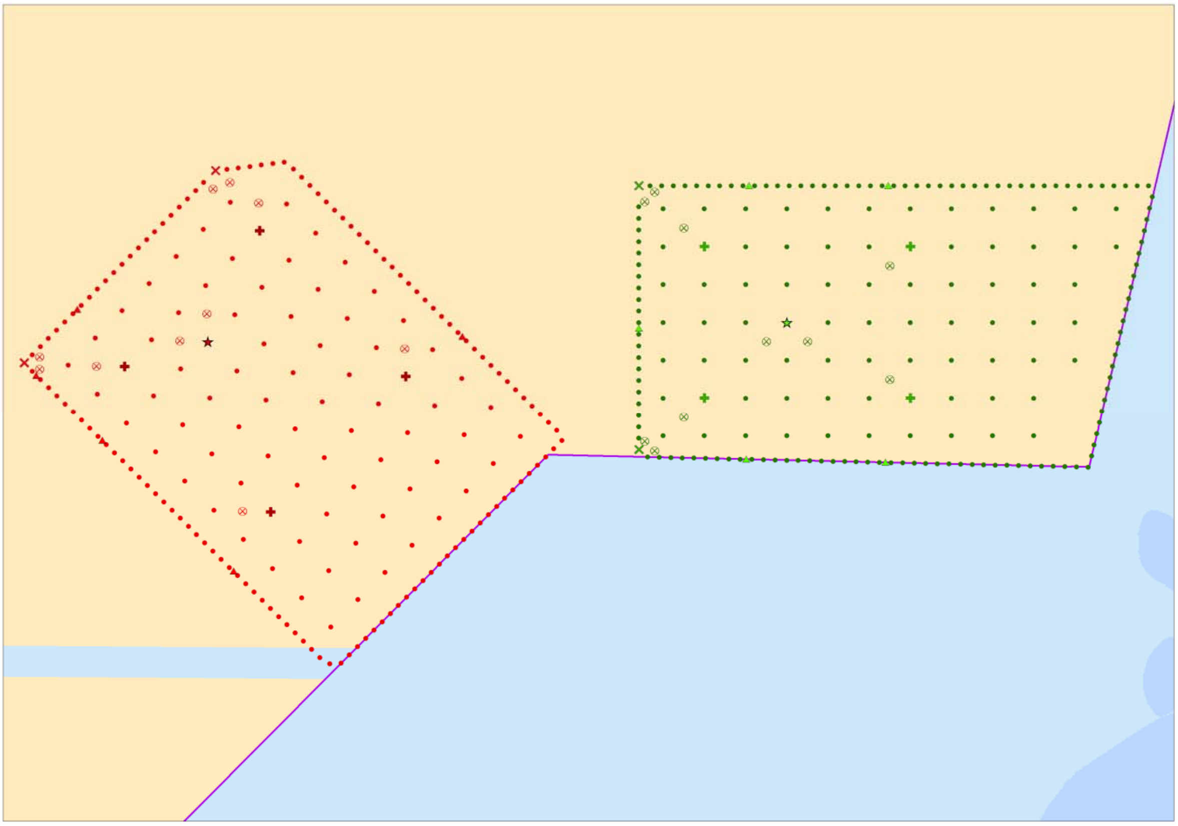
DOGGER BANK
TEESSIDE A & B

March
2014

Environmental Statement Chapter 9 Appendix A Assessment of Effects Technical Report

Application Reference 6.9.1



Dogger Bank Teesside A & B Marine Physical Processes

Assessment of Effects

12 March 2014

Final Report

9X5889

HASKONING UK LTD.
WATER

Rightwell House
Bretton
Peterborough PE3 8DW
United Kingdom
+44 1733 334455 Telephone
Fax
info@peterborough.royalhaskoning.com E-mail
www.royalhaskoning.com Internet

Document title	Dogger Bank Teesside A & B Marine Physical Processes Assessment of Effects
Document short title	Teesside A & B Physical Processes
Status	Final Report
Date	12 March 2014
Project name	
Project number	9X5889
Client	Forewind
Reference	9X5889/R06/303996/PBor

Drafted by	David S Brew, Henrik Rene Jensen, Tanja Cooper, Keming Hu, Hans Fabricius Hansen and Nick Cooper
Checked by	Nick Cooper
Date/initials check	12.03.2014 N. J. Cooper
Approved by	David Brew
Date/initials approval	12.03.2014 David S Brew

EXECUTIVE SUMMARY

This report provides an assessment of the potential effects of the proposed Dogger Bank Teesside A & B development on marine physical processes. In order to assess the potential effects of the wind farm (including all associated infrastructure), the export cable corridor and the landfall site, relative to baseline (existing) conditions, a combination of expert geomorphological assessment, empirical evaluation and detailed numerical modelling has been used. These effects have been assessed using the worst case characteristics of the proposed development as provided by the project and presented, in part, within **Chapter 5** of the Environmental Statement. Considerations of the proposed effects upon the wave, tidal current and sediment transport regimes have been made for the construction, operation and decommissioning phases of the development.

Construction

Over the period of construction there is the likelihood for discrete short-term disturbances of the offshore seabed as the wind turbine foundations are installed and the export and inter-array cables are laid sequentially across the development site. Seabed sediments have the potential to be released into the water column resulting in the formation of sediment plumes. At the landfall site, construction activities may result in short-term changes to the sediment budget, as infrastructure causes temporary blockages to alongshore sediment transport. The decommissioning phase is generally considered to have a similar or lesser effect than the construction phase.

In this assessment, the effect on sediment transport of foundation and cable installation was modelled together over a 30-day installation period that included a one-year storm. A worst case total of 24 foundations were assumed to be installed sequentially at the same time as the laying of a single export cable and 20 inter-array cables. The foundations that were tested were located close to sensitive sandeel habitat. Two types of foundation installation were modelled to determine the worst case for plume dispersion. These were conical GBS foundations, where sediment is released through seabed preparation and scour, and 12m pile foundations, where sediment is released through drill arisings and scour. The cable laying process and sequencing was the same for both types of foundation installation.

The results show that the worst case sediment plume is generated by the installation of the 12m monopole. For this foundation, maximum suspended sediment concentration at any time throughout the 30-day simulation period was predicted to be elevated above natural background levels (2mg/l) by two orders of magnitude (greater than 200mg/l) within the 24-foundation layout and along the in-Zone section of the cable route. Maximum concentrations reduce away from the foundations and the in-Zone section of the cable route until they are at background values, up to 40km north and south. Along the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank

Zone, suspended sediment concentrations are typically less than 100mg/l, reducing to the background of 2mg/l up to 50km to the north and south.

Maximum bed thickness change (sediment deposition from the plume) throughout the 30-day simulation period was predicted to be 10-50mm within the boundary of the layout, decreasing to less than 5mm along the Dogger Bank Teesside A & B export cable corridor, and then reducing to 0.5mm up to 35km away from the corridor. The highest average deposition was predicted to be 1-5mm within the foundation layout and up to 10km away from its centre to the north and in small patches along the Dogger Bank Teesside A & B export cable corridor. Predicted average deposition is less than 0.5mm along most of the Dogger Bank Teesside A & B export cable corridor.

Time series of bed thickness at several discrete points show that within the foundation layout, deposited sediment was predicted to persist at thicknesses greater than 1mm for a continuous period of up to 174 hours (7.25 days) at any time throughout the 30 days. Thicknesses of greater than 10mm could persist for a maximum continuous period of 32 hours (1.33 days). Along the Dogger Bank Teesside A & B export cable corridor, deposition at any one time throughout the 30-day simulation period was predicted to not exceed 1.5mm. The predicted bed thickness at the end of the 30-day simulation was equal to or less than 0.1mm across the whole of the footprint.

At the coastal landfall site, physical processes have the potential to be affected by the temporary construction of infrastructure. The worst case scenario for changes to sediment transport is considered to be construction, over a continuous period of 14 weeks, of two 15m-long cofferdams across the intertidal (beach) zone. These structures offer partial barriers to alongshore sediment transport, which is to the southeast. The results of expert geomorphological assessment showed that potential alongshore sediment transport rates at Redcar to Marske-by-the-Sea are low. Hence, although the coastline to the southeast may be affected by construction works, the magnitude of change is likely to be low and temporary.

Operation

The greatest potential for changes to the wave and tidal current regimes occurs during the operational stage of the wind farm. In this assessment, the effect of operation on these processes was modelled using layouts of foundations across Dogger Bank Teesside A & B. The worst case scenario was determined to be a perimeter of 6MW conical GBS#1 foundations at their minimum 750m spacing with a wider spaced grid of foundations across the rest of each project, including platforms, meteorological masts and vessel moorings. No potential effects are considered for the inter-array cables and most of the length of the export cables because, during operation, they will be buried. However, there is the possibility that in the nearshore subtidal zone the export cables will be on the surface and covered by remedial protection), which could potentially create a partial barrier to sediment transport.

The results show predicted changes to both waves and tidal currents would be relatively small. The maximum change to depth-averaged current velocity is predicted to be +/-0.006m/s with the greatest effect occurring at the project boundaries. The maximum change in current velocity is approximately 2% within 2km wide areas along the western boundaries of the projects.

Predicted maximum changes (worst case) in significant wave height were for one-year waves from the north and northeast. Significant wave heights change by up to +/-0.04m immediately outside the boundaries of the projects. The predicted pattern is a maximum increase in wave height of 1% along the northern boundary of Dogger Bank Teesside A due to up-wave reflection and a maximum decrease in wave height of 1% along the southern boundary of Dogger Bank Teesside B due to down-wave blocking.

The predicted changes in wave heights and tidal current velocities are so small that they would not translate into changes to regional sediment transport pathways and morphology.

Over the period of operation, there is the potential for creation of sediment plumes caused by seabed scour around non-scour protected wind turbine foundations after they have been installed. In this assessment, the effect of scour on sediment transport was modelled using the same gridded layout as that used to model changes to waves and tidal currents. Two scenarios were tested as the worst case for plume dispersion using a minimum construction period of two years. These are a scenario after one year when half the foundations are operational and subject to a 30-day simulation including a one-year storm, and a scenario after two years when all the foundations are operational and subject to a 30-day simulation including a larger 50-year storm.

The results show that the maximum suspended sediment concentration after one year of operation at any time throughout the 30-day simulation period was predicted to be 50-100mg/l above natural background levels (2mg/l). Maximum concentrations reduce to background levels up to approximately 37km from the project boundaries. The highest average suspended sediment concentration was 10-20mg/l reducing to background levels up to approximately 28km from the project boundaries.

After two years, the maximum concentration was predicted to increase to greater than 200mg/l in areas up to 20km long and 6km wide along the boundaries of the projects. Across the whole of both projects, maximum suspended sediment concentrations were greater than 20mg/l reducing to background levels up to approximately 54km from the project boundaries. The highest average concentrations after two years were 10-50mg/l within the projects and up to 19km outside their boundaries. Average concentrations reduce to background levels up to approximately 36km from the project boundaries.

After one year, maximum sediment deposition of 0.1-0.5mm occurs within both projects during the 30-day simulation period, reducing to 0.1mm up to approximately 30km outside the project boundaries. Average deposition was predicted to be mainly less than 0.1mm. Time series of bed thickness show that throughout the footprint the maximum within the foundation layout doesn't exceed 0.7mm. The predicted bed thickness at the end of the 30-day simulation period was effectively zero across much of the depositional area.

After two years, maximum deposition of 0.5-5mm occurs across each project with deposition reducing to less than 0.1mm up to 35km from the boundaries. Average deposition is predicted to be 0.5-5mm between the projects reducing to less than 0.1mm up to approximately 23km outside the project boundaries. Time series of bed thickness show that the thickness within the foundation layout may exceed 1mm continuously for up to 72 hours (3.00 days). The predicted bed thickness at the end of the 30-day simulation period was less than 0.1mm across much of the depositional area.

A comparison of operational scour volumes with naturally occurring release of sediment during a one-year storm shows that predicted scour volumes are five times less than half the volume that would be suspended without the foundations in place. For a 50-year storm, scour volumes are six times less than the volumes that would be suspended without the foundations in place during a storm of the same magnitude.

In the nearshore, remedial protection is anticipated to be up to about 15m wide and stand 1.5m above the surrounding seabed and could potentially affect longshore sediment transport processes in the active transport zone (about 2km wide offshore from mean low water spring along the cable route). Longshore sediment transport rates are low and although some sediment would be trapped on the 'updrift' side of the remedial protection, it is anticipated to be a small volume. Therefore, the magnitude of changes 'downdrift' of the cable corridor due to the remedial protection is likely to be small.

Cumulative Effects

Modelling of the cumulative effects on tidal currents, waves and sediment transport of Dogger Bank Teesside A & B with Dogger Bank Creyke Beck and Dogger Bank Teesside C & D, assuming simultaneous operation, have been completed. The effect on tidal currents is greatest along the project boundaries where the maximum change is about 0.01m/s. Predicted maximum changes of up to 0.004m/s occur across all projects. The maximum change in current velocity is approximately 3% along the western boundaries of the projects.

Predicted maximum changes (worst case) in significant wave height were for one-year waves from the north and northeast. Predicted maximum changes are up to +/-0.06m at the southern/southwestern and northern/northeastern boundaries of the projects. The maximum change in significant wave height is approximately up to 1.5% along the southern and southwestern boundaries of Dogger Bank Creyke Beck A.

The percentage changes in tidal current velocity and wave height are within their natural variation across Dogger Bank and surrounding sea areas and are unlikely to affect the form of recent sediments over and above the natural processes.

Maximum suspended sediment concentrations after one year of operation are predicted to be 50-100mg/l above natural background levels (2mg/l) reducing to background levels up to approximately 48km from the project boundaries. The highest predicted average suspended sediment concentration was 20mg/l reducing to background levels up to approximately 28km from the project boundaries.

After two years, the maximum concentration was predicted to increase to greater than 200mg/l in areas up to 22km long and 7km wide along the boundaries of the projects. Across all projects, suspended sediment concentrations are generally greater than 50mg/l, reducing to the background of 2mg/l up to approximately 55km from the project boundaries. Average suspended sediment concentrations are 50-100mg/l across the boundaries of Dogger Bank Creyke Beck A & B, reducing to the background of 2mg/l up to approximately 39km from the project boundaries.

After one year, maximum sediment deposition of 0.1-0.5mm is predicted to occur across all the projects and up to approximately 23km from the project boundaries. Average change in deposition is predicted to be less than 0.5mm. Time series of bed thickness demonstrates that the maximum thickness of sediment never exceeds 0.7mm across the footprint of deposition. The predicted bed thickness at the end of the 30-day simulation period was effectively zero across much of the depositional area.

After two years, maximum deposition of 5mm occurs across all project areas with deposition reducing to less than 0.1mm up to 43km from the boundaries. Average deposition is predicted to be 0.1-0.5mm reducing to 0.1mm close to the southern boundaries and up to approximately 32km north of the northern boundaries. Time series of bed thickness show that it in places it may exceed 3mm continuously for up to 244 hours (10.17 days). Over most of the deposit footprint the thickness only exceeds 1mm for several days continuously. The predicted bed thickness at the end of the 30-day simulation period was less than 0.1mm across the depositional area.

Cumulative effects of Dogger Bank Teesside A to D and Dogger Bank Creyke Beck with other offshore wind farms, aggregate license areas and potash mining dredge disposal have been considered with respect to sediment plume interaction. It is unlikely that the construction plumes of other wind farms will interact with the Dogger Bank plumes. Plumes from aggregate dredging areas and potash mining dredge disposal would be small and short-lived in comparison to the Dogger Bank plumes and no cumulative effects are anticipated.

CONTENTS

APPENDICES

GLOSSARY

Abbreviation	Full description
2D	Two Dimensional
3D	Three Dimensional
ADCP	Acoustic Doppler Current Profiler
AGDS	Acoustic Ground Discrimination
ATL	Advance the Line
BERR	Department of Business, Enterprise and Regulatory Reform
CIA	Cumulative Impact Assessment
CPT	Cone Penetration Test
cSAC	Candidate Special Area of Conservation
d_{50}	Median Particle Diameter
DHI	Danish Hydraulic Institute
EIA	Environmental Impact Assessment
ES	Environmental Statement
GBS	Gravity Base Structure
GW	Gigawatt
HD	Hydrodynamic
HDD	Horizontal Directional Drilling
HTL	Hold the Line
in-Zone	Inside the Dogger Bank Zone
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
kg/m^3	Kilograms Per Metre Cubed
km	Kilometre
km^2	Kilometre Squared
LAT	Lowest Astronomical Tide

Abbreviation	Full description
m	Metre
m^2	Metre Squared
m^3	Metre Cubed
m/s	Metres Per Second
mg/l	Milligrams Per Litre
mm	Millimetre
mm/s	Millimetres Per Second
MR	Managed Realignment
MT	Mud Transport
MW	Megawatt
N/A	Not available/Not applicable
NAI	No Active Intervention
NECAG	North East Coastal Authority Group
ODN	Ordnance Datum Newlyn
RIGS	Regionally Important Geological and Geomorphological Sites
s	Second
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SW	Spectral Waves
UK	United Kingdom of Great Britain and Northern Ireland
UKCIP	UK Climate Impacts Programme
UKCP09	United Kingdom Climate Projections 2009
ZAP	Zone Appraisal and Planning

1 INTRODUCTION

1.1 Dogger Bank Development

1.1.1 Dogger Bank is a large and isolated positive bathymetric feature located in the central North Sea. The bathymetric high is approximately 300km long and is elongate east-northeast to west-southwest. It occupies approximately 17,600km^2 of United Kingdom (UK), Dutch, German and Danish waters (**Figure 1.1**). In UK waters, Dogger Bank forms a plateau about 30m above the surrounding seabed. The shallowest areas are in less than 20m of water along its southern edge.

1.1.2 Forewind has been awarded development partner status by The Crown Estate for Zone 3: Dogger Bank, as part of the third round of offshore wind licensing arrangements (Round 3). The Dogger Bank Zone outlined for development, occupies an area of 8,639km^2 across the UK part of Dogger Bank (**Figure 1.1**). It is bordered by deeper water to the north, by the shallowest part of Dogger Bank to the south and by the median line between the United Kingdom and European waters to the east.

1.1.3 Forewind has agreed with The Crown Estate a target zone capacity of nine Gigawatt (GW) by 2020. The development at Dogger Bank is anticipated to be taken forward in four tranches (A to D) with each tranche containing up to two projects. The location of Tranche A covering 2,000km^2 of seabed across the southwestern part of the Dogger Bank Zone (**Figure 1.1**) was identified through the Zone Appraisal and Planning (ZAP) process undertaken in 2010 (EMU Ltd, 2010). The first project areas identified were Dogger Bank Creyke Beck A & B; these projects are collectively referred to as Dogger Bank Creyke Beck and have a proposed installed capacity up to 2.4GW (up to 1.2GW in each) (**Figure 1.1**). Following the identification of Tranche A in 2010, Tranche B (approximately 1,520km^2) was identified in 2011 as the second area for development. Forewind's priority is to secure the first six projects, each up to 1.2GW, or a total installed capacity of 7.2GW.

1.1.4 The second application by Forewind will cover two further project areas; Dogger Bank Teesside A & B (**Figure 1.1**). These two projects are also anticipated to have a combined installed capacity of up to 2.4GW. Two further projects which are to be identified within Tranche C of the Dogger Bank Zone, which lies north of Tranche A are also planned. Collectively, Teesside A & B and the two other planned projects are referred to as the Dogger Bank Teesside projects.

1.1.5 Electricity from Dogger Bank Teesside A & B will be transferred to shore by export cables, which will be routed to landfall sites between the coastal towns of Redcar and Marske-by-the-Sea on the Borough of Redcar and Cleveland coast. The proposed works to install the cables will be both offshore and onshore, as the cables run from the wind farms to the coast. A 1,500m wide export cable corridor has been delineated with the flexibility to place the cables anywhere within the corridor). The corridor exits the westernmost tip of Tranche A and is 157km long from its connection with Tranche A to the beach at Redcar and Cleveland (**Figure 1.1**). The location of the landfall corridor is shown in **Figure 1.2**.

1.2 This Assessment

1.2.1 Royal HaskoningDHV and its sub-contractors Danish Hydraulic Institute (DHI) and Richard Swift (Independent Consultant) have been appointed by Forewind to undertake the Marine Physical Processes Assessment as part of the Environmental Impact Assessment (EIA) process for the Dogger Bank Teesside A & B offshore wind farm application. This report provides an assessment of the potential changes to prevailing hydrodynamic and geomorphological conditions arising as a result of the construction, operation and decommissioning of Dogger Bank Teesside A & B, both alone and cumulatively with other plans and projects. The assessment of effects, in turn, informs the assessment of direct, indirect and cumulative impacts on a range of parameters (e.g. benthic ecology) that will be studied as part of the EIA process.

1.2.2 This report presents an understanding of the existing marine physical processes across Dogger Bank Teesside A & B summarised in three conceptual models; Dogger Bank Zone, the Dogger Bank Teesside A & B export cable corridor and the landfall site located between Redcar and Marske-by-the-Sea (**Appendices A, B** and **C**, respectively). This is followed by the definition of realistic worst case scenarios for each element of the development in terms of their potential effects on marine physical processes, which are then numerically modelled and compared to the existing conditions.

1.3 Project Description

1.3.1 The key components of the offshore wind farm development, in the context of potential effects on marine physical processes, are the type and size of foundations and their layout pattern, the installation of the export and inter-array cables and construction works at the landfall site.

1.3.2 A number of wind turbine foundation types are being considered, including monopoles (monopiles and mono-buckets), multilegs (jackets, tripods) and gravity base structures (GBS), including flat and conical base options. A range of different foundation types could be combined to create the up to 2.4GW capacity for Dogger Bank Teesside A & B. Forewind is considering two wind turbine sizes:

- a minimum size six Megawatt (6MW), of which a maximum of 200 wind turbine foundations could be installed in each Dogger Bank Teesside A & B project, to reach the 1.2GW capacity; and
- a maximum size 10MW, with a maximum installation of 120 wind turbine foundations in each project.

1.3.3 The 6MW and 10MW are the minimum and maximum turbine sizes being considered by Forewind so that any turbine between these two sizes will be covered by the assessment of effects.

1.3.4 The maximum number of each size of turbine excludes any platforms (seven per project), meteorological masts (five per project) and moorings (ten per project). Foundation options for the meteorological masts include monopoles, multiple leg structures or GBS. The worst case equivalent foundation is considered to be a 4MW conical GBS.

1.3.5 Minimum wind turbine spacing parameters have been defined by Forewind for Dogger Bank Teesside A & B. The minimum permitted spacing will vary with the size of the wind turbine, and is defined as whichever is the greater of two stated limits (**Table 1.1**). The 750m absolute minimum spacing limit is stated in order to provide clarity for the smallest turbines and avoid the need to consider unrealistically small spacings. The majority of turbines with larger rotors would be limited by the variable 'six rotor diameter' value. It is also noted that the indicative likely turbine spacing range is seven to 15 rotor diameters.

1.3.6 For EIA purposes a set of 'realistic worst case' minimum spacing values have been developed by Forewind in line with these rules (**Table 1.1**). The smallest known turbines in each size category were identified, and their minimum spacing was calculated based on six times their rotor diameter, then rounded down to the nearest 50m. For the 6MW and 10MW turbines, this methodology is considered by Forewind to provide robust and highly conservative results, since the turbines have been assessed as being 'outliers'; with unusually small rotors for their capacity.

Table 1.1. Minimum spacings of foundations for 6MW and 10MW wind turbines.

Wind Turbine Size	Minimum Turbine Spacing	
	Absolute Minimum Centre to Centre	Realistic Worst Case for EIA
6MW	750m (six rotor diameters if greater than 750m)	750m (based on a 126m diameter 6MW turbine)
10MW		1,080m (based on a 180m diameter 10MW turbine)

1.3.7 Forewind has indicated that the Dogger Bank Teesside A & B export and inter-array cables could be buried by one or more different techniques, based on industry practice. The listed techniques include jetting, ploughing, trenching, cutting, mass flow excavation and pre-sweeping (dredging). If there is a need to lay cables on the seabed, they would be protected by a variety of methods, including, but not limited to, rock armour, concrete mattressing, piping, half piping and cable clipping.

1.3.8 The main aspect of the landfall, in the context of potential effects on physical processes, is the method that will be used to construct the connection between the offshore export cables and the onshore cable. A variety of methods could be adopted that are likely to involve one or more cofferdams, open trenching and the use of horizontal directional drilling (HDD). A cofferdam is a temporary enclosure located across the intertidal or subtidal zone to create a dry working area in which construction can proceed. HDD will provide passage for the cables from the coastal zone, under the beach and up behind the cliffs to connect to the onshore portion of the cable. Beach trenching may be required as an exit from the cofferdams.

1.4 Data Collection

Bathymetry Data

1.4.1 The two key datasets collected by Forewind for input into the numerical models are bathymetry and metocean. These are described in detail in **Appendix A** and summarised here.

1.4.2 Gardline (2011a) collected bathymetric data across the Dogger Bank Zone to provide a broad characterisation of the potential development area. This survey was carried out between May 2010 and August 2010 and deployed single and multibeam echo sounder covering about 15% of the Dogger Bank Zone's surface. GEMS (2011) carried out a bathymetric survey of Tranche A between July 2010 and December 2010 to support development of Dogger Bank Creyke Beck within this area. Gardline (2012a) carried out a bathymetric survey of Tranche B between June 2011 and October 2011, and between March 2012 and May 2012. These surveys deployed single and multibeam echosounders and side scan sonar achieving 100% coverage of bathymetry.

Metocean Data

1.4.3 Currently, there are three locations where Forewind has deployed instruments to collect time series metocean data; the northern limit of the Dogger Bank Zone, inside Tranche A and inside Tranche B (**Figure 1.3**). At all these locations, wave and tidal current data has been collected using waveriders and Acoustic Doppler Current Profilers (ADCPs) and is listed in **Table 1.2**.

Table 1.2. Metocean data available from the deployments in the Dogger Bank Zone.

Location (and type)	Coordinates (and water depth)	Currents		Waves	
		Start	End	Start	End
Tranche A Waverider	54° 51.72', 01° 59.83' (22m)	-	-	23/09/2010	31/03/2013
Tranche A ADCP	54° 51.61', 01° 59.64' (22m)	29/02/2012	31/03/2013	-	-
Tranche B Waverider	55° 05.90', 02° 42.04' (26m)	-	-	29/02/2012	31/03/2013
Tranche B ADCP	55° 05.90', 02° 42.04' (26m)	29/02/2012	31/03/2013	-	-
Northern Waverider	55° 29.54', 02° 09.71' (45m)	-	-	06/11/2011	31/03/2013
Northern ADCP (1)	55° 29.54', 02° 09.71' (52m)	07/11/2010	16/06/2012		
Northern ADCP (2)	55° 29.46', 02° 09.58' (52m)	09/05/2012	16/06/2012		

1.5 Modelling Techniques

1.5.1 The marine physical processes effects are predicted by comparing the existing environmental conditions with the conditions created by the construction, operation and decommissioning of the Dogger Bank Teesside A & B development. Several numerical modelling tools and conceptual techniques have been used to support the assessment of existing conditions and the potential effects of the proposed wind farm and cables on marine physical processes.

Tidal Current (Hydrodynamic) Modelling

1.5.2 The hydrodynamic regime is defined as the behaviour of bulk water movements driven by the action of tides. In order to investigate tidal current flows across the central North Sea and provide a baseline for prediction of changes due to the development, a hydrodynamic model was run.

1.5.3 Tidal current simulations were carried out using DHI's fully calibrated and developed regional MIKE3-FM hydrodynamic (HD) model, which covers the entire North Sea and is forced by tide, atmospheric pressure and wind stresses. Details of the calibration and validation are provided in **Appendix D**. It is a flexible grid model with triangular and quadrilateral cells. The size of the computational cell varies over the model domain, and the model has been refined in and around the Dogger Bank Zone to provide a detailed representation of the flow across Dogger Bank Teesside A & B.

1.5.4 Open boundary conditions to the model consist of water levels and currents obtained from DHI's 3D North Sea Model (covering the seas around the UK and in the North Sea), which in turn uses open boundary conditions from DHI's larger 2D North Atlantic model.

Wave Modelling

1.5.5 The existing wave regime is defined as the combination of swell waves moving into and propagating through the area, and more locally generated wind waves. In order to investigate waves and provide a baseline for prediction of changes due to the development, a wave model was run.

1.5.6 Wave conditions were simulated using the spectral model MIKE21-SW (Spectral Waves), which describes the wave conditions by the directional frequency spectrum. The model includes effects like wave generation due to wind, energy dissipation due to bed friction, white-capping and depth-induced wave breaking, depth and current refraction, reflection and diffraction. The model uses a flexible computational mesh, so a fine mesh can be applied to the areas where the locations of the foundations are proposed.

1.5.7 The wave model has been successfully calibrated against the three largest events that were recorded by the two Forewind waveriders, one deployed in Tranche A and one in the north of the Dogger bank Zone (**Figure 1.3**) (Gardline, 2011b). The data used in the models was captured up to the end of October 2011. Any additional data collected since October 2011 would not substantively change the conclusions reached based upon the wave sample used in the models. The use of wave data up to October 2011 duplicates the method adopted by Forewind (2013) in the Dogger Bank Creyke Beck Environmental Statement to assess effects of Dogger Bank Creyke Beck. Details of the calibration and validation are provided in **Appendix D**.

Dispersion Modelling

1.5.8 The simulation of the release and spreading of fine sediments (mud to fine sand) as a result of foundation and cable installation activities and operation of the wind farm have been modelled using the 3D model MIKE3-FM Mud Transport (MT). MIKE3-FM MT is integrated with MIKE3-FM HD, which has been used to predict tidal current changes, and takes into account:

- the actual release of sediments as a function of time, location and sediment characteristics;
- advection and dispersion of the suspended sediment in the water column as a function of the 3D flow field predicted by MIKE3-FM HD;

- settling and deposition of the dispersed sediment; and
- re-suspension of the deposited sediment, predominantly by bed shear stresses from surface waves.

