axis of wave approach, but with low magnitudes (only a few percent change across this wider area). This is confirmed by a review of modelling studies from around 30 wind farms in the UK and European waters (Seagreen, 2012) and existing guidance documents (ETSU, 2000; ETSU, 2002; Lambkin et al., 2009). The consequential effects of changes to the wave climate on the sediment transport systems is assessed further in section 8.7.7.3.

368. Numerical modelling of changes in the wave regime under return period events of 1 in 0.1 year, 1 in 1 year and 1 in 10 years, associated with the East Anglia ONE project (ABPmer, 2012b) also describe small magnitude and localised changes in waves. This

wave modelling incorporated a worst case of 240 GBS with a basal diameter of 50m and up to 10m in height off the seabed. The results were:

- Maximum percentage reductions in baseline wave height occur within or along the boundary of the East Anglia ONE site;
- During 1 in 10-year storm events, the percentage reductions in wave heights may be up to approximately 20% within the East Anglia ONE site;
- At approximately 40km from the East Anglia ONE site, maximum reductions in wave height are typically less than about 2%; and
- Regardless of return period or direction of the incoming wave conditions, the presence of an array of foundations within the East Anglia ONE site does not cause a measurable change in wave characteristics at the coast.

369. The likely envelope of wind turbine numbers and GBS foundation sizes for Norfolk Boreas is presented in Table 8.33. The modelling for the East Anglia ONE project is similar in terms of the number and size of foundations being considered for Norfolk Boreas (see section 8.7.3).

Table 8.33 Likely wind turbine arrangements for the worst-case scenario

Turbine rating (MW)	Maximum number of wind turbines	Maximum basal diameter of GBS (m)
10	180	40 (200m with scour protection with a maximum height of 5m)
20	90	50 (250m with scour protection with a maximum height of 5m)

8.7.7.2.1 Assessment of effect magnitude and/or impact significance

370. The worst-case changes in wave regime due to the presence of GBS foundations are likely to have the magnitudes of effect shown in Table 8.34. Scour protection would protrude up to 5m above the seabed and would not influence wave climate in the water depths across the Norfolk Boreas site.

Table 8.34 Magnitude of effect on the wave regime under the worst-case scenario for the presence of GBS foundations

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field	Low	High	Medium	Negligible	Low
Far-field	Negligible	High	Medium	Negligible	Negligible

371. These effects on the wave regime have been translated into a ‘zone of potential influence’ based on an understanding of the wave roses, previous numerical modelling of effects, and using expert-based assessment (Figure 8.14).

372. Figure 8.7 shows the regional wave roses and Plate 8.5 illustrates the Norfolk Boreas site specific wave conditions. These are generally aligned north-north-west and

south-south-west at Norfolk Boreas. This would be the axis of greatest potential influence at the site.

373. In addition, wave modelling of the effect of the East Anglia ONE project on the wave regime has been used as an analogue for delineating the ‘zone of potential influence’. In that previous modelling assessment, the greatest change along the defined axis of greatest potential influence arose under a 1 in 10-year wave condition. The spatial extent of measurable changes (≥ ±5% of the baseline conditions) under such an event was mapped and superimposed over the Norfolk Boreas site. The resulting ‘zone of influence’ on the wave regime is presented in Figure 8.14.

374. All the identified receptor groups for marine physical processes are remote from the zone of influence. Due to this, no pathway exists between the source and the receptor in these areas, and so in terms of impacts on these receptor groups there is **no impact** associated with the project.

8.7.7.3 Impact 3: Changes to the sediment transport regime due to the presence of wind turbine foundation structures

375. Modifications to the tidal regime and/or the wave regime due to the presence of the foundation structures during the operational phase may affect the sediment regime.

376. This section addresses the broader patterns of suspended and bedload sediment transport across, and beyond, the Norfolk Boreas site and sediment transport at the coast.

8.7.7.3.1 Assessment of effect magnitude and/or impact significance

377. The predicted reductions in tidal flow (operational impact 1) and wave height (operational impact 2) associated with the presence of the worst case GBS during the operational phase would result in a reduction in the sediment transport potential across the areas where such changes are observed. Conversely, the areas of increased tidal flow around each wind turbine would result in increased sediment transport potential.

378. These changes to the marine physical processes would be both low in magnitude and largely confined to local wake or wave shadow effects attributable to individual wind turbine foundations and, therefore, would be small in geographical extent. In the case of wave effects, there would also be reductions due to a shadow effect across a greater seabed area, but the changes in wave heights across this wider area would be notably lower (a few percent) than the changes local to each wind turbine foundation (tens of percent). Since it is expected that the changes in tidal flow and wave heights during the operational phase would have no significant far-field

effects, then the changes in sediment transport would be similar, with the likely magnitudes of effects described in Table 8.35.

Table 8.35 Magnitude of effect on the sediment transport regime under the worst-case scenario for the presence of foundations

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field	Low	High	Medium	Negligible	Low
Far-field	Negligible	High	Medium	Negligible	Negligible

379. The impacts on the sediment transport regime would not extend beyond the zones of influence previously illustrated for the changes to the tidal and wave regimes (Figure 8.13 and Figure 8.14) and therefore, there is **no impact** associated with Norfolk Boreas on the marine physical processes receptor groups.

8.7.7.4 Impact 4: Loss of seabed morphology due to the footprint of wind turbine foundation structures

380. The seabed morphology would directly be impacted by the footprint of each foundation structure within Norfolk Boreas. This would constitute a ‘loss’ in natural seabed area during the operational life of the project. This direct footprint due to the presence of foundation structures could occur in one of two ways; without and with scour protection. Scour protection will be installed at all locations where required, as determined by pre-construction surveys. A worst-case scenario of all foundations having scour protection is considered to provide a conservative assessment.

381. Under the worst-case scenario of scour protection being provided for all foundations, the seabed would be further occupied by material that is ‘alien’ to the baseline environment, such as concrete mattresses, fronded concrete mattresses, rock dumping, bridging or positioning of gravel bags. The diameter of scour protection would be approximately five times the diameter of the associated foundation.

382. The total worst case direct wind turbine foundation footprint (for GBS foundations) across the project would be 5.65km^2. This represents 0.78% of the total seabed area within the Norfolk Boreas site. The total worst-case footprint of all foundations (including wind turbine foundations, platforms, meteorological masts and other infrastructure) would be approximately 5.73km^2 (0.79% of the Norfolk Boreas site).

8.7.7.4.1 Assessment of effect magnitude and/or impact significance

383. The worst-case loss of seabed morphology due to the presence of foundation structures with scour protection is likely to have the following magnitudes of effect (Table 8.36). It is likely that any secondary scour effects associated scour protection

would be confined to within a few meters of the direct footprint of that scour protection material.

Table 8.36 Magnitude of effect on seabed morphology under the worst-case scenario for the footprint of foundations and scour protection

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	High	High	High	Negligible	High
Far-field	No change	-	-	-	No change

*The near-field effects are confined to the footprint of each foundation structure.

384. The near-field effects are confined to the footprint of each foundation structure, and therefore have no pathway to the relevant impact receptors.

385. The significance of these effects on other receptors is addressed within relevant chapters of this ES.

8.7.7.5 Impact 5: Morphological and sediment transport effects due to cable protection measures within the Norfolk Boreas site and Project Interconnector Search area.

