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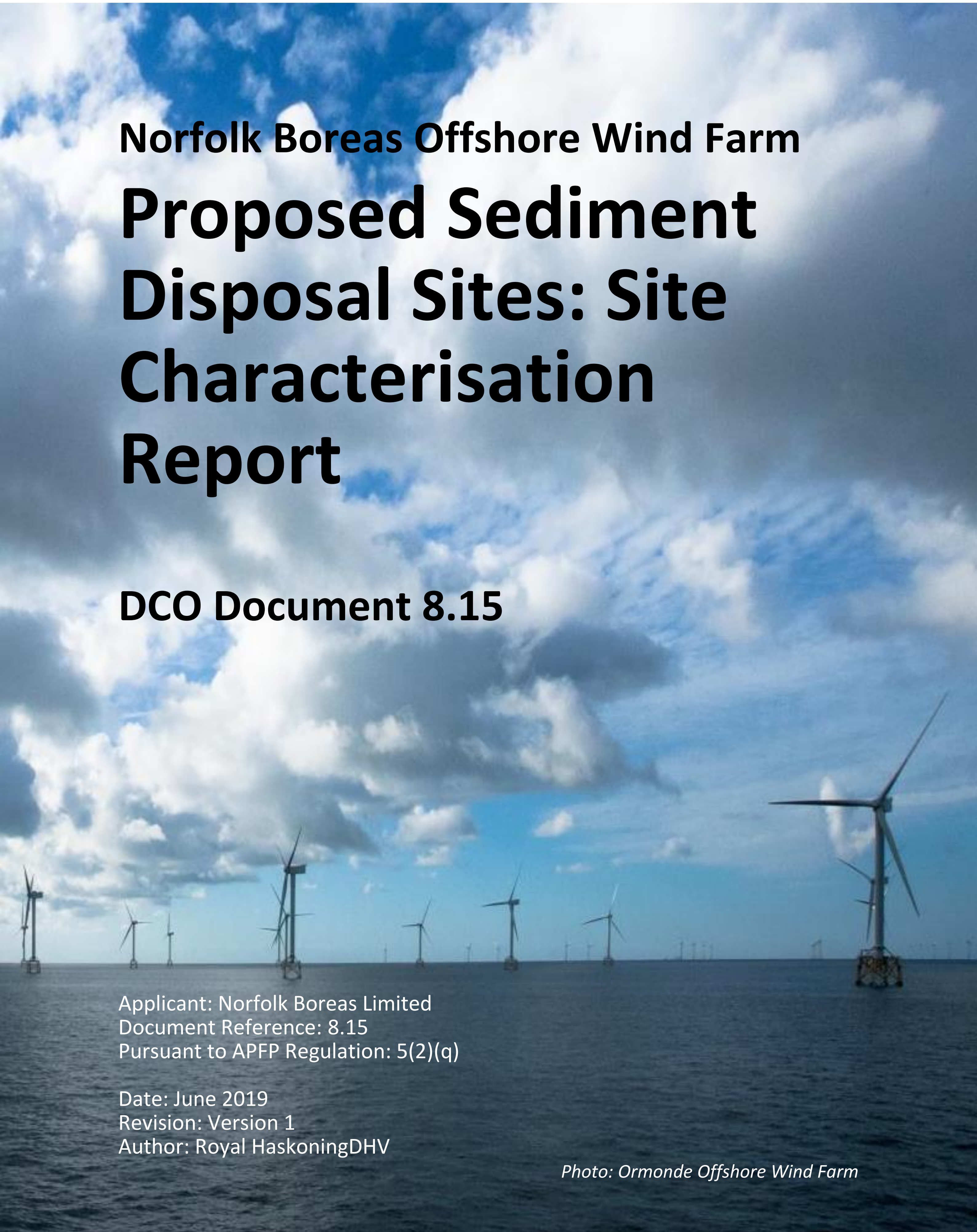
Norfolk Boreas Offshore Wind Farm

Proposed Sediment Disposal Sites: Site Characterisation Report

DCO Document 8.15



Applicant: Norfolk Boreas Limited
Document Reference: 8.15
Pursuant to APFP Regulation: 5(2)(q)

Date: June 2019
Revision: Version 1
Author: Royal HaskoningDHV

Photo: Ormonde Offshore Wind Farm

Date	Issue No.	Remarks / Reason for Issue	Author	Checked	Approved
26/03/2019	01D	First draft for Norfolk Boreas Limited Review	KC	DT/JL	AD
29/03/2019	02D	Second draft for Norfolk Boreas Limited review and MMO review	KC/DT	JL	PP
16/05/2019	03D	Updated following MMO review	KC	AD/DT	JL
22/05/2019	01F	Final version for DCO submission	KC	DT	JL

Table of Contents

Figures

Tables

Glossary of Acronyms

Cefas	Centre for Environment, Fisheries and Aquaculture Science
cm	Centimetres
DCO	Development Consent Order
DML	Deemed Marine Licence
EIA	Environmental Impact Assessment
EPP	Evidence Plan Process
ES	Environmental Statement
GBS	Gravity Based Structure
HDD	Horizontal Dirctional Drilling
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
KM	Kilometres
LAT	Lowest Astronomical Tide
LiDAR	Light Detection And Ranging
m	Metres
MARPOL	International Convention For The Prevention Of Pollution From Ships
MarESA	Marine Evidence Based Sensitivity Assessment
mg/l	Milligrams Per Litre
mm	Millimetres
Mm	Million Metres
MMO	Marine Management Organisation
MW	Megawatt
NV East	Norfolk Vanguard East
NV West	Norfolk Vanguard West
OWF	Offshore Wind Farm
PEMP	Project Environmental Information Plan
SAC	Special Area Of Conservation
VWPL	Vattenfall Wind Power Limited

Glossary of Terminology

Array cables	Cables which link wind turbine to wind turbine, and wind turbine to offshore electrical platforms.
Capital dredging	Dredging of an area which has not previously been dredged (see Maintenance Dredging) for a new capital project, e.g. an offshore wind farm, port or harbour.
Interconnector cables	Offshore cables which link offshore electrical platforms within the Norfolk Boreas site.
Landfall	Where the offshore cables come ashore at Happisburgh South.
Maintenance dredging	The action of dredging to keep an existing navigation channel open
Offshore cable corridor	The corridor of seabed from the Norfolk Boreas site to the landfall site within which the offshore export cables will be located.
Offshore electrical platform	A fixed structure located within the Norfolk Boreas site, containing electrical equipment to aggregate the power from the wind turbines and convert it into a suitable form for export to shore.
Offshore export cables	The cables which transmit power from the offshore electrical platform to the landfall.
Offshore project area	The area including the Norfolk Boreas site, project interconnector search area and offshore cable corridor.
Offshore service platform	A platform to house workers offshore and/or provide helicopter refuelling facilities. An accommodation vessel may be used as an alternative for housing workers.
Safety zone	An area around a vessel which should be avoided during offshore construction.
Scour protection	Protective materials to avoid sediment being eroded away from the base of the foundations as a result of the flow of water.
The Applicant	Norfolk Boreas Limited
The project	Norfolk Boreas Wind Farm including the onshore and offshore infrastructure.

1 INTRODUCTION

1.1 Purpose of this Document

1. Norfolk Boreas Limited is applying to designate the following areas for the disposal of material extracted during the construction of the Norfolk Boreas, an offshore wind farm (e.g. drilling and / or seabed preparation (dredging)). The proposed disposal areas are:

- Norfolk Boreas site;
- Project interconnector search area;
- The section of the offshore cable corridor from the western boundary of the Haisborough, Hammond and Winterton (HHW) SAC to the Norfolk Boreas site, excluding the deep-water shipping route.

2. The locations of the proposed disposal sites are shown in Figure 1.1 and the coordinates are provided in Appendix 1 of this report.

3. The purpose of this document is to provide the information required to enable site designation. Accordingly, this document sets out:

- The need for disposal of material;
- Alternatives considered;
- The location of the disposal sites;
- The types of material to be disposed of;
- The quantity of the material to be disposed; and
- Potential impacts of disposal.

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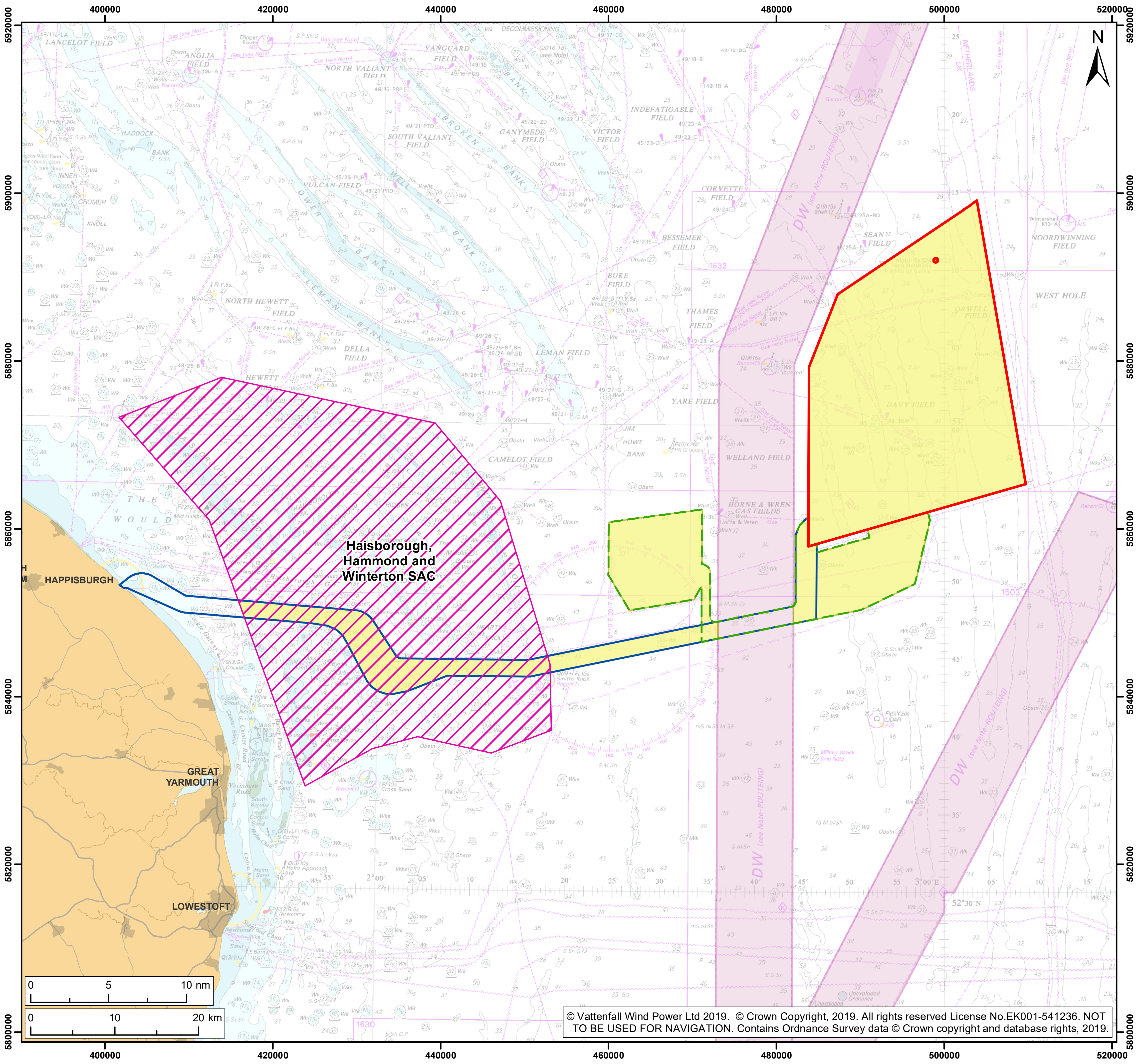

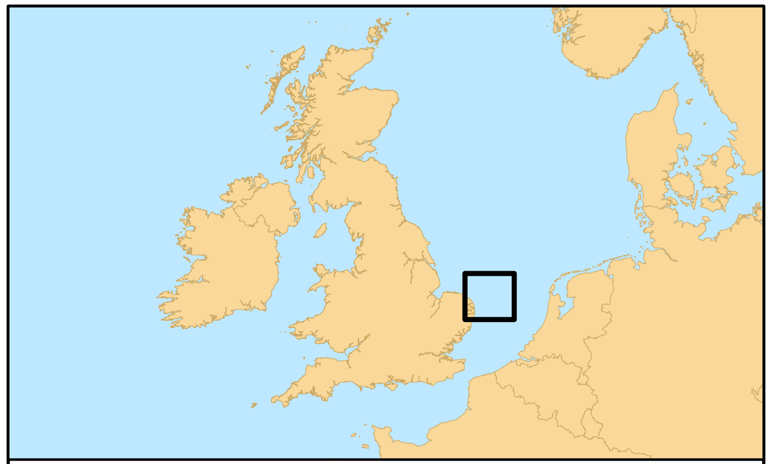

Legend:

- 🟥 Norfolk Boreas site
- 🟦 Offshore cable corridor
- ▭ Project interconnector search area
- ▨ Special Area of Conservation (SAC)[1]
- 🟨 Disposal site
- 🟪 Deep water shipping route

[1] JNCC, 2019.

Project:	Report:
Norfolk Boreas	Proposed Sediment Disposal Sites:Site Characterisation Report

Title:

Disposal Sites

Figure: 1.1 Drawing No: PB5640-007-004-001

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
02	22/05/2019	LB	DT	A3	1:450,000
01	11/03/2019	JT	DT	A3	1:450,000

Co-ordinate system: ETRS 1989 UTM Zone 31N **EPSG:** 25831

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1.2 Background

4. Norfolk Boreas Limited (an affiliate company of Vattenfall Wind Power Limited (VWPL), ‘the Applicant’) is proposing to develop Norfolk Boreas, an offshore wind farm in the southern North Sea.