Conceptual Modelling

1.5.9 Expert geomorphological assessment, using the Dogger Bank Teesside A & B landfall conceptual model (**Appendix C**) as a basis, has been used to assess the effects of the landfall works on existing physical processes and future evolution of the coastline. As long as due regard is taken of data origins and accuracy, predictions based on extrapolation of historical trends provide a reliable estimate of the most probable evolution of the coastline during construction and operation of landfall infrastructure.

1.5.10 Expert geomorphological assessment has also been used to assess the fate of the coarser sand that is not suspended during the foundation installation activities.

2 REALISTIC WORST CASE CHARACTERISTICS

2.1 Introduction

2.1.1 In accordance with the requirements of the Rochdale Envelope approach to EIA (Planning Inspectorate, 2012), the worst realistic case characteristics of the proposed development in terms of its effects on marine physical processes are adopted. The worst case characteristics that have been assessed for the development during its construction, operation and decommissioning phases are described in this section.

2.2 Worst Case Foundation Type for Effects on Waves and Tidal Currents

2.2.1 Five different foundation types are being considered by Forewind for Dogger Bank Teesside A & B. These include:

- monopoles;
- multi-legs (jackets);
- multi-legs (tripods);
- flat base GBS; and
- conical GBS.

2.2.2 In its assessment of effects for Dogger Bank Creyke Beck, Forewind (2013) (Environmental Statement) showed that conical GBS represent the worst case foundations, in terms of physical blockage to waves and tidal currents. Hence, this type of foundation has been incorporated in the numerical modelling of operational effects on these physical processes elements for Dogger Bank Teesside A & B. Should other foundation types ultimately be selected following the design optimisation of the development, then the effects on waves and tidal currents will be less than those presented for the worst case conical GBS.

2.2.3 Further, in order to inform the Dogger Bank Creyke Beck assessment, Forewind (2013) described six different types of conical GBS foundation in order to quantify the variable geometry options available for a gravity base of broadly conical type. These foundation designs were provided by a range of potential suppliers from the market. In order to define the overall worst case conical GBS foundation, encompassing the variability in this foundation type, with respect to waves and tidal currents, a series of tests were run to quantify the 'blocking effect' of each type (Forewind, 2013). The results showed that for 10MW wind turbines designed for a water depth of 35m (the default design depth provided), the worst case foundation option for 'blocking' of both waves and tidal currents was GBS$^{\#}$1 (with a 55m diameter base plate). The characteristics of this foundation have been taken forward into the numerical modelling for Dogger Bank Teesside A & B.

2.2.4 This means that all foundations with a lesser 'blocking' effect (including all of the other conical GBS geometry options and other foundation types, including monopoles and multi-legs) will have a lower overall effect than GBS#1 and, as such, are considered to be covered within the assessment envelope.

2.3 Quantifying the Wave Blocking Effect of 6MW and 10MW GBS#1 Foundations

2.3.1 The effect of the 6MW and 10MW conical GBS#1 foundations on waves was quantified using the WAMIT model. This is a radiation/diffraction panel program developed for linear analyses of the interaction of surface waves with marine and offshore structures. It is widely recognised to be an industry standard for the analysis of floating and fixed structures and was developed at the Department of Ocean Engineering at Massachusetts Institute of Technology.

2.3.2 The WAMIT computations have been carried out where the geometry of the conical GBS foundation is represented by small quadrilateral panels and the velocity potential is assumed constant on each panel. An example of the representation of a foundation from the sea surface to the seabed is shown in **Figure 2.1**. The velocity potentials on each panel were evaluated by WAMIT.

2.3.3 The WAMIT computations were carried out using wave periods between two and 25 seconds in steps of one second on GBS#1 geometries in 35m of water. The output from WAMIT is a set of wave reflection factors as a function of wave period (**Figure 2.2** and **Table 2.1**).

Table 2.1. Wave reflection factors of the 6MW and 10MW conical GBS#1 foundations in 35m of water.

Wave Period (s)	GBS#1	
	6MW	10MW
2.0	5.7	5.8
3.0	5.3	5.7
4.0	6.8	7.2
5.0	6.6	8.0
6.0	4.0	5.4
7.0	2.6	3.6
8.0	1.8	2.5
9.0	1.6	2.0
10.0	1.5	1.8
11.0	1.4	1.7
12.0	1.2	1.4
13.0	1.0	1.2
14.0	0.9	1.1
15.0	0.8	1.1
16.0	0.6	0.8
17.0	0.6	0.8
18.0	0.5	0.6
19.0	0.5	0.6
20.0	0.4	0.5
21.0	0.3	0.4
22.0	0.3	0.4
23.0	0.3	0.4
24.0	0.2	0.3
25.0	0.1	0.2

2.3.4 The total wave reflection of a foundation depends on the distribution of wave energy over different wave periods (the wave energy frequency spectrum). Short waves are generally unaffected by the deeper portions of the foundation, while longer waves disturb the entire water column. In order to quantify the resulting reflection, the wave period-dependent reflection factors are integrated with the average wave spectrum (**Figure 2.2**).

2.3.5 The average spectrum has been obtained by averaging the measured spectra collected by the Forewind northern waverider (**Figure 1.3**) between 6th November 2010 and 10th August 2011. A total of 13,117 half-hourly measurements have been obtained. Although the measurements do not cover an entire year and may be affected by some seasonality, the average spectrum is fit for purpose to define the relative distribution over the different wave periods, rather than the exact magnitude of wave energy at a given wave period.

2.3.6 Integration of the reflection factors with the average wave spectrum provides a weighted average equivalent width of the foundation. The integrated wave reflection factors of the 6MW and 10MW conical GBS$^{\#}$1 foundations in 35m of water are 2.09 and 2.66, respectively. These values do not have a physical interpretation but are merely representative values of the wave period-dependent equivalent widths.

2.3.7 To use the 6MW and 10MW conical GBS$^{\#}$1 foundation types as input to the hydrodynamic and wave models required further analysis. This is because the tidal flow reductions and wave reflection factors were calculated using conical GBS$^{\#}$1 geometries in 35m of water (the default design depth provided). Across the Dogger Bank Teesside A & B project areas, the bathymetry varies from 22.0m to 34.0m (Dogger Bank Teesside A) and 23.25m to 37.0m (Dogger Bank Teesside B). Hence, the geometries of the majority of foundations are scaled down in size for water depths less than 35m, with a few scaled up in size for water depths greater than 35m.

2.3.8 A set of scaling rules were developed by Forewind for calculating a conservative geometry for the conical GBS$^{\#}$1 foundations in varying water depths relative to the foundation geometry in 35m of water:

- the conical GBS$^{\#}$1 in 35m of water (the default design depth provided) is the ‘starting point’ for scaling and all scaled dimensions are relative to that foundation geometry.
- the four aspects of the conical GBS$^{\#}$1 which change with water depth are the cone height (the distance between the top and bottom of the cone), the base plate diameter, the cone bottom diameter and the scour protection diameter (if any).
- all other dimensions stay constant in different water depths; the top shaft diameter, top shaft length below the water surface, scour protection height and the base slab height are all fixed.
- the geometry changes in different water depths as follows:
  - the cone height changes to track the changes in water depth. For example, if water depth shallows by 15m, then the cone shortens by 15m.
  - the base plate diameter changes by a factor of 1.1 with every 15m change in water depth. For example, reducing water depth from 35m to 20m means the base diameter will decrease by a factor of 1.1; an increase in water depth from

35m to 50m means the base diameter will increase by a factor of 1.1;

- the horizontal distance between the outside edge of the cone bottom and the outside edge of the baseplate is fixed, as is the horizontal distance between the outside edge of the scour protection and the outside edge of the baseplate.

2.3.9 Using these rules, the geometries of the 6MW and 10MW conical GBS#1 foundations in water depths of 20m, 27.5m, 35m, 42.5m and 50m (**Figures 2.3** and **2.4**) were tested using WAMIT to determine wave reflection factors as a function of wave period for each water depth (**Figures 2.5** and **2.6** and **Tables 2.2** and **2.3**).

Table 2.2. Wave reflection factors of the 6MW and 10MW conical GBS#1 foundations in five different water depths.

Wave Period (s)	Water Depth (m) and GBS#1 Foundation Size									
	20.0		27.5		35.0		42.5		50.0	
	6MW	10MW	6MW	10MW	6MW	10MW	6MW	10MW	6MW	10MW
2.0	5.7	5.8	5.7	5.8	5.7	5.8	5.7	5.8	5.7	5.8
3.0	5.3	5.8	5.3	5.7	5.3	5.7	5.3	5.7	5.3	5.7
4.0	7.0	7.4	6.9	7.3	6.8	7.2	6.8	7.1	6.7	7.1
5.0	7.0	8.4	6.8	8.2	6.6	8.0	6.4	7.8	6.3	7.7
6.0	5.5	7.0	4.4	5.9	4.0	5.4	3.8	5.1	3.7	4.9
7.0	4.0	5.8	3.0	4.2	2.6	3.6	2.3	3.3	2.2	3.0
8.0	2.9	4.1	2.4	3.3	1.8	2.5	1.5	2.1	1.3	1.8
9.0	2.6	3.2	2.0	2.5	1.6	2.0	1.2	1.6	1.0	1.3
10.0	2.2	2.5	1.9	2.3	1.5	1.8	1.2	1.4	0.9	1.1
11.0	2.0	2.2	1.7	2.1	1.4	1.7	1.1	1.3	0.9	0.9
12.0	1.9	2.2	1.4	1.7	1.2	1.4	1.0	1.2	0.9	0.9
13.0	1.7	2.0	1.2	1.5	1.0	1.2	0.9	1.1	0.8	0.7
14.0	1.5	1.9	1.1	1.3	0.9	1.1	0.8	0.9	0.7	0.7
15.0	1.4	1.7	1.0	1.3	0.8	1.1	0.6	0.7	0.6	0.6
16.0	1.1	1.4	0.9	1.1	0.6	0.8	0.6	0.7	0.5	0.4
17.0	1.0	1.3	0.7	0.9	0.6	0.8	0.5	0.5	0.5	0.4
18.0	0.9	1.2	0.7	0.9	0.5	0.6	0.5	0.5	0.4	0.2
19.0	0.8	1.1	0.5	0.7	0.5	0.6	0.3	0.3	0.4	0.2
20.0	0.7	0.9	0.5	0.6	0.4	0.5	0.3	0.4	0.4	0.2
21.0	0.7	1.0	0.5	0.7	0.3	0.4	0.4	0.4	0.2	0.1
22.0	0.5	0.7	0.4	0.5	0.3	0.4	0.2	0.2	0.2	0.0
23.0	0.5	0.7	0.3	0.4	0.3	0.4	0.2	0.1	0.2	0.1
24.0	0.5	0.7	0.3	0.4	0.2	0.3	0.2	0.2	0.3	0.1
25.0	0.4	0.6	0.3	0.5	0.1	0.2	0.2	0.2	0.2	0.0

Table 2.3. Integrated wave reflection factors of the 6MW and 10MW conical GBS#1 foundations in five different water depths.

Water Depth (m)	Integrated Reflection Factor	
	6MW	10MW
20	2.97	3.78
27.5	2.47	3.14
35	2.09	2.66
42.5	1.85	2.35
50	1.68	2.09

2.3.10 The results show that, for both foundation sizes, the worst case wave blocking effect occurs in the shallowest water (20m). The shallowest waters in Dogger Bank Teesside A & B are 22.0m and 23.25m, respectively. For each project, integrated reflection factors relating to each of these 'minimum developable depths' (calculated using interpolation of the factors in **Table 2.3**) are applied to each foundation. In this way, the worst case blocking effect is applied at each location regardless of the actual water depth and used as input to the wave model runs for 6MW and 10MW layouts.

2.4 Worst Case Operational Foundation Layout for Effects on Waves and Tidal Currents

2.4.1 The two projects comprising Dogger Bank Teesside A & B are located in Tranche B (Dogger Bank Teesside A) and overlapping the Tranche A and Tranche B boundary (Dogger Bank Teesside B) (**Figure 1.1**). The assessment of effects on waves and tidal currents is based on the use of a precautionary worst case scenario that assumes the whole of each project area is filled with foundations. Within the limits of Dogger Bank Teesside A & B, the maximum number of 6MW conical GBS foundations in each project would be 200, whereas 120 foundations of 10MW size could fill each project. At this stage, the Rochdale Envelope for the layout of each project is flexible and any one of a number could ultimately be used. A range of layout patterns are being considered by Forewind, including:

- regular grids extending over most or all of the project areas with or without a smaller spaced perimeter of foundations;
- lines of foundations, either straight or curved in single or multiple rows; and
- discrete blocks of foundations with several variations possible including regular grids or curved grids.

2.4.2 For the purpose of predicting effects on waves and tidal currents, the worst case scenario is considered to be a perimeter of foundations at their minimum spacing with a wider spaced grid of foundations across the bulk of each project (**Figures 2.7** and **2.8**). This provides the layout with the maximum potential for interaction of wave and tidal current processes relative to an equally spaced grid throughout each project. Hence, this layout would produce the worst case effect irrespective of any other complex layout options that are possible.

2.4.3 Two potential worst case gridded layouts for Dogger Bank Teesside A & B have been assessed. The first is a grid composed entirely of 6MW conical GBS#1 foundations; this represents the smallest foundation type with a relatively narrow spacing (**Figure 2.7**). The second is a grid composed entirely of 10MW conical GBS#1 foundations; this represents the largest foundation type with a relatively wide spacing (**Figure 2.8**).

2.4.4 In addition to the turbine foundations, each project layout also includes other structures; seven platforms (accommodation, collector and converter), five meteorological masts and ten moorings. For the meteorological masts and moorings, the worst case equivalent foundation is considered to be a 4MW conical GBS, which has been applied at each location where they are present (**Table 2.4**). This approach is considered to be the worst case because it over-estimates the effect of the meteorological mast foundations and significantly over-estimates the effect of the moorings.

Table 2.4. Overview of infrastructure elements (number per Dogger Bank Teesside A & B project) and their equivalent GBS foundation size.

Structure	10MW layout		6MW layout	
	Equivalent conical GBS (MW)	Number	Equivalent conical GBS (MW)	Number
Foundation	10	120	6	200
Accommodation	10	2	10	2
Collector	10	4	10	4
Convertor	10	1	10	1
Meteorological Mast	4	5	4	5
Mooring	4	10	4	10

2.4.5 For platform structures, the worst case equivalent foundation is considered to be a 10MW conical GBS (**Table 2.4**). This is based on a comparison of the platform structures with the 10MW conical GBS foundations, which shows that the foundations have a greater 'blockage area'. However, there is the potential for the platform foundations to be conical GBS with a baseplate diameter of 75m. This is greater than the 10MW conical GBS foundation (which has a 55m diameter baseplate). Because of this possibility, the 10MW conical GBS were used for the platforms, but one or more moorings have been located close to the platforms in each project (**Figures 2.7 and 2.8**). Through this approach, any slight under-estimate in the effect of the platform foundations (if a 75m-diameter baseplate was to be selected) would be offset by the over-estimate in effect of the moorings.

2.4.6 The overall location of these infrastructure elements has not been decided by Forewind, so for the worst case scenario they have been placed conservatively with a bias within the west half of Dogger Bank Teesside A and the northwest half of Dogger Bank Teesside B (closest to the most sensitive habitat, see Section 2.6) (**Figures 2.7 and 2.8**).

2.5 Worst Case Foundation Type for Scour Volume

2.5.1 Scour refers to the development of depressions in the seabed around the base of the foundations. It is the result of net sediment removal over time, due to the interaction between the foundation and the waves and tidal current flows. These interactions result in a local acceleration in mean flow velocity and locally elevated levels of turbulence that enhance sediment transport potential. The dimensions of a scour depression and its rate of development depend on the following characteristics:

- the dimensions, shape and orientation of the foundation;
- the depth, magnitude, orientation and variation in waves and/or tidal current flows; and
- the characteristics of the seabed sediment.

2.5.2 Based on existing literature and knowledge, an estimate of equilibrium scour volume for sand can be derived empirically for each of the different foundation types as a basis for comparison to establish which one would be the worst case. In its assessment of foundation scour for Dogger Bank Creyke Beck, Forewind (2013) (Environmental Statement) showed that 10MW conical GBS$^{\#}$1 foundations constitute the worst case for release of scoured sediment for a design in 35m of water. Forewind (2013) calculated the scour volume for the combined action of waves and tidal currents during a one-year storm event. The scour volumes conservatively assume maximum equilibrium scour depths created through non-cohesive sandy sediments.

2.6 Worst Case Installation Process for Foundations and Cables for Effects on Sediment Transport

2.6.1 Increases in suspended sediment concentration may result from disturbance arising from construction activities. In order to define the realistic worst case scenario for foundation installation and cable laying a conservative approach was adopted. In this approach, 24 conical GBS or monopole foundations, a set of inter-array cables connecting them and one export cable were all installed together within a 30-day period. It is considered that phasing these activities over this time period provided a conservative representation of the possible construction process.

Foundation Installation Process

2.6.2 The greatest effect on sediment transport during the construction phase of the development will depend on the installation method used; different installation methods are required for different foundation types. Monopoles and multi-legs are likely to be driven, drilled or drilled-driven into the seabed. Drilling has the potential to disturb seabed and sub-seabed sediments, which are raised to the sea surface from where they may be dispersed into the water column. For GBS foundations, an area of seabed may need to be ploughed or dredged in order to provide a level surface upon which they are installed. The greatest effect in this regard is associated with the GBS foundation which has the largest footprint and, hence, volumes of seabed disturbance. Both conical GBS foundations and drilled foundations have been modelled to determine the worst case effect on sediment dispersion and deposition from the created plume.

2.6.3 Seabed preparation is potentially required for many conical GBS foundation types in order to provide them with a stable surface on which to sit. Forewind has specified a worst case seabed preparation volume of 3,675m^3. This volume is for a 10MW conical GBS$^{\#}$1 foundation, which has the largest 55m base plate diameter and is therefore assumed to be the worst case foundation for seabed preparation. This estimate of seabed preparation volume is considered conservative as it does not account for slope at the edges of the excavation (due to the shallowness of the layer) and multiplies seabed area (which is the maximum area) by height.

2.6.4 It is assumed that all sediment arising from seabed preparation is side cast close to the foundation and is available to be dispersed by waves and tidal currents. This is a highly conservative assumption and would generate the total sediment from all anticipated elements of seabed preparation, particularly shallow excavation. It is also assumed that there is no sediment released during any ballasting operations at the sea surface and hence the numerical model only incorporates sediment released at the seabed (preparation and scour).

2.6.5 Apart from the GBS foundations, no seabed preparation is necessary for any other foundation type. Monopoles and multilegs using piled footings may require drilling to complete pile installation. Forewind has specified that two different types of pile may be used in the construction process; concrete and steel. Concrete piles would be drilled in 100% of cases, whereas steel piles would be drilled in only 10% of cases.

2.6.6 According to Forewind, the worst case drill arisings volume for a concrete pile would be 6,220m^3. This volume is for a drill diameter of 12m penetrating to 55m into the seabed upon which will sit a 12m diameter monopole foundation capable of supporting a 10MW wind turbine in the water column. For steel piles, a drill diameter of 8m would be used for both 11m and 12m diameter monopole foundations (capable of supporting 6MW and 10MW wind turbines, respectively), with drill arisings of 2,513m^3 and 2,765m^3 per pile, respectively. Hence, the worst case pile for release of drill arisings during installation is the 12m diameter concrete pile. The depth of drill penetration (55m below seabed) is above the level of the top of the chalk and so drill arisings only contain sediment from Quaternary formations (**Appendix A**).

2.6.7 Various drilling methods are possible, but drills are typically lifted by crane into a part-installed pile and ride inside the pile during drilling. Water is continuously pumped into the drill area and any drill arisings generated are flushed out and allowed to disperse naturally at the sea surface.

Location and Sequencing of Foundations

2.6.8 In order to determine the 'worst case location' for the 24 foundations to be modelled, the most sensitive seabed habitats to physical disturbance were identified. According to Envision Mapping (2012), Dogger Bank Teesside A & B will be located on habitats that vary from very low sensitivity to low to moderate sensitivity to physical disturbance (**Figure 2.9**).

2.6.9 In addition, sandeels are thought to be potentially sensitive to an increased content of fine particles on the seabed. An area where higher densities of sandeels are believed to occur (based on proxy data from Danish satellite vessel monitoring system) is the western corner of Dogger Bank Teesside B (**Figure 2.9**). The proxy data also suggests that sandeel densities are relatively high to the north and west of Dogger Bank Teesside B. Elsewhere, relatively low densities occur across the two project areas.

2.6.10 Given that the benthic habitat mapping shows that most of the seabed habitat does not have sensitivities greater than moderate, the sandeel data is used as the main driver for locating the foundations. Hence, the 24 foundations are placed in a triangular grid in the high sandeel density area in the western corner of Dogger Bank Teesside B to represent the worst case location (**Figure 2.9**).

2.6.11 It is assumed that foundations will be installed on a daily basis as described in **Table 2.5**. The distance between each of the foundations in the grid is 1,080m (minimum spacing of 10MW foundations) (**Table 1.1**). The large number of foundations and their construction sequencing are considered to be very conservative and capture a realistic worst case scenario.

Table 2.5. Sequencing of sediment release from the 24 foundations in Dogger Bank Teesside B during construction.

Day	Sediment Release		Condition	Rationale
	Conical GBS	Pile		
1-2	One foundation seabed preparation per day	One foundation drill arisings per day	Typical spring-neap	Provides understanding of dispersion at a rate of one foundation per day and how this may accumulate over consecutive days
3	Two foundations seabed preparation	Two foundations drill arisings	Typical spring-neap	Provides understanding of dispersion at a rate of two foundations per day
4-5	One foundation seabed preparation per day	One foundation drill arisings per day	Typical spring-neap	
6	No foundation installation		Typical spring-neap	Provides understanding of dispersion at a rate of zero foundations per day
7	One foundation seabed preparation	One foundation drill arisings	Typical spring-neap	Shows whether the dispersion had reduced following no foundation installation on the previous day
8	One foundation seabed preparation plus scour	One foundation drill arisings plus scour	One-year storm	Scour added to determine level of dispersion enhancement
9-24	One foundation seabed preparation per day	One foundation drill arisings per day	Typical spring-neap	
25-30	No more foundation installation		Typical spring-neap	Shows how quickly the dispersion reduces and how bed deposition alters with no more supply

2.6.12 The worst case scenario is that after each daily installation of the first eight foundations, the seabed preparation sediment or drill arisings are dispersed by typical wave and tidal current conditions. After installation of the eighth foundation, a one-year storm event takes place and equilibrium scour is reached at each foundation. Whether equilibrium scour is actually achievable depends on the duration of the storm. For the worst case scenario, it is assumed that the storm releases the full sediment load through scour. Thereafter, in the 30 days of simulation, another one-year storm does not take place, and only seabed preparation or drill arisings are taken into account for the subsequent 16 foundation installations. At day 25, no more foundations are installed, but the model is run up to day 30 to determine how dispersion and bed deposition react to no more sediment supply.

2.6.13 With respect to the inter-array cables, it has not yet been determined when they may be installed within the sequencing of the foundations. The assumption is made here that each of the foundations are connected by cables after all 24 have been installed. The inter-array cables will be variable lengths depending on which two foundations are being connected together. They will be excavated up to 2.5m deep and 1.5m wide (in an approximate 'U' shape), potentially releasing approximately 3,750m^3 of sediment for each 1,000m length. A continuous excavation rate of 270m/hour is assumed and will start in the southwest corner of the grid proceeding to the northeast corner over a period of 3.2 days.

Scour Volumes

2.6.14 Using empirical methods, worst case scour volumes have been estimated for the northwest row of eight foundations (10MW conical GBS$^{\#}$1 and 12m pile foundations). The volumes and areas were estimated using empirical methods, as explained in detail in **Appendix E**. For conical GBS, scour volumes were calculated for a 55m diameter base plate (maximum diameter GBS$^{\#}$1) (**Table 2.6**). Scour volumes between 2,933m^3 and 5,810m^3 were estimated for the conical GBS$^{\#}$1 foundations. For 12m pile foundations, the equilibrium scour volumes at each location are estimated to be 365-756m^3. The scour volumes were predicted using empirical formulae devised for granular sand under waves and tidal currents and conservatively assume maximum equilibrium scour depths created through non-cohesive sandy sediments with a friction angle of 38.6^o.

Table 2.6. Predicted equilibrium scour volumes at eight locations specified in Dogger Bank Teesside B as the scour release points during construction.

Foundation Location (Southwest to Northeast)		Parameters			Equilibrium Scour Volume (m^3)	
Easting	Northing	Wave Height (m)	Wave Period (s)	Water Depth (m)	55m Base Plate Conical GBS$^{\#}$1	12m Pile
433199	6096472	6.34	13.09	26.30	5,184	672
433959	6097238	6.46	13.09	25.41	5,810	756
434720	6098005	6.41	13.09	28.19	4,654	598
435481	6098772	6.44	13.09	28.43	4,628	594
436242	6099538	6.38	13.07	27.53	4,806	617
437002	6100305	6.36	13.06	28.32	4,494	575
437763	6101071	5.99	13.04	31.09	3,183	397
438524	6101838	6.12	13.04	33.19	2,933	365

Cable Trench Excavation Method

2.6.15 The Dogger Bank Teesside A & B export cable corridor outside of the Dogger Bank Zone is approximately 157km long from its exit point at the western tip of Tranche A to the landfall at Redcar and Cleveland. The cable will then connect to sub-stations in Dogger Bank Teesside A & B along a currently undefined 'in-Zone' route between Dogger Bank Creyke Beck A & B. The 'in-Zone' section of the cable route chosen for the worst case installation process to connect the out of Dogger Bank Zone export cable corridor with the sub-station is 59km long (**Figure 2.9**). The total length of Dogger Bank Teesside A & B export cable corridor is therefore 216km.

2.6.16 Forewind has defined a variety of techniques that could be used to excavate a trench for an export cable. These include jetting, ploughing, trenching, cutting, mass flow excavation and pre-sweeping (dredging). Installation of a single cable in a trench over the 30-day simulation period was modelled as the worst case scenario. To be conservative, and regardless of technique, it is assumed that the whole volume of sediment from the trench dimensions is released for dispersion.

2.6.17 Excavation rates for cable installation can vary widely between 50m/hour and 500m/hour depending on the methodology that is adopted, the nature of the substrate, target burial depths, bathymetry, weather and other factors. Forewind considered typical values to be 50-300m/hour for a mechanical trencher, 150-400m/hour for a jetter and 250-500m/hour for a plough (Leon Notkevich, Forewind, personal communication).

2.6.18 A provisional burial assessment of the export cables by Forewind indicates that there is a high level of uncertainty regarding the potential for the cable to be buried. It is therefore assumed that all of the 216km of cable could be fully buried, producing disturbance that would potentially release sediment.

2.6.19 For the worst case scenario, it is assumed that the duration of the entire 216km excavation is continuous over the 30-day period and takes place simultaneously with the installation of the 24 foundations. This equates to an excavation rate of 300m/hour. This excavation rate is within the typical ranges for several different methods. According to Forewind, the width of trenching would be 1.5m with a maximum depth of 3m (in an approximate 'U' shape), producing approximately 1,350m^3 of sediment for every hour of trenching or a total of 972,000m^3 of sediment over the entire construction.

Overall Sequencing

2.6.20 For the construction worst case scenario, the locations of the foundation sediment sources are shown in Figure 2.9. An overview of the time schedule of all sediment releases during the 30-day simulation period is provided in Table 2.7. For the export cable, sediment is released continuously as the excavation progresses.

Table 2.7. Timings of the four types of sediment release during the 30-day simulation period during construction.

Release type / days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Seabed preparation or drill arisings	1	1	2	1	1		1	1	1	1	1	1	1	1	1
Scour															
Inter-array cable															
Export cable															
Release type / days	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Seabed preparation or drill arisings	1	1	1	1	1	1	1	1	1						
Scour															
Inter-array cable															
Export cable															

Particle Size Distribution

2.6.21 **Appendices A** and **B** summarise particle size distributions for surface sediment samples recovered across Tranche B and the Dogger Bank Teesside A & B export cable corridor, respectively. A conservative particle size distribution for released sediment due to seabed preparation and scour is based on an average, with samples with greater than 3% gravel removed. **Table 2.8** presents the average particle size distribution for Tranche B and the Dogger Bank Teesside A & B export cable corridor.

Table 2.8. Average particle size distribution based on surface sediment samples from Tranche B and the Dogger Bank Teesside A & B export cable corridor.

Size Range (mm)	Class	% (Average)	
		Tranche B	Dogger Bank Teesside A & B Export Cable Corridor
0.50-20	>Medium Sand	2.60	3.10
0.355-0.50	Medium Sand	1.95	3.53
0.25-0.355		5.96	8.11
0.18-0.25	Fine Sand	27.27	18.26
0.125-0.18		60.34	63.73
0.09-0.125	Very Fine Sand	0.40	0.31
0.063-0.09		0.16	0.23
<0.063	Mud	1.32	2.73

2.6.22 A different particle size estimate is used for drill arisings because each pile will be drilled into the sub-seabed and will penetrate geological formations with different characteristics to the surface sediment. RPS Energy (2012) analysed borehole data from Dogger Bank Teesside A & B to estimate average particle size characteristics for drill arisings. **Table 2.9** describes the average particle size distribution for Dogger Bank Teesside A & B boreholes (seven in total).

Table 2.9. Average particle size distribution in boreholes across Dogger Bank Teesside A & B.

Size Range (mm)	Size	% (Average)
>60	Cobble	0
2-60	Gravel	2
0.06-2	Sand	55
0.002-0.06	Silt	23
<0.002	Clay	18

Source: RPS Energy (2012)

2.6.23 According to RPS Energy (2012) the drill arisings will contain the following proportions of sediment size:

- Fraction 1: 55% of the drilling volume comprises sand with particle size of 0.06-2mm and assumes 100% disaggregation; and
- Fraction 2: 28.7% of the drilling volume (23% silt and 18% clay with particle size less than 0.06mm, assuming 70% disaggregation in to its particulate constituents).

