East Anglia TWO Offshore Windfarm

Chapter 7

Marine Geology, Oceanography and Physical Processes

Environmental Statement
Volume 1

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Table of Contents

The figures in ***Chapter 7 Marine Geology, Oceanography and Physical Processes*** are listed in the table below and can be found in ***Volume 2***.

Figure number	Title
7.1	Receptor groups for marine geology, oceanography and physical processes
7.2	Bathymetry and bedforms of the East Anglia TWO windfarm area
7.3	Bathymetry and bedforms of the offshore cable corridor
7.4	Position of the amphidromic point
7.5	Zone of potential influence on the tidal regime
7.6	Zone of potential influence on the wave regime
7.7	Refined offshore cable corridor
7.8	Zone of potential cumulative influence on the wave regime
7.9	Zone of potential cumulative influence on the tidal regime

Chapter 7 Marine Geology, Oceanography and Physical Processes appendices are presented in **Volume 3** and listed in the table below.

Appendix number	Title
7.1	Marine Geology, Oceanography and Physical Processes Consultation Responses
7.2	Individual Project and Cumulative Wave Modelling
7.3	Assessment of Transboundary Effects

Glossary of Acronyms

CIA	Cumulative Impact Assessment
DCO	Development Consent Order
EIA	Environmental Impact Assessment
EPP	Evidence Plan Process
ES	Environmental Statement
GBS	Gravity Base Structure
HDD	Horizontal Directional Drilling
km	Kilometre
km^2	Kilometre Squared
LAT	Lowest Astronomical Tide (CD)
m	Metre
m^2	Metre Squared
m^3	Metre Cubed
m/s	Metres Per Second
MCZ	Marine Conservation Zone
mg/l	Milligrams Per Litre
mm	Millimetre
MW	Megawatt
OD	Ordnance Datum
PEIR	Preliminary Environmental Information Report
rMCZ	Recommended Marine Conservation Zone
s	Second (unit of time)
SMP	Shoreline Management Plan
SAC	Special Area of Conservation
SPA	Special Protection Area
SPR	ScottishPower Renewables
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
ZEA	Zonal Environmental Appraisal

Glossary of Terminology

Amphidromic point	The centre of an amphidromic system; a nodal point around which a standing-wave crest rotates once each tidal period.
Applicant	East Anglia TWO Limited.
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 bed.
Beach	A deposit of non-cohesive sediment (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively ‘worked’ by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds.
Bedforms	Features on the 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	A change in global or regional climate patterns. Within this chapter this usually relates to any long-term trend in mean sea level, wave height, wind speed etc., due to climate change.
Closure depth	The depth that represents the ‘seaward limit of significant depth change’ but is not an absolute boundary across which there is no cross-shore sediment transport.
Coastal processes	Collective term covering the action of natural forces on the coastline and nearshore sea bed.
Cohesive sediment	Sediment containing a significant proportion of clays, the electromagnetic properties of which causes the particles to bind together.
Construction, operation and maintenance platform	A fixed offshore structure required for construction, operation, and maintenance personnel and activities.
Crest	Highest point on a bedform or wave.
Cross-shore	Perpendicular to the coastline. Also referred to as shore normal.
Current	Flow of water generated by a variety of forcing mechanisms (e.g. waves, tides, wind).
East Anglia TWO project	The proposed project consisting of up to 75 wind turbines, up to four offshore electrical platforms, up to one construction operation and maintenance platform, inter-array cables, platform link cables, up to one operational meteorological mast, up to two offshore export cables, fibre optic cables, landfall infrastructure, onshore cables and ducts, onshore substation, and National Grid infrastructure.
East Anglia TWO windfarm site	The offshore area within which wind turbines and offshore platforms will be located.
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).
Evidence Plan Process	A voluntary consultation process with specialist stakeholders to agree the approach to the EIA and the information required to support HRA.

Export cables	The cables which transmit electricity from the offshore electrical platform to the landfall.
Flood tide	The rising tide, immediately following the period of low water and preceding the period of high water.
Foreshore	A morphological term for the lower shore zone/area on the beach that lies between mean low and high water.
Glacial till	Poorly-sorted, non-stratified and unconsolidated sediment carried or deposited by a glacier.
Gravel	Loose, rounded fragments of rock larger than sand but smaller than cobbles. Sediment larger than 2mm (as classified by the Wentworth scale used in sedimentology).
Habitat	The environment of an organism and the place where it is usually found.
High water	Maximum level reached by the rising tide.
Holocene	The last 10,000 years of earth history.
Horizontal directional drilling (HDD)	A method of cable installation where the cable is drilled beneath a feature without the need for trenching.
Hydrodynamic	The process and science associated with the flow and motion in water produced by applied forces.
Inter-array cables	Offshore cables which link the wind turbines to each other and the offshore electrical platforms, these cables will include fibre optic cables.
Intertidal	Area on a coast that lies between Lowest Astronomical Tide (LAT) and Highest Astronomical Tide (HAT).
Landfall	The area (from Mean Low Water Springs) where the offshore export cables would make contact with land and connect to the onshore cables.
Lithology	The description of the macro features of a rock or rock-type.
Longshore transport rate	Rate of transport of sediment parallel to the coast. Usually expressed in cubic metres per year.
Long-term	Refers to a time period of decades to centuries.
Low water	The minimum height reached by the falling tide.
Mean sea level	The average level of the sea surface over a defined period (usually a year or longer).
Megaripples	Bedforms with a wavelength of 0.6 to 10.0m and a height of 0.1 to 1.0m. These features are smaller than sand waves but larger than ripples.
Neap tide	A tide that occurs when the tide-generating forces of the sun and moon are acting at right angles to each other, so the tidal range is lower than average.
Nearshore	The zone which extends from the swash zone to the position marking the start of the offshore zone (~20m).
Numerical modelling	Refers to the analysis of coastal processes using computational models.
Offshore	Area to seaward of nearshore in which the transport of sediment is not caused by wave activity.
Offshore cable corridor	This is the area which will contain the offshore export cables between offshore electrical platforms and transition bays located at landfall.
Offshore development area	The East Anglia TWO windfarm site and offshore cable corridor (up to Mean High Water Springs).

Offshore electrical platform	A fixed structure located within the windfarm 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 would bring electricity from the offshore electrical platforms to the landfall. These cables will include fibre optic cables.
Offshore platform	A collective term for the construction, operation and maintenance platform and the offshore electrical platforms.
Platform link cable	Electrical cable which links one or more offshore platforms, these cables will include fibre optic cables.
Pleistocene	An epoch of the Quaternary Period (between about 2 million and 10,000 years ago) characterised by several glacial ages.
Quaternary Period	The last 2 million years of earth history incorporating the Pleistocene ice ages and the post-glacial (Holocene) Period.
Safety zone	A marine area declared for the purposes of safety around a renewable energy installation or works / construction area under the Energy Act 2004.
Sand	Sediment particles, mainly of quartz with a diameter of between 0.063mm and 2mm. Sand is generally classified as fine, medium or coarse.
Sand wave	Bedforms with wavelengths of 10 to 100m, with amplitudes of 1 to 10m.
Scour protection	Protective materials to avoid sediment being eroded away from the base of the foundations as a result of the flow of water.
Sea level	Generally refers to 'still water level' (excluding wave influences) averaged over a period of time such that periodic changes in level (e.g. due to the tides) are averaged out.
Sea-level rise	The general term given to the upward trend in mean sea level resulting from a combination of local or regional geological movements and global climate change.
Sediment	Particulate matter derived from rock, minerals or bioclastic matter.
Sediment transport	The movement of a mass of sediment by the forces of currents and waves.
Shallow water	Commonly, water of such depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than half the surface wave length as shallow water.
Shore platform	A platform of exposed rock or cohesive sediment exposed within the intertidal and subtidal zones.
Short-term	Refers to a time period of months to years.
Significant wave height	The average height of the highest of one third of the waves in a given sea state.
Silt	Sediment particles with a grain size between 0.002mm and 0.063mm, i.e. coarser than clay but finer than sand.
Spring tide	A tide that occurs when the tide-generating forces of the sun and moon are acting in the same directions, so the tidal range is higher than average.
Storm surge	A rise in water level on the open coast due to the action of wind stress as well as atmospheric pressure on the sea surface.
Surge	Changes in water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and the astronomical tide predicted using harmonic analysis.
Suspended sediment	The sediment moving in suspension in a fluid kept up by the upward components of the turbulent currents or by the colloidal suspension.

Swell waves	Wind-generated waves that have travelled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter crests than waves within their fetch.
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.

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7 Marine Geology, Oceanography and Physical Processes

7.1 Introduction

1. This chapter of the Environmental Statement (ES) describes the marine physical environment of the proposed East Anglia TWO project, including the East Anglia TWO windfarm site and the offshore cable corridor to the landfall location just north of Thorpeness.

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

3. This chapter of the ES was written by Royal HaskoningDHV marine physical processes specialists and incorporates interpretation of geophysical survey data collected by Gardline (2017) and benthic survey data collected by Bibby Hydromap and Benthic Solutions (2018a, b).

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

   - A Physical Process Method Statement (Appendix 2.1 of the Scoping Report (ScottishPower Renewables (SPR) (2017)), prepared as part of the Evidence Plan Process (EPP), incorporating a baseline assessment of winds, water levels, waves, sediment regime, process controls on sediment mobility and morphological regime, as well as detailed reviews of the findings from: (i) Zonal Cumulative Impact Assessment for the former East Anglia Zone; (ii) East Anglia ONE ES; and (iii) East Anglia THREE ES;
   - Interpretation of existing datasets collected for earlier projects (most notably the Zonal Cumulative Impact Assessment for the former East Anglia Zone) and survey data specifically collected for the present project including bathymetry, geophysical, geotechnical, metocean and environmental data;
   - The existing evidence base regarding the effects of offshore windfarm developments on the physical environment;
   - ***Appendix 7.2*** which provides an Individual Project and Cumulative Wave Modelling Study, assessing potential impacts of the proposed East Anglia

TWO project on the wave climate, alone and cumulatively with other windfarms;

- ***Appendix 7.3*** which provides an Assessment of Transboundary Effects;
- Detailed numerical modelling studies undertaken previously for both the East Anglia Zonal Environmental Appraisal (ZEA) and the ES of East Anglia ONE;
- Desk-based assessments undertaken for the East Anglia THREE Environmental Impact Assessment (EIA) and the Norfolk Vanguard EIA;
- Discussion and agreement with key stakeholders; and
- Expert-based assessment and judgement by Royal HaskoningDHV.

5. The potential effects on marine physical processes are assessed conservatively using realistic worst-case scenarios for the project.

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

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

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

7.2 Consultation

8. Consultation is a key feature of the EIA process, and continues throughout the lifecycle of the proposed East Anglia TWO project, from the initial stages through to consent and post-consent.

9. To date, consultation with regards to Marine Geology, Oceanography and Coastal Processes has been undertaken via Expert Topic Group (ETG), described within ***Chapter 5 EIA Methodology***, with meetings held in April 2017 March 2018 and June 2019, through the East Anglia TWO Scoping Report (SPR, 2017) and the Preliminary Environmental Information Report (PEIR) (SPR 2019). Feedback received through this process has been considered in preparing the ES where appropriate and this chapter has been updated for the final assessment submitted within the Development Consent Order (DCO) application.

10. The responses received from stakeholders with regards to the Scoping Report, PEIR, as well as feedback to date from the ETGs, are summarised in ***Appendix 7.1***, including details of how these have been taken account of within this chapter.

11. Ongoing public consultation has been conducted through a series of Public Information Days (PIDs) and Public Meetings. PIDs have been held throughout Suffolk in November 2017, March / April 2018, June / July 2018 and February / March 2019.

12. Consultation phases are explained further in ***Chapter 5 EIA Methodology***. Full details of the proposed East Anglia TWO project consultation process are presented in the Consultation Report (document reference 5.1), which has been submitted as part of this DCO application.

13. ***Table 7.1*** summarises public consultation feedback pertaining to Marine Geology, Oceanography and Physical Processes.

Table 7.1 Public Consultation Responses relevant to Marine Geology, Oceanography and Physical Processes

Topic	Response / where addressed in the ES
Phase 1	
• Concerns over coastal erosion from construction work and presence of offshore export cables • Cumulative shoreline impacts outside natural variations in relation to wind pressure and velocity perturbation at the turbine array propagating along the wave fetch length	Project design decisions for the landfall and nearshore cable routeing and protection are discussed in ***Chapter 4 Site Selection and Alternatives*** and ***Chapter 6 Project Description***. Also see ***section 7.5.8*** and ***7.6.2.7.*** Cumulative impacts with regards to the wave regime are discussed in ***section 7.7.1***.
Phase 2	
• Concerns over impact of windfarms on waves and shores	Wave modelling was conducted to assess the potential impacts of the proposed East Anglia TWO project and cumulatively with other windfarms in the areas. This information is presented in ***Appendix 7.2***
Phase 3	
None	n/a
Phase 3.5	
• Fragile coastline • Impacts of vibration causing coastal erosion/ retreat and leading to impacts down the coast • Unstable cliffs are receding • Damage to Thorpeness cliffs • Impacts on coastal processes	Wave modelling was conducted to assess the potential impacts of the proposed East Anglia TWO project and cumulatively with other windfarms in the areas. An assessment of the potential impacts of the project(s) on the shoreline has been produced and is presented in ***Appendix 7.2.*** The potential impacts of the project on sediment transport processes and morphological effects due to the installation of project infrastructure are assessed in ***section 7.6.2***.

Topic	Response / where addressed in the ES
Phase 4	
- Further information regarding site selection for landfall - Concerns regarding coastal erosion, cliff stability and coralline crag.	A landfall site selection report has been appended (***Appendix 4.6***) for ES ***Chapter 4 Site Selection***. This is a desk based assessment which carefully considers the history and status of the Coraline Crag and Sizewell cliffs. This has been factored into the selection of an optimum location for the landfall at the southern end of the offshore cable corridor at the coast.

7.3 Scope

7.3.1 Study Area

14. The East Anglia TWO windfarm site is in the southern North Sea, encompassing a sea bed area of approximately 218.4km^2. It is located approximately 33km from its nearest point to the coast at Southwold and 37km to the port at Lowestoft. The offshore cable corridor joins the East Anglia TWO windfarm site to the landfall location just north of Thorpeness. The offshore infrastructure required for the proposed East Anglia TWO project is outlined in ***Chapter 6 Project Description***.

15. The assessment of effects on marine geology, oceanography and physical processes considers the direct footprint of the proposed East Anglia TWO project (near-field) and the wider areas of sea bed and coast that potentially could be affected (far-field).

7.3.2 Worst Case

16. The design of the proposed East Anglia TWO project (including number of wind turbines, layout configuration, requirement for scour protection, electrical design, etc.) is not yet fully determined, and may not be known until sometime after the DCO has been granted. Therefore, in accordance with the requirements of the Project Design Envelope (also known as the Rochdale Envelope) approach to EIA (Planning Inspectorate 2018) (as discussed in ***Chapter 5 EIA Methodology***), realistic worst case scenarios in terms of potential effects upon marine geology oceanography and physical processes are adopted to undertake a precautionary and robust impact assessment.

17. Definition of the realistic worst case scenarios has been made from consideration of the proposed East Anglia TWO project that is presented in ***Chapter 6 Project Description***, alongside the mitigation measures that have been embedded in the design (***section 7.3.3***).

7.3.2.1 Foundation Layout

18. The worst case scenario is based on wind turbines with a blade tip height of between 250 and 300m, therefore the worst case is based on either 60 x 300m or 75 x 250m turbines. The wind turbines would be arranged with a minimum separation between each of 800m in an in-row direction and 1,200m in an inter-row direction although the nominal separation distances are anticipated to be greater.

7.3.2.2 Foundation Type

19. There may be only one foundation type used or alternatively a combination of types and sizes could be used across the East Anglia TWO windfarm site. Some types and sizes of foundation are more favourable for certain water depths, ground conditions or wind turbine models and the final arrangements would be confirmed during detailed design.

20. Accordingly, to ensure that the proposed East Anglia TWO project is adequately assessed for the purposes of EIA, foundation sizes covering the range from 250m to 300m wind turbines, and including monopiles, four-legged jackets on pin piles, four-legged jackets on suction caissons, suction caissons and gravity base structures (GBS) have been considered to determine the realistic worst case scenario. ***Table 7.2*** presents a summary of the physical properties of each of these foundation options to enable a direct comparison between them, to assist with defining the worst case scenario.

Table 7.2 Comparison of Physical Parameters for Different Foundation Types

Foundation Type	Wind Turbine blade tip height (m)	Maximum Foundation Dimensions (m/foundation)	Maximum Foundation Footprint (m^2/foundation)	Maximum Foundation Footprint with Scour Protection (m^2/foundation)	Maximum Volume of Surface Sediment Release from Sea Bed Preparation (m^3/foundation)	Maximum Volume of Sub-surface Sediment Release from Foundation Drilling (m^3/foundation)
Gravity base structure	250	53 (basal diameter)	2,206	19,856	22,585	N/A
	300	60 (basal diameter)	2,827	25,447	25,875	N/A
Jacket with pin piles (4 legs)	250	45 x 45 (leg spacing)	2,025	4,726	19,125	3,016
	300	52 x 52 (leg spacing)	2,767	5,331	22,405	4,321
Jacket with suction caissons (4 legs)	250	14.5 (diameter per caisson)	3,080	9,801	23,732	N/A
	300	16 (diameter per caisson)	4,096	12,544	27,865	N/A
Suction caisson	250	31 (diameter)	755	3,020	13,840	N/A
	300	35 (diameter)	963	3,849	15,250	N/A
Monopile	250	13 (diameter)	133	3,319	8,485	5,972.95
	300	15 (diameter)	177	4,418	9,000	7,952.16

21. Due to their presence on the sea bed and / or in the water column, wind turbine foundations have the potential to cause the following principal effects on the physical environment:

- Footprint effects – the presence of a foundation would have a direct covering effect on the underlying sea bed morphology, resulting in direct loss of a feature.

- Blockage effects – the presence of a foundation may modify the progression of waves, tidal currents, and sediment transport over the lifetime of a project.
- Sediment disturbance effects – foundations may lead to disturbance of the sea bed sediments due to dredging or piling operations during the construction phase or scour hole formation during the operational phase.

22. With respect to footprint effects, jackets with (up to four) suction caissons present the greatest physical footprint on the sea bed without scour protection, whereas GBS present the greatest footprint when considered with scour protection. On an individual wind turbine basis without scour protection, the 300m jacket with suction caissons foundation has the greatest individual and overall footprint at 4,096m^2 and 245,760m^2 respectively. When scour protection is considered, the 300m GBS foundation has the greatest individual footprint and overall footprint at 25,446m^2 and 1,526,814m^2 respectively.

23. With respect to blockage effects, there is now a considerable evidence base across the offshore windfarm industry derived from numerous EIA that are available in the public domain (confirmed by a review of modelling studies from around 30 windfarms in the UK and European waters presented in Seagreen 2012) which indicates that the greatest potential effect is associated with conical GBS. This is because these structures occupy a significant proportion of the water column as a solid mass (as opposed to an open lattice of slender columns and cross-members, found in jackets or tripods, or a single slender column like a monopile). They do, therefore, have the potential to affect wave propagation and near-surface tidal currents in a manner that other foundation types do not. In addition, conical GBS can influence near-bed currents and sea bed sediment transport processes.