5. The Norfolk Boreas project comprises the Norfolk Boreas site, within which wind turbines, associated platforms and array cables will be located. The offshore wind farm will be connected to the shore by offshore export cables installed within the offshore cable corridor from the wind farm to a landfall point at Happisburgh South, Norfolk. From there onshore cables would transport power over approximately 60km to the onshore project substation near to the village of Necton, Norfolk. A full project description is given in the Environmental Statement (ES), Chapter 5 Project Description.

6. Vattenfall Wind Power Limited (VWPL) (the parent company of Norfolk Boreas Limited) is also developing Norfolk Vanguard, a ‘sister project’ to Norfolk Boreas. Norfolk Vanguard’s development schedule is approximately one year ahead of Norfolk Boreas and as such the Norfolk Vanguard project is now under examination.

7. Norfolk Vanguard may undertake some onshore enabling works for Norfolk Boreas, but these are not relevant to this document. Should Norfolk Vanguard proceed to construction Norfolk Boreas wish to maintain the option to connect to the Norfolk Vanguard project via a “project interconnector”. Further information on when a project interconnector may be required is provided in ES Chapter 5 Project description section 5.4.12.

8. As it is not yet known whether Norfolk Vanguard will obtain development consent or proceed to implementation and construction, the Norfolk Boreas application needs to seek consent to implement Norfolk Boreas as an independent project. Therefore, Norfolk Boreas Limited has included two scenarios in the development consent application as follows:

- Scenario 1: Norfolk Vanguard and Norfolk Boreas are both delivered (with associated synergies), and Norfolk Vanguard carries out shared works, onshore to benefit Norfolk Boreas (Scenario 1).
- Scenario 2: Only Norfolk Boreas is delivered; Norfolk Vanguard does not proceed to construction and Norfolk Boreas proceeds alone. Norfolk Boreas undertakes all works required as an independent project (Scenario 2).

9. Both scenarios have been considered when drafting this document, The main difference between the two scenarios would be that under Scenario 1 the project interconnector could be required, which would be installed within the project

interconnector search area (Figure 1.1) whereas under Scenario 2 it would not be required as Norfolk Vanguard would not exist and therefore it would not be possible to connect to that project. Therefore, under Scenario 2 disposal within the project interconnector search area shown in Figure 1.1 would not be required. Under Scenario 1 the proposed Norfolk Boreas disposal areas would overlap with the Norfolk Vanguard disposal sites (disposal site references HU213, HU214, HU215 and HU216).

10. Once built, Norfolk Boreas would have a capacity of up to 1800MW, with the offshore components comprising:

- Wind turbines;
- Offshore electrical platforms;
- A service platform;
- Met masts;
- Lidar;
- Array cables;
- Inter-connector cables or project interconnector cables[1]; and
- Export cables.

11. The key onshore components of the project are as follows:

- Landfall;
- Onshore cable route, accesses, trenchless crossing (e.g. Horizontal Directional Drilling (HDD)) zones and mobilisation areas;
- Onshore project substation; and
- Extension to the Necton National Grid substation and overhead line modifications.

12. The Norfolk Boreas site is located approximately 73km from the closest point of the Norfolk Coast. The site covers an area of approximately 725km^2.

13. The detailed design of Norfolk Boreas (e.g. numbers of wind turbines, layout configuration, foundation type and requirement for scour protection) would not be determined until post-consent. Therefore, realistic worst case scenarios in terms of potential impacts/effects are adopted to undertake a precautionary and robust impact assessment.

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[1] There may also be a requirement for cables to be placed within the project interconnector search area (Figure 5.1 of the ES) which would link the Norfolk Boreas project to the Norfolk Vanguard project (section 5.4.12 of ES Chapter 5 Project Description). Either “Interconnector cables”, which would link platforms within the Norfolk Boreas site, would be installed or “project interconnector cables” would be installed. Under no scenario would both be required.

14. For Norfolk Boreas, several different sizes of wind turbine are being considered in the range of 10MW and 20MW. In order to achieve the maximum 1,800MW installed capacity, there would be between 90 (20MW) and 180 (10MW) wind turbines.

15. In addition, up to two offshore electrical platforms, a service platform, two meteorological masts, two LiDAR platforms and two wave buoys, plus a network of up to 740km of offshore cables are considered as part of the worst-case scenario within the Norfolk Boreas site.

16. Norfolk Boreas Limited is considering constructing the project in either a single phase of up to 1,800MW or in two phases (up to a maximum of 1800MW). The layout of the wind turbines will be defined post consent.

17. The full construction window is expected to be up to three years for the full 1,800MW capacity and offshore construction would be anticipated to commence around 2025. Chapter 5 Project Description provides indicative construction programmes for the single phase and two phase options. Further detail on construction programme is provided in section 4.3.

2 THE NEED FOR DISPOSAL OF MATERIAL

18. The type of foundation and installation method required for the wind turbines and other offshore structures associated with Norfolk Boreas are yet to be determined. Foundation types currently under consideration include gravity base structures (GBS), monopiles, suction caissons, quadropod or tripod pin-piles (jackets) and Tetrabase foundations.

19. Seabed preparation and potential drilling of pin-piles and monopiles, if required, would result in the production of material which requires disposal. Therefore, practicable options for the disposal of "capital" dredged material must be assessed.

20. Furthermore, the option of sandwave levelling (pre-sweeping) to a stable reference seabed level may be undertaken to reduce the potential that cables become unburied over the life of the project. Natural England has requested that where sandwave levelling is undertaken within the Haisborough, Hammond and Winterton SAC, any disturbed seabed sediment should be deposited back into the SAC to ensure material is not lost from the system. Further information about how this would be achieved is provided in section 5.4.13 of Chapter 5 Project Description of the Norfolk Boreas ES.

2.1 Foundation installation

21. As previously stated there are several possible foundation types currently being considered for the wind turbines. Within these categories there are a number of variants which include:

- GBS – which rely on the weight of the structure to anchor it to the seabed;
- Quadropod and tripod - jacket foundations with either three or four feet attached to the seabed with either 3 or 4 suction caissons or piles;
- Suction caissons – cylindrical tubes which are installed by reducing the pressure inside the tube to draw the caisson into the seabed;
- Monopiles – large cylinders which are hammered into the seabed; and
- TetraBase – installed using either three pin piles or three suction caissons per foundation.

22. The following foundation options are also being considered for the other offshore infrastructure:

- Jacket, GBS or monopile for meteorological mast (met mast) foundations;
- Jacket or GBS for offshore electrical platforms and offshore service platforms;
- Anchored or monopile LiDAR; and
- Anchored buoys.

23. Further information on the foundation types being considered for the project can be found in Chapter 5 Project Description of the Norfolk Boreas ES.

24. Information regarding the maximum predicted amounts of material arising from the installation of foundations is provided in Section 4 of this document. The installation processes associated with the need for sediment disposal are summarised below.

2.1.1 Piled jacket foundations

25. For jacket foundations some dredging may be required for levelling the seabed prior to the installation of a pile template (if used). However, it should be possible to spread this material close to the installation works.

26. Based on preliminary geotechnical information from the Norfolk Boreas site (Fugro 2017), it is thought that pile driving would be possible across the whole project site, which will not generate spoil material. However, until more detailed geotechnical assessments are carried out, the possibility of drilling must be considered at some locations. As at the date of this document, Norfolk Boreas has limited information to assess the percentage of drilled piles required.

27. If drilling is required it will generate some spoil material that will require removal and disposal. It is proposed that the spoil will be disposed of within the wind farm area, adjacent to each location from where the material was derived, with the spoil subsequently winnowed away by the natural tide and wave driven processes as described in Chapter 8 Marine Geology, Oceanography and Physical Processes.

2.1.2 Gravity Base Structures

28. For GBS, it is possible that seabed preparation would be required. This is dependent on the ground conditions present. The preference is that GBS foundations are installed where no or limited ground preparation is required with micro-siting used to minimise any dredging requirements. Assessment of the available geophysical data (Fugro, 2017) indicates that there are areas within the Norfolk Boreas site which if chosen for GBS foundation locations would require seabed preparation. The worst case scenario for GBS therefore assumes an excavation to level of an area of sandwaves up to 5m in depth and 60m diameter for the largest GBS foundations.

2.1.3 Suction Caisson

29. As with GBS, it is possible that seabed preparation will be required for suction caisson foundations. The worst case excavation estimated volumes are predicted to be no worse than for the GBS foundations, as identified above.

2.1.4 Monopiles

30. It is expected that monopiles will be positioned to avoid seabed preparation, however if sand waves are present, the seabed might need to be levelled first by excavation to the trough of the sand wave. The worst case assumption is that excavation to 5m depth is required from an area with a diameter of 15m.

31. If drilling is required it will generate some spoil material that will require removal and disposal. It is proposed the spoil will be disposed of within the wind farm area, adjacent to each location from where the material was derived, with the spoil subsequently winnowed away by the natural tide and wave driven processes.

2.1.5 TetraBase

32. It is unlikely that TetraBase foundations would require significant seabed preparation. However, depending on the ground conditions and anchor type selected (gravity, pin pile or suction bucket), there might be a requirement to carry out some seabed levelling at few locations; this would be to provide a more level area on which to install the foundation. The structure would be able to accommodate inclinations but some dredging may be required to cover areas with steeper slopes. The volume and area impacted by seabed preparation would be significantly less than that of a GBS. Sediment disposal would be as discussed for Jacket foundations in section 2.1.1.

33. In all cases it is proposed that material will be redistributed within the wind farm area and close to the individual foundation locations.

2.2 Cable installation

34. Seabed preparation could be required for installation of all offshore electrical cables including:

- Up to 600km of array cables;
- Up to 250km of export cable trenches (including approximately 50km of export cable trenching within the Norfolk Boreas site);
- Up to 60km of interconnector cable trenches within the Norfolk Boreas site or up to 92km of project interconnector cable trenches within the project interconnector search area[2]; and
- Fibre optic cables may also be installed; however, these would be bundled with the electrical cables and installed within the same trenches.

35. Any dredged seabed material would be disposed of within the cable corridor or wind farm area, with the exception of material removed from within the SAC which would be disposed of back within the SAC to ensure that this material is not lost from the system.

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[2] This will depend on which electrical solution is chosen (see section 5.4.12 of Chapter 5 Project description of the ES). It should be noted that either "Interconnector cables" would be installed or "project interconnector cables" would be installed. Under no scenario would both be required.

2.3 Embedded mitigation

36. Norfolk Boreas Limited has committed to a number of areas of embedded mitigation in order to reduce the potential impacts of the project. The following examples of embedded mitigation are of relevance to sediment disposal:

- Reduction of turbine numbers by committing to use larger turbines within the range of 10MW to 20MW and thereby reducing the volume of foundation pre-sweeping required.
- Committing to using a High Voltage Direct Current (HVDC) solution in order to reduce the number of export cables and offshore electrical platforms when compared to the High Voltage Alternating Current (HVAC) option. This significantly reduces the volume of pre-sweeping required, particularly in the HHW SAC.
- Pre-construction surveys (secured within the relevant Deemed Marine Licences (DMLs) of the DCO (document reference 3.1) and in accordance with the In Principle Monitoring Plan, document reference 8.12) to be undertaken in advance of any cable and foundation installation works. The methodology for the pre-construction surveys would be agreed with the MMO, in consultation with Natural England. The results of this survey would be used to plan the location of wind turbines and the routing of all Norfolk Boreas cables, including micrositing where possible. The locations and cable routes would then be agreed with the MMO and Natural England through agreement of the final Cable Statement (document reference 7.1).
- All seabed material arising from the HHW SAC during cable installation would be placed back into the SAC using an approach, to be agreed with the MMO in consultation with Natural England, which would ensure that the sediment is available to replenish the sandbank features.
- Sediment would not be disposed of within 50m of confirmed core *Sabellaria Spinulosa* reef in with advice from Natural England.
- Norfolk Boreas Limited have committed to production of a Norfolk Boreas HHW SAC Site Integrity Plan (Condition 9 (1)(m) of Schedules 11 and 12 (Transmission DMLs) of the Norfolk Boreas DCO). This document would be the primary mechanism by which the Applicant to agree all works and mitigation associated with cable installation (including seabed preparation) and maintenance within the HHW SAC, with the MMO in consultation with Natural England, in order to ensure there would be no adverse effect on integrity (AEoI) of the site as a result of Norfolk Boreas.

3 TYPE OF MATERIAL TO BE DISPOSED

37. As discussed below, materials to be disposed of would be comprised either of seabed and shallow near-bed surface sediments as a result of dredging, or, sub-surface sediments, if drilling is required. Details on the physical characteristics of the seabed and subsurface material across the offshore project area are presented within Chapter 8 Marine Geology, Oceanography and Physical Processes with the main characteristics summarised within this chapter.

3.1 Seabed Sediment Type

38. This section describes the surface and subsurface sediment types which may be dredged or drilled as part of Norfolk Boreas construction and would therefore require disposal.

3.1.1 Seabed Surface Sediments

39. Grab samples of surface sediments were collected as part of a comprehensive benthic survey undertaken in 2010 across the former East Anglia Zone and geophysical and grab sampling was undertaken in the former East Anglia FOUR (now Norfolk Vanguard East) in 2012.

40. Project-specific surveys were undertaken for Norfolk Vanguard to supplement the data collected for the former East Anglia FOUR site. A geophysical survey was also completed for Norfolk Vanguard West and the offshore cable corridor between September and November 2016 (Fugro, 2017a). These cover the project interconnector search area and the offshore cable corridor.

41. Geophysical and grab survey samples have also been taken from the Norfolk Boreas site as part of the benthic ecology site characterisation survey (Fugro, 2018). The survey methodology and sampling effort was agreed with Natural England and the MMO.

3.1.1.1 The Norfolk Boreas site

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

3.1.1.2 Offshore cable corridor

43. A total of 47 seabed samples have been collected along the offshore cable corridor. Sediment distribution is variable depending on location. However, the dominant

sediment size is sand. Higher proportions of mud (greater than 10%) were found in 25% of samples with two samples containing greater than 60% mud. Many samples closer to the coast contained greater than 50% gravel.