2.6.24 The other 16.3% of silt and clay will not disaggregate into its constituent particles (based on the analysis of RPS Energy, 2012) and so will settle rapidly to the seabed (as larger 'lumps') without entering the plume.

Modelling Methodology

2.6.25 Realistic worst case scenarios related to installation of conical GBS$^{\#}$1 foundations and 12m piles in a small area of Dogger Bank Teesside B have been analysed by dispersion modelling. The following sediment release processes have been captured by the model over a 30-day simulation period (**Table 2.7**):

- seabed preparation for the foundations (released at the seabed for conical GBS only);
- drill arisings for the foundations (released at the sea surface for piles only)
- scouring of the foundations (all foundation types);
- trenching of the inter-array cables; and
- trenching of an export cable (both out of Zone and in-Zone).

2.6.26 For all processes associated with the conical GBS foundations, the available sediment has been released in the model bottom layer (corresponding to the lower 5m of the water column) and exposed to dispersion by waves and currents. For drill arisings, sediment was released in the model top layer at the sea surface. The release of sediment results in dispersion that has been estimated as suspended sediment concentration in excess of the natural sediment concentration in the area. No new data has been collected to measure background turbidity and so the modelled excess suspended sediment concentration was compared with background values measured by Eisma and Kalf (1987). Their data shows that Dogger Bank and much of the Dogger Bank Teesside A & B export cable corridor is characterised by suspended sediment concentration values lower than 2mg/l (**Appendices A** and **B**).

2.6.27 Two sediment fractions have been used as input to the dispersion model:

- Fraction 1: particle size greater than 0.090mm and less than 0.180mm (mainly very fine to fine sand); and
- Fraction 2: particle size less than 0.090mm (mainly mud).

2.6.28 Sediment particles larger than 0.177mm are assumed to deposit at the source position. It is conservatively assumed that both fractions contribute to the suspended sediment concentration. However, part of the coarser sediment (Fraction 1) that is released may be deposited rapidly and not contribute to the excess suspended sediment concentration. Particle size distributions used in the simulation of the conical GBS foundations and the piles are provided in **Tables 2.8** and **2.9**, respectively.

2.6.29 Each size fraction simulated with MIKE3-FM MT is defined by its settling velocity and its critical shear stress. **Table 2.10** shows the applied settling velocities and critical shear stresses used in the model for Fractions 1 and 2. The critical shear stress for erosion is the shear stress above which the sediment is re-suspended. A sediment dry density of 1,590kg/m^3 has been used to represent the undisturbed seabed sediments, assuming a porosity of 0.4 and a density of quartz of 2,650kg/m^3. The 'looseness' of the dispersed sediment was represented by a bed layer density of 300kg/m^3.

Table 2.10. Parameters input into the dispersion model.

Fraction	Sediment	Settling Velocity (mm/s)	Critical Shear Stress for Erosion (Mm^{-2})
1	Coarse	5	0.1
2	Fine	0.5	0.1

2.6.30 The modelling of sediment dispersion for the wind farm was carried out over a 30-day simulation period using the baseline 30-day hydrodynamic simulation already established (described in **Section 3.1**). The time series of waves applied in the sediment dispersion modelling over the simulation period is shown in **Figure 2.10**. The data is from the Tranche A buoy (location shown in **Figure 1.3**) and was selected because it contains the maximum wave height of the entire time series for this buoy (up to October 2011). This peak wave height was positioned at day eight of the time series for input into the model and was increased to 'manufacture' a one-year significant wave height of just over 7.5m (Mathiesen et al., 2011). This one-year storm was included because sediment suspension and dispersion is expected to arise during stormy weather.

2.6.31 Sediment release at the foundations was assumed to take place on a daily basis (apart from day six) throughout the simulation, up to and including day 24. This means that dispersion from foundation construction has been modelled on each of those days (**Table 2.7**). The sediment along the Dogger Bank Teesside A & B export cable corridor was released continuously for dispersion as the excavation progresses starting from the seaward end of the cable. Along the inter-array cables, the sediment was also released continuously as the excavation progresses.

2.7 Worst Case Operational Foundation Layout for Effects on Sediment Transport

2.7.1 Within the limits of Dogger Bank Teesside A & B, the maximum number of 6MW conical GBS foundations in each project would be 200, whereas 120 foundations of 10MW size could fill each project. Hence, the larger number of 6MW conical GBS foundations would create a larger total volume of scoured sediment compared to the smaller number of 10MW foundations, given the relatively small difference in scour for each foundation size. **Table 2.11** presents the estimated total scour volume for each type of layout under one-year and 50-year conditions.

Table 2.11. Total scour volumes for 6MW and 10MW layouts.

Foundation	Total Scour Volume (m^3)	
	One-year return	50-year return
10MW	156,000	566,000
6MW	240,000	877,000

2.7.2 For the purpose of predicting scour and sediment transport effects, the worst case scenario is considered to be 200 6MW conical GBS foundations in each project. The worst case layout is the same as that for modelling the effects of waves and tidal currents, comprising a perimeter of 6MW GBS#1 foundations at their minimum spacing (750m) with a wider spaced grid of foundations across the bulk of each project (**Figure 2.7**). This is considered to be the worst case layout because a closer spaced perimeter would increase the intensity of the sediment dispersion closer to the most sensitive habitat to the north and west, relative to an equally spaced grid throughout each project. Also, the perimeter encompasses the full area available to the project and the central grid fills this perimeter, ensuring the sediment dispersion is maximised over the widest possible area. The layout is also in line with the need for layout flexibility defined by Forewind, and although conservative it is realistically in line with layouts under consideration. The layouts in Dogger Bank Teesside A & B have been modelled together.

2.7.3 In addition to the foundations, a set of seven platforms (four collector, one converter and two accommodation), five meteorological masts and ten vessel moorings in each project have been incorporated in the layout for modelling (**Figure 2.7**).

2.8 Worst Case Operational Scour for Effects on Sediment Transport

Location and Sequencing of Foundations

2.8.1 It is assumed that the 400 6MW conical GBS#1 foundations (plus associated platforms, meteorological masts and moorings) (**Figure 2.7**) will be installed over a (minimum) two year construction period. This means that more foundations will be installed in the first year compared to a potentially longer total construction period (e.g. three years) and, in the event of a one year storm, more sediment will be available for scour. Hence, a two year construction period is considered the worst case scenario.

2.8.2 Two years of construction equates to installation of 200 foundations per year, with 100 foundations installed in Dogger Bank Teesside A at the same time as 100 foundations in Dogger Bank Teesside B, each year (**Figure 2.11**). At the end of year one it is assumed that each of the 200 conical GBS foundations has been scoured to its equilibrium volume for ‘typical’ spring-neap tidal conditions.

2.8.3 After one year of installation, a one-year storm takes place and equilibrium scour is reached at each of the 200 foundations. For the worst case scenario, it is assumed that the storm releases the full sediment load through scour. The release volumes input to the dispersion model equal the one-year storm scour volumes minus the volumes already scoured during the typical condition.

2.8.4 At the end of year two, an assumption is made that the second batch of 200 conical GBS#1 foundations will scour to their equilibrium volume for ‘typical’ spring-neap tidal conditions. It is also assumed that there is no partial re-filling of the first 200 foundations installed and so at the end of year two they are still scoured to their one-year storm equilibrium volume. This is based on the methods of Soulsby (1997), which when applied to Dogger Bank show that the depth-averaged current velocity for the threshold of motion of sand is approximately 0.55m/s. **Appendix A** shows that the mean flow velocities across the Dogger Bank area do not exceed 0.4m/s. Hence, the transport of seabed sediment by tidal currents is likely to be a relatively infrequent event.

In addition, the long-term 'typical' wave conditions are insufficiently severe to result in the transport of significant volumes of sediment. Once a storm has occurred and a scour hole has been formed, it is unlikely that the hole will be filled in by subsequent hydraulic activity.

2.8.5 At the end of year two, both Dogger Bank Teesside A & B are subject to a 50-year storm. The release volumes input to the dispersion model for the first 200 foundations are equivalent to the 50-year storm scour volume minus the one-year storm scour volumes. The release volumes for the second 200 foundations equal the 50-year storm scour volumes minus the volumes lost during the typical condition.

2.8.6 With respect to locations of the foundations during the phased installation, it is assumed that the first 200 turbines will be constructed along the eastern sides of each project and the second 200 along the western sides (**Figure 2.11)**. This is considered to be the worst case scenario because it would release the largest volume of sediment over the sensitive sandeel habitat to the north and west of the projects when the 50-year storm hits at the end of year two.

Scour Volumes and Plan Areas

2.8.7 Scour volumes and plan areas were estimated for all 400 6MW conical GBS#1 foundations for typical conditions, one-year storm and 50-year storm events. The volumes and areas were estimated using a combination of empirical methods in three stages, as explained in detail in **Appendix E** and the Dogger Bank Creyke Beck Environmental Statement (Forewind, 2013). In summary, these three stages were:

- Stage 1: predict scour volumes and areas using various empirical formulae devised for granular sand under waves and tidal currents;
- Stage 2: take account of the strength of the deeper sub-seabed sediments and their ability to resist scour; and
- Stage 3: take account of the scour-resistant clay layer that directly underlies the sand at various depths across Dogger Bank Teesside A & B.

2.8.8 From these data the scour volumes input to the dispersion model and the associated scour plan areas and scour depths were calculated. A summary of the estimated volumes, plan areas and depths is presented in **Table 2.12**. The estimates where depth and volume of scour are zero relate to the parts of Dogger Bank Teesside A & B where the scour-resistant clay is at the seabed. The minimum plan area of 1,964m^2 relates to the direct loss of seabed by the 6MW 50m-diameter foundation base plate where there is no scour around it due to the clay outcropping at the seabed.

Table 2.12. Predicted equilibrium scour volumes, plan areas and depths for 6MW conical GBS#1 foundations across Dogger Bank Teesside A & B.

Return Period	Dogger Bank Teesside A			Dogger Bank Teesside B		
	Predicted Scour Volume (m^3)	Predicted Scour Plan Area (m^2)*	Predicted Scour Depth (m)	Predicted Scour Volume (m^3)	Predicted Scour Plan Area (m^2)*	Predicted Scour Depth (m)
'Typical' Condition	0-21	1,964-2,073	0-0.39	0-14	1,964-2,051	0-0.31
One-year Storm	0-709	1,964-2,625	0-2.2	0-709	1,964-2,265	0-2.2
50-year Storm	0-2,843	1,964-3,350	0-4.3	0-2,843	1,964-3,350	0-4.3

*these numbers include the area of the 6MW base plate itself (1,964m^2)

2.8.9 The depth limits of scour based on the strength of the sediment are 2.2m for the one-year storm event and 4.3m for the 50-year storm, which equate to maximum scour volumes of 709m^3 and 2,843m^3, respectively. These scour depths and volumes are equivalent to a situation where there is a sufficient thickness of non-cohesive sandy sediments that scour does not reach the resistant clay. At locations where the scour resistant clay layer is closer to the surface than the maximum depths, the scour volumes and depths will be less (in places the scour depth is zero where the clay is at the seabed).

2.8.10 Scour volumes and depths were also estimated, using the same three-stage method, for the seven platforms, five meteorological masts and ten vessel moorings in each project. The estimates are summarised in **Table 2.13**.

Table 2.13. Predicted equilibrium scour volumes and depths for different types of structure (excluding foundations) across Dogger Bank Teesside A & B.

Infrastructure	Return Period	Dogger Bank Teesside A		Dogger Bank Teesside B	
		Predicted Scour Volume (m^3)	Predicted Scour Depth (m)	Predicted Scour Volume (m^3)	Predicted Scour Depth (m)
Collector Platform	'Typical' Condition	11-24	0.32-0.47	0-17	0.27-0.39
	One-year Storm	547	2.2	325-547	0.81-2.2
	50-year Storm	1,958-2,181	2.89-4.3	668-2,181	0.81-4.3
Converter Platform	'Typical' Condition	128	2.05	128	1.93
	One-year Storm	652	2.2	698	2.2
	50-year Storm	2,181	4.3	2,181	4.3
Accommodation Platform	'Typical' Condition	0-128	0-2	128	1.54-2.01
	One-year Storm	0-698	0-2.2	436-698	1.54-2.2
	50-year Storm	0-2,181	0-4.3	436-2,181	1.54-4.3
Meteorological Mast	'Typical' Condition	0-27	0-0.5	17-21	0.3-0.43
	One-year Storm	0-547	0-2.2	293-547	0.73-2.2
	50-year Storm	0-2,181	0-4.3	603-2,181	0.73-4.3
Vessel Mooring	'Typical' Condition	0-221	0-0.93	91-218	0.6-0.92
	One-year Storm	0-166	0-0.81	91-164	0.6-0.8
	50-year Storm	0-221	0-0.93	91-218	0.6-0.92

Modelling Methodology

2.8.11 Realistic worst case scenarios for operation of conical GBS#1 foundations and other structures in Dogger Bank Teesside A & B have been analysed by dispersion modelling. Scouring around the foundations and other structures is the only sediment release process captured by the models over a 30-day simulation period. The scoured sediment has been released in the model bottom layer and exposed to dispersion by waves and currents. Particle size distributions and other physical parameters used in the simulation of the operational phase are shown in **Tables 2.8** and **2.10** (same as those used for the installation of conical GBS#1 foundations).

2.8.12 The 30-day time series of waves applied in the sediment dispersion modelling after the first year (one-year storm) and second year (50-year storm) of operation are shown in **Figures 2.12** and **2.13**. The peak wave heights were positioned at the beginning of the time series for input into the model and were increased to 'manufacture' one-year and 50-year significant wave heights of 7.5m and 11.5m, respectively (Mathiesen et al., 2011). Throughout the simulation, all sediment (both Fractions 1 and 2) deposited on the seabed during calm periods is re-suspended during subsequent more turbulent periods.

2.9 Worst Case Landfall Construction Process

2.9.1 As part of the landfall construction process, HDD is anticipated to be carried out landward from multiple cofferdams on the foreshore together with open trenching to bury cables seaward of the cofferdams. The main uncertainties in the construction methodology are where and how the HDD component of the onshore cables will be connected to the landing points of the export cables at the coast and the methodology by which the cables will be buried seaward of the cofferdams. The key components of the construction methodology with the potential to affect coastal processes are:

- the connection of the landfall to the onshore portion of the cables;
- the connection of the landfall to the offshore export cables;
- the placement of structures on the shore to achieve the connections; and
- the sequencing of activities.

Nearshore Configuration of the Export Cables

2.9.2 OMM (2013) indicated that the substrate across the first 25km of seabed offshore from the landfall site is poor for burial of cables. Here, the seabed comprises rock, which is anticipated to consist of Triassic to Cretaceous mudstone, sandstone, limestone and chalk. They suggested that along parts of this 25km-stretch of the Dogger Bank Teesside A & B export cable corridor, the cables would potentially have to be surface laid and then protected by rock armour or mattressing. A full geotechnical assessment will be undertaken as part of a full burial assessment and before commencement of installation.

2.9.3 Interpretation of the nearshore geophysical data by Forewind has provided an estimate of the anticipated amount of remedial protection required in the nearshore area, approaching the Redcar and Cleveland coast. Forewind indicate that no remedial protection will be necessary from the mean low spring tide mark to 350m seaward of this mark. At Marske-by-the-Sea, mean low spring tide (-1.95m OD) is about 400m seaward of the cliffs. This means that from the cliffs to approximately 750m seaward (across the intertidal zone and shallow subtidal zone), the export cables will be buried.

2.9.4 The landfall cable configuration will either consist of two pairs of bundled cables (i.e. requiring two entry points to the landfall) or four unbundled cables (requiring four entry points to the landfall). These configurations represent one pair of cables per project. As a worst case, remedial protection of the export cable will be 15m wide and stand 1.5m above the surrounding seabed. As there is the potential for up to four export cables requiring protection, then four 15m wide (at the base, 5m at the top), 1.5m high structures have been assessed as the worst case scenario.

2.9.5 The connection of the landfall (cofferdams) to the offshore export cable corridor may be constructed by open trenching across the subtidal zone. The cables will be buried in the resulting trench. The indicative length, width and depth of each open trench are 30m, 1.5m and 2m, respectively. Each trench would be excavated with a mechanical digger. The cofferdam would be constructed first and then opened up on the seaward side to access the trench. It is possible for the trench to be installed without the use of a cofferdam.

HDD and Cofferdams

2.9.6 As the worst case scenario, the exit points for HDD would be in the nearshore zone 400m from the top of the beach at the approximate position of low tide. The proposed HDD will be 700m long from the exit point under the beach and then across the onshore, including the 50-year erosion of the shoreline.

2.9.7 The exit points in the intertidal zone may require some form of temporary retainer (cofferdam) to create a dry area for cable jointing. The construction of multiple cofferdams in the intertidal zone (to cater for multiple cable exits) is considered to be the worst case scenario for effects on marine physical processes along the Redcar and Cleveland coast. The two main options would be to construct four cofferdams, each containing a single cable, or two cofferdams, each containing a cable pair.

2.9.8 Each cofferdam would have a maximum width of 10m (alongshore) to allow space for trenching tools, and be excavated to a maximum depth of 3m into the substrate. For four cofferdams, Forewind has indicated that a cross-shore length of 10m would be required for each cofferdam, whereas for two cofferdams, the length required is 15m.

Construction Programme

2.9.9 Four construction scenarios are provided by Forewind:

- Single build; assumes construction of Dogger Bank Teesside A only or Dogger Bank Teesside B only;
- Parallel (combined) build; assumes that Dogger Bank Teesside A & B are constructed together;
- Sequential build; assumes construction of one project commences after the start of the other. This may result in projects overlapping, occurring in series or having a gap between projects; and
- Enabling build; partial installation of some onshore elements for the second project takes place while constructing the first project.

2.9.10 The scenarios for single, sequential and enabling builds are assumed to require installation of either two small cofferdams (10m by 10m by 3m) or one large cofferdam (15m by 10m by 3m) for each construction phase. The single build has one construction phase over an indicative period of eight weeks. A sequential build scenario is assumed to take eight weeks for the initial construction phase and eight weeks for the second construction phase. The gap between the two builds may be up to five years. The scenario for the enabling build is assumed to take eleven weeks for the first construction phase and eight weeks for the second construction phase, with a gap of up to five years between the two phases.

2.9.11 A parallel (combined) build of both projects is assumed to require either four small cofferdams or two large cofferdams over an indicative period of 14 weeks. The relatively long duration between construction and removal of the cofferdams in combination with four cofferdams is considered the worst case scenario for the landfall, with respect to excavated sediment. However, in terms of physical blockage to longshore sediment transport, two large cofferdams (15m-long in a cross-shore direction) over a 14 week construction period is considered to be the worst case scenario.

2.9.12 A small 10m by 10m by 3m cofferdam will require excavation of up to 300m^3 of sediment, whereas a large 15m by 10m by 3m cofferdam would require removal of up to 450m^3 of sediment. Hence, four small cofferdams would have a total excavated volume of 1,200m^3 of sediment whereas two large cofferdams require removal of 900m^3 of sediment.

2.9.13 It is anticipated that the excavated sediment will be stored on a barge for backfill after the cofferdam has been removed. The hole left in the foreshore by the cofferdam and trench will be backfilled mechanically using some type of excavator, which will transfer sediment from the barge. Backfilling will be undertaken by refilling with stored till, followed by topping off with stored beach sediment. During the backfilling process the beach will be re-profiled, with the re-instatement of beach levels.

2.9.14 It is anticipated that two large cofferdams would be constructed over the same period of time as four small cofferdams. Given the identical construction period, a large cofferdam would provide a longer (15m cross-shore) potential barrier to sediment transport than a shorter (10m) cofferdam. The number of cofferdams would be irrelevant in this regard as most of any sediment trapping would take place on the northwest side of the first cofferdam along the sediment transport pathway. The remaining cofferdams would not contribute to the effect.

2.10 Summary

2.10.1 The worst case characteristics that have been assessed for the development during the construction, operation and decommissioning phases of Dogger Bank Teesside A & B are summarised in **Table 2.14**.

Table 2.14. Worst case characteristics and related physical processes elements.

Effect	Realistic Worst Case Scenario	Rationale
Construction		
Offshore	The 10MW conical GBS#1 foundation is the worst case type for release of scoured sediment	The scour volumes for different types and sizes of foundation were predicted using empirical methods from existing literature and knowledge using the following criteria: • the equilibrium scour volume for sand was derived for foundation designs in 35m of water; • they were calculated for the combined action of waves and tidal currents during a one-year storm event; and • they conservatively assume maximum equilibrium scour depths
	A worst case seabed preparation volume of 3,675m^3 is applied for a conical GBS Sediment arising from seabed preparation is side cast close to the foundation and is available for dispersion	This volume is for a 10MW GBS#1 foundation, which has the largest 55m base plate diameter and was defined by Forewind
	A worst case drill arisings volume of 6,220m^3 is applied for installation of a 12m piled concrete foundation, the widest diameter needed to support a 12m-diameter monopole to hold a 10MW wind turbine	Forewind calculated this volume based on a pile diameter of 12m and an average drill penetration depth of 55m
	A worst case drill arisings volume of 2,765m^3 is applied for installation of an 8m piled steel foundation, the widest diameter needed to support a 12m-diameter monopole	Forewind calculated this volume based on a pile diameter of 8m and an average drill penetration depth of 55m

Effect	Realistic Worst Case Scenario	Rationale
	The worst case equilibrium scour volume for a 12m monopole foundations ranges from 365m^3 to 756m^3, depending on applied wave climate and water depth The worst case equilibrium scour volumes for conical GBS#1 foundations range from 2,933m^3 to 5,810m^3, depending on applied wave climate and water depth	The scour volumes for the monopole and GBS#1 foundations were predicted using empirical methods from existing literature and knowledge using the following criteria: • the equilibrium scour volumes for sand were derived in various water depths defined by the location of the foundations; • they were calculated for the combined action of waves and tidal currents during a one-year storm event; and • they conservatively assume maximum equilibrium scour depths
	The worst case installation process for foundations for effects on sediment transport that was modelled is 24 12m-diameter monopole foundations, a set of inter-array cables connecting them and one export cable (in-Zone and outside the Dogger Bank Zone) installed together over a 30-day period. The worst case installation sequencing is: • foundations installed on a daily basis; • after each daily installation of the first eight foundations, the drill arisings are dispersed by typical wave and tidal current conditions; • after installation of the eighth foundation, a one-year storm event takes place and equilibrium scour is reached at each foundation releasing the full sediment load through scour;	An installation process was developed that would be realistic, but that would also be very conservative in terms of numbers of foundations and their phasing over a relatively short period

Effect	Realistic Worst Case Scenario	Rationale
	• at day 25, no more foundations are installed; • each foundation is connected to an adjacent foundation by an inter-array cable after all 24 foundations have been installed; and • excavation of the export cable is assumed continuous over the 30-day period and takes place simultaneously with the installation of the 24 foundations The worst case scenario assumes that all sediment with a particle size less than 0.18mm is suspended in the plume	
	The inter-array cables will release approximately 3,750m^3 of sediment per km length excavated The export cable will produce 971,000m^3 of sediment over its 216km length or approximately 4,500m^3 per km or 1,344m^3 for every hour of trenching	The inter-array cable volume released is based on cables that are excavated up to 2.5m deep and 1.5m wide in an approximate 'U' shape The export cable volume released is based on a cable that will be placed in a trench 1.5m wide with a maximum depth of 3m (in an approximate 'U' shape) over a length that can be excavated of 216km (the assumed cable length from landfall to project). An excavation rate of 298.6m/hour was used (total time to complete excavation would be 30 days)
	The worst case location for the 24 foundations is in the western corner of Dogger Bank Teesside B.	The foundations have been located near to the habitats most sensitive to increases in suspended sediment concentration. Sandeels are considered the most sensitive, and the highest densities (proxy data from Danish satellite vessel monitoring system) occur in the western corner of Dogger Bank Teesside B and outside and adjacent to its northern and western boundaries

Effect	Realistic Worst Case Scenario	Rationale
	The worst case scenario for the fate of sediment not suspended during foundation installation assumes that all sediment with a particle size greater than 0.18mm falls to the seabed and does not enter the plume	An installation process was developed that would be realistic in terms of particle size distribution released into the water column
Landfall	The worst case landfall construction would be in the intertidal zone The worst case scenario for interruption to sediment transport is two large cofferdams measuring 15m long by 10m wide by 3m deep installed over a 14-week period	A landfall construction in the intertidal zone (at the location of low tide) will have the greatest effect on sediment transport processes of any cross-shore position as this is where the majority of sediment transport is likely to take place. Installation of four small cofferdams and two large cofferdams were compared. Given their identical construction period, the large cofferdams would provide a longer (15m cross-shore) barrier to sediment transport than a shorter 10m cofferdam.
Operation		
Offshore	Conical GBS are the generic worst case foundation type for effects on waves and tidal currents	Selection is based on the foundation type with the greatest cross-sectional area within the water column representing the greatest physical blockage to waves and tidal currents. Conical GBS were compared with monopoles, multi-legs and flat GBS
	Conical GBS#1 is the worst case foundation for effects on tidal currents	This was quantified using a tidal current model which predicts the reduction in tidal flow around each foundation. The characteristics of the worst case conical gravity base foundation were selected from a range of six alternative conical gravity base designs which were interrogated using the tidal current model

Effect	Realistic Worst Case Scenario	Rationale
	Conical GBS#1 is the worst case foundation for effects on waves	This was quantified using the WAMIT model which calculates reflection factors for different wave periods which are then integrated with the average wave spectrum to predict the overall wave reflection ('blockage') induced by each foundation. The characteristics of the worst case conical gravity base foundation were selected from a range of six alternative conical gravity base designs which were interrogated using the WAMIT model
	An array of 400 6MW conical GBS#1 foundations across Dogger Bank Teesside A & B, spaced 750m apart around their perimeters with a wider internal spacing, is the worst case layout for effects on tidal currents An array of 400 6MW conical GBS#1 foundations across Dogger Bank Teesside A & B, spaced 750m apart around their perimeters with a wider internal spacing, is the worst case layout for effects on waves	The worst case scenario layout is considered to be a grid of foundations that fills each project, with the minimum spacing around the perimeter, providing the maximum potential for interaction of tidal current and wave processes between foundations in areas of sensitive habitat. Two scenarios were tested: • grid of 6MW foundations across Dogger Bank Teesside A & B; and • grid of 10MW foundations across Dogger Bank Teesside A & B

Effect	Realistic Worst Case Scenario	Rationale
	An array of 400 6MW conical GBS#1 foundations across each project is the worst case operational foundation layout for effects on sediment transport The worst case layout comprises a perimeter of foundations at their minimum spacing (750m) with a wider spaced grid of foundations across the bulk of each project The foundations would be installed over a (minimum) two year construction period	The worst case scenario layout is considered to be a grid of foundations that fills each project providing the maximum potential for creation of high suspended sediment plumes: • a 'perimeter plus grid' layout is considered to be a realistic potential project layout; • a closer spaced perimeter would increase the intensity of the sediment dispersion close to the most sensitive habitat, relative to an equally spaced grid throughout each project; • the perimeter encompasses the full area available to the project and the central grid fills this perimeter, ensuring the sediment dispersion is maximised over the widest possible area; • after one year of installation, a one-year storm takes place and equilibrium scour is reached at 200 foundations (half of the total number of foundations to be installed). The storm releases the full sediment load through scour; and • at the end of year two, after all 400 foundations have been installed, both projects are subject to a 50-year storm and the storm releases the full sediment load through scour

Effect	Realistic Worst Case Scenario	Rationale
	The worst case operational scour volumes for the conical GBS[#]1 foundations are: • 0-21m^3 for typical conditions; • 0-709m^3 for a one-year storm; and • 0-2,843m^3 for a 50-year storm The worst case operational scour plan areas (including the base plate area itself) for the conical gravity base foundations are: • 1,964-2,073m^2 for typical conditions; • 1,964-2,625m^2 for a one-year storm; and • 1,964-3,350m^2 for a 50-year storm The worst case operational scour depths for the conical gravity base foundations are: • 0-0.39m for typical conditions; • 0-2.2m for a one-year storm; and • 0-4.3m for a 50-year storm	The worst case scour volumes, plan areas and depths were estimated using a combination of empirical methods in three stages: • Stage 1: predict scour volumes, areas and depths using various empirical formulae devised for granular sand under waves and tidal currents; • Stage 2: take account of the strength of the sub-seabed Holocene sediments and their ability to resist scour; and • Stage 3: take account of the scour-resistant clay layer that directly underlies the sand at various depths across Dogger Bank Teesside A & B
	The worst case operational linear cable protection would be for remedial protection across the whole of the nearshore subtidal zone to an unspecified distance offshore. Between the cliff line and mean low water spring the cables will be buried. The protection would be up to 15m wide and stand up to	The worst case operational length and position of cable protection is based on an assumption of no restriction on remedial protection in the nearshore zone.

Effect	Realistic Worst Case Scenario	Rationale
	approximately 1.5m above the surrounding seabed.	
Decommissioning		
Offshore	Removal of foundations, export and inter-array cables and cable protection	Effects are expected to be less than construction because there will be no need for seabed preparation or pile drilling and there is a possibility that cables are left *in situ* with no consequential increase in suspended sediment concentration
Landfall	Removal of cable from the cliff, beach and intertidal zone	If the cable is removed from the beach and intertidal area, there will be temporary local effects of a type and duration likely to be similar to the construction phase activities

3 MODELLED BASELINE CONDITIONS

3.1 Tidal Currents

3.1.1 Current flows across the central North Sea vary temporally, as a function of the tide and tidal range, and spatially as they interact with bathymetry such as banks and channels. Hence, to simplify the results, an understandable representation of the current regime is maximum depth-averaged velocity at any time over the 30-day simulation period. **Figure 3.1** shows that modelled maximum depth-averaged current velocities across the Dogger Bank Zone are predominantly 0.3-0.5m/s. The velocity increases to the south across the Dogger Bank Zone.