24. The greatest blockage effect from an individual wind turbine arises from a GBS for a 300m wind turbine. For the windfarm site as a whole, it is not possible to quantify whether a larger number of smaller rated wind turbines would cause worse blockage than a smaller number of larger rated wind turbines (or some combination in between) without detailed numerical modelling. As a conservative approach, the largest dimensions for a GBS (the 300m wind turbine foundation) together with the greatest number of wind turbines (the 250m layout) have been adopted as a worst case scenario. Whilst these arrangements would not be used in practice, their consideration avoids potential uncertainty if different combinations were considered.

25. With respect to sediment disturbance effects, these can be considered separately for the construction phase, the operational phase and the decommissioning phase.

26. During the construction phase, it is probable that there would be a need for some sea bed preparation associated with all foundation types. This has the potential to disturb sediments at, or near to, the surface of the sea bed (down to relatively shallow depths below the bed), hereafter called near-surface sediments.

27. The greatest volumes of near-surface sediment disturbance due to sea bed preparation activities during construction of individual wind turbines would be associated with jackets with suction caissons for the 300m wind turbines (this is marginally greater than for the conical GBS for the 300m wind turbines). When considering the whole windfarm site, the combined effects of the larger number of smaller (250m) wind turbines on jackets with suction caissons yields the greatest volumes (1,779,890.63m^3).

28. In addition, there is potential that the installation of some foundation types (notably monopiles and jackets using four pin piles) may require drilling (although the preference is for driving the piles wherever it is feasible to achieve this). Any drilling of piles into the sea bed would have the greatest potential to release sediments from tens of metres below the sea bed, hereafter called sub-surface sediments, into the water column (to depths of up to 45m below the sea bed for monopiles and up to 65m below the sea bed for pin piles). These sub-surface sediments are likely to have a different physical composition to near-surface sediments and therefore may be more widely dispersed by tidal currents (i.e. the drill arisings may be overall finer than the near-surface sediments).

29. The greatest volumes of sub-surface sediment disturbance due to drilling activities during construction of individual wind turbines would be associated with monopiles for the 300m wind turbines. When considering the windfarm site as a whole, the 60 300m wind turbines yields the greatest volumes (47,713m^3).

30. During the operational phase, there is potential, if no scour protection is provided, for the presence of the foundations to cause scour-hole formation in the sea bed adjacent to the foundation due to flow acceleration in its immediate vicinity (tens of metres).

31. As the need for scour protection is not being determined until the wind turbine locations and the associated foundation types are known, the worst case scenario needs to consider both the formation of scour holes in the absence of scour protection (and the associated fate of the scoured sea bed sediment) and, as a corollary, the extent of scour protection that would be required if it is deemed necessary to limit scour hole development.

32. Scour assessments have been completed for other windfarms in the former East Anglia Zone using metocean data derived from earlier modelling studies

(GL Noble Denton 2011) and both zone-wide and project-specific field surveys (water depth, soil type and soil strength), to enable first-order estimates of scour hole formation to be made for a range of different foundation types and sizes. These previous assessments identified that the scour volumes for all foundation types considered were greatest in relatively shallow water and reduced with increasing water depth. This was primarily because of a reduction in wave-induced stirring at the sea bed with greater water depth.

33. These previous scour assessments showed that the maximum volumes of sediment likely to be released from sea bed preparation are considerably greater (greater than five times) than the maximum volumes likely to be released by scour, even under the conservative worst case scour scenarios considered. Due to this, the assessment of scour during the operational phase (in the absence of scour protection) has been based on the findings from the assessments of the effect of sea bed preparation, and scaled down by a factor of five.

34. During the decommissioning phase, worst case scenarios involve activities that are similar to those that would take place during the construction phase.

35. ***Table 7.3*** presents a summary of the worst case scenarios for individual wind turbine foundations and whole-windfarm foundations.

Table 7.3 Summary of Realistic Worst Case Scenarios for Wind Turbine Foundations

Type of Effect	Individual wind turbine	Whole windfarm site
Footprint - Foundation only	Jacket with suction caissons (300m wind turbine) = 4,096m^2	Jackets with suction caissons (300m wind turbine) = 245,760m^2
Footprint - Foundation and scour protection	GBS (300m wind turbine) = 25,446.9m^2	GBS (300m wind turbine) = 1,526,814.03m^2
Blockage	GBS (300m wind turbine)	GBS (300m wind turbine)
Near-surface sediment disturbance (construction/decommissioning)	Jacket with suction caissons (300m wind turbine) = 27,865m^3	Jackets with suction caissons (250m wind turbine) = 1,779,890.63m^3
Sub-surface sediment disturbance (construction / decommissioning)	Monopile (300m wind turbine) = 7,952.16m^3	Monopile (300m wind turbine) = 47,712.94m^3
Near-surface sediment disturbance (scour during operation, in the absence of scour protection)	Jacket with suction caissons (300m wind turbine), reduced by a factor of five = 5,000m^3	Jackets with suction caissons (300m wind turbine), reduced by a factor of five and conservatively applied to maximum turbine number

Type of Effect	Individual wind turbine	Whole windfarm site
		layout (250m wind turbine) = 375,000m^3

7.3.2.3 Meteorological Masts

36. One operational meteorological mast may be installed within the East Anglia TWO windfarm site. This may be installed on a monopile, four-legged jacket on pin piles, four-legged jacket on suction caissons, a suction caisson or GBS foundation.

37. ***Table 7.4*** presents a summary of the worst case scenarios for a single meteorological mast foundation.

Table 7.4 Summary of Realistic Worst Case Scenarios for a Meteorological Mast Foundation

Type of Effect	Individual met mast / whole windfarm
Footprint - Foundation only	Jacket with suction caissons (650m^2)
Footprint - Foundation and scour protection	GBS (based on 300m wind turbine foundation) (3,141.59m^2)
Blockage	GBS (based on 300m wind turbine foundation)
Near-surface sediment disturbance (construction/decommissioning)	Jacket with suction caissons (based on 300m wind turbine foundation) = 27,865m^3
Sub-surface sediment disturbance (construction/decommissioning)	Monopile (based on 300m wind turbine foundation) = 7,952.16m^3
Near-surface sediment disturbance (scour during operation, in the absence of scour protection)	Jacket with suction caissons (based on 300m wind turbine foundation), reduced by a factor of five

7.3.2.4 Offshore Platforms

38. Up to four offshore electrical platforms and up to one construction, operation and maintenance platform could be used within the East Anglia TWO windfarm site. The offshore platforms would be installed on eight-legged jackets on pin piles, eight-legged jackets on suction caissons or GBS foundations.

39. ***Table 7.5*** presents a summary of the worst case scenarios for offshore platform foundations.

Table 7.5 Summary of Worst Case Scenarios for Offshore Platform Foundations

Type of Effect	Individual platform	Whole Windfarm (five platforms)
Footprint - Foundation only	Jacket with suction caissons (5,676m^2)	Jackets with suction caissons (28,380m^2)

Type of Effect	Individual platform	Whole Windfarm (five platforms)
Footprint - Foundation and scour protection	Jacket with suction caissons (15,276m^2)	Jackets with suction caissons (76,380m^2)
Blockage	GBS (based on 300m wind turbine foundation)	
Near-surface sediment disturbance (construction/decommissioning)	Jacket with suction caissons (133,760m^3)	Jacket with suction caissons (668,800m^3)
Sub-surface sediment disturbance (construction/decommissioning)	Jacket with pin piles (8,641.89m^3)	Jacket with pin piles (43,209.45m^3)
Near-surface sediment disturbance (scour during operation, in the absence of scour protection)	Jacket with suction caissons (based on 300m wind turbine foundation), reduced by a factor of five.	

7.3.2.5 Cables

40. There would be export cables, inter-array cables and platform link cables installed, with slight differences in the cable requirements depending on the choice of either a northern route or southern route for the offshore cable corridor. The maximum length of each export cable required would be 80km.

41. For the purposes of this assessment, the worst case scenario in terms of area of sea bed affected accounts for a maximum length of 80km for each export cable. There would be up to two cables installed resulting in a maximum cable length of 160km.

42. Up to two export cables would each be located within the offshore cable corridor, making landfall just north of Thorpeness in Suffolk. In addition, there would be up to 75km of platform link cables and up to 200km of inter-array cables installed (under the worst case).

7.3.2.5.1 Cable Laying

43. It is intended that the cables for the proposed East Anglia TWO project would be buried below the sea bed to depths of 1 to 3m. The actual depths would be determined following detailed investigations and design. In some areas, where large sand waves or megaripples are present, sea bed levelling may be required before the cables can be installed. Such levelling would only be intended to prevent exposure of the cables and the formation of free-spans. None of the levelling would affect areas close to the coast where large sand waves have a wave-breaking effect.

44. Indicative volumes of sediment removed for sand wave levelling (pre-sweeping) would be up to 1,550,000m^3 (550,000m^3 in the windfarm site and 1,000,000m^3 in the offshore cable corridor). This volume is based on the under-construction

East Anglia ONE project which is similar in scale and has a similar geographical area to the proposed East Anglia TWO project. The sediment released at any one time would depend on the capacity of the dredger. For pre-sweeping in the offshore cable corridor, the profile of levelling works along the export cables would be 60m wide, with an average depth of 2.5m and a slope gradient of 1:4. An assumption of 10km of sand wave levelling / pre-sweeping in the offshore cable corridor results in an area of sea bed of up to 800,000m^2 being affected. Any required sand wave levelling is anticipated to be in discrete areas and not along the full length of the corridor. Sediment arising from sand wave clearance in the offshore cable corridor would be deposited back within the corridor at locations which avoid sensitive features. These locations within the disposal sites would be determined post consent in consultation with Natural England and the MMO.

45. There may also be a requirement for backhoe dredging in the offshore cable corridor, for example, at the Horizontal Direct Drilling (HDD) pop-out location or in areas of difficult ground, which could result in a V-shaped trench cross section of up to 8.6m wide x 4m deep x 2,000m long per export cable which would result in a maximum area of sea bed disturbance of 34,400m^2 and a maximum volume of 68,800m^3 of sediment displacement for two export cables. All sediment material generated would be disposed of in a licensed disposal area as set out in the Site Characterisation Report (Windfarm Site) (document reference 8.15) and the Site Characterisation Report (Offshore Cable Corridor) (document reference 8.16).

46. Indicative installation methods and rates presently being considered are described in ***Table 7.6***.

Table 7.6 Cable Installation Methods and Rates

Technique	Description	Installation Rate (m/hour)
Ploughing	Cutting through the sea bed with a blade, behind which the cable is laid	300
Trenching or cutting	Excavating a trench whilst temporarily placing the excavated sediment adjacent to the trench and back-filling the trench once the cable has been laid	30-80
Jetting	Fluidising the sea bed using a combination of high-flow low pressure and low-flow high pressure water jets, enabling	150-450

Technique	Description	Installation Rate (m/hour)
	the cable to sink beneath the sediment surface	
Vertical injector (shallow water only)	Using a large jetting or cutting share strapped to the side of a barge for cable laying at the foot of a trench in shallow waters	30-80

47. Jetting is considered to be the worst case cable installation technique since it results in the largest volume of suspended sediment off the sea bed and into the water column.

48. For purposes of the EIA, the worst case scenario assumes that some form of cable protection measures would be required in areas where the cable cannot be buried (e.g. areas of exposed bedrock) and at cable crossings. Cable protection measures presently being considered include rock placement, concrete mattresses, fronded concrete mattresses, and uraduct shell.

49. The worst case scenario assumes that all cable crossings and up to 5% of the length of the export cables, and 10% of the length inter-array cables and platform link cables would be unburied and require protection. This is based on experience from East Anglia ONE. This would amount to a combined sea bed area of 417,350m^2, representing approximately 0.12% (when assuming as a realistic worst case that the larger northern offshore cable corridor route option is chosen) of the total sea bed area within the East Anglia TWO windfarm site (218.4km^2) and northern offshore cable corridor area (137.6km^2).

50. The maximum height of cable protection measures above the sea bed would range up to 2.25m.

51. During the construction phase, cables would be installed using a best practice approach with the objective of minimising, as far as practicable, possible effects on key receptors (e.g. marine water and sediment quality, fish and shellfish ecology, commercial fisheries, benthic ecology, etc.). A detailed cable laying plan would be developed pre-construction which would incorporate a cable burial risk assessment (see ***Appendix 6.3***). This would ascertain burial depths and cable laying techniques with the objective of achieving optimum cable burial, thereby minimising the lengths of remaining unburied cable that would require protection.

52. The applicant would adopt a hierarchical approach to cable protection options. Cable will be buried where this can be practicably achieved. In the event that full burial of lengths of inter-array, platform links and export cable cannot be

achieved, protection options would be assessed using a number of criteria, including selection of protection methods that would cause least disturbance to sensitive receptors.

7.3.2.6 Cable Landfall

53. The export cables would make landfall just to the north of Thorpeness in Suffolk. Assessments of coastal erosion have been undertaken to ensure that the cable ducts will be installed onshore with a suitable setback distance to allow for natural coastal erosion.

54. Horizontal Directional Drilling (HDD) techniques will be used to install the export cable at the landfall, ensuring no impacts on the intertidal zone. Although the achievable length of HDD will be affected by limitations of cable characteristics and the drill profile (i.e. the angle of the bore), the maximum length would be 2km.

7.3.3 Mitigation and Best Practice

55. The Applicant 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.

56. A range of different information sources have been considered as part of embedding mitigation into the design of the project (for further details see ***Chapter 6 Project Description***, ***Chapter 4 Site Selection and Assessment of Alternatives***) including engineering requirements, ongoing discussions with stakeholders and regulators, commercial considerations and environmental best practice.

57. Where possible, the embedded mitigation has been taken into account in each relevant impact assessment when assessing the potential magnitude of the impact.

58. In addition to embedded mitigation, if further mitigation is required and possible, (i.e. those measures to prevent or reduce any remaining significant adverse effects) these are discussed in the relevant impact sections and the post-mitigation residual impact significance is provided. The embedded mitigation is specified below:

- Micrositing will be used to minimise the requirement for sea bed preparation prior to foundation installation. GBS will not be used in areas characterised by sand banks or sand waves with heights greater than 5m in further pursuance of this aim.

- Cables will be buried where possible, to a minimum burial depth of 1m. This however, may vary between a range of 1 to 3m. The optimum burial depths will be determined during pre-construction engineering studies. Cable burial to appropriate depths will reduce the risk of its exposure due to bed level changes, reducing the need for subsequent re-burial, which would cause further disturbance to the sea bed. In addition, ensuring cable burial in areas where it is practicable to do so would minimise the requirement for cable protection measures. Cable protection would only be applied in areas where burial is not possible. These would include where the proposed cables are required to cross existing cables or in areas of hard ground.
- The landfall location has been chosen and refined based on consideration of the physical process interactions and marine geology along the Suffolk coast and adjacent nearshore sea bed, including the role of the nearshore Sizewell and Dunwich banks, the outcrop of Coraline Crag offshore from Thorpeness and the rates of erosion of the Sizewell cliffs, as well as the circulatory sediment transport pathways between the shore and nearshore (see ***Appendix 4.5*** of ES ***Chapter 4 Site Selection and Assessment of Alternatives***). Consideration has also been given to the proximity to the Sizewell nuclear power station cooling water infrastructure with respect to tidal streams. This has led to the preference for a location for cable installation towards the southern side of the cable corridor, and an extension of the original corridor further to the south in order to accommodate this.
- A commitment has also been made to install the export cable at the landfall using HDD techniques, thus minimising disturbance and avoiding the need for cable protection in the intertidal and shallowest nearshore zones. It is likely that the HDD pop-out location will be to the south of the outcrop of Coralline Crag (see ***section 7.6.2.7***). Hence, there will be no interruption of the circulatory sediment transport pathways between the coast and Sizewell Bank and there is a strong likelihood of the export cable requiring no protection measures within the closure depth of the active beach profile, due to the presence of a veneer of sand on the sea bed in this location.

59. Further mitigation of relevance to marine geology, oceanography and physical processes includes:

    - For the foundation types that would experience the potential for greatest scour, protection material shall be installed during the construction process in accordance with the Scour Protection Management and Cable Protection Plan which will be produced post consent. This is secured under the requirements of the draft DCO in order to mitigate the effects of scour, increased suspended sediment concentrations, and bed level changes in the vicinity of each wind turbine.

- For other foundation types, where the scour potential involves smaller volumes of sediment release due to scour processes, the design would, in accordance with the Design Plan as secured under the requirements of the draft DCO, allow for local scour around the piles to minimise the scour protection footprint that is introduced on the sea bed.
- For piled foundation types, such as monopiles and jackets with pin piles, pile-driving will be used in preference to drilling (where ground conditions allow) in accordance with the Construction Method Statement as secured under the requirements of the draft DCO. This would minimise the quantity of sub-surface sediment that is released into the water column from the installation process.

7.3.4 Monitoring

60. Post-consent, the final detailed design of the proposed East Anglia TWO project will refine the worst-case parameters assessed in this ES. It is recognised that monitoring is an important element in the management and verification of the actual impacts based on the final detailed design

61. Outline Management Plans, across a number of environmental topics, have been submitted with the DCO application. These Outline Management Plans contain key principles that provide the framework for any monitoring that could be required. The requirement for final design and scope of monitoring will be agreed with the regulator and relevant stakeholders and included within the relevant Management Plan, submitted for approval, prior to construction works commencing.

62. Outline Management Plans as secured under the draft DCO which are relevant to marine geology, oceanography and physical processes include:

- In Principle Monitoring Plan (document reference 8.13); and
- Outline Offshore Operations and Maintenance Plan (document reference 8.12).

7.4 Impact Assessment Methodology

7.4.1 Guidance

63. The assessment of potential impacts on marine geology, oceanography and physical processes has been made with specific reference to the relevant NPS. These are the principal decision making documents for Nationally Significant Infrastructure Projects (NSIPs). Those relevant to the proposed East Anglia TWO project are:

- Overarching NPS for Energy (EN-1) (Department for Energy and Climate Change (DECC), 2011a); and

- NPS for Renewable Energy Infrastructures (EN-3) (DECC 2011b).

64. ***Table 7.7*** summarises the relevant NPS text and provides references to sections in this ES where each is addressed.