386. The preferred method for cable protection would be burial. However, where this is not possible due to substrate type or requirements for cable crossings, cable protection will be used, including rock placement, concrete mattresses, and frond mattresses.

387. The effects that such works may have on marine physical processes primarily relate to the potential for interruption of sediment transport processes and the footprint they present on the seabed.

388. In areas of active sediment transport, any linear protrusion on the seabed may interrupt bedload sediment transport processes during the operational phase of the project. There is unlikely to be any significant effect on suspended sediment processes since most of the proposed cable protection works are relatively low above the seabed (up to a maximum of 0.5m). However, there would be additional cable protection requirements where the cables cross existing cables or pipelines. The maximum height of cable crossing protection measures from the seabed would be 0.9m.

389. The presence and asymmetry of sand waves across Norfolk Boreas indicates that some bedload sediment transport exists, with a net direction towards the north. Protrusions from the seabed are unlikely to significantly affect the migration of sand waves, since sand wave heights (up to 4.5m) in most areas would exceed the height of cable protection works, and would pass over them.

390. If the protection does present an obstruction to bedload transport the sand would first accumulate one side or both sides of the obstacle (depending on the gross and

net transport at that location) to the height of the protrusion (up to 0.5m in most cases). With continued build-up, it would then form a ‘ramp’ over which sand transport would eventually occur by bedload processes, thereby bypassing the protection. The gross patterns of bedload transport across Norfolk Boreas would therefore not be affected significantly.

391. The presence of cable protection works on the seabed would represent the worst case in terms of a direct loss of seabed area, but this footprint would be lower than that of the wind turbine foundations (and associated scour protection works) within Norfolk Boreas.

8.7.7.5.1 Assessment of effect magnitude and/or impact significance

392. The worst-case changes to the seabed morphology and sediment transport due to cable protection measures for array cables, interconnector cables, project interconnector cables and export cables within the Norfolk Boreas site and project interconnector search area are likely to have the following magnitudes of effect (Table 8.37).

Table 8.37 Magnitude of effect on seabed morphology and sediment transport under the worst-case scenario for cable protection measures for array cables, interconnector cables, project interconnector cables and export cables within the Norfolk Boreas site and project interconnector search area

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	High	High	High	Negligible	High
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

*The near-field effects are confined to a small area (likely to be within the footprint of cable protection works), and would not cover the whole Norfolk Boreas site.

393. The effects on seabed morphology and sediment transport arising from the presence of array cable, interconnector cable, project interconnector cable, and export cable protection measures within the Norfolk Boreas site and project interconnector search area would not extend far beyond the direct footprint. Therefore, there is **no impact** associated with the project on the identified marine physical processes receptor groups since these are located remotely from this zone of potential effect.

394. The significance of these effects on other receptors is addressed within the relevant chapters of this ES.

8.7.7.6 Impact 6: Morphological and sediment transport effects due to cable protection measures within the offshore cable corridor.

395. As a worst-case scenario, it has been assumed that burial of the export cables would not practicably be achievable within some areas of the cable corridor and, instead, cable protection measures would need to be provided to surface-laid cables in these

areas. The effects that cable protection may have on marine physical processes primarily relate to the potential for interruption of sediment transport and the footprint they present on the seabed.

396. In the nearshore zone and landfall, an assumption is made that cable protection will only be used at the HDD exit point for each of the six cables. This would entail one mattress (6m long, 3m wide and 0.3m high) plus rock dumping (5m long, 5m wide and 0.5m high) at each exit point (up to six cables).

397. This means that cable protection in the nearshore zone where the water is shallow and sediment transport is most active along the coast driven by waves (landward of the closure depth) would be limited to very short lengths at each of the HDD exit points. However, protection further offshore (seaward of the closure depth) would potentially affect sediment transport across the seabed.

398. This approach ensures that the requirement for cable protection along the sections of export cables that are located inshore of the closure depth are significantly reduced as a form of mitigation that has been embedded into the design.

399. The locations where cable protection measures are most likely to be required in deeper water are those areas of seabed characterised by exposed bedrock. The preferred method for cable protection would be concrete mattresses, although other methods may be used.

400. Given that there would be very limited protrusions from the seabed associated with cable protection measures inshore of the 10m bathymetric contour (most of the inshore cable will be buried beneath the seabed), there would be minimal effect on sediment transport and hence geomorphological change (erosion and accretion) in the nearshore.

401. VWPL commissioned an HDD feasibility study (Riggall, 2016 unpublished) which investigated several possible locations along the Norfolk coast and identified Happisburgh South as a viable landfall option using HDD. The study used available information to assess feasibility, including suitable geology to maintain stability during HDD works. A coastal erosion study (Appendix 4.5) was undertaken by Royal HaskoningDHV, and considered the likely impact of climate change on the coastal erosion in the area. This study informed the landfall site selection and design of the HDD works. In addition, ground investigation boreholes were undertaken at Happisburgh South in 2017. The analysis of these data informed the decision to use long HDD at the landfall.

402. The HDD will be designed to be sufficiently far below the cliff base (including a significant margin for safety) to have no effect on the natural erosion of the cliff. The HDD will be secured beneath the surface of the shore platform and the base of the

cliff, drilled from a location greater than 150m landward of the cliff edge. The material through which the HDD will pass, and through which the cables will ultimately be located, is consolidated and will have sufficient strength to maintain its integrity during the construction process and during operation. Also, the cable will be located at sufficient depth to account for shore platform steepening (downcutting) as cliff erosion progresses, and so will not become exposed during the design life of the project (approximately 30 years). Hence, the continued integrity of the geological materials and the continued depth of burial of the cables mean that they will have **no impact** on coastal erosion during both construction and operation.

403. Along the sections of the offshore cable corridor that are located seaward of 10m water depth, any protrusions from the seabed associated with cable protection measures could affect sediment transport. However, in a similar way to array and interconnector cables, the sand would accumulate against the cable protection, eventually forming a ‘ramp’ over which the transport would eventually continue.

404. The protection is also unlikely to significantly affect the migration of sand waves, since their heights (up to 9m) would exceed the likely height of cable protection works (0.5m along most of the cable up to 0.9m at cable and pipeline crossings). There may be localised interruptions to bedload transport in some areas, but the gross patterns of bedload transport would not be affected significantly.

405. Up to 0.05km^2 of cable protection may be required in the Haisborough, Hammond and Winterton SAC could be based on the following:

- Six crossings for each of the two cable pairs within the SAC with a total footprint of 12,000m^2 (0.012km^2) (100m length and 10m width of protection); and
- A contingency of up to 4km of cable protection per cable pair, resulting in a footprint of 40,000m^2 (0.04km^2) based on 5m wide cable protection.

8.7.7.6.1 Assessment of effect magnitude and/or impact significance

406. The worst-case changes to the seabed morphology and sediment transport due to cable protection measures for export cables within the offshore cable corridor are likely to have the magnitudes of effect described in Table 8.38. The worst-case changes to erosion are likely to have the magnitudes of effect described in Table 8.39.