3.2 Waves

3.2.1 The MIKE21-SW model has been used to simulate baseline significant wave heights, using one-year and 50-year wave conditions, from both north and northeast directions. The north and northeast directional sectors were chosen because offshore waves from these two sectors, as recorded by the Forewind waveriders, are larger and more frequent compared to other directions (**Figure 3.2**).

3.2.2 **Figures 3.3** to **3.6** show the simulated wave heights for the baseline condition. **Figure 3.3** shows that baseline one-year waves approaching from the north have significant wave heights mainly between 4.0m and 7.0m across the Dogger Bank Zone. **Figure 3.4** shows that one-year waves from the northeast are smaller than waves from the north, with significant wave heights ranging from 3.5m to 5.0m across the Dogger Bank Zone. There is a gradual decrease of wave height from north to south across the Dogger Bank Zone in both cases.

3.2.3 The baseline 50-year wave heights are greater than the one-year wave heights. Fifty-year waves approaching from the north have significant wave heights greater than 9.5m across the northern Dogger Bank Zone, reducing to 5.5m in the southern part of Tranche A (**Figure 3.5**). Waves approaching from the northeast reduce from a significant wave height of 7.5m in the northeast to 4.5m in the southwest of the Dogger Bank Zone (**Figure 3.6**).

4 ASSESSMENT OF CONSTRUCTION EFFECTS

4.1 Introduction

4.1.1 The construction phase of Dogger Bank Teesside A & B has the potential to affect marine physical processes both locally and further afield. Construction activities include installation of the foundations, laying of inter-array and export cables (both inside and outside the Dogger Bank Zone), and installation of landfall infrastructure, all of which may affect the tidal current regime, wave climate and sediment transport processes.

4.1.2 Over the construction period, there is potential that the seabed and coastline will be disturbed as a consequence of these activities. Installation of foundations and cables will potentially generate additional suspended sediment into the water column, which may result in the formation of sediment plumes. The mobilised sediment may then be transported away from the disturbance by waves and tidal currents. The magnitude of the plume will be a function of seabed type, the installation method and the hydrodynamic conditions in which dispersion takes place. Over the longer term, the sediment behaviour will determine the morphological development of the area.

4.1.3 Mobilisation of sediment on the seabed occurs when the wave and tidal current forces exert a shear stress that exceeds a threshold relevant to the sediment type. When shear stress drops below this threshold, the sediment begins to fall out of suspension and is re-deposited on the seabed. If the shear stress is then increased above the threshold again, the sediment will be re-suspended. It is, therefore, possible for sediment to be continually re-deposited and re-suspended, as tidal and wave conditions change. Typically, finer sediments are suspended at lower shear stresses compared to coarser sediments, and will remain in the water column for longer periods of time. Coarser sediments are more likely to be transported as bedload.

4.1.4 At the landfall site, activities to install the cables (including the potential for cofferdams and open trenching in the intertidal zone and rock armour in the shallow subtidal zone) can affect coastal processes. Changes to the bedload sediment transport processes between Redcar and Marske-by-the-Sea may result in disturbances to the sediment supply to other parts of the coast and construction activities may increase turbidity in the water column.

4.2 Increase in Suspended Sediment Concentrations as a Result of Combined Conical GBS#1 Foundation and Cable Installation Activities

4.2.1 The results of the sediment dispersion modelling are presented as a series of maps showing suspended sediment concentration in the bottom layer and sediment deposition on the seabed from the plume, using the following statistical measures:

- the maximum values of suspended sediment concentration above a background of 2mg/l and thickness of deposited sediment over the 30-day simulation period;
- the average values of suspended sediment concentration above a background of 2mg/l and thickness of deposited sediment over the 30-day simulation period; and
- the time over which suspended sediment concentration exceeds 2mg/l.

4.2.2 These statistical measures are intended to support the assessment of ecological impact. The maps showing average values provide a basis for the assessment of long-term impact (over the construction period) and the maps with maximum values provide a basis for the assessment of peak impact. The exceedance map provides information on the probability of the predicted concentrations occurring (e.g. how frequently a given limit is exceeded).

Predicted Suspended Sediment Concentrations in the Bottom Layer for Construction of Conical GBS

4.2.3 **Figures 4.1** to **4.3** show maps of predicted suspended sediment concentration in the bottom layer. The concentrations are presented as excesses over the natural background concentration (2mg/l). **Figure 2.9** shows the worst case location of the 24 foundations relative to sensitive habitats.

4.2.4 **Figure 4.1** shows the maximum concentration in the bottom layer predicted by the model at any time over the 30-day simulation period. Suspended sediment concentrations are increased in a band either side of the 24 foundations and Dogger Bank Teesside A & B export cable corridor. A maximum suspended sediment concentration of greater than 200mg/l is predicted to occur within the confines of the 24 foundations and along the in-Zone section of the cable route and between approximately 1km and 11km either side of the route. Maximum concentrations gradually reduce with distance from the foundations and the in-Zone section of the cable route until they are at the background of 2mg/l, up to 40km to the north and up to 40km south.

4.2.5 Along the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank Zone, the maximum predicted suspended sediment concentration is 100-200mg/l in two small patches, near the coast (about 4km long) and about 50km offshore (**Figure 4.1**). However, concentrations are typically less than 100mg/l along large proportions of the Dogger Bank Teesside A & B export cable corridor. Maximum concentrations gradually reduce with distance from the Dogger Bank Teesside A & B export cable corridor until they are predicted to be at the background of 2mg/l, up to 50km to the north and up to 45km south of the corridor.

4.2.6 The average suspended sediment concentration in the bottom layer predicted over the simulation period is presented in **Figure 4.2**. The results show that within the confines of the 24 foundations and up to approximately 17km along the in-Zone section of the export cable route (a band up to 6km wide adjacent to and north of the route), the predicted suspended sediment concentration is between 50mg/l and 100mg/l. The average suspended sediment concentration reduces to the background of 2mg/l approximately 18km (south) to 32km (north) from the in-Zone section of the cable route. Relatively small changes in average suspended sediment concentration of up to 10mg/l are predicted along the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank Zone.

4.2.7 **Figure 4.3** presents the exceedance time during the simulation of the predicted suspended sediment concentration above the background of 2mg/l. The map shows that 2mg/l is exceeded 80-90% of the 30-day simulation period for 25km along the in-Zone section of the cable route from the centre of the foundations. The width of the 80-90% band is up to10km either side of the route.

4.2.8 Where suspended sediment concentrations are greater that 200mg/l close to the coast, the exceedance time for concentrations greater than 2mg/l is less than 10% of the simulation period (**Figure 4.3**). Analysis of the time series data at a point in the centre of the high suspended sediment coastal plume shows that 200mg/l is only exceeded for two hours of the 30-day simulation before returning to lower concentrations.

Predicted Deposition and Re-suspension of Dispersed Sediment for Construction of Conical GBS

4.2.9 **Figure 4.4** shows the maximum change in deposition predicted at any time over the 30-day simulation period. The largest predicted change is a small patch within the confines of the foundation layout where the maximum deposition reaches 10-50mm. Away from the foundations and along the Dogger Bank Teesside A & B export cable corridor, the maximum deposition decreases to less than 5mm. Predicted deposition reduces to 0.5mm up to approximately 35km north of the in-Zone section of the cable route and 25km north of the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank Zone.

4.2.10 **Figure 4.5** describes the predicted average deposition from the plume predicted over the 30-day simulation period. Average deposition of 1-5mm occurs within and 10km to the north of the foundations, and in small patches along the Dogger Bank Teesside A & B export cable corridor. Predicted average deposition decreases to less than 0.5mm along the remainder of the Dogger Bank Teesside A & B export cable corridor, and is effectively zero in places.

4.2.11 Analysis of the time series of predicted deposition from the plume over the 30-day simulation period at five selected points (Points P1 to P5 in **Figure 4.6**) describes the persistency of sediment thickness on the seabed. **Table 4.1** demonstrates that within the foundation layout (Point P1), sediment thicknesses predicted to be greater than 3mm persist continually for a maximum of 102 hours (4.25 days) within the simulation period before dropping to below 3mm at all other times. Thicknesses greater than 7mm and 10mm occur continuously for a maximum of 36 hours (1.50 days) and 18 hours, respectively. The longest continuous period where predicted thicknesses are greater than 1mm at Point P1 is 176 hours (7.33 days).

Table 4.1. Maximum persistency of sediment thickness over the 30-day simulation period for installation of conical GBS#1 foundations.

Point	Maximum Thickness (mm)	Maximum Continuous Time of Sediment Thickness (hours with days in brackets)				Thickness at End of Simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
P1	13.26	18 (0.75)	36 (1.50)	102 (4.25)	176 (7.33)	<0.1
P2	3.11	0	0	6	22	<0.1
P3	1.35	0	0	0	6	<0.1
P4	1.26	0	0	0	2	<0.1
P5	1.00	0	0	0	2	<0.1

4.2.12 Approximately 20km west-southwest of the foundation layout (Point P2, **Figure 4.6**), predicted sediment thicknesses do not exceed 3.2mm at any time over the simulation period and the longest period where they continuously exceed 1mm is 22 hours (0.92 days). At Point P3, approximately 55km to the west of the foundation layout (and positioned outside the western boundary of the Dogger Bank Zone in the vicinity of a zone of sandeel habitat), the deposition at any one time rarely exceeds 1mm.

4.2.13 At a point mid-way along the Dogger Bank Teesside A & B export cable corridor (Point P4), predicted deposition never exceeds 1.3mm over the simulation period. The longest continuous period when it exceeds 1mm is 2 hours (0.08 days). At Point P5, about 20km from the coast, total deposition from the plume never exceeds 1mm.

4.2.14 **Table 4.1** shows that, at the end of the simulation, the predicted thickness of sediment resting on the seabed is less than 0.1mm. This demonstrates that once the supply of sediment from foundation installation was stopped at day 25, then re-suspension of the deposited sediment was the dominant process to reduce the thickness to effectively negligible values.

4.2.15 There is no discernible difference in deposition (i.e. it cannot be detected in the data) caused by changing the construction sequence from one foundation per day to no foundation on a single day (day six) or two foundations on a single day (day three).

4.3 Increase in Suspended Sediment Concentrations as a Result of Combined Drilled 12m Monopole Foundation and Cable Installation Activities

4.3.1 The results of the sediment dispersion simulation are presented as a series of maps showing predicted suspended sediment concentration in the bottom layer and bed thickness change.

Predicted Suspended Sediment Concentrations in the Bottom Layer for Construction of 12m Monopoles

4.3.2 **Figures 4.7** to **4.10** show maps of predicted suspended sediment concentration in the bottom layer for a 12m monopole. The concentrations are presented as excesses over the natural background concentration (2mg/l). **Figure 2.9** shows the worst case location of the 24 foundations relative to sensitive habitats.

4.3.3 **Figure 4.7** shows that the maximum suspended sediment concentrations predicted for construction of 12m monopole foundations are higher than those predicted for the conical GBS#1 foundations (**Figure 4.1**). Although the suspended sediment concentration decays to background levels at similar distances away from the foundation layout, the geographical spread of higher concentrations within the plume is greater for the 12m monopole foundations. For example, the maximum predicted suspended sediment concentration of greater than 200mg/l is predicted to occur a similar distance along the in-Zone section of the export cable route from the centre of the layout, but has a greater distribution to its north and to the north of the 24 foundations. Also, the geographical spread of concentrations greater than 2mg/l is greater, noticeably to the east of the 24 foundations. The predicted suspended sediment concentrations along the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank Zone are the same, given that the construction methodology of cable laying input into the model has not changed.

4.3.4 **Figure 4.8** shows the difference in suspended sediment concentration between the 12m monopole and conical GBS model runs. Differences are predominantly between 2mg/l and 20mg/l with larger (greater than 20mg/l confined to the location of the foundations and to their north. The difference along the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank Zone is zero.

4.3.5 The spatial extent of average predicted suspended sediment concentrations is generally greater for construction of the 12m monopoles (**Figure 4.9**) than the conical GBS#1 construction (**Figure 4.2**). However, the maximum distance from the centre of the foundations to where the background concentration of 2mg/l is reached is similar (approximately 18km to the south and 32km to the north of the in-Zone section of the cable). The results show that predicted average suspended sediment concentrations between 50mg/l and 100mg/l extend up to approximately 20km from the centre of the layout in a southwest direction in a band up to 9km wide adjacent to and north of the in-Zone section of the cable route.

4.3.6 **Figure 4.10** shows that the predicted exceedance times for suspended sediment concentration above background 2mg/l are greater for construction of the 12m monopoles than the installation of the conical GBS#1 foundations (**Figure 4.3**). It shows that 2mg/l is exceeded over 90% of the 30-day simulation period up to 15km southwest of the centre of the foundations, along the in-Zone section of the cable route. The predicted exceedance over 90% for the conical GBS#1 foundations occupies a smaller area. The predicted exceedance times along the Dogger Bank Teesside A & B export cable corridor outside the Dogger Bank Zone are the same, given that the construction methodology of cable laying input into the model has not changed.

Predicted Deposition and Re-suspension of Dispersed Sediment for Construction of 12m Diameter Monopoles

4.3.7 The greater suspended sediment concentrations predicted for constructing the 12m monopoles translate into small increases in the extent and maximum thickness of sediment deposition (**Figure 4.11**) compared to the installation of the conical GBS#1 foundations (**Figure 4.4**). However, the predicted greatest deposition (maximum 5-50mm) occurs over a broadly similar area and similar direction to the conical GBS#1 foundations. Away from the foundations and along the Dogger Bank Teesside A & B export cable corridor, the maximum deposition decreases to less than 5mm; the same as for conical GBS#1 foundations (because the construction methodology of cable laying input into the model has not changed).

4.3.8 Predicted average deposition is greater for constructing the 12m monopoles (**Figure 4.12**) than installation of the conical GBS#1 foundations (**Figure 4.5**). Average deposition between 1mm and 5mm occurs within the confines of the foundations over a larger area than the conical GBS#1 foundations. Predicted average deposition decreases to less than 0.5mm along much of the Dogger Bank Teesside A & B export cable corridor, and is effectively zero in places.

4.3.9 **Table 4.2** describes the maximum lengths of time that sediment maintains predicted thicknesses greater than 10mm, 7mm, 3mm and 1mm, based on time series of the plume over the 30-day simulation period at the same five selected points (Points P1 to P5 in **Figure 4.6**) used for the conical GBS#1 analysis. The results from Points P3, P4 and P5 are the same as those for the conical GBS#1 foundations (**Table 4.1**) as the construction methodology of the export cable is the same for both scenarios.

Table 4.2. Maximum persistency of sediment thickness over the 30-day simulation period for construction of a 12m monopole.

Point	Maximum Thickness (mm)	Maximum Continuous Time of Sediment Thickness (hours with days in brackets)				Thickness at End of Simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
P1	13.71	32 (1.33)	38 (1.58)	80 (3.33)	174 (7.25)	<0.1
P2	3.19	0	0	10	22	<0.1
P3	1.35	0	0	0	6	<0.1
P4	1.26	0	0	0	2	<0.1
P5	1.00	0	0	0	2	<0.1

4.3.10 The longest continuous time periods that sediment remains at predicted thicknesses greater than 10mm and 7mm at Points P1 and P2 are longer than those for the conical GBS#1 foundations. **Table 4.2** demonstrates that within the foundation layout (Point P1), sediment thicknesses greater than 10mm and 7mm persist for maximum continuous periods of 32 hours (1.33 days) and 38 hours (1.58 days), respectively. Thicknesses greater than 3mm and 1mm occur continuously for a maximum of 80 hours (3.33 days) and 174 hours (7.25 days), respectively; shorter than the conical GBS#1 foundations. At Point P2 (**Figure 4.6**) sediment thicknesses greater than 3mm only persist for a maximum continuous period of 10 hours (0.42 days) (longer than the conical GBS#1 foundations), whereas 1mm thick sediment persists for a maximum continuous period of 22 hours (0.92 days) (same as the conical GBS#1 foundations).

4.3.11 **Table 4.2** shows that at the end of the simulation the predicted thickness of sediment resting on the seabed is slightly thicker than for the conical GBS#1 foundations, but still less than 0.1mm.

Predicted Suspended Sediment Concentrations in the Surface Layer for Construction of 12m Monopoles

4.3.12 **Figure 4.13** shows the maximum suspended sediment concentration in the sea surface layer predicted for construction of 12m monopole foundations. **Figure 4.14** compares the maximum suspended sediment concentration at the surface and in the bottom layer, along a north-south section through the middle of the foundation layout. Although concentrations are similar in magnitude to the bottom layer their spatial extent above background concentrations is limited to within the foundations and less than 8km from their centre.

4.4 Fate of sediment that is not suspended during installation of drilled 12m monopole and GBS foundations

4.4.1 The plume dispersion model assumes that all sediment particles less than 0.18mm in diameter enter the water column in suspension as part of the plume. Sediment particles larger than 0.18mm are assumed to deposit at the source position.

4.4.2 For installation of a conical GBS, a worst case volume of 3,675m^3 is assumed for the side cast seabed preparation sediment (**Table 2.14**). A conservative particle size distribution for released sediment due to seabed preparation is based on an average from samples collected across Tranche B, with samples with greater than 3% gravel removed. The data shows that on average about 62% of the sediment (2,279m^3) less than 0.18mm is suspended in the plume model and 38% greater than 0.18mm remains (1,396m^3) at the source position as a residual side cast mound.

4.4.3 For installation of a 12m monopole foundation, a worst case volume of 6,220m^3 is estimated for the drill arisings which are released at the sea surface. An estimate of the average particle size characteristics for drill arisings was made by RPS Energy (2012b). Using these data and data from seabed sediment samples shows that about 63% of the sediment (3,919m^3) is suspended in the plume model and 37% (2,301m^3) settles rapidly to the seabed without entering the plume. The deposition of sediment from drill arisings is therefore considered as the worst case scenario.

Potential Morphology of the Deposited Sediment

4.4.4 The results from geotechnical assessments of the surface sediments show that the friction angle of the top 15-20cm of seabed sediment is around 30°, exemplary of that applying to loose granular sand. Immediately beneath the loose upper layer, the friction angle quickly rises indicatively to 45-50°.

4.4.5 An assumption is made that the non-suspended sediment initially forms a cone on the seabed with a friction angle of 30^o. In its undisturbed state this would produce a 9m high cone with a circular seabed footprint of about 750m^2 (diameter approximately 31m). However, due to subsequent reworking of the sediment pile by waves and tidal currents, it will be reduced in height and distributed over a wider area of seabed.

4.4.6 This is an extremely idealised worst case situation in that an assumption is made that the sand drops vertically through the water column from a point source without the effect of at least some dispersion by tidal currents and waves as it settles through the water column. In reality, as the sediment settles through the column it will be transported horizontally as well as vertically and would not deposit as the idealised cone, but as a flatter and wider based 'mound'. The geometry of this mound would depend on the particle size of the sediment, the settling velocity and the different forces applied to it as it falls through the water column (waves and tidal currents). It is difficult to determine what this shape would be so a cone shape has been chosen, because this was quantifiable.

4.4.7 Over time, due to subsequent reworking of the sediment pile, it will be reduced in height and distributed over a wider area of seabed. Given that the predominant driver for sediment transport across Dogger Bank is waves, it is believed conceptually that a cone that stands 9m proud of the seabed would be impacted regularly by waves and the sediment both transported along the bed and suspended into the water column through this process. The sediment that is initially moved by the waves would also be temporarily entrained close to the seabed by the prevailing tidal currents and transported a short distance by both mechanisms. Over time the gradual erosion of the top of the cone through wave action and its transport would lower the cone height, and its shape would be adapted into some form of low mound with a larger footprint than the original cone.

4.4.8 The shape of the mound would be difficult to determine precisely (and could not be modelled), but given the predominant waves from the north and the predominant north and south tidal current directions, it is assumed that most transport would be north and south forming an elongate north-south mound.

4.4.9 The closest analogy to the mound would be natural sand waves across Tranche A, which have an average wavelength of 100m (range 50-150m) and average crest height of 0.5m (maximum 2m). As a best estimate, if an elongate mound created by installation of a single foundation is assumed to form from 2,301m^3 of sediment (total sediment minus dispersed sediment in the plume), that is 100m wavelength and 31m wide, it will have a crest height of about 1.5m. The mound footprint will be about 3,100m^2.

Potential Particle Size of the Deposited Sediment

4.4.10 The seabed sediments of Dogger Bank are the surface expression of the thicker Holocene sands that sit on top of the Dogger Bank Formation which is predominantly mud. The build-up of these sand bodies has taken place over a long period of time under similar conditions to the present day, and hence they are expected to have similar particle sizes at depth to those on the seabed. Hence, in the modelling of the drill arisings scenario the sand fraction is broken down into its constituent particle sizes based on the surface averages.

4.4.11 The average particle size distribution of the drill arisings (this includes the Holocene sands and the Dogger Bank Formation mud) is described in Table 2.9. It shows that about 41% of the sediment is mud which is predominantly derived from the Dogger Bank Formation. The Holocene sands contain very low quantities of mud. About 55% of the sediment (on average) is sand-sized, with a particle size distribution similar to that of the seabed sediments (Table 2.8). This sand is mainly derived from the Holocene unit.

4.4.12 Sediment particles larger than 0.18mm will deposit at the source position. Table 2.8 shows that a high proportion (87%) of the sand in the drill arisings falls between 0.125 and 0.25mm (fine sand). On average, the sand of the drill arisings contains 60% between 0.125mm and 0.18mm and 27% between 0.18mm and 0.25mm. The 0.125-0.18mm component will be dispersed in the plume, but the 0.18-0.25mm component will deposit at the source position. This means that the median particle size of the disposed sediment will become slightly coarser (i.e. the median will shift towards the coarser part of the 0.125-0.25mm range) but will still remain within the fine sand classification. The particle size distribution of the sediment deposited at the source position will not be significantly different from the surrounding seabed sediments.

4.4.13 The mud fraction and the fraction of sand less than 0.18mm are assumed to disperse in the plume. This means that the sediment deposited at the source position will contain no mud regardless of how much mud the drill arisings contained at the initial time of dispersal. Hence, although there is a large difference between the mud contents of the drill arisings and the surrounding seabed, this variance does not make any difference with respect to the effect on the seabed at the disposal site.

4.5 Temporary Changes to Suspended Sediment Concentration at the Cleveland Potash Seawater Intake

4.5.1 The southern boundary of the nearshore portion of the export cable corridor is approximately 4km north of the Cleveland Potash intake pipe. The sediment plume released during construction of the export cable will impinge on the position of the intake. **Table 4.3** describes the suspended sediment concentrations through the water column at the location of the intake, extracted from the plume dispersion model outputs.

Table 4.3. Maximum suspended sediment concentrations through the water column at the Cleveland Potash intake.

Depth of Water from the Sea Surface(m)	Maximum Suspended Sediment Concentration (mg/l)
0	0
1	0
2	0
3	0
4	0
5	0
6	0
7	1
8	1
9	3

10	6
11	22
12	43
13	58
14	72

4.5.2 **Table 4.3** shows that the top 10m of the water column contains very small maximum suspended sediment concentrations at the intake pipe, which are insignificant compared to both background levels nearshore and concentrations developed during storm conditions. Below 10m water depth, maximum suspended sediment concentrations increase to between 22mg/l (11m water depth) and 72mg/l (at the seabed), which are within the range of background levels and smaller than those typically associated with storms.

4.5.3 The suspended sediment concentrations in the bottom layer climb to over 20mg/l about three days before the end of the 30-day simulation. During this time, excavation of the export cable trench is nearing the coast and so a plume that impinges on the location of the seawater intake is created. Values persist above 20mg/l until the end of the simulation. Because the simulation was not continued beyond the end of trenching, it is difficult to ascertain how quickly the suspended sediment concentrations will reduce back to effectively zero. However, once trenching is completed, the high energy nearshore zone is likely to rapidly disperse (i.e. over a period of hours) the suspended sediment in the absence of any further sediment input.

4.6 Interruption of Sediment Transport as a Result of Landfall Construction Activities

4.6.1 The consideration of the assessment of effects at the landfall site uses the conceptual understanding (**Appendix C**) as a baseline against which the potential effects and sensitivities of sediment transport to changes in the system are determined. Sediment transport across the intertidal zone has the potential to be affected by the installation and operation of a worst case scenario of two large temporary cofferdams, which would protect excavated trenches within which the export cables will be placed. Each cofferdam comprises a 15m-long cross-shore obstruction to sediment transport stretching seaward from the HDD exit hole.

4.6.2 Net sediment transport between Redcar and Marske-by-the-Sea is to the southeast, driven by waves approaching predominantly from the north. It is recognised that a cofferdam may intercept mobile sands along its northwest side that would otherwise be transported further southeast. This would, over time, result in a build-up (accretion) of sediment on the ‘updrift’ (northwest) side of the cofferdam and depletion (erosion) of sediment on the ‘downdrift’ (southeast) side. As the dominant net transport is southeasterly, no effects are anticipated to features north of the landfall due to this process.

4.6.3 For a single small cofferdam, the worst case scenario is that there would be an obstacle of only 15m extending across the intertidal zone. This has the potential to act as a short groyne-like structure, partially interrupting alongshore sediment transport. Assuming the worst case scenario, two cofferdams will be constructed and this will provide an almost continuous barrier to sediment transport for a period of up to 14 weeks. It is likely that the cofferdams will be operational during the summer months when there is relatively low wave action compared to winter, and longshore sediment transport will be at a minimum.

4.6.4 The rate of net annual alongshore transport specifically at the landfall site has not been established. However, only small sediment build-up on the west side of groynes at Redcar indicates that actual longshore sediment transport is low in this area (**Appendix C**). This means that whilst the 'downdrift' coastline may be affected by construction works, the magnitude of change is likely to be low and temporary. The presence of the cofferdams will not have an effect on natural coastal erosion rates given the short-term nature of the construction programme.

4.6.5 Not all of the alongshore transport of sediment occurs in the intertidal zone. Sediment transport occurs throughout what is termed the 'active' beach profile, which extends offshore from the high water mark to a nearshore point below low water, which is determined by the 'closure depth' of the beach profile (a parameter defined by the wave height and period in the nearshore zone). This could be described as the water depth offshore from which sediment is not disturbed during fair weather (wave) conditions. Whilst the predominant transport is from northwest to southeast, onshore to offshore movement occurs during storms.

4.6.6 The beach levels on the northwest and southeast sides of the cofferdams will be monitored and bypassing will be implemented if there is evidence for accretion to the northwest coupled with depletion to the southeast.

4.7 Increased Turbidity as a Result of Landfall Construction Activities

4.7.1 With respect to turbidity, part of the works in the intertidal zone will be confined within the cofferdams and isolated from the marine environment. Sediment removed from the cofferdam would be transferred to a barge for storage before being used for backfilling. No loss of sediment is expected during this exercise. Excavated sediment would be backfilled into the cofferdam pit by mechanical means (excavator) from the barge, and the beach re-instated. This activity would result in some disturbance to a strip of the beach alongside the pit. Any effect would be localised and short term and this would be assisted by the surface layers of sand replaced into the footprint being similar to that present in undisturbed adjacent areas.

4.7.2 Trenching, stock-piling and backfilling of the open trenches for placement and burial of the cables connecting the landfall to the offshore export cable has the potential to temporarily increase suspended sediment concentrations in the nearshore zone. Some of the sediment displaced during trenching and temporary stock-piling will become mobilised by wave and tidal action, and dispersed across the foreshore or advected by tidal currents in the nearshore zone, where dispersion would be widespread and rapid. Due to the low volumes of sediment displacement and the wide and rapid dispersion, the effects are predicted to be small.

5 ASSESSMENT OF EFFECTS DURING OPERATION

5.1 Introduction

5.1.1 The operational phase of the proposed Dogger Bank Teesside A & B equates, at a minimum, to the duration of the lease (nominally 50 years). During this time, the marine physical processes effects of the development are likely to be evident through persistent and direct changes, resulting from wave and tidal current interactions with the foundation structures.

5.1.2 There are anticipated to be no marine physical processes effects during the operation of the inter-array cables or export cables, where they are buried beneath the seabed, or during the operation of the landfall site, because the cables will be buried beneath the shore platform and cliff. However, potential effects to sediment transport may arise across the immediate subtidal zone and further offshore, where a cable on the seabed, protected by a variety of methods, including, but not limited to, rock armour, concrete mattressing, pipe, half-pipe or cable clip, is a possibility.

5.2 Effects of Foundation Structures on Tidal Currents

5.2.1 The effects on tidal currents of the conical GBS#1 foundations and associated infrastructure can be divided into two types:

- local changes in the vicinity of each foundation and infrastructure element created by interaction with the currents; and
- regional changes, which are the overall changes created by the group of foundations and infrastructure in a particular layout pattern.

5.2.2 To predict the effect of individual structures, each 6MW and 10MW GBS#1 foundation the geometries in 35m of water shown in **Figure 5.1** were used. Because the water depths across Dogger Bank Teesside A & B range from approximately 22m to 37m, the principles of scaling introduced in **Section 2.3** have been applied in the model at each foundation location. The 4MW foundation geometry is used to represent meteorological masts and vessel moorings and the 10MW geometry is also used to represent platforms (**Section 2.4**).

5.2.3 The regional effects on tidal currents of the foundation layouts have been predicted as changes to depth-averaged current velocity relative to the baseline. The foundation layouts in Dogger Bank Teesside A & B used in the simulations are shown in **Figures 2.7** (6MW layout) and **2.8** (10MW layout). The results of the hydrodynamic modelling are presented as maximum changes in tidal current velocity due to the foundations and infrastructure predicted over the entire 30-day simulation period.

5.2.4 **Figure 5.2** shows the maximum absolute change (increase or decrease) in depth-averaged tidal current velocity, predicted for the 10MW conical GBS#1 foundation layout over the 30-day simulation period. The strongest effect occurs along the project boundaries where the density of the foundations is highest. The maximum change is up to 0.006m/s along the project perimeters reducing to below 0.002m/s up to approximately 5km either side of the perimeter.

5.2.5 The maximum change of 0.006m/s corresponds with the maximum depth-averaged tidal current velocity of approximately 0.4m/s (**Figure 3.1**), although the two events may not necessarily be simultaneous. The maximum relative effect is up to approximately 2%, restricted to narrow (up to 2km wide) patches along the western boundaries of Dogger Bank Teesside A & B (**Figure 5.3**).