Table 7.7 NPS Assessment Requirements

NPS Requirement	NPS Reference	Section Reference
EN-1 NPS for Energy (EN-1)		
'where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures'	Section 5.5, paragraph 5.5.6	The approach adopted in this ES is a conceptual model based on expert judgement. This was agreed in general terms through the Benthic and Physical Processes ETG.
'the ES should include an assessment of the effects on the coast. In particular, applicants should assess: • The impact of the proposed project on coastal processes and geomorphology, including by taking account of potential impacts from climate change. If the development will have an impact on coastal processes the applicant must demonstrate how the impacts will be managed to minimise adverse impacts on other parts of the coast. • The implications of the proposed project on strategies for managing the coast as set out in Shoreline Management Plans (SMPs) and any relevant Marine Plans and capital programmes for maintaining flood and coastal defences. • The effects of the proposed project on marine ecology, biodiversity and protected sites. • The effects of the proposed project on maintaining coastal recreation sites and features. • The vulnerability of the proposed development to coastal change, taking account of climate change, during the project's operational life and any decommissioning period.'	Section 5.5, paragraph 5.5.7	The assessment of potential construction and operation and maintenance impacts are described in ***sections 7.6.1*** and ***7.6.2*** respectively. The project will not affect the Shoreline Management Plan and allowance has been made for predicated erosion rates during the project design (further detail is provided in ***Chapter 4 Site Selection and Assessment of Alternatives***). Mitigation and best practice to minimise potential impacts at the coast of cable installation and operation are described in ***section 7.3.3*** Effects on marine ecology biodiversity and protected sites are assessed in ***Chapter 9 Benthic Ecology, Chapter 10 Fish and Shellfish Ecology, Chapter 11 Marine Mammals*** and ***Chapter 12 Offshore Ornithology*** Effects on recreation are assessed in ***Chapter 30 Tourism Recreation and Socio-Economics***. As described above the project has been designed so that it is

NPS Requirement	NPS Reference	Section Reference
		not vulnerable to coastal change or climate change.
'the applicant should be particularly careful to identify any effects of physical changes on the integrity and special features of Marine Conservation Zones, candidate marine Special Areas of Conservation (SACs), coastal SACs and candidate coastal SACs, coastal Special Protection Areas (SPAs) coastal SPAs, Sites of Community Importance (SCIs), potential SCIs and Sites of Special Scientific Interest (SSSI).'	Section 5.5, paragraph 5.5.9	The East Anglia TWO windfarm site and offshore cable corridor does not overlap with any international, national or local sites designated for sea bed features.
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.' Geotechnical investigations should form part of the assessment as this will enable design of appropriate construction techniques to minimise any adverse effects.	Section 2.6, paragraph 2.6.193 and 2.6.194	Each of the impacts in ***sections 7.6.1*** and ***7.6.2*** 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 the proposed East Anglia TWO project.
'where necessary, assessment of the effects on the subtidal environment should include: • Loss of habitat due to foundation type including associated sea bed preparation, predicted scour, scour protection and altered sedimentary processes. • Environmental appraisal of inter-array and cable routes and installation methods. • Habitat disturbance from construction vessels extendible legs and anchors. • Increased suspended sediment loads during construction. • Predicted rates at which the subtidal zone might recover from temporary effects.'	Section 2.6, paragraph 2.6.113	The quantification and potential impact of sea bed loss due to the footprints of the project infrastructure is covered in ***section 7.6.2.5***. A worst-case scenario of all foundations having scour protection is considered to provide a conservative assessment. The worst-case scenario cable-laying technique is jetting and is considered as such in all the cable construction assessments. The disturbance to the subtidal sea bed caused by indentations due to installation vessels is assessed in ***section 7.6.2.9.*** The potential increase in suspended sediment concentrations and change in

NPS Requirement	NPS Reference	Section Reference
		sea bed level is assessed in ***sections 7.6.1.1*** to ***7.6.1.8*** The recoverability of receptors is assessed for all the relevant impacts, particularly those related to changes in sea bed level due to export cable installation (***section 7.6.1.6)***, interruptions to bedload sediment transport due to sand wave levelling in the offshore cable corridor (***section 7.6.2.3***) and morphological and sediment transport effects due to cable protection measures for export cables (***section 7.6.2.8***).
'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 for the final choice. • Potential loss of habitat. • Disturbance during cable installation and removal (decommissioning). • Increased suspended sediment loads in the intertidal zone during installation. • Predicted rates at which the intertidal zone might recover from temporary effects.'	Section 2.6, paragraph 2.6.81	Landfall Site Selection and Assessment of Alternatives are provided in ***Chapter 4 Site Selection and Assessment of Alternatives***. A range of cable installation methods are required and these are detailed in ***Chapter 6 Project Description***. The worst-case scenario for marine physical processes is provided in ***section 7.3.2*** Potential habitat loss in the intertidal zone is covered in ***Chapter 9 Benthic Ecology***. Assessment of the potential disturbance and increased suspended sediment concentrations in the nearshore (including the intertidal zone) due to cable installation is provided in ***section 7.6.1.5*** The recoverability of the coastal receptor (East Anglia coastline) is assessed for morphological and sediment transport effects due to cable protection measures at the coast (***section 7.6.2.8***).

65. The Marine Policy Statement (MPS, HM Government, 2011; discussed further in ***Chapter 3 Policy and Legislative Context***) provides the high-level approach

to marine planning and general principles for decision making that contribute to achieving this vision. It also sets out the framework for environmental, social and economic considerations that need to be considered in marine planning. 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."

66. 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 the proposed East Anglia TWO project 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".

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

- Offshore windfarms: 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 Windfarm Environmental Impact Assessment (Lambkin et al. 2009).
- Review of Cabling Techniques and Environmental Effects applicable to the Offshore Windfarm 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).

7.4.2 Data Sources

68. Information to support this ES has come from a series of previous surveys described in ***Table 7.8*** (Gardline 2011; MESL 2011; EMU 2013), along with further project specific surveys to inform the proposed East Anglia Two project (***Table 7.9***) (Bibby Hydromap 2018a, b).

69. Previous studies to support this ES also include numerical modelling studies, which were undertaken to inform the ZEA (GL Noble Denton 2011; ABPmer 2012a; Deltares 2012) and the EIAs for the proposed East Anglia ONE (ABPmer 2012b) and East Anglia THREE projects (EATL 2015).

Table 7.8 Available Relevant Physical Environment Datasets

Data set	Spatial coverage	Survey year
Geophysical Survey (Gardline Geophysical Ltd.)	East Anglia Zone	2010
Benthic survey (PSA analysis of grab samples) (Marine Ecological Surveys Ltd)	East Anglia Zone	2010
Benthic survey (PSA analysis of grab samples) (Marine Ecological Surveys Ltd)	East Anglia ONE offshore cable corridor	2011
Benthic survey (PSA analysis of grab samples) (Marine Ecological Surveys Ltd)	East Anglia ONE windfarm site	2011
Metocean Survey (current speed, water levels and wave heights) (Cefas)	East Anglia Zone	2012
Benthic survey (PSA analysis) of grab samples	East Anglia THREE offshore cable corridor	2013

Table 7.9 Site Specific Survey Data

Data set	Year collected	Spatial coverage
Geophysical Survey (Gardline 2017): Side-scan sonar	2017	East Anglia TWO windfarm site

Data set	Year collected	Spatial coverage
Multibeam echosounder		
Geophysical Survey (Bibby Hydromap 2018 a, b): Side-scan sonar Multibeam echosounder Sub-bottom profiler Grab samples	2018	East Anglia TWO offshore cable corridor
Benthic survey (Bibby Hydromap 2018c): PSA analysis of grab samples	2018	East Anglia TWO offshore cable corridor

70. The bathymetry and geology of the offshore cable corridor were reported in Bibby Hydromap (2018a, b). Both the inshore part of the cable corridor and the offshore part were surveyed between March and May 2018.

71. Sea bed sediment samples were not collected specifically for the East Anglia TWO windfarm site, and data collected as part of the East Anglia Zonal Survey have been used (MESL 2011). For the offshore cable corridor, a combination of Zonal data and data collected specifically for East Anglia TWO (Bibby Hydromap 2018c) have been combined.

72. Other information that is available and has helped to inform this chapter of the ES includes:

- Marine Renewable Atlas (BERR, 2008);
- Wavenet (Cefas);
- National Tide and Sea Level Forecasting Service;
- Extreme sea levels database (Environment Agency);
- TotalTide (UK Hydrographic Office tidal diamonds);
- British Oceanography Data Centre (BODC);
- National Oceanographic Laboratory Class A tide gauges;
- UK Climate Projections ‘09 (UKCP09, Lowe et al., 2009);
- British Geological Survey 1:250,000 sea bed sediment mapping;
- British Geological Survey bathymetric contours and paper maps;
- Admiralty Charts and UK Hydrographic Office raw survey data;
- Southern North Sea Sediment Transport Study;

- Futurecoast;
- Shoreline Management Plans;
- Thames Regional Environmental Characterisation; and
- East Coast Regional Environmental Characterisation.

7.4.3 Impact Assessment Methodology

73. In ***Chapter 5 EIA Methodology***, an overarching method is presented for enabling assessments of the potential impacts arising from the proposed East Anglia TWO project on the receptors under consideration. Such assessments incorporate a combination of the sensitivity of the receptor, its value (if applicable) and the magnitude of the change to determine a significance of impact. This method has been followed for the assessment of marine geology, oceanography and physical processes receptors.

74. For the impacts on marine geology, oceanography and physical processes a number of discrete receptors can be identified. These include certain morphological features with ascribed inherent values, such as:

- Offshore sand banks – these morphological features play an important role in influencing the baseline tidal, wave and sediment transport regimes;
- Nearshore intertidal and subtidal rock platforms – these morphological features play an important role in anchoring the coastal form; and
- Beaches, dunes and sea cliffs - these morphological features play an important natural coastal defence role.

75. In respect of the above considerations, the East Anglia ZEA identified 17 receptor groups in total. The location of these is shown in ***Figure 7.1***.

76. Seven receptor groups covered sensitive coasts in both eastern England (two receptor groups, ‘East Anglia’ and ‘Essex & Kent’) and across northern mainland Europe (five receptor groups, including ‘France’, ‘Belgium’, ‘Southern Netherlands’, ‘Western Netherlands’ and ‘Northern Netherlands’).

77. Nine further receptor groups were identified to cover the designated Natura 2000 sites in eastern England (five receptor groups, ‘The Wash’, ‘Central North Sea’, ‘Norfolk’, ‘Kent & Essex’ and ‘Suffolk’) and wider Europe (four receptor groups, ‘France’, ‘Belgium’, ‘Southern Netherlands’ and ‘Northern Netherlands’). It should be noted that the Natura 2000 sites often comprise groupings of multiple distinct (and designated) features, such as sand banks, sand dunes, and sand and shingle beaches.

78. One further receptor group covered nearby ‘non-designated sand banks’ in the Outer Thames Estuary, including Inner Gabbard, Outer Gabbard, The Galloper, North Falls and one un-named bank.

79. The East Anglia ZEA assessed the potential cumulative impacts arising from development of the whole East Anglia Zone in relation to marine geology, oceanography and physical processes (ABPmer 2012a). It concluded there would be:

- No significant impacts on all 17 receptor types in relation to changes in the wave regime. However, it was recommended that the potential impact should be considered further to confirm this at EIA stage for individual projects for four receptor groupings (the sensitive ‘East Anglia’ coast, ‘Norfolk’ Natura 2000 site, ‘Suffolk’ Natura 2000 site and ‘non-designated sand banks’) due to some uncertainty regarding the magnitude of changes to the wave regime outside the East Anglia Zone.
- No significant impacts on all 17 receptor types in relation to changes in the tidal regime. However, it was recommended that the potential impact should be considered further to confirm this at EIA stage for individual projects for three receptor groupings (the ‘Norfolk’ Natura 2000 site, ‘Suffolk’ Natura 2000 site and ‘non-designated sand banks’) due to some uncertainty regarding the magnitude of changes to the flow speed outside the East Anglia Zone.
- Impacts of moderate significance on the sensitive ‘East Anglia’ coast, with no significant impacts on the other 16 receptor types in relation to changes in the sediment transport regime. However, it was recommended that the potential impact should be considered further to confirm this at EIA stage for individual projects for one receptor grouping (the ‘Norfolk’ Natura 2000 site) due to some uncertainty regarding the importance of different sediment transport pathways to morphological features within this receptor group.

80. The specific features defined within the four receptor groupings mentioned above as requiring further assessment at the EIA stage for individual projects are listed in ***Table 7.10***. Additionally, in response to comments from Natural England on the PEIR, Orford Inshore Marine Conservation Zone (MCZ) has also been included in ***Table 7.10***.

Table 7.10 Marine Geology, Oceanography and Physical Processes Receptors

Receptor group (see *Figure 7.1*)	Extent of coverage	Description of features
East Anglian coast (waves and sediment transport)	Felixstowe to King's Lynn	Shingle and sand beaches, dunes and cliffs
Norfolk Natura 2000 Site (waves, currents and sediment transport)	Haisborough, Hammond and Winterton SAC	Offshore sand banks
	North Norfolk Sand banks and Saturn Reef SAC	Offshore sand banks and reef
	Great Yarmouth and North Denes SPA	Shingle beach and sand dunes
Suffolk Natura 2000 Site (waves and currents)	Outer Thames Estuary SPA	Sand banks and associated channels
	Minsmere to Walberswick Heaths and Marshes SAC and SPA	SAC: sand dunes, sand and shingle beaches SPA: beach, spit and bars
	Alde, Ore and Butley Estuaries SAC	Mudflats, saltmarsh and embayments
	Alde-Ore Estuary SPA	Mudflats, saltmarsh and shingle beach
	Orfordness – Shingle Street SAC/ GCR	Shingle beach, spits and bars
	Benacre to Easton Bavents SPA	Estuary, mud and sandflats, sand dunes and shingle beach
Nearby non-designated sand banks (waves and currents)	Inner Gabbard Outer Gabbard The Galloper North Falls un-named bank	Offshore sand banks
Orford Inshore MCZ	Orford Inshore MCZ	Subtidal mixed sediments

81. This chapter 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' coast, the 'Norfolk' Natura 2000 site, the 'Suffolk' Natura 2000 site and the 'non-designated sand banks'.

82. However, in addition to identifiable receptors listed above, there are other changes to the marine geology, oceanography and physical processes which

may potentially be caused by the proposed East Anglia TWO project which in themselves are not 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 the suspended sediment concentrations in the water column) represent an 'effect' which may manifest itself as an impact upon other receptors, most notably water and sediment quality, benthic ecology, fisheries or navigation (e.g. in terms of increased suspended sediment concentrations or erosion or smothering of habitats on the sea bed).

83. Hence, the assessment presented in this chapter follows two approaches. The first assessment approach is designed for situations where potential impacts can be defined as directly affecting receptors which possess their own intrinsic morphological value. In this case, the determination of significance of the impact is based on an assessment of sensitivity of the receptor and magnitude of effect (***section 7.4.3.1***) by means of an impact significance matrix (***section 7.4.3.2***).

84. The second assessment approach is designed for situations where effects (or changes) in the baseline marine geology, oceanography or physical processes conditions may occur which could potentially manifest as impacts upon other receptors. In this case, the magnitude of effect is determined in a similar manner to the first assessment method but the sensitivity of the other receptors and the significance of impacts on them is assessed within the relevant chapters of this ES pertaining to those receptors.

7.4.3.1 Sensitivity, Value and Magnitude

85. The sensitivity and value of discrete morphological receptors and the magnitude of effect are assessed using expert judgement and described with a standard semantic scale. These expert judgements of receptor sensitivity, value and magnitude of effect are guided by the conceptual understanding of baseline conditions presented in detail in Appendix 2.1 of the Scoping Report (SPR 2017) and summarised in ***section 7.5***.

86. The sensitivity of a receptor (***Table 7.11***) is dependent upon its:

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

Table 7.11 Definitions of Sensitivity Levels for a Morphological Receptor

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

87. In addition, a *value* component may also be considered when assessing a receptor (***Table 7.12***). This ascribes whether the receptor is rare, protected or threatened.

Table 7.12 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 or 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 or physical processes
Low	Value: Receptor is not designated but is of local importance for marine geology, oceanography or physical processes
Negligible	Value: Receptor is not designated and is not deemed of importance for marine geology, oceanography or physical processes

88. The magnitude of an effect (***Table 7.13***) is dependent upon its:

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

Table 7.13 Definitions of the Magnitude of Effect Levels for a Morphological Receptor

Value	Definition
High	Fundamental, permanent / irreversible changes, over the whole receptor, and / or fundamental alteration to key characteristics or features of the particular receptors character or distinctiveness
Medium	Considerable, permanent / irreversible changes, over the majority of the receptor, and / or discernible alteration to key characteristics or features of the particular receptors character or distinctiveness
Low	Discernible, temporary (throughout project duration) change, over a minority of the receptor, and / or limited but discernible alteration to key characteristics or features of the particular receptors character or distinctiveness
Negligible	Discernible, temporary (for part of the project duration) change, or barely discernible change for any length of time, over a small area of the receptor, and/or slight alteration to key characteristics or features of the particular receptors character or distinctiveness

7.4.3.2 Impact Significance

89. 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 7.14*** as a framework to show how a judgement of the significance of an impact has been reached.

Table 7.14 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*

90. Through use of this matrix, an assessment of the significance of an impact can be made in accordance with the definitions in ***Table 7.15***. Impacts may be deemed as being either positive (beneficial) or negative (adverse).

Table 7.15 Impact Significance Definitions

Value	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 are likely to be important considerations at a local level
Minor	Small change in receptor condition, which may be raised as local issues but are unlikely to be important in the decision-making process
Negligible	No discernible change in receptor condition
No change	No impact, therefore no change in receptor condition

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

92. Following initial assessment, if the impact does not require additional mitigation (or none is possible) the residual impact will remain the same. If, however, additional mitigation is proposed there will be an assessment of the post-mitigation residual impact.

7.4.4 Cumulative Impact Assessment

93. Cumulative impacts are assessed through consideration of the extent of influence of changes or effects upon marine geology, oceanography and physical processes arising from the proposed East Anglia TWO project alone and those arising from the proposed project cumulatively with other offshore windfarm developments (particularly East Anglia ONE and the proposed East Anglia ONE North, East Anglia THREE, Norfolk Vanguard and Norfolk Boreas projects). Consideration is also given to the export cables crossing those for Greater Gabbard and Galloper and other nearby sea bed activities, including marine aggregate extraction and marine disposal.

94. 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 zone, and the ES for the proposed East Anglia ONE project (ABPmer 2012b), which considered cumulative effects from that project and marine aggregate extraction activities in proximity to the offshore cable corridor.

95. Cumulative impacts with EDF Energy's Sizewell C development were screened out due to avoidance in project design due to the cable corridor siting south of Sizewell (see ***section 3*** of ***Appendix 4.6 Coastal Processes and Landfall Site Selection***).

7.4.5 Transboundary Impact Assessment

96. Transboundary impacts are 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 EU member states. It is concluded that transboundary impacts are unlikely to occur or are unlikely to be significant.

97. This conclusion is supported by the assessments that have previously been completed in the East Anglia ZEA (ABPmer 2012a), the ES of the East Anglia ONE project (ABPmer 2012b) and the ES's of the proposed East Anglia THREE and Norfolk Vanguard projects (EATL 2015; Norfolk Vanguard Limited 2018) (see ***Appendix 7.3***).

7.5 Existing Environment

98. This section provides an overview of the key information from the assessment of the existing physical environment.

99. Given the extensive work that has previously been undertaken to characterise the baseline physical environment across the former East Anglia Zone, the approach taken in the proposed East Anglia TWO project has been to:

- Review existing relevant data and reports from across the former East Anglia Zone;
- Acquire additional data to fill any gaps specific to the proposed East Anglia TWO project;
- Undertake wave modelling to assess the individual and cumulative effects of the proposed East Anglia TWO project on the wave regime; and
- Formulate a conceptual understanding of the baseline physical environment, specific to the proposed East Anglia TWO project.

100. It is important to recognise that the baseline physical environment is not static, but instead will exhibit considerable variability due to cycles or trends of natural change. These can include (for example) the short-term effects of storms and surges, the well-observed patterns in the movement of tides during spring and neap cycles and the longer-term effects of sea-level rise associated with global climate change.

7.5.1 Bathymetry

101. The East Anglia TWO windfarm site covers an area of approximately 218.4km^2 of sea bed in the southern North Sea, off the coast of East Anglia. The offshore cable corridor would cover up to an additional 194.5km^2 of sea bed, extending from the windfarm site to the landfall just north of Thorpeness in Suffolk.

