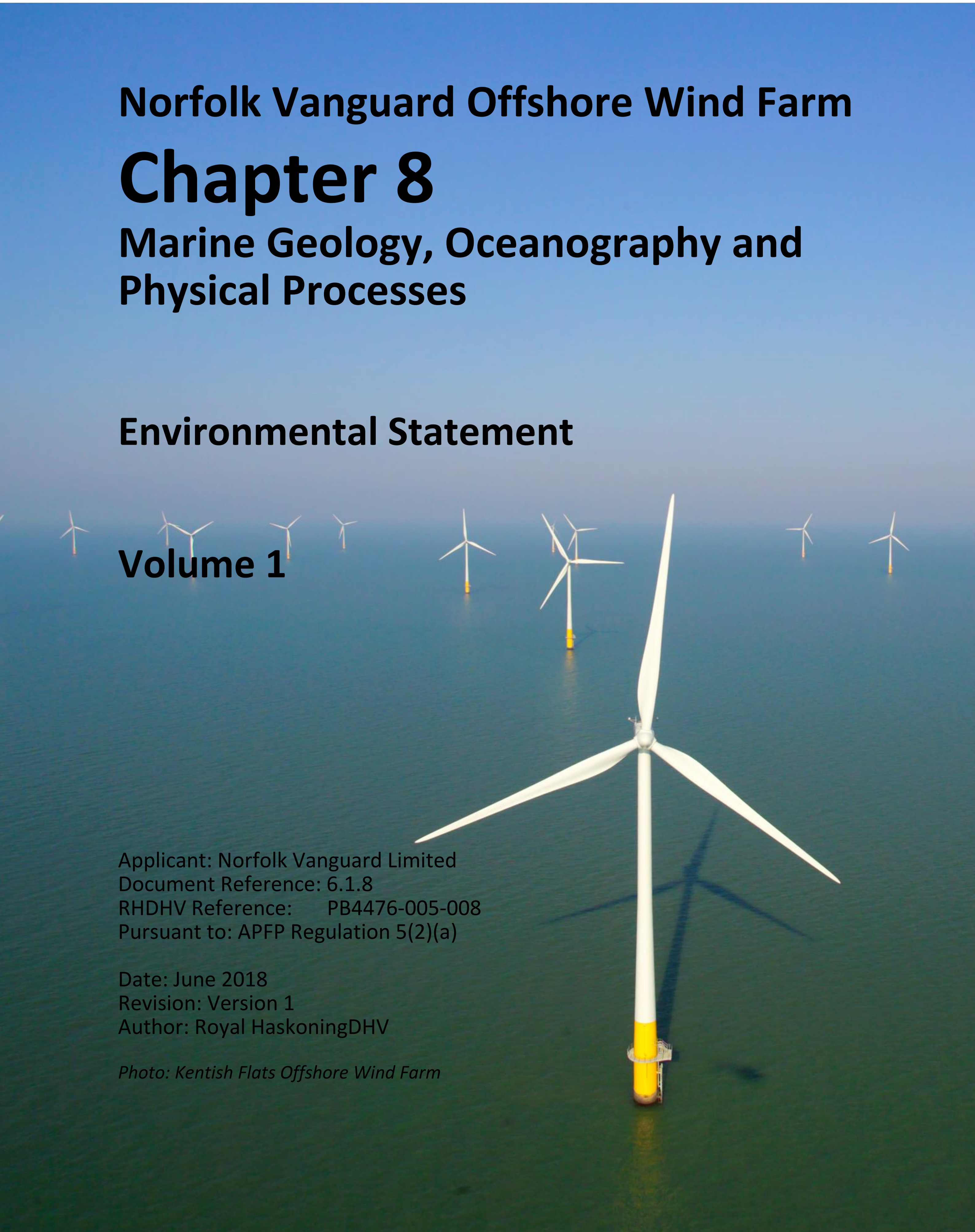

Norfolk Vanguard Offshore Wind Farm

Chapter 8

Marine Geology, Oceanography and Physical Processes

Environmental Statement

Volume 1

Applicant: Norfolk Vanguard Limited
Document Reference: 6.1.8
RHDHV Reference: PB4476-005-008
Pursuant to: APFP Regulation 5(2)(a)

Date: June 2018
Revision: Version 1
Author: Royal HaskoningDHV

Photo: Kentish Flats Offshore Wind Farm

Environmental Impact Assessment

Environmental Statement

Document Reference: PB4476-005-008

June 2018

For and on behalf of Norfolk Vanguard Limited

Approved by: Ruari Lean, Rebecca Sherwood

Signed: [redacted]

Date: 8th June 2018

For and on behalf of Royal HaskoningDHV

Drafted by: David Brew and Courtney Clemence

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Signed: [redacted]

Date: 23rd May 2018

Date	Issue No.	Remarks / Reason for Issue	Author	Checked	Approved
23/03/2018	01D	First draft for Norfolk Vanguard Limited review	DB/CC	GK	PP
20/04/2018	02D	Second draft for Norfolk Vanguard Limited review	DB/CC	GK	AD
23/05/2018	01F	Final for ES submission	DB	GK	AD

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Appendix 8.1 Particle Size Characteristics

Glossary

3D	Three Dimensional
ADCP	Acoustic Doppler Current Profiler
AWAC	Acoustic Wave and Current Meter
BGS	British Geological Society
CIA	Cumulative Impact Assessment
cSAC	Candidate Special Area of Conservation
CPT	Cone Penetration Test
CWS	County Wildlife Site
DCO	Development Consent Order
DWR	Directional Waverider Buoy
EIA	Environmental Impact Assessment
EPP	Evidence Plan Process
ES	Environmental Statement
GBS	Gravity Base Structure
GMSL	Global Mean Sea Level
HDD	Horizontal Directional Drilling
IPMP	In Principle Monitoring Plan
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
MAREA	Marine Aggregate Regional Environmental Assessment
MCZ	Marine Conservation Zone
MESL	Marine Ecological Surveys Limited
mg/l	Milligrams Per Litre
mm	Millimetre
MMO	Marine Management Organisation
MPS	Marine Policy Statement
MW	Megawatt
NPS	National Policy Statements
NSIP	Nationally Significant Infrastructure Projects
NV	Norfolk Vanguard
NV East	Norfolk Vanguard East
NV West	Norfolk Vanguard West
OD	Ordnance Datum
O&M	Operation and Maintenance
OWF	Offshore Wind Farm
PEIR	Preliminary Environmental Information Report
PEMP	Project Environmental Management Plan
s	Second (unit of time)
SAC	Special Area of Conservation
SMP	Shoreline Management Plan
SCI	Site of Community Importance

SPA	Special Protection Area
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
UKCP09	United Kingdom Climate Projections 2009
ZEA	Zone Environmental Appraisal

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 the wind turbine generators and the 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 sea floor
Beach	A deposit of non-cohesive material (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 sea bed (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	Refers to any long-term trend in mean sea level, wave height, wind speed etc.
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 sea bed
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 sea bed by natural forces (e.g. wind, waves, currents, chemical weathering)
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. Material 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	Buried offshore cables which link the offshore electrical platforms.
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 sedimentary material 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 over a period of approximately 12 months, taking account of all tidal effects but excluding surge events
Megaripples	Bedforms with a wavelength of 0.6 to 10.0 m and a height of 0.1 to 1.0 m. 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)
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 accommodation platform	A fixed structure (if required) providing accommodation for offshore personnel. An accommodation vessel may be used instead.
Offshore cable corridor	The corridor of seabed from the Norfolk Vanguard OWF sites to the landfall site within which the offshore export cables would 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 electricity from the offshore electrical platform to the landfall.
Offshore project area	The overall area of Norfolk Vanguard East, Norfolk Vanguard West and the offshore cable corridor.
Pleistocene	An epoch of the Quaternary Period (between c. 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 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 sedimentary material 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 material 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 Vanguard Limited.
The OWF sites	The two distinct offshore wind farm areas, Norfolk Vanguard East and Norfolk Vanguard West.
The project	Norfolk Vanguard Offshore 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 Vanguard Offshore Wind Farm (OWF) (herein ‘the project’ or ‘Norfolk Vanguard’).

2. Norfolk Vanguard comprises two distinct areas, Norfolk Vanguard West (NV West) and Norfolk Vanguard East (NV East) (“the OWF sites”) as well as the offshore cable corridor from the OWF sites to the landfall at Happisburgh South.

3. This chapter provides a summary description of key aspects relating to existing marine geology, oceanography and 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 geology, oceanography and physical processes specialists, and incorporates survey data collected by Fugro and Marine Ecological Surveys Limited (MESL). In addition, ABPmer has undertaken a Sand Wave Study (Appendix 7.1 of the Information to Support HRA report, 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. The assessment process has been informed by the following:

- Interpretation of survey data specifically collected for the project including bathymetry, geophysical, geotechnical, environmental and metocean;
- Interpretation of survey data collected for the previous East Anglia FOUR project (located in a similar position to Norfolk Vanguard East);
- Consideration of 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 report (document reference 5.3) provides a sand wave study by APBmer, assessing potential impacts of cable installation activities on the Annex 1 Sandbanks features of the Haisborough, Hammond and Winterton SAC;
- Cross-reference to previous detailed numerical modelling studies undertaken for both the East Anglia Zone Environmental Appraisal (ZEA) and the ES of East Anglia ONE and desk-based assessments undertaken for the ES of East Anglia THREE;
- Discussion and agreement with key stakeholders; and

- Application of expert-based assessment and judgement by Royal HaskoningDHV.

6. The potential effects on marine geology, oceanography and physical processes have been assessed conservatively using realistic 'worst case' scenarios for the project.

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

8.2 Legislation, Guidance and Policy

8. 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 geology, oceanography and physical processes are:

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

9. 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.
'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	Section 5.5, paragraph 5.5.7	The assessment of potential construction and operation and maintenance impacts are described in sections 8.7.7.5 and 8.7.8.6, respectively. The project will not affect the Shoreline Management Plan and allowance has been made for natural erosion during the project design. Embedded mitigation to minimise potential impacts at the coast of cable installation and operation are described in section

NPS Requirement	NPS Reference	ES Reference
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.'		8.7.4.
'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 considered to be Haisborough, Hammond and Winterton SAC, North Norfolk Sandbanks and Saturn Reef cSAC/SCI, 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 8.7.7.3, 8.7.6.4, 8.7.7.6 and 8.7.7.10) and interruption to bedload sediment transport by sand wave levelling for cable installation (section 8.7.7.7).
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 section 8.7 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 Vanguard. Scour resulting from the proposed development is not assessed because scour protection will be used, reducing sediment release to negligible quantities.
'where necessary, assessment of the effects on	Section 2.6,	See above for scour. The

NPS Requirement	NPS Reference	ES Reference
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.’	paragraph 2.6.113	quantification and potential impact of seabed loss due to the footprints of the project infrastructure is covered in section 8.7.8.4. A worst case scenario of all foundations having scour protection is considered in order to provide a conservative assessment. The worst case scenario cable-laying technique is considered to be 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 8.7.7.11. The potential increase in suspended sediment concentrations and change in seabed level is assessed in sections 8.7.6.2 and 8.7.6.6 to 8.7.6.7. The recoverability of receptors is assessed for all the relevant impacts, particularly those related to changes in seabed level due to export cable installation (section 8.7.7.6), interruptions to bedload sediment transport due to sand wave levelling in the offshore cable corridor (section 8.7.7.7) and morphological and sediment transport effects due to cable protection measures for offshore cables (section 8.7.8.6).
‘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.	Section 2.6, paragraph 2.6.81	Landfall Site Selection and Assessment of Alternatives is 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 geology, oceanography and physical processes is provided in section 8.7.6. Potential habitat loss in the intertidal zone is covered in

NPS Requirement	NPS Reference	ES Reference
• 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.'		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 sections 8.7.7.6 and 8.7.8.6. 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 8.7.8.6).

10. 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 taken into account in marine planning. With regard to 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."

11. The MPS is also the framework for preparing individual Marine Plans and taking decisions affecting the marine environment. England currently has nine marine plans; those relevant to Norfolk Vanguard 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".*

12. In addition to NPS, MPS and East Inshore and East Offshore Marine Plans, guidance on the generic requirements, including spatial and temporal scales, for 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' (COWRIE, 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 & 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

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

- Expert Topic Group meetings as part of the Evidence Plan Process (EPP) and review of documents (e.g. Method Statements and draft chapter);
- Scoping Report (Royal HaskoningDHV, 2016); and
- Section 42 consultation on the Preliminary Environmental Information Report (PEIR, Norfolk Vanguard Limited, 2017).

14. An outline of the project consultation process is presented within Chapter 7 Technical Consultation.

15. Detailed minutes and logs of the EPP meetings are provided in Appendices 9.16 and25.6 of the Norfolk Vanguard Consultation Report.

Table 8.2 Consultation responses

Consultee	Date /Document	Comment	Response / where addressed in the 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	The approach adopted in this ES is expert-based assessment and judgement by Royal HaskoningDHV including use of the

Consultee	Date /Document	Comment	Response / where addressed in the ES
		development?	results of previous numerical modelling for East Anglia ONE. Conceptual modelling is being undertaken only for Norfolk Vanguard.
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 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 4.1) 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, taking into account estimates of natural erosion rates in this area.
Secretary of State	Scoping Opinion November 2016	The 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 EPP and is outlined in sections 8.4.1 and 8.7.3
Secretary of State	Scoping Opinion November 2016	Scour mitigation measures should be detailed within the ES; the EIA should outline a clear justification for the quantity and area to be covered, in addition to the total area of seabed likely to be covered by hard substrata.	Scour protection is explained in Chapter 5 Project Description and taken into account in defining the worst case scenarios for this assessment (section 8.7.4).
Secretary of	Scoping Opinion	The Secretary of State welcomes	Noted, these are assessed in

Consultee	Date /Document	Comment	Response / where addressed in the ES
State	November 2016	the consideration of the potential effects of sedimentary processes on Haisborough, Hammond and Winterton SCI.	section 8.7.
Secretary of State	Scoping Opinion November 2016	Paragraph 304 of the 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 4.1) informed the assessment of the potential impacts at the landfall. Section 8.7.7 discusses this element of the assessment.
Norfolk County Council	Scoping Opinion November 2016	The ES/EIA will need to address the potential impact on Ecology, including in particular, impact on the following interests: designated sites e.g. Sites of Special Scientific Interest (SSSI), National Nature Reserves, Special Protection Areas (SPA), Special Area for Conservation (SAC), County Wildlife Sites (CWS) etc.; Coastal and sedimentary processes.	The impacts of changes to marine physical processes on ecological features are assessed in Chapter 10 Benthic and Intertidal Ecology and Chapter 11 Fish and Shellfish. In addition, changes to these ecology receptors are assessed in Chapter 12 Marine Mammals and Chapter 13 Offshore Ornithology. Consideration is given to designated sites, where appropriate.
MMO	Scoping Opinion November 2016	The scoping report is overall considered adequate and has scoped in the correct impacts. The following points should be noted and addressed through the EIA. Wave data presented in the scoping report is contradictory to paragraphs 297, 298 and 299. Wave date or wind-stress in the form of wave or wind roses are not used to show the measured wave climate and proportions of wave height, periods or directions across the Vanguard East and West Sites. Vanguard East is shallower on the extreme east flank, where depths may be down to 15m. Under moderate storm	The bathymetry indicates that in NV West and NV East, the water depths are never less than 20m. So water depths are considered large enough to limit the effect of wave action on seabed sediments and scour

Consultee	Date /Document	Comment	Response / where addressed in the ES
		conditions bed sediments will be suspended under orbital wave currents, with a potential to generate scour. With various water depths involved the effects of orbital wave currents and their potential to create scour in these shallower locations will need to be assessed in the ES.	
MMO	Scoping Opinion November 2016	Ebb tidal asymmetry, the existence of sandbanks and a continuous net flux of bedload transport through the Vanguard site has been noted in paragraph 308. Where cable routes cross the banks, the impact on the banks in terms of hiatus or disruption to sediment transport processes will need to be considered. The ability to install and maintain cable, the potential use of cable protection, and the need for seabed preparation and the resulting impacts should also be considered. A detailed assessment of the construction footprint and degree of coverage is needed to assess the likely scale and area of impact of deposition of sediments from construction activities. Note: - Should disposal be required, the Applicant should engage with the MMO on OSPAR disposal site characterisation and sampling requirements.	The impacts associated with the offshore cable corridor passing through the Norfolk Bank system are addressed in the following sections: Section 8.7.7.5, section 8.7.7.6 and section 8.7.7.7 include impacts of offshore cable installation. Section 8.7.8.5 - impacts of cable protection. The impact of construction on deposition of sediment from foundation installation is covered in section 8.7.7.3 and section 8.7.7.4. The operational impact of the direct footprint is considered in section 8.7.8.4. Norfolk Vanguard Limited will seek to designate the Norfolk Vanguard OWF sites and the section of the offshore cable corridor that overlaps the SAC as a disposal site, subject to agreement from the MMO.
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.	This information was outlined in the draft PEIR chapter provided to the Expert Topic Group in June 2017 and discussed further at the subsequent EPP meeting (05/07/17). 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 Vanguard

Consultee	Date /Document	Comment	Response / where addressed in the ES
Cefas	EPP Meeting 16th February 2017	At the EIA stage, some wind farms have underestimated the volume of scour protection required	Norfolk Vanguard Limited has assumed scour protection will be used at all wind turbines where it is required, and the assessment uses 100% of locations as the worst case scenario.
Cefas	EPP Meeting 16th February 2017	Need to consider secondary effects of scour protection The Marine Aggregate Regional Environmental Assessment (MAREA) could be a helpful source of information for seabed characterization, however the data should be used with caution given the uncertainty provided for some bathymetry data e.g. in the south region of the UK.	Discussed at the subsequent EPP meeting (05/07/17) and agreed that this impact does not require further consideration.
Cefas	EPP Meeting 16th February 2017	Discussion of transboundary impacts	Transboundary impacts have been scoped out. Tidal ellipses show that all movement is in a north south direction so will not be across the international boundary.
Cefas	EPP Meeting 5th July 2017	Discussion of comments subsequently provided as written feedback (06/07/17)	See responses below.
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	The draft PEIR repeats throughout that marine physical process impacts have been generated by 'expert-based assessment and judgement' (8.1, p1). As there is no identification of the experts nor their specific expertise it is assumed that this refers to 'the authors'.	Expert-based assessment and judgement has been undertaken by Royal HaskoningDHV. This is clarified in sections 8.1 and 8.4.
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	Paragraph 139 states that the modelling simulations undertaken for the East Anglia ONE confirm the expert-based assessment of suspended sediment concentrations arising from seabed preparation. However it is not clear that the expert-based assessment is entirely independent of this evidence i.e., it can't confirm the opinion if the opinion has been based on it in the first place.	The emphasis has been changed to demonstrate that the East Anglia ONE modelling was used as part of the expert-based assessment and judgement (various sections).