3.1.1.3 Project Interconnector search area

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

45. 18 seabed sediment samples have been collected in the project interconnector search area in the southern half of Norfolk Vanguard West (a total of 18). The dominant sediment type is medium-grained sand with median particle sizes mainly between 0.25 and 0.40mm. The mud content is less than 5% in 83% of the samples. However, 17% of the samples contain greater than 15% mud, ranging from 15% to 45%. The gravel content varies from zero to 9% in all the samples.

46. 18 seabed sediment samples have also been collected in in the project interconnector search area in the north-west part of Norfolk Vanguard East (a total of 18). The dominant sediment type is medium-grained sand (82-100% sand) with median particle sizes between 0.20mm and 0.37mm, with most samples (90%) containing less than 5% mud. The gravel content varies from zero to 7% in all the samples.

3.1.2 Sub-surface sediments

47. Sub-surface sediments within the Norfolk Boreas site are described using data collected during the May – August 2017 surveys conducted by Fugro and reported in Fugro (2018). The offshore cable corridor and project interconnector search area were surveyed in September – November 2016 as reported in Fugro (2016). The Former East Anglia FOUR site (project interconnector search area within NV East) was surveyed in June – September 2012 (Fugro EMU, 2013).

48. The geology of the offshore project area generally consists of Holocene sand deposits overlying a series of Pleistocene sands and clays.

49. The sequence between the Smith's Knoll Formation and the Twente Formation is Pleistocene in age, whereas the Elbow Formation and Bligh Bank Formation are Holocene. The sequence between the Westkapelle Ground Formation and the Twente Formation is Pleistocene in age, whereas the Elbow Formation and Bligh Bank Formation are Holocene. The thickness of the Holocene sediment varies from less than 1m to greater than 20m in the sand wave fields and sand banks.

3.1.2.1 Norfolk Boreas Site and Project Interconnector Search Area

50. Fugro (2017) described eight geological formations (Table 3.1). The sequence between the Westkapelle Ground Formation and the Twente Formation is Pleistocene in age, whereas the Elbow Formation and Bligh Bank Formation are Holocene.

51. The geology of the Norfolk Boreas site generally consists of Holocene sand deposits overlying a series of Pleistocene sands and clays. The Bligh Bank Formation blankets most of the site with variable thickness. It is thickest beneath the sandbanks (up to 11m) and is a thin seabed veneer (less than 1m) in the bathymetric lows. It represents the sediment currently being reworked into sandbanks, sand waves and megaripples

Table 3.1 Geological formations present under the Norfolk Boreas site and the project interconnector search area in the southern half of NV West* (Fugro, 2016; Fugro, 2017a).

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

3.1.2.2 Offshore cable corridor

52. Fugro (2017a) completed the offshore cable corridor geophysical survey in 2016 using three different survey vessels. This was due to vessel operation limitations with regards to minimum water depths, and so the corridor was split into three sub-

sections (west, central and east). The sub-sections were surveyed using a pinger sub-bottom profiler, achieving a typical penetration of about 15m below seabed in the eastern sub-section, whereas the western and central sub-sections achieved 5m penetration. Differences in ground conditions along each section resulted in different attenuations of the seismic signal using the same pinger.

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

3.1.2.3 Project interconnector search area

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

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

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

3.2 Sediment Contamination Analysis

57. Alongside defining the biological and physical characteristics of the Norfolk Boreas offshore project area, benthic and contaminant surveys were undertaken in August 2017 across the Norfolk Boreas site. This survey aimed to characterise the physical,

biological and chemical nature of the seabed. As Norfolk Boreas shares the majority of its offshore cable corridor with Norfolk Vanguard it was agreed through the Evidence Plan Process (EPP) with the regulators (see Chapter 7 Technical consultation of the ES for further detail on the EPP), that the Norfolk Vanguard survey would be used to inform the EIA for Norfolk Boreas.

58. As part of the Norfolk Boreas site survey, sediment grab samples were obtained from 35 locations within the site. Of the 35 samples collected, eight were selected for contaminant analysis on the basis of the percentage of fine material present (as requested by the MMO) and two were selected to ensure even coverage across the site.

59. Table 3.2 provides reference to the sample numbers which are located within the proposed disposal site area and their respective locations. A spatial representation is provided in Chapter 9, Figure 9.2 of the Norfolk Boreas ES.

Table 3.2 Contaminant samples and their associated location

Location	Sample Number
Norfolk Boreas site	ST03, ST05, ST10, ST14, ST16, ST22, ST23, ST30, ST31, ST35ST
Project interconnector search area	16MS, 03MS
Offshore cable corridor	38_CR, 41_CR, 45_CR, 48_CR 56 CR

60. Sediment contaminant data is summarised in Table 3.3. Data highlighted in yellow indicates concentrations of contaminants over Cefas Action Level 1 (Cefas, undated) (there are no concentrations greater than Cefas Action Level 2). All organotin and PCB results were below the limits of detection (0.004 mg/kg and 0.0001 mg/kg respectively) and therefore have not been included in the table.

61. The data summarised in Table 3.3 illustrates that sediment contamination within the offshore cable corridor and the Norfolk Boreas site is low. Only four sites exceeded Cefas Action Level 1 and this was just for concentrations of arsenic at ST03, ST14, 03_MS and 56_CR (highlighted in Table 3.3). These exceedances are marginal as they are only just over the Action Level 1 concentration. The elevated levels of arsenic which were recorded are typical of the region; in the offshore environment these are associated with estuarine and geological inputs and sea bed rock weathering.

62. Since these results indicate low levels of contamination across the site and are in line with samples from other relevant projects, analysis of the reserved stored samples was considered unnecessary. This was agreed with the MMO, Natural England and Cefas, through consultation in October and November 2017 (see section 9.3 of Chapter 9 Marine Water and Sediment Quality of the ES for further detail).

Table 3.3 Sediment contamination analysis results compared to Cefas Action Levels.

Contaminant (mg/kg)	Sample site in Norfolk Boreas site										Offshore cable corridor							Project interconnector search area		
	ST31	ST03	ST10	ST14	ST23	ST30	ST16	ST05	ST35	ST22	24_CR	48_CR	45_CR	56_CR	38_CR	26_CR	41_CR	03_MS	05_MS	16_MS
Arsenic	13.3	21	12	32.7	14.9	10.5	9.4	12.9	8.76	14.4	12.6	11.9	9.75	35.2	10	5.39	11.4	20.4	16.7	10.7
Cadmium	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Chromium	12.2	10	7.43	13.9	12.9	7.81	14.5	15.6	14.3	11	3.8	12.8	9.1	4	2.2	4.8	<2	5.3	7.8	11.6
Copper	1.75	1.19	1.14	1.81	1.35	1.06	3.17	3.08	1.38	1.7	1.66	3.35	1.78	<1	<1	<1	<1	1.45	<1	1.95
Nickel	5.4	4.41	4.57	6.41	5.22	4.2	6.95	7.85	5.49	6.1	3.5	6.7	4.4	2.8	1.3	2.25	1.26	3.4	3.5	5.5
Mercury	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0108	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Lead	4.39	7.17	4.67	9.91	5.09	4.63	6.62	6.74	4.61	4.87	7.16	8.36	4.75	6.36	<2	3.59	2.34	5.12	5.96	5.69
Zinc	15.2	22.3	17.3	27	18.3	16.1	23.7	22.6	14.8	14.7	8.3	22.6	14.4	14.2	5.8	9.9	5.5	12	13.3	18.6
Acenaphthene	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.001	0.00101	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Acenaphthylene	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Anthracene	<1	<1	<1	<1	<1	<1	<1	2.02	<1	<1	<0.001	0.00129	0.00111	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Benzo(a)anthracene	<1	<1	<1	<1	<1	<1	2.11	3.82	<1	<1	<0.001	0.00415	0.00392	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.00429
Benzo(a)pyrene	<1	<1	<1	<1	<1	<1	2.54	3.96	<1	<1	<0.001	0.00558	0.00392	<0.001	<0.001	0.00142	<0.001	0.00152	<0.001	0.00543
Benzo(b)fluoranthene	<1	<1	<1	<1	1.56	<1	4.07	5.04	<1	<1	<0.001	0.00759	0.00695	<0.001	<0.001	0.0015	<0.001	0.00234	<0.001	0.0074
Benzo(e) pyrene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<0.005	0.00703	0.0058	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.00605
Benzo(ghi)perylene	<1	<1	<1	<1	1.29	<1	3.78	4.13	<1	<1	<0.001	0.0068	0.00514	<0.001	<0.001	0.00111	<0.001	0.00187	<0.001	0.00526
Benzo(j)fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(k)fluoranthene	<1	<1	<1	<1	<1	<1	1.85	2.49	<1	<1	<0.001	0.00319	0.0030	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.00341
Chrysene + Triphenylene	<3	<3	<3	<3	<3	<3	3.16	4.52	<3	<3	<0.003	0.00629	0.00618	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.00579
Chrysene	<3	<3	<3	<3	<3	<3	<3	3.55	<3	<3	<0.003	0.00432	0.00434	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.00418
Dibenzo(ah)anthracene	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dibenzothiophene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fluoranthene	<1	<1	<1	<1	1.55	<1	4.26	9.01	<1	<1	<0.001	0.00809	0.00879	<0.001	<0.001	0.00231	<0.001	0.00186	<0.001	0.00933
Fluorene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Indeno(1,2,3-c,d)pyrene	<1	<1	<1	<1	<1	<1	2.39	3.15	<1	<1	<0.001	0.00528	0.00452	<0.001	<0.001	0.00102	<0.001	0.0015	<0.001	0.00491
Naphthalene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<0.005	0.00616	0.00599	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Perylene	<5	<5	<5	<5	<5	<5	<5	7.88	<5	<5	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Phenanthrene	<5	<5	<5	<5	<5	<5	6.03	6.62	<5	<5	<0.005	0.00958	0.00953	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.00845
Pyrene	<1	<1	<1	<1	1.3	<1	3.84	7.71	<1	<1	<0.001	0.00699	0.00739	<0.001	<0.001	0.00230	<0.001	0.00160	<0.001	0.00779
Triphenylene	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Hydrocarbons: Total	4.29	2.35	6.97	4.63	10.8	2.31	23.7	16	3.53	1.96	5.51	47 3	33.1	<0.9	<0.9	5.02	<0.9	10	3.06	26.2

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4 QUANTITY OF MATERIAL TO BE DISPOSED

63. Material to be disposed may arise from the following sources:

- Seabed preparation for foundations;
- Drill arising when installing foundations; and
- Seabed levelling for cable installation.

64. Taking a precautionary approach, it has been estimated that a maximum of 50% of the foundation locations within the Norfolk Boreas site would require drilling. Drill arisings would fall rapidly to the seabed in the vicinity of the activity and would not be brought to the surface for disposal.

65. As discussed in section 1.1, Norfolk Boreas could be installed in a single or two phased approach. The spatial requirements for a single or two phased approach are the same and therefore the volume of sediment arising would be the same regardless of the build out scenario. However, the construction programme would vary and this is outlined in Section 4.3 of this document.

4.1 Seabed Preparation

66. Table 4.1 shows the volumes associated with seabed preparation for foundation and cable installation within the proposed disposal sites. The maximum sediment removal during foundation installation would be GBS foundations, any other foundation options would result in less material.

67. The maximum sediment disturbance in relation to seabed levelling for offshore export cable installation would be in relation to a trench length of 250km. This is based on four HVDC cables in two trenches to the wind farm site with a maximum length of 125km from landfall to the offshore electrical platforms.

68. Cable installation will require preparation of the offshore export cable corridor (pre-sweeping by dredging) excluding the nearshore within the 10m water depth contour as Norfolk Boreas Limited has committed to no seabed preparation in this area. These activities are outlined in Table 4.1. Subsequent trenching (e.g. by jetting or ploughing) will then be required to bury the cables. This sediment would not be affected and would therefore not require disposal. The impacts associated with trenching are assessed in the ES (Document reference 6.1; Chapters 8, 9, 10, 11 and 12).

Table 4.1 Total disturbance/preparation footprints during construction assessed within the EIA.

Infrastructure	Worst Case Scenario type	Worst Case Scenario volume (m^3)
Seabed preparation – turbines	180 x 10MW turbines on GBS foundations	1,767,146
Seabed preparation – offshore electrical platforms	Based on two 100m x 75m platforms	75,000
Seabed preparation - met masts	Based on 40m diameter – 1,257m^2 x 2 met masts	12,566
Seabed preparation – offshore service platform	Based on one 100m x 75m platforms	37,500
Array cable pre-sweeping	Width 20m x 600,000m	36,000,000
Interconnector pre-sweeping	Width 20m x 60,000m*	3,600,000*
Export cable pre-sweeping and cable trenching within Norfolk Boreas site	Based on 3,000,000** pre- sweeping and 1,500,000 cable trenching for 2 cable trenches	4,500,000
Total volume to be deposited in Norfolk Boreas site	1,892,212m^3 foundation pre-sweeping; and 44,100,000m^3 Cable pre-sweeping and trenching	**45,992,212**
Export cable pre-sweeping within the offshore cable corridor overlap with the SAC	Based on 2 cable trenches	500,000
Export cable pre-sweeping within the offshore cable corridor which does not overlap with the SAC	Based on 2 cable trenches	100,000
Total volume to be deposited in the offshore cable corridor		**600,000**
Total volume to be deposited in the project interconnector search area	Based on up to 10 trenches at 30m x 92,000m	**5,520,000***

* This would also be the maximum worst case scenario for the project interconnector cables, however as either the project interconnector cable or interconnector cables would be installed but never both this value is only included once.

** 3,000,000m^3 of material being disturbed as a result of trenching has been assessed with in the EIA as some of this material would be bought into suspension, However, as this material would not be dredged from the seabed and disposed of, this will not form part of the disposal licence application volumes.

69. In terms of the deposition of dredged material, the sediment dredged from within the HHW SAC will be deposited within this site to ensure that the sediment remains within the SAC, all other dredged material will be deposited at a suitable location within the disposal sites.