7.5.1.1 Windfarm Site

102. Water depths within the East Anglia TWO windfarm site vary from a minimum depth of 33m below LAT to a maximum depth of 67m below LAT (***Figure 7.2***), with the exception of 29m below LAT on a sand wave near the centre of the site, and 76m below LAT in a depression to the east of the site. This depression is approximately 400m across and 20m deep (***Figure 7.2***).

103. The bathymetry of the East Anglia TWO windfarm site is dominated by areas of megaripples, and sand waves are widespread. Sand waves are dominant in the east and southeast of the site, separated by flat sea bed from a smaller area of sand waves in the west. The largest sand waves are generally 5-10m high (with one reaching 14m) with a wavelength of up to 500m. The smaller sand waves are approximately 2-3m high with a wavelength of between 20m and 40m (Gardline 2017).

104. Crests are predominantly oriented east-southeast to west-northwest and few differing from this. Most sand waves are asymmetrical, with the steeper flank facing south-southwest (indicating a dominant south-southwest component in the bottom current vector).

105. Megaripples and ripples are common throughout the windfarm site. However, there are several large areas where there are no bedforms. In the absence of bedforms, the sea bed is flat with a few local irregularities dependent on the underlying geology, such as where London Clay sub-crops. Such an area is present across the north of the site where it is shallower (35-40m below LAT) and devoid of morphological features except for a few megaripples.

7.5.1.2 Offshore Cable Corridor

106. Water depths across the offshore cable corridor vary from a minimum depth of 2m below LAT inshore (across an area of outcropping rock), to a maximum depth of 53m below LAT at the seaward end (***Figure 7.3***). Bibby Hydromap and Benthic Solutions (2018a, b) completed benthic and geophysical surveys of the offshore cable corridor to enable characterisation of the sea bed.

107. Closest to the coast, the bathymetry of the offshore cable corridor is dominated by rock outcrop (Coralline Crag) with an irregular surface formed of southwest-northeast oriented ridges between 0.5m and 2m high. To the north of this outcrop, areas of megaripples are present, oriented west-southwest to east-northeast, up to 0.5m high with wavelengths ranging from 3m to 15m. Across the northern part of the inshore section, there is a sand-shoal at around 3.5m below LAT. Both north and south of the rock outcrop, closest to the coast, there are also areas of featureless sand.

108. Further the east, sea bed levels deepen gently towards the south-east before crossing a 150-700m wide low-lying ridge formed of hard substrate up to 3m high. Mobile sands up to 2m thick are found discontinuously within this part of the cable corridor. Further offshore, a veneer of granular materials is present, with occasional patches of megaripples.

109. Offshore from where the offshore cable corridor curves to orientate towards the east-southeast, the sea bed is dominated by irregular areas of megaripples composed of gravelly sand, with sand waves and occasional areas of hard substrate. Bedforms are predominantly oriented between west to east and west-northwest to east-northeast. There is a broad depression across the southern extent of this part of the offshore cable corridor which reaches 28m below LAT at its deepest point and spans 1500m. Further offshore is an area of hard substrate for 4.7km, split in two by a small area of sand waves up to 5m high with steeper south-facing slopes.

110. Seaward of the hard substrate, the sea bed undulates with a range of approximately 6m over a large area of megaripples and sand waves. These mobile sediments span the width of the corridor and extend southeast along the cable corridor for over 4km.

111. A channel crosses the cable corridor at the 30m contour, containing a highly variable sea bed with areas of mobile sediment surrounding an area of hard substrate in the centre. Some sand waves within this channel reach up to 7m high with steep slopes. From here to the edge of the windfarm site, the offshore cable corridor is comprised mostly of mobile sediments with an area of large symmetrical sand waves up to 7m high, exhibiting unusual scouring up to 6m below the sea bed at their north-western and south-eastern extremities. A depression intersects this area of mobile sediments where the sea bed deepens to greater than 50m below LAT.

7.5.2 Geology

7.5.2.1 Windfarm Site

112. No site specific geological surveys of the East Anglia TWO windfarm site have been conducted however EMU (2013) describes how the geology of the East Anglia Zone generally consists of Pleistocene sands and clays overlain by Holocene sand deposits. The thickness of the Holocene sediments of the East Anglia Zone varies from less than 1m across most of the area to greater than 20m in the sand wave fields and on the sand ridges, especially in the north of the Zone.

7.5.2.2 Offshore Cable Corridor

113. The geology of the offshore cable corridor close to the coast comprises mainly Pleistocene sediments with Red Crag Formation in the southern parts of the corridor, and London Clay in the northern parts. There is an area of outcropping Coralline Crag Formation close to the coast, characterised by cemented shelly sandstone. This extends offshore for a maximum of about 3km.

114. Further offshore, Westkapelle Ground Formation overlies the Red Crag Formation. There is a buried channel up to 20m deep infilled with Brown Bank Formation near the offshore end of the cable corridor. The offshore section of the route is overlain by Holocene sediments as described in ***section 7.5.1.2***.

7.5.3 Water Levels

115. Marine water levels are predominantly governed by astronomical effects but can also be significantly influenced (elevated or depressed) by meteorological influences and surge effects.

7.5.3.1 Astronomical Tidal Levels

116. The East Anglia TWO windfarm site, and the former East Anglia Zone in general, is within a micro-tidal regime. The average spring tidal range varies between 0.1m and 2.0m (EAOW 2012) and typically weakens towards deeper areas.

117. This relatively low tidal range is due to general proximity to an amphidromic point in the southern North Sea that is positioned just outside the central, eastern boundary of the former East Anglia Zone (***Figure 7.4***). Due to this, the tidal range across the windfarm site is modest (0.5m-1.2m) and not extreme. At the amphidromic point, the tidal range is near zero. Tidal range then increases with radial distance from this point.

118. At the coast, tidal range reaches 2.55m on mean spring tides at Sizewell (just to the north of the offshore cable corridor landfall).

7.5.3.2 Non-tidal Water Levels

119. The North Sea is particularly susceptible to storm surges and water levels can become elevated around 2.05m above astronomical tidal levels during a one-year return period surge event, and around 3.09m during a 100-year return period surge event, as measured at Sizewell.

7.5.4 Tidal Currents

120. Within the East Anglia TWO windfarm site, tidal currents are strongest across the west of the site, reaching up to 1.4m/s on spring tides and 0.9m/s on neap tides at an Admiralty Diamond close to the offshore cable corridor. Tidal streams are directed towards the south-southwest on a flooding tide and towards the north-northeast on the ebbing tide. Speeds reduce to around 0.7m/s on spring tides and 0.4m/s on neap tides in shallow water just off the Suffolk coast.

121. The southern North Sea is prone to storm surges, with a predicted maximum surge current of 0.4m/s (HSE 2002). Whilst this is less than the typical daily current speeds recorded within the East Anglia TWO windfarm site and offshore cable corridor, surge currents can combine with tidal currents to create faster overall currents.

7.5.5 Waves

122. The baseline offshore wave climate can comprise both swell waves and wind waves.

123. Offshore, waves in the southern North Sea are frequently directed away from the coast. This is due to the prevailing wind direction being from the southwest. However, waves from the north through to the south-eastern sector are also recorded, and it is waves from these approach directions which have the greatest potential to interact with the windfarm and cause effects on the identified receptors.

124. The significant wave heights from these sectors are greatest from a northerly approach, reaching 4.77m in a one-year return period event and 7.59m in a 50-year return period event.

125. As waves approach the shallower nearshore waters, they become transformed and generally reduce in height. The nearshore Dunwich and Sizewell banks also play an important sheltering effect to the coast.

126. Further details on the baseline wave conditions is presented in ***Appendices 7.1** and **7.3***.

7.5.6 Sea Bed Sediments

127. As part of the zone-wide survey between September 2010 and January 2011, a total of 31 grab samples were collected from within the East Anglia TWO windfarm site by Marine Ecological Surveys Limited (MESL 2011). No site specifc samples were collected within the East Anglia TWO windfarm site as the zone-wide survey covered all of the East Anglia TWO windfarm site.

128. The data suggests that sea bed composition is primarily medium sand. The proportion of silt within samples tends to be higher in samples collected from deeper areas of the windfarm site, mainly in the south-east of the windfarm site (see ***Figure 9.3a***).

129. Grab samples collected within the offshore cable corridor (83 samples) as part of the project-specific benthic survey (Bibby Hydromap and Benthic Solutions, 2018b) show the majority of the sediments to be slightly gravelly sand (using the Folk scale). In contrast to the East Anglia TWO windfarm site sediments, coarser sediment is present in the offshore cable corridor furthest offshore, with samples containing higher percentages of sand than the rest of the route. Slightly gravelly sand and gravelly muddy sand are the two most common classifications of sediment in the section of the offshore cable corridor closest to the East Anglia TWO windfarm site (see ***Figure 9.3a***).

130. The central section of the offshore cable corridor has the highest percentage of fines in samples collected (reaching over 90%), with sediment mainly falling within the sandy mud classification on the Folk scale. This central section also has the lowest percentages of gravel in samples.

131. Closest to landfall, sediment size is highly variable, ranging from sandy mud to sandy gravel in the samples that were taken. One sample was found to contain 53% gravel while another was calculated at less than 1% gravel.

7.5.7 Suspended Sediments

132. Baseline suspended sediment concentrations within the former East Anglia Zone are typically between 1mg/l and 35mg/l (Dolphin et al. 2011), with a clear pattern of enhancement due to wave-stirring of sediment from the sea bed during storm conditions (HR Wallingford et al. 2002).During such conditions, values can reach greater than 80mg/l offshore (EAOW 2012), with up to 170mg/l having been recorded at the coast (Hanson Aggregates Marine Limited 2005).

133. Data from the Cefas Suspended Sediment Climatology model show that over the period between 1998 – 2015, Suspended Particulate Matter (SPM) mean values range between 4.88-18.08mg/l across the East Anglia TWO windfarm site and 12.83-56.05mg/l across the offshore cable corridor (CEFAS 2016). Over winter, SPM mean values can reach up to 19.40mg/l in the East Anglia TWO windfarm site and 59.41 mg/l in the offshore cable corridor. On 5th January 2014, following the 'exceptionally' stormy winter of 2013/14, SPM mean values reached up to 69.14mg/l in the East Anglia TWO windfarm site and 322.26mg/l in the offshore cable corridor. Results from Cefas are consistent with those outlined above. This dataset was based on the Ifremer OC5 algorithm (Gohin et al. 2011).

134. These suspended sediment concentrations provide a natural background context for the assessment of effects of any temporary increases that may arise due to the proposed East Anglia TWO project.

7.5.8 Shoreline Transport Pathways and Coastal Erosion

135. Based on analysis of erosion rates along the coast between Dunwich and Thorpeness, using survey data of changes over time, it is known that the coast is relatively stable with rates of cliff recession generally being less than 0.1m/year. However, these are longer-term average values and larger episodes of recession can occur during individual storms if they are particularly severe. The relative stability is due largely to the sheltering presence of the Dunwich and Sizewell sand banks and the sheltering presence of Thorpe Ness.

136. Projections have been made of future coastal erosion in different zones along the coast and these have been used to inform engineering decisions about the location of onshore infrastructure to ensure they are suitably set back from projected erosion.

137. Consideration has also been given to sediment transport processes operating along the coast to inform decisions about the landfall location for the offshore cable corridor. The findings of relevance are:

- Net transport of sediment along the coast is limited, but gross transport can be higher and its direction is dependent on the prevailing wave conditions.
- Alongshore transport of shingle is restricted to the surf zone under predominantly storm conditions.
- Under normal conditions sand moves alongshore in the intertidal zone; under storm conditions, sand transport predominantly takes place along nearshore bars.
- The nearshore area is characterised predominantly by fine to medium sand, with only minimal shingle present.

- Sediments greater than 2mm in size are not mobilised in offshore regions; therefore, it is unlikely that shingle is transported onshore.
- Thorpe Ness, while limiting supply to the south plays a major role in retaining material to the north. Most of the sand transported south each year is therefore likely to be recirculated north into the Sizewell and Dunwich sand banks. Indeed, sand has been noted to move offshore at Thorpe Ness from the coast onto the Sizewell bank system.
- The Sizewell and Dunwich banks are sinks for medium to fine sand, with no shingle. There is potential for movement of sand on the banks under both average and storm wave conditions, and sand within the first 4km offshore could be mobilised and moved onshore under both storm and moderate wave conditions.
- There may be some re-circulation of sediment from the Sizewell and Dunwich banks to the Dunwich coastline.

7.5.9 Designated Sites

138. The East Anglia TWO windfarm site and offshore cable corridor does not overlap with any international, national or local sites designated for sea bed features. The offshore cable corridor is adjacent to sand banks which are supporting features of the Outer Thames Estuary SPA. These features have been considered within the assessment of effects on the ‘Suffolk’ Natura 2000 site.

139. The offshore cable corridor is 2.1km from the Orford Inshore MCZ. It is predicted that there would be no potential for the proposed East Anglia TWO project activities to adversely impact upon the sites’ designated features of subtidal mixed sand and gravels. This is due to a lack of physical overlap and negligible impact in the far-field as a result of an increase in suspended sediment concentrations during construction (see ***section 7.6.1.5***). This conclusion is supported by an assessment (EATL 2016) that was carried out for the East Anglia THREE project which is closer to the MCZ at only 300m away. This assessment was carried out when the MCZ was a recommended MCZ (rMCZ). The East Anglia THREE assessment concluded that there would be, at worst, negligible impact from indirect effects and concluded no adverse effect on the site should it be designated. Therefore, the MCZ is not considered further.

140. A HRA screening exercise has been undertaken which concluded no impact on any sites designated for sea bed or benthic ecology features (see Appendix 1 of the Information to Support the Appropriate Assessment report, document reference 5.3).

7.5.10 Climate Change and Natural Trends

141. Due to global climate change and local land level changes, mean sea level at the coast is expected to be between 0.19 and 0.27m higher by 2050 compared to 1990 values (Lowe et al. 2009). This is not deemed particularly significant over the lifetime of the proposed East Anglia TWO project and is well within the range of natural variability in water levels.

142. Climate change is projected to have an insignificant effect on the height of storm surges over the lifetime of the proposed East Anglia TWO project (Lowe et al. 2009), although there is generally expected to be an increase in their frequency of occurrence.

143. Climate projections indicate that wave heights in the southern North Sea will increase by 0.05m by 2100 (Lowe et al. 2009). This is not significant over the lifetime of the proposed East Anglia TWO project and is well within the range of natural variability in wave heights.

7.6 Potential Impacts

144. Potential effects in relation to marine physical processes to be considered within the EIA have been agreed with statutory advisors (MMO, Natural England and Cefas) through the EPP (ETG meeting 12th April, 2017). A briefing document outlining the refinements made to the offshore cable corridor was submitted to stakeholders in July / August, 2017 detailing the approach to filling data gaps. An updated method statement combining both documents can be found in Appendix 2.1 of the Scoping Report (SPR 2017). This method statement provides a full list of impacts to be assessed as part of the EIA.

145. As far as practically possible, works will be undertaken in such a way as to reduce the volume of suspended sediment released and minimise the use of cable or scour protection. Specific mitigation, if required will be identified through the EIA.

7.6.1 Potential Impacts during Construction

146. During the construction phase of the proposed East Anglia TWO project, there is potential for wind turbine, foundation and cable installation activities to cause sediment disturbance effects, potentially resulting in changes in suspended sediment concentrations and / or sea bed or, in the case of nearshore cable installation, shoreline levels due to deposition or erosion.

7.6.1.1 Impact 1 Changes in Suspended Sediment Concentrations due to Foundation Installation

147. The installation of wind turbine foundations has the potential to disturb sediments from (i) the sea bed (near-surface sediments); and (ii) from several tens of metres below the sea bed (sub-surface sediments), depending on

foundation type and installation method. The worst case scenario assumes that the disposal of any sediment that would be disturbed or removed during foundation installation would occur within the East Anglia TWO windfarm site.

7.6.1.1.1 Near-surface Sediments

148. Sea bed sediments and shallow near-bed sediments within the East Anglia TWO windfarm site would be disturbed during any levelling or dredging activities that may be needed at each foundation location to create a suitable base prior to installation.

149. This process would cause localised and short-term increases in suspended sediment concentrations both at the point of dredging at the sea bed and, more importantly, at the point of its discharge back into the water column which, in the worst case scenario, would be at the water surface.

150. Activities such as sand wave levelling may be required up to a sediment depth of 5m. The worst case scenario considers the maximum volumes of sediment disturbed during any levelling or dredging for the project and assumes sediment would be dredged and returned to the water column at the sea surface during disposal from the dredger vessel.

151. 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, meteorological mast or offshore platform location are likely to last for no more than a few days of construction activity.

152. Baseline suspended sediment concentrations within the former East Anglia Zone are typically between 1mg/l and 35mg/l, with a clear pattern of enhancement in values due to wave-stirring of sediment from the sea bed during storm conditions. During such conditions, values can reach greater than 80mg/l offshore, with up to 170mg/l recorded at the coast.

153. The sea bed sediments across the East Anglia TWO windfarm site are typically characterised by medium sand with some coarser biogenic material (shells and shell fragments), with only a very small percentage content of mud-sized material (typically less than 5%).

154. The worst case scenario involves the maximum volume of sediment released through sea bed preparation activities for the worst case foundations being considered:

- Jackets with caissons for the maximum number of 250m wind turbines; and
- Jackets with caissons (equivalent to those used for 300m wind turbines) for one meteorological mast and five offshore platforms.

155. For the total volume released during the construction phase, the worst case assumes that up to 2,476,555.63m^3 of near-surface sediment would be removed by means of dredging and returned to the water column at its surface layer as overflow from a dredger vessel.

156. Expert-based assessment suggests that, due to the sediment particle sizes present across the East Anglia TWO windfarm site, the sediment disturbed from the sea bed by the drag head of the dredger would remain close to the bed and rapidly settle. Most of the sediment released at the water surface from the dredger vessel would rapidly (order of minutes or tens of minutes) fall to the sea bed as a highly turbid dynamic plume immediately upon its discharge.

157. 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 (tens of mg/l) plume for around half a tidal cycle (up to six hours). Sediment would eventually fall to the sea bed in relatively close proximity to its release (within a few hundred metres up to around a kilometre, along the axis of the tidal flow) within a short period of time (hours).

158. This 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 sea bed 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). This review identified that the highest suspended sediment concentrations associated with dredging occur for only a short duration and remain local to the point of sediment release into the water column, while within the wider licensed dredge area concentrations typically remain modest (i.e. of the order of tens of mg/l). Whilst lower concentrations extend beyond licensed dredge areas, along the axis of predominant tidal flows, the magnitudes are indistinguishable from background levels.

159. Modelling simulations undertaken for the East Anglia ONE windfarm site using the Delft3D plume model (ABPmer 2012b) support the above expert-based assessments of suspended sediment concentrations arising from disturbance of near-surface sediments. There are good similarities in sediment types and distributions between the East Anglia ONE (5% gravel, 93% sand and 2% mud) and East Anglia TWO windfarm sites. The water depths for each site are also similar. Overall, therefore, the modelling studies for the East Anglia ONE windfarm site represent a suitable analogue for verifying the conclusions of the more qualitative expert-based assessment described above.

160. In the East Anglia ONE modelling studies, consecutive daily releases of 22,500m^3 of sediment (mostly medium-grained sand, but also with small proportions of gravel, other sand fractions and muds) were simulated at the water surface at 15 wind turbine locations. This sediment release represents a suitable analogue for the type and magnitude of effect that would be anticipated from the proposed East Anglia TWO project.