Consultee	Date /Document	Comment	Response / where addressed in the ES
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	The draft section 8.7.4 stated that minimum turbine separation is 616m to minimise interaction and wake effects. Table 8.12 defines near-field effects (of suspended sediment concentrations) as affecting up to 1km from each foundation i.e., potential effects effectively extend over the whole area. There is no significant other mention of wake effects/plume in this report but the descriptions of impact indicate that there is potential for wake effects and plumes of sediment suspension to be generated. This should be discussed as a separate potential source of environmental effect.	Norfolk Vanguard Limited has revised the minimum spacing to 680m. This statement still stands in that 680m is the minimum separation between turbines in order to minimise any effects, not completely eradicate them. The wake effect that is referred to is for the changes to tidal currents and waves during the operation and maintenance phase of the wind farm. The wake effect is discussed in the individual operational impact sections for tidal currents and waves and a zone of influence is defined for each of these (i.e. extending over the whole OWF sites as commented on). Plumes created by scour during the operation and maintenance phase are not discussed because scour protection would be used, reducing sediment release to negligible quantities. Table 8.15 refers to the plume that would be generated for drill arisings during construction and so there would not be the 'cumulative' effect (i.e. over the whole area) that might occur for all the turbines in place during operation and maintenance.
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	The draft Impact 2A noted that mounds of sediment up to several metres high may be formed, and considers these small compared to the absolute depth of water >20m. However, water depth is less than that in some parts of the area and 'several metres' may amount to 30% or more. The applicant would not be justified in saying that the change in elevation is within the natural change caused by sand waves and ridges and that hence blockage is negligible, because the mounds would be separate to the natural	The bathymetry indicates that in NV West and NV East, the water depths are never less than 20m. Hence, the statement in the ES remains valid. The plume assessment is construction only and is not related to wakes around turbines but to simple release of sediment into the water column through drill arisings or seabed preparation and its re-distribution by tidal currents (without creation of wakes). Due to Norfolk Vanguard Limited's commitment to use scour

Consultee	Date /Document	Comment	Response / where addressed in the ES
		features and represent an additional blockage. However, Cefas concur with the final statement in this paragraph – "The mound will be mobile and be driven by the physical processes, rather than the physical processes being driven by it". This is a key point in the assessment – that the majority of effects on physical processes are temporary redistribution of sediment, largely confined within the area of the OWF which is therefore the maximum extent of initial seabed disturbance, and that processes will re-equilibrate with the bed relatively quickly.	protection where required, this will minimise any potential plumes due to wakes around turbines during operation and maintenance and so this has not been assessed further (also see response above). The potential for secondary scour around scour protection was also discussed during the EPP but was agreed in July 2017 that this is not a potential issue.
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	Draft Impact 5 - The applicant indicates that some of the removed bed sand could be disposed on the (residual) upstream side of the cable such that natural processes could redistribute the sand back over the levelled areas to reform the natural bed sand waves. This is an approach which should, be encouraged and, over the works as a whole, a similar approach would minimise disturbance of the natural processes i.e. timing works to encourage the redistribution of disturbed sediment in an initial (residual) upstream direction would see the natural process restore the residual downstream bed over time.	The potential re-distribution of sediment after disposal within Norfolk Vanguard is discussed in section 8.7.7.9.1.
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	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 8.7.7.5
Cefas	Written feedback	The statement in paragraph 189	Removed. In this impact section

Consultee	Date /Document	Comment	Response / where addressed in the ES
	dated 1st July 2017 (provided 6th July 2017) in response to an early draft of the PEIR chapter dated 21st June 2017	of the draft PEIR "As there is a large separation distance (well beyond one tidal ellipse) there is no evidence to support the existence of a pathway between the source and the receptor groups for marine physical processes" appears to be out of place in this location - as a general assessment of physical process impacts, this should be introduced where supported by the physical evidence it is based on (i.e., the wave, tidal and transport information given in sections 8.5 and 8.6, and so in conjunction with the suggested illustration of the sediment transport system). Paragraph 189 of the draft PEIR is not justifiable in its present form - the size of the tidal ellipse does not limit the range over which changes to the transport regime may propagate over multiple tidal cycles and so should probably be removed from this sentence (the same could also apply to paragraph 241).	and the previous seabed preparation impact section it is shown that there is the potential for the plume to extend approximately 50km from the release point (based on East Anglia ONE modelling). It is also stated that at these large distances the thickness of deposition from the plume would be very small (less than 0.15mm thick). So, although removal of the tidal ellipse statement is justified, the overall conclusion of negligible impact in the far-field is also justified.
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	Paragraph 251 of the draft PEIR could be supported quantitatively and potentially also relocated to form part of a defined section outlining the support and justification for considering EA OWF as primary evidence for NV assessment.	A section was added to the PEIR (section 8.7.3 in this ES) that discusses in detail the justification for using the modelling results of East Anglia ONE as analogies for the potential effects/impacts of Norfolk Vanguard
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	The applicant has made the case for sufficient similarity between the East Anglia and Norfolk Vanguard OWFs, but the case could be made more effectively and easier to assess with more considered presentation. Evidence is presented in the Sections dealing with the assessment of impact e.g., draft PEIR paragraphs 139-140. This	A section was added to PEIR (section 8.7.3 in this ES) that discusses in detail the justification for using the modelling results of East Anglia ONE as analogies for the potential effects/impacts of Norfolk Vanguard

Consultee	Date /Document	Comment	Response / where addressed in the ES
		comparison should be made in advance, immediately following the description of the regional physical environment (sections 8.5, 8.6; see next comments).	
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 and explanation added to section 8.6.8
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	Section 8.7.1 of the draft PEIR indicates 'receptor groupings' relevant to Norfolk Vanguard, and references Figure 8.11, but the text and figure refer to different named areas, with no indication of how the two are related. This information is provided afterwards – paragraph 104 and Table 8.9 should precede the Figure.	Section 8.7.1 re-arranged to clarify
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	The cable corridor bridges the offshore-inshore transition and will require consideration of nearshore processes in addition to offshore processes at the turbine site, with the possibility of affecting the defined receptors by a different pathway – this too will benefit from mapping what is understood of the regional transport systems.	Offshore cable construction activities including the inshore transition are covered in sections 8.7.7.5 to 8.7.7.8. The supporting information on regional transport pathways is included in section 8.6.8

Consultee	Date /Document	Comment	Response / where addressed in the ES
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	Cefas is unsure of the intention behind the statement made in paragraph 228 – that "the value of the East Anglia coast is deemed medium; it … is of regional importance for coastal processes".	This was removed from the PEIR and does not appear in this ES.
Happisburgh Parish Council	12th September 2017 PEIR Response	There is a worrying lack of understanding of coastal process given the short tidal window to manage and complete work on one the most dynamic full tidal beaches in the UK. No methodology has been given to the management of the beach or public safety. The Parish Council is concerned that Vattenfall does not seem to understand that one metre of beach can be lost during a storm - that is the depth at which the cable would be buried with a short drill!	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.
North Norfolk District Council	8th December 2017 PEIR Response	In respect of the Construction Phase, the Council's Coastal Manager considers that the horizontal directional drilling (HDD) long exit option is preferred as it would prevent any clear interference with coastal processes.	A decision has been made, based on consultation feedback, to use the long HDD option at the landfall so impacts on coastal processes are minimised.
North Norfolk District Council	8th December 2017 PEIR Response	In respect of the Operation Phase, the Council's Coastal Manager considers that as there is a preference for buried cabling in the seabed in the nearshore, there are limited concerns with regards to wider impacts to coastal erosion/processes during operation. The PEIR suggests that buried cabling is preferred in all but incompatible circumstances, if it was not possible to bury cabling in the nearshore environment, further consideration would be required. One area where issues could arise is ensuring the depth of cable under the foreshore is sufficient to prevent uncovering as the cliff, beach and shore platform erodes (and lowers) over time. This may be more likely	This impact is covered in section 8.7.8.6. An Outline Scour Protection and Cable Management Plan (document reference 8.16) as well as an Offshore In Principle Monitoring Plan (document reference 8.12) are provided with the DCO application to outline the approach to monitoring and management of cables. Details of required monitoring will be agreed with Marine Management Organisation (MMO) in advance of construction.

Consultee	Date /Document	Comment	Response / where addressed in the ES
		under the short HDD exit option. A post construction monitoring plan should identify such risks and ensure appropriate coastal monitoring of coastal processes to ensure early identification of issues and timely remediation should they occur.	
North Norfolk District Council	8th December 2017 PEIR Response	In terms of cable decommissioning, the PEIR identifies that the cabling can simply be pulled from the ducting for disposal, however, there should be recognition that as the coast erodes, there is a risk that the seaward, and, over the long term, landward duct and infrastructure will be exposed and will require removal. Currently there are no funded mechanisms for the removal of historical/redundant infrastructure as it is exposed via erosion and as such these burdens often fall to the Local Authority. Long term arrangements would be beneficial to ensure that such implications do not, through default, fall to future generations of local government.	A Decommissioning Plan will be produced for the project prior to construction.
North Norfolk District Council	8th December 2017 PEIR Response	The horizontal directional drilling (HDD) long exit option is preferred when bringing the offshore cable onto land.	A decision has been made, based on consultation feedback, to use the long HDD option at the landfall.
Environment Agency	11th December 2017 PEIR Response	Our preferred option would be to use long HDD to minimise impact on the shore face and emerged beach.	A decision has been made, based on consultation feedback, to use the long HDD option at the landfall.
Environment Agency	11th December 2017 PEIR Response	An idea of error introduced from geo-referencing and digitisation from the desktop survey of historic erosion rates would be useful (see Appendix 4.1 in the draft PEIR).	This was discussed with the Environment Agency during an Expert Topic Group meeting on the 31st Jan 2018. It was accepted that the majority of the coastal erosion study is based on interpretation of rates published in the SMP and coastal study. Digitisation is a limited part of the assessment, and its uncertainty is captured in the broader uncertainty that has been reported.
MMO	11th December 2017 PEIR Response	No specific surveys have been carried out for this report, essentially only a transfer of	New surveys, specific to the project, have been carried out for bathymetry, geology and

Consultee	Date /Document	Comment	Response / where addressed in the ES
		previous analyses of modelling results for other similar works to this context (principally the East Anglia ONE OWF). The original analyses have not been reviewed here and will have been subject to assessment as part of the relevant application.	metocean (see Table 8.8).
MMO	11th December 2017 PEIR Response	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.
MMO	11th December 2017 PEIR Response	The assessment has not considered the actual function of wave action within the regional sediment transport system. Physical process impacts are presented as the percentage changes to currents and wave height but these are not quantified in terms of the receptors i.e., the percentage change in sediment transport this would cause.	The reasoning behind there being no impact on sediment transport is related to scaling. The larger scale processes of the southern North Sea (altered albeit locally by the changes to waves and tidal currents) would continue undisturbed and effectively immeasurable. This is described in more detail in section 8.7.8.3.
MMO	11th December 2017 PEIR Response	Table 8.1 in the PEIR indicates that the applicant was advised that coastal geomorphology and sediment transport modelling should be performed, and that (it was agreed that) the PEIR would do so on the basis of a conceptual model and expert judgment. This approach is weakest in the nearshore zone as no specific information has been presented only assumptions, such as higher suspended sediment concentration. The PEIR mentions an installation	Data on suspended sediment in the nearshore zone has been requested from the Environment Agency or MMO through the EPP. It was discussed and agreed during the Expert Topic Group meeting on the 31st Jan 2018 that no data are available and that the approach taken to the assessment is appropriate. The CWind study (2017 unpublished, provided in Volume 3 Appendix 4.2) was provided to the Expert Topic Group in January

Consultee	Date /Document	Comment	Response / where addressed in the ES
		study (CWind, 2017), which is unpublished and not provided, that may contain some relevant details, but there is no specific presentation of this information. Please provide that information in the Environmental Statement.	2017. This contains no information on the nearshore zone.
MMO	11th December 2017 PEIR Response	Proactive mitigation of engineering risk has been indicated, in the form of widespread scour protection around assets. This is not mitigating for impact on Marine Processes as such, as this is simply replacing one impact for another. I.e. a scour hole being replaced by a complete change of substrate. The total area of seabed disruptions is not really amenable to mitigation. The impact on the designated areas in particular is a fixed quantity caused by the construction process. Thus, no mitigation is possible for the disruption of seabed sediment (the reason for designation of Haisborough, Hammond and Winterton SAC). Also the choice of scour protection (concrete mattresses or plastic fronts, for example) is not significant in these terms. Please reflect this in the Environmental Statement.	This ES chapter has removed reference to scour protection as mitigation; rather it is the reason why the impact of scour has not been assessed. The impact of habitat loss associated with scour protection is assessed in full in section 8.7.8 of this ES chapter. The direct loss of habitat caused by scour protection around the foundation structures will have no impact on Haisborough, Hammond and Winterton SAC because they are outside the SAC boundary. Embedded mitigation associated with minimising disruption to sediment in the SAC are outlined in section 8.7.4. The effect on sediment transport processes in the SAC of sand wave levelling along the export cable corridor is addressed in section 8.7.7.6.
MMO	11th December 2017 PEIR Response	Monitoring is necessary to verify the assumptions of localised impact. i.e. bathymetry to demonstrate recovery of the sand waves and that the sea bed level changes associated with trenches, mounds and depression created do not spread but are gradually erased.	An Offshore In Principle Monitoring Plan (document reference 8.12) is provided with the DCO application to outline the approach to monitoring. Details of required monitoring will be developed in consultation with the MMO in advance of construction.
MMO	11th December 2017 PEIR Response	Monitoring of the nearshore geomorphology, where temporarily affected by works, should be carried out around the period of development. This is to demonstrate that no major changes have occurred due to the development since this area has been assessed in very vague terms only.	An Offshore In Principle Monitoring Plan (document reference 8.12) is provided with the DCO application to outline the approach to monitoring. Details of required monitoring will be developed in consultation with the MMO in advance of construction.
Natural England	31st January 2018 EPP meeting	Further information required in relation to sand wave	These are addressed in Appendix 7.1 of the Information to Support

Consultee	Date /Document	Comment	Response / where addressed in the ES
		levelling in the SAC in relation to: • Confirm that the sediment would remain within the SAC • What difference it would make if the sediment is disposed of at the water surface or near the seabed • Consider the effects of phasing • Incorporate evidence from other projects where possible	HRA report (document reference 5.3).

8.4 Assessment Methodology

16. In order 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

17. The assessment of effects on marine geology, oceanography and 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.

18. 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).

19. Consideration of the potential effects of Norfolk Vanguard on the marine geology, oceanography and 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 and along the offshore cable corridor; 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).

20. 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.

21. For the effects on marine geology, oceanography and physical processes, the assessment follows two approaches. The first type of assessment is impacts on marine geology, oceanography and 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.

22. 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 Environmental Impact Assessment (EIA) Methodology provides an overview of this approach to the assessment of impacts.

23. In addition to identifiable receptors, the second type of assessment covers changes to marine geology, oceanography and 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).

24. Hence, the two approaches to the assessment of marine geology, oceanography and 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 at the receptor location, taking into the near-field or far-field nature of the effect from the receptor. An impact significance matrix (section 8.4.1.2) is used as a guide to determine the impact significance.

- Situations where effects (or changes) in the baseline marine geology, oceanography and physical processes may occur which could manifest as impacts upon receptors other than marine geology, oceanography and 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.

8.4.1.1 Sensitivity, value and magnitude

25. The sensitivity of a receptor is dependent upon its:

- *Tolerance* to an effect (the extent to which the receptor is adversely affected by a particular effect);
- *Adaptability* (the ability of the receptor to avoid adverse impacts that would otherwise arise from a particular 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).

26. In addition, a value component may also be considered when assessing a receptor. This ascribes whether the receptor is rare, protected or threatened.

27. The magnitude of an effect 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).

28. 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. Definitions for each term are provided in Table 8.3, Table 8.4 and Table 8.5. These expert judgements of receptor sensitivity, value and magnitude of effect are guided by the conceptual understanding of baseline conditions.

Table 8.3 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

Sensitivity	Definition
	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)

Table 8.4 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 geology, oceanography and 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 geology, oceanography and physical processes
Low	Value: Receptor is not designated but is of local importance for marine geology, oceanography and physical processes
Negligible	Value: Receptor is not designated and is not deemed of importance for marine geology, oceanography and physical processes

Table 8.5 Definitions of magnitude of effect levels for marine geology, oceanography and 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)

Magnitude	Definition
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

29. 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 8.6 as a framework to guide how a judgement of the significance is determined.

Table 8.6 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*

30. Through use of the matrix shown in Table 8.6, an assessment of the significance of an impact can be made in accordance with the definitions in Table 8.7.

Table 8.7 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

31. 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 in their own right, it is important to distinguish these from other non-significant (negligible) impacts as they may contribute to significant impacts cumulatively.

8.4.2 Cumulative Impact Assessment

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

33. The cumulative impact assessment 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) and the ES for East Anglia ONE (EAOW, 2012b) which considered cumulative effects from those projects and other project activities in close proximity.

8.4.3 Transboundary Impact Assessment

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

35. Transboundary impacts were considered in the Scoping Report for this topic and it was concluded that "transboundary impacts are unlikely to occur or are unlikely to be significant." (Royal HaskoningDHV, 2016). This statement is supported by the assessments that have been completed for the East Anglia ZEA (ABPmer, 2012a), 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, 2016; the Planning Inspectorate, 2016) and Evidence Plan Process (meeting 16th February 2017).

8.5 Scope

8.5.1 Study Area

36. Norfolk Vanguard is located in the southern North Sea, encompassing a seabed area of approximately 592km^2. Norfolk Vanguard comprises two distinct areas, NV West and NV East, which at their nearest points are located approximately, 47km and 70km from the coast of Norfolk, respectively. An offshore cable corridor joins the OWF sites to the landfall at Happisburgh South. The offshore infrastructure required for Norfolk Vanguard is outlined in section 8.7.4.

37. Norfolk Vanguard Limited has committed to using long 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.

8.5.2 Data Sources

38. 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 East Anglia THREE (EATL, 2015) and the ES for East Anglia ONE (EAOW, 2012b) (Table 8.8).

39. A geophysical survey was completed between 7th September and 14th November 2016 (Fugro, 2016). For NV East, geophysical data are available from a survey of the former East Anglia FOUR site (completed between 19th June and 4th September 2012) (Fugro EMU, 2013). This approach was agreed with the Marine Management Organisation, Cefas and Natural England (meeting 21st March 2016).

40. Appendix 7.1 of the Information to Support HRA report (document reference 5.3) provides a sand wave study which has informed the assessment of potential impacts from cable installation activities on the Annex 1 Sandbanks features of the Haisborough, Hammond and Winterton SAC.

41. 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., 2015);
- United Kingdom 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);
- United Kingdom Climate Projections ’09 (UKCP09) (Lowe *et al*., 2009);
- British Geological Survey 1:250,000 seabed sediment mapping;
- British Geological Survey bathymetric contours and paper maps; and
- Admiralty Charts and United Kingdom Hydrographic Office survey data.