Table 8.38 Magnitude of effect on seabed morphology and sediment transport under the worst-case scenario for cable protection measures for export cables within the offshore cable corridor

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Landfall	Negligible	High	High	Negligible	Negligible
Shallower than 10m water depth (excluding landfall)	No change	-	-	-	No change
Deeper than 10m water depth	Low	High	High	Negligible	Low

Table 8.39 Magnitude of effect on cliff erosion under the worst-case scenario for cable operation

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Landfall	No change	-	-	-	No change

407. The seabed morphology and sediment transport effects could potentially directly affect parts of the East Anglian coast and so its sensitivity and value is presented in Table 8.40.

Table 8.40 Sensitivity and value assessment for the East Anglian coast

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
East Anglian coast	Low	Low	Negligible	High	Medium

408. The significance of impacts relating to seabed and coastal morphology and sediment transport arising from the presence of cable protection measures for export cables within the offshore cable corridor would differ depending on the location of the works and the identified receptor groups under consideration.

409. It is considered that the extremely small areas associated with cable protection (0.001% of the total area of the Haisborough, Hammond and Winterton SAC and 0.002% of the area of sandbanks within the SAC) would have no significant effect on the governing processes of the SAC. Therefore, there would be **negligible impact** on the Haisborough, Hammond and Winterton SAC.

410. As no cable protection is expected to be required in the nearshore area of the offshore cable corridor, no morphological effects would take place and so there would be **no impact** on coastal morphology at the cable landfall during the operational phase of Norfolk Boreas.

411. The significance of these effects on other receptors is addressed within relevant chapters of this ES.

8.7.7.7 Impact 7: Cable repairs/reburial and maintenance vessel footprints

412. Cable repairs and reburial could be needed, as outlined in section 8.7.5.7 and in Table 8.16. Turbine repairs may also need to be carried out as required. The disturbance areas for reburial and repairs of cables are extremely small in comparison to construction.

413. There is potential for temporary physical disturbance to Annex I Sandbanks in the offshore cable corridor due to cable maintenance and repair operations. The maximum disturbance area would be 900m^2 for each cable repair (including anchor placement associated with repair works). This equates to less than 0.001% of the total SAC area (1,468km^2) and the sandbank area (678km^2). The sandbank would have recovered from any temporary disturbance from one repair before any further repairs are required.

414. The maximum disturbance area for cable reburial activities within the SAC has been estimated as 60,000m^2 (0.6km^2) over the life of the project (0.04% of the total area of the SAC or 0.09% of the sandbank area). This is estimated from 20km per cable pair within the SAC, with a disturbance width of 3m. However, if reburial is required, it is likely that this would be for shorter sections (e.g. 1km) at any one time.

415. There is potential for certain vessels used during the maintenance of the wind turbines to directly impact the seabed during the operational phase. This applies for those vessels that utilise jack-up legs or several anchors to hold station and to provide stability for a working platform. Where legs or anchors are temporarily placed on the seabed, there is potential for an indentation to remain proportional in size to the dimensions of the object. There is also potential for local effects on waves, tides and sediment transport and for local scour-hole formation around the legs or anchors while they remain in place for the duration of the maintenance works.

416. The worst-case scenario is considered to correspond to the use of jack-up vessels for wind turbine repairs since the depressions and potential for effects on marine physical processes and scour-hole formation would be greater than the anchor scars.

417. For purposes of a worst-case scenario, it has been assumed that the total area of seabed that may be affected by these activities is 0.58km^2 per year (based on up to two visits per day by jack-up vessels with a footprint of 792m^2). It is possible that different areas would be affected in each year of the operational phase.

418. The effects of the jack-up legs on waves, tides and sediment transport would be localised since the legs are small and would only be temporary. Once the maintenance activities are complete the jack-up barges would be moved on and no permanent effects on marine physical processes would remain.

419. The legs of the jack-up barge would be small in diameter and this would place a physical limit on the depth and plan area of any scour-hole formation (and hence the volume of scour material that would be released into the water column). This process would be further influenced by the physical conditions at each site (e.g. waves, currents, seabed sediments, strength of underlying geology, etc.). The sediment volumes arising from scour would therefore be small in magnitude and cause an insignificant effect in terms of enhanced suspended sediment concentrations and deposition elsewhere.

8.7.7.7.1 Assessment of effect magnitude and/or impact significance

420. The worst-case changes in terms of indentations on the seabed due to maintenance vessels are likely to have the magnitudes of effect shown in Table 8.41.

Table 8.41 Magnitude of effect on the seabed under the worst-case scenario for maintenance vessels

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field (immediate vicinity of leg)	High	Negligible	Negligible	Medium	Medium
Near-field (beyond immediate vicinity of leg)	No change	-	-	-	No change
Far-field	No change	-	-	-	No change

421. There is **no impact** under a worst-case scenario on the identified morphological receptor groups since they are remote from the immediate vicinity of each leg.

422. The sensitivity and value of the Haisborough, Hammond and Winterton SAC to disturbance is shown in Table 8.42.

Table 8.42 Sensitivity and value assessment of Haisborough, Hammond and Winterton SAC

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
Haisborough, Hammond and Winterton SAC	Negligible	Negligible	Negligible	High	Negligible

423. The governing processes within the SAC occur at a much larger scale than the potential temporary physical disturbance which may occur because of cable installation. Temporary physical disturbance as a result of cable maintenance or repair is likely to be intermittent and on a much smaller scale than during cable installation. The volume and area affected would be very small in comparison to the volume of sediment within the local sandbank systems (i.e. the Newarp Banks system) and the Haisborough, Hammond and Winterton SAC.

424. The assessment indicates that temporary physical disturbance may occur within the offshore cable corridor, with a maximum disturbance area of 0.6km^2 (0.04% of the total area of the SAC or 0.09% of the sandbank area), based on the worst-case

scenario. Although temporary physical disturbance may occur, this area is a very small part of the SAC, and the need for cable repairs is likely to be intermittent in nature. In addition, no sediment would be removed from the SAC during maintenance activities. Due to the short duration and small scale of any maintenance works (if required) there will be no effect on the form or function of the sandbank systems. Therefore, it is assessed as **negligible impact**.

425. The significance of these effects on other receptors is addressed within relevant chapters of this ES.

8.7.8 Potential Impacts during Decommissioning

426. The scope of the decommissioning works would most likely involve removal of the accessible installed components. This is outlined in section 5.4.19 of Chapter 5 Project Description and the detail would be agreed with the relevant authorities at the time of decommissioning. Offshore, this is likely to include removal of all the wind turbine components, part of the foundations (those above seabed level), removal of some or all the array cables, interconnector cables, and export cables. Scour and cable protection would likely be left in situ.

427. During the decommissioning phase, there is potential for wind turbine foundation and cable removal activities to cause changes in suspended sediment concentrations and/or seabed or shoreline levels because of sediment disturbance effects. The types of effect would be comparable to those identified for the construction phase:

- Impact 1: Changes in suspended sediment concentrations due to wind turbine foundation removal;
- Impact 2: Changes in seabed level (morphology) due to wind turbine foundation removal;
- Impact 3: Changes in suspended sediment concentrations due to removal of parts of the array, interconnector or project interconnector cables;
- Impact 4: Changes in seabed level due to removal of parts of the array, interconnector or project interconnector cables;
- Impact 5: Changes in suspended sediment concentrations due to removal of parts of the export cable (including nearshore and at the coastal landfall); and
- Impact 6: Indentations on the seabed due to decommissioning vessels.