70. Due to the fact that the EIA takes a geographical approach to assessing impacts and the DCO secures maximum parameters through conditions based on specific infrastructure, the values for parameters such as the maximum quantities of disposal of material are not easily cross referenced between the DCO and the EIA. Document 6.7 EIA and DCO Reconciliation Document explains how these values can be reconciled. Table 3.6 of the reconciliation document explains that the DCO aims to

secure disposal of a total of 48,692,212m^3 whereas the EIA has assessed a maximum disposal of 55,112,212m^3. Table 4.1 presents the disposal volumes which have been assessed within the EIA, whereas the maximum amount of material to be disposed is secured through Schedule 1 Requirement 1 (c) of the DCO (document reference 3.1).

4.2 Drilling

71. Table 4.2 shows the volumes associated with drilling for foundation installation within the Norfolk Boreas Site. The maximum sediment arising during foundation drilling would be from monopile turbine foundations, as well as offshore service platforms and offshore electrical platforms on six-legged foundations and met masts on quadropods.

Table 4.2 Maximum drill arisings during construction

Infrastructure	Worst Case Scenario type	Worst Case Scenario volume (m^3)
Turbines	45 (50%) x 20MW turbines on monopiles	397,608
Offshore electrical platforms	2 x six-legged platforms with 18 pin pile	14,137
Offshore service platform	1 x six-legged platforms	848
Met masts	2 x quadropods	1,131
Lidar	2 x monopile	189
Total		**413,913**

4.3 Programme

72. The full construction window is expected to be up to approximately three years for the full 1800MW capacity. Table 4.3 and Table 4.4 provide indicative construction programmes for the single phase and two phase options, respectively.

Table 4.3: Indicative Norfolk Boreas construction programme – single phase

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

Table 4.4: Indicative Norfolk Boreas construction programme – two phase

		2024				2025				2026				2027				2028			
Indicative Programme	**Approximate duration**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Pre-construction survey	12 months				■	■	■														
UXO survey and licensing	12 months				■	■	■														
UXO clearance following licencing	9 months							■	■	■											
Foundation seabed preparation	3 months									■											
Foundation installation	2 x 9 months										■	■	■		■	■	■				
Scour protection installation	2 x 6 months									■	■			■	■						
Offshore Electrical Platform Installation Works	2 x 6 months										■	■			■	■					
Array & interconnector cable seabed preparation	2 x 3 months									■				■							
Array & interconnector cable installation	2 x 9 months										■	■	■		■	■	■				
Export cable installation seabed preparation	2 x 3 months								■				■								
Export cable installation	2 x 9 months									■	■	■		■	■	■					
Cable protection installation	2 x 9 months										■	■	■		■	■	■				
Wind turbine installation	18 months														■	■	■		■	■	■
Total construction works	39 months								■	■	■	■	■	■	■	■	■	■	■	■	■

4.4 Daily Disposal Amounts

73. It is anticipated, that approximately 50,000m^3 of daily sediment disposal may be required based on 3 to 4 dredge and deposit activities per day for foundation seabed preparation and/or cable pre-sweeping.

74. It is anticipated that construction of the turbine foundations would either be over an 18 month period under a single phase approach or two nine month periods under the phased approach. Seabed preparation would be a small proportion of this programme and therefore it can be expected that the daily disposal rate quoted above would only occur for limited and discrete periods within the construction phase.

5 ALTERNATIVES CONSIDERED

5.1 Use of Material for Ballast

75. Where extensive excavation works are required, such as for seabed preparation for foundation installation, it is possible that material could be retained and used for infill works or ballast material, if geotechnically suitable for purpose. Ballast material is heavy material which is used to enhance stability of foundations and is likely to be composed of locally dredged sand.

76. As described above, Norfolk Boreas Limited is considering the use of several different foundation types. Sand dredged locally during the seabed preparation could be used as ballast material for GBS foundations during the foundation preparation works if geotechnically suitable for purpose (ballast material is likely to be composed of locally dredged sand). The remainder would be disposed of as described in section 4 above.

77. The use of excavated material as ballast would depend on a suitable foundation type being used and the results of detailed post-consent geotechnical investigations. However, for the purposes of the EIA, and as a worst case for this report, it has been assumed that all drilled and dredged material would be disposed of on site, rather than being used as ballast material.

5.2 Other Disposal Sites

78. Through consultation with Natural England during the Norfolk Vanguard EPP it was identified that it is preferable to dispose of dredged sediment as close to the source as possible, in particular in the HHW SAC, in order to minimise potential disturbance impacts.

79. However, the suitability and capacity of existing disposal sites within a 50km radius of the Norfolk Boreas offshore project area has also been considered (Table 5.1).

Table 5.1 Existing Disposal Sites within 60km of the Norfolk Boreas offshore project area

Site Name	Site ID	Area km^2	Distance from Norfolk Boreas offshore project area (km)
East Anglia THREE	HU212	935	13.0
East Anglia ONE	TH023	129.4	56.4
Great Yarmouth	HU150	0.67	19.0
Cross Sands 2	HU176	0.30	21.5
Burgh Castle Yacht Station	HU208	0.015	23.8
Reedham Marina	HU159	0.001	26.7
Lowestoft Circular North	TH005	0.431	29.4
Lowestoft Marina Temporary Disposal Site	TH011	<0.001	31.5
Wells Outer Harbour B1	HU157	0.02	49.3

Site Name	Site ID	Area km^2	Distance from Norfolk Boreas offshore project area (km)
Well Beneficial use site2	HU156	0.57	49.3
Wells outer harbour site C	HU154	0.002	49.3
Wells outer harbour site A	HU152	0.006	49.4
Galloper Offshore wind farm	TH057	219.0	59.4

80. The largest sites within 50km of Norfolk Boreas are East Anglia ONE (TH023) and Galloper offshore wind farm (TH057). None of the other disposal sites listed in Table 5.1 are considered large enough to accommodate worst case scenario of up to 48,692,212m^3 of sediment that could require disposal through the construction of Norfolk Boreas.

81. The East Anglia ONE, East Anglia THREE and Galloper Offshore wind farm disposal sites have been licenced specifically to receive material from within those wind farms and would therefore not be able to receive any material from Norfolk Boreas.

6 POTENTIAL IMPACTS OF DISPOSAL

82. The impact of disposal of material within the Norfolk Boreas site and offshore cable corridor has been incorporated into impacts assessed within the Norfolk Boreas EIA and presented within the ES; specifically within Chapter 8 Marine Geology, Oceanography and Physical Processes, Chapter 9 Marine Water and Sediment Quality and Chapter 10 Benthic and Intertidal Ecology. It should be noted however that the impacts presented within the ES assess the impacts of the project as a whole and so the specific parts of the assessment that consider disposal of sediment have been drawn out and are presented below.

83. The assessment methodology for sediment and seabed changes associated with the installation of foundations, array cables and the export cables is provided in Chapter 8 Marine Geology, Oceanography and Physical Processes.

84. The assessment of significance has been based on the following;

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

85. The sensitivity and value of discrete morphological receptors have been assessed using expert judgement and described with a standard semantic scale. Definitions are provided in Chapter 8 Marine Geology, Oceanography and Physical Processes.

86. The magnitude of effect is dependent upon its;

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

87. The magnitude of effect has been assessed using expert judgement and described with a standard semantic scale. Definitions for each term are provided in Chapter 8 Marine Geology, Oceanography and Physical Processes.

88. Within Chapter 8 Marine Geology, Oceanography and Physical Processes of the ES, impacts on the physical characteristics of the site have been assessed. The impacts which contain relevant information for this assessment are as follows:

- Changes in suspended sediment concentrations due to seabed preparation for wind turbine foundation installation;
- Changes in suspended sediment concentrations due to drill arisings for installation of piled foundations for wind turbines;
- Changes in seabed level due to seabed preparation for wind turbine foundation installation;
- Changes in seabed level due to drill arisings for installation of piled foundations for wind turbines;
- Changes in suspended sediment concentrations during cable installation within the offshore cable corridor;
- Changes in seabed level due to disposal of sediment from sand wave levelling in the offshore cable corridor;
- Changes in seabed level due to cable installation within the offshore cable corridor;
- Changes in suspended sediment concentrations during cable installation within the Norfolk Boreas site and project interconnector search area; and
- Changes in seabed level due to cable installation within the Norfolk Boreas site and project interconnector search area.

89. Chapter 9 Marine Water and Sediment Quality of the ES incorporates the potential effects of disposal on water and sediment quality. This assessment directly builds upon the assessment in Chapter 8 Marine Geology, Oceanography and Physical Processes. The impacts which contain relevant information for this assessment are as follows:

- Deterioration in offshore water quality due to increased suspended sediment concentrations created by seabed preparation during foundation installation;
- Deterioration in offshore water quality due to increased suspended sediment concentrations due to drill arisings for installation of piled foundations. s;
- Deterioration in water quality due to increased suspended sediment concentrations during installation of cables within the offshore cable corridor;
- Deterioration in offshore water quality due to increased suspended sediment concentrations during cable installation within the Norfolk Boreas site and Project interconnector search area.; and
- Deterioration in water quality (offshore and nearshore) due to re-suspension of sediment bound contaminants.

90. In the ES, Chapter 10 Benthic and Intertidal Ecology incorporates the potential effects of disposal on the biological characteristics of the project. This assessment also builds upon the assessment in Chapter 8 Marine Geology, Oceanography and Physical

Processes. The impacts which contain relevant information for this assessment are as follows:

- Temporary habitat loss / disturbance;
- Temporary increase in suspended sediment concentrations and associated sediment deposition; and
- Changes to water quality due to re-mobilisation of contaminated sediments.

91. The impact assessments presented in the ES discuss the impacts of constructing Norfolk Boreas in one or two phases. The results indicate that there is no material difference in the impacts on marine physical processes, water and sediment quality, or benthic ecology for either phasing option, and therefore phasing is not discussed further in this report.

6.1 Norfolk Boreas Site

6.1.1 Potential Impacts of Sediment Disposal on Physical Characteristics in the Norfolk Boreas Site

92. As discussed in section 1.1, the following infrastructure could be located in the Norfolk Boreas Site:

- Between 90 (20MW) and 180 (10MW) wind turbines;
- Up to two offshore electrical platforms;
- One offshore service platform;
- Up to two met masts;
- A network of array cables
- Sections of export cables; and
- Interconnector cables or project interconnector cables.

93. The installation of wind turbine foundations and electrical cables has the potential to disturb sediments from: (i) the seabed (surface or shallow near-surface sediments, e.g. from seabed levelling); and (ii) from several tens of metres below the seabed (sub-surface sediments, e.g. from foundation drilling), depending on installation type and method.

94. Section 4.1 shows that up to 46Mm^3 of sediment arising from seabed preparation could be deposited in the Norfolk Boreas site.

6.1.1.1 Changes in suspended sediment concentrations due to foundation installation in the Norfolk Boreas site

95. Foundation installation has the potential to disturb the seabed and shallow near-bed sediments through the dredging required pre-installation and subsequent release of dredged material to the site. In some cases, foundation installation will require drilling

activities to be conducted, therefore potentially impacting sub-surface sediments. These impacts are discussed in turn.

6.1.1.1.1 Seabed and shallow near-bed sediments

96. Seabed sediments and shallow near-bed sediments within the Norfolk Boreas site would be disturbed during any levelling or dredging activities to create a suitable base prior to foundation installation.

97. For a sediment release from a single turbine foundation, the worst case scenario is associated with the dredging volume for each 20MW

98. GBS foundation, with a maximum preparation area of 2,827m^2. This yields a worst-case dredging volume of 14,137m^3 per foundation based on levelling up to 5m of sediment.

99. The worst case total volume for the project is associated with the maximum number (180) of 10MW GBS foundations with a maximum preparation area of 1,963m^2. This yields a total dredging volume of 1,767,146m^3. Also, using a worst-case approach the following platforms would be installed:

- Up to two meteorological masts yielding a dredging volume of 12,566m^3;
- Up to two offshore electrical platforms yielding a dredging volume of 75,000m^3; and
- One offshore service platform yielding a dredging volume of 37,500m^3.

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

101. The worst case total volume of sediment disturbed as a result of cable installation within the Norfolk Boreas site is estimated to be 44.1Mm^3, this is based on the installation of 600km of array cable, 60km of interconnector cable and 50km of export cable (Table 4.1). The assessment assumes that the sediment would be returned to the water column at the sea surface during disposal from the dredger vessel.

102. This process would cause localised and short-term increases in suspended sediment concentrations both at the point of dredging at the seabed and, more importantly, at the point of its discharge back into the water column.

103. Expert-based assessment suggests that, due to the predominance of medium-grained sand across the Norfolk Boreas site, the sediment disturbed by the drag head of the dredger at the seabed would remain close to the bed and settle back to the bed rapidly. Most of the sediment released at the water surface from the

dredger vessel would fall rapidly (minutes or tens of minutes) to the seabed as a highly turbid dynamic plume immediately upon its discharge (within a few tens of metres along the axis of tidal flow).

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

105. Due to the predominance of medium-grained sand across The Norfolk Boreas site, the sediment disturbed by the drag head of the dredger at the seabed would remain close to the bed and settle back to the bed rapidly.

106. The conclusions of the assessment on changes in suspended sediment concentrations due to foundation installation in the Norfolk Boreas Site, presented in Chapter 8 Marine Geology, Oceanography and Physical Processes of the ES, are based on the results of modelling simulations undertaken for the East Anglia ONE site using the Delft3D plume model (ABPmer, 2012b). The sediment types across East Anglia ONE (5% gravel, 93% sand and 2% mud) are similar to those across the Norfolk Boreas site (5% gravel, 65-100% sand and 10% mud).

107. Also, Norfolk Boreas and East Anglia ONE are similar distances from the amphidromic point, and therefore the tidal currents and hence sediment dispersion patterns would be similar. Given these similarities, the earlier modelling studies for East Anglia ONE are considered to represent a suitable analogue for verifying the conclusions of the more qualitative expert-based assessment described in ES Chapter 8 Marine Geology, Oceanography and Physical Processes.

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

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

110. There would be little additional effect of scaling-up from the modelled 15 foundations to the 180 foundations proposed across Norfolk Boreas because the modelled results show that after completion of installation of a foundation, the suspended sediment concentrations do not persist but rapidly return to background levels. Hence, the release of sediment from one foundation installation would not last for a long enough time to interact with the next installation. This would be the case regardless of the number of foundations that were installed and so the cumulative effects of 15 and 180 installations would be similarly small. Given this finding from the modelled consecutive installation of 15 wind turbine foundations (ABPmer, 2012b), it is expected that effects from installation of 180 foundations across the whole of Norfolk Boreas would be less.