Table 8.8 Data sources

Data	Year	Coverage	Confidence	Notes
Geophysical Survey	Oct 2010	East Anglia Zone (partial)	High	High-resolution swath bathymetric survey.
Geophysical Survey	Sept – Nov 2016	NV West site	High	High-resolution seabed bathymetry, sea bed texture and morphological features, and shallow geology using multibeam echo sounder, side-scan sonar, magnetometer, sparker and pinger.
Geophysical Survey	June – Sept 2012	East Anglia FOUR site (NV East)	High	High-resolution seabed bathymetry, sea bed texture and morphological features, and shallow geology using multibeam echo sounder, side-scan sonar, magnetometer, sparker and pinger.
Geophysical Survey	Sept – Nov 2016	Norfolk Vanguard offshore cable corridor	High	High-resolution seabed bathymetry, sea bed texture and morphological features, and shallow geology using multibeam echo sounder, side-scan sonar, magnetometer and pinger
Metocean Survey	Dec 2012 – Dec 2013	East Anglia FOUR site (NV East)	High	Acoustic Wave and Current (AWAC) meter and Directional Waverider (DWR) buoy
ADCP Spring tidal data	Sept 2013	East Anglia FOUR site (NV East)	High	Tidal velocity and direction through the water column
ADCP Neap tidal data	July 2013	East Anglia FOUR site (NV East)	High	Tidal velocity and direction through the water column
Grab Sample Survey	Sept 2010 – Jan 2011	East Anglia Zone	High	Grab samples at selected sites (33 within NV West, 44 within NV East and 14 within the offshore cable corridor)
Grab Sample Survey	Oct – Nov 2016	NV West site	High	15 grab samples at selected sites
Grab Sample Survey	Oct – Nov 2016	NV East site	High	Eight grab samples at selected sites
Grab Sample Survey	Oct – Nov 2016	Norfolk Vanguard offshore cable corridor	High	33 grab samples at selected sites
Geotechnical Survey	Aug 2010	East Anglia Zone	High	Boreholes at selected sites across the zone

8.5.3 Assumptions and Limitations

42. 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 8.8), there is a good understanding of the existing marine geology, oceanography and physical processes environment at Norfolk Vanguard and its adjacent areas.

43. Although seabed surveys for the ZEA and Norfolk Vanguard were six years apart, this does not create any problems with respect to their compatibility and comparability because conditions at the offshore seabed at a regional scale will have changed little over this time period. Local changes may have taken place (due to migration of bedforms) but these will not be significant for the purposes of site characterisation.

44. 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 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.

45. Data for the ambient suspended sediment concentrations at the Happisburgh coast is not available (as discussed with the Expert Topic Group through the Evidence Plan Process), and therefore 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, but estimates at the coast are extrapolated from a couple of locations further offshore. Hence, there is doubt 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 Norfolk Vanguard West

46. Water depths across NV West vary between approximately 25 and 50m below LAT. The minimum water depth is along the north-central edge of the site and the maximum water depth is within the south-west corner of the site (Figure 8.1).

47. The primary bathymetric features are broad (2.5 to 3.0km apart) but low (typically 5m high) sandbanks which trend north-south through the site and represent the south-east limit of the Norfolk Bank System. The westernmost sandbank is slightly higher (up to 7m), broader (up to 4km wide) and continues past the southern boundary of NV West.

48. At a more local scale the seabed is uneven due to the presence of bedforms of various sizes. Sand waves within NV West are up to 6m high with crests oriented approximately east-west, indicative of north-south tidal currents. The majority of the sand waves are asymmetric with their steeper sides facing north, indicating migration towards the north.

49. The sand waves are overlain by megaripples which also blanket the site where sand waves are not present. Where megaripples are present on a relatively smooth or only mildly undulating seabed, such as the centre of the site, their crests are linear with a consistent spacing of about 8 to 10m, and typical heights of 0.5m.

50. To the north of NV West 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 Norfolk Vanguard East

51. The bathymetry within NV East varies from a maximum depth of 42m below LAT across the north-east part of the site to a minimum depth of 22m below LAT on the crest of a sand ridge in the north-east part of the site (Figure 8.3).

52. The bathymetry is dominated by a series of four north-south oriented sandbanks with widths of 2 to 3km and heights up to 17m above the surrounding seabed. Smaller bedforms include sand waves (greater than 2m high), megaripples (less than 2m high) and sand ridges.

53. Asymmetric sand waves occur across much of the seabed of NV East. Where they are present along the tops of the sandbanks, their crests are oriented predominantly north-west to south-east. In deeper locations, the crests are oriented more west to east. The sand waves have wavelengths of 200 to 300m and heights of 2 to 7m and their flanks are generally covered by megaripples, which are also common throughout the site. The megaripples have typical wavelengths of 5 to 20m and heights of 0.3 to 2m, with crests oriented west to east.

8.6.1.3 Offshore cable corridor

54. Water depths within the offshore portion of the cable corridor, in the region of the NV West and NV East sites, are typically 40 to 50m below LAT (Figure 8.4). 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.

55. 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.

56. 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.

57. Megaripples cover the sand waves, and also 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.

58. 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.

8.6.1.3.1 Haisborough, Hammond and Winterton SAC

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

60. 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).

61. Water depths within the sandbank system range from approximately 12 to 52m below LAT. Approximately two thirds of the sandbank habitat occurs in 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.

8.6.2 Geology

62. The geology of Norfolk Vanguard generally consists of Holocene sand deposits overlying a series of Pleistocene sands and clays. The thickness of the Holocene sediment varies from less than 1m to greater than 20m in the sand wave fields and sandbanks.

8.6.2.1 Norfolk Vanguard West

63. Fugro (2016) described nine geological formations (Table 8.9). The sequence between the Westkapelle Ground Formation and the Twente Formation is Pleistocene in age, whereas the Elbow Formation and Bligh Bank Formation are Holocene.

Table 8.9 Geological formations present under the Norfolk Vanguard West site (Fugro, 2016)

Formation[1]	Lithology (BGS Lexicon http://www.bgs.ac.uk/lexicon)
Bligh Bank	Marine, medium- or fine- to medium-grained, clean, yellow-brown sands
Elbow	Brackish-marine, fine-grained sands and clays with discontinuous basal peat bed
Twente	Fine-grained, well-sorted, wind-blown periglacial sands
Brown Bank	Brackish-marine, grey-brown silty clays. Pass upwards into lacustrine clays in the east, include interbeds gravelly sand towards base in west
Swarte Bank	Infilled glacial tunnel valleys
Yarmouth Roads	Mainly riverine, fine or medium-grained grey-green sands, typically non-calcareous, with variable clay lamination and local intercalations of reworked peat
Winterton Shoal	Fine- or medium-grained sands with minor clay laminations
Smith's Knoll	Fine to medium-grained, muddy marine sands, with clay intercalations in the east
Westkapelle Ground	Marine clays with thin sandy laminae passing gradationally upwards to sand with thin clay laminae

64. The Bligh Bank Formation blankets the majority of the site as a thin seabed veneer and represents the sediment currently being reworked into sandbanks, sand waves and megaripples (Plate 8.1). The formation is present across most of the NV West site, except along the western margin where Holocene sand is absent or only a patchy veneer and Pleistocene formations outcrop at the seabed.

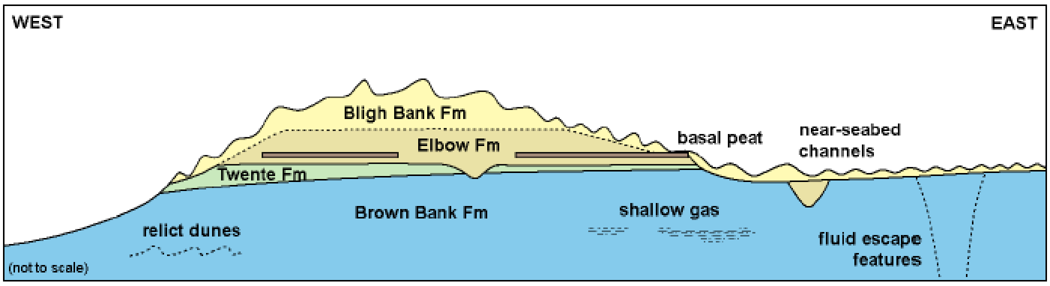

Plate 8.1 Schematic representation of the shallow geology of NV West (Fugro, 2016)

8.6.2.2 Norfolk Vanguard East

65. Fugro EMU (2013) described three geological formations within NV 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

[1] Eem formation was not recorded within NV West during

Formation (Holocene sand). The Holocene sand varies in thickness from several metres beneath sandbanks and sand waves to a thinner veneer in deeper areas.

66. The base of the Yarmouth Roads Formation was not imaged by the sub-bottom profiler across the former East Anglia FOUR site, and so the older formations described at NV West (Fugro, 2016) were not delineated across NV East.

8.6.2.3 Offshore cable corridor

67. Fugro (2017a) completed the geophysical survey of the offshore cable corridor between 1st September and 15th November 2016 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 only a 5m penetration. The differences in ground conditions resulted in different attenuations of the seismic signal.

68. Pinger sub-bottom profiler penetration is potentially limited by subsurface sediment type and structure. 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, the shallow geological sequence is only divided into Holocene sands and the underlying undifferentiated Pleistocene sediments. Along the eastern sub-section, Fugro (2017a) described the Pleistocene Yarmouth Roads Formation overlain in sequence by the Pleistocene Eem Formation (fine- to medium-grained shelly marine sands), Brown Bank Formation and Twente Formation, and then Holocene formations to the seabed (Plate 8.2).

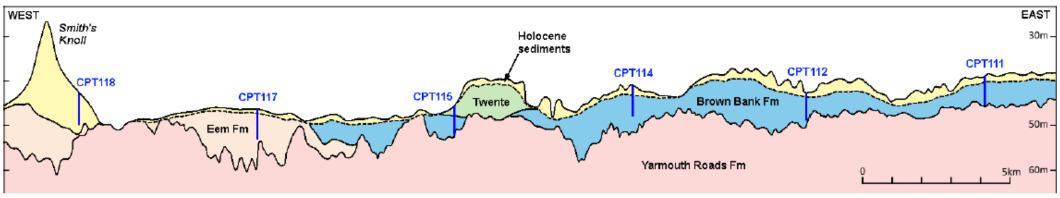

Plate 8.2 Shallow geology of the eastern sub-section of the offshore cable corridor (Fugro, 2017a)

8.6.3 Water Levels

69. Norfolk Vanguard is located within an area of seabed that is subject to a micro-tidal regime, with an average spring tidal range of up to 1.5m. This low tidal range is due to the proximity of an amphidromic point that is positioned to the south of NV East (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 around this point once during each tidal period.

70. The southern boundary of NV West is about 40km from the amphidromic point, but is still only subject to tidal ranges less than 1.5m. The southern boundary of NV East is located about 30km north of the amphidromic point and subject to a tidal range of approximately 1m (Figure 8.5).

71. Due to the regional tidal regime being influenced by an 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

72. The North Sea is particularly susceptible to storm surges and water levels at Norfolk Vanguard 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).

73. 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. Environment Agency (2011) calculated 1 in 1 year water levels of 1.1m above 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

74. 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 a number of previous observations (ABPmer, 2012a) and shows that in the vicinity of NV West and NV East, currents are generally aligned along a north to south axis. South of the projects, 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.

75. Regional tidal current velocities show spatial variation, with stronger currents in the south and west. NV West and NV East experience tidal velocities of up to 1.2m/s associated with the ebb tide (Deltares, 2015a, 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.

76. Tidal currents modelled as part of the East Anglia ZEA (ABPmer, 2012a) replicate the recorded directional and velocity data (Figure 8.7).

77. Tidal current data measured by the Acoustic Wave and Current Meter (AWAC) located in 40m water depth within the NV East site between 4th December 2012 and 4th December 2013 (Table 8.8) describes the dominant current velocities and directions. Diagram 8.1 shows a time series of tidal current velocities and Diagram 8.2 shows a current rose for the sea surface (where the currents are greatest). The majority 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.

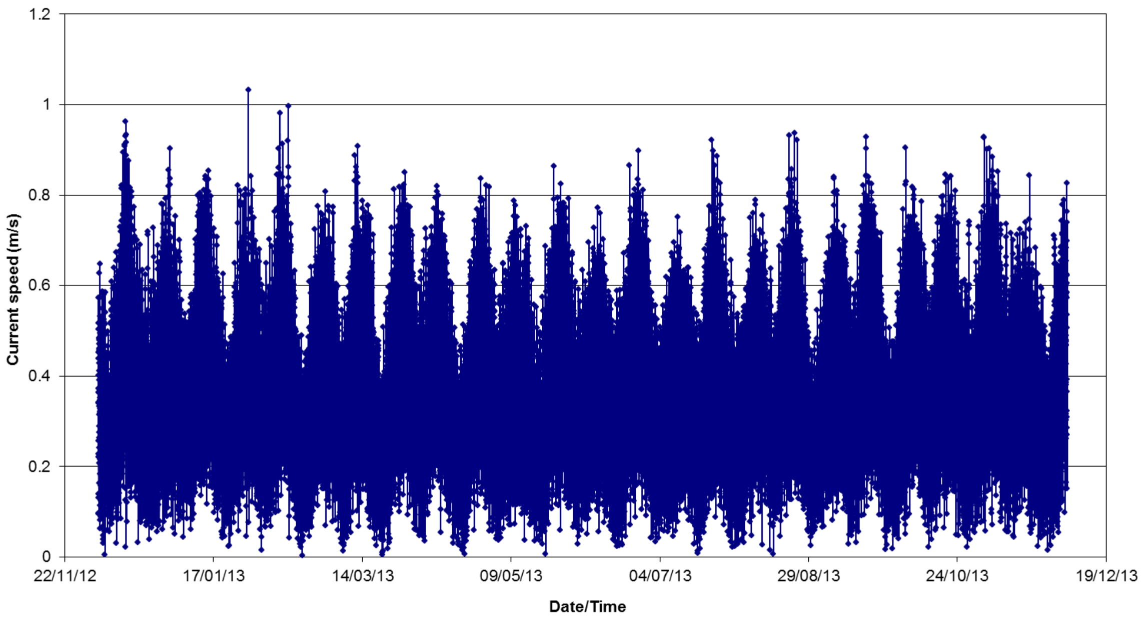

Diagram 8.1 Time series of current velocity measured by the AWAC in NV East between December 2012 and December 2013

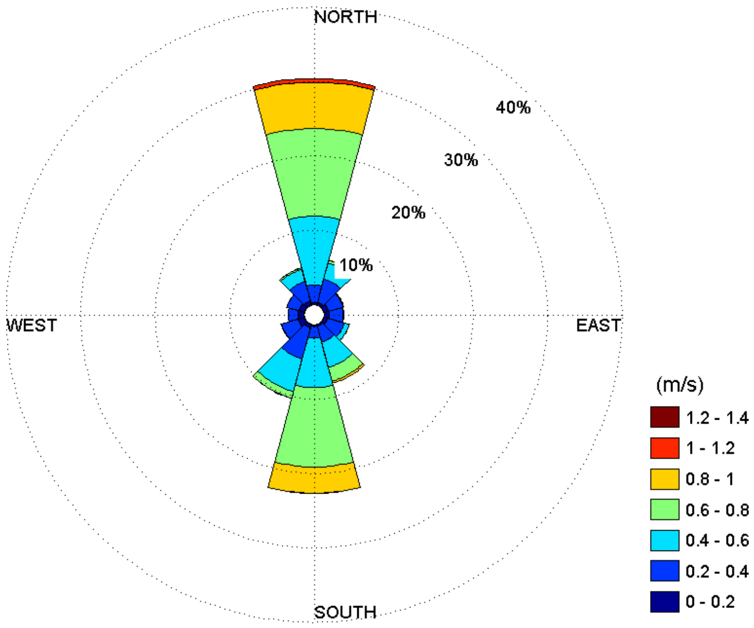

Diagram 8.2 Near sea surface current rose measured in NV East between December 2012 and December 2013

78. 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

79. 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 Vanguard arrive from the south-south-west with subordinate waves from the north (ABPmer, 2012a) (Figure 8.8).

80. The 1 in 50 year return period significant wave height is 7m in NV West (Deltares, 2015b) and 8.2m in NV East (Deltares, 2012).

81. Across the majority of Norfolk Vanguard, 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.

82. Wave data measured by the AWAC in 40m water depth located within the NV East site between 4th December 2012 and 4th December 2013 (Table 8.8) describes the dominant wave heights, periods and directions.

83. Diagram 8.3 shows the wave rose derived from the AWAC data. The waves mimic, to some extent, the dominant regional wave climate (ABPmer, 2012a), with the majority of 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.

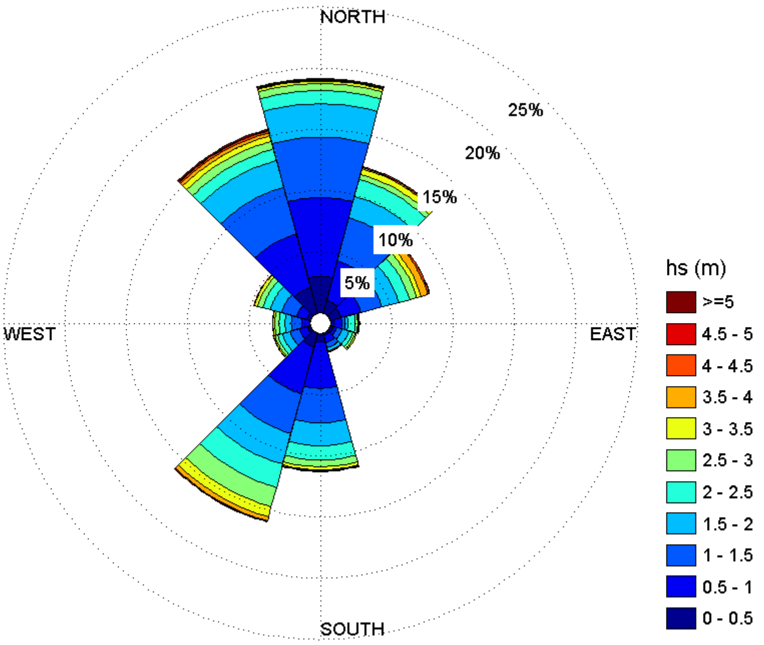

Diagram 8.3 Wave rose measured in NV East between December 2012 and December 2013

84. Diagram 8.4 shows a time series of significant wave heights recorded by the AWAC in NV East. The minimum significant wave height recorded during this period was 0.18m, with a maximum value of 5.94m. The mean significant wave height was 1.41m.

85. There were only six unique periods within the time series when wave heights exceeded 4m. In general, the waves appear to be confined to less than 3m, apart from during storm events when the wave height significantly increases.