161. The previous modelling predicted that close to the release locations, suspended sediment concentrations would be very high (orders of magnitude greater than natural background levels), but of very short duration (seconds to minutes) as the dynamic plume falls to the sea bed. Within the passive plume, suspended sediment concentration 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 in accordance with the direction of residual tidal flow. Sediment concentrations rapidly (within a small number of hours) returned to background levels after cessation of the release into the water column.

162. Given this finding from modelled consecutive installation of 15 wind turbine foundations, it is expected that effects from installation across the whole East Anglia TWO windfarm site would be similar, although with the point of release moving across the site with progression of the construction sequence.

7.6.1.1.2 Sub-surface Sediments

163. Deeper sub-surface sediments within the East Anglia TWO windfarm site would become disturbed during any drilling activities that may be needed at the location of each monopile or four-legged jacket (with pin piles).

164. For the total volume released during the construction phase, the worst case is associated with:

- Monopiles for the maximum number (i.e. 60) of 300m wind turbines;
- Monopile (equivalent to that of a 300m wind turbine foundation) for the meteorological mast; and
- Jackets with four pin piles (equivalent to those used for 300m wind turbines) for up to five offshore platforms.

165. This worst case assumes that up to 98,874.56m^3 of sub-surface sediment would be released in total throughout the anticipated construction programme.

166. 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 wave and tidal action in suspension in the water column.

167. The disturbance effects at each wind turbine location are only likely to last for a few days of construction activity, with the overall offshore construction programme expected to last up to 27 months.

168. Although the sub-surface sediment release volumes under the worst case scenario are considerably lower than those for the worst case scenario for the near-surface sediments, the sediment types would differ, with a larger proportion of finer materials.

169. Expert-based assessment suggests that the coarser sediment fractions (medium and coarse sands and gravels) and aggregated 'clasts' of finer sediment would settle out of suspension close to the foundation location, whilst disaggregated finer sediments (fine sands and muds) would be more prone to dispersion. Due to the small quantities of sediment release involved, however, these disaggregated finer sediments are likely to be widely and rapidly dispersed, resulting in only low elevations in suspended sediment concentration.

170. Modelling simulations undertaken for East Anglia ONE (ABPmer 2012b) support the above expert-based assessments of suspended sediment concentrations arising from disturbance of deeper sub-surface sediments. These modelling studies make a suitable analogue for the present assessments, with any key differences between the two windfarm sites being noted.

171. In the East Anglia ONE modelling studies, 982m^3 of variably graded fine sediment (sand, clay and silt) was released into the water column once every two days to simulate the construction of eight consecutively drilled (jacket) foundations over a 15-day simulation period. This value is acknowledged to be less than the worst case scenario for the monopile foundations being considered for the proposed East Anglia TWO project but, nonetheless, the previous modelling results support the general principles of the expert-based assessments. Away from the immediate release locations, near-field elevations in suspended sediment concentration above background levels were low (less than 10mg/l) and within the range of natural variability. Indeed, concentrations were generally no greater than 5mg/l at 5km from the release location, indicating wide dispersion in low concentrations. Net movement of fine-grained sediment retained within the 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 the timing of release. Sediment concentrations arising from installation of one foundation were deemed unlikely to persist for sufficiently long that they significantly interact with subsequent operations and therefore no cumulative effect was anticipated.

172. The larger release volumes associated with the worst case scenario for the proposed East Anglia TWO project may result in larger concentrations above background levels than previously modelled. However, these are likely to still be modest (tens of mg/l) due to the low volumes of disaggregated fine-grained sediment in the drill arisings. Hence, the principle of wide dispersion in relatively low concentrations remains valid. Also, a conservative assumption was made in the modelling that all drilled sediment would disperse. However, in reality some of the drill arisings would arrive at the sea surface as larger aggregated clasts which would settle rapidly.

173. The changes in suspended sediment concentrations (magnitudes, geographical extents and durations of effect) that are anticipated above would move across the windfarm 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.

7.6.1.1.3 Assessment of Effect Magnitude and / or Impact Significance

174. Given that the expert-based assessments of the dynamic and passive plume effects on suspended sediment concentrations for the proposed East Anglia TWO project are consistent with the findings of the earlier modelling studies for the East Anglia ONE project, there is high confidence in the assessment of effects.

175. The worst case changes in suspended sediment concentrations due to foundation installation are likely to have the following magnitudes of effect (***Table 7.16***).

Table 7.16 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 of the order of several hundred metres up to a kilometre from each foundation location) and would not cover the East Anglia TWO windfarm site.

176. The effects on suspended sediment concentrations due to foundation installation for the proposed project do not directly impact upon the identified receptor groups for marine geology, oceanography and physical processes, so there is no impact associated with the proposed East Anglia TWO project.

177. The effects do have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.1.2 Impact 2 Changes in Sea Bed Level due to Foundation Installation

178. The increases in suspended sediment concentrations associated with Impact 1 (***section 7.6.1.1***) have the potential to deposit sediment and raise the sea bed level slightly. There would be different settling rates for the sediment types associated with the near-surface sediment disturbance compared to the deeper sub-surface sediment disturbance, so each is discussed in turn.

7.6.1.2.1 Near-surface Sediments

179. Expert-based assessment suggests that the coarser sediment would rapidly (within the order of minutes or tens of minutes) fall to the bed as a highly turbid dynamic plume immediately upon its discharge. Deposition of this sediment would form a 'mound' local to the point of release. Due to the sediment particle sizes observed across the windfarm site (predominantly medium sand or coarser, with very little fine sand or muds), a large proportion of the disturbed sediment would behave in this manner.

180. The resulting mound would be a measurable protrusion above the existing sea bed (likely to be tens of centimetres to a few metres high) but would remain local to the release point. The precise configuration of height and spreading distance of each mound would vary across the windfarm site, depending on the prevailing physical conditions, but in all cases the sediment within the mound would be similar to that on the existing sea bed. This would mean that there would be no discernible change in sea bed sediment type.

181. In addition to the localised mounds, some of the sediment from this release (mainly the fine sand fraction and the very small proportion of muds) is likely to form a passive plume and become more widely dispersed before settling on the sea bed. Expert-based assessment suggests that due to the dispersion by tidal currents, the thickness of deposits from the plume across the wider sea bed area would be very small (order of millimetres).

182. This assessment is supported by an evidence-base obtained from research into the physical impacts of marine aggregate dredging on sediment plumes and sea bed 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) which also indicates the propensity for wide dispersion and only small thicknesses of deposits on the sea bed from the release of similar sediments in similar physical environments.

183. The Delft3D plume modelling studies for East Anglia ONE (ABPmer 2012b) considered the bed level changes resulting from deposition of sediments from the passive plume due to sea bed preparation for 15 foundations. This involved a worst case near-surface sediment release of 22,500m^3 per foundation (i.e. around 80% of the value of the average conservative volume considered as the worst case for an individual wind turbine in the East Anglia TWO windfarm site). For the most part, the deposited sediment layer across the wider sea bed was found to be less than 0.2mm thick and did not exceed 2mm anywhere. The area of sea bed 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 sea bed (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 sea bed sediment layer, thus further reducing any potential effect.

7.6.1.2.2 Sub-surface Sediments

184. Expert-based assessment suggests that due to the finer-grained nature of any sub-surface sediment released into the water column from drilling, there would be greater dispersion across a wider area, in keeping with the pattern of the tidal ellipses.

185. The earlier Delft3D plume modelling studies (ABPmer 2012b) considered sea bed level changes resulting from deposition of sediments from drilling eight piled (jacket) foundations. The coarser sediment deposited near to the point of release to thicknesses of up to a few centimetres and over a sea bed area within a few hundred metres of each foundation. For the most part, the deposited sediment layer across the wider sea bed area was predicted to be less than 0.025mm thick.

186. Although the modelling used a smaller volume of sediment than the worst case scenario for the proposed East Anglia TWO project, it does support the principles of the expert-based assessment that the envisaged scale of sea bed level change would be very small (largely immeasurable).

187. The sea bed-level changes that are anticipated above 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.

7.6.1.2.3 Assessment of Effect Magnitude and/or Impact Significance

188. Given that the expert-based assessment of the sea bed level changes associated with foundation installation for the proposed East Anglia TWO project are consistent with the findings of the modelling studies for the East

Anglia ONE project, 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 windfarm site.

189. The worst case changes in sea bed levels due to foundation installation are likely to have the following magnitudes of effect (***Table 7.17***).

Table 7.17 Magnitude of Effects on Sea bed Level Changes due to Foundation Installation Under the Worst Case 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 sea bed (likely to be of the order of several hundred metres up to a kilometre from each foundation location), and would not cover the whole East Anglia TWO windfarm site.

190. These effects on sea bed level have the potential to impact directly upon the identified receptor groups at the maximum values 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.

191. The effects on sea bed level have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40*****)**.

7.6.1.3 Impact 3 Changes in Suspended Sediment Concentrations During Inter-Array Cable and Platform Link Cable Installation

192. The details of the inter-array and platform link cabling are dependent upon the final project design, but present estimates are that the total length of inter-array cables would be up to 200km, and the total length of platform link cable may be up to 75km. The worst case cable laying technique is considered to be jetting.

193. The installation of the cabling has the potential to disturb the sea bed down to a sediment thickness of up to 3m directly through the installation method chosen, or down to 5m through sea bed levelling of any large sand waves that may be present along the route of any cables prior to cable installation.

194. The volume of sediment affected due to sand wave excavation for inter-array and platform link cable installation is estimated to be up to 550,000m^3 (400,000m^3 and 150,000m^3, respectively). The sediment released at any one time would depend on the capacity of the dredger.

195. 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.

7.6.1.3.1 Assessment of Effect Magnitude and/or Impact Significance

196. It is anticipated using expert-based assessment that the changes in suspended sediment concentration due to inter-array cable and platform link cable installation would be lower than those arising from the disturbance of near-surface sediments during foundation installation activities including sea bed preparation. This is because the overall sediment release volumes would be low and confined to near the sea bed (rather than higher in the water column) along the alignment of the cables, and the rate at which sediment is released from the jetting process would be relatively slow.

197. Using this evidence, the worst case changes in suspended sediment concentrations due to inter-array cable and platform link cable installation are likely to have the following magnitudes of effect (***Table 7.18***).

Table 7.18 Magnitude of Effect on Suspended Sediment Concentrations due to Inter-Array Cable and Platform Link 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 (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 sea bed area within the East Anglia TWO windfarm site.

198. The effects do have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.1.4 Impact 4 Changes in Sea Bed Level due to Inter-array Cable and Platform Link Cable Installation

199. The increases in suspended sediment concentrations associated with Impact 3 (***section 7.6.1.3***) have the potential to result in changes in sea bed level as the suspended sediment deposits.

200. As discussed in ***section 7.6.1.3*** up to 400,000m^3 of sediment may be released as a result of pre-sweeping up to 200km of inter-array cables plus 150,000m^3 of sediment from up to 75km of platform link cables. The dynamic nature of the sand waves in this area means that any direct changes to the sea bed level

associated with sand wave levelling are likely to recover over a short period of time due to natural sand transport pathways.

201. Any excavated sediment due to sand wave levelling for the inter-array and platform link cables would be disposed of within the East Anglia TWO windfarm site itself. This means there will be no net loss of sand from the site. It is likely that some of this sand would be disposed in areas of the windfarm site where tidal currents would, over time, re-distribute the sand back over the levelled area (as re-formed sand waves). The extent of sand wave levelling required and specific disposal locations within the East Anglia TWO windfarm site would be determined post consent following detailed geophysical surveys, however, given the relatively low volumes of sand likely to be affected, the overall effect of changes to the sea bed would be minimal.

7.6.1.4.1 Assessment of Effect Magnitude and/or Impact Significance

202. The changes in suspended sediment concentration due to inter-array cable and platform link cable installation would be less than those arising from the disturbance of near-surface sediments during foundation installation activities. Therefore, the sea bed level changes would also be lower.

203. Using this as a basis, the worst case changes in sea bed level due to inter-array cable and platform link cable installation are likely to have the following magnitudes of effect (***Table 7.19***).

Table 7.19 Magnitude of Effect on Sea Bed Level Changes due to Inter-Array Cable and Platform Link 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 inter-array cable) and would not cover the whole East Anglia TWO windfarm site.

204. These effects on sea bed level are considered highly unlikely to have the potential to impact directly upon the identified receptor groups for marine geology, oceanography and physical processes. This is because the magnitude of effect is smaller than that associated with foundation installation and there is a large separation distance (greater than one tidal ellipse) which does not support the existence of a pathway between the source and receptor.

205. The overall impact of inter-array cable and platform link cable installation activities on sea bed level changes under a worst case scenario for identified morphological receptor groups is regarded as **no impact**.

206. In many parts of the East Anglia TWO windfarm site there would not be the need for release of volumes of sediment considered under this worst case scenario. Optimisation of inter-array cable and platform link cable alignment, depth and installation methods during detailed design would ensure that impacts are minimised.

207. The effects do have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.1.5 Impact 5 Changes in Suspended Sediment Concentrations During Export Cable Installation

208. The assessment of changes in suspended sediment concentration during export cable installation has been considered separately from those for the inter-array and platform link cables because parts of the offshore cable corridor are in shallower water and closer to the identified morphological receptor groups.

209. The detail of the export cabling is dependent upon the final project design, but present estimates are that the maximum length of each export cable could be up to 80km. Up to two cables would be installed providing a total maximum length of 160km of export cable. The worst case cable laying technique is considered to be jetting.

210. The installation of the export cables has the potential to disturb the sea bed down to a sediment thickness of up to 3m, directly through the installation method chosen, or up to 5m through sea bed levelling of any large sand waves that may be present along the offshore cable corridor prior to cable installation. The release of sediment from both construction phase activities, with the release points along the offshore cable corridor, has been considered here.

211. The volume of sediment affected due to sand wave levelling for the export cable installation is estimated to be up to 1,000,000m^3. The sediment released at any one time would depend on the capacity of the dredger.

212. 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.

7.6.1.5.1 Assessment of Effect Magnitude and/or Impact Significance

213. It is anticipated using expert-based assessment that the changes in suspended sediment concentration due to export cable installation would be less than those arising from the disturbance of near-surface sediments during foundation installation activities, although the location of effect would differ as it would be focused along the offshore cable corridor.

214. This assessment is based on the overall sediment release volumes being low and confined to near the sea bed (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 being relatively slow.

215. It is likely that the concentrations would be enhanced by the greatest amount in the shallowest sections of the offshore cable corridor, but in these locations the background concentrations are also greater than in deeper waters, typically up to 170mg/l.

216. Modelling simulations undertaken for East Anglia ONE (ABPmer 2012b) support the expert-based assessment and provided the following quantification of magnitude of change:

- Sand-sized sediment (which represents most of the 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.
- 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.
- 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 the coast (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.
- After 180 hours following cessation of installation activities any plume would have been fully dispersed.

217. There are similarities in water depth, sediment types and metocean conditions between the offshore cable corridor for East Anglia ONE and for the proposed East Anglia TWO project making the earlier modelling studies a suitable analogue for the present assessments.

218. Using this as a basis, the worst case changes in suspended sediment concentrations due to export cable installation are likely to have the following magnitudes of effect (***Table 7.20***).

Table 7.20 Magnitude of Effect on Suspended Sediment Concentrations due to Export Cable Installation Under the Worst Case Scenario

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field* (nearshore)	High	Negligible	Negligible	Negligible	Medium
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.

219. These effects on suspended sediment concentrations are considered highly unlikely to have the potential to impact directly upon the identified receptor groups for marine geology, oceanography and physical processes due to separation distances, except for parts of the Suffolk Natura 2000 site across which part of the offshore cable corridor crosses.

220. Effects will be spread along the offshore cable corridor with the slow progression of the cable installation.

221. Given these aspects, the sensitivity and value of the 'Suffolk Natura 2000' site are presented in ***Table 7.21***.

Table 7.21 Sensitivity and Value Assessment for the 'Suffolk Natura 2000' Site

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
'Suffolk Natura 2000' site	Negligible	Negligible	Negligible	High	Negligible

222. The overall impact of export cable installation activities under a worst case scenario on suspended sediment concentrations for the identified morphological receptor groups is considered to be **no impact**, except for the 'Suffolk Natura 2000' site which is assessed to have an impact of **minor adverse** to **negligible** significance.

223. The impacts arising from subsequent deposition of the suspended sediments on the sea bed are discussed under Impact 6 (***section 7.6.1.6***).

224. The effects do have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.1.6 Impact 6 Changes in Sea Bed Level due to Export Cable Installation

225. The increases in suspended sediment concentration associated with Impact 5 have the potential to result in changes in sea bed level as the suspended sediment deposits.

226. As discussed in ***section 7.6.1.5*** up to 1,000,000m^3 of sediment may be released as a result of pre-sweeping of up to 160km of export cables. The dynamic nature of the sand waves in this area means that any direct changes to the sea bed elevation associated with sand wave levelling are likely to recover over a short period of time due to natural sand transport pathways.

227. Any excavated sediment due to sand wave levelling for the export cables would be disposed of within the East Anglia TWO windfarm site itself. This means there will be no net loss of sand from the site. It is likely that some of this sand would be disposed in areas of the windfarm site where tidal currents would, over time, re-distribute the sand back over the levelled area (as re-formed sand waves). The extent of sand wave levelling required and specific disposal locations within the East Anglia TWO windfarm site would be determined post consent following detailed geophysical surveys, however, given the relatively low volumes of sand likely to be affected, the overall effect of changes to the sea bed would be minimal.

7.6.1.6.1 Assessment of Effect Magnitude and/or Impact Significance

228. The changes in suspended sediment concentration due to export cable installation would be lower than those arising from the disturbance of near-surface sediments during foundation installation activities. Therefore, the magnitude of bed level changes would also be lower, although the location of effect would differ as it would be focused along the offshore cable corridor.

229. Modelling simulations undertaken for East Anglia ONE (ABPmer 2012b) estimate that sea bed level changes of up to 2mm would be observed within a few hundred metres of the inshore sections of the offshore cable corridor and further afield the sea bed level changes are not expected to be measurable.

230. Using this as a basis, the worst case changes in sea bed level due to export cable installation are likely to have the following magnitudes of effect (***Table 7.22***).

Table 7.22 Magnitude of Effect on Sea Bed Level Changes due to Export 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.

231. These effects on sea bed level are considered highly unlikely to have the potential to impact directly upon the identified receptor groups for marine geology, oceanography and physical processes due to separation distances, except for parts of the Suffolk Natura 2000 site across which part of the offshore cable corridor crosses.

232. For most receptor groups the magnitude of effect is lower than that associated with foundation installation and there is a large separation distance (greater than one tidal ellipse) which does not support the existence of a pathway between the source and receptor.

233. Given these aspects, the sensitivity and value of the ‘Suffolk Natura 2000’ site are presented in ***Table 7.23***.

Table 7.23 Sensitivity and Value Assessment for the ‘Suffolk Natura 2000’Site

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
‘Suffolk Natura 2000’ site	Negligible	Negligible	Negligible	High	Negligible

234. The overall impact of export cable installation activities under a worst case scenario on bed level changes for the identified morphological receptor groups is considered to be no impact, except for the ‘Suffolk Natura 2000’ site which is assessed to have an impact of **negligible** significance.