6.1.1.1.2 Sub-surface sediments

111. Deeper sub-surface sediments within the site could become disturbed during any drilling activities that may be needed at the location of each piled foundation. Although it is not confirmed that drilling will be required the possibility of drilling must be considered as a worst case scenario. Up to 50% of turbines may require drilling activities as part of the foundation installation process. It should be noted that should piled foundations which require drilling be used, then the volume of pre-sweeping for GBS foundations described above would be minimised or avoided.

112. The drilling process would result in the production of drill arisings, which would cause localised and short term increases in suspended sediment concentrations at the point of discharge of the drill arisings.

113. The worst case scenario for the total volume of drill arisings released during the construction period would consist of a total of 413,913m^3 in the Norfolk Boreas site (with 50% of turbine foundations plus other platforms requiring drilling). Although the sub-surface sediment release quantities involved under this worst case scenario for drill arisings are considerably lower than those involved in the worst case scenario for the surface and near-bed sediments from pre-sweeping, the sediment

types would differ, with a larger proportion of finer materials and therefore it is important to assess the potential impact of drill arisings.

114. The disturbance effects at each structure location are likely to last for no more than a few days of construction activity. 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 in relatively close proximity to the foundation location, whilst disaggregated finer sediments (fine sands and muds) would be more prone to dispersion across a wider area. 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 until they ultimately come to rest on the seabed.

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

115. The worst case changes in suspended sediment concentrations due to seabed preparation for foundation installation are likely to have the magnitudes of effect shown in Table 6.1.

Table 6.1 Magnitude of effect on suspended sediment concentrations due to foundation installation in the Norfolk Boreas site under the worst case scenario

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

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

116. The effects on suspended sediment concentrations due to offshore cable installation (including any sand wave levelling) would have **no impact** upon the marine physical processes of the Norfolk Boreas site. This is because the processes are active along the seabed and are not affected by sediment suspended in the water column. The impact of suspended sediment on water quality and benthic receptors is discussed in section 6.1.2 and 6.1.3.

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

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

disturbance, this would not materially change the assessment of significance compared with a single-phase approach.

6.1.1.2 Changes in seabed levels due to foundation installation in the Norfolk Boreas site

118. The increases in suspended sediment concentrations associated with the impact discussed in section 6.1.1.1 have the potential to result in changes in seabed levels as the suspended sediment deposits on the surrounding seabed potentially raising the seabed level slightly. There would be different settling rates for the different sediment types associated with the seabed and shallow near-bed sediment disturbance and the deeper sub-surface sediment disturbance, so each is discussed in turn.

6.1.1.2.1 Seabed and shallow near-bed sediments

119. 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, forming a deposit ('mound') local to the point of release. Due to the sediment grain sizes observed across the 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.

120. When the medium sand and courser material settle out the resulting mound would be a measurable protrusion from the sea bed (likely order of tens of centimetres to a few metres in height) but would remain highly localised to the release point. The material within the mound would be similar to that on the existing sea bed and therefore there would be no significant change in sediment type. Also, the overall change in elevation of the seabed is small compared to the absolute depth of water (greater than 20m). The change in seabed elevation is within the natural change to the bed caused by sand waves and sand ridges and hence the blockage effect on physical processes would be negligible.

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

122. In addition to the local mounds, the very small proportion of mud present within the sediment would form a passive plume and become more widely dispersed before settling on the seabed. The East Anglia ONE modelling (ABPmer, 2012b) considered seabed level changes resulting from deposition of sediments from the passive plume due to seabed preparation for 15 foundations. This involved a worst-case sediment release of 22,500m^3 per foundation (i.e. around twice the volume considered as the worst case for an individual wind turbine foundation in Norfolk Boreas). The deposited

sediment layer across the wider seabed was found to be less than 0.2mm thick in most areas and did not exceed 2mm anywhere. The area of seabed upon which deposition occurred (at these low values) extended a considerable distance from the site boundary (around 50km), but in doing so only covered a very narrow width of seabed (a few hundred metres). This is because the dispersion of the plume followed the axis of tidal flow. The previous assessment also concluded that this deposited sediment has the potential to become re-mobilised and therefore would rapidly become incorporated into the mobile seabed sediment layer, thus further reducing any potential effect.

123. Using the plume modelling studies for East Anglia ONE as part of the expert-based assessment suggests that deposition of sediment from the Norfolk Boreas plume would occur across a wide area of seabed and would be very thin (millimetres). Given that the maximum sediment volume released through seabed preparation would be less than the modelled release at East Anglia ONE; the worst case thickness of sediment deposited from the plume will also be less (given similar hydrodynamic conditions). Hence, it is anticipated that the worst case sediment thicknesses at Norfolk Boreas would not likely exceed a maximum of 1.4mm and be less than 0.14mm over larger areas of the seabed.

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

6.1.1.2.2 Sub-surface sediments

125. 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.

126. The bed level changes that are anticipated 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 at different locations.

127. A very conservative worst case scenario has also been considered whereby the sediment released from the drilling is assumed to be wholly in the form of aggregated ‘clasts’ of finer sediment that remain on the sea bed (at least initially), rather than being disaggregated into individual fine-grained sediment components immediately upon release. Under this scenario, the worst case assumes that a ‘mound’ would

reside on the sea bed near the site of its release, in this case surrounding the wind turbine foundations.

128. The maximum footprint of an individual mound arising would be 8,836m^2 from a 20MW monopile turbine foundation.

129. The maximum area of footprint for drilling mounds associated with the whole project would be 441,800m^2 for 45 (50%) of the 10MW monopile foundations, as well as offshore service platform and offshore electrical platforms on six-legged foundations and met masts on quadropods.

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

130. The models of East Anglia ONE were successfully calibrated and verified with existing data, and so there is high confidence in the assessment of effects, including their scaling up from modelling results of a sub-set of wind turbines to the whole Norfolk Boreas project area.

131. The changes in seabed levels due to foundation installation under the worst case sediment dispersal scenario are likely to have the magnitudes of effect shown in Table 6.2.

Table 6.2 Magnitude of effects on seabed level changes due to sediment deposition following foundation installation under the worst case sediment dispersal scenario

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
Near-field[3]	Medium	Negligible	Negligible	Negligible	Low
Far-field	Negligible	Negligible	Negligible	Negligible	Negligible

132. It was concluded that the overall impact of foundation installation activities on sea bed levels in the Norfolk Boreas site would be **negligible impact**.

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

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

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

6.1.1.3 Changes in suspended sediment concentrations during cable installation in the Norfolk Boreas site

134. The installation of the array, export and interconnector cables has the potential to disturb seabed sediment to a depth of up to 3m. Disturbance could be through levelling of sand waves that may be present along the cables prior to installation or directly through installation of the cable (worst case scenario is jetting) and finally through the disposal of dredged material back onto the site, temporarily increasing sediment concentrations in the water column.

135. Any excavated sediment due to sand wave levelling for the array and interconnector cables would be disposed of within the Norfolk Boreas site. For the worst-case scenario, it is assumed that sand wave levelling may be required for 100% of the array cables, interconnector cables, project interconnector cables or export cables to an average depth of 3m and with an average width of 20m. This equates to a total of 802km of cable, 16km^2 of seabed or excavation of 48,120,000m^3 of sediment, see ES Chapter 8 Marine Geology, Oceanography and Physical Processes for further details.

136. Optimisation of array cable and interconnector cable alignment, depth and installation methods during detailed design would ensure that effects are minimised. The direct impact of change to the substrate elevation is about 2% of the Norfolk Boreas site. In addition, the dynamic nature of the sand waves in this area means that any direct changes to the seabed associated with sand wave levelling are likely to recover over a short period of time due to natural sand transport pathways.

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

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

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

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

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

141. The worst case changes in suspended sediment concentrations due to array cable and interconnector cable installation (including any necessary sand wave levelling) are likely to have the magnitudes of effect described in Table 6.3.

Table 6.3 Magnitude of effect on suspended sediment concentrations due to cable installation in the Norfolk Boreas site under the worst case scenario

Location	Scale	Duration	Frequency	Reversibility	Magnitude of Effect
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 of seabed (likely to be of the order of several hundred metres up to a kilometre from the cable), and would not cover the entirety of the seabed area within Norfolk Boreas

142. Overall, these effects will have **no impact** on identified receptors associated with the suspended sediment generated by disposal of material due to interconnector and array cable installation in the Norfolk Boreas site.

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

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

6.1.1.4 Changes in seabed levels during cable installation in the Norfolk Boreas site

144. The increases in suspended sediment concentrations associated with the impact described in section 6.1.1.3 have the potential to result in changes in seabed levels as the suspended sediment deposits on the seabed.

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

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

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

147. Expert-based assessment indicates that changes in suspended sediment concentration due to array, interconnector or project interconnector and export cable installation (including any necessary sand wave levelling) within the Norfolk Boreas site would be minor and are likely to have the magnitudes of effect shown in Table 6.4.

Table 6.4 Magnitude of effect on seabed level changes due to array, interconnector or project interconnector and export cable installation in the Norfolk Boreas site (including sand wave levelling) under the worst case scenario

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

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

148. These effects on seabed level are considered highly unlikely to have the potential to impact directly upon the identified receptor groups for marine physical processes. Any impacts will be of a significantly lower magnitude than those seabed level impacts

already considered for the installation of foundations. Consequently, the overall impact of array, interconnector or project interconnector and export cable installation activities within the Norfolk Boreas site under a worst case scenario on seabed level changes for identified morphological receptor groups is therefore considered to be **negligible impact**.

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

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

6.1.1.5 Summary of impacts of sediment disposal on physical characteristics in the Norfolk Boreas site

150. As the conclusion of all relevant impacts on physical characteristics was that there would be negligible impact, it is unlikely that there would be any discernible effect on the physical characteristics of the sites due to the proposed sediment disposal.

6.1.2 Potential Impacts of Sediment Disposal on Water and Sediment Quality in the Norfolk Boreas site

151. Disposal of sediment has the potential to change water quality, either through increased sediment concentrations resulting from the disposal plume or impacts associated with the release of sediment bound contaminants. This is considered in detail in Chapter 9 Marine Water and Sediment Quality of the ES.

152. A summary of the potential impacts to water and sediment quality due to sediment disposal is summarised below.

6.1.2.1 Change in water quality due to re-suspension of sediments in the Norfolk Boreas site

153. Seabed sediments and shallow near-bed sediments within the Norfolk Boreas site would be disturbed during any levelling or dredging activities to create a suitable base prior to the installation of foundations. The worst case scenario assumes that sediment would be dredged and returned to the water column at the sea surface as overflow from a dredging vessel. This process would cause localised and short-term increases in suspended sediment concentrations both at the seabed and at the point of discharge into the water column, however the disturbance effect at each wind turbine location are likely to last for no more than a few days.

154. Sections 6.1.1.1 and 6.1.1.3 outline the volumes of sediment that will be disposed of in Norfolk Boreas site in the worst case scenario of foundations, export, array, interconnector or project interconnector cable installation.

6.1.2.1.1 Assessment of effect magnitude and / or impact significance

155. The changes in suspended sediment concentrations due to seabed preparation are predicted to be low in magnitude due to the localised and short term nature of the predicted sediment plumes. Baseline conditions of suspended sediment concentrations are expected to return to normal rapidly following cessation of activity, therefore any impact will only be present during the installation process. The sensitivity in the offshore project area is deemed to be low due to the large volume of the receiving water and the capacity for dilution and flushing and therefore a **minor adverse** impact significance is predicted.

6.1.2.2 Change in water quality in the Norfolk Boreas site due to re-suspension of contaminants within sediment

156. The disposal of dredged material has the potential to release sediment-bound contaminants, such as heavy metals and hydrocarbons, into the water column.

157. The data discussed in section 3.2 of this report shows that the levels of contaminants within the Norfolk Boreas site are very low, with only two marginal exceedances in Cefas Level 1 for Arsenic reported. Therefore, the potential magnitude of the effect is considered negligible.

6.1.2.2.1 Assessment of effect magnitude and / or impact significance

158. As a result of the negligible magnitude of effect and low receptor sensitivity, the re-suspension of contaminated sediment from construction activities is considered to be of **negligible** significance.

6.1.2.3 Summary of impacts of sediment disposal on water and sediment quality in the Norfolk Boreas site

159. As the conclusion of all relevant impacts on water and sediment quality was that they would be of minor and negligible significance it is considered that, should the Norfolk Boreas site be designated a disposal site, impacts to water and sediment quality would be of no greater than **minor adverse** significance.

6.1.3 Potential Impacts of Sediment Disposal on Benthic Ecology in the Norfolk Boreas site

160. Chapter 10 Benthic and Intertidal Ecology of the ES provides a detailed assessment of the impacts of the project on benthic habitats and species. Provided below is a summary of the important findings which relate to the disposal of sediment.

6.1.3.1 Increased suspended sediment concentrations

161. Increases in suspended sediment concentrations within the water column has the potential to affect the benthos through blockage to the sensitive filter feeding apparatus of certain species and / or smothering of sessile species upon deposition of the sediment. Changes in turbidity decrease the depth to which natural light can penetrate into the water column and may therefore result in a reduction in primary productivity. Additionally, sediment plumes can create barriers to movement of marine ecological parameters.

162. The worst case scenario would result in 1,892 ,212m^3 of sediment being disposed of in the Norfolk Boreas site due to seabed preparation (sand wave levelling of up to 5m) for the following:

- Foundations;
    - 180 of the foundations (requiring preparation for a circular area with diameter of 50m);
    - Two offshore electrical platforms and one offshore service platform with 7,500m^2 preparation areas each;
    - Up to 40m diameter pre-sweeping for two met masts;
- Cable installation with 20m disturbance width;
    - 50km of export cables;
    - 600km of array cables; and
    - 60km of interconnector or project interconnector cables.