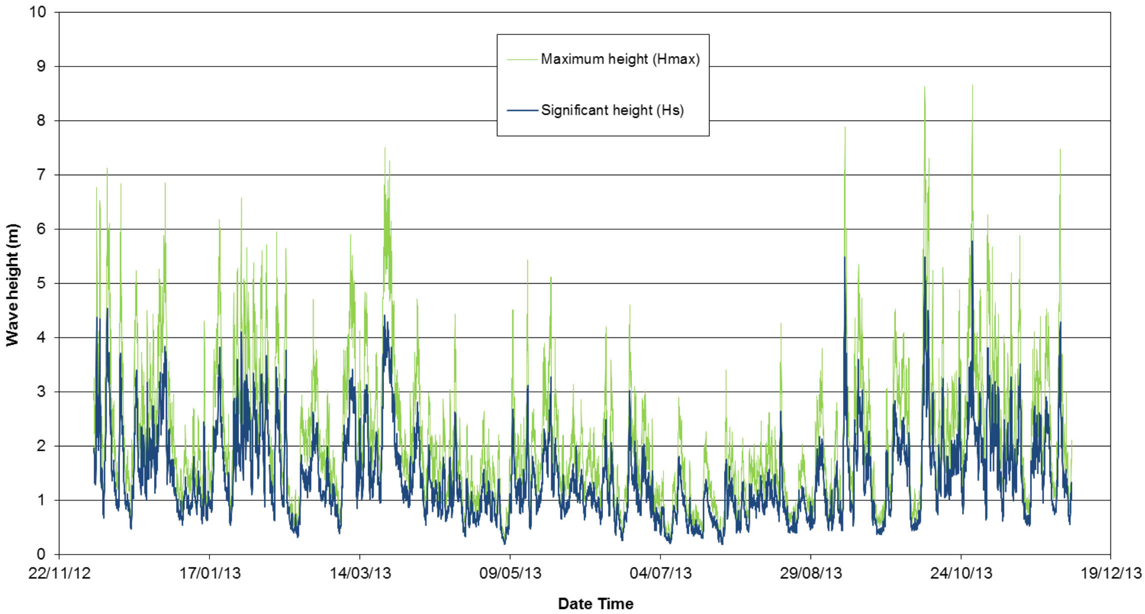

Diagram 8.4 Time series of wave heights measured by the AWAC in NV East between December 2012 and December 2013

86. 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

87. 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.

88. As a result of future global warming, sea-level is predicted to rise at accelerated rates. Estimates of mean annual Global Mean Sea Level (GMSL) rise since 1993 are 2.4 to 3.2mm/year, an increase in the mean annual GMSL for the 20th century (European Environment Agency, 2017). The rise in GMSL by 2100 is projected to be

in the range of 0.53 to 0.97m, with the rate during 2081-2100 of 7 to 15mm per year. Due to global climate change and local land level changes, mean sea level at the UK coast is expected to be between 0.19 and 0.27m higher by 2050 than 1990 values (Lowe *et al*., 2009).

89. As the indicative design life of the project is 35 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.

90. 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 Vanguard (Lowe *et al*., 2009).

91. 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

92. A regional seabed sediment grab sampling campaign was completed between September 2010 and January 2011, recovering 33 samples from NV West and 44 samples from NV East (MESL, 2011) (Figure 8.9). A total of 14 samples also fell within the bounds of the offshore cable corridor (Figure 8.10). Additional surveys were undertaken by Fugro (2017b) between 29th October and 10th November 2016 to fill gaps in NV West and NV East, and to cover the entire length of the offshore cable corridor. In total, 15 grab samples were collected from NV West, eight from NV East (Figure 8.9) and 33 from the offshore cable corridor (Figure 8.10).

93. In 2016, Fugro undertook a shallow geotechnical investigation within the OWF sites (Fugro, 2017c). This included cone penetration test (CPT) sampling to a maximum depth of 50m below the seabed, and vibrocores with a maximum recovery of 6.5m below the seabed. Within the offshore cable corridor, CPT sampling was undertaken to a maximum of 7m below the seabed and vibrocore recovery to a maximum of 6.5m below seafloor. A total of 64 vibrocores were recovered during the geotechnical site investigation.

8.6.7.1 Norfolk Vanguard West

94. The particle size characteristics of all the seabed sediment samples collected in NV West (a total of 48) are presented in Appendix 8.1, Table 8.1. The dominant sediment type is medium-grained sand with median particle sizes mainly between

0.32 and 0.39mm. The mud content is less than 5% in 75% of the samples. However, 15% of the samples contain greater than 10% mud, ranging from 10% to 77%. The gravel content varies from zero to 10% in 98% of the samples.

95. The vibrocores recovered an upper unit of silty fine to medium or coarse sand across most of NV West (Fugro, 2017c). The thickness of this layer varied between several centimetres to approximately 3m. Below the sand, the sediment composition varied across the site, with pockets of organic material at a number of sample sites. The depth of this organic material varied between sites, with a number of sites having several pockets throughout the core. The majority of NV West consisted of clayey sediment below the sand to the full depth of the vibrocores, interspersed with laminae of shell fragments, gravel, or fibrous material.

8.6.7.2 Norfolk Vanguard East

96. The particle size characteristics of all the seabed sediment samples collected in NV East (a total of 52) are presented in Appendix 8.1, Table 8.2. The dominant sediment type is medium-grained sand (90-100% sand) with median particle sizes between 0.20mm and 0.35mm, with most samples (90%) containing less than 4% mud. The gravel content varies from zero to 5% in 95% of the samples.

97. The vibrocores across NV East recovered a similar stratigraphy to those across NV West, with an upper unit of silty fine to medium sand at all sample locations. The layer of sand extends to a depth of up to 6m below the seabed with occasional pockets of fragmented shell. Below this layer (at the majority of locations) is slightly sandy clay to depth. As with NV West, there were small pockets and laminae of blackish material in a number of samples, with varying depths and amounts. This is a possible indicator of organics. With many locations also having laminae of very dark grey sand and/or decomposed plant material.

8.6.7.3 Offshore cable corridor

98. 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, Table 8.3. 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. A number of samples closer to the coast contained greater than 50% gravel.

99. Along the offshore cable corridor, the majority of the vibrocores recovered an upper unit of slightly silty fine to medium sand. However, unlike the OWF sites, there are some sample sites where clay material is at the seabed. The majority of cores described some laminae and pockets of black material both close to the surface and deeper in the core, as well as interspersed pockets of shell fragments (Fugro, 2017c).

8.6.8 Bedload Sediment Transport

100. Regional bedload sediment transport pathways in the southern North Sea have been investigated by Kenyon and Cooper (2005) (Figure 8.11). 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 Vanguard OWF sites and to the south and north closer to the coast. There are very few transport vectors directed to the west or the east either in the vicinity of Norfolk Vanguard or between the project and the coast.

101. Sediment transport pathways within Norfolk Vanguard have been analysed using the orientation of bedforms. Sand waves are present across parts of NV West and NV East, 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.

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

8.6.9 Suspended Sediment Transport

103. Suspended sediment concentrations across Norfolk Vanguard could range from 1 to 35mg/l. During the Land Ocean Interaction Study (NERC, 2016), measurements in the vicinity of Norfolk Vanguard recorded a maximum concentration of 83mg/l, but a mean value of only 15mg/l during an 18 month deployment.

104. Eisma and Kalf (1987) carried out a water sampling programme in the North Sea in January 1980 and differentiated general surface concentrations from bottom concentrations. They showed that in the vicinity of Norfolk Vanguard, the concentrations were similar at both elevations, ranging from 5 to 10mg/l.

105. Measurements of suspended sediment concentrations were carried out at the AWAC station in NV East between December 2012 and December 2013 (Diagram 8.5). Overall, suspended sediment concentrations 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.

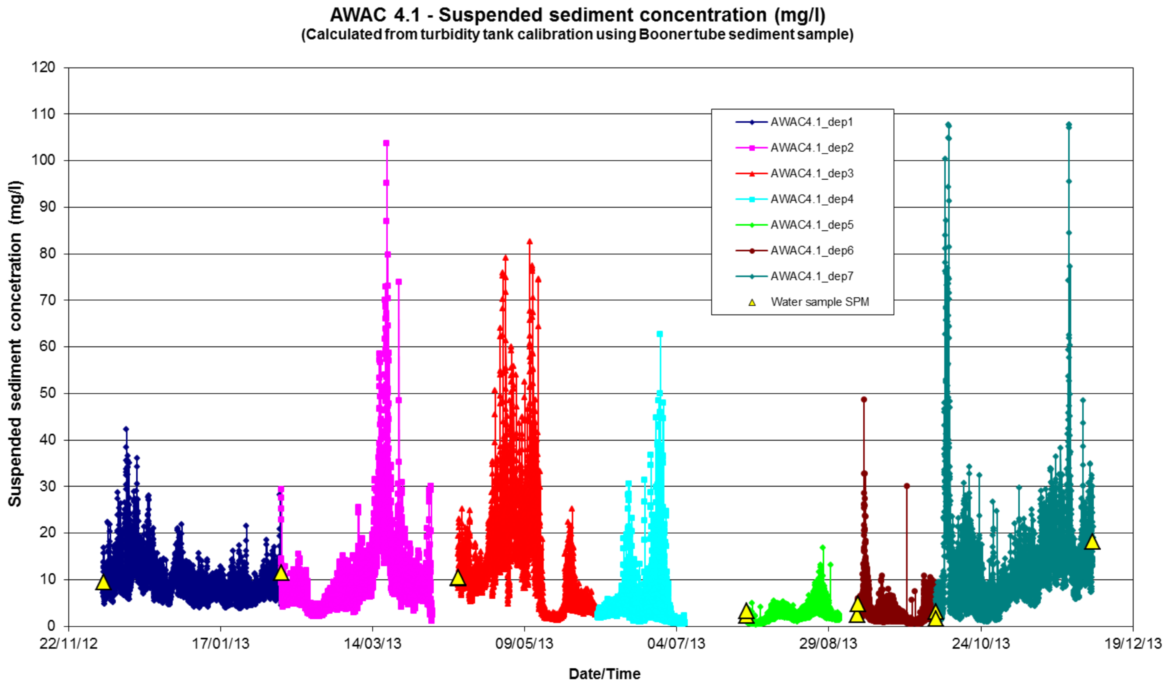

Diagram 8.5 Time series of suspended sediment concentrations measured at the AWAC station in NV East between December 2012 and December 2013

8.6.10 Morphological Change of the Haisborough Sandbank System

106. 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 Vanguard passes through the southern end of this sandbank system.

107. 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). Fugro (2017b) completed grab sampling in this area which indicated that the seabed sediment is mainly slightly gravelly sand with local areas of gravelly sand, gravelly sandy mud and sandy gravel.

108. 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.

109. 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).

110. 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).

111. 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.

112. 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 5m and 30m/year with both northerly and southerly migrating sand waves present within the cable corridor (Appendix 7.1 of the Information to Support HRA report, document reference 5.3).

8.6.11 Coastal Processes at the Landfall

113. 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, and foreshore steepening is an issue throughout this frontage. Severe storm events can rapidly change beach levels and the degree of exposure of the natural or defended coastline.

114. Along the north-east Norfolk coastline, net sediment transport is to the south-east and the potential for transport increases with distance south as the coastline 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.

115. 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 coastline. 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.

116. The cliffs at the Happisburgh South landfall are eroding (see Appendix 4.1). 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.

117. 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.

118. 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).

119. Any impacts of climate change on coastal erosion (including those to be managed as part of the managed realignment) have been taken into account in the embedded mitigation for the project including 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 would be positioned far enough back from the cliffs, and offshore works would be below -5.5m LAT, so as to not interact with the coast.

8.6.12 Anticipated Trends in Baseline Conditions

120. The baseline conditions for marine geology, oceanography and physical processes will continue to be controlled by waves and tidal currents driving changes in sediment transport and then seabed morphology. Natural feedback processes will lead to changes in the physical drivers as the morphology changes, and *vice versa*, leading to a pseudo-dynamic equilibrium. In addition to the long-term established performance of these drivers, the future baseline will be affected by environmental changes including climate change driven sea-level rise (see Section 8.6.6). 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 in the marine sector 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

121. The principal receptors with respect to marine geology, oceanography and 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 geology, oceanography and physical processes should be considered for four receptor groupings, two of which are relevant to Norfolk Vanguard; the sensitive 'East Anglia' coastline and the 'Norfolk' Natura 2000 site. These receptor groups have been retained for Norfolk Vanguard to allow comparability with previous work and cumulative impact assessment. The other two receptors ('Suffolk' Natura 2000 site and 'non-designated sandbanks') are considered to be too distant from the project to be influenced. The specific features defined within these two receptor groupings as requiring assessment are listed in Table 8.10 and shown in Figure 8.12.

Table 8.10 Marine geology, oceanography and physical processes receptors relevant to Norfolk Vanguard

Receptor group (Figure 8.18)	Extent of coverage	Description of features	Distance from Norfolk Vanguard
East Anglian coast (waves and sediment transport)	King's Lynn to Felixstowe	Sand and gravel beaches, dunes and cliffs	47km from the nearest point of NV West 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. NV West is 6.5km 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 SAC	Offshore sandbanks and reef	The SAC is 2km to the north of NV West

122. 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

123. 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.

124. 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

125. North Norfolk Sandbanks and Saturn Reef SAC is located off the north-east coast of Norfolk approximately 2km north of NV West. The marine features and conservation objectives are the same as those for Haisborough, Hammond and Winterton SAC above.

8.7.1.3 Cromer Shoal Chalk Beds MCZ

126. 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 Norfolk coast, covering an area of 321km^2, with maximum depth of 20m.

127. 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).

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

8.7.2 Effects

129. In addition to the receptor groups listed in Table 8.10, there are other potential changes (effects) to marine physical processes associated with Norfolk Vanguard 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.

130. In respect of these effects, the 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 of the Use of Existing Numerical Modelling at East Anglia ONE

131. Considerable previous numerical modelling work has been undertaken specifically for the adjacent East Anglia ONE project 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 East Anglia Zone) are used as part of the expert-based assessment and judgement of potential construction and operation and maintenance effects/impacts at Norfolk Vanguard 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 similar to NV West and NV East and therefore provide suitable evidence (and is a suitable analogue) to support the assessment of effects/impacts at Norfolk Vanguard.

132. Justification for using the modelling results at East Anglia ONE as the principal evidence of potential effects/impacts at Norfolk Vanguard is provided in Table 8.11, 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.

133. The similarities (and dissimilarities) between the characteristics of each site are:

- Water depths at East Anglia ONE (30-53m LAT) are slightly greater than those at NV West (25-50m LAT) and NV East (22-42m 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 1.1-1.2m/s at NV West and NV East;

- Predominant waves approach all sites from similar directions (from the south-south-west in East Anglia ONE and NV West and from the south-west in NV East);
- The mean and maximum significant wave heights at NV East were 1.4m and 5.9m, respectively, between December 2012 and December 2013, and 1.3m and 5.5m, respectively, at East Anglia ONE over the same period; and
- Seabed sediments at all three sites are predominantly medium-grained sand with mud comprising less than 5%.

134. 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 all three sites with crests oriented perpendicular to the predominant current direction;
- The majority 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.

135. Whilst it is recognised that there are small differences in water depth and metocean conditions, and likely gravity base structure (GBS) sizes between the East Anglia ONE and Norfolk Vanguard projects, the highly conservative nature of the previous numerical modelling (discussed further throughout the impact assessments) more than covers any differences in the effect that may arise due to these factors.

Table 8.11 Comparison of design and marine physical processes parameters at East Anglia ONE, NV East and NV West

Parameter	East Anglia ONE	NV West	NV East
Area	300km^2	295km^2	297km^2
Distance from shore	43.4km at closest point	47km at closest point	70km at closest point
Indicative capacity	Up to 1200MW	Up to 1800MW	Up to 1800MW
		Combined maximum capacity of 1800MW	
Maximum number of largest turbine foundations	150 (8MW)	90 (20MW).	
Maximum number of smallest turbine foundations	240 (5MW)	200 (9MW)	
Maximum GBS foundation diameter	50m (240 turbines with 50m diameter GBS foundations were modelled)	50m (20MW)	
Maximum foundation dimensions for a floating platform	N/A	70 x 70m (20MW)	
Offshore cable corridor length	73km	85km	100km
Cable landfall	Bawdsey	Happisburgh South	
Minimum water depth (LAT)	30.5m	25m	22m
Maximum water depth (LAT)	53.4m	50m	42m
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 speeds within the East Anglia ONE site are around 1.15 to 1.25m/s, with the fastest velocities recorded in the north of the site. Mean neap	In the vicinity of NV West, currents are generally aligned along a north-south axis. Tidal currents generally flow north to south on the flooding tide and south to north on the ebbing tide. The fastest flows across NV West are typically associated with the ebb tide, with velocities up to 1.2m/s.	In the vicinity of NV East, currents are generally aligned along a north-south axis. Tidal currents generally flow north to south on the flooding tide and south to north on the ebbing tide. Maximum velocities at NV East are up to about 1.2m/s during spring tides and up to 0.6m/s during neap tides.

Parameter	East Anglia ONE	NV West	NV East
	values are approximately half of that recorded during spring 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.	The predominant waves at NV West arrive from the south-south-west with subordinate waves from the north.	Waves measured within the NV East site over a period of a year (December 2012 to December 2013) show a large percentage of waves arriving from the south-west with a maximum significant wave height of 5.94m. The mean significant wave height was 1.41m.
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 grained sand (in the range 0.25 to 0.5mm).	The dominant sediment type in NV West is medium-grained sand with median particle sizes mainly between 0.32 and 0.39mm. The mud content is mainly less than 5%. The gravel content varies from zero to 10% in most samples.	The dominant sediment type in NV East is medium-grained sand with median particle sizes between 0.20mm and 0.35mm, with most samples containing less than 4% mud. The gravel content varies from zero to 5% in 95% in most samples.
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 CD, 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	Tidal currents are the main driving force of sediment transport and, due to the tidal asymmetry, move sediments in a northerly direction. Across the majority of Norfolk Vanguard, 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.	

Parameter	East Anglia ONE	NV West	NV East
	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 NV West are up to 6m high with crests oriented approximately east-west, indicative of north-south tidal currents. The majority of the sand waves are asymmetric with their steeper sides facing north, indicating migration towards the north.	Asymmetric sand waves occur across much of the seabed of NV East with crests oriented north-west to south-east or west to east. The sand waves have wavelengths of 200 to 300m and heights of 2 to 7m.
Suspended sediment concentrations	Late winter and spring (near-bed) suspended sediment concentration values are typically in the range 0 to 40mg/l and finer material held in suspension will generally be transported in a northerly direction across the East Anglia ONE site.	Measurements of suspended sediment concentrations in NV 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

136. Norfolk Vanguard Limited has committed to a number of techniques and engineering designs/modifications inherent as part of the project, during the pre-application phase, in order 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.

137. 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 Geology, Oceanography and Physical Processes

138. A minimum separation of 680m has been defined between adjacent wind turbines (based on four times the rotor diameter of the smallest 9MW turbines which is 170m) within each row and between rows. This is required in order to minimise aerodynamic wake effects from the wind turbine generators but also servers to minimise the potential for marine physical process interactions between adjacent wind turbine foundations.

139. The selection of appropriate foundation designs and sizes at each wind turbine location would be made post consent based on further site investigation and best available technology at the time of construction.

140. 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. It is estimated that drilling may be required at 50% of the locations in order to provide a conservative assessment.