235. In many parts of the offshore cable corridor there would not be the need for release of such volumes of sediment as considered under this worst case scenario, and optimisation of the export cable route selection within the offshore cable corridor, depth and installation methods during detailed design would ensure that impacts are minimised.

236. The effects do have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.1.7 Impact 7 Indentations on the Sea Bed due to Installation Vessels

237. There is potential for certain vessels used during the installation of the windfarm and cable infrastructure to directly impact the sea bed. This applies for those vessels that utilise jack-up legs or several anchors to hold station and to provide stability for a working platform. Where legs or anchors (and associated chains) have been inserted into the sea bed and then removed, there is potential for an indentation to remain, proportional 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.

238. As the leg is inserted, the sea bed sediments would primarily be compressed vertically downwards and displaced laterally. This may cause the sea bed 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 pit would become shallower and less distinct due to infilling with mobile sediments.

239. A single jack-up barge leg would have a footprint of 50 to 500m^2 and a jack-up vessel would have up to six legs. Each leg could penetrate up to 20m into the sea bed and may be cylindrical, triangular, truss leg or lattice.

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

7.6.1.7.1 Assessment of Effect Magnitude and/or Impact Significance

241. The worst case changes in terms of indentations on the sea bed due to installation vessels are likely to have the following magnitudes of effect (***Table 7.24***).

Table 7.24 Magnitude of Effect on Sea Bed 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	No change	-	-	-	No change

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
immediate vicinity of leg)					
Far-field	No change	-	-	-	No change

242. 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.

243. The significance of these effects on other receptors is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.1.8 Impact 8 Changes to Suspended Sediment Concentrations and Coastal Morphology at the Landfall

244. At the landfall just north of Thorpeness, the worst case scenario includes installation of two cables using HDD techniques. As a consequence of the chosen method there would be **no impacts** on the morphology within the intertidal zone.

7.6.1.8.1 Assessment of Effect Magnitude and/or Impact Significance

245. The worst case changes to suspended sediment concentrations and coastal morphology at the cable landfall are likely to have the following magnitudes of effect (***Table 7.25***).

Table 7.25 Magnitude of Effects on Suspended Sediment Concentrations and Coastal Morphology at the Cable Landfall Under the Worst Case Scenario

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

7.6.2 Potential Impacts during Operation

246. During the operational phase of the proposed East Anglia TWO project, there is potential for the presence of the foundations of the turbines, meteorological masts and offshore platforms to cause changes to the tidal and wave regimes due to physical blockage effects. These changes could potentially affect the sediment regime and / or sea bed morphology. These potential effects are considered as Operational Impacts 1 to 5. Effects due to the presence of cable protection measures are considered in Operational Impacts 6 to 8. In addition, there is potential for the temporary presence of engineering equipment, for

example, 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 9.

7.6.2.1 Impact 1 Changes to the Tidal Regime due to the Presence of Foundation Structures

247. The presence of foundation structures within the East Anglia TWO windfarm site has the potential to alter the baseline tidal regime, particularly tidal currents and water levels. Any changes in the tidal regime may have the potential to contribute to changes in the sea bed morphology due to alteration of sediment transport patterns (see operational impact 3, ***section 7.6.2.3***) or due to initiation of sea bed scour (see operational impact 4, ***section 7.6.2.4***).

248. Expert-based assessment suggests that each foundation would present an obstacle to the passage of currents locally, causing a small modification to the height and/or phase of the water levels and a wake in the current flow. This latter process involves a deceleration of flow immediately upstream and downstream of each foundation and an acceleration of flow around the sides of each foundation. 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 separation distances.

249. There is a pre-existing evidence base which demonstrates that changes in the tidal regime due to the presence of foundation structures are both small in magnitude and localised in spatial extent. This is confirmed by existing guidance documents (ETSU 2000; ETSU 2002; Lambkin et al. 2009) and numerous EIAs for offshore windfarms, including Delft3D numerical modelling of changes in hydrodynamics associated with East Anglia ONE (ABPmer 2012b). This modelling was based on a worst case of 240 GBS (50m base diameter and height up to 10m above the sea bed) and showed changes in water level of less than ±0.007m across a small geographical area.

250. With respect to changes in tidal currents, the previous modelling (see ***section 7.4.2***) predicted maximum reductions in peak flow speeds of 0.05 to 0.1m/s and maximum increases in peak flow speeds of 0.05m/s, from peak baseline values of around 1m/s. The geographical extent of these maximum changes was largely confined to the near-field environment (a wake zone local to each wind turbine foundation).

7.6.2.1.1 Assessment of Effect Magnitude and/or Impact Significance

251. Given that the expert-based assessments of the changes in the tidal regime associated with the presence of foundation structures for the proposed East Anglia TWO project are consistent with the findings of the earlier modelling

studies for East Anglia ONE, there is high confidence in the assessment of effects.

252. The worst case changes to tidal currents due to the presence of GBS foundations are likely to have the following magnitudes of effect (***Table 7.26***).

Table 7.26 Magnitude of Effects 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	No change	-	-	-	No change

253. 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 7.5***.

254. The identified receptor groups for marine geology, oceanography and physical processes are remote from the ‘zone of potential influence’ on the tidal regime. Due to this, no pathway exists between the source and the receptor, so in terms of impacts on these receptor groups there is **no impact** associated with the proposed East Anglia TWO project.

7.6.2.2 Impact 2 Changes to the Wave Regime due to the Presence of Foundation Structures

255. The presence of foundation structures within the East Anglia TWO windfarm site has the potential to alter the baseline wave regime, particularly in respect of wave heights and directions. Any changes in the wave regime may have the potential to contribute to changes in the sea bed morphology due to alteration of sediment transport patterns (see operational impact 3, ***section 7.6.2.3***) or due to initiation of sea bed scour (see operational impact 4, ***section 7.6.2.4***).

256. 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.

257. 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 both relatively small in magnitude (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 windfarms in the UK and European waters (Seagreen 2012), existing guidance documents (ETSU 2000; ETSU 2002; Lambkin et al. 2009), published research (Ohl et al. 2001) and post-installation monitoring (Cefas 2005).

258. This is further supported by numerical modelling of changes in the wave regime under return period events of 0.1 year, one year and ten years, for East Anglia ONE (ABPmer 2012b). This wave modelling incorporated a worst case of 240 gravity base structures with a basal diameter of 50m and up to 10m in height above the sea bed. The results were:

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

259. Due to proximity of the East Anglia ONE windfarm site to the ‘non designated sand banks’ receptor group and also the Galloper Offshore Windfarm site, wave height reductions of up to about 5% were observed under the largest storm events considered at these locations. These were not considered to be significant impacts by the East Anglia ONE assessment (either alone or cumulatively with Galloper). Changes under lesser magnitude events were not noticeable at the ‘non designated sand banks’ receptor group or the Galloper site.

260. The worst case scenario included in the East Anglia ONE wave modelling considered 240 GBS with a basal diameter of 50m and up to 10m in height

above the sea bed. The likely envelope of wind turbine numbers and GBS foundation sizes for the East Anglia TWO site is presented in ***Table 7.27***.

Table 7.27 Likely Wind Turbine Arrangements for Worst Case Scenario at East Anglia TWO

Turbine blade tip height	No. wind turbines	Maximum basal diameter of gravity base structure (m)
250m	75	53
300m	60	60

261. The modelling for East Anglia ONE is considerably more conservative in terms of the number of foundations being considered for the proposed East Anglia TWO project.

262. Expert-based assessment suggests, therefore, that both the magnitude and spatial extent of effects on the wave climate at the East Anglia TWO windfarm site would be less than those previously assessed for East Anglia ONE.

263. For the purposes of the proposed East Anglia TWO project assessments, a wave modelling exercise was completed to assess the effects of a worst case scenario of 67[1] GBS wind turbine foundations, each with a basal diameter of 60m, with one meteorological mast and five offshore platforms based on identical foundation types and sizes (i.e. 73 foundations in total).

264. The wave modelling involved three stages: (i) defining a suitable offshore wave climate based on data analysis; (ii) local-scale wave modelling using DIFFRACT to characterise wave reflection properties of different foundation types and sizes to determine a worst case; and (iii) regional-scale wave modelling using the MIKE21-SW (spectral wave) model to quantify far-field effects.

265. The modelling results presented in ***Figure 7.6*** show that the effects on baseline wave conditions from the East Anglia TWO windfarm site alone cover only a small spatial extent. The magnitude of modelled changes in significant wave height is typically less than 1% only a short distance away from the windfarm array. Further information about the wave modelling is provided in ***Appendix 7.2***.

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[1] Note that this number differs to the current maximum wind turbine parameters (i.e. up to 75) due to changes in the anticipated project design since the modelling was undertaken. However, this assessment can still be deemed conservative given that it has applied the 60m basal diameter foundation for up to 67 turbines. The worst case scenario for other relevant assessments in this ES assumes a maximum of 60 GBS wind turbine foundations each with a basal diameter of 60m or 75 wind turbine GBS foundations each with a basal diameter of 53m.

7.6.2.2.1 Assessment of Effect Magnitude and/or Impact Significance

266. The worst case changes to the wave regime due to the presence of foundations are likely to have the following magnitudes of effect (***Table 7.28***).

Table 7.28 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

267. The identified receptor groups for marine geology, oceanography and physical processes are remote from the zone of effect arising from changes in the baseline wave regime. Due to this, no pathway exists between the source and the receptor, so in terms of impacts on these receptor groups there is **no impact** associated with the proposed East Anglia TWO project.

7.6.2.3 Impact 3 Changes to the Sediment Transport Regime due to the Presence of Foundation Structures

268. 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.

269. This section addresses patterns of suspended and bedload sediment transport across, and beyond, the East Anglia TWO windfarm site and littoral sediment transport at the coast. The issue of local scour around the foundations is considered separately (see operational impact 4***, section 7.6.2.4***).

7.6.2.3.1 Assessment of Effect Magnitude and/or Impact Significance

270. The predicted reductions in tidal flow (operational impact 1) and wave height (operational impact 2) associated with the presence of the worst case foundation structures 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 (and in so doing generate local scour – see operational impact 4 ***section 7.6.2.4***).

271. These changes to the marine physical processes would be 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 sea bed area, but the changes in wave heights across this wider area would be notably lower (typically less than 1%)

than the changes local to each wind turbine foundation. 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 following magnitudes of effect (***Table 7.29***).

Table 7.29 Magnitude of Effects 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

272. 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 7.5*** and ***Figure 7.6*** respectively) and therefore, there is **no impact** associated with the proposed project on the marine geology, oceanography and physical processes receptor groups.

7.6.2.4 Impact 4 Changes in Suspended Sediment Concentrations due to Scour Around Foundation Structures

273. Findings from the second assessment approaches (***section 7.4.3***) have previously been verified against field measurements and laboratory scale physical model tests (Bolle et al. 2009; 2010; Khalfin 2007; Larsen and Frigaard 2005; Margheritini 2012; Raaijmakers and Rudolph 2008; Stahlmann and Schlurmann 2010; Whitehouse et al. 2010; Yeow and Cheng 2003; Yang et al. 2010).

274. Using these approaches, the previous studies have revealed (overly-conservative) a worst case scour volume under a 50-year return period event of about 5,000m^3 per wind turbine, for an individual foundation of similar type and size to the worst case for the proposed East Anglia TWO project. This value is considerably less than the worst case volume of sediment potentially released following sea bed preparation activities (which are around five times greater per wind turbine) and therefore the magnitude of effect would be much lower than previously assessed for that impact.

275. In addition, given the sediment types prevalent across the East Anglia TWO windfarm site, most of the relatively small quantities of sediment released at each wind turbine foundation due to scour processes would rapidly settle within a few hundred metres of each one.

7.6.2.4.1 Assessment of Effect Magnitude and / or Impact Significance

276. The worst case changes in suspended sediment concentrations due to scour around foundation structures are likely to have the following magnitudes of effect (***Table 7.30***).

Table 7.30 Magnitude of Effects on the Suspended Sediment Regime due to Scour Around Foundations Under the Worst Case Scenario

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field*	Low	High	Medium	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 foundation) and would not cover the whole East Anglia TWO windfarm site.

277. The effects on suspended sediment transport arising from scour processes would not extend more than a few hundred metres away from each wind turbine location before the sediment settles on the sea bed. Therefore, there is **no impact** associated with the proposed project on the marine geology, oceanography and physical processes receptor groups since these are located remotely from this zone of potential effect.

278. However, the effects do have the potential to impact upon other receptors and therefore the assessment of impact significance is addressed within the relevant chapters of this ES (see ***Table 7.40*)**.

7.6.2.5 Impact 5 Changes to the Sea Bed Morphology due to the Footprint of the Foundation Structures

279. The sea bed morphology would directly be impacted by the footprint of each foundation structure on the sea bed within the East Anglia TWO windfarm site. This would constitute a ‘loss’ in natural sea bed area during the operational life of the proposed project.

280. This direct footprint could be further enhanced due to the presence of foundation structures in one of two ways. Under a scenario of no scour protection, a scour hole would be likely to develop around each foundation. This would have two implications for sea bed morphology, in addition to the direct foundation footprint. The scour hole would directly affect an area of the sea bed, lowering sea bed levels locally around each foundation and mobile sediments would become suspended into the water column. These sediments would ultimately settle back to the sea bed potentially causing bed level changes due to deposition.

281. Under an alternative scenario of scour protection being provided, the sea bed 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.

282. The worst case of these two scenarios is associated with the provision of scour protection. For the whole windfarm site, the maximum footprint on the sea bed from the foundation and scour protection for each wind turbine, meteorological mast and offshore platform is 1,719,856m^2. This is associated with GBS foundations.

7.6.2.5.1 Assessment of Effect Magnitude and/or Impact Significance

283. The worst case changes to the sea bed morphology due to the presence of foundation structures are likely to have the following magnitudes of effect (***Table 7.31***).

Table 7.31 Magnitude of Effects on Sea Bed Morphology due to the Presence of Foundations 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 within the footprint of scour protection (should it be provided) and would not cover the whole East Anglia TWO windfarm site.

284. The effects on sea bed morphology arising from the presence of foundation structures are manifest upon other topics, such as benthic ecology. The significance of these effects on other receptors is addressed within the relevant chapters of this ES (see ***Table 7.40*)**.

7.6.2.6 Impact 6 Morphological and Sediment Transport Effects due to Cable Protection Measures for Inter-array Cables and Platform Link Cables

285. As a worst case scenario it has been assumed that up to 10% of the inter-array cables and platform link cables may need to be protected in some manner, and that cable protection would also be required at any cable crossings.

286. Cable protection may take the form of rock placement, concrete mattresses, fronded concrete mattresses, or uraduct shell.

287. 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 sea bed.

288. In areas of active sediment transport, any linear protrusion on the sea bed may interrupt bedload sediment transport processes during the operational phase of the proposed project. There is unlikely to be any significant effect on suspended sediment processes since armoured cables or cable protection works are relatively low above the sea bed (a maximum of 1m), except in areas where the cable crosses other sub-marine infrastructure (e.g. pipelines and cables) where it may extend to a height of up to 4m.

289. The presence and asymmetry of sand waves across some of the sea bed within the East Anglia TWO windfarm site indicates that some bedload sediment transport exists. There are also megaripples present across the East Anglia TWO windfarm site. Protrusions from the sea bed are unlikely to significantly affect the migration of sand waves, since sand wave heights (up to 14m) in most areas would exceed the height of cable protection works, and would pass over them. There may be localised interruptions to bedload transport in other areas, but the gross patterns of bedload transport across the East Anglia TWO windfarm site would not be affected significantly.

290. The presence of cable protection works on the sea bed would represent the worst case in terms of a direct loss of sea bed area, but this footprint is likely to be lower than that of the foundations (and associated scour hole or scour protection works) within the East Anglia TWO windfarm site.

7.6.2.6.1 Assessment of Effect Magnitude and/or Impact Significance

291. The worst case changes to the sea bed morphology and sediment transport due to cable protection measures for inter-array cables and platform link cables are likely to have the following magnitudes of effect (***Table 7.32***).

Table 7.32 Magnitude of Effects on Sea Bed Morphology and Sediment Transport due to Cable Protection Measures for Inter-Array Cables and Platform Link 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 East Anglia TWO site.

292. The effects on sea bed morphology and sediment transport arising from the presence of inter-array cable and platform link cable protection measures would not extend far beyond the direct footprint. Therefore, there is **no impact** associated with the proposed project on the identified marine geology,

oceanography and physical processes receptor groups since these are located remotely from this zone of potential effect.

293. The significance of these effects on other receptors is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.2.7 Impact 7 Morphological and Sediment Transport Effects due to Cable Protection Measures for Export Cables

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

295. The locations where cable protection measures are most likely to be required are areas of cable crossings and in areas of sea bed characterised by exposed bedrock.

296. Cable protection may take the form of rock placement, concrete mattresses, fronded concrete mattresses, or uraduct shell.

297. The effects that cable protection 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 sea bed.

298. In areas of active sediment transport, any linear protrusion on the sea bed may interrupt bedload sediment transport processes during the operational phase. There is likely to be a difference in effect depending on whether the cable protection works are in ‘nearshore’ or ‘offshore’ areas within the offshore cable corridor. Any works in areas closest to the coast have the potential to affect alongshore sediment transport processes and circulatory pathways across the nearshore banks and those areas further offshore potentially affecting sediment transport processes across the sea bed.

299. The seaward limit which marks the effective boundary of wave-driven sediment transport pathway mechanisms is called the ‘closure depth’ of the shore profile and can be calculated using the methods of Hallermeier (1978). For the sea bed offshore from the landfall, this would be typically located in around 5m of water.

300. In addition, tidally-driven sediment transport occurs in a circulatory motion between the coast and the nearshore banks, where these are present within the offshore cable corridor (i.e. the southern end of the nearshore Sizewell Bank occupies a small part of the cable corridor across its northern boundary). These circulatory sediment transport processes occur inshore of the 10m depth

contour, but only in the northern part of the offshore cable corridor, due to the physical location of the nearshore Sizewell Bank.

301. Any protrusions from the sea bed associated with cable protection measures inshore of the closure depth (i.e. shallower than -5m CD) or within the active circulatory pathway between the coast and sand banks (i.e. shallower than -10m CD in areas occupied by sand banks) could potentially have an effect on sediment transport in the nearshore and along the coast. Any interruptions to sediment transport locally within this zone could, in turn, affect the morphological response of wider areas (e.g. frontages along the sediment transport pathway, links with the nearshore banks, etc.) due to reductions in sediment supply to those areas.

302. Along the sections of the offshore cable corridor that are located seaward of the closure depth and/or seaward of the active circulatory pathway between the coast and sand banks (where present), any protrusions from the sea bed associated with cable protection measures are unlikely to significantly affect the migration of sand waves, since their heights would in most areas where they are present exceed the likely height of cable protection works (up to 2.25m). There may be localised interruptions to bedload transport in some areas, especially at cable crossings, but the gross patterns of bedload transport would not be affected significantly.

303. In recognition of these potential effects, considerable effort has been given to selecting an appropriate landfall location and export cable route within the offshore cable corridor to minimise sediment transport effects as far as practicably achievable. The different important marine geological and geomorphological features that are present include the outcrop of Coralline Crag, the ness at Thorpeness and the nearshore Sizewell and Dunwich Banks. Importantly, there are also physical process interactions between these features. This understanding has led to selection of a preferred location for the export cable landfall towards the southern end of the offshore cable corridor at the coast. To ensure that such a location is achievable, the offshore cable corridor in the landfall area has been refined (area increased to the south) to create additional sea bed area within which to accommodate a southern export cable route within the offshore cable corridor (see ***Figure 7.7***).