163. As discussed in section 6.1.1.1 the sediment in the Norfolk Boreas site is predominantly medium grain sand with very small percentages of mud and gravel. As a result, this sediment would fall as a highly turbid dynamic plume upon its discharge, reaching the seabed within minutes or tens of minutes and within tens of metres along the axis of tidal flow from the location at which it was released. The resulting mound would be likely to be tens of centimetres to a few metres high. The small proportion of fine sand and mud would stay in suspension for longer and form a passive plume. This plume (tens of mg/l) would be likely to exist for around half a tidal cycle (i.e. approximately 6 hours). Sediment would settle to the seabed within approximately 1km along the axis of tidal flow from the location at which it was released. These deposits would be very thin (millimetres).

164. Additionally, the potential sediments raised from drillings may form clasts on the seabed, however this would be temporary and within the seabed preparation footprint.

6.1.3.1.1 Assessment of effect magnitude and / or impact significance

165. The sensitivity of the receptors in Norfolk Boreas to increases in suspended sediments and smothering are shown below in Table 6.5. The majority of receptors are not sensitive to increased suspended sediments and smothering (Tyler-Walters 2004, Lear and Allen, 2004; Tillin et al*.,* 2015; Jackson & Hiscock, 2008; Ager, 2005). *S. spinulosa* and *Spiophanes bombyx* use sediment to build tubes and can therefore thrive in environments with increased suspended sediments. The maximum sensitivity is shown for *S. spinulosa,* where smothering reaches a level at which there is no tolerance, in which case the recoverability would be medium when the deposited sediments disperse resulting in medium sensitivity. The worst case scenario is therefore an impact of **minor adverse** significance.

Table 6.5 Sensitivities of receptors within the Norfolk Boreas site to increased suspended sediment and smothering by deposited sediment (source: Tyler-Walters 2004, Lear and Allen, 2004; Tillin et al*.,* 2015; Jackson & Hiscock, 2008; Ager, 2005)

Receptor	Tolerance	Recoverability	Overall sensitivity
Light smothering – up to 5cm			
Sublittoral sands and muddy sands	Not available		
***S. spinulosa* on stable circalittoral mixed sediment**	High	High	Not sensitive
Sabellaria spinulosa	Low	Immediate	Not sensitive
Spiophanes bombyx	Low	High	Low
Abra alba	Low	Immediate	Not sensitive
Polinices Pulchellus	Not available		
Heavy smothering – up to 30cm			
Sublittoral sands and muddy sands	Not available		
***S. spinulosa* on stable circalittoral mixed sediment**	None	Medium	Medium
S. spinulosa	Medium		
S. bombyx	Not available		
A. alba	Not available		
P. Pulchellus	Not available		
Increased Suspended Sediment Concentrations			
Sublittoral sands and muddy sands	Not available		
***S. spinulosa* on stable circalittoral mixed sediment**	High	High	Not sensitive
S. spinulosa	Low	Immediate	Not sensitive
S. bombyx	Tolerant	N/A	Not sensitive

Receptor	Tolerance	Recoverability	Overall sensitivity
A. alba	Tolerant	N/A	Not sensitive
P. Pulchellus	Not available		

* Based on Natural England's advice during relevant representation for Norfolk Vanguard (see Table 10.2 of ES Chapter 10 Benthic Ecology (document reference 6.1.5).

6.1.3.2 Re-mobilisation of contaminated sediments

166. Given the low level of contaminants present in the sediments within the Norfolk Boreas site (see section 3.2), changes in water and sediment quality throughout the study area due to re-suspension of contaminants during construction have been assessed as minor.

167. Marine Evidence based Sensitivity Assessment (MarESA) (MarLIN, 2017) shows that, where contaminants levels are within environmental protection standards, marine species and habitats are not sensitive to changes that remain within these standards.

168. All construction activities will be covered by a Project Environmental Management Plan (PEMP) as well as emergency plans in the case of an accidental spillage or leak to ensure no release of contaminants as a result of the project. In addition to this, all vessels must adhere to the requirements of the MARPOL Convention Regulations with appropriate preventative and control measures.

6.1.3.2.1 Assessment of effect magnitude and / or impact significance

169. As a result of the absence of existing contamination and mitigation to avoid release of contaminants, there would be **no impact** to the benthic or intertidal ecology.

6.1.3.3 Summary of impacts of sediment disposal on benthic ecology in the Norfolk Boreas site

170. As the conclusion of all relevant impacts on benthic ecology was that they would range from no impact to minor adverse significance it is considered that, should the proposed Norfolk Boreas disposal site be designated, impacts would occur to benthic species however these would be no greater than of minor adverse significance.

6.2 Project Interconnector Search Area

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

172. Maximum length of project interconnector cable trenches[4] would be up to 92km within the project interconnector search area. Of this total, depending on which electrical solution is chosen either a maximum of 60km would be located in the overlap with the offshore cable corridor and 20km would be within the overlap with Norfolk Vanguard West (Electrical solution c) described in section 5.4.12.3 of Chapter 5 Project description), or all 92km would be within the overlap with the Norfolk Vanguard East (Electrical solution b) described in section 5.4.12.3 of Chapter 5 Project description).

6.2.1 Potential Impacts of Sediment Disposal on Physical Characteristics in the Project Interconnector Search Area

173. In a similar way to the export cables within the offshore cable corridor, the installation of the project interconnector and export cables in the project interconnector search area has the potential to disturb seabed sediment to a depth of up to 3m. Disturbance could be through levelling of sand waves that may be present along the cables prior to installation or directly through installation of the cable (worst-case scenario is jetting).

174. Any sediment due to sand wave levelling for the project interconnector and export cables would be disposed of within the project interconnector search area.

6.2.1.1 Changes in suspended sediment concentrations and seabed levels during cable installation in the Project Interconnector Search Area

175. Substrate types, as well as sediment transport, wave and tidal processes, are similar to the Norfolk Boreas site. The project interconnector and export cables that could be installed in the project interconnector search area would be the same as the Norfolk Boreas site and therefore the potential impacts on suspended sediment concentrations are as described in section 6.1.1.3 and potential impacts on seabed levels are as described in section 6.1.1.4.

6.2.2 Potential Impacts of Sediment Disposal on Water and Sediment Quality in the Project Interconnector Search Area

176. The disposal of dredged material has the potential to release sediment-bound contaminants, such as heavy metals and hydrocarbons, into the water column.

177. The data discussed in section 3.2 of this report shows that the levels of contaminants within the project interconnector search area are very low, with marginal exceedances

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

of arsenic which are deemed to be from natural sources. Therefore, the potential magnitude of the effect is considered **negligible**.

6.2.3 Potential Impacts of Sediment Disposal on Benthic Ecology in the Project Interconnector Search Area

6.2.3.1 Increased suspended sediment concentrations

178. The sensitivity of the receptors in project interconnector search area to increases in suspended sediments and smothering are shown below in Table 6.6.

179. Most receptors are not sensitive to increased suspended sediments and smothering (Tyler-Walters 2004, Lear and Allen, 2004; Tillin et al*.,* 2015; Jackson & Hiscock, 2008; Ager, 2005, Tillin 2016d). *S. spinulosa* and *S. bombyx* use sediment to build tubes and can therefore thrive in environments with increased suspended sediments. There is no sensitivity assessment available for the *Capitella* genus, however *Capitella Capitata* is commonly found in the UK and has been used as a proxy for the *Capita* genus. The maximum sensitivity is shown for *S. spinulosa,* where smothering reaches a level at which there is low tolerance, in which case the recoverability would be medium when the deposited sediments disperse resulting in medium sensitivity. The worst case scenario is therefore an impact of **minor adverse** significance.

Table 6.6 Sensitivities of receptors within the project interconnector search area to increased suspended sediment and smothering by deposited sediment (source: Tyler-Walters 2004, Lear and Allen, 2004; Tillin et al., 2015; Jackson & Hiscock, 2008; Ager, 2005, Tillin 2016d)

Receptor	Tolerance	Recoverability	Overall sensitivity
Light smothering – up to 5cm			
Circalittoral coarse sediment	Not available		
***S. spinulosa* on stable circalittoral mixed sediment**	High	High	Not sensitive
Sabellaria spinulosa	Low	Immediate	Not sensitive
Spiophanes bombyx	Low	High	Low
N.Cirrosa	Not available		
Polinice pulchellus	Not available		
Capitella.sp	Low	High	Low
Heavy smothering – up to 30cm			
Circalittoral coarse sediment	Not available		
***S. spinulosa* on stable circalittoral mixed sediment**	None	Medium	Medium
S. spinulosa	Medium *		
S. bombyx	Not available		
Nephtys cirrosa	Not available		

Receptor	Tolerance	Recoverability	Overall sensitivity
P. Pulchellus	Not available		
Capitella.sp	Low	High	Low
Increased Suspended Sediment Concentrations			
Circalittoral coarse sediment	Not available		
***S. spinulosa* on stable circalittoral mixed sediment**	High	High	Not sensitive
S. spinulosa	Low	Immediate	Not sensitive
S. bombyx	Tolerant	N/A	Not sensitive
N. Cirrosa	Not available		
P. Pulchellus	Not available		
Capitella.sp	Medium	Low	High

* Based on Natural England's advice during relevant representation for Norfolk Vanguard (see Table 10.2 of ES Chapter 10 Benthic Ecology).

6.2.3.2 Re-mobilisation of contaminated sediments

180. Given the low level of contaminants present in the sediments within the project interconnector search area (see section 3.2), changes in water and sediment quality throughout the study area due to re-suspension of contaminants during construction have been assessed as negligible.

181. MarESA (MarLIN, 2017) shows that, where contaminants levels are within environmental protection standards, marine species and habitats are not sensitive to changes that remain within these standards.

182. All construction activities will be covered by a PEMP as well as emergency plans in the case of an accidental spillage or leak to ensure no release of contaminants as a result of the project. In addition to this, all vessels must adhere to the requirements of the MARPOL Convention Regulations with appropriate preventative and control measures.

6.2.3.2.1 Assessment of effect magnitude and / or impact significance

183. As a result of the absence of existing contamination and mitigation to avoid release of contaminants, there would be **no impact** to the benthic or intertidal ecology.

6.2.3.3 Summary of impacts of sediment disposal on benthic ecology in the project interconnector search area

184. As the conclusion of all relevant impacts on benthic ecology was that they would range from no impact to minor adverse significance it is considered that, should the proposed project interconnector search area disposal site be designated, impacts

would occur to benthic species however these would be no greater than **minor adverse** significance.

6.3 Offshore Cable Corridor

6.3.1 Potential Impacts of Sediment Disposal on Physical Characteristics in the offshore cable corridor

185. A total of four HVDC cables will connect the offshore wind farm to landfall. These cables will be installed in two trenches (two cables per trench), with a maximum total trench length of 250km. In terms of the worst case scenario. The sediment released due to disposal of pre-swept sediment in the offshore cable corridor would equate to up to 600,000m^3. The sediment released at any one time would be subject to the capacity of the dredger(s); however as agreed with Natural England, disposal would be at least 50m from *S.spinulosa* reef identified during pre-construction surveys.

186. Trenching for the offshore export cables would be back filled either naturally or through the use of a trenching tool with no sediment disposal and therefore this is not discussed further in this report, but is assessed in the ES.

6.3.1.1 Potential Impacts of Sediment Disposal on Physical Characteristics in the SAC

187. The southern portion of the Haisborough, Hammond and Winterton SAC is comprised of a series of sand ridges. These sand bank features are a primary reason for the designation of the SAC and the driving mechanisms for the formation and maintenance of these banks includes physical characteristics; tidal currents, waves and sea-level change, whilst sediment transport (supply to/loss from) is also important in enabling growth or decay.

188. The SAC is designated for two Annex I habitats ‘Sand banks slightly covered by sea water all the time’ and ‘Reefs’ formed by *S. spinulosa*. The Conservation Objectives for this SAC are:

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

189. The Information to Support the HRA (document reference 5.3) provides an assessment of the potential effects associated with Norfolk Boreas in relation to these conservation objectives.

6.3.1.2 Changes in Suspended Sediment Concentrations during cable installation within the offshore cable corridor;

190. There are similarities in water depth, sediment types and metocean conditions between the offshore cable corridor for Norfolk Boreas and the East Anglia ONE offshore wind farm. Hence, the earlier modelling studies (discussed in section 6.1.1.1) provide a suitable analogue for the present assessments and the sediment would be dispersed in a similar manner.

191. 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.

192. Following cessation of installation activities, any plume would have been fully dispersed as a result of advection and diffusion. Sediments arisings from the offshore cable corridor would tend to be advected to the north.

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

193. The effects on suspended sediment concentrations due to offshore cable installation (including any sand wave levelling) would have **no impact** upon the offshore cable corridor (including within the HHW SAC) for marine physical processes. This is because the receptors are dominated by processes that are active along the seabed and are not affected by sediment suspended in the water column.

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

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

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

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

6.3.1.3 Changes in Seabed Levels during cable installation within the offshore cable corridor;

197. The increases in suspended sediment concentrations associated with the impact discussed above (section 6.3.1.2) has the potential to result in changes in seabed levels as the suspended sediment deposits on the seabed.

198. Based on a maximum potential disturbance width of 10m (for ploughing) along the 250km length of the export cable within the offshore cable corridor, the area of disturbance would be up to 2.5km^2. Up to 40km of these cable trenches would be within the SAC and this would represent a footprint of 0.8km^2. The maximum volume associated seabed levelling for the export cables would be 600,000m^3 (up to 500,000m^3 of which could be within the SAC), (Table 4.1).

199. Following pre-sweeping, the sediment disturbed due to trenching for the export cables would equate to a maximum of 3,000,000m^3 of sediment. up to 1,200,000m^3 of this disturbed material would be within the HHW SAC, and the remainder from the rest of the offshore cable corridor. Ploughing would create temporary mounds either side of the trench and therefore it is expected that only a small proportion of the 3,000,000m^3 would result in sediment plumes during cable installation. It should be noted that this material would not be dredged from the seabed and disposed of and therefore would not form part of the disposal licence application.

200. The East Anglia ONE plume modelling simulations (ABPmer, 2012b) suggest that sand-sized material (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. Due to the coarser sediment particle sizes observed across the site (predominantly medium-grained sand), a large proportion of the disturbed sediment would behave in this manner.