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

142. Cables would be buried where possible, minimising the requirement for cable protection measures and thus potential 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.

143. A long HDD would be used to install the cables at the landfall, exiting in water deeper than -5.5m LAT. Cables would be installed at sufficient depth below the

coastal shore platform and cliff base by the HDD, in order 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 Vanguard. Natural coastal erosion throughout the lifetime of the project has been allowed for within the project design by ensuring appropriate set back distances from the coast for the HDD entry point.

144. Norfolk Vanguard Limited has committed to routing the offshore cable corridor to the south of the Cromer Shoal Chalk Beds MCZ to avoid potential impacts on the MCZ.

145. All seabed material 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.

8.7.5 Monitoring

146. An In Principle Monitoring Plan (document reference 8.12) and outline PEMP (document reference 8.14) is submitted with the DCO application. The development of the detailed design and final PEMP will refine the worst case impacts assessed in this EIA. 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 would be agreed with the MMO in consultation with the relevant SNCB prior to construction works commencing.

8.7.6 Worst Case Scenarios

147. The offshore project area consists of:

- The offshore cable corridor with landfall at Happisburgh South;
- Norfolk Vanguard West (NV West); and
- Norfolk Vanguard East (NV East).

148. The detailed design of Norfolk Vanguard (including numbers of wind turbines, layout configuration, requirement for scour protection etc.) will not be determined until after the DCO has been determined. Therefore, realistic worst case scenarios in terms of potential impacts/effects on marine geology, oceanography and physical processes are adopted to undertake a precautionary and robust impact assessment. The realistic worst case scenarios used are described in the sections below.

8.7.6.1 Foundations

149. Within Norfolk Vanguard, several different sizes of wind turbine are being considered in the range between 9MW and 20MW. In order to achieve the

maximum 1,800MW export capacity, there would be between 90 (20MW) and 200 (9MW) wind turbines.

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

151. A range of foundation options are currently being considered, these include:

- Wind turbines – jacket (pin-pile or suction caisson), GBS, monopile (piled or suction caisson) and tension leg floating platforms;
- Offshore electrical platforms – GBS, pin-pile or suction caisson;
- Accommodation platforms – GBS, pin-pile or suction caisson;
- Met masts - GBS, monopile or pin-pile;
- LiDAR - floating with anchors or monopile; and
- Wave buoys – floating with anchors.

152. The largest disturbance areas are associated with gravity anchors for floating foundations.

8.7.6.2 Layout

153. The layout of the wind turbines would be defined post consent but would be based on the following maxima:

- 1800MW in NV East, 0MW in NV West; or
- 0MW in NV East, 1800MW in NV West.

154. Any other potential layouts that are considered up to a maximum of 1800MW (e.g. 900MW in NV West and 900MW in NV East) lie within the envelope of these scenarios and will have a smaller effect on marine geology, oceanography and physical processes than the two potential worst cases.

8.7.6.3 Phasing

155. Norfolk Vanguard Limited is currently considering constructing the project in one of the following phase options.

- A single phase of up to 1800MW; or
- Two phases of up to a combined 1800MW capacity.

156. Phasing is only applicable to the assessment of construction and decommissioning impacts and not the assessment of impacts during the O&M phase. Where appropriate, each construction impact is assessed for the one and two phase scenarios to take account of the different temporal aspects of each option and to clearly demonstrate which one is the worst case scenario. For certain impacts,

phasing is not relevant and this is explained in the assessment. The infrastructure would be the same for each phasing scenario.

8.7.6.4 Construction programme

157. The maximum construction window is five years, with an indicative offshore construction window of four years is anticipated for the full 1800MW capacity. Table 8.12 and Table 8.13 provide indicative construction programmes for the single phase and two phase options, respectively.

Table 8.12 Indicative Norfolk Vanguard construction programme – single phase

Indicative Programme	Approximate duration	2024				2025				2026				2027				2028			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Foundation installation	20 months																				
Array and interconnector cable installation	19 months																				
Export cable installation	6 months																				
Wind turbine installation	20 months																				
Total construction works	23 months																				

Table 8.13 Indicative Norfolk Vanguard construction programme – two phases

Indicative Programme	Approximate duration	2024				2025				2026				2027				2028			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Foundation installation	2 x 8 months																				
Array and interconnector cable installation	2 x 7 months																				
Export cable installation	2 x 3 months																				
Wind turbine installation	2 x 8 months																				
Total construction works	2 x 12 months																				

8.7.6.5 Cable installation

8.7.6.5.1 Pre-installation works

Boulder clearance

158. Pre-construction surveys will identify any requirement for boulder clearance within the offshore project area. Boulder clearance would involve localised relocation of boulders which would have no overall impact on marine geology, oceanography and physical processes and is therefore not considered further.

Pre-lay grapnel run

159. A pre-lay grapnel run would be undertaken to clear any identified debris in advance of each phase of 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

160. The potential for sand wave levelling (pre-sweeping) has been assessed as a potential strategy for cable installation to ensure the cables are installed at a depth below the seabed surface that is unlikely to require 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 this would be made after consent, in the Cable Specification, Installation and Monitoring Plan (required under [condition 14(1)(g) (DCO Schedules 9 and 20) and condition 9.(1) (g) (DCO Schedules 11 and 12)]) following pre-construction surveys.

161. Indicative pre-sweeping volumes and areas for the offshore cable corridor are outlined in Table 8.14. 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 1:3 and a width of 7m at the base of the dredged area. This would be in discrete areas only and not along the full length of the corridor.

Table 8.14 Parameters for pre-sweeping activity for the offshore export cables

Parameter	Maximum volume for the section of offshore cable corridor within the Haisborough, Hammond and Winterton SAC (m^3)	Maximum volume for the entire offshore export cables (including the SAC volume) (m^3)
Per trench (pair of export cables)	250,000	1,200,000
Total for two trenches	500,000	2,400,000

162. Sediment arising from pre-sweeping in the Haisborough, Hammond and Winterton SAC would be disposed 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 Natural England and the MMO following the pre-construction surveys. Sediment arising from pre-sweeping in the offshore cable corridor to the east of the SAC would be deposited in this section of the offshore cable corridor or in the OWF sites. Figure 2 of Chapter 5 Project Description displays the disposal sites. No pre-sweeping or disposal is anticipated in the nearshore section of the offshore cable corridor.

163. The worst case scenario for the volume of sediment arising from seabed preparation in the OWF sites would be associated with levelling the seabed for 90 20MW floating tension leg platforms with gravity anchors (approximately 90m x 90m preparation area) resulting in a total footprint of 729,000m^2 (8,100m^2 per foundation) and a potential sediment volume of 3,645,000m^3 (based on a maximum thickness of 5m of sediment levelled). In addition, levelling of 7,500m^2 per offshore accommodation and electrical platform and 1,257m^2 per met mast may be required resulting in a footprint of 32,513m^2 and sediment volume of 162,566m^3. Sediment arising within the OWF sites would be deposited back into the OWF sites (Figure 2 of Chapter 5 Project Description).

Removal of existing disused cables

164. There are seven out-of-service cables in the offshore cable corridor (all in the Haisborough, Hammond and Winterton SAC). Four are 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.

8.7.6.5.2 Cable burial

165. Following the cable pre-installation works as described in section 8.7.6.5.1, the cables would be installed and buried. The following methods may be used for cable burial and the final burial technique would be dependent on the results of the pre-construction surveys 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.

166. The maximum length of export cable trenches is 200km from the offshore electrical platforms in NV East to landfall, based on an average length of 100km per trench for a total of two trenches, each containing a pair of cables. The maximum volume of

sediment arising from cable burial (using ploughing as the worst case method) would therefore be 3,000,000m^3 based on a realistic worst case average burial depth of 3m with a V-shaped cross-section of 10m width at the seabed surface (see section 5.4.13.2.4 of Chapter 5 Project Description). 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.

167. 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.

8.7.6.5.3 Landfall

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

8.7.6.5.4 Cable protection

Unburied cable

169. Cable burial is expected to be possible throughout the offshore cable corridor, with the exception of cable crossing locations. In order to provide a conservative impact assessment, a contingency estimate is included, should cable burial not be possible due to unexpected hard substrate. The assessment includes 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. The maximum width and height of cable protection for unburied cable (per pair of cables) would be 5m and 0.5m, respectively.

Cable or pipeline crossings

170. There are nine existing cables and two pipelines which the Norfolk Vanguard export cables would need to cross (five cables and one pipeline within the SAC). Each crossing would require a carefully agreed procedure between the respective cable/pipeline owners.

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

172. 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

173. The following cable protection options may be used and this 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.

8.7.6.6 Vessel footprints

174. 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).

175. 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 as a worst case. A jack-up footprint of 792m^2 has been assessed based on up to six legs per vessel.

8.7.6.7 Maintenance

8.7.6.7.1 Turbines

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

8.7.6.7.2 Cable repairs

177. 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.

178. 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 (one repair every five years within the SAC) is included in the assessment. In addition, one inter-connector cable and two array cable repairs every five years has been assessed.

179. In most cases a cable 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 inter-connector 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.

8.7.6.7.3 Cable reburial

180. Cables could become exposed due to migrating sand waves, although this is unlikely if pre-sweeping is used to bury the cables below the reference seabed level. An In Principle Monitoring Plan (document 8.12) is submitted with the DCO application which outlines the types of monitoring that may be required, including a cable burial survey to ensure the cables remain buried and if they do become exposed, re-burial works would be undertaken. The details of any monitoring would be determined post consent in consultation with the relevant Regulators and stakeholders.

181. For the export cables installed without pre-sweeping, a worst case scenario of reburial of up to 20km length per export cable pair at approximately 5 year intervals is assumed in order 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. However, re-burial requirements would be substantially lower if pre-sweeping is carried out prior to cable installation.

182. Given the small scale of the predicted repairs, the changes to suspended sediment concentrations and seabed level as a result of repair work would be negligible in

magnitude and short-lived, with no potential significant impact and therefore this is not assessed further.

183. Table 8.15 describes the relevant worst case scenarios for marine geology, oceanography and physical processes.

Table 8.15 Summary of worst case scenarios for Norfolk Vanguard

Impact	Parameter	Worst Case	Rationale
Construction			
Impact 1: Changes in suspended sediment concentrations due to foundation installation in the offshore wind farm	1A. Sediment plume created by seabed preparation	Worst case scenario for a single wind turbine foundation would be a 20MW gravity anchor for a floating 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 gravity anchor foundation is 40,500m^3 (based on an approximately 90m x 90m preparation area). Total maximum seabed preparation volumes for 1800MW capacity (all in NV East, all in NV West, or split between the sites): • 90 x 20MW floating turbines on gravity anchor foundations (requiring preparation area of approximately 90m x 90m and 5m prep depth) = 3,645,000m^3 • 2 meteorological masts (1,257m^2, 5m depth) = 12,570m^3 • 2 electrical platforms (7,500m^2 x 5m depth) = 75,000m^3 • 2 accommodation platforms (7,500m^2 x 5m depth) = 75,000m^3 Total worst case seabed preparation volume for foundations is 3,807,566m^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 90 x 20MW monopile foundations, two meteorological masts on pin-pile quadropods, two accommodation platforms and two offshore electrical platforms on six-legged pin-piles and 2 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 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 for 45 x 20MW	Up to 50% of the turbines and platform foundations may need to be drilled (**NB** if piled foundations with drilling are used, the level of seabed preparation described above for gravity anchors would not be required).

Impact	Parameter	Worst Case	Rationale
		quadropod foundations is 397,608m^3. Drill arisings from other platforms: • Meteorological masts - 2 x pin-pile quadropod = 1,131m^3 • Accommodation platforms - 2 x six legged pin-pile = 1,696m^3 • Offshore electrical platforms - 2 x six legged pin-pile = 1,696m^3 • LiDAR - 2 x monopiles = 189m^3 Total drill arisings volume for foundations in the OWF sites is 402,320m^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 a 20MW quadropod foundation would be 8,836m^2 (or 450,636m^2 total for the whole site including 50% of the 90 20MW wind turbines plus accommodation platforms, met masts and offshore electrical platform foundations).	Up to 50% of the turbines may need to be drilled (**NB** 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 offshore export cable installation (including nearshore)	3. Sediment plume created by offshore export cable installation	Pre-sweeping (dredging) of the offshore export cable route may be required for up to 2,400,000m^3 of dredged sediment, including: • Up to 500,000m^3 pre-sweeping within the Haisborough, Hammond and Winterton SAC based on calculations by CWind (2017); • Up to 100,000m^3 for the rest of the offshore cable corridor based on calculations by CWind (2017); and	Maximum offshore export cable trench length is 200km based on four HVDC cables in 2 trenches (either 2 trenches from West, 2 from East or 1 from each site) and 100%

Impact	Parameter	Worst Case	Rationale
		• Up to 1,800,000m^3 based on 30km export cable length in the OWF sites that may require pre-sweeping (assuming a width of 20m and average depth of 3m). 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 offshore cable will make landfall at Happisburgh South. Cable ducts would be installed at the landfall so that the ends of the offshore cables can be pulled through from the landward side. The HDD will exit an offshore location, away from the beach (up to 1000m 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 reef identified during pre-construction surveys. The sediment released due to trenching for the offshore 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.	burial. 80km of this will be within the Haisborough, Hammond and Winterton SAC (based on 40km x 2 trenches).
Impact 4: Changes in seabed level due to offshore export cable installation	4A. Changes in seabed level due to disposal of sediment from sand wave levelling	As Impact 3.	
	4B. 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 Vanguard offshore cable corridor. Sediment from the Haisborough, Hammond and Winterton SAC would be deposited back within the SAC.	

Impact	Parameter	Worst Case	Rationale
	4C. Changes in seabed level due to deposition from the suspended sediment plume during offshore export cable installation	As Impact 3.	
Impact 5: Changes in suspended sediment concentrations during array and interconnector cable installation	5A. Sediment plume created by array cable installation	Worst case scenario is 600km of array cables with 100% burial. Potential for pre-sweeping a 20m wide corridor to clear debris or level sand waves prior to excavation of trenches. Average depth of 3m. Total volume 36,000,000m^3.	
	5B. Sediment plume created by interconnector cable installation	Maximum parameters for interconnector cables between offshore electrical platforms are: • 150km trench length based on up to three trenches (50km length) 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 volume = 9,000,000m^3	In the OWF sites and/or in the offshore cable corridor between NV East and NV West depending on the location of the offshore electrical platforms.
Impact 6: Changes in seabed level due to array and interconnector cable installation	6A. Sediment deposited from plume created by array cable installation	As Impact 5A.	As Impact 5A.
	6B. Sediment deposited from plume created by interconnector cable installation	As Impact 5B.	The disposal of any sediment that would be disturbed or removed during seabed preparation would occur within the Norfolk Vanguard OWF

Impact	Parameter	Worst Case	Rationale
			sites.
Impact 7: Indentations on the seabed due to installation vessels	7A. Jack-up footprints	Total footprint is 316,800m^2 (based on two jacking operations per platform (6 total) and two per wind turbine for 200 x 9MW turbines).	Worst case scenario is jack-up barges with six legs per barge (792m^2 combined leg area).
	7B. Anchor footprints	Total impacted volume of 91,800m^3 (1,800m^3 of which is within the export 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.
Operation and Maintenance			
Impact 1: Changes to the Tidal Regime due to the Presence of Structures in the OWF sites (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 (1800MW in one site). This equates to a worst case scenario of 200 9MW GBS wind turbine foundations (based on a 40m base diameter plus scour protection of 200m diameter) totalling 6,283,186m^2 of obstructions with a foundation height of 12m and minimum spacing of 680m. The worst case scenario also includes two meteorological masts on GBS, two accommodation platforms and two electrical platforms on GBS.	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 OWF sites	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 (680m). As Impact 1.	GBS are the worst case foundation types for effects on waves due to the height of the foundation above the sea floor.
Impact 3: Changes to the Sediment Transport Regime due to the Presence of Structures in the OWF sites	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 sea floor.
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 footprint per turbine foundation would be a 70 x 70m gravity anchor for a floating platform with 350 x 350m area including scour protection diameter (i.e. 0.1km^2). The total worst case for 1800MW capacity would be 290 20MW gravity anchors for floating platforms = 11km^2 Footprints of platforms and other infrastructure: Two electrical platforms with scour protection 35,000m^2 Two accommodation platforms with scour protection 35,000m^2 Two met masts with scour protection 15,708m^2 Two wave buoys 300m^2 Two LiDAR monopiles with scour protection 3,927m^2	

Impact	Parameter	Worst Case	Rationale
		Total footprint due to foundations: 11.6km^2	
Impact 5: Morphological and Sediment Transport Effects due to Cable Protection Measures for Array and Interconnector Cables	5A. Seabed morphology and sediment transport along array cables	Up to 60km of cable protection may be required in the unlikely event that array cables cannot be buried (based on 10% of the length) resulting in a footprint of 300,000m^2 and volume 150,000m^3 (based on 0.5m height). Array cable protection at turbines 100m cable length x 5m width x 200 turbines = 100,000m^2 (50,000m^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).	Cable protection for unburied cables will be up to 0.5m in height and 5m wide in a trapezoid shape. Cable protection for crossings will require 250m^3 per crossing.
	5B. Seabed morphology and sediment transport along interconnector cables	Interconnector cable protection approaching platforms 100m cable length x 5m width x 2 platforms = 1,000m^2 footprint, with volume 500m^3 (based on 0.5m height). Surface laid interconnector cable protection 5m width x 15,000m (10% of the length) = 75,000m^2 (volume 37,500m^3). Interconnector cable crossings protection crossings – captured within export cable/array cable crossing total.	Cable protection for unburied cables will be up to 0.5m in height and 5m wide in a trapezoid shape.
Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures for Offshore Export Cables (including nearshore and at the coastal landfall)	6. Seabed morphology and sediment transport along offshore 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 eleven crossings are required for each cable pair (up to 22 crossings) resulting in a total footprint of 22,000m^2 (based on a width of 10m and length of 100m of cable protection per crossing). The volume of cable protection would be 19,800m^3 (based on 0.9m height). • 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 86m^2 and volume of 36m^3 • Unburied cables	

Impact	Parameter	Worst Case	Rationale
		In the unlikely event that cable burial is not possible due to hard substrate being encountered, up to 10km per cable pair outside the SAC and 4km inside the SAC per cable pair (28km in total) could require additional protection resulting in a footprint of 140,000m^2 and volume of 7000m^3.	
Impact 7: Cable repairs/reburial and maintenance vessel footprints	Repairs/Reburial	Unplanned repairs and reburial of cables may be required during O&M: • 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 = 36,360m^2. • One interconnector repair per year is estimated – 10m disturbance width x 300m repair length = 3,000m^2. • 1 x 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) The need for reburial would be significantly less where pre-sweeping is used. **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 6 anchors per vessel Reburial of up to up to 10km per export cable pair may be required should pre-sweeping not be undertaken. The disturbance width would be approximately 3m and therefore the total disturbance would be 60,000m^2. If reburial is required, it is likely that this would be in relatively short sections (e.g. 1km) at any one time.	