428. The magnitude of effects would be comparable to or less than those identified for the construction phase. Accordingly, given the construction phase assessments concluded “no impact” or impacts of “negligible significance” for marine physical processes receptors, it is anticipated that the same would be valid for the decommissioning phase.

429. The significance of effects on other receptors is addressed within relevant chapters of this ES (Chapter 9 Marine Water and Sediment Quality, Chapter 10 Benthic and Intertidal Ecology, Chapter 11 Fish and Shellfish Ecology, Chapter 12 Marine Mammal Ecology and Chapter 13 Offshore Ornithology).

8.8 Cumulative Impacts

430. The receptors that have been specifically identified in relation to marine physical processes are the 'East Anglia' coastline, the Haisborough, Hammond and Winterton SAC, the Cromer Shoal Chalk Beds MCZ and the North Norfolk Sandbanks and Saturn Reef SAC. Impacts (including Cumulative Impacts) to the relevant designated features of these sites are assessed in Chapter 9 Marine Water and Sediment Quality, Chapter 10 Benthic and Intertidal Ecology, and Chapter 11 Fish and Shellfish Ecology.

431. The marine physical processes effects that have been assessed for Norfolk Boreas alone are mostly anticipated to result in **no impact** or **negligible impact** to the above-mentioned receptors. This is primarily because these receptors are located remotely from the zones of influence arising from most of the effects and no pathway has been identified that can link the source to the receptor in most cases. This assessment remains valid for both the single-phase and two-phase construction approaches considered.

432. However, there may be potential cumulative effects on some of the identified receptor groups arising due to:

- Installation of foundation structures for Norfolk Boreas with the proposed East Anglia THREE and Norfolk Vanguard[2] projects;
- Installation or decommissioning of the export cable (including works at the landfall) for Norfolk Boreas with the Norfolk Vanguard[1] project;
- Installation or decommissioning of the export cable (including works at the landfall) for Norfolk Boreas and marine aggregate dredging activities in adjacent areas of the seabed; and
- Operation and maintenance of Norfolk Boreas with the proposed East Anglia THREE and Norfolk Vanguard project[1].

433. A summary of the screening of potential impacts is set out in Table 8.43.

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[2] Cumulative impacts with Norfolk Vanguard would only occur under a scenario where Norfolk Vanguard is built (see Chapter 5 project description for further detail)

Table 8.43 Potential cumulative impacts

Impact		Potential for cumulative impact	Rationale
Construction			
1	Changes in Suspended Sediment Concentrations due to Seabed Preparation and drill arisings associated with foundations	Yes	Where construction windows could overlap for projects adjacent to Norfolk Boreas i.e. Norfolk Vanguard and East Anglia THREE there is potential for cumulative impact
2	Changes in Seabed Level due to Seabed Preparation and drill arisings associated with foundations	Yes	Where construction windows could overlap for projects adjacent to Norfolk Boreas i.e. Norfolk Vanguard and East Anglia THREE there is potential for cumulative impact
3	Changes in Suspended Sediment Concentrations during Export Cable Installation	Yes	Norfolk Boreas and Norfolk Vanguard share an offshore cable corridor and therefore there is potential for cumulative impacts. Consideration is also given to Marine Aggregate Dredging
4	Changes in Seabed Level and interruptions to bedload due to Export Cable Installation	Yes	Norfolk Boreas and Norfolk Vanguard share an offshore cable corridor and therefore there is potential for cumulative impacts. Consideration is also given to Marine Aggregate Dredging
5	Changes in Suspended Sediment Concentrations during array, interconnector and project interconnector cable Installation	Yes	Where construction windows could overlap for projects adjacent to Norfolk Boreas i.e. Norfolk Vanguard and East Anglia THREE there is potential for cumulative impact
6	Changes in Seabed Level due to array, interconnector and project interconnector cable Installation	Yes	Where construction windows could overlap for projects adjacent to Norfolk Boreas i.e. Norfolk Vanguard and East Anglia THREE there is potential for cumulative impact
7	Indentations on the Seabed due to Installation Vessels	No	Impacts will be localised to the area of seabed affected by the installation vessel legs/anchors and therefore there will be no cumulative impact beyond this area

Impact		Potential for cumulative impact	Rationale
Operation			
1	Changes to the Tidal Regime due to the Presence of Wind Turbine Structures	Yes	Additive changes to the tidal regime of Norfolk Boreas, Norfolk Vanguard and East Anglia THREE due to their proximity.
2	Changes to the Wave Regime due to the Presence of Wind Turbine Structures	Yes	Additive changes to the wave regime of Norfolk Boreas, Norfolk Vanguard and East Anglia THREE due to their proximity.
3	Changes to Bedload Sediment Transport through the Cumulative and Combined change to the Tidal and Wave Regimes due to the Presence of Wind Turbine Structures	Yes	The combined effects of changes to the wave and tide regime as a result of Norfolk Boreas, Norfolk Vanguard and East Anglia THREE due to their proximity.
4	Changes to the Sediment Transport Regime due to the Presence of Foundation Structures	No	Impacts will be highly localised around the foundations and therefore there will be no cumulative impact.
5	Loss of Seabed Morphology due to the Footprint of Wind Turbine Foundation Structures	No	Impacts will be highly localised around the foundations and therefore there will be no cumulative impact.
6	Morphological and Sediment Transport Effects due to Cable Protection for array, interconnector and project interconnector cables	No	Impacts will be highly localised around the cable protection measures and therefore there will be no cumulative impact.
7	Morphological and Sediment Transport Effects due to Cable Protection Measures.	No	Impacts will be highly localised around the cable protection measures and therefore there will be no cumulative impact.
8	Cable repairs/reburial and maintenance vessel footprints	No	Impacts will be highly localised around the foundations and cables and therefore there will be no cumulative impact.
Decommissioning			
The detail and scope of the decommissioning works will be determined by the relevant legislation and guidance at the time of decommissioning and agreed with the regulator. A decommissioning plan will be provided. As such, cumulative impacts during the decommissioning stage are assumed to be no worse than those identified during the construction stage.			

434. These potential interactions are included in the (CIA) (Table 8.44). Interaction with the proposed East Anglia ONE project is excluded from the CIA. This is because the EIA for East Anglia THREE (EATL, 2015) provided evidence for no operational interaction between East Anglia ONE and East Anglia THREE. The assessment showed that there was no overlap of the zones of influence arising cumulatively from the

East Anglia ONE and East Anglia THREE projects in relation to changes on the tidal and wave regimes.

435. Given that Norfolk Boreas is further away from East Anglia ONE, then there will also be no interactions from this or any other offshore wind farms of comparable or greater distance to Norfolk Boreas. In addition, the cable corridor for East Anglia ONE is directed west-south-west towards Bawdsey, whereas the cable corridor for Norfolk Boreas is directed west to Happisburgh, and the distance between the two corridors is sufficient for there to be no marine physical processes interactions during the construction phases of the two projects.