201. The footprint and thickness of the disposed sediment would be dependent on the method of placement, the volume deposited at any one time, the local water depth and the ambient environmental conditions during disposal. The ABPmer sandwave bed levelling assessment (Appendix 7.1 of the Information to Support the HRA, document reference 5.3) concludes that the spoil would be likely to range from 0.05m to 4.2m. Sandwaves within the indicative spoil zone typically have amplitudes of 3 to 6m and wavelengths of about 100m. Therefore, there is already some variation in seabed depths within the disposal area and depending on the deposition characteristics (i.e. location, thickness and extent) the result would likely be within the range already encountered within the indicative spoil zone.

202. The commitment to deposit the dredged sand within the sandbank system of the SAC enables the sand to become re-established within the local sediment transport system by natural processes and encourages the re-establishment of the bedform features. Appendix 7.1 of the Information to Support the HRA (document reference 5.3) estimates transport rates for sand within the SAC of between 0.01m^3/m/ hr to 3.4m^3/m/ hr, which are also within the range modelled for the wider region of the Southern North Sea (HR Wallingford, 2012).

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

203. The East Anglia ONE plume modelling simulations discussed above and the ABPmer sandwave levelling assessment indicates that the changes in seabed elevation would be temporary and within the existing variation in seabed morphology. This means that, given these low magnitude changes in seabed level arising from sediment disposal the impact on bed level changes is considered to be of **negligible impact** for offshore cable corridor (including within the SAC).

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

204. Under the two-phase approach, the principal difference compared to the single-phase assessment is that described above. Consequently, there would be no material change to the assessment of significance for this impact compared to a single-phase approach.

6.3.1.4 Summary of impacts of sediment disposal on physical characteristics in the offshore cable corridor

205. As the disposal of sediment would be local to dredged area there will be no net gain or loss of sediment from the offshore project area. Therefore, it is considered that there would be no significant impact to the physical characteristics of the section of the offshore cable corridor proposed for designation as a result of installation of the offshore export cable.

6.3.2 Potential Impacts of Sediment Disposal on Water and Sediment Quality in the offshore cable corridor

206. Disposal of sediment within the offshore cable corridor has the potential to change water quality, either through increased sediment concentrations in the water column or impacts associated with the release of sediment bound contaminants.

6.3.2.1 Change in water quality due to re-suspension of sediments

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

208. The magnitude of the impact is therefore anticipated to be low and, combined with low sensitivity of the receptor, the overall significance is predicted to be **minor adverse**.

6.3.2.2 Change in water quality due to re-suspension of contaminants within sediment

209. Disturbance of seabed sediments has the potential to release any sediment-bound contaminants, such as heavy metals and hydrocarbons, into the water column. The data in section 3.2 indicates the low levels of contaminants in the sediment within the offshore cable corridor; only one marginal exceedance in Cefas Level 1 for Arsenic is reported.

210. As a result of the low magnitude of effect, the re-suspension of contaminated sediment from construction activities is considered to be of **negligible** significance.

6.3.2.3 Summary of impacts of sediment disposal on water and sediment quality in the offshore cable corridor

211. As the worst case conclusion of all relevant impacts on the physical characteristics of the offshore cable corridor was **minor adverse** significance, there will be no greater impact on the water and sediment quality within the offshore cable corridor as a result of sediment extraction and subsequent disposal required for the installation of the offshore export cable.

6.3.3 Potential Impacts of Sediment Disposal on Benthic Ecology in the offshore cable corridor

6.3.3.1 Increased suspended sediment concentrations

212. As discussed in previous sections, there are likely to be increases in suspended sediment concentrations in the water column due to activities relating to the export cable installation.

213. Increases in suspended sediment concentrations within the water column has the potential to affect the benthos through blockage to the sensitive filter feeding apparatus of certain species and / or smothering of sessile species upon deposition of the sediment. Changes in turbidity decrease the depth to which natural light can penetrate into the water column and may therefore result in a reduction in primary productivity. Additionally, sediment plumes can create barriers to movement of marine ecological parameters.

6.3.3.1.1 Assessment of effect magnitude and / or impact significance

214. The sensitivity of these receptors to increases in suspended sediments and smothering are shown below in Table 6.7. As some areas of potential *S. spinulosa* reef were found along the offshore cable corridor, there is the potential for these areas to be impacted by increased suspended sediment concentrations and smothering. As *S. spinulosa* rely on suspended solids in order to filter feed and build tubes, they are often found in areas of high levels of turbidity and have been found to maintain a cumulative growth rate a few hundred metres from primary aggregate extraction sites (Davies *et al.,* 2009).

Table 6.7 Sensitivities to increased suspended sediment and smothering by deposited sediment (source: Tillin, 2016; Tillin & Marshall, 2015; Tillin, 2016b)

Receptor	Tolerance	Recoverability	Overall sensitivity
Light smothering – up to 5cm			
Circalittoral coarse sediment	Not available		Not sensitive**
Circalittoral mixed sediment	Not available		
***Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel**	Medium	High	Not Sensitive* - Low
***S. spinulosa* on stable circalittoral mixed sediment**	High	High	Not sensitive
***Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand**	Not available		
Heavy smothering – up to 30cm			
Circalittoral coarse sediment	Not available		Not sensitive**
Circalittoral mixed sediment	Not available		
***Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel**	Medium	Medium	Medium
***S. spinulosa* on stable circalittoral mixed sediment**	None	Medium	Medium
***Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand**	Not available		

Receptor	Tolerance	Recoverability	Overall sensitivity
Increased Suspended Sediment Concentrations			
Circalittoral coarse sediment	Not available		
Circalittoral mixed sediment	Not available		
***Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel**	Medium	High	Low
***S. spinulosa* on stable circalittoral mixed sediment**	High	High	Not sensitive
***Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand**	High	High	Not sensitive*

* based on assessments in Tillin (2014b) which focus on the species which define the biotope

** Based on natural England's advice during relevant representation for Norfolk Vanguard (see Table 10.2 of ES Chapter 10 Benthic Ecology).

215. As shown in Table 6.7, the greatest overall sensitivity of biotopes recorded within the offshore cable corridor to smothering or increased suspended sediment is likely to be medium, with this occurring when between 5cm and 30cm of sediment is deposited on the receptor.

216. In accordance with Table 6.7, a medium sensitivity, and low magnitude of effect for the offshore cable corridor mean that this impact would likely be of **minor adverse** significance. Re-mobilisation of contaminated sediments

217. Given the low level of contaminants present in the sediments within the offshore cable corridor (Table 3.3), changes in water and sediment quality throughout the study area due to re-suspension of contaminants during construction have been assessed as negligible.

218. MarESA (MarLIN, 2017) shows that, where contaminants levels are within environmental protection standards, marine species and habitats are not sensitive to changes that remain within these standards.

219. All construction activities will be covered by a PEMP (as well as emergency plans in the case of an accidental spillage or leak to ensure no release of contaminants as a result of the project. In addition to this, all vessels must adhere to the requirements of the MARPOL Convention Regulations with appropriate preventative and control measures.

6.3.3.1.2 Assessment of effect magnitude and / or impact significance

220. As a result of the absence of existing contamination and mitigation to avoid release of contaminants, there would be **no impact** to the benthic or intertidal ecology.

6.3.3.2 Summary of impacts of sediment disposal on benthic ecology in the offshore cable corridor

221. As the conclusion of all relevant impacts on benthic ecology was that they would range from **no impact** to **minor adverse** significance it is considered that, should the proposed disposal site be designated within the offshore cable corridor, impacts would occur to benthic species however these would be no greater than of minor adverse significance.

6.4 Cumulative Impacts

222. Given that only minor impacts are predicted within the Norfolk Boreas site, project interconnector search area, and the section of the offshore cable corridor which is proposed to be designated as a disposal site there is not predicted to be any cumulative effects between each site's associated disposal activities.

223. Consideration is given in ES Chapters 8, 9 and 10 to potential cumulative effects on the seabed (and therefore on the marine physical processes, water and sediment quality and benthic ecology) associated with other plans and projects. Those of relevance to sediment disposal are:

- Installation of foundation structures for Norfolk Boreas and installation of the East Anglia THREE and Norfolk Vanguard projects;
- Installation of the offshore export cable for Norfolk Boreas and Norfolk Vanguard; and
- Installation of the offshore export cable for Norfolk Boreas and marine aggregate dredging activities in adjacent areas of the seabed.

6.4.1 Cumulative Impacts on Physical Characteristics as a Result of Adjacent Wind Farms

224. The impacts of the foundation and offshore cable installation activities were identified to be of negligible impact for Norfolk Boreas alone.

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

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

227. As for Norfolk Boreas alone, the majority of suspended sediment arising from each project would fall rapidly to the seabed after the start of construction and therefore the potential cumulative impact would be of negligible magnitude. The receptor sensitivity would also be negligible and therefore it is considered that the cumulative impact of two or three projects constructing in this area at the same time would be **negligible.**

6.4.2 Cumulative Impacts on Physical Characteristics as a Result of Marine Aggregate Dredging

228. In order to assess the potential for cumulative effects between the installation of the offshore cable and marine aggregate dredging activities in adjacent areas of the seabed, reference has been made to the EIA for the East Anglia ONE project. Although the cable corridor location is different, the results in relation to physical processes provide a useful and appropriate analogy for Norfolk Boreas.

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

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

6.4.3 Cumulative Impacts on Marine Water and Sediment Quality as a Result of Adjacent Wind Farms

231. As described above, the short duration of sediment disturbance anticipated during these installation activities means that changes in water quality due to sediment plumes would be temporary and short term.

232. As a result, it is considered that the cumulative impact for two or three projects would not increase the impact significance predicted as a result of construction of Norfolk Boreas alone (i.e. either **minor adverse** or **negligible** impact significance).

6.4.4 Cumulative Impacts on Marine Water and Sediment Quality as a Result of Marine Aggregate Dredging

233. The maximum plume concentrations associated with Norfolk Boreas and Marine Aggregate dredging would be no greater overall (as shown by modelling for the East Anglia ONE EIA) and therefore the cumulative impact magnitude would be low. As Norfolk Boreas is located over 5km from the nearest aggregate extraction site the potential risk of plumes overlapping would be less than assessed for East Anglia ONE.

234. As a result, it is considered that the potential cumulative impacts would also be of low magnitude. With the sensitivity of the water being low, an overall impact significance of **minor adverse** is predicted.

6.4.5 Cumulative Impacts on Benthic Ecology as a Result of Suspended Sediment Concentrations and Associated Sediment Deposition in the Norfolk Boreas Site

235. As there is no physical overlap with the Norfolk Boreas site and other projects, the potential cumulative impacts on benthic ecology are limited to those associated with increased suspended sediment from the adjacent Norfolk Vanguard and East Anglia THREE projects.

236. There is potential for the construction phase of Norfolk Boreas to overlap with Norfolk Vanguard and East Anglia THREE. The majority of suspended sediment from Norfolk Boreas is expected to settle to the seabed within tens of metres of the source location and the small proportion of fine sand and mud would settle to the seabed within approximately 1km forming a very thin deposit (millimetres) with the sediment travelling with the tidal flow. The East Anglia THREE EIA (EATL, 2015) and Norfolk Vanguard EIA (Norfolk Vanguard Limited, 2018) provide similar estimates and it is assumed that the Norfolk Boreas impacts will be comparable. Cumulative impacts would only occur if sediment is deposited at locations on the edge of each wind farm, within range of potential overlap of sediment deposition. This will be few in number and as the cumulative impact of deposition would only be millimetres in

sediment depth the cumulative impact would be **negligible** at these edge locations, with **no impact** for the majority of locations within the Norfolk Boreas site.

6.4.6 Cumulative Impacts on Benthic Ecology as a Result of Marine Aggregate Dredging

237. As discussed above, theoretical bed level changes of up to 2mm are estimated as a result of cumulative impacts from the Norfolk Boreas cable installation and dredging at nearby aggregate sites. The sensitivity of benthic receptors to this level of change would be as described in Section 6.3 and the magnitude of this level of change is negligible and therefore the cumulative impact significance will be **negligible.**

7 SUMMARY

238. As part of the DCO application for the proposed Norfolk Boreas project, Norfolk Boreas Limited is applying to designate the Norfolk Boreas site, project interconnector search area and a section of the offshore cable corridor as disposal sites. This would allow Norfolk Boreas Limited to dispose of material extracted during construction drilling and seabed preparation (dredging) for associated cable and foundation works. The sea bed sediments in each disposal site are predominantly sand.

239. The following alternative disposal options have been considered for the disposal of drilled and dredged material:

- Use of the material for ballast for certain foundation types;
- Use of material for coastal defence; and
- Use of other existing disposal sites.

240. Worst case scenarios for maximum quantities of material which would need to be excavated for foundations and cable pre-sweeping are provided along with maximum quantities of material released should piled foundations be utilised.

241. The results show that the sediment deposited following pre-sweeping would remain of a similar nature to the adjacent ambient sea bed sediments. Consequently, any subsequent transport would occur at the same time and in the same manner as the ambient sea bed sediments.

242. Release of sediment within the Norfolk Boreas site would result in finer grained material associated with the passive plume phase deposited over a wide area with a deposited sediment layer predicted of less than <0.2mm thick. Under the prevailing hydrodynamic conditions, this material would be readily re-mobilised and would therefore quickly be incorporated into the mobile surficial sea bed sediment layer.

243. The footprint and thickness of the sediment deposited in the offshore cable corridor would be dependent on the method of placement, the volume deposited at any one time, the local water depth and the ambient environmental conditions during disposal. The spoil height is likely to be within the range of seabed morphology already encountered within the indicative spoil zone. The deposited sediment would then be incorporated back into the natural sediment transport processes.

244. Sand sized material from drilling would settle out of suspension within 1km of the release location and persist in the water column for no more than tens of minutes. Once this material has settled to the sea bed, it would quickly be incorporated into the natural mobile bed regime.

245. Effects from any one foundation installation are unlikely to persist long enough in the same locality to significantly interact with subsequent operations and so no cumulative effects are expected.