5.2.6 **Figure 5.4** presents the predicted effect of the 6MW conical GBS#1 foundation layout. The greatest effect occurs around the perimeters of Dogger Bank Teesside A & B, similar to the results of the simulation of the 10MW foundations. However, the effect is greater, with the maximum change to the depth-averaged current velocity predicted to be 0.008m/s along the project boundaries where the density of the foundations is highest. The effect of Dogger Bank Teesside A is greater than the effect of Dogger Bank Teesside B with changes reducing to less than 0.002m/s up to approximately 8km either side of the perimeter. The larger effect for the 6MW layout compared to the 10MW layout is related to the closer spacing between the 6MW foundations.

5.2.7 The maximum change in current velocity is less than 2% along narrow (up to 3km wide) bands restricted to the project boundaries (**Figure 5.5**). This maximum percentage change is within the natural variation of tidal current velocity across Dogger Bank and surrounding sea areas.

5.2.8 Overall, the effect on tidal currents of the 6MW conical GBS#1 foundation layout is generally greater than the effect of the 10MW foundation layout, and is considered to be the worst case scenario. However, the predicted change in tidal current velocities is so small (up to only 2%) that it is unlikely to affect the form of recent sediments over and above the natural tidal processes. For the worst case scenario, there are no interactions with the Hornsea Offshore Wind Farm Zone or the coast.

5.3 Effect of Foundation Structures on Waves

5.3.1 Waves are the primary control on sediment transport across Dogger Bank (**Appendix A**). Four different wave conditions were modelled, combining the two commonest directions of approach across Dogger Bank and two return periods:

- one-year return period waves approaching from the north;

- one-year return period waves approaching from the northeast;
- 50-year return period waves approaching from the north; and
- 50-year return period waves approaching from the northeast.

5.3.2 The wave model boundary is defined by the rectangle in **Figures 5.6** to **5.9**, and because there are no results outside this boundary, it is not possible to show any wave effects to the east of the Dogger Bank Zone. However, it is assumed that the wave effects to the east are approximate 'mirror-images' of the effects to the west that occur within the project boundary. Instead of attempting to delineate specific magnitude of effect in these areas, a box has simply been applied to indicate the general location of the potential effects.

5.3.3 The wind, wave and water level conditions input to the model are shown in **Table 5.1**.

Table 5.1. Wind, wave and water level input into MIKE21-SW.

Return Period	Wind Speed* (m/s)	Wave Height (m)	Wave Period (s)	Wave Direction (North°)	Water Level (m, mean sea level)
One-year	21.5	7.3	12.1	0	-1.6
	19.0	5	10.4	60	-1.6
50-year	26.6	11.5	15	0	-1.6
	24.1	7.5	12.2	60	-1.6

*wind direction was assumed to be in the same direction as offshore waves

5.3.4 **Figures 5.6** to **5.9** show the difference in significant wave height between the baseline condition and the conical GBS#1 layouts for the four input wave conditions. Comparison of **Figures 5.6** and **5.7** with **Figures 5.8** and **5.9**, respectively, shows that the effect of the 6MW conical GBS#1 foundation layout is greater than the effect of the 10MW conical GBS#1 foundation layout. In both scenarios there are no interactions with the Hornsea Offshore Wind Farm Zone or the coast.

5.3.5 Changes in significant wave height vary depending on the scenario that was modelled. The changes in wave height under the 50-year return period condition are less than for the one-year return period. This trend can be explained by the parameters shown in **Tables 5.1** and **5.2**. The 50-year condition has a maximum wave period of 15 seconds, compared to the one-year condition which has a maximum wave period of 12.1 seconds. According to **Table 5.2** (extracted from **Table 2.2**), the wave reflection factor for the shorter wave period is 27-71% higher under the one-year condition. This means that the reduced effect using the 50-year condition is due to the increased wave period and the reduction of the effect on the wave propagation process by the foundation.

Table 5.2. Wave reflection factors for 12 and 15 second wave periods.

Wave Period (s)	Foundation and Water Depth (m)									
	20.0		27.5		35.0		42.5		50.0	
	10MW	6MW	10MW	6MW	10MW	6MW	10MW	6MW	10MW	6MW
12.1	2.2	1.9	1.7	1.4	1.4	1.2	1.2	1.0	0.9	0.9
15.0	1.7	1.4	1.3	1.0	1.1	0.8	0.7	0.6	0.6	0.6

5.3.6 Maximum changes in significant wave height are for one-year waves from the north and northeast (for both layouts, **Figures 5.6** and **5.8**). At locations immediately outside the perimeter of the 10MW layout, significant wave heights change by up to +/-0.03m. The change reduces to less than +/-0.02m and +/-0.01m, up to approximately 8km and 50km from the boundaries, respectively (**Figure 5.6**). For the 6MW layout, the changes are up to +/-0.04m at the southern/southwestern and northern/northeastern perimeters of the projects reducing to less than +/-0.02m up to approximately 22km (waves from the north) and 17km (waves from the northeast) from the boundaries (**Figure 5.8**). Significant wave height reduces to less than +/-0.01m up to 75km north of the projects for waves from the north.

5.3.7 The pattern of decreased and increased wave heights along opposite sides of the project areas is due to simultaneous down-wave blocking and up-wave reflection. The wave energy that is not passing through the foundations is reflected by 180^{o} so that wave height increases on the 'up-wave' side of the projects and decreases on the 'down-wave' side. Between these two areas, within the main confines of each project, the wave reflection and blockage cancel each other out (**Figures 5.6** to **5.9**).

5.3.8 By comparing the change in significant wave height to the baseline condition for the worst case one-year waves (**Figures 3.3** and **3.4**), the percentage change has been calculated. **Figures 5.10** and **5.11** show the maximum relative change in wave height for one-year waves from the north and northeast directions for both the 10MW and 6MW layouts.

5.3.9 **Figure 5.10** shows that the maximum change in significant wave height for the 10MW conical GBS$^{\#}$1 foundations is approximately 1% along the outside edge of the southwestern perimeter of Dogger Bank Teesside B (a band about 5km wide). For the layout of 6MW conical GBS$^{\#}$1 foundations, the maximum increase is also 1% along the southern/southwestern perimeter of Dogger Bank Teesside B (in a band about 12km wide) and the northern perimeter of Dogger Bank Teesside A (**Figure 5.11**). These percentage changes are within the natural variation of wave height across Dogger Bank and surrounding sea areas and are unlikely to affect the form of recent sediments over and above the natural processes.

5.4 Increase in Suspended Sediment Concentrations as a Result of Foundations

5.4.1 The results of the plume dispersion modelling of the operational phase are presented as maximum and average changes in suspended sediment concentration in the bottom layer and sediment thickness deposited from the plume. The results are presented for a run of the model after one year (a one-year storm is applied to half of the foundations) and a run of the model after two years (all the foundations are struck by a 50-year storm). The following statistical measures were used:

- the maximum values of suspended sediment concentration and thickness of deposited sediment over the 30-day simulation period;
- the average values of suspended sediment concentration and thickness of deposited sediment over the 30-day simulation period; and
- the time over which suspended sediment concentration exceeds 2mg/l.

Predicted Suspended Sediment Concentrations in the Bottom Layer after One Year of Operation (One-year Storm)

5.4.2 **Figures 5.12** to **5.14** show maps of suspended sediment concentration in the bottom layer after one year of operation. The concentrations are presented as excesses over the natural background concentration (2mg/l).

5.4.3 **Figure 5.12** shows that the maximum suspended sediment concentrations predicted by the model at any time over the 30-day simulation period range from 50mg/l to 100mg/l. These concentrations occur as 4km wide patches along the perimeter of Dogger Bank Teesside A. Maximum concentrations are predicted to be 20-50mg/l across much of Dogger Bank Teesside A & B, gradually reducing with distance from the foundations until they are at the background of 2mg/l approximately 20-37km south of the projects boundaries and 13-34km north of the projects boundaries.

5.4.4 The average suspended sediment concentration in the bottom layer predicted over the simulation period is presented in **Figure 5.13**. The results show that across much of Dogger Bank Teesside A, average suspended sediment concentrations are less than 20mg/l, reducing to less than 10mg/l across Dogger Bank Teesside B. The concentration reduces to the background of 2mg/l approximately 12-28km south of the projects boundaries and 4-16km north of the projects boundaries.

5.4.5 **Figure 5.14** presents the exceedance time during the simulation of the predicted suspended sediment concentration above the background of 2mg/l. The map shows that 2mg/l is exceeded greater than 90% of the 30-day simulation period within the central part of Dogger Bank Teesside A and immediately to its south. Exceedance is generally greater than 60% across both Dogger Bank Teesside A & B.

Predicted Deposition and Re-suspension of Dispersed Sediment after One Year of Operation (One-year Storm)

5.4.6 **Figures 5.15** and **5.16** shows the maximum and average changes in deposition predicted at any time over the 30-day simulation period. The maximum deposition is predominantly 0.1-0.5mm with isolated patches up to 1mm. Deposition of 0.1mm is reached up to approximately 23km south and 30km north of the project boundaries. Average deposition is mainly less than 0.1mm with small patches between 0.1mm and 0.5mm.

5.4.7 Analysis of the time series of deposition from the plume over the 30-day simulation period at seven selected points (Points R1 to R7 in **Figure 5.17**) describes the persistency of sediment thickness on the seabed. **Table 5.3** demonstrates that the maximum thickness of sediment never exceeds 0.7mm at any of the Points.

Table 5.3. Maximum persistency of sediment thickness over the 30-day simulation period after one year of operation.

Point	Maximum Thickness (mm)	Maximum Continuous Time of Sediment Thickness (hours)				Thickness at End of Simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
R1	0.66	0	0	0	0	<0.1
R2	0.15	0	0	0	0	<0.1
R3	0.14	0	0	0	0	<0.1
R4	0.16	0	0	0	0	<0.1
R5	<0.1	0	0	0	0	<0.1
R6	0.22	0	0	0	0	<0.1
R7	<0.1	0	0	0	0	<0.1

Predicted Suspended Sediment Concentrations in the Bottom Layer after Two Years of Operation (50-year Storm)

5.4.8 **Figures 5.18** to **5.20** show maps of suspended sediment concentration in the bottom layer after two years of operation. The concentrations are presented as excesses over the natural background concentration (2mg/l).

5.4.9 **Figure 5.18** shows that the maximum suspended sediment concentration predicted after two years of operation induced by a 50-year storm for all 400 foundations (and other infrastructure) is higher than that predicted after one year of operation induced by a one-year storm for 200 foundations (and other infrastructure). Maximum suspended sediment concentrations predicted to be greater than 200mg/l occur as up to 20km long, 6km wide patches along the northern and southern perimeters of Dogger Bank Teesside A and the southwestern perimeter of Dogger Bank Teesside B. Across both projects, suspended sediment concentrations are greater than 20mg/l. Suspended sediment concentrations reduce to the background of 2mg/l approximately 40-54km south of the projects southern boundaries and 20-37km north of the northern boundaries.

5.4.10 Average suspended sediment concentrations are also greater and spread spatially further for the two-year operational scenario than the averages for the one-year operational scenario (**Figure 5.19**). Suspended sediment concentrations are between 10mg/l and 50mg/l across both projects and for up to approximately 19km to their south. Concentrations reduce to the background of 2mg/l up to approximately 36km south of the projects southern boundaries and up to 26km north of Dogger Bank Teesside A northern boundary.

5.4.11 **Figure 5.20** shows that the exceedance times for suspended sediment concentration above 2mg/l are predicted to be greater for the two-year operation than the one-year operation. The map shows that 2mg/l is exceeded greater than 90% of the 30-day simulation period in two patches, one to the south of Dogger Bank Teesside B and one within and to the south of Dogger Bank Teesside A, up to 15km south of their southern boundaries. Exceedance is generally greater 70% across both Dogger Bank Teesside A & B.

Predicted Deposition and Re-suspension of Dispersed Sediment after Two Years of Operation (50-year Storm)

5.4.12 The greater suspended sediment concentrations predicted after two years of operation translate into increases in the extent and maximum thickness of sediment deposition compared to after one year of operation (**Figure 5.21**). The predicted maximum thickness over the simulation period is 5mm with the majority of the project areas subject to maximum deposition between 0.5mm and 5mm. Thicknesses reduce to below 0.1mm approximately 16-30km from the southern boundaries of the projects and 13-35km from the northern boundaries.

Average deposition is predicted to be between 0.5mm and 5mm in a 32km long, 14km wide area located between the two projects (**Figure 5.22**). Elsewhere the maximum average deposition is less than 0.5mm reducing to less than 0.1mm approximately 23km southwest of Dogger Bank Teesside B and 19km north of Dogger Bank Teesside A.

5.4.13 **Table 5.4** describes the maximum lengths of time that sediment maintains thicknesses greater than 10mm, 7mm, 3mm and 1mm, based on time series of the plume over the 30-day simulation period at the same seven selected points (Points R1 to R7 in **Figure 5.17**) used for one year of operation. **Table 5.4** demonstrates that maximum sediment thickness is 1.7mm at R5. Thicknesses greater than 1mm persist for 72 hours (3.00 days), 70 hours (2.92 days), 32 hours (1.33 days) and 34 hours (1.42 days) at Points, R1, R3, R4 and R5, respectively.

Table 5.4. Maximum persistency of sediment thickness over the 30-day simulation period after two years of operation.

Point	Maximum Thickness (mm)	Maximum Continuous Time of Sediment Thickness (hours with days in brackets)				Thickness at End of Simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
R1	1.62	0	0	0	72 (3.00)	<0.1
R2	0.75	0	0	0	0	<0.1
R3	1.65	0	0	0	70 (2.92)	<0.1
R4	1.06	0	0	0	32 (1.33)	<0.1
R5	1.74	0	0	0	34 (1.42)	<0.1
R6	0.96	0	0	0	0	<0.1
R7	0.21	0	0	0	0	<0.1

Comparison of Scour Volumes against Naturally Occurring Release of Sediment during One-year and 50-year Storms

5.4.14 In order to compare the predicted sediment volumes released by the scour process into the context of the scale of natural processes, empirical formulae were used to determine sediment volumes disturbed during a one-year and 50-year storms across Dogger Bank without foundations in place.

5.4.15 The natural background suspended sediment concentration that could be expected to arise during an extreme condition of waves and currents was estimated using the methods recommended by Soulsby (1997) and augmented for wave-current interaction using the solution developed by Soulsby and Clarke (2005). The methods adopted are described in Section 4.7 of **Appendix E**.

5.4.16 In order to place the suspended sediment volumes into context, they were referenced to the total volume of sediment that would be suspended within a volume of water around a foundation in the proposed layout. Along the project boundaries the foundations are spaced at 750m centres. Accordingly, the natural suspended sediment volumes were predicted for a body of water with a footprint of 750m x 750m (the water depth was taken as a representative mean value of 27.6m). The total volume of suspended sediment within the associated volume of water was then compared against that which is predicted to be released due to scour around one foundation at the same storm return period.

5.4.17 The suspended volume of sediment was also converted to an equivalent depth of sand released from the seabed and compared against the potentially available sediment in borehole records. Provided that there is sufficient material available on the seabed, then the predicted volume of suspended sediment can occur under natural conditions. **Table 5.5** shows the results of the predictions.

Table 5.5. Natural suspended and GBS scour volumes released during one- and 50-year storm conditions.

Storm	Naturally Suspended Volume (m^3)	Maximum Scour Volume from GBS (m^3)	Equivalent Bed Depth Released in Suspension (mm)
One year	3,440	709	6
50 year	16,254	2,843	29

5.4.18 **Table 5.5** shows that, under a one-year storm, the naturally-occurring volumes of suspended sediment are predicted to be almost five times larger than those that could arise due to scour predicted around a 6MW conical GBS foundation. In order to sustain the predicted natural suspended sediment volume under one-year conditions, only 6mm of sand needs to be lifted off the seabed. The borehole logs suggest that the depth of free granular sediment on the seabed is probably at least of the order of 100-300mm and, therefore, there is more than sufficient naturally occurring sediment to sustain the predicted suspended volume at the one-year return period.

5.4.19 Under 50-year storm conditions, the naturally-occurring volumes of suspended sediment are almost six times greater than those that could arise due to scour predicted to occur around a 6MW conical GBS foundation. In order to sustain the predicted natural suspended sediment volume, only 29mm of sand needs to be lifted off the seabed. Compared to the depth of granular sediment suggested by the borehole logs, there is more than sufficient naturally occurring sediment to sustain the predicted suspended volume at the 50-year return period.

5.5 Effect on Sediment Transport of Seabed Cable Protection

5.5.1 During the lifetime of operation, the export cables will be buried below the intertidal zone and cliffs. Therefore, there will be no effects on coastal processes during the operational phase in these areas. However, in the subtidal zone, there is a possibility that up to four export cables will be on the surface each protected by 15m wide, 1.5m high rock armour (or some other form of remedial protection), which could potentially create a partial barrier to sediment transport. The main reason for the export cables to be surface laid is the absence of surface sand and the proximity of bedrock to the seabed.

5.5.2 Forewind indicate that from the cliffs for 750m seaward (across the intertidal zone and shallow subtidal zone), the export cables will be buried and have no effect on coastal processes. Forewind is also confident that burial or trenching of the export cables will be achievable for a minimum of 176.8km of the total 261km length of each cable in Teesside A, leaving a potential maximum of 84.2km of remedial protection per export cable. For Teesside B, Forewind is confident that a minimum of 144.3km of the total 220km length of each cable would be buried, leaving a potential maximum of 75.7km of remedial protection per export cable.

5.5.3 For the inter-array cables, the worst case dimensions of the remedial protection are 4.5m wide at the base, 0.5m wide at the top, and 0.7m high. The worst case length of inter-array cables is 1,900km (across both projects), of which 1,536km may be buried leaving a potential maximum of 364km of remedial protection.

5.5.4 The worst case dimensions for the inter-platform cables are the same as the export cables (15m wide at the base, 5m wide at the top and 1.5m high). The worst case length of inter-platform cables is 640km (across both projects), of which 508.8km may be buried leaving a potential maximum of 131.2km of remedial protection.

5.5.5 The key factors in determining the magnitude of the potential effect on bedload sediment transport of remedial protection are the type and aerial extent of transport on the bed. The two main drivers of transport in the nearshore zone are waves approaching the coast predominantly from the northeast and tidal currents further offshore. The aerial extent of transport will depend on the size of the zone in which sediment is actively mobile and the magnitude of transport within this zone. Along the coastline in the vicinity of the landfall, sediment transport takes places under three principal mechanisms (**Appendix C**):

- Longshore sediment transport: this transport mechanism occurs along the nearshore seabed as a result of wave-driven processes and occurs primarily as bedload transport. The net longshore sediment transport direction is from north to south but reversals in transport do occur due to local promontories (such as the South Gare Breakwater) and variations in wave climate, such as during storm events from a particular offshore direction.

- Cross-shore sediment transport: this transport mechanism also occurs along the nearshore seabed as a result of wave-driven processes and occurs primarily as bedload transport. However, the sediment is generally transported offshore from the beach to the nearshore during storm events and returned to the beach during more constructive wave conditions.

- Suspended sediment transport: this transport mechanism occurs across the wider seabed of Tees Bay and involves the transportation of sediments in suspension in the water column by the action of tidal currents. Often, wave stirring initiates the mobilisation of seabed sediments.

5.5.6 The placement of cables on the seabed in areas where burial cannot be achieved, and the potential remedial protection of these lengths, could potentially affect the longshore sediment transport processes if placed in the active transport zone. Cables, or cable protection works, would be unlikely to significantly affect cross-shore sediment transport since they would be laid broadly in alignment with the cross-shore transport direction, providing little obstruction to sediment movement. Cables, or cable protection works, would also be unlikely to significantly affect suspended sediment transport since this occurs throughout the water column and not only near to the bed in the layer occupied by cables or protection works.

5.5.7 To investigate the potential effect of remedial protection on the longshore sediment transport regime, it is necessary to define the active littoral zone. Houston (1995) provided a simple formula based on a mean annual significant wave height ($\dot{H}_s$):

$$h_{in} = 6.75\ \dot{H}_s$$

where (h_{in}) is the seaward limit of the active zone or closure depth.

5.5.8 The mean annual wave climate towards the western end of the Dogger Bank Teesside A & B export cable corridor is approximately 1.0–1.5m (**Appendix B**). Taking the higher value as a conservative approach, the Houston formula yields a closure depth in about 10m water depth, which is approximately 2km offshore from mean low water spring along the cable route. Consequently, any remedial protection seaward of 2km offshore would have no effect on longshore sediment transport processes.

5.5.9 Within the 2km nearshore zone defined by the closure depth, the main wave activity, and hence wave-driven sediment transport, is in the intertidal and shallow subtidal zones, with most of the sediment transport (although low along this coastline) to the southeast taking place in the intertidal zone. Given that the cables will be buried in the intertidal zone and for 350m seaward of mean low water spring, there will be no barrier to sediment transport and no effect on the highest magnitude longshore sediment transport at the landfall. Hence, there will be no effect on sediment supply to the beaches south of Marske-by-the-Sea and on the coastal geomorphology of adjacent coasts.

5.5.10 The presence of any remedial protection on the seabed, between 350m and 2km offshore from mean low water spring, would provide partial physical barriers to sand transport on, and close to, the seabed. Here, the rate of sediment transport is even lower (driven by tidal currents and lower energy waves) than the already low rates of wave-driven sediment transport along the coastline. Along the coastline, the low rates are manifest in only small sediment build-up on the west side of the Redcar groynes (northwest of the cable corridor). There is, therefore, limited potential for interruption of sediment transport in the 350m to 2km offshore zone. Hence, the magnitude of changes at locations 'downdrift' of the export cables, both locally and further down the sediment transport pathway, are likely to be very small. Larger volumes of sediment are transported in cross-shore directions during storm events, but this mode of transport is not affected by the remedial protection.

5.5.11 The remedial protection along the export cables may also provide a barrier to sand transport driven by tidal current flows. Flows would tend to accelerate over the protection and then decelerate on the 'down-flow' side, returning to baseline values a short distance from the structure. These changes in velocity would occur in a north to south direction on the flood flow and south to north on the ebb flow. The interruption to flows due to the presence of remedial protection could, potentially, have two effects:

- stop or slow down the bedload transport of sediment across the seabed by acting as a physical barrier; and
- induce local turbulence in the flow field which could cause unwanted secondary scour in a 'down-flow' direction.

5.5.12 The flood current along the Redcar and Cleveland coastline generally is to the south, flowing parallel to the coast. However, the presence of the Tees Estuary, various maritime structures, headlands and outcrops do locally affect the broader patterns. For example, a localised gyre exists immediately east of the South Gare Breakwater on the flooding tide which has the potential to move sediment transported in suspension in the water column westwards, back towards the mouth of the River Tees estuary.

5.5.13 Also, the majority of this sediment would most likely become entrained in the increased flow path over the protection and be transported from one side to the other, either as near-bed suspended sediment or 'rolled' over the armour as bedload. Any sediment that does become trapped against the cable protection will, eventually (over a long period of time given the volumes), create a 'ramp' across which other sediments can bypass the armouring.

5.5.14 Some sediment would infill the interstices between adjoining rocks within the structure and some would remain on the up-flow side of the armour that would otherwise have been transported beyond this position on the seabed. However, the relatively shallow side-slopes of the armour, about 1 in 4 (14°), are shallower than the critical angle of repose of wet sand (45º) and therefore the 'blocking' effect will be relatively small (compared with, for example, the entrapment against a vertical side slope of a protection structure).

5.5.15 With respect to local turbulence induced in the flow field, this could cause unwanted secondary scour in a 'down-flow' direction. However, it is considered to be small in comparison to the potential effects on net bedload transport, and is likely to be local in extent and temporary in nature.

5.5.16 In addition, the flood and ebb currents are different in magnitude, so that there is a net (residual) current. As the flood tide has slightly stronger currents than the ebb tide, the residual current generally is to the southeast. Given that the residual current is small, the secondary scour hole created in the down-flow direction on one side of the cable protection would be partially infilled by deposition into the scour on the reverse tide.

6 POTENTIAL EFFECTS DURING DECOMMISSIONING

6.1 Foundations and Cables

6.1.1 The effects are likely to include short-term increases in suspended sediment concentration and sediment deposition from the plume caused by foundation cutting or dredging and seabed disturbance caused by removal of cables and cable protection. The effects during decommissioning of the foundations, inter-array cables and export cables are considered to be less than those described during the construction phase. This is because there will be no need for seabed preparation or pile drilling and there is a possibility that cables are left *in situ* with no consequential increase in suspended sediment concentration.

6.2 Landfall

6.2.1 A plan for decommissioning the cable at the landfall has yet to be defined, although at the end of its field life it may be dismantled and re-used or decommissioned and left *in situ*, depending on foreseeable cliff erosion. During any decommissioning process, sections of buried cable under the cliff may be removed if there is a potential for exposure due to cliff erosion. This could have local effects on the stability of the cliff. If the cable is left *in situ*, there will be no effects on coastal processes. If the cable is removed from the beach and intertidal zone, there will be temporary local effects of a type and duration likely to be similar to the construction phase activities.

7 CUMULATIVE EFFECTS

7.1 Cumulative Impact Assessment Strategy

7.1.1 There are two key steps to the Forewind Cumulative Impact Assessment (CIA) Strategy, which both involve 'screening' in order to arrive, ultimately, at an informed, defensible and reasonable list of other plans, projects and activities to take forward in the assessment.

7.1.2 The first step in the CIA for marine physical processes involved an appraisal of the key effects relevant to each of the receptors that have been identified (**Table 7.1**). For each effect, the potential for effects to occur on a cumulative basis has been identified, both within and beyond the Dogger Bank Zone. This also identifies where cumulative impacts are not anticipated, thereby screening them out from further assessment. For marine physical processes, the potential for cumulative impacts is identified in relation to other renewable energy projects and aggregates (**Table 7.1**).

Table 7.1. Potential cumulative impacts.

Effect	Potential cumulative impact in the Dogger Bank Zone and cable corridors	Potential cumulative impact outside the Dogger Bank Zone	Data confidence (Dogger Bank Zone and cable corridors)	Data confidence (outside the Dogger Bank Zone)
Offshore wind farms	Yes	Yes	Medium to High	Low to High
Aggregates	Yes	Yes	N/A	Low to High
Potash mining dredge disposal	Yes	Yes	Medium to High	Medium to High
Subsea cables and pipelines	No	No	N/A	N/A
Other renewable energy projects	No	No	N/A	N/A
Underground coal gasification	No	No	N/A	N/A
Oil and gas	No	No	N/A	N/A
Dredging	No	No	N/A	N/A
Marine disposal	No	No	N/A	N/A
Carbon capture	No	No	N/A	N/A

7.1.3 Where the first step has indicated the potential for cumulative impacts, the second step in the CIA has involved the identification of the actual individual plans, projects and activities within those broad industry levels for inclusion.

In order to inform this, Forewind has produced an exhaustive list of plans, projects and activities occurring within a very large study area encompassing the greater North Sea and beyond (referred to as the 'long list'). The long list has been appraised, based on the confidence Forewind has in being able to undertake an assessment from the information and data available, enabling individual plans, projects and activities to be screened in or out.

7.1.4 The plans, projects and activities relevant to marine physical processes are presented in **Table 7.1** along with the results of the screening exercise that identifies whether there is sufficient confidence to take these forward in a detailed cumulative assessment. It should be noted that where Forewind is aware that a plan, project or activity could take place in the future, but has no information on how the plan, project or activity will be executed, it is screened out of the assessment. Also, existing projects, activities and plans are considered to be a part of the established baseline and are therefore not included in the cumulative assessment.

7.1.5 Specific plans, projects and activities screened in include the following offshore wind farm developments (**Figure 7.1**):

- Dogger Bank Creyke Beck;
- Dogger Bank Teesside C & D;
- Project One of the Hornsea Zone;
- Teesside;
- Blyth Demonstration;
- H2-20;
- Idunn Energipark; and
- Nord-Ost Passat I, II and III.

7.1.6 Also screened in are aggregate license areas in the Humber Aggregate Region (all the license areas are owned by CEMEX UK Marine Ltd) (**Figure 7.1**):

- application Area 466 immediately northwest of Dogger Bank Creyke Beck B; and
- application Area 485 (1 and 2) approximately 25km to the southwest of Dogger Bank Creyke Beck A and 20km south of the Dogger Bank Creyke Beck export cable corridor.

7.1.7 Dredge disposal from potash mining outfalls is also screened in (**Figure 7.1**).

7.1.8 Forewind has developed a range of potential construction programmes that may apply to Dogger Bank Teesside A & B, Dogger Bank Creyke Beck, and

Dogger Bank Teesside C & D. The minimum and maximum construction periods for each project are three years and six years, respectively. The worst case scenario from a marine physical processes perspective would be for all projects to be constructed at the same time over a three-year period. This would provide the greatest opportunity for interaction of waves, tidal currents and sediment transport during construction and operation of all projects.

7.2 Cumulative Construction Effects of Dogger Bank Teesside A & B with Dogger Bank Creyke Beck and Dogger Bank Teesside C & D

7.2.1 Cumulative construction effects between the six individual projects within the Dogger Bank Zone will be restricted to the potential interaction of sediment plumes that may arise during the construction phases, particularly from foundation installation and cable (export and inter-array) laying activities, and the subsequent deposition of disturbed sediments on the seabed.

7.2.2 The sediment plume and deposition effects arising from the worst case construction scenario adopted for Dogger Bank Teesside B (foundation installation and cable laying activities) are described in **Section 4** of this Environmental Statement. This assessment considered both conical GBS and 12m pile foundations. The similar effects arising from both of these foundation options for the worst case construction scenario adopted for Dogger Bank Creyke Beck B were similarly assessed and described in the Dogger Bank Creyke Beck Environmental Statement (Forewind, 2013). The worst case scenario for cumulative effects would potentially arise if the construction programme for foundation installation and cable laying activities is synchronous across projects and any plumes that are created overlap across project areas.