Impact	Parameter	Worst Case	Rationale
	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).	
	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 and Interconnector Cables	3. Suspended sediment concentrations	Removal of some or all of the array cables, interconnector cables, and offshore export cables. Cable protection would likely be left *in situ*.	
Impact 4: Changes in Seabed Level due to Removal of parts of the Array and Interconnector Cables	4. Seabed morphology	Removal of some or all of the array cables, interconnector cables, and offshore export cables. Cable protection would likely be left *in situ*.	

Impact	Parameter	Worst Case	Rationale
Impact 5: Changes in Suspended Sediment Concentrations during Offshore Export Cable Removal (including nearshore and at the coastal landfall)	5. Suspended sediment concentrations	Removal of some or all of the array cables, interconnector cables, and offshore 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 six legs per barge (792m^2 combined leg area). Total footprint is 316,800m^2 (based on two jacking operations per wind turbine and per platform for 200 x 9MW turbine sites). 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.	

8.7.7 Potential Impacts during Construction

184. During the construction phase of Norfolk Vanguard, 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.

185. The two worst case layout scenarios (discussed in section 8.7.6.2) are 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 NV East and NV West as well as the two-phase approach.

8.7.7.1 Impact 1A: Changes in suspended sediment concentrations due to seabed preparation for wind turbine gravity anchor foundation installation

186. Seabed sediments and shallow near-bed sediments within Norfolk Vanguard 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 Vanguard OWF sites.

187. 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.

188. The median particle sizes of seabed sediments across NV West and NV East are predominantly 0.32mm to 0.39mm (medium-grained sand) and 0.20mm to 0.35mm (medium-grained sand), respectively. Most seabed samples contained less than 5% mud and less than 10% gravel. Baseline suspended sediment concentrations in NV East 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.

189. For a sediment release from an individual wind turbine foundation, the worst case scenario is associated with the dredging volume for each 20MW gravity anchor foundation, with a maximum preparation area of 8,100m^2. This yields a worst case dredging volume of 40,500m^3 per foundation based on levelling up to 5m of sediment.

190. For the total volume released during the construction phase, the worst case scenario is associated with the maximum number (90) of 20MW gravity anchor foundations with a maximum preparation area of 8,100m^2. This yields a total dredging volume of 3,645,000m^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 two accommodation platforms yielding a dredging volume of 75,000m^3.

191. Therefore, the total maximum seabed preparation volume under the single-phase approach would be 3,807,566m^3 of excavated sediment. All of this volume would be from NV East or NV West (if all 1800MW is located in a single site) or would be split between the sites for the two-phased approach.

192. Expert-based assessment suggests that, due to the predominance of medium-grained sand across the Norfolk Vanguard OWF sites, 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. The majority 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).

193. 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.

194. 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).

195. 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 similar to those across NV West and NV East (10% gravel, 85% sand and 5% mud).

196. Also, NV West, NV East 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.

197. 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. Although, this sediment release is about half the release volume from each of the 20MW wind turbine foundations (40,500m^3), it can still be used as a comparative analogue for a single or two concurrent foundation installations (in NV West or in NV East) to establish the broad magnitude of effect.

198. The ABPmer (2012b) model predicted that close to the release locations, suspended sediment concentrations would be very high (orders of magnitude in excess of 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.

199. Given this finding from the modelled consecutive installation of 15 wind turbine foundations (ABPmer, 2012b), it is expected that effects from installation of 90 foundations across the whole of Norfolk Vanguard would be greater. Given that the maximum sediment volume released through seabed preparation at Norfolk Vanguard would be greater than the modelled release at East Anglia ONE; the worst case suspended sediment concentrations will also be greater (given similar hydrodynamic conditions). Hence, it is anticipated that the worst case suspended sediment concentrations at Norfolk Vanguard 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.

200. 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 90 foundations proposed across Norfolk Vanguard. This is because the modelled results show that after completion of installation of a

foundation, the suspended sediment concentrations do not persist but rapidly 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 90 installations would be similarly small.

8.7.7.1.1 Assessment of effect magnitude and/or impact significance – Single phase for NV West and/or NV East

201. The expert-based assessment of the dynamic and passive plume effects on suspended sediment concentrations for Norfolk Vanguard 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.

202. 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 8.16. These magnitudes of effect are the same regardless of whether all the foundations are in NV West or in NV East (the two worst case layout options). There are no cumulative effects associated with concurrent installations of foundations in the two sites, as individual plumes from concurrent installations would not overlap spatially.

Table 8.16 Magnitude of effect on suspended sediment concentrations due to foundation installation under the worst case scenario

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.

203. The effects on suspended sediment concentrations due to foundation installation for Norfolk Vanguard do not directly impact upon the identified receptor groups for marine geology, oceanography and physical processes (i.e. the offshore SACs and East Anglia coast). This is because the designated features of North Norfolk Sandbanks and Saturn Reef SAC/ (2km north of NV West) and the Haisborough, Hammond and Winterton SAC (6.5km west of Norfolk Vanguard) 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.

8.7.7.1.2 Assessment of effect magnitude and/or impact significance – Two phases for NV West and/or NV East

204. 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.

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

205. Sub-seabed sediments within Norfolk Vanguard would become disturbed during any drilling activities that may be needed 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 Vanguard OWF sites. 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. This compares with a maximum volume of 1,155m^3 for each monopile foundation for an individual 9MW wind turbine with a maximum diameter of 7m drilled to a maximum depth of 30m.

206. Norfolk Vanguard Limited estimates that the maximum number of foundations that would require drilling would be 50%. 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) compared with 115,454m^3 for 100 9MW wind turbines.

207. Also, piled quadropod foundations with a diameter 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 accommodation platforms and two offshore electrical platforms, both on six-legged pin pile foundations, would yield up to 3,392m^3 of sediment in total. Two LiDAR monopiles may also be required, yielding up to 189m^3 of sediment.

208. The total volume of drill arisings under the single-phase approach would therefore be 402,320m^3. This volume would all be from NV West or NV East if all 1,800MW is in one site. In the two-phased approach, this volume would be split 50% in each site.

209. 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, see section 8.6.7), 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).

210. 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 20MW monopile foundations being considered for Norfolk Vanguard (8,836m^3).

211. The larger release volumes associated with the worst case scenario for Norfolk Vanguard 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 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 8.7.7.4).

212. 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 a distance of 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 for sufficiently long for them to interact with subsequent operations, and therefore no cumulative effect was anticipated from multiple installations.

213. The changes in suspended sediment concentrations (magnitudes, geographical extents and durations of effect) that are anticipated at Norfolk Vanguard 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.

8.7.7.2.1 Assessment of effect magnitude and/or impact significance – Single phase for NV West and/or NV East

214. 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 8.7.7.1), and are shown in Table 8.17.

Table 8.17 Magnitude of effect on suspended sediment concentrations due to foundation installation under the worst case scenario

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.

215. In a similar way to seabed preparation (section 8.7.7.1) 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.

8.7.7.2.2 Assessment of effect magnitude and/or impact significance – Two phases for NV West and/or NV East

216. The worst-case release of sediments through drilling would occur over two distinct phases, each lasting up to eight months, respectively (rather than a single 20 month period), for the installation of the monopiles. 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.

8.7.7.3 Impact 2A: Changes in seabed level due to seabed preparation for wind turbine gravity anchor foundation installation

217. The increased suspended sediment concentrations associated with construction impact 1A (section 8.7.7.1) have the potential to deposit sediment and raise the seabed elevation slightly.

218. 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.

219. 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 Vanguard, depending on the prevailing physical conditions, but in all cases the sediment within the mound would be similar to 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.

220. 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.

221. In addition to the local 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 half the volume considered as the worst case for an individual wind turbine foundation in Norfolk Vanguard). 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.

222. Using the plume modelling studies for East Anglia ONE as part of the expert-based assessment suggests that deposition of sediment from the Norfolk Vanguard 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 Vanguard would be less than the modelled release at East Anglia ONE; the worst case thickness of sediment deposited from the plume will also be greater (given similar hydrodynamic conditions). Hence, it is anticipated that the worst case sediment thicknesses at Norfolk Vanguard would not likely exceed a maximum of 4mm and be less than 0.4mm over larger areas of the seabed.

223. 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).

8.7.7.3.1 Assessment of effect magnitude and/or impact significance – Single phase for NV West and/or NV East

224. The expert-based assessment of seabed level changes associated with foundation installation for Norfolk Vanguard 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, both for all foundations being in either NV West or NV East.

225. 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 8.18.

Table 8.18 Magnitude of effects on seabed level changes due to sediment deposition following foundation installation under the worst case sediment dispersal scenario

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 Vanguard.

226. 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 2km north of NV West, and the Haisborough, Hammond and Winterton SAC 6.5km west of Norfolk Vanguard) 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 1.5mm. 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.

227. 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.

228. 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.

8.7.7.3.2 Assessment of effect magnitude and/or impact significance – Two phases for NV West and/or NV East

229. Under a two-phase 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.

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

230. The increased suspended sediment concentrations associated with construction impact 1B (section 8.7.7.2) have the potential to deposit sediment and raise the seabed elevation slightly.

231. 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.

232. 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 dominantly sand deposit would be released into the water column and dispersed before settling on the seabed.

233. 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.

234. Although the modelling used a smaller volume of sediment (982m^3) than the worst case for Norfolk Vanguard (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 tens of centimetres with thickness up to 0.23mm across the wider seabed.

235. The seabed level changes that are anticipated would move across Norfolk Vanguard 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.

236. 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.

237. For an individual wind turbine, the worst case is associated with a 20MW 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).

238. For drill arisings from the project as a whole, the worst case is for 45 20MW quadropods (i.e. 50% of turbine locations) along with two LiDAR, two meteorological masts, two accommodation platforms and two offshore electrical platforms, amounting to total volume of 402,320m^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.

239. 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) on the basis of 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.

240. 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 450,636m^2 for the whole of Norfolk Vanguard under the single-phase approach, assuming a worst case scenario of 45 wind turbines and six platforms are drilled). When compared to Norfolk Vanguard as a whole (592km^2), the worst case mound footprint is only 0.08% of the seabed within the wind farm area.

241. This footprint would all be from NV West or NV East if all 1,800MW is located in one site. If the numbers of turbines are split, the footprint will be 225,318m^2 in each site (assumes a worst case scenario of 22 or 23 wind turbines and three other structures drilled in each site).

8.7.7.4.1 Assessment of effect magnitude and/or impact significance – Single phase for NV West and/or NV East

242. The expert-based assessment of seabed level changes associated with foundation installation for Norfolk Vanguard 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.

243. 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 8.19 and Table 8.20, respectively.

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

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 Vanguard.

Table 8.20 Magnitude of effects on seabed level changes due to sediment deposition following the worst case sediment mound scenario

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 Vanguard.

244. 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 2km 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 (SACs and coast).

245. 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. The worst case scenario of drilling 50% of turbine locations is also deemed to be conservative.

246. 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 (see section 8.9).

8.7.7.4.2 Assessment of effect magnitude and/or impact significance – Two phases for NV West and/or NV East

247. 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.

8.7.7.5 Impact 3: Changes in suspended sediment concentrations during export cable installation

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

249. The installation of the offshore 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 all of these construction phase activities, with the release points along different parts of the offshore cable corridor, is considered here.

250. 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.

8.7.7.5.1 Cable installation (trenching and sand wave levelling)

251. The sediment released due to pre-sweeping for the export cables would equate to about 2,400,000m^3 of sediment. Approximately 500,000m^3 would be within the Haisborough, Hammond and Winterton SAC; 100,000m^3 would be within the rest of the offshore cable corridor (excluding the nearshore (10m water depth contour) where no pre-sweeping is proposed); and 1,800,000m^3 would be associated with up to 30km of export cable within the OWF sites. The latter is assessed in Impact 5 (section 8.7.7.9).

252. 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.

253. There are similarities in water depth, sediment types and metocean conditions between the offshore cable corridor for East Anglia ONE and Norfolk Vanguard. 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:

- 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.
- 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.
- Following cessation of installation activities, any plume would have been fully dispersed as a result of advection and diffusion. Sediments arisings from the offshore cable corridor would tend to be advected to the north helping to keep it within the Haisborough, Hammond and Winterton SAC for some parts of the offshore cable corridor.
- The residual plume concentrations resulting from the East Anglia ONE model (and hence as an analogue for Norfolk Vanguard) are likely to be overly conservative. This is because the plume dispersion model takes into consideration the potential for re-mobilisation of the sediment arisings once they have settled to the bed.

254. 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.

255. 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.

8.7.7.5.2 Landfall construction activities

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

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

257. 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 portion of the offshore cable on the seaward side of the landfall HDD. This

excavation has the potential to increase suspended sediment concentrations close to shore.

258. As discussed in section 0, 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.

259. 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.

8.7.7.5.3 Assessment of effect magnitude and/or impact significance – Single phase for Offshore Cable Corridor

260. The worst case changes in suspended sediment concentrations due to offshore cable installation are likely to have the magnitudes of effect shown in Table 8.21.

Table 8.21 Magnitude of effect on suspended sediment concentrations due to offshore cable installation (including any sand wave levelling and landfall construction activities) under the worst case scenario

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

261. These effects on suspended sediment concentrations due to offshore cable installation (including that from any sand wave levelling) would have **no impact** upon the identified receptors groups for marine geology, oceanography and 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 8.7.7.6).

262. 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.

8.7.7.5.4 Assessment of effect magnitude and/or impact significance – Two phases for Offshore Cable Corridor

263. 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.

264. For the two-phase approach, the worst case installation period for the export cables would either be installation separately or in parallel with other elements of the offshore wind farm. 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.

265. 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 occurrences of disturbance events, there would be less volume disturbed during each event compared to the single-phase approach.

8.7.7.6 Impact 4A: Changes in seabed level due to disposal of sediment from sand wave levelling in the offshore cable corridor

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

267. The maximum volume of sediment arising as a result of pre-sweeping for export cables would equate to approximately 2,400,000m^3; 500,000m^3 of which would be deposited within the SAC and 1,900,000m^3 would be deposited in the OWF sites. The impact of sediment deposited in the OWF sites is assessed in Impact 6 (section 8.7.7.10).

268. As discussed in section 8.7.4, Norfolk Vanguard is committed to depositing all sediment arising from the SAC during cable installation placed back into the SAC as embedded mitigation, ensuring that the sediment is not lost from the system.

269. 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 (2018) 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 spoil zone. 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.

270. 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 spoil deposition '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 spoil zone and the resulting thickness.

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

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

273. 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 report, document reference 5.3), however as described in the Appendix 7.1 of the Information to Support HRA report (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 grain size of 350µm (which would be expected to have a settling rate of 0.05m/s).

274. 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 spoil zone typically have amplitudes of over 3m and wavelengths of about 100m. Therefore, there is already some variation in seabed depths within the indicative spoil zone and depending on the deposition characteristics (i.e. location, thickness and extent) the result would potentially be within the range already encountered within the indicative spoil zone. 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.

8.7.7.6.1 Assessment of effect magnitude and/or impact significance – Single phase for offshore cable corridor

275. The worst case changes in seabed levels due to disposed sediment from sand wave levelling are likely to have the magnitudes of effect described in Table 8.26.

Table 8.22 Magnitude of effect on seabed level changes due to disposed sediments from sand wave levelling under the worst case scenario

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 sea bed (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.

276. The main area of sand wave levelling for the offshore cable corridor will be within the southern part of the Haisborough, Hammond and Winterton SAC. The sensitivity and value of the SAC is presented in Table 8.27.

277. No sand wave levelling is expected along the western, nearshore end of the cable corridor. 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. Any sediment arising from the eastern end of the offshore cable corridor outside the SAC would be deposited in this section of the offshore cable corridor or within the OWF sites.

Table 8.23 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

278. The overall impact of sand wave levelling activities 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.

279. 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.

8.7.7.6.2 Assessment of effect magnitude and/or impact significance – Two phases for offshore cable corridor

280. 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.

281. 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.

8.7.7.7 Impact 4B: Interruptions to bedload sediment transport due to sand wave levelling in the offshore cable corridor

282. The removal of sand waves could potentially interfere with sediment transport pathways that supply sediment to the sandbank system. Sand wave levelling for the offshore export cables is estimated to require excavation of 2,400,000m^3 of sediment, of which up to 500,000m^3 would be within the Haisborough Hammond and Winterton SAC.

283. As previously discussed the 500,000m^3 of sediment arising from the SAC would be disposed back into the SAC; the 100,000m3 of sediment arising from the rest of the offshore cable corridor would be deposited in the corridor or within the OWF sites and the 1,800,000m^3 from the export cable installation within the OWF sites would be deposited in the OWF sites. As the excavated sediment would be disposed of within the SAC there would be no net loss of sediment within the designated site.

284. The total area of sandbanks within the SAC is 678km^2 and the area of the SAC as a whole 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 are to be extracted.

285. ABPmer 2018) (provided in Appendix 7.1 of the Information to Support HRA report, document 5.3) also concludes 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 particular sand wave, or the SAC sandbank system as a whole, is not disrupted.

286. 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 as a whole. 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.

287. Analysis by Burningham and French (2016) (see section 8.6.10) 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.

8.7.7.7.1 Assessment of effect magnitude and/or impact significance – Single phase for offshore cable corridor

288. The worst case changes in bedload sediment transport due to sand wave levelling are likely to have the magnitudes of effect described in Table 8.24.

Table 8.24 Magnitude of effect on bedload sediment transport due to sand wave levelling under the worst case scenario

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

289. 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 8.25.

Table 8.25 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

290. 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 (0.25-0.5mm) within the SAC of between $0.01m^3/m/$ hr to $3.4m^3/m/$ hr (using representative annual average waves combined with current speeds ranging from 0.5m/s to 1.29m/s), which are also within the range modelled for the wider region of the Southern North Sea (HR Wallingford, 2012).

291. The ABPmer (2018) study (Appendix 7.1 of the Information to Support HRA report, document reference 5.3) also found that the sediment would be naturally transported back into the dredged area within a short period of time given the local favourable conditions that enable sandwave development. 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.

292. 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 as a result 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 a whole. 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.

293. Hence, the overall impact of sand wave levelling activities under a worst case scenario for the identified morphological receptor groups is considered to be **no impact**, except for Haisborough, Hammond and Winterton SAC which is assessed as **negligible impact**.

294. 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.

8.7.7.7.2 Assessment of effect magnitude and/or impact significance – Two phases for offshore cable corridor

295. 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.

8.7.7.8 Impact 4C: Changes in seabed level due to deposition from the suspended sediment plume during export cable installation

296. The increases in suspended sediment concentrations associated with cable installation 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.

297. The maximum potential disturbance width of 30m (for ploughing) along the length of the trenching provides a footprint of 2.4km^2 based on two 40km cable trenches within the SAC. The maximum volume associated with trenching for the export

cables would be 3,000,000m^3 (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 average 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.

298. The East Anglia ONE plume modelling simulations (ABPmer, 2012b) suggest that any suspended sand-sized material (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.

299. Mud-sized material (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 in excess of 0.2mm (and up to 0.8mm) are predicted at a distance of 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 material 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 offshore cable trench, bed level changes and any changes to seabed character are expected to be not measurable in practice.