246. No significant changes in water quality as a result of sediment contaminant release are expected due to the low levels of existing contaminants and therefore, no resultant impacts on the benthic fauna are predicted.

247. The marine fauna present within disposal sites are largely tolerant of the increases in sediment suspension and deposition predicted and therefore would not be significantly impacted by the proposed designation of the disposal sites.

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APPENDIX 1 DISPOSAL SITE COORDINATES

Coordinates are all provided in WGS84 Decimal Degrees format

Norfolk Boreas Site	
2.759524	52.87063
2.759586	52.901708
2.75991	53.062782
2.810675	53.141047
3.034321	53.231259
3.035314	53.231658
3.039289	53.233253
3.045347	53.235684
3.05352	53.239183
3.058682	53.24133
3.144725	52.937489
2.97096	52.907509

Coordinates for the section of the SAC section of the offshore cable corridor proposed for designation					
1.963446	52.797691	2.037851	52.747536	2.123208	52.729031
1.966845	52.797343	2.038003	52.747502	2.054031	52.712268
1.970089	52.796726	2.038529	52.747387	2.052723	52.711987
1.976061	52.795137	2.038683	52.747355	2.051374	52.711769
1.980321	52.793554	2.038838	52.747326	2.029068	52.70876
1.985477	52.791031	2.039374	52.747232	2.027872	52.708627
1.988725	52.788879	2.039531	52.747206	2.027512	52.708597
1.99178	52.786272	2.03969	52.747183	2.026302	52.708528
2.031076	52.750945	2.040234	52.747109	2.025086	52.708515
2.031164	52.750869	2.040394	52.747089	2.024723	52.708521
2.03144	52.750635	2.040554	52.747072	2.023659	52.708565
2.031646	52.750454	2.041106	52.747019	2.013824	52.709215
2.031744	52.750375	2.041267	52.747005	2.011373	52.709504
2.032086	52.750108	2.041429	52.746994	2.011014	52.709566
2.032188	52.750031	2.041984	52.746963	2.009828	52.709806
2.032294	52.749956	2.042147	52.746955	2.002126	52.711569
2.032663	52.749702	2.042309	52.74695	2.00002	52.712163
2.032773	52.749628	2.042784	52.746941	1.999727	52.712264
2.032886	52.749558	2.042955	52.74694	1.998766	52.712624
2.033281	52.749318	2.263881	52.747005	1.99191	52.715399
2.033398	52.749249	2.264262	52.74701	1.991645	52.715515
2.033519	52.749183	2.264769	52.747019	1.990165	52.716216
2.033937	52.748959	2.264932	52.747023	1.989912	52.716345
2.034061	52.748895	2.265094	52.747031	1.989052	52.716853
2.034188	52.748833	2.26565	52.747062	1.988165	52.717461
2.03463	52.748626	2.265812	52.747072	1.98255	52.721628
2.03476	52.748566	2.265973	52.747086	1.981932	52.722118
2.034893	52.74851	2.266474	52.747133	1.981418	52.722579
1.752005	52.806559	2.266614	52.747148	1.981271	52.722721
1.954956	52.798101	2.266752	52.747164	1.980804	52.723208
2.035355	52.748319	2.269604	52.747531	1.945329	52.762806
2.035491	52.748265	2.269604	52.747531	1.940906	52.767267
2.03563	52.748214	2.299699	52.751397	1.940577	52.767648

Coordinates for the section of the SAC section of the offshore cable corridor proposed for designation

2.036111	52.748041	2.304132	52.742842	1.936707	52.771549
2.036252	52.747992	2.304565	52.733644	1.925991	52.776955
2.036396	52.747946	2.271965	52.729455	1.910827	52.780976
2.036893	52.747793	2.269445	52.729217	1.889199	52.78282
2.03704	52.747749	2.266712	52.729065	1.881206	52.783192
2.037188	52.747709	2.265061	52.729036	1.763589	52.788064
2.0377	52.747574	2.264295	52.729025		

Coordinates for the section of the offshore cable corridor outside the SAC proposed for designation

2.299699	52.751397	2.737338	52.880646	2.749307	52.896651
2.396411	52.763765	2.737421	52.88109	2.749811	52.896977
2.396416	52.763766	2.737516	52.881533	2.750325	52.897299
2.444106	52.769833	2.737623	52.881975	2.750846	52.897615
2.546802	52.782828	2.737742	52.882416	2.751376	52.897926
2.549213	52.783132	2.737872	52.882855	2.751914	52.898232
2.561787	52.784716	2.738014	52.883294	2.75246	52.898533
2.562717	52.784833	2.738167	52.883731	2.753014	52.898829
2.564853	52.785102	2.738332	52.884166	2.753576	52.899119
2.564854	52.785102	2.738509	52.8846	2.754145	52.899403
2.571457	52.785933	2.738696	52.885032	2.754722	52.899682
2.596612	52.789095	2.738896	52.885462	2.755306	52.899956
2.598917	52.789385	2.739106	52.88589	2.755897	52.900224
2.600009	52.789522	2.739328	52.886316	2.756496	52.900486
2.304565	52.733644	2.739561	52.88674	2.757101	52.900742
2.600009	52.77116	2.739805	52.887162	2.757712	52.900993
2.571671	52.767596	2.74006	52.887581	2.758331	52.901237
2.304132	52.742842	2.740326	52.887998	2.758955	52.901476
2.733339	52.806608	2.740604	52.888412	2.759582	52.901707
2.733556	52.806697	2.740892	52.888823	2.759586	52.901708
2.733998	52.806904	2.741191	52.889231	2.759524	52.87063
2.734418	52.807127	2.741501	52.889637	2.774386	52.873237
2.734814	52.807366	2.741821	52.890039	2.774365	52.864158
2.735185	52.80762	2.742152	52.890439	2.774198	52.792904
2.735528	52.807887	2.742493	52.890835	2.759462	52.791075
2.735844	52.808167	2.742845	52.891228	2.73418	52.787933
2.736129	52.808458	2.743208	52.891617	2.733339	52.787829
2.736384	52.80876	2.74358	52.892003		
2.736607	52.80907	2.743963	52.892385		
2.736798	52.809388	2.744355	52.892763		
2.736955	52.809714	2.744758	52.893138		
2.737078	52.810044	2.74517	52.893508		
2.737167	52.810378	2.745592	52.893875		
2.737221	52.810715	2.746024	52.894237		
2.737231	52.810896	2.746465	52.894595		
2.737231	52.81101	2.746916	52.894949		
2.737234	52.857675	2.747376	52.895299		
2.737261	52.87929	2.747845	52.895644		

Coordinates for the section of the offshore cable corridor outside the SAC proposed for designation					
2.737262	52.880201	2.748324	52.895984		
2.737266	52.880201	2.748811	52.89632		

Coordinates for the section of the SAC section of the offshore cable corridor proposed for designation					
1.963446	52.797691	2.037851	52.747536	2.123208	52.729031
1.966845	52.797343	2.038003	52.747502	2.054031	52.712268
1.970089	52.796726	2.038529	52.747387	2.052723	52.711987
1.976061	52.795137	2.038683	52.747355	2.051374	52.711769
1.980321	52.793554	2.038838	52.747326	2.029068	52.70876
1.985477	52.791031	2.039374	52.747232	2.027872	52.708627
1.988725	52.788879	2.039531	52.747206	2.027512	52.708597
1.99178	52.786272	2.03969	52.747183	2.026302	52.708528
2.031076	52.750945	2.040234	52.747109	2.025086	52.708515
2.031164	52.750869	2.040394	52.747089	2.024723	52.708521
2.03144	52.750635	2.040554	52.747072	2.023659	52.708565
2.031646	52.750454	2.041106	52.747019	2.013824	52.709215
2.031744	52.750375	2.041267	52.747005	2.011373	52.709504
2.032086	52.750108	2.041429	52.746994	2.011014	52.709566
2.032188	52.750031	2.041984	52.746963	2.009828	52.709806
2.032294	52.749956	2.042147	52.746955	2.002126	52.711569
2.032663	52.749702	2.042309	52.74695	2.00002	52.712163
2.032773	52.749628	2.042784	52.746941	1.999727	52.712264
2.032886	52.749558	2.042955	52.74694	1.998766	52.712624
2.033281	52.749318	2.263881	52.747005	1.99191	52.715399
2.033398	52.749249	2.264262	52.74701	1.991645	52.715515
2.033519	52.749183	2.264769	52.747019	1.990165	52.716216
2.033937	52.748959	2.264932	52.747023	1.989912	52.716345
2.034061	52.748895	2.265094	52.747031	1.989052	52.716853
2.034188	52.748833	2.26565	52.747062	1.988165	52.717461
2.03463	52.748626	2.265812	52.747072	1.98255	52.721628
2.03476	52.748566	2.265973	52.747086	1.981932	52.722118
2.034893	52.74851	2.266474	52.747133	1.981418	52.722579
1.752005	52.806559	2.266614	52.747148	1.981271	52.722721
1.954956	52.798101	2.266752	52.747164	1.980804	52.723208
2.035355	52.748319	2.269604	52.747531	1.945329	52.762806
2.035491	52.748265	2.269604	52.747531	1.940906	52.767267
2.03563	52.748214	2.299699	52.751397	1.940577	52.767648
2.036111	52.748041	2.304132	52.742842	1.936707	52.771549
2.036252	52.747992	2.304565	52.733644	1.925991	52.776955
2.036396	52.747946	2.271965	52.729455	1.910827	52.780976
2.036893	52.747793	2.269445	52.729217	1.889199	52.78282
2.03704	52.747749	2.266712	52.729065	1.881206	52.783192
2.037188	52.747709	2.265061	52.729036	1.763589	52.788064
2.0377	52.747574	2.264295	52.729025		

Coordinates for the project interconnector search area (area 1 west of shipping route)

2.44373	52.80087	2.582502	52.847729	2.588706	52.790725
2.409224	52.835594	2.583074	52.847283	2.589101	52.790486
2.409151	52.835666	2.583598	52.846816	2.58952	52.790262
2.409091	52.835727	2.584072	52.84633	2.589961	52.790054
2.408807	52.836012	2.584496	52.845827	2.590423	52.789863
2.406031	52.838803	2.584866	52.845309	2.590904	52.789691
2.406031	52.838807	2.585182	52.844778	2.591402	52.789537
2.406031	52.838833	2.585442	52.844236	2.591914	52.789403
2.40604	52.895223	2.585929	52.842478	2.59244	52.789288
2.40604	52.895225	2.585921	52.833931	2.592977	52.789193
2.571103	52.909809	2.585929	52.833039	2.593522	52.789119
2.57107	52.850986	2.586067	52.818589	2.594074	52.789066
2.571073	52.850986	2.58611	52.814025	2.59463	52.789034
2.571997	52.850968	2.586153	52.809462	2.595188	52.789024
2.572925	52.850915	2.586296	52.794405	2.595747	52.789034
2.573846	52.850827	2.586313	52.794078	2.596303	52.789066
2.574756	52.850704	2.586366	52.79374	2.596612	52.789095
2.575652	52.850547	2.586453	52.793406	2.598917	52.789385
2.576529	52.850356	2.586575	52.793075	2.600009	52.789522
2.577385	52.850131	2.586731	52.79275	2.600009	52.77116
2.578216	52.849875	2.58692	52.792431	2.571671	52.767596
2.579018	52.849588	2.587142	52.792121	2.571457	52.785933
2.57979	52.849271	2.587395	52.791819	2.57149	52.790416
2.580527	52.848925	2.58768	52.791527	2.571058	52.827454
2.581226	52.848551	2.587994	52.791247	2.557873	52.813187
2.581885	52.848152	2.588336	52.790979		

Coordinates for the project interconnector search area (area 2 east of shipping route)

2.733339	52.806608	2.738896	52.885462	2.750846	52.897615
2.733556	52.806697	2.739106	52.88589	2.751376	52.897926
2.733998	52.806904	2.739328	52.886316	2.751914	52.898232
2.734418	52.807127	2.739561	52.88674	2.75246	52.898533
2.734814	52.807366	2.739805	52.887162	2.753014	52.898829
2.735185	52.80762	2.585645	52.843685	2.753576	52.899119
2.735528	52.807887	2.74006	52.887581	2.754145	52.899403
2.735844	52.808167	2.740326	52.887998	2.754722	52.899682
2.736129	52.808458	2.740604	52.888412	2.755306	52.899956
2.736384	52.80876	2.740892	52.888823	2.755897	52.900224
2.736607	52.80907	2.741191	52.889231	2.756496	52.900486
2.736798	52.809388	2.741501	52.889637	2.757101	52.900742
2.736955	52.809714	2.741821	52.890039	2.757712	52.900993
2.737078	52.810044	2.742152	52.890439	2.758331	52.901237
2.737167	52.810378	2.742493	52.890835	2.758955	52.901476
2.737221	52.810715	2.742845	52.891228	2.759582	52.901707
2.737231	52.810896	2.743208	52.891617	2.759586	52.901708
2.737231	52.81101	2.74358	52.892003	2.759524	52.87063
2.737234	52.857675	2.743963	52.892385	2.774386	52.873237
2.737261	52.87929	2.744355	52.892763	2.774365	52.864158

Coordinates for the project interconnector search area (area 2 east of shipping route)					
2.737262	52.880201	2.744758	52.893138	2.86782	52.880416
2.737266	52.880201	2.74517	52.893508	2.865859	52.884551
2.737338	52.880646	2.745592	52.893875	2.863809	52.888874
2.737421	52.88109	2.746024	52.894237	2.97096	52.907509
2.737516	52.881533	2.746465	52.894595	2.973006	52.903173
2.737623	52.881975	2.746916	52.894949	2.974995	52.898955
2.737742	52.882416	2.747376	52.895299	2.94838	52.830584
2.737872	52.882855	2.747845	52.895644	2.853913	52.802762
2.738014	52.883294	2.748324	52.895984	2.774198	52.792904
2.738167	52.883731	2.748811	52.89632	2.759462	52.791075
2.738332	52.884166	2.749307	52.896651	2.73418	52.787933
2.738509	52.8846	2.749811	52.896977	2.733339	52.787829
2.738696	52.885032	2.750325	52.897299		

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