7.2.3 To assess this worst case, it has been assumed that a similar construction sequence is adopted for foundation installation and cable laying in all other projects at the same time as Dogger Bank Teesside B and Dogger Bank Creyke Beck B. In this scenario, there would be potential for some of the respective plumes to interact, creating a larger overall plume, with higher suspended sediment concentrations and, potentially, a greater depositional footprint on the seabed. However, given that the numerical modelling has identified that the maximum thickness of sediment that would remain deposited on the seabed at the end of the 30-day simulation periods for both Dogger Bank Teesside B and Dogger Bank Creyke Beck B would be less than 0.1mm (for both conical GBS and 12m pile foundation scenarios), it is considered, using expert judgment, that the potential for thick sequences of sediment persistently accumulating on the seabed due to plume interaction from all six projects is low, even if the construction programmes coincide.

7.3 Cumulative Operation Effects of Dogger Bank Teesside A & B with Dogger Bank Creyke Beck and Dogger Bank Teesside C & D

7.3.1 The cumulative effect of operation of two or more projects could occur for one or more of the marine physical processes parameters; tidal currents, waves and/or sediment transport. If Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck are completed at a similar time, and all without scour protection, then there will be cumulative effects. In order to predict the potential cumulative effects, hydrodynamic, wave and sediment plume dispersion models have been run for all six projects simultaneously.

7.3.2 The models have been run for 6MW layouts in each project, on the assumption that in each project they are the worst case for marine physical processes. This is supported by the results of the modelling for Dogger Bank Teesside A & B only which shows that the 6MW layout is the worst case for effects on tidal currents, waves and sediment transport. The 4MW foundation geometry is used to represent meteorological masts and vessel moorings and the 10MW geometry is used to represent platforms (**Section 2.4**). The principles of scaling foundations in different water depths introduced in **Section 2.3** have also been applied in Dogger Bank Creyke Beck and Dogger Bank Teesside C & D at each foundation location.

Predicted Cumulative Effects of Operation of Projects on Tidal Currents

7.3.3 The regional effects on tidal currents of the foundation layouts have been predicted as changes to depth-averaged current velocity relative to the baseline. The GBS#1 foundation layouts in Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck used in the simulations are shown in **Figure 7.2**. The results of the hydrodynamic modelling are presented as maximum changes in tidal current velocity due to the foundations and infrastructure predicted over the 30-day simulation period.

7.3.4 **Figure 7.3** shows the maximum absolute change (increase or decrease) in depth-averaged tidal current velocity over the 30-day simulation period. The strongest effect occurs along the project boundaries where the density of the foundations is highest. The greatest effect is predicted along the western boundaries of Dogger Bank Creyke Beck B and Dogger Bank Teesside D where the maximum change is just over 0.01m/s in small patches less than 1km wide. Maximum changes of up to 0.004m/s occur across most of each project with changes reducing to 0.002m/s up to approximately 17km outside the boundaries.

7.3.5 The maximum relative effect is up to approximately 3%, restricted to narrow (up to 2km wide) patches along the western boundaries of Dogger Bank Creyke Beck B and Dogger Bank Teesside D (**Figure 7.4**). This predicted change in tidal current velocities is so small that it is unlikely to affect the form of recent sediments over and above the natural tidal processes. For the worst case scenario, there are no cumulative tidal current interactions with the Hornsea Offshore Wind Farm Zone or the coast.

Predicted Cumulative Effects of Operation of Projects on Waves

7.3.6 The same four wave conditions that were used to model Dogger Bank Teesside A & B only (**Section 5.3**) have been applied in the cumulative wave model runs and their description is not repeated here. **Figures 7.5** and **7.6** show the difference in significant wave height between the baseline condition and the conical GBS#1 layouts for the four input wave conditions.

7.3.7 Maximum changes in significant wave height are for one-year waves from the north and northeast (**Figures 7.5**). For one-year waves from the north the changes are up to +/-0.06m at the southern and northern perimeters of all the projects apart from Dogger Bank Creyke Beck B reducing to less than +/-0.02m up to approximately 30km south from the southern boundary of Dogger Bank Creyke Beck A and greater than 60km north from the northern boundaries of Dogger Bank Teesside C & D. For one-year waves from the northeast, changes are up to +/-0.05m at the southwestern and northeastern perimeters of the projects apart from Dogger Bank Teesside B and Dogger Bank Teesside C reducing to less than +/-0.02m up to approximately 65km southwest of the Dogger Bank Creyke Beck southwest boundaries and northeast of the Dogger Bank Teesside D boundary.

7.3.8 **Figure 7.7** shows the maximum relative change in wave height for one-year waves from the north and northeast directions. The maximum change in significant wave height is approximately up to 1.5% along the southern and southwestern boundaries of Dogger Bank Creyke Beck A (a band up to 4km or 13km wide, depending on wave direction). Along the northern and northeastern boundaries of Dogger Bank Teesside A, Dogger Bank Teesside C and Dogger Bank Teesside D, predicted changes are mainly up to 1%. These percentage changes are within the natural variation of wave height across Dogger Bank and surrounding sea areas and are unlikely to affect the form of recent sediments over and above the natural processes.

Predicted Cumulative Suspended Sediment Concentrations in the Bottom Layer after One Year of Operation (One-year Storm)

7.3.9 The worst case operational layouts, location and sequencing of GBS#1 foundations and estimates of scour described in **Sections 2.7** and **2.8** for modelling the operational plume dispersion for Dogger Bank Teesside A & B only have been applied in the cumulative assessment of changes in suspended sediment concentrations. The methodology is not repeated here. It is assumed that the 400 6MW conical GBS#1 foundations (plus associated platforms, meteorological masts and moorings) will be installed over a (minimum) two year construction period simultaneously in each pair of projects (200 per project area) (**Figure 7.2**). The cumulative operational layout after one year of operation is shown in **Figure 7.8**.

7.3.10 **Figures 7.9** to **7.11** show maps of predicted suspended sediment concentration in the bottom layer. The concentrations are presented as excesses over the natural background concentration (2mg/l).

7.3.11 **Figure 7.9** shows the maximum concentration in the bottom layer predicted by the model at any time over the 30-day simulation period. The maximum suspended sediment concentration is predicted to be 50-100mg/l in the eastern corners of Dogger Bank Creyke Beck A and Dogger Bank Teesside A (patches up to 15km long and 6km wide). Across all project areas, suspended sediment concentrations range mainly from 10mg/l to 50mg/l with lower values (2-10mg/l) across parts of Dogger Bank Teesside C & D. Predicted concentrations gradually reduce to the background of 2mg/l up to approximately 48km south of the southern project boundaries.

7.3.12 Predicted average suspended sediment concentrations in the bottom layer are below 20mg/l (**Figure 7.10**). They are highest across Dogger Bank Creyke Beck A and Dogger Bank Teesside A and lowest across Dogger Bank Teesside C & D. The average suspended sediment concentration reduces to the background of 2mg/l approximately 28km south of the southern project boundaries.

7.3.13 **Figure 7.11** presents the exceedance time during the simulation of the predicted suspended sediment concentration above the background of 2mg/l. The map shows that 2mg/l is exceeded over 90% of the 30-day simulation within and south of Dogger Bank Creyke Beck A and Dogger Bank Teesside A. Exceedance time is generally greater across Dogger Bank Creyke Beck (20-90%) and Dogger Bank Teesside A & B (20-90%), than across Dogger Bank Teesside C & D (10-70%).

Predicted Cumulative Deposition and Re-suspension of Dispersed Sediment after One Year of Operation (One-year Storm)

7.3.14 **Figure 7.12** shows that the maximum change in deposition predicted at any time over the 30-day simulation period is less than 1mm in patches across and immediately outside each project. Deposition between 0.1mm and 0.5mm is predicted to occur across all the project areas and up to approximately 23km north and south of the project boundaries. Average change in deposition is 0.1-0.5mm in large patches (up to 48km long and 17km wide) across Dogger Bank Teesside C & D, and Dogger Bank Creyke Beck A (**Figure 7.13**).

7.3.15 Analysis of the time series of deposition from the plume over the 30-day simulation period at seven selected points (Points S1 to S7 in **Figure 7.14**) describes the persistency of sediment thickness on the seabed. **Table 7.2** demonstrates that the maximum thickness of sediment never exceeds 0.7mm at any of the Points.

Table 7.2. Maximum persistency of sediment thickness over the 30-day simulation period after one year of operation.

Point	Maximum Thickness (mm)	Maximum Continuous Time of Sediment Thickness (hours)				Thickness at End of Simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
S1	0.66	0	0	0	0	<0.1
S2	0.23	0	0	0	0	<0.1
S3	<0.1	0	0	0	0	<0.1
S4	<0.1	0	0	0	0	<0.1
S5	0.58	0	0	0	0	<0.1
S6	0.36	0	0	0	0	<0.1
S7	0.51	0	0	0	0	<0.1

Predicted Cumulative Suspended Sediment Concentrations in the Bottom Layer after Two Years of Operation (50-year Storm)

7.3.16 **Figures 7.15** to **7.17** show maps of suspended sediment concentration in the bottom layer after two years of operation. The concentrations are presented as excesses over the natural background concentration (2mg/l).

7.3.17 **Figure 7.15** shows that the maximum suspended sediment concentration predicted after two years of operation is higher than that predicted after one year of operation. Maximum suspended sediment concentrations are predicted to be greater than 200mg/l in up to 22km long, 7km wide patches along the perimeters of all projects except Dogger Bank Teesside C. Across all projects, suspended sediment concentrations are generally greater than 50mg/l. Concentrations reduce to the background of 2mg/l up to approximately 55km south of the southern boundaries and up to 39km north of the northern boundaries.

7.3.18 Average suspended sediment concentrations are also greater and spread spatially further for the two-year operational scenario than the averages for the one-year operational scenario (**Figure 7.16**). Suspended sediment concentrations are between 50mg/l and 100mg/l across the adjacent boundaries of Dogger Bank Creyke Beck A & B. Predicted concentrations across all projects are generally 10mg/l and 50mg/l reducing to the background of 2mg/l up to approximately 39km south of the southern boundaries and up to 24km north of the northern boundaries.

7.3.19 **Figure 7.17** shows that for the two-year operation, 2mg/l is exceeded greater than 90% of the 30-day simulation period in large areas across and up to 17km south of Dogger Bank Creyke Beck and Dogger Bank Teesside A.

Exceedance is generally greater 70% across Dogger Bank Creyke Beck and Dogger Bank Teesside A & B, reducing to 50-70% across Dogger Bank Teesside C & D.

Predicted Cumulative Deposition and Re-suspension of Dispersed Sediment after Two Years of Operation (50-year Storm)

7.3.20 The greater suspended sediment concentrations predicted after two years of operation translate into increases in the extent and maximum thickness of sediment deposition compared to after one year of operation (**Figure 7.18**). The majority of the project areas are predicted to have maximum thickness of sediment over the simulation period of 5mm, reducing to 0.1mm about 31-43km from the southern boundaries of the projects and 23-33km from the northern boundaries.

7.3.21 Average deposition is predicted to be 0.1-0.5mm in numerous patches across and outside most of the projects (**Figure 7.19**). The largest patch is up to 22km long and up to 12km wide. Average deposition is generally higher across Dogger Bank Teesside C & D than across the other projects. Average deposition is predicted to reduce to 0.1mm close to the southern boundaries and approximately 12-32km north of the northern boundaries.

7.3.22 **Table 7.3** describes the maximum lengths of time that sediment maintains thicknesses greater than 10mm, 7mm, 3mm and 1mm, based on time series of the plume over the 30-day simulation period at the same seven selected points (Points S1 to S7 in **Figure 7.14**) used for one year of operation. **Table 7.3** demonstrates that maximum sediment thickness is 5.7mm at S1 and thicknesses greater than 3mm and 1mm persist for 244 hours (10.17 days) and 332 hours (13.83 days), respectively. At all other points, thicknesses never exceed 2.2mm and persist at greater than 1mm between 2 hours (0.08 days) (S4) and 80 hours (3.33 days) (S5).

Table 7.3. Maximum persistency of sediment thickness over the 30-day simulation period after two years of operation.

Point	Maximum Thickness (mm)	Maximum Continuous Time of Sediment Thickness (hours with days in brackets)				Thickness at End of Simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
S1	5.70	0	0	244 (10.17)	332 (13.83)	0.13
S2	1.22	0	0	0	52 (2.17)	<0.1
S3	1.18	0	0	0	50 (2.08)	<0.1
S4	1.03	0	0	0	2	<0.1
S5	1.41	0	0	0	38 (1.58)	<0.1
S6	1.63	0	0	0	6	<0.1
S7	2.17	0	0	0	80 (3.33)	<0.1

7.4 Cumulative Effects of the Dogger Bank Projects with Project One of Hornsea Offshore Wind Farm

7.4.1 The northern perimeter of the Hornsea Round 3 Zone is located approximately 75km south of the southern boundary of the Dogger Bank Zone (**Figure 7.1**). The Hornsea Zone covers an area of 4,735km^2. With a maximum capacity of 1.2GW, Project One (407km^2), located towards the centre of the Hornsea Zone, is the first of a number of wind farm projects planned for the Hornsea Zone to meet a target zone capacity of 4GW by the year 2020. Based on a capacity of up to 1.2GW, there will be between 150 and 332 wind turbines (depending on wind turbine type) within Project One, with wind turbine capacities ranging from 3.6MW up to 8MW.

7.4.2 Smart Wind is currently completing the Environmental Statement for Project One within the Hornsea Round 3 Zone (RPS Energy, 2013). The assessment of effects on marine physical processes at the wind farm site was carried out on the basis of the likeliest densest layout and the use of conical gravity base foundations presenting the greatest overall blockage effect. The worst case construction scenario was considered to be up to 332 foundations with a minimum spacing of 924m with up to 17,839m^3 of sediment excavated per foundation with disposal of the dredged sediment from the dredging vessel approximately 500m from the seabed preparation site.

7.4.3 The offshore cable route will extend from a proposed landfall at Horseshoe Point in Lincolnshire, offshore in a northeast direction to the southern boundary of Project One. For construction of the export cable, a worst case scenario of cables up to 150km in length was considered with a burial depth below seabed of 3m, excavated using jetting.

7.4.4 For plume dispersion modelling, RPS Energy (2013) assumed that 5% of the sediment that would be excavated for seabed preparation (892 m^3) would be dispersed into the water column as fines (less than 63 microns). Four foundation locations were simulated to capture differences in tidal flows (and consequent potential differences in plume dispersion patterns) across Project One. The indicative worst case of increases in suspended sediment concentration above background levels extends for approximately 10km north of the northern boundary of the Project One area.

7.4.5 RPS Energy (2013) also concluded that the dispersion of fine sediment from seabed preparation and disposal operations will be relatively rapid (lasting for less than 24 hours) and widespread. Increases in suspended sediment concentration greater than 10mg/l above background levels were not observed outside Project One and concentrations return to background levels almost immediately after the construction is complete.

7.4.6 Scour protection is an integral part of the Hornsea project design, meaning that operational scour will effectively be zero and no plume will be available to interact with the Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck plume.

Interaction of the Project One Construction Plume with the Combined Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck Construction Plume

7.4.7 It is considered unlikely that the construction plume of Hornsea (there will be no operational plume because of scour protection) would interact with the cumulative construction plume of Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D (foundations and cable laying) for several reasons:

- the shortest distance between the Dogger Bank and Hornsea developments is approximately 65km and construction plumes containing suspended sediment concentrations above the background are predicted to occur a maximum of 10km north of Project One; and
- there is a low probability that construction of Dogger Bank Teesside A & B, Dogger Bank C & D and Dogger Bank Creyke Beck will overlap with construction of Project One of Hornsea.

Interaction of the Project One Construction Plume with the Combined Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck Operation Plumes

7.4.8 The worst case plume and deposited sediment from the plume for the combined operation of Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck are predicted to extend up to within 30km of the northern boundary of Hornsea Project One. It is unlikely that the Project One construction plume will interact with the Dogger Bank plume because the latter is created by a 50-year storm during which time it is unlikely that any construction at Project One will be possible.

7.5 Cumulative Effects of the Dogger Bank Projects with Project Two of Hornsea Offshore Wind Farm

7.5.1 Smart Wind is currently undergoing the scoping phase of the Environmental Impact Assessment of Project Two within the Hornsea Round 3 Zone. To date a Scoping Report has been published (RPS Energy, 2012) which considers the potential effects of the wind farm and its associated offshore cable route and onshore infrastructure. The development is proposed with an estimated capacity of up to 1.8GW and covers an area of 400km^2 adjacent to the north and west of Project One

7.5.2 No specific project details are currently available, but given the similar size and position relative to Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck, similar conclusions to those drawn for Hornsea Project One apply.

7.6 Cumulative Effects of the Dogger Bank Projects with other UK Offshore Wind Farms

7.6.1 Teesside offshore wind farm (EDF Energy) is currently being constructed with a predicted completion date of summer 2013. The wind farm is located 1.5km from the Redcar and Cleveland coast (at its closest point, **Figure 7.1**) and will comprise 27 turbines with the capacity to produce over 60MW of electricity. The turbines will be located in a 10km^2 area of seabed, within which they will be installed in three rows in water depths of up to 16m.

7.6.2 The construction of the Teesside wind farm will be completed before construction/operation of the Dogger Bank projects. Hence, the only cumulative effects would arise from operation of the Teesside wind farm. However, given that it is the intention to place scour protection around the turbine foundations (Entec UK Ltd, 2004), there will be no operational sediment plume from the wind farm and hence no cumulative effect with the Dogger Bank projects.

7.6.3 The National Renewable Energy Centre (Narec) proposes to develop infrastructure for a 100MW offshore wind demonstration project (Blyth Demonstration Project). The development is proposed to consist of three arrays offshore (**Figure 7.1**), each containing five turbines. The turbines would be 1km apart with over 5km spacing between each array.

7.6.4 Given the coastal location of the site, the only potential cumulative effects may be with the Dogger Bank Teesside A & B and Dogger Bank Teesside C & D export cable constructions. The Blyth Demonstration Project is 55km north of the Dogger Bank Teesside A & B export cable corridor and the construction plume of the cable only extends for about 20km north (**Figure 4.1**). A similar plume can be expected from laying of the Dogger Bank Teesside C & D export cable which is a few kilometres closer to Teesside wind farm, and hence it is unlikely that the construction plume of the export cable corridors would overlap with either the construction or operation plumes of the limited number of turbines in the Blyth Demonstration Project, even if they were simultaneous.

7.7 Cumulative Effects of the Dogger Bank Projects with German and Norwegian Offshore Wind Farms

7.7.1 H2-20 and Nord-Ost Passat I, II and III offshore wind farms are in the German sector of the North Sea (**Figure 7.1**). The consent application for H2-20 has been submitted for a 400MW development containing 80 wind turbines. The proposed site has an area of 121km^2 and is approximately 90km east-northeast of Dogger Bank Teesside A and Dogger Bank Teesside D. The Nord-Ost Passat I, II and III wind farms are adjacent to each other (**Figure 7.1**) and all are in the early planning and consent stages. The proposed Nord-Ost Passat I and II wind farms are currently planned to both have a capacity of 360MW whereas the proposed capacity of Nord-Ost Passat III wind farm is 480MW.

7.7.2 Idunn Energipark is in the Norwegian sector of the North Sea and is in the early planning stages. The proposed development is currently planned to contain 200 6MW turbines.

7.7.3 The worst case cumulative operation plume for Dogger Bank Teesside A & B, Dogger Bank C & D and Dogger Bank Creyke Beck is predicted to be mainly confined to UK waters (**Figure 7.15**). Given the distance of the German and Norwegian wind farms from the Dogger Bank Zone, the likelihood of interaction with the Dogger Bank projects is low.

7.8 Cumulative Effects of the Dogger Bank Projects with Aggregates Area 466

7.8.1 Application Area 466 is located adjacent to the northern boundary of Dogger Bank Creyke Beck B and the western boundary of Dogger Bank Teesside C (**Figure 7.1**) and may become licensed during the lifetime of the Dogger Bank development. The aggregate area is located within the extent of the footprints of the Dogger Bank cumulative plumes generated from both construction and operation. Aggregate extraction activities at Area 466 have the potential to release further suspended sediment into the water column and to give rise to cumulative effects.

7.8.2 The Area 466 application is for the extraction of three million tonnes of aggregates over 15 years, with a maximum dredged volume of 600,000 tonnes in any one year (EMU Ltd, 2009). It is further proposed to limit the annual extraction for the first five years to a maximum of 200,000 tonnes.

7.8.3 The proposed extraction method is trailer dredging. During this operation, the drag head is trailed slowly over the seabed and a mixture of sediment and seawater is pumped up the dredge pipe and into the hold, with the excess water in the hold returned to the sea via spillways located along the sides of the dredger. The returned water would contain a proportion of suspended sediments. Screening may also be undertaken in order to increase the proportion of sand (or gravel) in the hold and results in a further return to the water column of a mix of sediment size fractions.

7.8.4 It is anticipated that, on average, one dredger will visit the site per week. The dredgers anticipated to work on Area 466 take approximately six hours to load a 7,000 tonne cargo. This equates to dredging taking place around 1% of any one year, if the estimated annual off-take of 200,000 tonnes is realised. When a maximum annual extraction of 600,000 tonnes is sought, the occupancy will potentially increase to 3% in any one year.

7.8.5 Some screening of the aggregate is expected in order to land a resource of 50% sand and 50% gravel. It is estimated that for every tonne of cargo loaded to a sand/gravel ratio of 50/50, about 0.43 tonnes of sand would be rejected as a result of screening. Therefore, for an average load of 7,000 tonnes, approximately 3,000 tonnes of predominantly fine grade sand will be returned to the seabed.

7.8.6 The Environmental Statement for aggregate Area 466 (EMU Ltd, 2009) concluded that increases in near-bed suspended sediment concentration during a spring tide are predominantly around 5mg/l (up to 2km east-southeast of the dredging path and up to 1.5km to the west), rising to 15mg/l (confined to a corridor 100-250m either side of the dredge path), peaking at 30mg/l within the dredge area itself. EMU Ltd (2009) suggested that these suspended sediment concentrations are similar to those expected during storm activity and the conclusion was reached that there would be no significant changes in the suspended sediment concentration above background levels.

7.8.7 Modelled deposition rates are predicted to be in the order of 1-2mm per tide within 100m of the dredge track and 0.5mm per tide away from the dredge track during spring tides. Deposition during neap tides was predicted as 5mm per tide along the dredge path and <0.5 mm per tide away from the dredger.

Interaction with the Combined Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck Construction Plume

7.8.8 In terms of potential cumulative effects resulting from the interaction of the Area 466 plume with the construction plumes of Dogger Bank Teesside A & B, Dogger Bank Creyke Beck, and Dogger Bank Teesside C & D (foundations and cable laying), the greatest effect will occur when:

- construction activities are taking place simultaneously along the northwestern part of Dogger Bank Teesside B, the northern part of Dogger Bank Creyke Beck B and the western part of Dogger Bank Teesside C, which are closest to Area 466; and
- the construction activities in these Dogger Bank projects and dredging in Area 466 are coincident.

7.8.9 The predicted worst case dispersion for a set of 24 foundations in the northwest corner of Dogger Bank Teesside B and laying of the export cable shows that the plume and deposition of sediment from it, over a 30-day simulation period, have the potential to spread northwest over Area 466 (**Figures 4.7** and **4.11**). A similar sized plume for Dogger Bank Teesside C & D foundations and cable would be expected. The predicted plume from the northern part of Dogger Bank Creyke Beck B would also migrate over Area 466 (Forewind, 2013) (Dogger Bank Creyke Beck Environmental Statement). If the dredging activity in Area 466 is synchronous with the construction activity in the Dogger Bank projects (foundations and cable laying) there is a possibility there will be interactions.

7.8.10 EMU Ltd (2009) showed that for Area 466, suspended sediment concentrations above 5mg/l are confined to the relatively small dredge path and dredge area. For the majority of the dispersed plume, the concentrations are less than 5mg/l. If interaction with the Dogger Bank cumulative construction plumes were to occur, the result will be:

- short-term; given a dredger will only visit Area 466 once a week;
- localised; given the limited extent of relatively high (greater than 5mg/l) suspended sediment concentration values for Area 466; and
- small; given that the predominant suspended sediment concentration in the Area 466 plume is 5mg/l or less.

7.8.11 In addition, analysis of time series of sediment deposition from the Dogger Bank Teesside A & B worst case construction plumes in the vicinity of Area 466 shows that sediment thickness at any time is predominantly less than 1mm (**Table 4.2**). Occasionally, sediment is thicker than 1mm and can be continuously greater than 1mm for a maximum period of 6 hours (0.25 days). For Dogger Bank Creyke Beck construction sediment is continuously greater than 1mm for only 42 hours (1.75 days) (Forewind, 2013). Hence, deposition out of the Dogger Bank cumulative construction plume would have little persistent effect on the characteristics of the seabed sediment in Area 466.

Interaction with the Combined Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck Operation Plume

7.8.12 The plume from aggregate extraction in Area 466 would be very small in comparison to the cumulative operation plume from Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck. Hence, inclusion of the short-lived Area 466 plume within the cumulative operational plume of Dogger Bank will have little effect on its overall size and it would be essentially unchanged in terms of suspended sediment concentration and distribution. Also, time series of deposition from the Dogger Bank operation plume immediately south of Area 466 shows that maximum sediment thickness at any time is less than 0.1mm for a 50-year storm after two years of operation (**Table 7.2**). This means that deposition out of the Dogger Bank cumulative operation plume would have little effect on the characteristics of the seabed sediment in Area 466.

7.9 Cumulative Effects of the Dogger Bank Projects with Aggregate Dredging Area 485

7.9.1 There is also an application for a licence for Area 485 (by the same company) located approximately 30km to the south of Dogger Bank Teesside A & B export cable corridor (about 20km south of the Dogger Bank Creyke Beck export cable corridor). Area 485 covers approximately 14.5km^2 and is separated into two distinct sub areas (**Figure 7.1**) with a proposal to remove up to one million tonnes per year of aggregate over an (initial) licence period of 15 years, with the maximum total extraction over the licence period being 7.5 million tonnes. If Area 485 is licensed during the lifetime of Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck, the aggregate extraction activities have the potential to release further suspended sediment into the water column and to give rise to cumulative effects.

7.9.2 EMU Ltd (2007) indicated that the seabed sediment at Area 485 is heterogeneous with gravels interspersed with high quantities of sand. The gravel content within Area 485 has been estimated at 35%. The extraction process will remove a mixture of gravels and sand from the seabed together with a high volume of water (the solids content is approximately 25% by volume). As the hopper in the dredging vessel loads, the excess water (together with a proportion of the finer sediment) returns overboard via spillways creating a turbid plume of water. EMU Ltd (2007) presented the results of plume modelling studies that simulated the proposed dredging operations in both sub-areas of Area 485.

7.9.3 For dredging in the western sub-area, the increases in suspended sediment concentration above background were predicted to be less than 75mg/l and 100mg/l outside and inside the sub-area, respectively (EMU Ltd, 2007). Close to and within the streamline of the dredger the increases may be higher as suspended sediment concentrations are not uniformly mixed through the water column. Suspended sediment concentration decreases with distance away from a dredger. The plume was predicted to disperse up to 5km north-northwest and up to 3km south-southeast of the sub-area. At these distances the predicted increases in suspended sediment concentration were approximately 10mg/l or less.

7.9.4 For dredging in the eastern sub-area, the depth-averaged increases in suspended sediment concentration were predicted to be less than 50mg/l both outside and inside the sub-area (EMU Ltd, 2007). However, outside the immediate dredge track, increases in suspended sediment concentration are unlikely to exceed 25mg/l. Within the sub-area increases in suspended sediment concentration are up to 75mg/l above background. The plume was predicted to disperse up to 5km north-northwest and up to 4.5km south-southeast of the sub-area. At these distances the predicted increases in suspended sediment concentration are approximately 10mg/l or less. The footprint of deposition was predicted to extend up to 2km north of the eastern sub-area.

7.9.5 EMU Ltd (2007) concluded that increases above background suspended sediment concentration would be temporary, brief in duration and highly tide dependant. Predicted mean increases above background levels were 1-2mg/l and time series analysis showed that increases of more than 5mg/l occur for up to 10% of time outside the dredge area and up to 18% of time within the dredge area. The predicted mean increases in suspended sediment are within the natural range of conditions likely to be experienced at the proposed dredging area.

Interaction with the Combined Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck Construction Plume

7.9.6 The extent of the plume away from Area 485 towards Dogger Bank (up to 4km), and the distance of Area 485 from the Dogger Bank projects (25km) means that the cumulative construction plume of Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck could potentially overlap with the dredging plume of Area 485. The extent of overlap will depend on the relative timing of the respective activities and the extent and concentrations within the overlapping plumes.

7.9.7 EMU Ltd (2007) showed that for Area 485, suspended sediment concentrations above 5mg/l would only be present for up to 10% of the time outside the dredge area. If interaction with the Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck plume were to occur, the result will be short term, localised and small, given the limited extent and duration of high suspended sediment concentrations from aggregate dredging at Area 485.

Interaction with the Combined Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck Operation Plume

7.9.8 The suspended sediment concentration within and the extent of the cumulative operation plume from Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck would be large in comparison to the plume from aggregate extraction in Area 485. Hence, inclusion of the short-lived and localised plume from Area 485 within the Dogger Bank operational plume will have little effect on its overall size and will be essentially unchanged in terms of suspended sediment concentration and distribution.

7.10 Cumulative Effects of the Dogger Bank Projects with Dredge Disposal for Potash Mining

7.10.1 Cleveland Potash Ltd operates a potash mine and refining plant on the North Sea coast south of the Tees Estuary and has an effluent line which discharges clay, salt and brine into the nearshore area. The discharge point consists of two outfalls which are approximately 62m apart located about 1.5km offshore (**Figure 7.1**).