8.7.7.8.1 Assessment of effect magnitude and/or impact significance – Single phase for offshore cable corridor

300. The worst case changes in seabed levels due to offshore cable installation are likely to have the magnitudes of effect described in Table 8.26.

Table 8.26 Magnitude of effect on seabed level changes due to offshore cable installation under the worst case scenario

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 sea bed (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.

301. 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 8.27.

Table 8.27 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

302. As the North Norfolk and Saturn Reef SAC is approximately 2km from the offshore cable corridor, there would be no discernible impact associated with deposition of suspended sediment as a result of cable installation.

303. Based on the East Anglia ONE plume modelling simulations discussed above, expert-based assessment of deposition from the plume generated from cable installation 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 offshore cable installation the impacts on the Haisborough, Hammond and Winterton SAC and Cromer Shoal Chalk Beds MCZ receptors would not be significant.

304. The overall impact of offshore cable installation activities 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.

305. 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.

8.7.7.8.2 Assessment of effect magnitude and/or impact significance – Two phases for offshore cable corridor

306. Under the two-phase approach, the principal difference compared to the single phase assessment is that described previously for construction impact 3.

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

8.7.7.9 Impact 5: Changes in suspended sediment concentrations during cable installation in the OWF sites

308. Disturbance of suspended sediment in the OWF sites could arise through levelling of sandwaves that may be present along the cable routes prior to installation and directly through installation of the cable (worst case scenario is jetting).

309. The details of the array and interconnector cabling are dependent upon the final project design, but present estimates for a single-phase approach are that the total length of the array cables would be up to 600km and the total length of the interconnector cable trenches would be up to 150km. As discussed in section 8.7.7.5.1, up to 30km of offshore export cables in the OWF sites is included in this assessment.

8.7.7.9.1 Sandwave levelling

310. For the worst case scenario, it is assumed that sandwave levelling may be required for 100% of the array cables and interconnector cables to an average depth of 3m and with an average width of 20m. This equates to a total of 15km^2 of seabed or excavation of 45,000,000m^3 of sediment. As discussed in section 8.7.7.5.1, up to 1,900,000m^3 of sediment may be released in the OWF sites as a result of pre-sweeping of up to 30km of offshore export cables in the OWF sites plus 100,000m^3 from the offshore cable corridor. This would equate to approximately 3,000,000m^3 per square kilometre of seabed in the OWF sites.

311. 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.

312. Any excavated sediment due to sand wave levelling for the array and interconnector cables would be disposed of within the Norfolk Vanguard OWF site itself. This means there will be no net loss of sand within the site. It is likely that some of this sand could be disposed on the upstream side of the 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.

313. Also, in many parts of Norfolk Vanguard 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.

8.7.7.9.2 Installation of the cable

314. 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 8.7.7.5 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 and interconnector cable installation (including any sandwave levelling) 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 array and interconnector cables, and the rate at which the sediment is released into the water column would be relatively low.

315. 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.

316. Mud-sized material (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.

8.7.7.9.3 Assessment of effect magnitude and/or impact significance - Single phase for NV West and/or NV East

317. The worst case changes in suspended sediment concentrations due to array cable and interconnector cable installation (including any necessary sand wave levelling) are likely to have the magnitudes of effect described in Table 8.28.

Table 8.28 Magnitude of effect on suspended sediment concentrations due to array cable and interconnector cable installation (including sandwave levelling) under the worst case scenario

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 entirety of the seabed area within Norfolk Vanguard or the entirety of the cable corridor.

318. These effects on suspended sediment concentrations do not directly impact upon the identified receptor groups for marine geology, oceanography and physical processes (i.e. the offshore SACs). This is because the designated features of North Norfolk Sandbanks and Saturn Reef SAC (2km north of NV West) and the

Haisborough, Hammond and Winterton SAC (6.5km west of Norfolk Vanguard) 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.

319. 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.

8.7.7.9.4 Assessment of effect magnitude and/or impact significance – Two phases for NV West and/or NV East

320. 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 seven months (rather than a single 19 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.

8.7.7.10 Impact 6: Changes in seabed level due to cable installation in the OWF sites

321. 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.

322. 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.

323. 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).

8.7.7.10.1 Assessment of effect magnitude and/or impact significance – Single phase for NV West and/or NV East

324. Expert-based assessment indicates that changes in suspended sediment concentration due to array cable and interconnector cable installation (including any deposition arising from spilled sediment from sand wave levelling) would be minor and are likely to have the magnitudes of effect shown in Table 8.29.

Table 8.29 Magnitude of effect on seabed level changes due to array cable and interconnector cable installation (including sandwave levelling) under the worst case scenario

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 Norfolk Vanguard.

325. These effects on seabed level are considered highly unlikely to have the potential to impact directly upon the identified receptor groups for marine geology, oceanography and 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 cable installation in the OWF sites under a worst case scenario on seabed level changes for identified morphological receptor groups is therefore considered to be **negligible impact**.

326. 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.

8.7.7.10.2 Assessment of effect magnitude and/or impact significance – Two phases for NV West and/or NV East

327. 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.

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

328. There is potential for certain vessels used during the installation of Norfolk Vanguard to directly impact the seabed. This applies for those vessels that utilise jack-up legs or a number of 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.

329. 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.

330. A single jack-up barge leg would have a footprint of 177m^2 and a jack-up vessel would have up to four legs (707m^2 combined footprint). Each leg could penetrate 5 to 15m into the seabed and may be cylindrical, triangular, truss leg or lattice.

331. The worst case 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.

8.7.7.11.1 Assessment of effect magnitude and/or impact significance – Single phase for NV West and/or NV East

332. 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 8.30.

Table 8.30 Magnitude of effect on seabed level changes due to installation vessels under the worst case scenario

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

333. 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.

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

8.7.7.11.2 Assessment of effect magnitude and/or impact significance – Two or three phases for NV West and/or NV East

335. 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.

8.7.8 Potential Impacts during Operation

336. During the operational phase of Norfolk Vanguard, 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.

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

8.7.8.1 Impact 1: Changes to the tidal regime due to the presence of wind turbine structures

338. The presence of foundation structures within Norfolk Vanguard 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 8.7.8.3).

339. 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; COWRIE, 2009) and numerous Environmental Statements for offshore wind farms (e.g. Dogger Bank Creyke Beck, Forewind, 2013).

340. 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 0.05m/s 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).

341. 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.

8.7.8.1.1 Assessment of effect magnitude and/or impact significance

342. The expert-based assessments of the changes in tidal currents associated with the presence of foundation structures for the proposed Norfolk Vanguard 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.

343. 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 8.31.

Table 8.31 Magnitude of effect on tidal currents due to the presence of foundations under the worst case scenario

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

344. 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 8.14.

345. The majority of the identified receptor groups for marine geology, oceanography and physical processes is 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. However, the first tidal ellipses from the northern part of NV West encroach about 15km into the southern part of the North Norfolk Sandbanks and Saturn Reef SAC. Given that the largest changes are confined to wake zones local to each wind turbine foundation, the change in overall current velocity in the SAC would be **negligible impact**.

8.7.8.2 Impact 2: Changes to the wave regime due to the presence of wind turbine structures

346. The presence of foundation structures within Norfolk Vanguard 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 (see operational impact 3, section 8.7.8.3).

347. 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.

348. 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 in close proximity to 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), existing guidance documents (ETSU, 2000; ETSU, 2002; COWRIE, 2009), published research (Ohl *et al*., 2001) and post-installation monitoring (Cefas, 2005).

349. 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 a distance of 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.

350. The likely envelope of wind turbine numbers and GBS foundation sizes for Norfolk Vanguard is presented in Table 8.32. The modelling for the East Anglia ONE project is similar in terms of the number and size of foundations being considered for the proposed Norfolk Vanguard project (see section 8.7.3).

Table 8.32 Likely wind turbine arrangements for the worst case scenario

Turbine rating (MW)	Maximum number of wind turbines	Maximum basal diameter of GBS (m)
9	200	40 (200m with scour protection)
20	90	50 (250m with scour protection)

8.7.8.2.1 Assessment of effect magnitude and/or impact significance

351. 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 8.33.

Table 8.33 Magnitude of effect on the wave regime due to the presence of foundations under the worst case scenario

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

352. 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 8.15).

353. Figure 8.8 shows the regional wave roses and describes waves that are likely to be aligned north to south at NV West and Diagram 8.3 indicates that waves are predominantly from the north/north-west and south/south-west at NV East. These would be the axes of greatest potential influence at these two sites.

354. 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 NV West and NV East sites. The resulting 'zone of influence' on the wave regime is presented in Figure 8.15.

355. The majority of the area of identified receptor groups for marine geology, oceanography and physical processes is 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.

356. However, the first tidal ellipses from the northern and southern parts of NV West encroach into the extreme south-east part of the North Norfolk Sandbanks and Saturn Reef SAC and the extreme south-east corner of the Haisborough, Hammond

and Winterton SAC, respectively. The change in wave height would only be a few percent within these zones of encroachment. Hence, the impact on this very small part of the designated area would be **negligible impact**.

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

357. 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.

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

8.7.8.3.1 Assessment of effect magnitude and/or impact significance

359. 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.

360. These changes to the 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 8.34.

Table 8.34 Magnitude of effect on the sediment transport regime due to the presence of foundations under the worst case scenario

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

361. 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 8.14 and Figure 8.15) and therefore, there is **no impact** associated with Norfolk Vanguard on a very large area of the marine geology, oceanography and physical processes receptor groups, with **negligible impact** on very small areas of the

Haisborough, Hammond and Winterton SAC and North Norfolk Sandbanks and Saturn Reef SAC.

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

362. The seabed morphology would directly be impacted by the footprint of each foundation structure within Norfolk Vanguard. 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 required locations, as determined by pre-construction surveys. A worst case scenario of all foundations having scour protection is considered in order to provide a conservative assessment.

363. 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. The total worst case direct wind turbine foundation footprint (for tension leg floating foundation with gravity anchor) across the project would be $11km^2$. This represents 1.86% of the total seabed area within the OWF sites (3.7% of either NV East or NV West).

364. The total worst case footprint of all foundations (including wind turbine foundations, platforms, met masts and other infrastructure) would be approximately $11.5km^2$ (1.96% of the OWF sites or 3.9% of either NV East or NV West).

8.7.8.4.1 Assessment of effect magnitude and/or impact significance

365. 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 8.35). 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 8.35 Magnitude of effect on sea bed morphology due to the presence of foundations and scour protection under the worst case scenario

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.

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

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

8.7.8.5 Impact 5: Morphological and sediment transport effects due to cable protection measures for array and interconnector cables

368. 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, frond.

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

370. 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.

371. The presence and asymmetry of sand waves across both NV West and NV East 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 (2-7m) in most areas would exceed the height of cable protection works, and would simply pass over them.

372. 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 particular 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 Vanguard would therefore not be affected significantly.

373. 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 Vanguard.

8.7.8.5.1 Assessment of effect magnitude and/or impact significance

374. The worst case changes to the seabed morphology and sediment transport due to cable protection measures for array cables and interconnector cables are likely to have the following magnitudes of effect (Table 8.36).

Table 8.36 Magnitude of effect on seabed morphology and sediment transport due to cable protection measures for array cables and interconnector cables under the worst case scenario

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 Vanguard site.

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

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

8.7.8.6 Impact 6: Morphological and sediment transport effects due to cable protection measures for offshore cables

377. As a worst case scenario, it has been assumed that burial of the offshore 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 geology, oceanography and physical processes primarily relate to the potential for interruption of sediment transport and the footprint they present on the seabed.

378. 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 two cable pairs. 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.

379. 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.

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

381. 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.

382. 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.

383. Norfolk Vanguard Limited commissioned an HDD feasibility study (Riggall, 2016 unpublished) which investigated a number of 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 4.1) 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.

384. 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.

385. 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 cables, the sand would accumulate against the cable protection, eventually forming a ‘ramp’ over which the transport would eventually continue.

386. The protection is also unlikely to significantly affect the migration of sand waves, since their heights (2-7m) 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.

387. Up to 0.05km^2 of cable protection may be required in the Haisborough, Hammond and Winterton SAC, 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 40,000m2 (0.04km^2) based on 5m wide cable protection.

8.7.8.6.1 Assessment of effect magnitude and/or impact significance

388. The worst case changes to the seabed morphology and sediment transport due to cable protection measures for offshore cables are likely to have the magnitudes of effect described in Table 8.37. The worst case changes to erosion are likely to have the magnitudes of effect described in Table 8.38.

Table 8.37 Magnitude of effect on seabed morphology and sediment transport due to cable protection measures for offshore cables under the worst case scenario

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 8.38 Magnitude of effect on cliff erosion due to cable operation under the worst case scenario

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

389. 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 8.39.

Table 8.39 Sensitivity and value assessment for the East Anglian coast

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

390. The significance of impacts relating to seabed and coastal morphology and sediment transport arising from the presence of cable protection measures for offshore cables

would differ depending on the location of the works and the identified receptor groups under consideration.

391. 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.

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

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

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

394. Cable repairs and reburial could be needed, as outlined in section 8.7.6.7 and in Table 8.15. 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.

395. 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 3,150m^2 (0.003km^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.

396. The maximum disturbance area for cable reburial activities within the SAC has been estimated as 0.4km^2 over the life of the project (0.03% of the total area of the SAC or 0.06% of the sandbank area). This is estimated from 4km per cable pair within the SAC, with a disturbance width of 10m. However, if reburial is required, it is likely that this would be for shorter sections (e.g. 1km) at any one time.

397. 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 a number of 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 also for local scour-hole formation around

the legs or anchors while they remain in place for the duration of the maintenance works.

398. 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 physical processes and scour-hole formation would be greater than the anchor scars.

399. For purposes of a worst case, 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.

400. 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 geology, oceanography and physical processes would remain.

401. 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 scour volumes arising would therefore be small in magnitude and cause an insignificant effect in terms of enhanced suspended sediment concentrations and deposition of sediments elsewhere.

8.7.8.7.1 Assessment of effect magnitude and/or impact significance of vessel footprints

402. 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 8.40.

Table 8.40 Magnitude of effect on the seabed due to maintenance vessels under the worst case scenario

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

403. 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.

8.7.8.7.2 Impacts to Haisborough, Hammond and Winterton SAC due to cable repairs/burial

404. The sensitivity and value of the Haisborough, Hammond and Winterton SAC to disturbance is shown in Table 8.41.

Table 8.41 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

405. The governing processes within the SAC occur at a much larger scale than the potential temporary physical disturbance which may occur as a result 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 as a whole.

406. The assessment indicates that temporary physical disturbance may occur within the offshore cable corridor, with a maximum disturbance area of $0.4km^2$ (0.03% of the total area of the SAC or 0.06% 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**.

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

8.7.9 Potential Impacts during Decommissioning

408. 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 of the wind turbine components, part of the foundations (those above seabed level), removal of some or all of the array cables, interconnector cables, and export cables. Scour and cable protection would likely be left *in situ.*

409. 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 as a result 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 and interconnector cables;
- Impact 4: Changes in seabed level due to removal of parts of the array and interconnector cables;
- Impact 5: Changes in suspended sediment concentrations due to removal of parts of the offshore export cables (including nearshore and at the coastal landfall); and
- Impact 6: Indentations on the seabed due to decommissioning vessels.

410. The magnitude of effects would be comparable to or less than those identified for the construction phase. Accordingly, given that negligible adverse or no impact was identified for the marine geology, oceanography and physical processes receptors during the construction phase, it is anticipated that the same would be valid for the decommissioning phase.

411. The significance of effects on other receptors is addressed within relevant chapters of this ES (see section 8.9).

8.8 Cumulative Impacts

412. The receptors that have been specifically identified in relation to marine geology, oceanography and 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, Chapter 11 Fish and Shellfish Ecology, Chapter 14 Commercial Fisheries, and Chapter 17 Offshore and Intertidal Archaeology and Cultural Heritage.

413. The marine geology, oceanography and physical processes effects that have been assessed for the proposed Norfolk Vanguard project 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.

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

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

415. A summary of the screening of potential impacts is set out in Table 8.42.

Table 8.42 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 Vanguard i.e. Norfolk Boreas 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 Vanguard i.e. Norfolk Boreas and East Anglia THREE there is potential for cumulative impact.
3	Changes in Suspended Sediment Concentrations during Offshore Export Cable Installation	Yes	Norfolk Vanguard and Norfolk Boreas 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 bed load due to Offshore Export Cable Installation	Yes	Norfolk Vanguard and Norfolk Boreas 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 and Interconnector Cable Installation	Yes	Where construction windows could overlap for projects adjacent to Norfolk Vanguard i.e. Norfolk Boreas and East Anglia THREE there is potential for cumulative impact.

Impact		Potential for cumulative impact	Rationale
6	Changes in Seabed Level due to Array and Interconnector Cable Installation	Yes	Where construction windows could overlap for projects adjacent to Norfolk Vanguard i.e. Norfolk Boreas 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.
Operation			
1	Changes to the Tidal Regime due to the Presence of Wind Turbine Structures	Yes	Additive changes to the tidal regime of Norfolk Vanguard, Norfolk Boreas 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 Vanguard, Norfolk Boreas and East Anglia THREE due to their proximity.
3	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.
4	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.
5	Morphological and Sediment Transport Effects due to Cable Protection Measures for Array and Interconnector Cables	No	Impacts will be highly localised around the cable protection measures and therefore there will be no cumulative impact.
6	Morphological and Sediment Transport Effects due to Cable Protection Measures for Offshore Cables	No	There is no impact predicated from Impacts will be highly localised around the cable protection measures and therefore there will be no cumulative impact.
7	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 the same as those identified during the construction stage.			

416. These potential interactions are included in the Cumulative Impact Assessment (CIA) (Table 8.43). 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.

417. Given that Norfolk Vanguard 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 Vanguard. In addition, the cable corridor for East Anglia ONE is directed west-south-west towards Bawdsey, whereas the cable corridor for Norfolk Vanguard is directed west to Happisburgh, and the distance between the two corridors is sufficient for there to be no marine geology, oceanography and physical processes interactions during the construction phases of the two projects.

418. The proposed landfall at Happisburgh South is to the south of the proposed sand engine (very large scale beach nourishment) for a coastal protection scheme in front of Bacton Gas Terminal. The effect of the beach nourishment is likely to be felt 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 Norfolk Vanguard HDD would have no impact on coastal erosion and the nearshore cable protection would have negligible impact on sediment transport processes at the coast; there will be no cumulative impacts between Norfolk Vanguard and Bacton sand engine.

419. The offshore cable for the proposed Norfolk Vanguard project passes north of a series of marine aggregate extraction areas offshore from Great Yarmouth. The southern edge of the 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 cable installation. This is because they are within one spring tidal excursion distance from each other.