436. The Norfolk Boreas Landfall is located to the south of the proposed Bacton to Walcott Coastal Management Scheme which will deposit sand in front of Bacton Gas Terminal. The effect of this beach nourishment is likely to be felt at the landfall location at Happisburgh South (i.e. some of the nourished sand will migrate from the main sand engine driven by longshore sediment transport). However, as the sand is due to be deposited between April and November 2019 and the Norfolk Boreas HDD work would occur at the earliest in 2022, the impacts from the two projects would not overlap. Furthermore, the Norfolk Boreas HDD would have no impact on coastal erosion and the nearshore cable protection would have only negligible impact on sediment transport processes at the coast. Therefore, there will be no cumulative impacts between Norfolk Boreas and Bacton to Walcott Coastal Management Scheme.

437. The export cables for Norfolk Boreas would pass north of a series of marine aggregate extraction areas offshore from Great Yarmouth. The southern edge of the offshore cable corridor is within 10km of the most northern extraction areas and there is the potential for some interaction between their dredging plumes and plumes from export cable installation. This is because they are within one spring tidal excursion distance from each other.

Table 8.44 Summary of projects considered for the CIA in relation to the topic

Project	Status	Indicative development period	Distance from Norfolk Boreas (km)	Project definition	Project data status	Included in CIA	Rationale
East Anglia THREE Offshore Wind farm	Consented	2022-2026	13	PDS available	Complete/high	Yes	This project would be located approximately 13km to the south of Norfolk Boreas. It has potential for interaction during the construction of foundations and their operation and maintenance
Norfolk Vanguard Offshore Wind farm	Application submitted	2024-2028	1	Outline only	Incomplete/low	Yes	This project would be adjacent to Norfolk Boreas and would share the offshore cable corridor. It has potential for interaction during the construction and operation and maintenance phases
Marine aggregate dredging	Licenced	In operation	Nearest 27km		Complete/high	Yes	The export cables for Norfolk Boreas pass north of marine aggregate extraction areas offshore from Great Yarmouth. There is potential for some interaction between their dredging plumes and plumes from cable installation

Project	Status	Indicative development period	Distance from Norfolk Boreas (km)	Project definition	Project data status	Included in CIA	Rationale
Bacton and Walcott Coastal Management Scheme	Application submitted August 2018	Expected construction date 2019	Nearest approximately 60km	Project description available	Complete/high	No	It is anticipated that the works will be undertaken in the period between April and November 2019 and as construction for Norfolk Boreas landfall would start in 2022 at the earliest no overlap in construction periods is anticipated. Modelling for the project indicates that once the sediment has been deposited it would not be particularly mobile and therefore would not act cumulatively with Norfolk Boreas construction to impact on water quality.
Coastal defence/protection works, Happisburgh PF/18/0751	Registered Application 24/04/2018	Coastal protection over 10 year duration	Approximately 1km	Outline	Medium	No	The Norfolk Boreas Long HDD would have no impact on coastal erosion, and the nearshore cable protection would have negligible impact on sediment transport processes at the coast. Therefore, no cumulative impact is anticipated.

8.8.1 Cumulative Construction and Decommissioning Impacts with Adjacent Wind Farms

438. The impacts of the foundation and export cable installation and decommissioning activities (including works at the landfall) on the identified receptors were identified to be of negligible impact for the Norfolk Boreas project alone.

439. The construction programmes of Norfolk Boreas, Norfolk Vanguard and/or East Anglia THREE may overlap depending on the final construction programmes. The Norfolk Boreas cable corridor and its landfall would be common to the Norfolk Vanguard project and so there is potential for cumulative impacts to arise during the construction and decommissioning stages.

8.8.1.1 Changes in suspended sediment concentrations (construction impacts 1, 3 and 5 in Table 8.43)

440. The cumulative worst-case scenario for increases in suspended sediment concentrations would occur if for Norfolk Boreas, Norfolk Vanguard and East Anglia THREE were to be in construction at the same time. This would provide the greatest opportunity for interaction of sediment plumes and a larger increase in suspended sediment concentrations during their construction. The combined sediment plume from foundation and cable installation could have a greater spatial extent than that of each individual project.

441. As with Norfolk Boreas in isolation, most of the suspended sediment arising from each project would fall rapidly to the seabed during construction and therefore the potential cumulative impact would be of negligible magnitude. The receptor sensitivity would also be negligible and therefore it is considered that the significance of a cumulative impact of two or three projects constructing in this area at the same time would be of **negligible** significance.

8.8.1.2 Changes in seabed level due to drill arisings and seabed preparation associated with foundations and cable installation (construction impacts 2 and 6 in Table 8.43)

442. The worst case scenario for changes in seabed level due to seabed preparation associated with foundations and cable installation and drill arisings associated with foundations would occur if all three projects (Norfolk Boreas, Norfolk Vanguard and East Anglia THREE) were constructed at the same time. This would provide the greatest opportunity for interaction of sediment plumes and a larger change in seabed level from deposition from the plume during their construction. The combined change in seabed level from foundation and cable installation could have a greater spatial extent and be greater vertically than each individual project.

443. In the unlikely event that sediment plumes would overlap, most of the changes in seabed level arising from each project would be small (up to a maximum of 3mm, based on each project contributing up to 1mm (see section 8.7.6.3 for further detail) of deposition from the plume). After this initial deposition, this sediment would be continually re-suspended to reduce the thickness even further to a point where it would be effectively zero. This would be the longer-term outcome, once the sediment supply from foundation installation had ceased. Hence, during construction the potential cumulative impact would be of negligible magnitude. The receptor sensitivity would also be negligible and therefore it is considered that the cumulative impact on seabed level within the windfarm sites of two or three projects constructing in this area at the same time would be of **negligible** significance.

8.8.1.3 Changes in seabed level and interruptions to bedload sediment transport due to export cable installation (construction impact 4 in Table 8.43)

444. Norfolk Boreas and Norfolk Vanguard share a common offshore cable corridor that passes through the Haisborough, Hammond and Winterton SAC which is designated for, among other features, “sandbanks” (see section 8.6.1.2.1). The offshore cable corridor for East Anglia THREE is located between approximately 4km and almost 100km south of the Norfolk Boreas offshore cable corridor. Therefore, as effects of export cable installation for Norfolk Boreas in isolation are predicted to be negligible in the far-field (greater than a few hundred meters) there would be no interaction with sediment transport between the two projects as a result of export cable installation. Therefore, the offshore cable corridor of East Anglia THREE is not considered further within this cumulative assessment.

445. If both the Norfolk Vanguard and Norfolk Boreas projects were constructed using a phased approach this could result in export cables being installed within the offshore cable corridor on four separate occasions (twice for Norfolk Vanguard and twice for Norfolk Boreas). Both the MMO (Table 8.2) and Natural England have highlighted the need to consider this as a worst case scenario for marine physical processes. Their main concern is that if seabed levelling for cable installation was required during consecutive years, sand waves which are in a recovery phase would have their recovery interrupted by subsequent phases of seabed levelling.

446. Appendix 7.1 of the Information to support HRA (document reference 5.3) assessed the possible effects of multiple phases of cable installation on the sand waves within the offshore cable corridor. The assessment used a worst case scenario of four export cables being installed with a gap of six to 24 months between each installation. The assessment used the findings of an export cable constructability study undertaken by GMSL which estimated the likely cable spacing arrangements within the offshore cable corridor for both the Norfolk Vanguard and Norfolk Boreas export cables. These are shown in Plate 5.9 of Chapter 5 Project description.