7.10.2 An Environmental Permit has been obtained to dredge sediment from close to the two outfall pipes and to dispose of the sediment nearby (**Figure 7.1**). The outfalls and dredge disposal area are located approximately 3.8km and 3km southeast of the Dogger Bank Teesside A & B export cable corridor, respectively. Two dredging periods per year take place, one in spring and one in autumn. The license for dredge disposal runs from September 2012 to November 2015 and approximately 100,000 tonnes of silt per year is expected to be extracted.

7.10.3 Dredging takes place using a suction hopper dredging vessel with a volume of 1500m^3 and a load rate of 1200 m^3/hour. The sediment is discharged into the water column at the disposal site. Modelling of the disposal has shown that the plume would disperse naturally at the point of disposal and would not impact on the nearby coastal area.

7.10.4 Potential cumulative effects resulting from the interaction of the dredge disposal plume with the construction plume of the Dogger Bank Teesside A & B export cable would occur when the activities are coincident. The plume from dredge disposal would only interact with the plume created at the landward end of the export cable corridor. Given that suspended sediment concentrations along the export cable are only elevated for a short period of time before dispersing to background levels, and the timings of the two operations are unlikely to overlap, the potential for interaction is very low.

7.10.5 Maximum suspended sediment concentrations as a result of the Dogger Bank Teesside A & B export cable construction could locally exceed 200mg/l close to the coast in the vicinity of the potash outfalls (**Figure 4.7**). However, this high concentration only translates into deposition on the seabed of less than 5mm (**Figure 4.11**). This is because the exceedance time for concentrations greater than 2mg/l in this area is less than 10% of the simulation period (i.e. less than three days) (**Figure 4.10**). So, the construction plume of the Dogger Bank Teesside A & B export cable corridor will have no effect on the dredging requirements of the potash outfalls.

7.11 Inter-relationships and Transboundary Effects

Inter-relationships

7.11.1 The manner in which marine physical processes are affected by the proposed Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck has the potential to result in indirect effects on a number of other environmental parameters. Those inter-relationships include:

- re-suspension of seabed sediments through seabed preparation, drill arisings and scour during the construction and operational phases has the potential to affect water and sediment quality;
- suspended sediments and changes in wave and tidal current regime have the potential to affect other ecological receptors including marine ecology and fish;
- changes to far-field wave and hydrodynamic conditions have the potential to affect designated habitats;
- re-suspension of seabed sediments through seabed preparation, drill arisings and scour during the construction and operational phases has the potential to affect marine archaeological resources;
- changes in coastal processes have the potential to affect ecological receptors; and
- scour of the seabed will result in direct loss of habitat.

Transboundary Effects

7.11.2 The eastern boundary of the Dogger Bank Zone is marked by the international boundary with Dutch and German waters. The eastern boundary of Dogger Bank Teesside A is located on the international boundary with The Netherlands.

7.11.3 Cumulative changes to wave and tidal current regimes were modelled using layouts of foundations across each of the six projects. The effects on tidal currents using these layouts do cross over the international boundary into Dutch waters (**Figures 7.3** and **7.4**). The effects on waves enter all adjacent international waters (**Figures 7.5** and **7.6**). However, the results show that predicted changes to both waves and tidal currents would be of small magnitude in international waters (**Figures 7.4** and **7.7**) with limited secondary effects on sediment transport or seabed morphology.

7.11.4 Cumulative sediment plumes predicted for operation of Dogger Bank Teesside A & B and Dogger Bank Creyke Beck only disperse up to about 15km into Dutch waters and do not cross into German, Danish or Norwegian waters. Scour of the seabed is limited to the immediate vicinity of the Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck wind farm foundations.

8 REFERENCES

Eisma, D. and Kalf, J. 1987. Dispersal, concentration and deposition of suspended matter in the North Sea. Journal of the Geological Society of London, 144, 161-178.

Entec UK Ltd. 2004. Teesside Offshore Wind Farm Environmental Statement. Report to EDF Energy (Northern Offshore Wind) Ltd, March 2004.

EMU Ltd. 2007. Area 485 Aggregate Extraction Licence Application Environmental Statement. Report to CEMEX, March 2007.

EMU Ltd. 2009. Area 466 Aggregate Extraction Licence Application Environmental Statement. Report to CEMEX, June 2009.

EMU Ltd. 2010. Dogger Bank Zonal Characterisation Interim Report. Report to Forewind Ltd, October 2010.

Envision Mapping. 2012. Dogger Bank Zone Wide Habitat Mapping. Interim interpretation of current data. Report to Forewind, December 2012.

Forewind. 2013. Dogger Bank Creyke Beck Final Environmental Statement. Chapter 9 Marine Physical Processes.

Gardline 2011a. Dogger Bank Zone Wide Acoustic and Geophysical Survey May to August 2010. Survey Report to Forewind, January 2011.

Gardline. 2012a. Dogger Bank Geophysical Survey Tranche B Project Areas 1A, 1B, 2A and 2B. June 2011 to May 2012. Survey Report to Forewind, July 2012.

Gardline. 2012b. Dogger Bank Tranche B Benthic Survey 2012. UKCS 38/27. Field Survey Report to Forewind, July 2012.

GEMS. 2011. Geophysics Results Report. Volume 4 of 9. Dogger Bank Tranche A Acoustic and Geophysical Survey. Report (Revision: 01) to Forewind, September 2011, 73pp.

Houston, J. R. 1995. Beach-fill volume required to produce specified dry beach width. Coastal Engineering Technical Note 11-32, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Mathiesen, M., Nygaard, E. and Andersen, O.J. 2011. Dogger Bank Wind Power Sites Metocean Design Basis. Statoil Report PTM MMG MGE RA 63, Rev no 3, October, 2011, 129pp.

OMM. 2013. Teesside A & B Export Cable Corridors Route Assessment. Technical Note to Forewind.

Planning Inspectorate. 2012. Using the ‘Rochdale Envelope’. Advice Note Nine: Rochdale Envelope. April 2012.

RPS Energy. 2012. Dogger Bank Drilling Arisings Study – Teesside A and B. Technical Note to Forewind, November 2012.

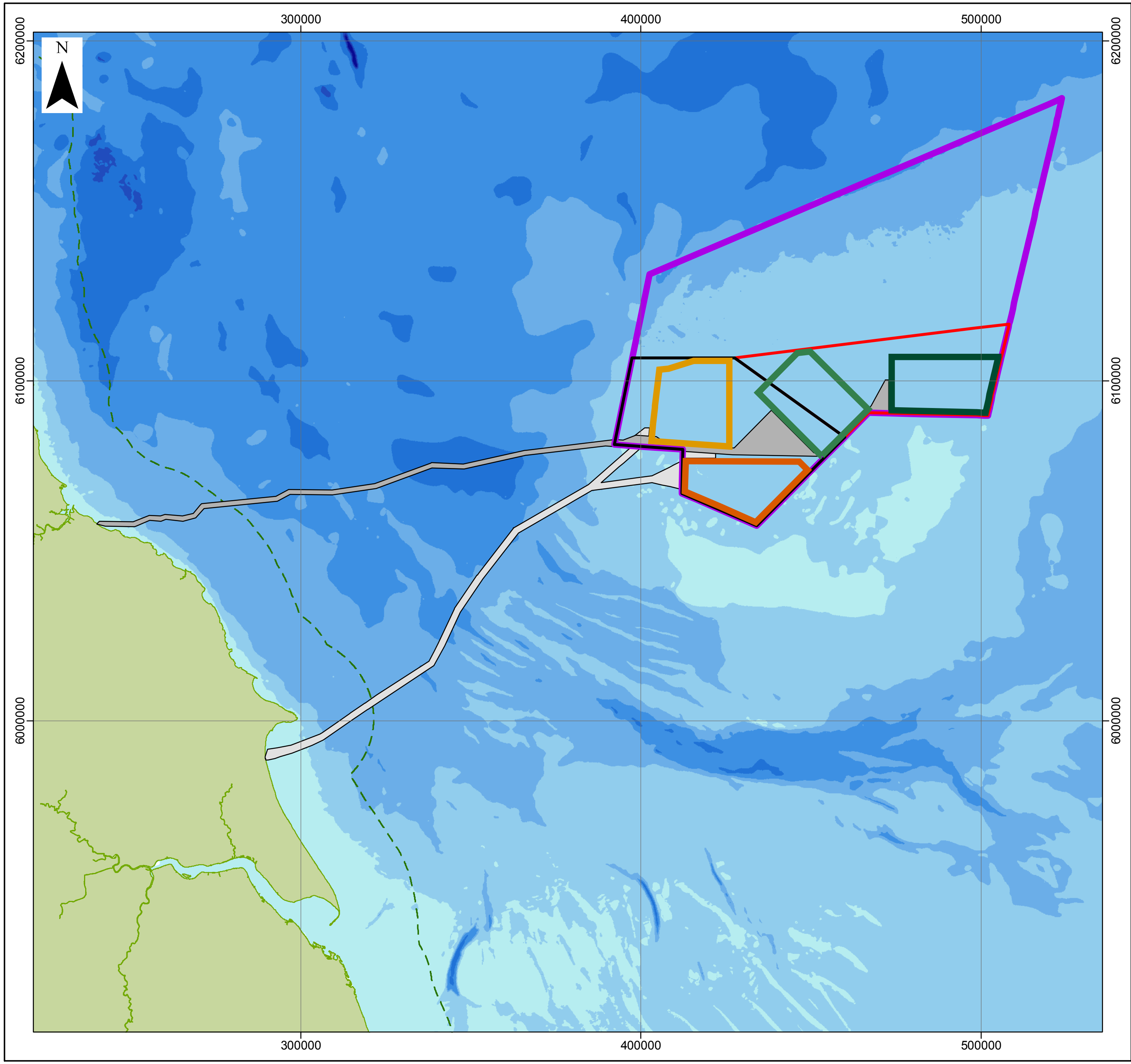
RPS Energy. 2012. Hornsea Project Two Environmental Impact Assessment scoping Report. Report to SMart Wind, October 2012.

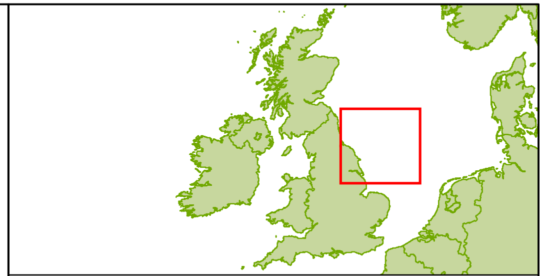
RPS Energy. 2013. Hornsea Offshore Wind Farm Project One Environmental Statement. Draft Report to SMart Wind, 2013.

Soulsby, R. L. 1997. Dynamics of Marine Sands. Thomas Telford Publications.

Soulsby, R.L. and Clarke, S. 2005. Bed shear stresses under combined waves and currents on smooth and rough beds. HR Wallingford Report TR137.

FIGURES





LEGEND

- Dogger Bank Zone
- Tranche A Boundary
- Tranche B Boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside A & B Export Cable Corridor
- Dogger Bank Creyke Beck A & B Export Cable Corridor
- 12nm Territorial Boundary

0 20 40
Kilometres

Data Source:
Round 3 © TCE, 2010,
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

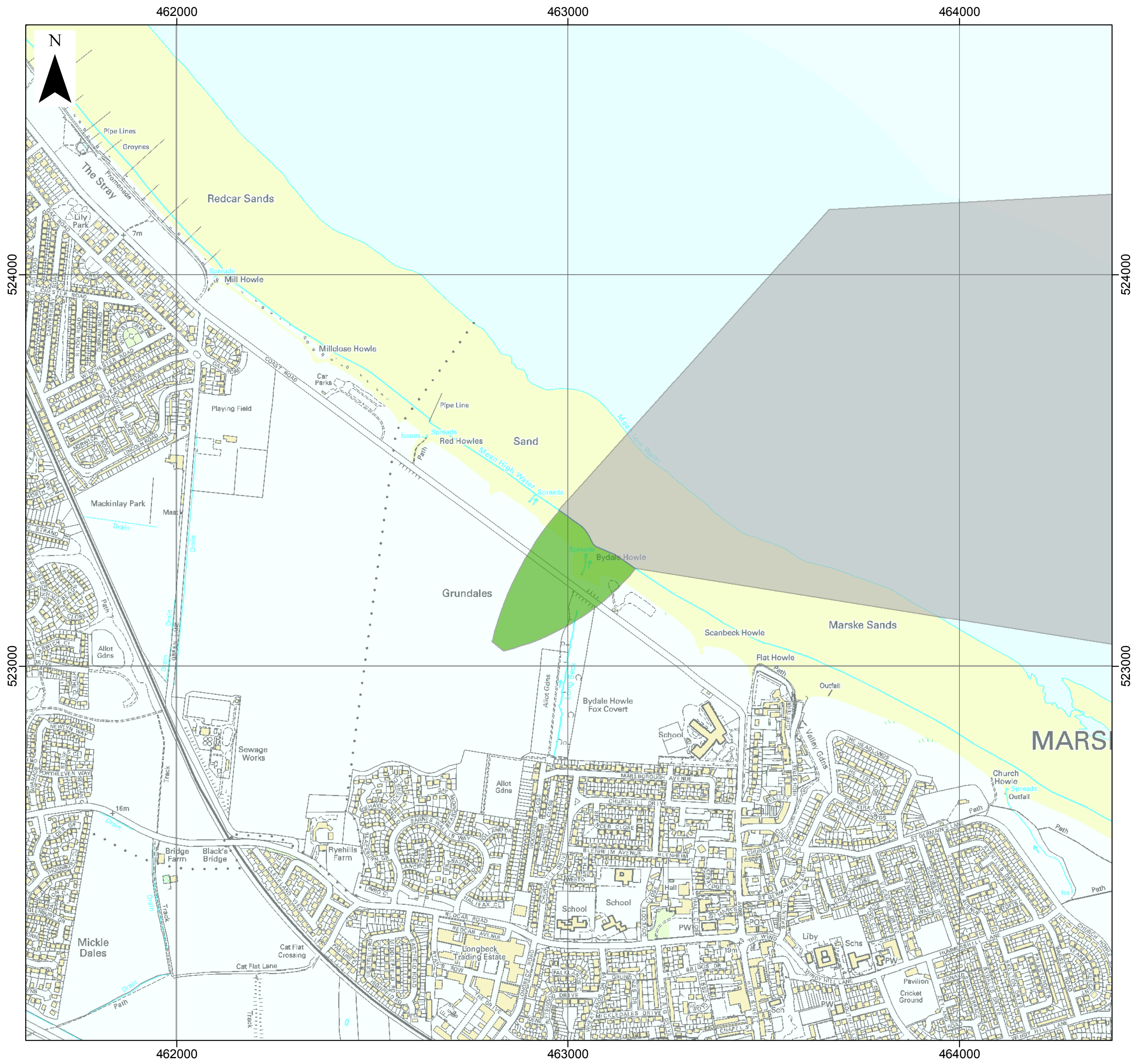
Figure 1.1 Location of the Dogger Bank Teesside A & B development

VER	DATE	REMARKS	Drawn	Checked
1	21/02/2013	Draft	FK	DB
2	14/10/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/050**

SCALE	1:1,700,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND



LEGEND

- Dogger Bank Teesside A & B Export Cable Corridor
- Dogger Bank Teesside A & B Landfall Area

0 — 500 Metres

Source:
Ordnance Survey data © Crown copyright and database right, 2012

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

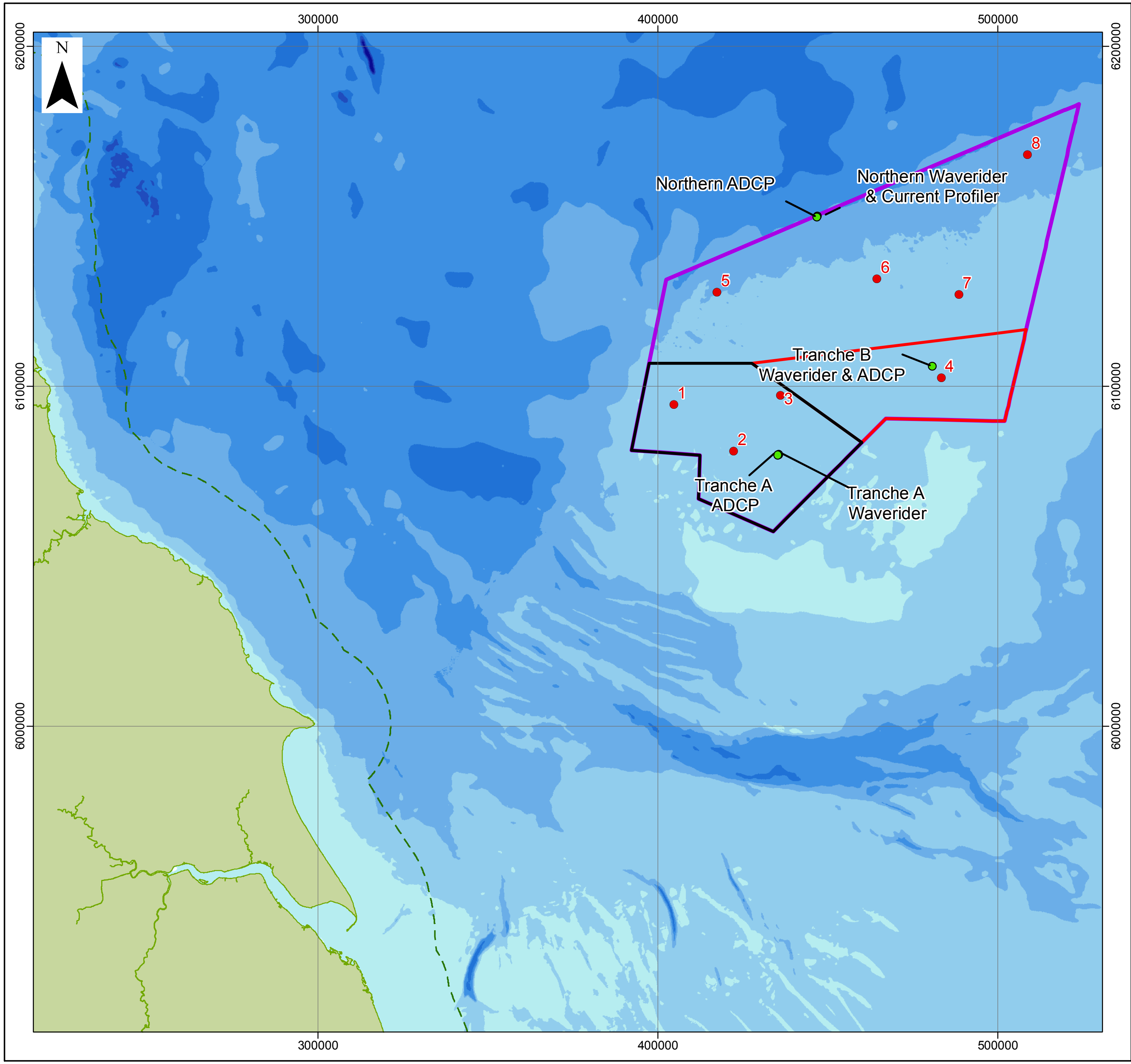
Figure 1.2 Location of the Landfall Corridor at Teesside

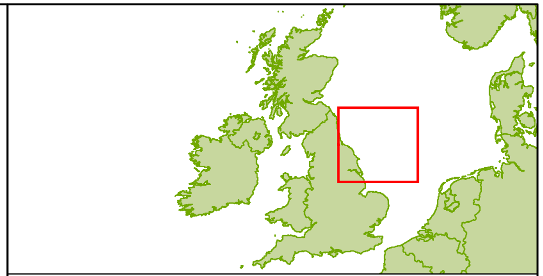
VER	DATE	REMARKS	Drawn	Checked
1	16/04/2013	Draft	FK	DB
2	14/10/2013	Final	LW	DB

DRAWING NUMBER: 9X5889/04/051

SCALE	1:15,000	PLOT SIZE	A4	DATUM	OSGB36	PROJECTION	BNG

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche A Boundary
- Tranche B Boundary
- 12nm Territorial Boundary
- Modelled Metocean Location
- Forewind Metocean Deployments

0 20 40
Kilometres

Data Source:
Modelled Metocean Locations © Statoil, 2011
Metocean Deployments © Gardline, 2012,
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

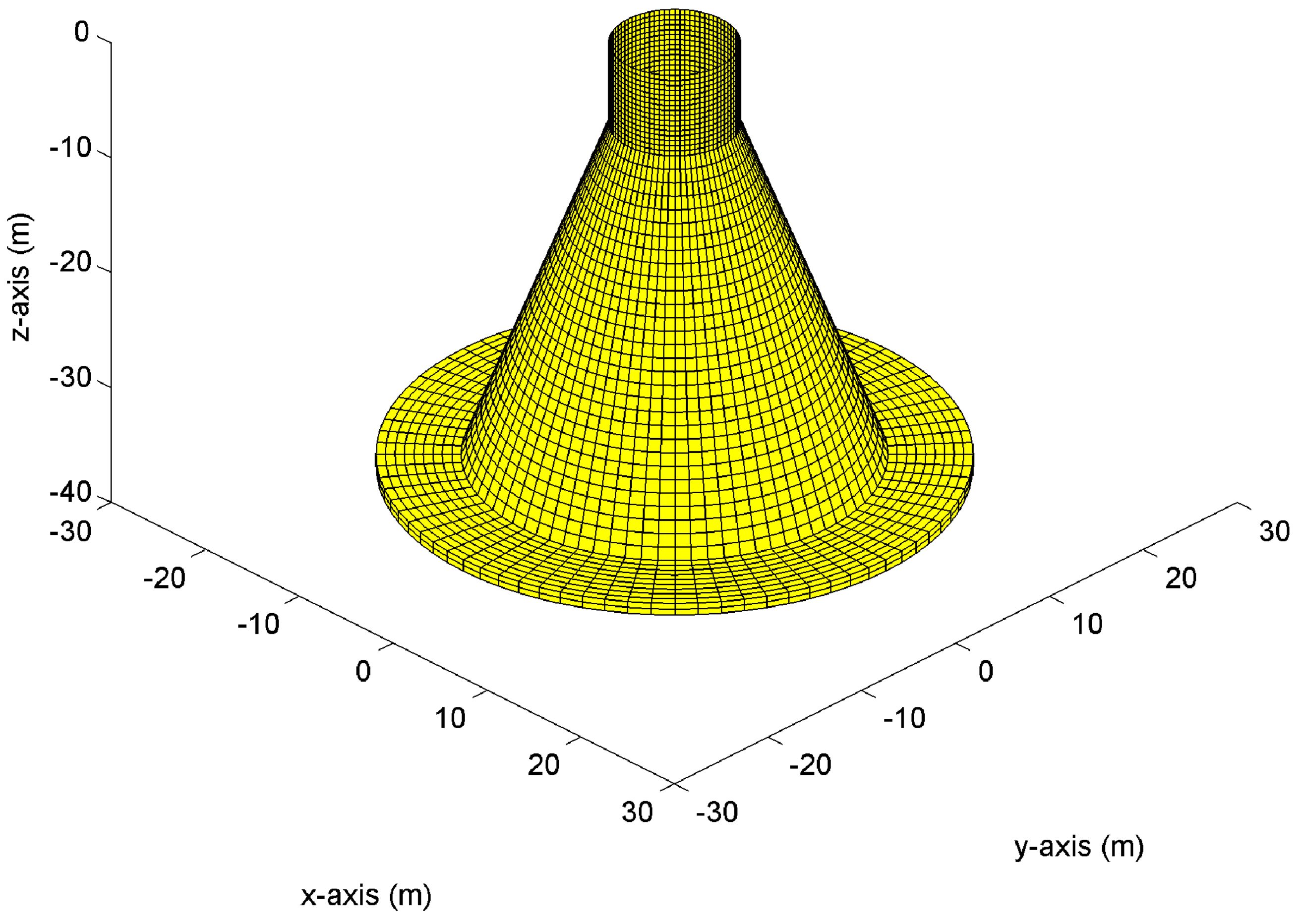
Figure 1.3 Metocean Data Points

VER	DATE	REMARKS	Drawn	Checked
1	21/02/2013	Draft	FK	DB
2	01/10/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/052**

SCALE	1:1,700,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND



Data Source:
Image supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

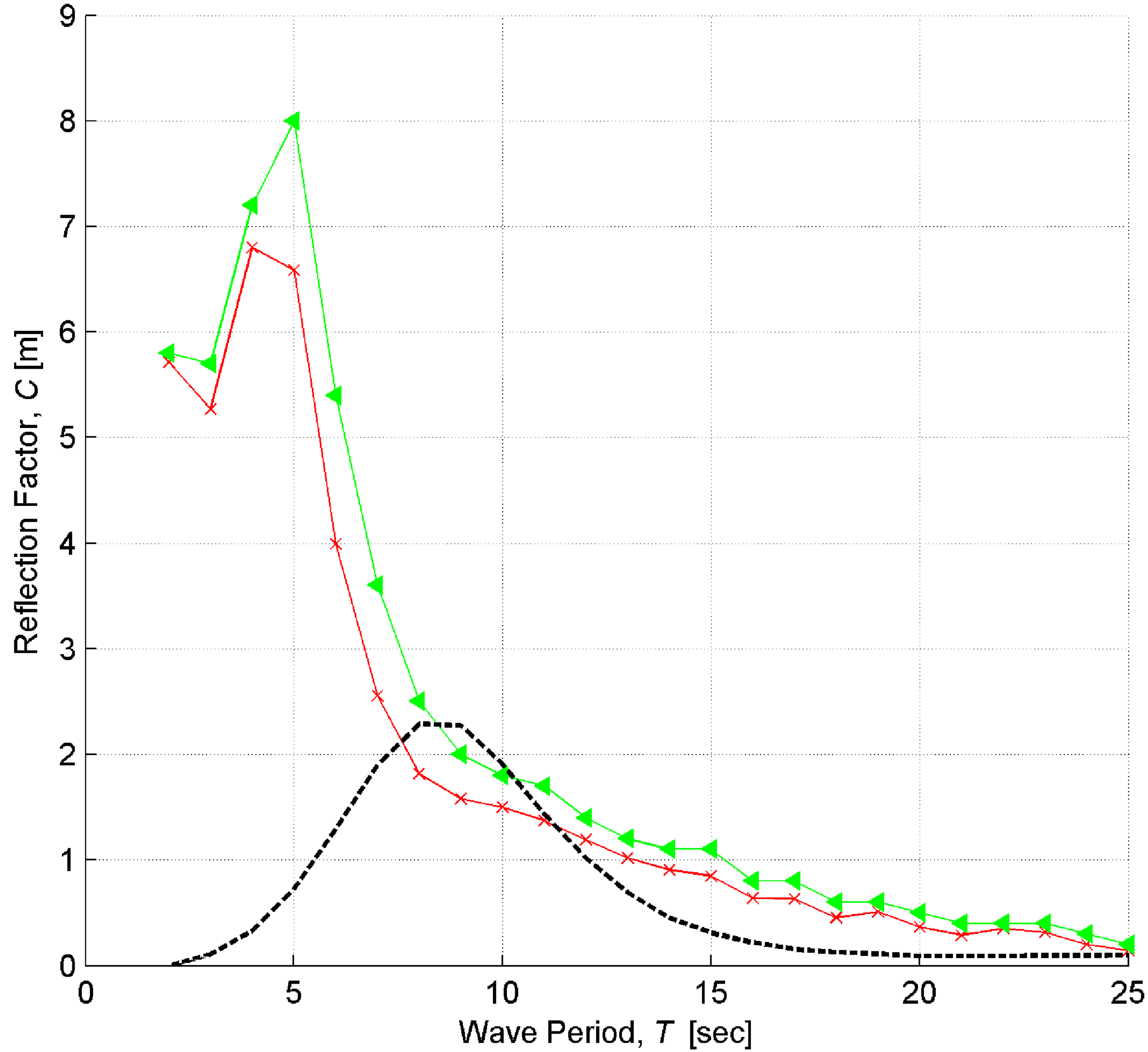
Figure 2.1 Example of a 10MW Conical GBS Foundation for WAMIT Computations

VER	DATE	REMARKS	Drawn	Checked
1	26/07/2012	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/53**

SCALE	PLOT SIZE	DATUM	PROJECTION

FOREWIND



LEGEND

- GBS#1 6MW Foundation
- GBS#1 10MW Foundation
- Average Spectrum (m^2s)