304. A commitment has also been made to install the export cable at the landfall using HDD techniques, thus minimising disturbance and avoiding the need for cable protection in the intertidal and shallowest nearshore zones. It is likely that the HDD pop-out location would be in water depths greater than 2m LAT (although most likely greater than 5m water depth) and to the south of the outcrop of Coralline Crag. Hence, there would be no interruption of the circulatory sediment transport pathways between the coast and Sizewell Bank

and there is a strong likelihood of the export cable requiring no protection measures within the closure depth of the active beach profile, due to the presence of sand on the sea bed in this location.

305. As a consequence of this embedded mitigation, the proposed HDD method and pop-out location:

- Avoids direct physical disruption to the nearshore Sizewell Bank;
- Avoids direct physical disruption to the outcrop of Coralline Crag;
- Avoids direct physical disruption to the ness at Thorpeness;
- Avoids interruption of circulatory sediment transport pathways;
- Avoids disturbance to the alongshore sediment transport processes;
- Reduces the risk of suspended sediment (during construction) affecting the Sizewell Nuclear Power Station’s cooling water infrastructure;
- Avoids the need for cable protection measures in the intertidal and shallowest nearshore zones; and
- Minimises the need for cable protection measures elsewhere across the sea bed.

306. The effects of export cable protection directly at the landfall (on the ‘East Anglia’ coast) are assessed under Operational Impact 8 in light of the above embedded mitigation (***section 7.6.2.8***).

7.6.2.7.1 Assessment of Effect Magnitude and/or Impact Significance

307. The worst case changes to the sea bed morphology and sediment transport due to cable protection measures for export cables are likely to have the following magnitudes of effect (***Table 7.33***).

Table 7.33 Magnitude of Effect on Sea Bed Morphology and Sediment Transport due to Cable Protection Measures for Export Cables Under the Worst Case Scenario

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Inshore of the closure depth and/or within active circulatory sediment transport pathways between the coast and banks	Negligible	Negligible	Negligible	Negligible	Negligible
Offshore of the closure depth and/or beyond active circulatory sediment transport	Low	High	High	Negligible	Low

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
pathways between the coast and banks					

308. Offshore of the closure depth and/or beyond active circulatory sediment transport pathways between the coast and Sizewell Bank, the effects on sea bed morphology and sediment transport arising from the presence of export cable protection measures would not extend far beyond the direct footprint. Therefore, there is **no impact** in these locations associated with the proposed project on the identified marine geology, oceanography and physical processes receptor groups since these are located remotely from this zone of potential effect.

309. However, inshore of the closure depth and/or within the active circulatory sediment transport pathways between the coast and Sizewell Bank, these effects could potentially affect parts of the 'Suffolk Natura 2000' site and, indirectly, parts of the 'East Anglia' coast. Given this, the sensitivity and value of these receptors are presented in ***Table 7.34***.

Table 7.34 Sensitivity and Value Assessment for the 'Suffolk Natura 2000 Site and 'East Anglia' Coast

Receptor	Tolerance	Adaptability	Recoverability	Value	Sensitivity
'Suffolk Natura 2000' site	Medium	Low	Negligible	High	Medium
'East Anglia' coast	Medium	Low	Negligible	High	Medium

310. In areas inshore of the closure depth and/or within the active circulatory sediment transport pathways between the coast and Sizewell Bank there would be direct impacts of **negligible significance** on the 'Suffolk Natura 2000' site and these, in turn, would cause **no change** or indirect impacts of **negligible significance** on the East Anglia coast due to interruptions to sediment transport processes.

311. There would be **no impact** on the other identified marine geology, oceanography and physical processes receptor groups since these are located remotely from the locations of potential effect.

312. The significance of these effects on other receptors is addressed within the relevant chapters of this ES (see ***Table 7.40*)**.

7.6.2.8 Impact 8 Morphological Effects due to Cable Protection Measures at the Export Cable Landfall

313. As the export cables would remain buried at the landfall throughout the design life of the proposed East Anglia TWO project, no cable protection would be required and as such no morphological effects would take place.

314. Analysis of past coastal change and future coastal projections would inform detailed engineering decisions about cable burial depths.

7.6.2.8.1 Assessment of Effect Magnitude and/or Impact Significance

315. The worst case effects on the coastal morphology at the cable landfall during the operational phase of the proposed East Anglia TWO project are **no impact**.

7.6.2.9 Impact 9 Indentations on the Sea Bed due to Maintenance Vessels

316. There is potential for certain vessels used during maintenance of the windfarm and cable infrastructure to directly impact the sea bed. This applies for those vessels that utilise jack-up legs or several anchors to hold station and to provide stability for a working platform. Where legs or anchors (and associated chains) have been inserted into the sea bed and then removed, there is potential for an indentation to remain, proportional to the dimensions of the object.

7.6.2.9.1 Assessment of Effect Magnitude and / or Impact Significance

317. The changes in terms of indentations on the sea bed due to maintenance vessels are likely to have the following magnitudes of effect (***Table 7.35***).

Table 7.35 Magnitude of Effect on Sea Bed Level Changes 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

318. 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.

319. The significance of these effects on other receptors is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.6.3 Potential Impacts during Decommissioning

320. There is a statutory requirement for the applicant to decommission the proposed East Anglia TWO project. The scope of the decommissioning works would most likely involve removal of the accessible installed components. Offshore, this is likely to include removal of all the wind turbine components, part of the foundations (those above sea bed level) and the sections of inter-array cables and platform link cables.

321. With regards to export cables, general UK practice would be followed. Buried cables would be cut at the ends and left *in situ*, except for the intertidal zone where the cables could be at risk of becoming exposed over time.

322. During the decommissioning phase, there is potential for wind turbine, foundation and (where undertaken), cable removal activities to cause changes in suspended sediment concentrations and / or sea bed 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 foundation removal;
- Impact 2 Changes in sea bed levels due to foundation removal;
- Impact 3 Changes in suspended sediment concentrations due to removal of parts of the inter-array and platform link cables;
- Impact 4 Changes in sea bed levels due to removal of parts of the inter-array and platform link cables;
- Impact 5 Changes in suspended sediment concentrations due to removal of parts of the export cable;
- Impact 6 Changes in sea bed levels due to removal of parts of the export cable;
- Impact 7 Indentations on the sea bed due to decommissioning vessels; and
- Impact 8 Changes to suspended sediment concentrations and coastal morphology at the offshore cable corridor landfall due to removal of the export cable.

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

324. The significance of effects on other receptors is addressed within the relevant chapters of this ES (see ***Table 7.40***).

7.7 Cumulative Impacts

325. The potential for all previously identified impacts to act in a cumulative manner are assessed in ***Table 7.36***.

Table 7.36 Potential Cumulative Impacts

Impact	Potential for cumulative impact	Data confidence	Rationale
Construction			
Construction Impact 1 Changes in suspended sediment concentrations due to foundation installation	No	High	Impacts occur at discrete locations for a time-limited duration and are low or negligible in magnitude. Suspended sediment rationale is further discussed in ***section 7.7.3***.
Construction Impact 2 Changes in sea bed levels due to foundation installation	No	High	
Construction Impact 3 Changes in suspended sediment concentrations during inter-array cable and platform link cable installation	No	High	
Construction Impact 4 Changes in sea bed levels due to inter-array cable and platform link cable installation	No	High	
Construction Impact 5 Changes in suspended sediment concentrations during export cable installation	No	High	
Construction Impact 6 Changes in sea bed levels due to export cable installation	No	High	
Construction Impact 7 Indentations on the sea bed due to installation vessels	No	High	
Construction Impact 8 Changes to suspended sediment concentrations and	No	High	

Impact	Potential for cumulative impact	Data confidence	Rationale
coastal morphology at the offshore cable landfall			
Operation			
Operation Impact 1 Changes to the tidal regime due to the presence of foundation structures	Yes	High	Impacts could potentially coalesce with those arising from other windfarm projects
Operation Impact 2 Changes to the wave regime due to the presence of foundation structures	Yes	High	
Operation Impact 3 Changes to the sediment transport regime due to the presence of foundation structures	Yes	High	
Operation Impact 4 Changes in suspended sediment concentrations due to scour around foundation structures	No	High	Impacts occur at discrete locations for a time-limited duration and are low or negligible in magnitude.
Operation Impact 5 Changes to the sea bed morphology due to the presence of foundation structures	No	High	Footprint affects a discrete area of sea bed
Operation Impact 6 Morphological and sediment transport effects due to cable protection measures for inter-array cables and platform link cables	No	High	Impacts are in a sufficient depth of water to not cause cumulative effects on identified sensitive receptors
Operation Impact 7 Morphological and sediment transport effects due to cable protection measures for export cables	Yes	High	Impacts could potentially coalesce with those arising from other windfarm projects and disturb sediment transport pathways, particularly if protection measures are near to shore
Operation Impact 8 Morphological effects due to cable protection measures at the export cable landfall	No	High	No cable protection measures at the offshore cable landfall

Impact	Potential for cumulative impact	Data confidence	Rationale
Operation Impact 9 Indentations on the sea bed due to maintenance vessels	No	High	Impacts occur at discrete locations for a time-limited duration and are low or negligible in magnitude.
Decommissioning			
Decommissioning Impact 1 Changes in suspended sediment concentrations due to foundation removal	No	High	Impacts occur at discrete locations for a time-limited duration and are low or negligible in magnitude
Decommissioning Impact 2 Changes in sea bed levels due to foundation removal	No	High	
Decommissioning Impact 3 Changes in suspended sediment concentrations due to removal of inter-array cables and platform link cables	No	High	
Decommissioning Impact 4 Changes in sea bed levels due to removal of inter-array cables and platform link cables	No	High	
Decommissioning Impact 5 Changes in suspended sediment concentrations due to removal of export cables	No	High	
Decommissioning Impact 6 Changes in sea bed levels due to removal of export cables	No	High	
Decommissioning Impact 7 Indentations on the sea bed due to decommissioning vessels	No	High	
Decommissioning Impact 8 Changes to suspended sediment concentrations and coastal morphology at the	No	High	

Impact	Potential for cumulative impact	Data confidence	Rationale
offshore cable landfall due to removal of the export cables			

Table 7.37 Summary of Projects Considered for the CIA in Relation to the Topic (see Appendices 7.1 and 7.2 for full discussions)

Project	Status	Construction period	Distance from East Anglia TWO windfarm site (km) [2]	Distance from East Anglia TWO offshore cable corridor (km)[3]	Project definition		Included in CIA	Rationale
Sizewell C Power Station	Pre-Application	2021-2031	31	2	Outline only		No	Screened out due to avoidance in project design due to the cable corridor siting south of Sizewell (see ***section 3*** of ***Appendix 4.6 Coastal Processes and Landfall Site Selection)***
Hornsea Project 1	Under construction	2018-2020	168	166	Project Design Statement		No	Screened out following cumulative

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[2] Shortest distance between the considered project and the East Anglia ONE North windfarm site – unless specified otherwise

[3] Shortest distance between the considered project and the East Anglia ONE North offshore cable corridor

Project	Status	Construction period	Distance from East Anglia TWO windfarm site (km) [2]	Distance from East Anglia TWO offshore cable corridor (km)[3]	Project definition		Included in CIA	Rationale
					(PDS) available			wave modelling
Hornsea Project 2	Consented	2020-2022	172	168	PDS available		No	Screened out following cumulative wave modelling
Hornsea Project 3	Pre-Application	2022-2025	158	156	Outline only		No	Screened out following cumulative wave modelling
Norfolk Boreas	Pre-Application	2024-2026	73	72	Outline only		Yes	Potential cumulative effect on wave regime
Norfolk Vanguard West	Pre-Application	2024-2026	56	55	Outline only		Yes	Potential cumulative effect on wave regime

Project	Status	Construction period	Distance from East Anglia TWO windfarm site (km) [2]	Distance from East Anglia TWO offshore cable corridor (km)[3]	Project definition		Included in CIA	Rationale
Norfolk Vanguard East	Pre-Application	2024-2026	62	61	Outline only		Yes	Potential cumulative effect on wave regime
East Anglia ONE	Under construction	2018-2020	11	19	PDS available		Yes	Potential cumulative effect on wave, tidal and sediment regimes
East Anglia ONE North	Pre-Application	2024-2026	10	0	Outline only		Yes	Potential cumulative effect on wave, tidal and sediment regimes
East Anglia THREE	Consented	2022-2025	45	45	PDS available		Yes	Potential cumulative effect on wave, tidal

Project	Status	Construction period	Distance from East Anglia TWO windfarm site (km) [2]	Distance from East Anglia TWO offshore cable corridor (km)[3]	Project definition		Included in CIA	Rationale
								and sediment regimes
Greater Gabbard	Active / in operation	2010-2013	13	20	‘As Built’ available		Yes	Potential cumulative effect on wave, tidal and sediment regimes
Galloper	Under construction	2016-2018	7	17	‘As Built’ available		Yes	Potential cumulative effect on wave, tidal and sediment regimes

7.7.1 Wave Regime

326. ***Appendix 7.2*** presents the results of wave modelling undertaken to assess the potential cumulative effects of the proposed East Anglia TWO project with other existing and proposed windfarm projects in the relevant section of the southern North Sea. The modelling is based on a worst case scenario with respect to the spatial extent of the windfarm boundary. The spatial extent of the windfarm boundary to the north has since been reduced and will therefore not have a significant effect on the results. Key cumulative wave modelling outputs are summarised in ***Figure 7.8***.

327. No potential for cumulative effects on the wave regime exists between the Hornsea Projects 1, 2 and 3 and the proposed East Anglia TWO windfarm. There is potential for cumulative effects within the former East Anglia Zone (Norfolk Boreas, Norfolk Vanguard East, Norfolk Vanguard West, East Anglia ONE, East Anglia ONE North, East Anglia TWO, East Anglia THREE).

328. The cumulative zone of effect arising from the Norfolk Boreas, Norfolk Vanguard East, Norfolk Vanguard West, East Anglia ONE, East Anglia ONE North, East Anglia TWO, East Anglia THREE, Greater Gabbard and Galloper windfarms is considerably greater in spatial extent than that arising from each of these projects individually.

329. Under some wave approach directions, the zone of cumulative effect can impinge upon some of the identified sensitive receptors identified for marine geology, oceanography and physical processes. However, the magnitude of effect is typically less than 1%, although increasing locally to typically less than 2% close to array boundaries. In the rare occasions where higher values are recorded close to array boundaries the change is always less than 5% of baseline conditions, which would represent a low to negligible magnitude, and is the accepted threshold of significance.

330. Cumulatively with other windfarms, the proposed East Anglia TWO project would cause **no significant cumulative impact on the baseline wave regime**.

7.7.2 Tidal Regime

331. To assess the potential for cumulative effects on the tidal regime, a ‘zone of potential cumulative influence’ approach has been adopted. This approach has previously been used for other windfarm projects in the former East Anglia Zone, such as East Anglia THREE, and was agreed with Cefas during the EPP.

332. The zone of potential cumulative influence on the baseline tidal regime is based on an understanding of the tidal ellipses in the area and knowledge that effects arising from wind turbine and platform foundations on the tidal regime are

relatively small in magnitude and local. It is likely that effects on the tidal regime are dissipated within one tidal ellipse of the obstacle.

333. Based on this principle a zone of potential cumulative influence on the tidal regime has been derived from all projects within the former East Anglia Zone as well as Galloper and Greater Gabbard (***Figure 7.9***). This shows that the zone of potential cumulative influence from these projects cumulatively can be separated into four distinct locations, with no potential interaction between them:

- Norfolk Vanguard West only;
- Norfolk Boreas, Norfolk Vanguard East and East Anglia THREE cumulatively;
- East Anglia ONE, East Anglia ONE North and East Anglia TWO cumulatively; and
- Galloper and Greater Gabbard cumulatively.

334. Whilst there is some minor overlap between the zone of influence from the East Anglia TWO windfarm site on the flooding tide and the zone of influence from the northern part of Galloper on the ebbing tide, both of these tidal events cannot occur simultaneously and there would also be a separation of the zone of influence between each project grouping.

335. The cumulative zone of influence arising from the East Anglia ONE, East Anglia ONE North and East Anglia TWO windfarm sites does marginally impinge upon the edge of part of the ‘Suffolk Natura 2000’ receptor and the non-designated sand banks. However, the magnitude of change at these locations would be at its lowest value since it is the most remote area of the zone of influence from the windfarms. Due to this, it is deemed that there would be **no significant cumulative impact on the baseline tidal regime**.

7.7.3 Sediment Regime

336. Cumulative effects on the sediment regime could arise from foundation installation, in the form of a sediment plume, or potentially during the operational phase if there are significant changes to the wave and / or tidal regimes due to the presence of the foundations.

337. Potential construction effects would be temporary in duration. Sediment disturbed from the sea bed during installation of cables or foundations may become entrained in a sediment plume and advected by tidal currents until the sediment re-settles on the sea bed. The distance that any plume would travel, and the concentrations of the suspended sediment in the water column would depend on both the direction and magnitude of the tidal currents and the particle size (and hence settling velocity) of the sediments.

338. Any plume that does occur would move in the direction of the tidal currents, which are governed by the tidal ellipses. There is potential physical connection, in terms of tidal currents, between the proposed East Anglia ONE North project and East Anglia ONE to the north and east respectively, and the Greater Gabbard and Galloper projects in the south. However, these areas are separated from the proposed East Anglia TWO project and it is inconceivable that sediment entrained within a plume would reside in the water column in sufficient quantities to reach measurable values to cause a significant effect.

339. Operational effects on the sediment regime arising due to the foundations may result from changes in the wave or tidal regimes. Any such changes could potentially alter pathways or rates of sediment transport across the sea bed. However, no significant operational cumulative effects are predicted to arise from changes to the wave or tidal regimes. There are no known mechanisms by which there could be significant effects on the sediment transport regime.

340. Due to the above considerations, it is deemed that there would be **no significant cumulative impact** on the baseline sediment regime associated with the foundations.

341. Changes in active sediment transport processes could potentially arise from projects cumulatively due to physical blocking effects of any cable protection measures that are placed in areas of unburied offshore cable. There will be no cable protection measures in the intertidal zone or shallow nearshore zone arising from the proposed East Anglia TWO project or any other windfarm project since all propose to use HDD for offshore cable installation at the landfall. However, the possibility of cable protection measures elsewhere along the offshore cable has not been ruled out in ***Chapter 6 Project Description*** for the proposed East Anglia TWO project or other planned projects in the former East Anglia Zone. Due to this there could be potential cumulative effects arising, with their magnitude being dependent on the location and extent of such measures. This, in turn, could potentially affect the features and attributes of the sea bed, nearshore banks, beaches and cliffs.

342. Due to the embedded mitigation associated with offshore cable installation for the proposed East Anglia TWO project, such potential effects for that project (both alone and cumulatively with other projects) has either been avoided (i.e. in the intertidal zone and shallow nearshore zone) or minimised (i.e. through routeing measures to limit cable crossings). Due to this, there would be **no cumulative impact** on the other identified marine geology, oceanography and physical processes receptor groups located offshore of the closure depth and / or beyond active circulatory sediment transport pathways between the shore and Sizewell Bank (since these receptor groups are located remotely from the locations of potential effect). In areas inshore of the closure depth of the active beach profile

(i.e. within 5m water depth), there would be cumulative impacts of **negligible significance** on the Suffolk Natura 2000 site and, in turn, **no cumulative impact** or indirect cumulative impacts of **negligible significance** on the East Anglia coast.