447. The sand wave bed levelling study considered migration rates of the sand waves within the offshore cable corridor and their likely spacing and predicted that there would be potential for a sand wave which has been impacted during the first phase of cable installation to be impacted again in future phases of installation. However, the assessment concluded that the likelihood of multiple phases of seabed levelling altering the form and function of the sand wave field and the wider sandbank system is minimal. This is because all the evidence suggested that the study area is in a dynamic environment conducive to the development and maintenance of sand waves. Sand wave bedforms are continually being modified, converging and bifurcating, also with new bedforms being created and migrating through the cable corridor.

448. Since the sand wave bed level study was completed further work has been undertaken to define construction programmes (see section 8.7.5.3). It is now anticipated that the location of each export cable would be sufficiently far apart (Plate 5.9 of Chapter 5 Project description) and the time between installation phases sufficiently small that given the migration rates of the sand waves no sand wave would be impacted on multiple occasions.

449. Norfolk Boreas Limited has committed to disposing of any seabed sediment dredged from within the SAC back into the SAC to ensure that no sediment is lost from sandbank system. The assessment undertaken in Appendix 7.1 of the Information to support HRA (document reference 5.3) also accounts for this disposal element.

450. Given the findings of the sand wave bed level study, the revised construction programmes and the commitment of Norfolk Boreas Limited to dispose of dredged sediment within the SAC, the magnitude of the impact is predicted to be, at worst, low. As discussed in section 8.7.6.6 and Table 8.24 the receptors of this impact are of negligible sensitivity. Therefore, the cumulative impact of seabed level change and interruptions to bedload sediment transport due to export cable installation from two offshore windfarms is predicted to be of **negligible** significance.

8.8.2 Cumulative Construction and Decommissioning Impacts with Marine Aggregate Dredging (construction impacts 3 and 4 in Table 8.43)

451. To assess the potential for cumulative effects between the installation of the export cables and marine aggregate dredging activities in adjacent areas of the seabed, reference has been made to the EIA for the East Anglia ONE project. Although the cable corridor route is different the results provide a useful and appropriate analogy for Norfolk Boreas.

452. The East Anglia ONE EIA was supported by numerical modelling, using Delft3D plume modelling software, of the potential for interactions of sediment plumes arising from export cable installation with those arising from marine aggregate dredging sites (and indeed other seabed activities) located within one spring tidal excursion distance from the East Anglia ONE offshore cable corridor. The modelling showed that some interaction could potentially occur between dredging plumes and plumes from cable installation and that the spatial extent of the combined plume is slightly greater than for the plumes originating from the export cable installation only. Whilst maximum plume concentrations would be no greater under the cumulative scenario, a larger geographical area might experience increases in suspended sediment concentrations than for the export cable installation only scenario. Following cessation of cable burial and aggregate dredging activities, a few 100m away from the immediate release locations maximum theoretical bed level changes of up to 2mm were identified by the model, with maximum levels of around 0.8mm at greater distances.

453. The Norfolk Boreas cable corridor is located over 5km from the nearest aggregate extraction site (North Cross Sands) with the Norfolk Boreas site located 49km from the nearest aggregate site. Considering the results from East Anglia ONE described above, the potential cumulative impacts between export cable installation for Norfolk Boreas and nearby marine aggregate dredging activities would be of **negligible** significance.

8.8.3 Cumulative Operation and Maintenance Impacts with Adjacent Wind Farms

8.8.3.1 Changes to the Tidal Regime due to the Presence of Wind Turbine Structures (operational impact 1 in Table 8.43)

454. During the operation of Norfolk Boreas, Norfolk Vanguard and East Anglia THREE wind farms there would be potential for the three projects to have a cumulative effect on the tidal regime due to the large combined number of structures across the three projects.

455. To assess the potential for cumulative effects on the tidal regime, a ‘zone of potential cumulative influence’ approach has been adopted. This approach has previously been used for other windfarm projects, including East Anglia THREE and Norfolk Vanguard.

456. The zone of potential cumulative influence on the baseline tidal regime is based on an understanding of the tidal ellipses in the area and knowledge that effects arising from wind turbine and platform foundations on the tidal regime are relatively small in magnitude and local. It is likely that effects on the tidal regime would be dissipated within one tidal ellipse of the obstacle. The zone of potential cumulative

influence for Norfolk Boreas was constructed using the tidal ellipses that cross the extremities of the site, with the boundary representing the tidal ellipse end points in all directions. This was repeated for Norfolk Vanguard and East Anglia THREE and the zones combined to create the zone of potential cumulative influence on the tidal regime. Figure 8.15 shows that the zone of potential cumulative influence from these projects can be separated into three distinct locations:

- Norfolk Boreas only;
- Norfolk Boreas and Norfolk Vanguard East cumulatively; and
- Norfolk Boreas, Norfolk Vanguard East and East Anglia THREE cumulatively;

457. Because of its north to south orientation, the cumulative zone of influence arising from the Norfolk Boreas, Norfolk Vanguard East and East Anglia THREE windfarm sites does not overlap with the Haisborough, Hammond and Winterton SAC or the North Norfolk Sandbanks and Saturn Reef SAC. Due to this, there would be no cumulative effect on the baseline tidal regime in the identified receptor groups for marine physical processes.

458. However, it is acknowledged that mobilisation of medium sand (the predominant seabed sediment local to the three wind farms) by tidal currents occurs under existing conditions greater than 70% of the time (ABPmer, 2018). It is possible that changes to the tidal current regime within the cumulative zone of influence could result in small changes to mobilisation rates. The changes are likely to be very minimal and therefore the cumulative magnitude of low is considered to be the worst case. As discussed above the influence of the cumulative effect on tidal regime would not extend to the identified receptor groups and therefore a negligible sensitivity has been applied. This would result in a cumulative impact of **negligible** significance.

8.8.3.2 Changes to the Wave Regime due to the Presence of Wind Turbine Structures (operational impact 2 in Table 8.43)

459. As with cumulative impacts on the tidal regime discussed in section 8.8.3.1 there would be potential for Norfolk Boreas, Norfolk Vanguard and East Anglia THREE to interact cumulatively on the wave climate.

460. To assess the potential for cumulative effects on the wave regime, the zone of potential cumulative influence approach has also been adopted. The zone of potential cumulative influence on the baseline wave regime is based on an understanding of the wave rose data in the area and that effects arising from wind turbine and platform foundations on the wave regime would be localised and relatively small in scale.

461. A zone of potential cumulative influence on the wave regime has been derived from all projects considered (Norfolk Boreas, Norfolk Vanguard and East Anglia THREE). Figure 8.16 shows how the zone of potential influence from these projects is predicted to overlap and it is in these three areas where cumulative effects may occur:

- Norfolk Boreas and Norfolk Vanguard East overlap;
- Norfolk Boreas, Norfolk Vanguard East and East Anglia THREE overlap; and
- Norfolk Vanguard East and East Anglia THREE overlap.

462. Norfolk Boreas would only contribute to the cumulative effects in the first two of these areas. Effects from Norfolk Boreas are not predicted to overlap with those caused by Norfolk Vanguard West.

463. Because of the general north east to south west orientation, the cumulative zone of influence arising from the Norfolk Boreas, Norfolk Vanguard East and East Anglia THREE wind farm sites does not overlap with the Haisborough, Hammond and Winterton SAC or the North Norfolk Sandbanks and Saturn Reef SAC. Due to this, there would be no cumulative impact on the baseline wave regime in the identified receptor groups for marine physical processes.