Table 8.43 Summary of projects considered for the CIA in relation to the topic

Project	Status	Indicative development period	Distance from Norfolk Vanguard (km)	Project definition	Project data status	Included in CIA	Rationale
East Anglia THREE OWF	Consented	2022-2026	0	PDS available	Complete/high	Yes	This project would be adjacent to NV East. It has potential for interaction during the construction of foundations and their operation and maintenance
Norfolk Boreas OWF	Pre-Application	2024-2028	1	Outline only	Incomplete/low	Yes	This project would be adjacent to NV East and may 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 offshore cable for Norfolk Vanguard passes 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

8.8.1 Cumulative Construction and Decommissioning Impacts with Adjacent Wind Farms

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

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

422. The worst case scenario from a marine geology, oceanography and physical processes perspective would be for all projects to be constructed at the same time. This would provide the greatest opportunity for interaction of sediment plumes and a larger change in seabed level during their construction. The combined change in seabed level sediment plume from foundation and cable installation could have a greater spatial extent and be greater in a vertical sense than each individual project.

423. As for Norfolk Vanguard alone, the majority of suspended sediment arising from each project would fall rapidly to the seabed after the start of 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 cumulative impact of two or three projects constructing in this area at the same time would be **negligible**.

8.8.2 Cumulative Construction and Decommissioning Impacts with Marine Aggregate Dredging

424. In order to assess the potential for cumulative effects between the installation of the offshore cable 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 Vanguard.

425. 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 offshore 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 offshore 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 offshore cable installation only scenario. Following cessation of cable burial and aggregate dredging activities, a few hundred metres 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.

426. Norfolk Vanguard is located over 5km from the nearest aggregate extraction site (North Cross Sands). Considering the results from East Anglia ONE described above, the potential cumulative impacts between offshore cable installation for Norfolk Vanguard and nearby marine aggregate dredging activities would be **negligible** as a conservative estimate.

8.8.3 Cumulative Operation and Maintenance Impacts with Adjacent Wind Farms

427. From an operation and maintenance perspective, Figure 8.16 and Figure 8.17 show overlap of the 'zones of influence' arising from the proposed East Anglia THREE and Norfolk Vanguard projects in relation to changes on the tidal and wave regimes, respectively. In addition, the 'zone of influence' of the yet to be assessed Norfolk Boreas may also overlap with those of NV East and East Anglia THREE.

428. The overlap of the 'zones of influence' effectively represents the enlargement of three separate zones into a single 'zone of influence' of a much larger wind farm. In this respect, the pre-existing scientific evidence base and the results of the East Anglia ONE modelling (sections 8.7.8.1 and 8.7.8.2), which demonstrate that changes in tidal currents and waves due to the presence of foundation structures are both small in magnitude and localised in spatial extent, applies cumulatively. Hence, the potential cumulative impact between Norfolk Vanguard, East Anglia THREE and Norfolk Boreas is considered to be **negligible**.

8.9 Inter-relationships

429. The range of effects on marine geology, oceanography and physical processes of the proposed Norfolk Vanguard project not only have the potential to directly affect the identified marine geology, oceanography and physical processes receptors but may also manifest as impacts upon receptors other than those considered within the context of marine geology, oceanography and physical processes. The assessments of significance of these impacts on other receptors are provided in the chapters listed in Table 8.44.

Table 8.44 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	8.7.7.1 and 8.7.7.2 (foundation installation) 8.7.7.5 (offshore cables installation) 8.7.7.9 (array 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).
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	8.6.6.1 and 8.6.6.2 (foundation installation) 8.7.7.5 (offshore cables installation) 8.7.7.9 (array cables installation) 8.7.7.11 (installation vessels) 8.7.8.3 (sediment transport regime) 8.7.8.5 (array cable protection) 8.7.8.6 (offshore 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	8.7.7.5 (cable landfall) 8.7.8.6 (offshore cable protection in nearshore and intertidal zone)	Changes to seabed morphology/sediment transport at the coast could affect the intertidal habitat.

8.10 Interactions

430. The impacts identified and assessed in this chapter have the potential to interact with each other, which could give rise to synergistic impacts as a result 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 8.45 along with an indication as to whether the interaction may give rise to synergistic impacts.

Table 8.45. 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 Offshore Export Cable Installation	Impact 4A: Changes in seabed level due to disposal of sediment from sand wave levelling in the offshore cable corridor	Impact 4B: Interruptions to Bedload Sediment Transport due to Sand Wave Levelling in the offshore cable corridor	Impact 4C: Changes in Seabed Level due to deposition from the suspended sediment plume during export cable installation	Impact 5: Changes in Suspended Sediment Concentrations during Array and Interconnector Cable Installation	Impact 6: Changes in Seabed Level due to Array and Interconnector Cable Installation	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	No	No	Yes	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	No	No	Yes	Yes	Yes	Yes
Impact 2A: Changes in Seabed Level due to Seabed Preparation for Wind Turbine Gravity Anchor Foundation Installation	Yes	No	-	No	Yes	No	No	Yes	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	No	No	Yes	Yes	Yes	Yes
Impact 3: Changes in Suspended Sediment Concentrations during Offshore Export Cable Installation	Yes	Yes	Yes	Yes	-	Yes	Yes	Yes	Yes	Yes	Yes
Impact 4A: Changes in seabed level due to disposal of sediment from sand wave levelling in the offshore cable corridor	No	No	No	No	Yes	-	Yes	Yes	Yes	Yes	Yes
Impact 4B: Interruptions to Bedload Sediment Transport due to Sand Wave Levelling in the offshore cable corridor	No	No	No	No	Yes	Yes	-	Yes	No	No	No
Impact 4C: Changes in Seabed Level due to Offshore Export Cable Installation due to deposition from the suspended sediment plume during export cable installation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	No	Yes	No
Impact 5: Changes in Suspended Sediment Concentrations during Array and Interconnector Cable Installation	Yes	Yes	Yes	Yes	Yes	Yes	No	No	-	No	No
Impact 6: Changes in Seabed Level due to Array and Interconnector Cable Installation	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	-	No
Impact 7: Indentations on the Seabed due to Installation Vessels	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	-

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 for Array and Interconnector Cables	Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures for Offshore Cables	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 for Array and Interconnector Cables	No	No	Yes	No	-	Yes	No
Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures for Offshore Cables	No	No	Yes	No	Yes	-	No
Impact 7: Cable repairs/reburial and maintenance vessel footprints	No	No	No	No	No	No	-

8.11 Summary

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

432. The receptors that have been specifically identified in relation to marine geology, oceanography and 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.

433. 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 8.45.

Table 8.45 Potential impacts identified for marine geology, oceanography and 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	Haisborough, Hammond and Winterton SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Wind Turbine Gravity Anchor Foundation Installation	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 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 Offshore Export Cable 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**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
	East Anglian coast	N/A	N/A	**No impact**	N/A	**No impact**
Impact 4A: Changes in seabed level due to disposal of sediment from sand wave levelling in 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 4B: 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 4C: Changes in Seabed Level due to Offshore Export Cable	Haisborough, Hammond and Winterton SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible**	Disposal in SAC	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Installation	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**
Impact 5: Changes in Suspended Sediment Concentrations during cable installation in the OWF sites	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: Changes in Seabed Level due to Cable Installation in the OWF sites	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**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual 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 cSAC/SCI)**	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 2: Changes to the Wave Regime due	Haisborough, Hammond and	Negligible	Low (near-field), negligible (far-field)	**Negligible (south-east extreme of cSAC/SCI)**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
to the Presence of Wind Turbine Structures	Winterton SAC					
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (south-east extreme of cSAC/SCI)**	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 cSAC/SCI)**	None proposed	**Negligible**
	North Norfolk Sandbanks and Saturn Reef SAC	Negligible	Low (near-field), negligible (far-field)	**Negligible (south and south-east extreme of cSAC/SCI)**	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**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual 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: Morphological and Sediment Transport Effects due to Cable Protection Measures for Array and 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**
Impact 6: Morphological and Sediment Transport Effects due to Cable Protection Measures for Offshore 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**
Impact 7: Cable	Haisborough,	Negligible	Low (near-field),	**Negligible**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
repairs/reburial and maintenance vessel footprints	Hammond and Winterton SAC		negligible (far-field)			
	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**
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	Haisborough, Hammond and Winterton SAC	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**
	North Norfolk	Negligible	Negligible (far-field)	**Negligible**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
foundation removal	Sandbanks and Saturn Reef SAC					
	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 Cables in the OWF sites	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 4: Changes in seabed level due to removal of parts of the cables in the OWF sites	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**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual 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 offshore export cable (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 cSAC/SCI	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**
Cumulative						
Cumulative Construction and	Haisborough, Hammond and	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Decommissioning Impacts with adjacent Wind Farms	Winterton SAC					
	North Norfolk Sandbanks and Saturn Reef cSAC/SCI	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 cSAC/SCI	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	Negligible	Low (near-field), negligible (far-field)	**Negligible**	None proposed	**Negligible**

Potential Impact	Receptor	Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
	Reef cSAC/SCI					
	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**

8.12 References

ABPmer. (2012a). East Anglia Offshore Wind Zonal Environmental Appraisal Report. Appendix G – Physical Processes Baseline and References.
ABPmer. (2012b). East Anglia Offshore Wind Project ONE Windfarm: Marine geology, oceanography and physical processes environmental baseline. Report R3945. May 2012.
ABPmer. (2018). Norfolk Vanguard and Norfolk Boreas Export Cable Route, Sandwave bed-levelling. ABPmer Report No Report R 2920. A report produced by ABPmer for Royal HaskoningDHV, April 2018.
AECOM. (2012). Kelling to Lowestoft Ness Shoreline Management Plan.
BERR. (2008). Review of Cabling Techniques and Environmental Effects applicable to the Offshore Windfarm Industry.
Burningham, H. and French, J. (2016). Historical morphodynamics of the Haisborough Sand bank system. Draft CERU Report No. 162-1. February 2016.
Cameron, T.D.J., Crosby, A., Balson, P.S., Jeffrey, D.H., Lott, G.K., Bulat, J. and Harrison, D.J. (1992). United Kingdom offshore regional report: the geology of the southern North Sea. HMSO, London, 152pp
Centre for Environment, Fisheries and Aquaculture Science (Cefas). (2004). 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. Available at: https://www.cefas.co.uk/publications/files/windfarm-guidance.pdf
Cefas. (2011). Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. Cefas contract report: ME5403 – Module 15
Cooper N. J. and Brew, D.S. (2013). Impacts on the physical environment. In: R.C. Newell and T.A. Woodcock (Eds.): Aggregate dredging and the marine environment: an overview of recent research and current industry practice. The Crown Estate.
Cooper, K., Boyd, S., Eggleton, J., Limpenny, D., Rees, H. & Vanstaen, K. (2007). Recovery of the seabed following marine aggregate dredging on the Hastings Shingle Bank off the southeast coast of England. *Estuarine, Coastal and Shelf Science* 75:547-558.
CWind (2017) unpublished. Norfolk Vanguard Offshore Windfarm Export Cable Installation Study
Deltares, (2012). East Anglia Offshore Wind Farm – Metocean Study. 1205361-000-HYE-0006, Version 1.1, November 2012
Deltares, (2015a). Memo: EAOW additional metocean study - Analyses of extreme water level, current and wind parameters. 1205361-000-HYE-0014, Version 3.0, March 2015.
Deltares, (2015b). Memo: Extreme design criteria at C-East and H. 1220301-000-HYE-0003, Version 1.0, March 2015.
Department of Energy and Climate Change (DECC) (2011a) Overarching National Policy Statement for Energy (EN-1). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_

data/file/47854/1938-overarching-nps-for-energy-en1.pdf
Department of Energy and Climate Change (DECC) (2011b) National Policy Statement for Renewable Energy Infrastructure (EN-3). Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47856/1940-nps-renewable-energy-en3.pdf
East Anglia Offshore Wind (EAOW). (2012a). East Anglia Offshore Wind Zonal Environmental Appraisal Report March 2012
East Anglia Offshore Wind (EAOW). (2012b). East Anglia ONE Environmental Statement. Report to East Anglia Offshore Wind, November 2012
East Anglia Three Ltd (EATL). (2015). East Anglia THREE Environmental Statement. Report to East Anglia Offshore Wind, November 2015
Eisma, D. and Kalf, J. (1987). Dispersal, concentration and deposition of suspended matter in the North Sea. Journal of the Geological Society of London, 144, 161-178.
Energy Technology Support Unit (ETSU) (2000) Wind Information Needs for Planners. ETSU W/14/00564/REP. DTI/Pubb URN 01/779. Available at: http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file18033.pdf
Energy Technology Support Unit (ETSU) (2002) Potential Effects of Offshore Wind Developments on Coastal Processes. ETSU W/35/00596/00/REP. URN 02/1336. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Potential_Effects_of_Offshore_Wind_Developments_on_Coastal_Processes.pdf
Environment Agency. (2011). Coastal flood boundary conditions for UK mainland and islands. Project: SC060064/TR2: Design sea levels. February 2011.
Environment Agency. (2015). Coastal Design Sea Levels - Coastal Flood Boundary Extreme Sea Levels. Available at: https://data.gov.uk/dataset/coastal-design-sea-levels-coastal-flood-boundary-extreme-sea-levels
European Environment Agency. (2017). Global and European Sea Level. Available at: https://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-5/assessment [Accessed on 13/04/2018]
Forewind. (2013). Dogger Bank Creyke Beck Environmental Statement.
Forewind. (2014). Dogger Bank Teesside A & B Environmental Statement.
Fugro EMU. (2013). East Anglia FOUR Offshore Wind Farm Geophysical Survey. Report to Scottish Power Renewables, February 2013.
Fugro (2016). Norfolk Vanguard Offshore Wind Farm. United Kingdom Continental Shelf, North Sea. Report 1 of 3: Geophysical Investigation Report. Volume 2 of 3: Geophysical Site Survey September to November 2016. Report to Vattenfall Wind Power Ltd. Fugro (FSBV) Report No.: GE050-R1.
Fugro. (2017a). Norfolk Vanguard Offshore Wind Farm. United Kingdom Continental Shelf, North Sea. Report 1 of 3: Geophysical Investigation Report. Volume 3 of 3: Geophysical Route Survey September to November 2016. Report to Vattenfall Wind Power Ltd. Fugro

(FSBV) Report No.: GE050-R1.
Fugro. (2017b). Environmental Investigation Report. Norfolk Vanguard Benthic Characterisation Report. UK Continental Shelf, North Sea. Report 3 of 3. Fugro (FSBV) Report No.: GE050-R3. Final (for review) Report to Vattenfall Wind Power Ltd, February 2017.
Fugro. (2017c). Norfolk Vanguard Offshore Wind Farm. United Kingdom Continental Shelf, North Sea. Report 2 of 3: Geotechnical Investigation Report. Measured and Derived Geotechnical Parameters and Final Results. Report to Vattenfall Wind Power Ltd. Fugro (FSBV) Report No.: GE050-R2.
Hiscock, D.R. and Bell, S. (2004). Physical impacts of aggregate dredging on sea bed resources in coastal deposits. Journal of Coastal Research, 20 (10), 101-114.
HM Government. (2011). UK Marine Policy Statement
HM Government. (2014). East Inshore and East Offshore Marine Plan
HR Wallingford, Posford Haskoning, Cefas and D'Olier, B. (2002). Southern North Sea Sediment Transport Study Phase 2: Sediment Transport Report. Report No. EX4526, August 2002.
JNCC and Natural England. (2010). Special Area of Conservation (SAC): Haisborough, Hammond and Winterton. SAC Selection Assessment, Version 6.0, August 2010.
JNCC and Natural England. (2011). General advice on assessing potential impacts of and mitigation for human activities on Marine Conservation Zone (MCZ) features, using existing regulation and legislation. Available at: http://jncc.defra.gov.uk/pdf/MCZ_ActivitiesAdvice_Final.pdf
John, S.A., Challinor, S.L. Simpson, M. Burt, T.N. and Spearman, J. (2000). Scoping the assessment of sediment plumes from dredging. CIRIA Publication.
Kenyon, N.H. and Cooper, W.S. (2005). Sand banks, sand transport and offshore wind farms. DTI SEA 6 Technical Report
Lambkin, D.O., Harris, J.M., Cooper, W.S., Coates, T., (2009). Coastal Process Modelling for Offshore Wind Farm Environment Impact Assessment: Best Practice Guide. COWRIE. Available at: https://www.thecrownestate.co.uk/media/5903/2009-09%20Coastal%20process%20modelling%20for%20offshore%20wind%20farm%20EIA%20-%20best%20practice%20guide.pdf
Lowe, J.A., Howard, T.P., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S., Bradley, S. (2009). UK Climate Projections science report: Marine and coastal projections. Met Office Hadley Centre, Exeter, UK.
Masselink, G. and Russell, P. (2013). Impacts of climate change on coastal erosion. *Marine Climate Change Impacts Partnership: Science Review.* 2013: 71-86
Marine Management Organisation (MMO). (2012). East Inshore and East Offshore Marine Plan Areas: Evidence and Issues. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/312393/east_evidence_issues_overview.pdf
MESL (Marine Ecological Surveys Ltd). (2011). East Anglia Offshore Windfarm Zonal

Environmental Appraisal: Benthic Biological characterisation Report.
Natura 2000. (2015). Haisborough, Hammond and Winterton Natura 2000 Standard Data Form. Available at <http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=UK0030369>
Natural Environment Research Council. (2016). Land-Ocean Interaction Study (LOIS). Found at https://www.bodc.ac.uk/projects/data_management/uk/lois/.
Newell, R.C., Seiderer, L.J., Robinson, J.E., Simpson, N.M., Pearce, B and Reeds, K.A., (2004). Impacts of overboard screening on sea bed and associated benthic biology community structure in relation to marine aggregate extraction. Technical Report to the Office of the Deputy Prime Minister and Minerals Industry Research Organisation. Project No. SAMP 1.022, Marine Ecological Surveys Ltd, St. Ives, Cornwall.
Norfolk Vanguard Ltd. (2017). Norfolk Vanguard Preliminary Environmental Information Report. Available at: https://corporate.vattenfall.co.uk/projects/wind-energy-projects/vattenfall-in-norfolk/norfolkvanguard/documents/preliminary-environmental-information-report/
Riggall. (2016). HDD Feasibility Report. Cable Landfalls for East Anglia North Tranche 1 (EAN) U.K. Report Reference No.:2015001RA-FR01.
Royal HaskoningDHV. (2016). Norfolk Vanguard Offshore Wind Farm Environmental Impact Assessment Scoping Report.
The Planning Inspectorate. (2016). Scoping Opinion Proposed Norfolk Vanguard Offshore Wind Farm.
Tillin, H.M., Houghton, A.J., Saunders, J.E. Drabble, R. and Hull S. C. (2011). Direct and indirect impacts of aggregate dredging. Science Monograph Series No. 1. MEPF 10/P144.
Vincent, C.E., McCave, I.N. and Clayton, K.M. (1983). The establishment of a sand budget for the East Anglian Coast and its implications for coastal stability. Shoreline Protection, Thomas Telford Ltd, London.
Whiteside. P.G.D., Ooms, K. and Postma, G.M. (1995). Generation and decay of sediment plumes from sand dredging overflow. Proceedings of the 14th World Dredging Congress. Amsterdam, The Netherlands. World Dredging Association, 877 – 892.