7.8 Transboundary Impacts

343. An assessment of transboundary effects was completed and is presented in ***Appendix 7.3*** and concludes that there is no potential for transboundary effects arising from changes to the wave, tidal or sediment regimes associated with the proposed East Anglia TWO project. The transboundary assessment is based on a worst case scenario with respect to the spatial extent of the windfarm boundary. The spatial extent of the windfarm boundary to the north has since been reduced and will therefore not have a significant effect on the results.

7.9 Interactions

344. 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 areas of interaction between impacts are presented in ***Table 7.38***, along with an indication as to whether the interaction may give rise to synergistic impacts. This provides a screening tool for which impacts have the potential to interact.

345. ***Table 7.39*** then provides an assessment for each receptor (or receptor group) related to these impacts in two ways. Firstly, the impacts are considered within a development phase (i.e. construction, operation or decommissioning) to see if, for example, multiple construction impacts could combine. Secondly, a lifetime assessment is undertaken which considers the potential for impacts to affect receptors across development phases. The significance of each individual impact is determined by the sensitivity of the receptor and the magnitude of effect; the sensitivity is constant whereas the magnitude may differ. Therefore, when considering the potential for impacts to be additive it is the magnitude of effect which is important – the magnitudes of the different effects are combined upon the same sensitivity receptor. If minor impact and minor impact were added this would effectively double count the sensitivity.

346. The impacts listed in ***Table 7.38*** are only expressed on two receptors in ***Table 7.39***:

- Suffolk Natura 2000 sites; and
- East Anglian Coast.

Table 7.38 Interaction Between Impacts

Potential Interaction between impacts								
Construction								
	Impact 1 Changes in suspended sediment concentrations due to foundation installation	Impact 2 Changes in sea bed level due to foundation installation	Impact 3 Changes in suspended sediment concentrations during inter-array and platform link cable installation	Impact 4 Changes in sea bed level during inter-array and platform link cable installation	Impact 5 Changes in suspended sediment concentrations during export cable installation	Impact 6 Changes in sea bed level due to export cable installation	Impact 7 Indentations on the sea bed due to installation vessels	Impact 8 Changes to suspended sediment concentrations and coastal morphology at the landfall
Impact 1 Changes in suspended sediment concentrations due to foundation installation	-	Yes	Yes	Yes	No	No	Yes	No
Impact 2 Changes in sea bed level due to foundation installation	Yes	-	Yes	Yes	No	No	Yes	No
Impact 3 Changes in suspended sediment concentrations during inter-array	Yes	Yes	-	Yes	No	No	Yes	No

Potential Interaction between impacts								
and platform link cable installation								
Impact 4 Changes in sea bed level during inter-array and platform link cable installation	Yes	Yes	Yes	-	No	No	Yes	No
Impact 5 Changes in suspended sediment concentrations during export cable installation	No	No	No	No	-	Yes	Yes	Yes
Impact 6 Changes in sea bed level during export cable installation	No	No	No	No	Yes	-	Yes	Yes
Impact 7 Indentations on the sea bed due to installation vessels	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes
Impact 8 Changes to suspended sediment concentrations	No	No	No	No	Yes	Yes	Yes	-

Potential Interaction between impacts								
and coastal morphology at the landfall								

Operation									
	Impact 1 Changes to the tidal regime due to the presence of foundation structures	Impact 2 Changes to the wave regime due to the presence of foundation structures	Impact 3 Changes to the sediment transport regime due to the presence of foundation structures	Impact 4 Changes in suspended sediment concentrations due to scour around foundation structures	Impact 5 Changes to the sea bed morphology due to the footprint of the foundation structures	Impact 6 Morphological and sediment transport effects due to cable protection measures for inter-array cables and platform link cables	Impact 7 Morphological and sediment transport effects due to cable protection measures for export cables	Impact 8 Morphological effects due to cable protection measures at the export cable landfall	Impact 9 Indentations on the sea bed due to maintenance vessels
Impact 1 Changes to the tidal regime due to the presence of foundation structures	-	Yes	No	No	No	No	No	No	Yes
Impact 2 Changes to the wave regime due to the presence of foundation structures	Yes	-	No	No	No	No	No	No	Yes

Potential Interaction between impacts									
Impact 3 Changes to the sediment transport regime due to the presence of foundation structures	No	No	-	Yes	No	Yes	Yes	No	Yes
Impact 4 Changes in suspended sediment concentrations due to scour around foundation structures	No	No	Yes	-	No	No	No	No	Yes
Impact 5 Changes to the sea bed morphology due to the footprint of the foundation structures	No	No	No	No	-	No	No	No	Yes
Impact 6 Morphological and sediment transport effects due to cable protection measures for inter-array cables	No	No	Yes	No	No	-	Yes	Yes	Yes

Potential Interaction between impacts									
and platform link cables									
Impact 7 Morphological and sediment transport effects due to cable protection measures for export cables	No	No	No	No	No	Yes	-	Yes	Yes
Impact 8 Morphological effects due to cable protection measures at the export cable landfall	No	No	No	No	No	Yes	Yes	-	Yes
Impact 9 Indentations on the sea bed due to maintenance vessels	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
Decommissioning									
The magnitude of effects would be comparable to those identified for the construction phase. Accordingly, given that no significant impact was assessed for the identified marine geology, oceanography and physical processes receptors during the construction phase, it is anticipated that the same would be valid for the decommissioning phase.									

Table 7.39 Potential Interactions between Impacts on Marine Geology, Oceanography and Physical Processes

	Highest level significance				
Receptor	**Construction**	**Operational**	**Decommissioning**	**Phase Assessment**	**Lifetime Assessment**
Suffolk Natura 2000 sites	Negligible	Negligible	Negligible	**No greater than individually assessed impact** ***Construction*** *Impact 5 Changes in suspended sediment concentrations during export cable installation, Impact 6 Changes in sea bed level due to export cable installation,* Given the negligible magnitude of effect especially in the far-field, it is considered that there is no potential for greater impact significance from interactions. ***Operation*** n/a There is only a single impact (*Impact 7 Morphological and sediment transport effects due to cable protection measures for export cables)* for the receptor, therefore no potential interactions	**No greater than individually assessed impact** With regard to effects on the seabed and suspended sediment these will be of greatest magnitude during construction, after which they will be episodic and highly localised. Given this it is considered that there is no potential for greater impact significance from interactions of these effects during the project lifetime.
East Anglian Coast	No Impact	Negligible	No Impact	***Operation*** n/a There is only a single impact (*Impact 7 Morphological and sediment transport effects due to cable protection measures*	**No greater than individually assessed impact** n/a There is only a single impact (*Impact 7 Morphological and sediment transport*

	Highest level significance				
Receptor	**Construction**	**Operational**	**Decommissioning**	**Phase Assessment**	**Lifetime Assessment**
				for export cables) for the receptor, therefore no potential interactions	*effects due to cable protection measures for export cables)* during any phase for the receptor, therefore no potential interactions

7.10 Inter-relationships

347. There are strong inter-relationships between the marine geology, oceanography and physical processes topic and several other topics that have been considered within this ES. ***Table 7.40*** provides a summary of the principal inter-relationships and sign-posts where those issues have been addressed in this chapter.

Table 7.40 Chapter Topic Inter-relationships

Topic and description	Related Chapter	Where addressed in this Chapter	Rationale
Effects on water column (suspended sediment concentrations)	***Chapter 8 Marine water and sediment quality*** ***Chapter 10 Fish and shellfish ecology*** ***Chapter 13 Commercial fisheries*** ***Chapter 9 Benthic ecology***	***Section 7.6.1.1*** (foundation installation) ***Section 7.6.1.3*** (inter-array cables installation) ***Section 7.6.1.5*** (export cables installation) ***Section 7.6.2.4*** (foundation scour)	Suspended sediment could be contaminated and could cause disturbance to fish and benthic species through smothering.
Effects on sea bed (morphology / sediment transport / sediment composition)	***Chapter 9 Benthic ecology*** ***Chapter 10 Fish and shellfish ecology*** ***Chapter 13 Commercial fisheries*** ***Chapter 14 Shipping and navigation*** ***Chapter 16 Offshore archaeology and cultural heritage*** ***Chapter 17 Infrastructure and other users***	***Section 7.6.1.2*** (foundation installation) ***Section 7.6.1.4*** (inter-array cables installation) ***Section 7.6.1.6*** (export cables) ***Section 7.6.1.7*** (installation vessels) ***Section 7.6.2.3*** (sediment transport regime) ***Section 7.6.2.5*** (foundation scour/scour protection) ***Section 7.6.2.6*** (inter-array cable protection) ***Section 7.6.2.7*** (export cable protection in offshore zone)	Disruption to sediment morphology, transport processes and composition could affect these receptors by altering the existing sedimentary environment however this is unlikely to be to levels which are significant.
Effects on shoreline (morphology / sediment	***Chapter 10 Benthic ecology***	***Section 7.6.1.8*** (cable landfall)	Disruption to shoreline morphology could potentially impact on these

Topic and description	Related Chapter	Where addressed in this Chapter	Rationale
transport / sediment composition)	***Chapter 20 Water resources and flood risk*** ***Chapter 28 Seascape, landscape and visual amenity***	***Section 7.6.2.7*** (export cable protection in nearshore and intertidal zone)	chapters through a change to the existing shoreline environment which could have implications for the receptors associated with these chapters.

7.11 Summary

348. The construction, operational and decommissioning phases of the proposed East Anglia TWO 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.

349. The receptors that have been specifically identified in relation to marine geology, oceanography and physical processes are the sensitive 'East Anglia' coast, the 'Norfolk' Natura 2000 site, the 'Suffolk' Natura 2000 site, and nearby 'non-designated sand banks'. Potential impacts upon the Orford Offshore MCZ were screened out.

350. 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. The only exceptions to this which could potentially result in impacts to these receptors are listed in ***Table 7.41***.

Table 7.41 Potential Impacts Identified for Marine Geology, Oceanography and Physical Processes Receptor Groups

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation Measures	Residual Impact
Construction						
Changes in Suspended Sediment Concentrations	'Suffolk Natura 2000' site	Negligible	Medium (near field inshore only)	**Negligible**	None	**Negligible**
Changes in sea bed levels due to export cable installation	'Suffolk Natura 2000' site	Negligible	Low (near field only)	**Negligible**	Optimisation of offshore cable route alignment, depth and	**Negligible**

Potential Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation Measures	Residual Impact
					installation methods	
Operation						
Morphological and sediment transport effects due to cable protection measures for offshore cables	'Suffolk Natura 2000' site (inshore of closure depth)	Medium	Negligible	**Negligible**	Optimisation of offshore cable route alignment cable installation techniques to avoid or minimise requirement for cable protection works inshore of closure depth (~5mCD)	**Negligible** to **no impact** (depending on % burial of cable length within closure depth and/or within sediment circulatory pathways between shore and banks)
	'East Anglia' coast	Medium	Low	**No change or negligible**		
Decommissioning						
None identified						

351. The significance of all changes in marine geology, oceanography and physical processes on other receptors has been assessed, where relevant, within the relevant chapters of this ES (see ***Table 7.40***).

352. No significant cumulative impacts have been identified on the marine geology, oceanography and physical processes receptor groups between the proposed East Anglia TWO project and other nearby marine developments and activities (including other windfarm developments, marine aggregate dredging and marine disposal).

Table 7.42 Potential Cumulative Impacts identified for Marine Geology, Oceanography and Physical Processes Receptor Groups

Potential Cumulative Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
Morphological and sediment	'Suffolk Natura	Medium	Negligible	**Negligible**	Optimisation of offshore	**Negligible** to **no**

Potential Cumulative Impact	Receptor	Value/ Sensitivity	Magnitude	Significance	Mitigation	Residual Impact
transport effects due to cable protection measures for offshore cables	2000’ site (inshore of closure depth)				cable route alignment cable installation techniques to avoid or minimise requirement for cable protection works inshore of closure depth (~5mCD)	**impact** (depending on % burial of cable length within closure depth and/or within sediment circulatory pathways between shore and banks)
	‘East Anglia’ coast	Medium	Low	**No change or negligible**		

353. No transboundary impacts have been identified on the marine geology, oceanography and physical processes receptor groups located within other EU member states.

7.12 References

ABPmer (ABP Marine Environmental Research Ltd). (2012a). *East Anglia Offshore Wind Zonal Environmental Appraisal Report. Appendix G – Physical Processes Baseline and References.*

ABPmer (ABP Marine Environmental Research Ltd). (2012b). *East Anglia Offshore Wind Project ONE Windfarm: Marine geology, oceanography and physical processes environmental baseline*. Report R3945. May 2012.

BERR. (2008). Review of Cabling Techniques and Environmental Effects applicable to the Offshore Windfarm Industry.

Bibby Hydromap and Benthic Solutions. (2018a). East Anglia One North and Two Geophysical and Benthic Survey. Volume 3 – Area A Results Report. July 2018.

Bibby Hydromap and Benthic Solutions. (2018b). East Anglia One North and Two Geophysical and Benthic Survey. Volume 3 – Area B Results Report Rev 01. August 2018.

Bibby Hydromap and Benthic Solutions. (2018c). East Anglia One North (EA1N) and East Anglia TWO (EA2) Benthic Survey Factual Data Report.

Bolle, A., Haerens, P., Trouw, K., Smits, J. and Dewaele, G. (2009). *Scour around gravity-based wind turbine foundations – prototype measurements*. In: *Coasts, Marine Structures and Breakwaters. Adapting to Change*. Ed Allsop, W. 103-118. Thomas Telford Books, London.

Bolle, A., Mercelis, P., Goossens, W. and Haerens, P. (2010). Scour monitoring and scour protection solution for offshore gravity based foundations. *Proceedings of the Fifth International Conference on Scour and Erosion*, San Francisco, 7-10 November 2010. Geotechnical Special Publication No. 120, ASCE (ISBN 978-0-7844-1147-6)

Cefas. (2011). Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects.

Cefas. (2005). Assessment of the significance of changes to the inshore wave regime as a consequence of an offshore wind array. Defra R&D report.

Cefas. (2004). *Offshore wind farms: guidance note for Environmental Impact Assessment in respect of FEPA and Coast Protection Act requirements*.

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

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.

Deltares. (2012). *East Anglia Offshore Wind Farm: Metocean Study*. Report to East Anglia Offshore Wind Ltd., October 2012.

Dolphin, T.J., Silva, T.A.A. and Rees, J.M. 2011. Natural Variability of Turbidity in the Regional Environmental Assessment (REA) Areas. MEPF-MALSF Project 09-P114. Cefas, Lowestoft. 41 pp

EAOW. (East Anglia Offshore Wind) (2012). East Anglia Offshore Wind Zonal Environmental Appraisal Report, March 2012.

EATL. (East Anglia Three Limited). (2015). East Anglia THREE Environmental Statement. Report to East Anglia Offshore Wind, November 2015.

EATL (2016) Orford Inshore rMCZ Assessment https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010056/EN010056-001460-4.Other%20Environmental%20Information%20Volume%202%20-%20Orford%20Inshore%20rMCZ%20Assessment.PDF

ETSU. (Energy Technology Support Unit). (2002). *Potential effects of offshore wind farms on coastal processes*. Report No. ETSU W/35/00596/REP.

ETSU. (Energy Technology Support Unit). (2000). *An assessment of the environmental effects of offshore wind farms.* Report No. ETSU W/35/00543/REP.

Fugro EMU (2013a). East Anglia THREE Offshore Wind Farm Geophysical Survey. Report to Scottish Power Renewables, February 2013.

Gardline. (2017). East Anglia Two Geophysical Survey May – June 2017.

GL Noble Denton. (2011). *Metocean Conditions Study*. Report No. L24718.

Hanson Aggregates Marine Ltd., 2005. Marine Aggregate Extraction Licence Area 401/2. Environmental Statement for Renewal of the License. Hanson Marine Aggregates, Southampton.

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.

HR Wallingford, Posford Haskoning, Cefas, D'Olier, B, 2002. Southern North Sea Sediment Transport Study Phase 2: Sediment Transport Report. Report No. EX4526, August 2002.

IPC (The Planning Inspectorate). (2011). Using the Rochdale Envelope. Advice Note 9: Rochdale Envelope

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.

JNCC (Joint Nature Conservancy Committee) 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.

Khalfin, I. Sh. (2007). Modelling and calculation of bed score around large-diameter vertical cylinder under wave action. Water Resources, Vol 34, No 1, 49-59.

Lambkin, D.O., Harris, J.M., Cooper, W.S. and Coates, T. (2009). Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide. Report to COWRIE, September 2009.

Larsen, B.J. and Frigaard, P. (2005). *Scour and scour protection for wind turbine foundations for the London Array*. University of Aalborg Coastal Engineering report No. 17, ISSN 1603-9874

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. and Bradley, S. (2009). *UK Climate Projections science report: Marine and coastal projections*. Met Office Hadley Centre, Exeter, UK.

Margheritini, L. (2012). Scour around offshore wind turbine foundations (comparison between monopiles and bucket foundations). Presentation at DTU May 15th, 2012.

MMO (Marine Management Organisation). (2012). East Inshore and East Offshore Marine Plan Areas: Evidence and Issues.

McBreen, F., Askew, N., Cameron, A., Connor, D., Ellwood, H. and Carter, A. (2011). UKSeaMap 2010 Predictive mapping of seabed habitats in UK waters, JNCC Report 446.

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 Limited. (2018). Norfolk Vanguard Limited Environmental Statement, June 2018.

Ohl, C.O.G., Taylor, P.H., Eatock Taylor, R. and Borthwick, A.G.L. (2001). Water wave diffraction by a cylinder array part II: irregular waves. *Journal of Fluid Mechanics*, 442, 33 – 66.

Raaijmakers, T. and Rudolph, D. (2008). Time-dependent scour development under combined current and waves conditions – laboratory experiments with online

monitoring technique. *Proceedings of the Fourth International Conference on Scour and Erosion* (2008).
Planning Inspectorate. (2018). Using the Rochdale Envelope: Advice Note Nine. Available at: https://infrastructure.planninginspectorate.gov.uk/wp-content/uploads/2013/05/Advice-note-9.-Rochdale-envelope-web.pdf

ScottishPower Renewables (2017). Scoping Report. Available at: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010078/EN010078-000059-EAN2%20-%20Scoping%20Report.pdf

ScottishPower Renewables (2019). Preliminary Environmental Information Report. Available at: https://www.scottishpowerrenewables.com/userfiles/file/EA2_PEI_Chapter_07_MGOPP.pdf

Seagreen. (2012). The Seagreen Project Environmental Statement. September 2012.

Stahlmann, A. and Schlurmann, T. (2010). Physical Modelling of Scour Around Tripod Foundation Structures for Offshore Wind Energy Converters. *Proc Conf Coastal Engrg*

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

Whitehouse, R.J.S., Harris, J. and Sutherland, J. (2010). *Evaluating scour at marine gravity structures*. First European IAHR Congress, Edinburgh, 4th – 6th May 2010

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.

Yang, R-Y., Chen, H-H., Hwung, H-H., Jiang, W-P. and Wu, N-T. (2010). Experimental study on the loading and scour of the jacket-type offshore wind turbine foundation. *Proc Intnl Conf Coastal Engrg*, 32

Yeow, K. and Cheng, L. (2003). Local scour around a vertical pile with a caisson foundation. *Proc. Cong Asian and Pacific Coasts 2003*

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