464. However, it is acknowledged that mobilisation of medium sand (the predominant seabed sediment local to the three wind farms) on the sandbanks and sand wave crests by waves occurs under existing conditions about 50% of the time (Appendix 7.1 of the Information to support HRA (document reference 5.3)). It is possible that changes to the wave regime within the cumulative zone of influence could result in minimal changes to mobilisation rates at these seabed elevations and therefore the cumulative magnitude of the impact can of low has been applied. The cumulative effect on wave regime would not extend to the identified receptor groups and therefore a negligible sensitivity has been applied. This would result in a cumulative impact of **negligible** significance.

8.8.3.3 Changes to Bedload Sediment Transport through the Cumulative and Combined change to the Tidal and Wave Regimes due to the Presence of Wind Turbine Structures (operational impact 3 in Table 8.43)

465. The zones of influence of combined tidal currents and waves for Norfolk Boreas, Norfolk Vanguard East and East Anglia THREE are shown in Figure 8.17. Combining tidal currents and waves results in a cumulative zone of influence for the three windfarm sites. This combined zone of influence is outside the boundaries of the Haisborough, Hammond and Winterton and North Norfolk Sandbanks and Saturn Reef SACs. Due to this, there would be no cumulative impact on the combined baseline tidal and waves regime, and hence bedload sediment transport, in the identified receptor groups for marine physical processes.

466. According to ABPmer (2018), mobilisation of medium sand by a combination of tidal currents and waves occurs under existing conditions greater than 85% of the time. It is possible that the combined changes to the tidal current and wave regimes within the cumulative zone of influence could result in changes to mobilisation rates. However, the impacts on the tidal regime and wave regimes alone are low which would only result in minimal changes to mobilisation rates, and the same level of impact can be applied to the combined effects of tidal currents and waves, together. Therefore, the cumulative magnitude of impact on bedload sediment transport due to the combined changes in tidal currents and waves is considered to be low.

467. The ABPmer (2018) study was completed within the Haisborough, Hammond and Winterton SAC parts of which are a lot shallower than the Norfolk Boreas site. As tide and particularly waves have a greater influence on sediment transport at shallower depth, the combined effects at the Norfolk Boreas site would be expected to be less than those estimated for the SAC by ABPmer (2018). Also, the combined influence of the tidal and wave regimes would not extend to the identified receptor groups and therefore a negligible sensitivity has been applied. This would result in a cumulative impact of **negligible** significance.

8.9 Inter-relationships

468. The range of effects on marine physical processes of the Norfolk Boreas project not only have the potential to directly affect the identified marine physical processes receptors but may also manifest as impacts upon receptors other than those considered within the context of marine physical processes. The assessments of significance of these impacts on other receptors are provided in the chapters listed in Table 8.45.

Table 8.45 Chapter topic inter-relationships

Topic and description	Related Chapter	Where addressed in this Chapter	Rationale
Effects on water column (suspended sediment concentrations)	9 – Marine water and sediment quality 11 – Fish and shellfish ecology 12 – Marine mammals 14 – Commercial fisheries	8.7.6.1 and 8.7.6.2 (foundation installation) 8.7.6.5 and 8.7.6.9 (cables installation	Suspended sediment concentrations are a measure of water quality and therefore changes are assessed in chapter 9. The receptors of changes in suspended sediment are fish and marine mammals and therefore these are assessed in Chapters 11 and 12. Changes to fish ecology could have impacts on commercial fisheries (assessed in Chapter 14).

Topic and description	Related Chapter	Where addressed in this Chapter	Rationale
Effects on seabed (morphology / sediment transport / sediment composition)	10 – Benthic and intertidal ecology 11 – Fish and shellfish ecology 14 – Commercial fisheries 17 – Offshore and intertidal archaeology and cultural heritage	8.7.6.3 and 8.7.6.4 (foundation installation) 8.7.6.5 and 8.7.6.10 (cables installation) 8.7.6.11 (installation vessels) 8.7.7.3 (sediment transport regime) 8.7.7.5 and 8.7.7.6 (cable protection)	Changes to seabed morphology/sediment transport could affect the habitat of benthic, fish and shellfish receptors. Changes to fish ecology could have impacts on commercial fisheries (assessed in Chapter 14). Changes to sediment transport could affect the exposure of, and therefore impacts on archaeological features.
Effects on shoreline (morphology / sediment transport / sediment composition)	10 – Benthic and intertidal ecology	8.7.6.5 (cable landfall) 8.7.7.6 (export cable protection in nearshore and intertidal zone)	Changes to seabed morphology/sediment transport at the coast could affect the intertidal habitat.

8.10 Interactions

469. The impacts identified and assessed in this chapter have the potential to interact with each other, which could give rise to synergistic impacts because of that interaction. The worst-case impacts assessed within the chapter take these interactions into account and for the impact assessments are considered conservative and robust. For clarity the areas of interaction between impacts are presented in Table 8.46 along with an indication as to whether the interaction may give rise to synergistic impacts. None of the interactions identified below are likely to give rise to significant impacts on marine physical processes. However, there is potential for these interactions to result in significant impacts for other receptors i.e. benthic ecology, fish ecology, commercial fisheries and water and sediment quality. The interactions and their potential to lead to significant impacts are assessed within the other relevant chapters of this ES (Chapter 9 Marine Water and Sediment Quality, Chapter 10 Benthic Ecology, Chapter 11 Fish and Shellfish Ecology, Chapter 13 Commercial Fisheries and Chapter 17 Offshore and Intertidal Archaeology and Cultural Heritage).

Table 8.46 Interaction between impacts

Potential interaction between impacts											
Construction											
	Impact 1A: Changes in Suspended Sediment Concentrations due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	Impact 1B: Changes in Suspended Sediment Concentrations due to Drill Arisings for Installation of Piled Foundations for Wind Turbines	Impact 2A: Changes in Seabed Level due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	Impact 2B: Changes in Seabed Level due to Drill Arisings for Installation of Piled Foundations for Wind Turbines	Impact 3: Changes in Suspended Sediment Concentrations during Cable Installation within the Offshore Cable Corridor	Impact 4A: Changes in Seabed Level due to Cable Installation within the Offshore Cable Corridor	Impact 4B: Changes in seabed level due to disposal of sediment from sand wave levelling within the Offshore Cable Corridor	Impact 4C: Interruptions to Bedload Sediment Transport due to Sand Wave Levelling	Impact 5: Changes in Suspended Sediment Concentrations during Cable Installation within the Norfolk Boreas site and Project Interconnector Search Area	Impact 6: Changes in Seabed Level due to Cable Installation within the Norfolk Boreas site and Project Interconnector Search Area	Impact 7: Indentations on the Seabed due to Installation Vessels
Impact 1A: Changes in Suspended Sediment Concentrations due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	-	No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes
Impact 1B: Changes in Suspended Sediment Concentrations due to Drill Arisings for Installation of Piled Foundations for Wind Turbines	No	-	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Impact 2A: Changes in Seabed Level due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	Yes	No	-	No	Yes	Yes	No	No	Yes	Yes	Yes
Impact 2B: Changes in Seabed Level due to Drill Arisings for Installation of Piled Foundations for Wind Turbines	No	Yes	No	-	Yes	Yes	No	No	Yes	Yes	Yes
Impact 3: Changes in Suspended Sediment Concentrations during Cable Installation within the Offshore Cable Corridor	Yes	Yes	Yes	Yes	-	Yes	Yes	Yes	Yes	Yes	Yes
Impact 4A: Changes in Seabed Level due to Cable Installation within the Offshore Cable Corridor	Yes	Yes	Yes	Yes	Yes	-	Yes	Yes	No	Yes	No
Impact 4B: Changes in seabed level due to disposal of sediment from sand wave levelling within the Offshore Cable Corridor	No	No	No	No	Yes	Yes	-	Yes	Yes	Yes	Yes
Impact 4C: Interruptions to Bedload Sediment Transport due to Sand Wave Levelling	No	No	No	No	Yes	Yes	Yes	-	No	No	No
Impact 5: Changes in Suspended Sediment Concentrations during Cable Installation within the Norfolk Boreas site and Project Interconnector Search Area	Yes	Yes	Yes	Yes	Yes	No	Yes	No	-	No	No
Impact 6: Changes in Seabed Level due to Cable Installation within the Norfolk Boreas site and Project Interconnector Search Area	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	-	No
Impact 7: Indentations on the Seabed due to Installation Vessels	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	-

Potential interaction between impacts

Operation

	Impact 1: Changes to the Tidal Regime due to the Presence of Wind Turbine Structures	Impact 2: Changes to the Wave Regime due to the Presence of Wind Turbine Structures	Impact 3: Changes to the Sediment Transport Regime due to the Presence of Wind Turbine Foundation Structures	Impact 4: Loss of Seabed Morphology due to the Footprint of Wind Turbine Foundation Structures	Impact 5: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Norfolk Boreas site and Project Interconnector Search Area	Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Offshore Cable Corridor	Impact 7: Cable repairs/reburial and maintenance vessel footprints
Impact 1: Changes to the Tidal Regime due to the Presence of Wind Turbine Structures	-	Yes	No	No	No	No	No
Impact 2: Changes to the Wave Regime due to the Presence of Wind Turbine Structures	Yes	-	No	No	No	No	No
Impact 3: Changes to the Sediment Transport Regime due to the Presence of Wind Turbine Foundation Structures	No	No	-	No	No	Yes	No
Impact 4: Loss of Seabed Morphology due to the Footprint of Wind Turbine Foundation Structures	No	No	No	No	No	No	No
Impact 5: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Norfolk Boreas site and Project Interconnector Search Area	No	No	Yes	No	-	Yes	No
Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Offshore Cable Corridor	No	No	Yes	No	Yes	-	No
Impact 7: Cable repairs/reburial and maintenance vessel footprints	No	No	No	No	No	No	-

8.11 Summary

470. The construction, operation and decommissioning phases of Norfolk Boreas would cause a range of effects on the marine physical processes. The magnitude of these effects has been assessed using expert judgement, drawing from a wide science base that includes project-specific surveys and previous numerical modelling activities.

471. The receptors that have been specifically identified in relation to marine physical processes are the sensitive 'East Anglia' coastline, Haisborough, Hammond and Winterton SAC, North Norfolk Sandbanks and Saturn Reef SAC and Cromer Shoal Chalk Beds MCZ.

472. The effects that have been assessed are mostly anticipated to result in no impact to the above-mentioned receptors because they are located remotely from the zones of influence and no pathway has been identified that can link the source to the receptor. A summary of impacts to these receptors are listed in Table 8.47.

Table 8.47 Potential impacts identified for marine physical processes

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Construction						
Impact 1A: Changes in Suspended Sediment Concentrations due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 1B: Changes in Suspended Sediment Concentrations due to Drill Arisings for Installation of Piled Foundations for Wind Turbines	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 2A: Changes in Seabed Level due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	Haisborough, Hammond and Winterton SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Impact 2B: Changes in Seabed Level due to Drill Arisings for Installation of Piled Foundations for Wind Turbines	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 3: Changes in Suspended Sediment Concentrations during Cable Installation within the Offshore Cable Corridor	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 4A: Changes in Seabed Level due to Cable Installation within the Offshore Cable Corridor	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	Disposal in SAC	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	N/A
	Cromer Shoal Chalk Beds MCZ	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Impact 4B: Changes in seabed level due to disposal of sediment from sand wave levelling within the Offshore Cable Corridor	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), Negligible (far-field)	**Negligible**	Disposal in SAC	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 4C: Interruptions to Bedload Sediment Transport due to Sand Wave Levelling	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	Disposal in SAC	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 5: Changes in Suspended Sediment Concentrations during Cable Installation within the Norfolk Boreas site and Project Interconnector Search Area	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Impact 6: Changes in Seabed Level due to Cable Installation within the Norfolk Boreas site and Project Interconnector Search Area	Haisborough, Hammond and Winterton SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 7: Indentations on the Seabed due to Installation Vessels	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Operation						
Impact 1: Changes to the Tidal Regime due to the Presence of Wind Turbine Structures	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	N/A
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (southern part of SAC)**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Impact 2: Changes to the Wave Regime due to the Presence of Wind Turbine Structures	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (south-east extreme of SAC)**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (south-east extreme of SAC)**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 3: Changes to the Sediment Transport Regime due to the Presence of Wind Turbine Foundation Structures	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (south-east extreme of SAC)**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (south and south-east extreme of SAC)**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 4: Loss of Seabed Morphology due to the Footprint of Wind Turbine Foundation Structures	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Impact 5: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Norfolk Boreas site and Project Interconnector Search Area	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures within the Offshore Cable Corridor	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 7: Cable repairs/reburial and maintenance vessel footprints	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Decommissioning						
Impact 1: Changes in Suspended Sediment Concentrations due to Wind Turbine Foundation Removal	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 2: Changes in seabed level (morphology) due to wind turbine foundation removal	Haisborough, Hammond and Winterton SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 3: Changes in Suspended Sediment Concentrations due to Removal of parts of the Array, Interconnector or Project Interconnector Cables	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Impact 4: Changes in seabed level due to removal of parts of the array, interconnector or project interconnector cables	Haisborough, Hammond and Winterton SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 5: Changes in suspended sediment concentrations due to removal of parts of the export cables (including nearshore and at the coastal landfall)	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	N/A
	Cromer Shoal Chalk Beds MCZ	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	East Anglian coast	N/A	N/A	**No impact**	N/A	N/A
Impact 6: Indentations on the Seabed due to Decommissioning Activities	Haisborough, Hammond and Winterton SAC	N/A	N/A	**No impact**	N/A	**No impact**
	North Norfolk Sandbanks and Saturn Reef SAC	N/A	N/A	**No impact**	N/A	**No impact**
	Cromer Shoal Chalk Beds MCZ	N/A	N/A	**No impact**	N/A	**No impact**
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Cumulative						
Cumulative Construction and Decommissioning Impacts with adjacent Wind Farms	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	East Anglian coast	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
Cumulative Construction and Decommissioning Impacts with Marine Aggregate Dredging	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	Cromer Shoal Chalk Beds MCZ	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	East Anglian coast	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
Cumulative Operation and Maintenance Impacts with adjacent Wind Farms	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
	Cromer Shoal Chalk Beds MCZ	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**
	East Anglian coast	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**

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