Data Source:
Image supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

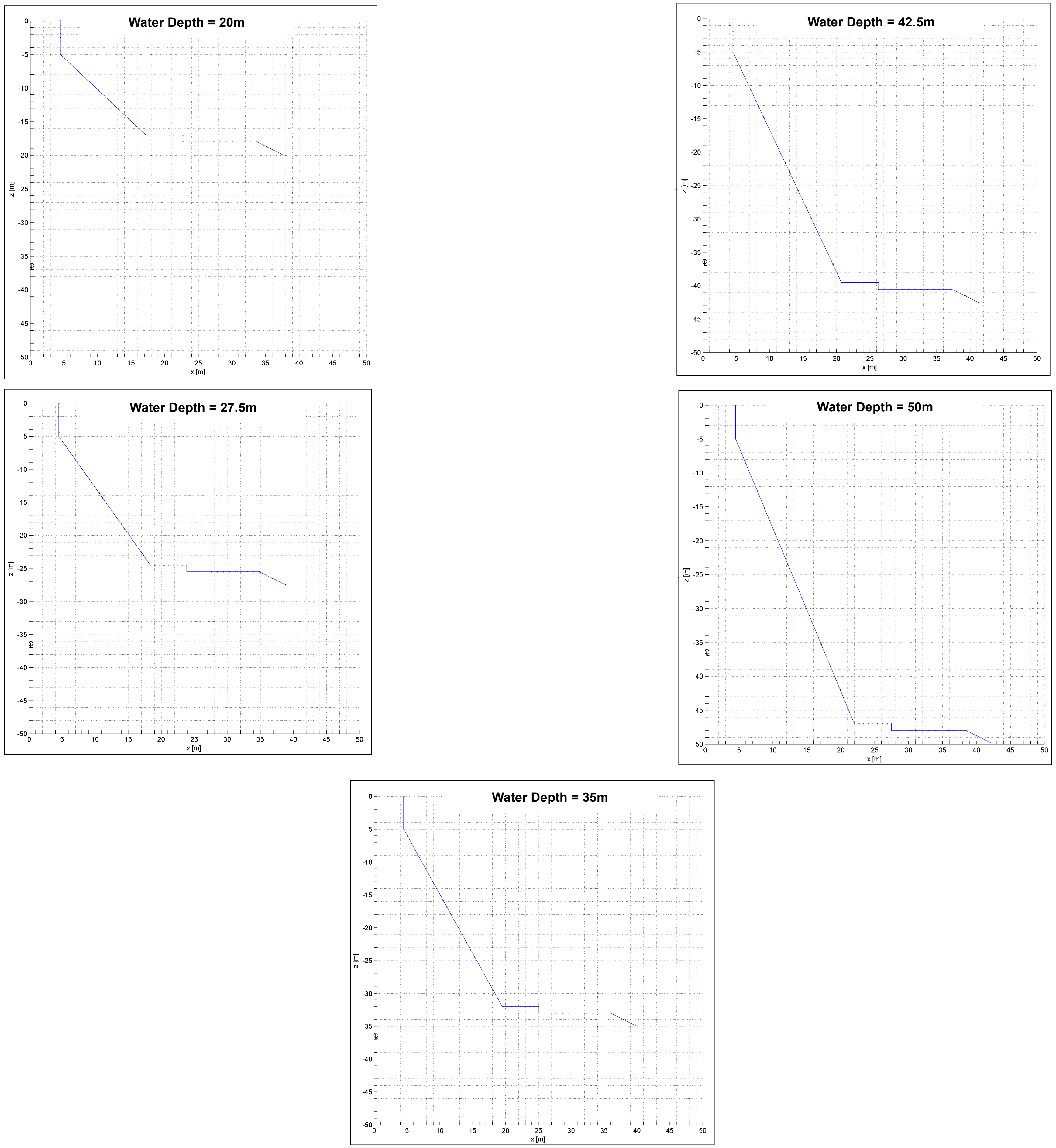
Figure 2.2 Wave Reflection Factors of 6MW and 10MW Conical GBS#1 Foundations

VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/54**

SCALE	PLOT SIZE A4	DATUM	PROJECTION

FOREWIND



Data Source:
Images supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

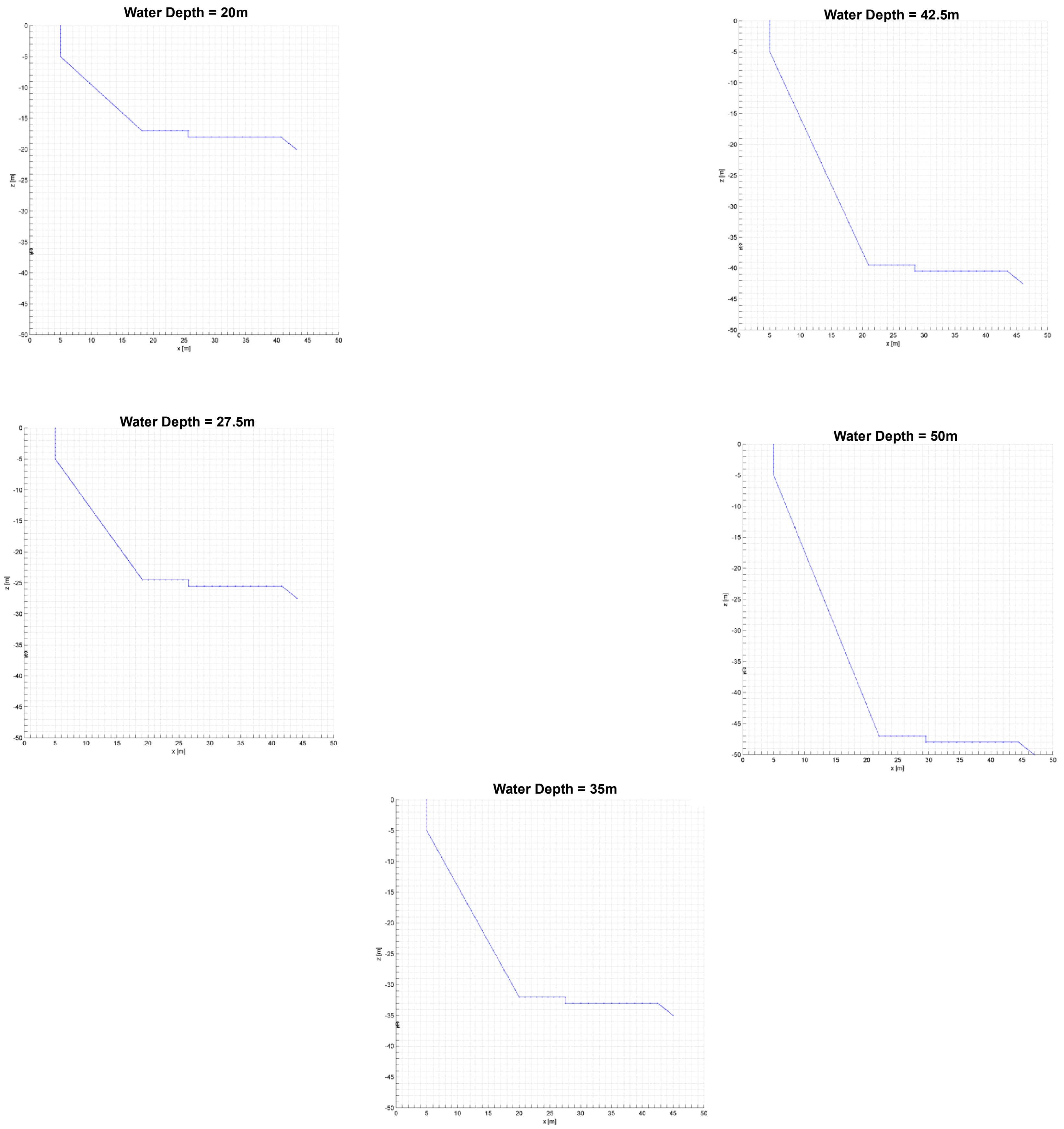
Figure 2.3 Half Cross Sections of 6MW Conical GBS#1 Foundations in Five Water Depths Analysed for their 'Blocking Effect'

VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/55**

SCALE	PLOT SIZE A3	DATUM	PROJECTION

FOREWIND



Data Source:
Images supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

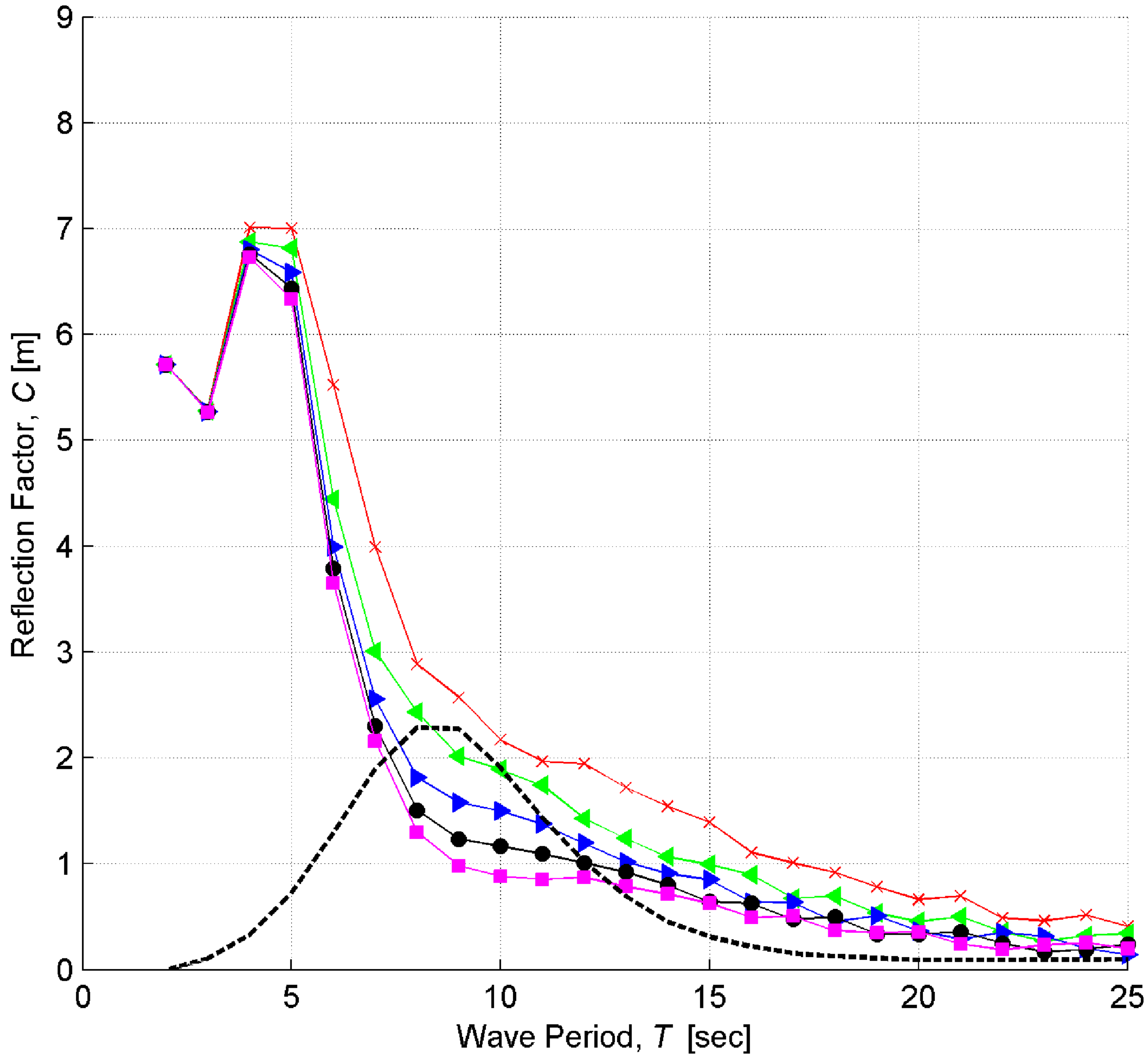
Figure 2.4 Half Cross Sections of 10MW Conical GBS#1 Foundations in Five Water Depths Analysed for their 'Blocking Effect'

VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/56**

SCALE	PLOT SIZE A3	DATUM	PROJECTION

FOREWIND



LEGEND

- 20m Water Depth
- 27.5m Water Depth
- 35m Water Depth
- 42.5m Water Depth
- 50m Water Depth
- Average Spectrum (m^2s)

Data Source:
Image supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

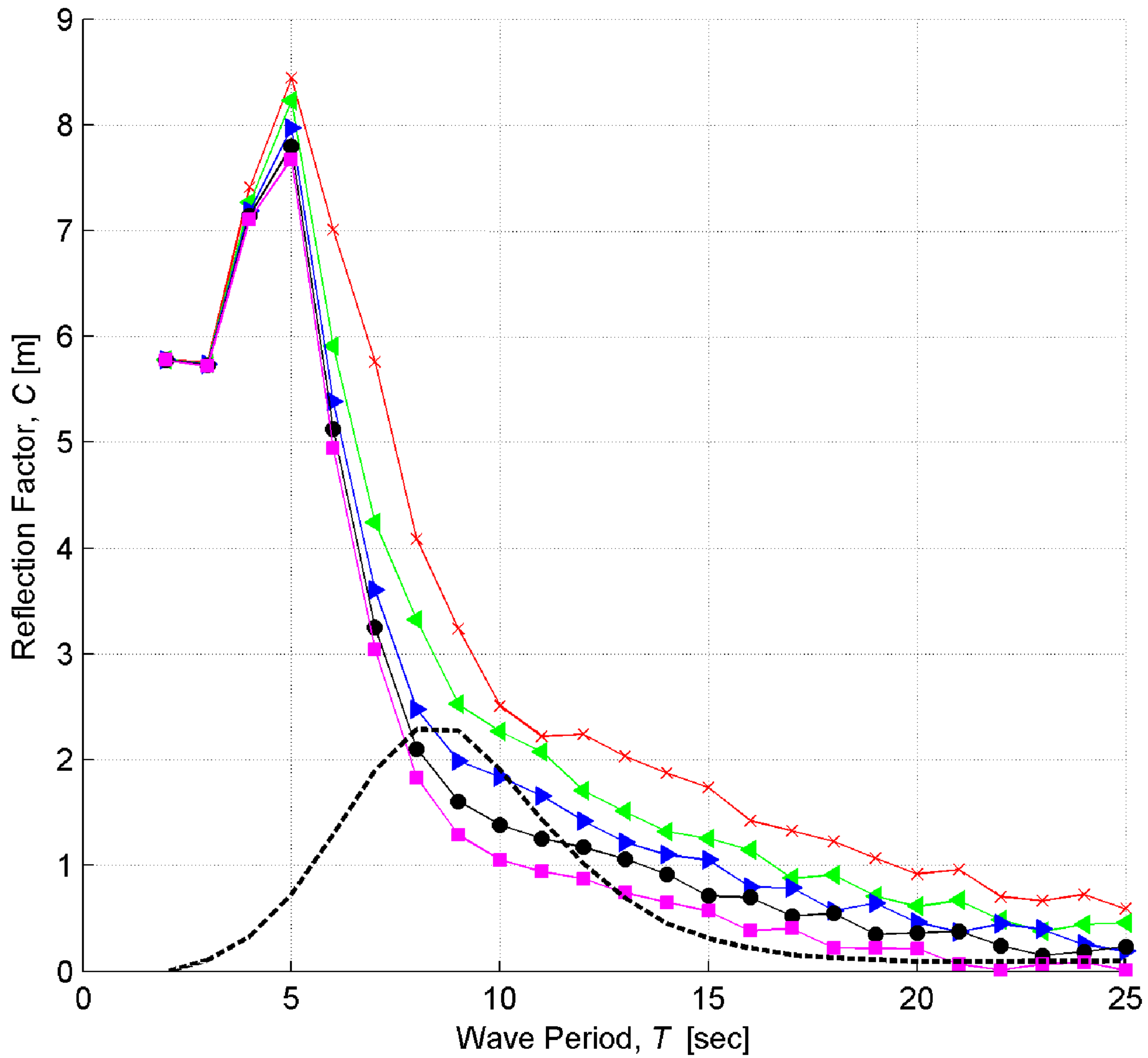
Figure 2.5 Wave Reflection Factors of 6MW Conical GBS#1 Foundations in Five Water Depths

VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/57**

SCALE	PLOT SIZE A4	DATUM	PROJECTION

FOREWIND



LEGEND

- 20m Water Depth
- 27.5m Water Depth
- 35m Water Depth
- 42.5m Water Depth
- 50m Water Depth
- Average Spectrum (m^2s)

Data Source:
Image supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

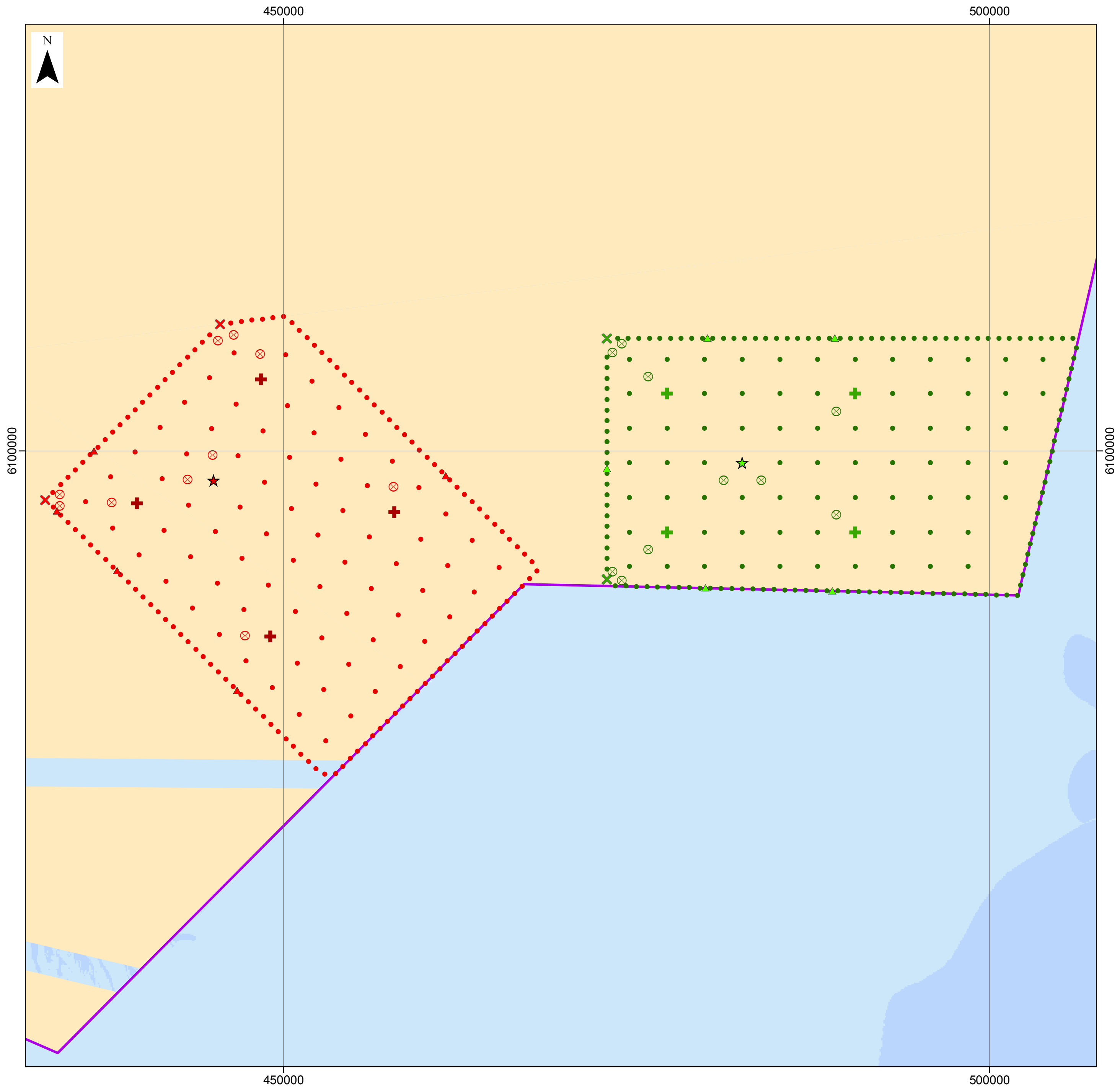
Figure 2.6 Wave Reflection Factors of 10MW Conical GBS#1 Foundations in Five Water Depths

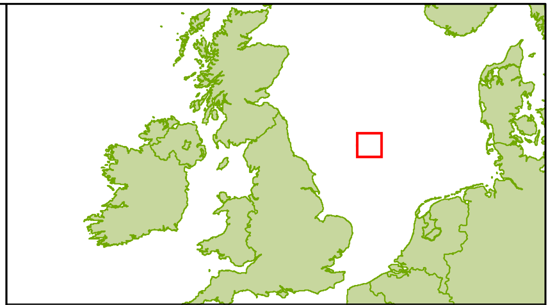
VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/58**

SCALE	PLOT SIZE A4	DATUM	PROJECTION

FOREWIND





LEGEND

- Dogger Bank Zone
- Dogger Bank Developable Area

<u>Dogger Bank Teesside A Layout</u>

- Accomodation Platform
- Collector Platform
- Converter Platform
- Met Mast
- Mooring
- Turbine

<u>Dogger Bank Teesside B Layout</u>

- Accomodation Platform
- Collector Platform
- Converter Platform
- Met Mast
- Mooring
- Turbine

0 10

Kilometres

Data Source:
© UKDeal
Round 3 © TCE, 2010.
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

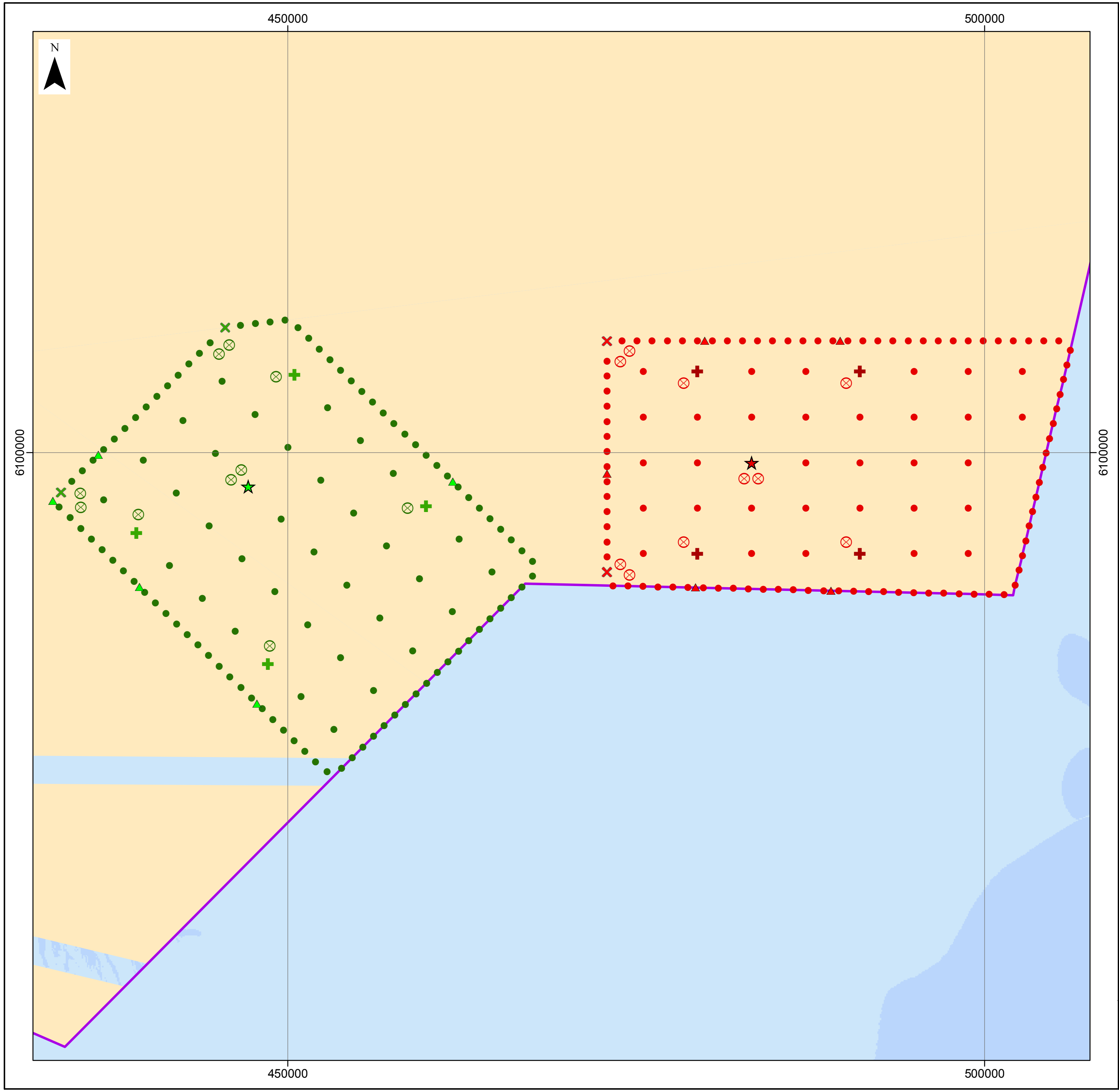
Figure 2.7 Dogger Bank Teesside A and Teesside B 6MW Layouts

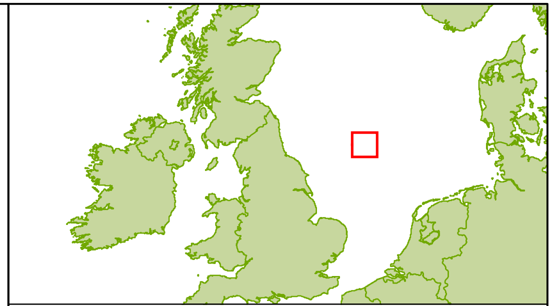
VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	15/10/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/59**

SCALE	1:410,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Dogger Bank Developable Area

Dogger Bank Teesside A Layout

- Accomodation Platform
- Collector Platform
- Converter Platform
- Met Mast
- Mooring
- Turbine

Dogger Bank Teesside B Layout

- Accomodation Platform
- Collector Platform
- Converter Platform
- Met Mast
- Mooring
- Turbine

0 10
Kilometres

Data Source:
© UKDeal
Round 3 © TCE, 2010.
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

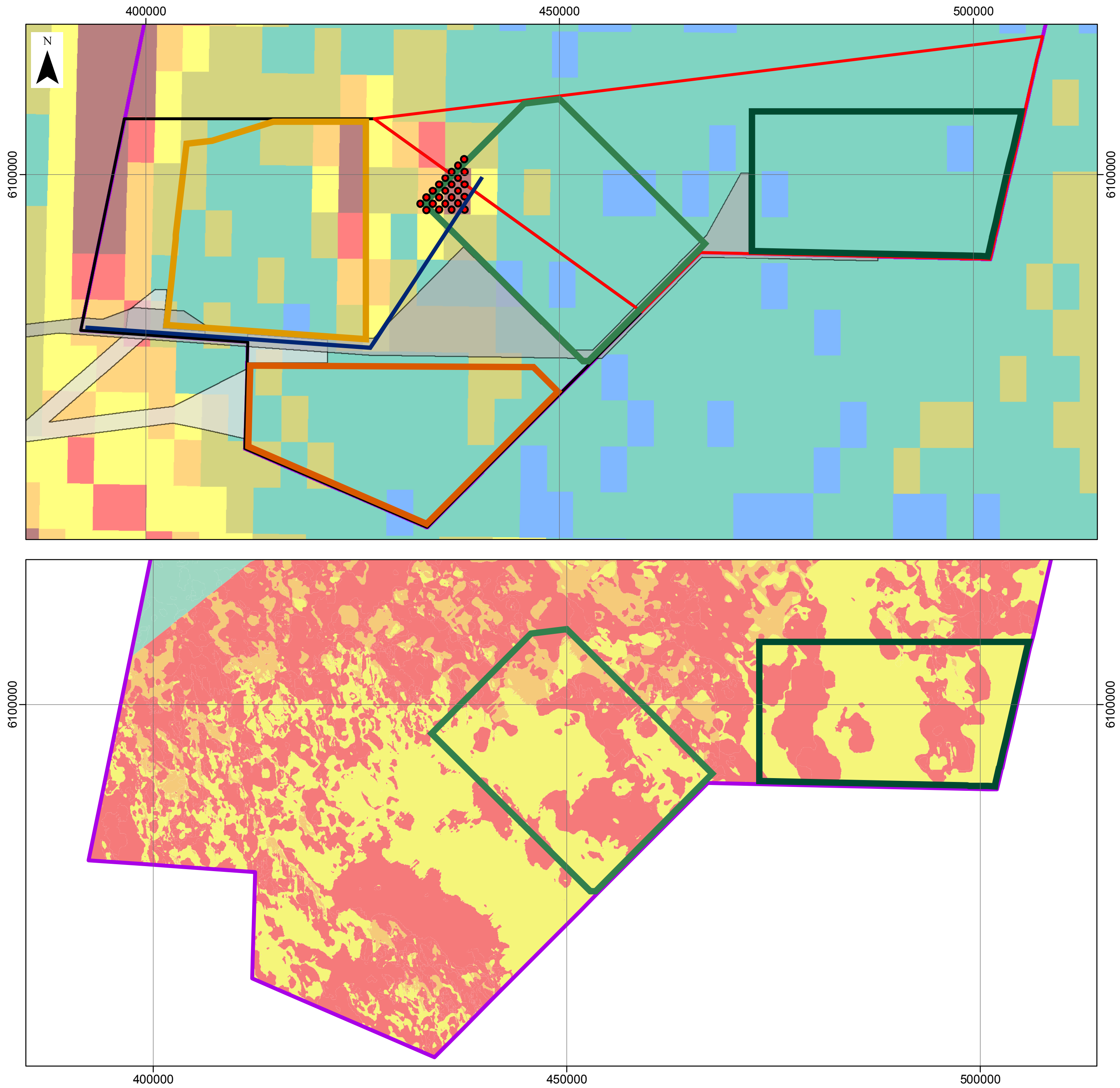
Figure 2.8 Dogger Bank Teesside A and Teesside B 10MW Layouts

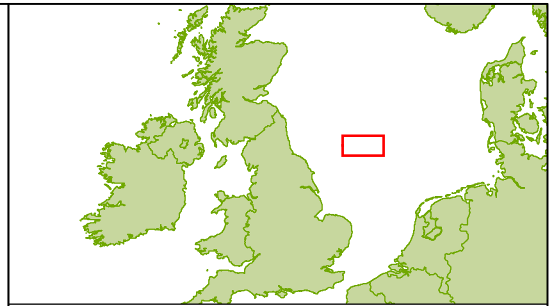
VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	15/10/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/60**

SCALE	1:410,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche A Boundary
- Tranche B Boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside B Indicative In-Zone Cable Corridor
- Dogger Bank Teesside A & B Export Cable Corridor
- Dogger Bank Creyke Beck A & B Export Cable Corridor

Danish Sandeel Satellite (VMS) Density Average 2007-2011 (Top Panel)

- 0 to 2
- 2 to 5
- 5 to 10
- 10 to 20
- 20 to 40
- 40 to 80
- Over 80

- 24 x Foundation Layout (1,080m spacing)

Dogger Bank Biotope Sensitivity (Bottom Panel)

- Low - Moderate Sensitivity; Outside SAC
- Moderate Sensitivity; Outside SAC
- Very Low Sensitivity; Inside SAC
- Low Sensitivity; Inside SAC
- Low - Moderate Sensitivity; Inside SAC

0 20

Kilometres

Data Source:
Round 3 © TCE, 2010.
Biotope Sensitivty data derived from Envision
Danish Sandeel VMS data derived from Ministry of Food Agriculture and Fisheries (Denmark) (MFAF)

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

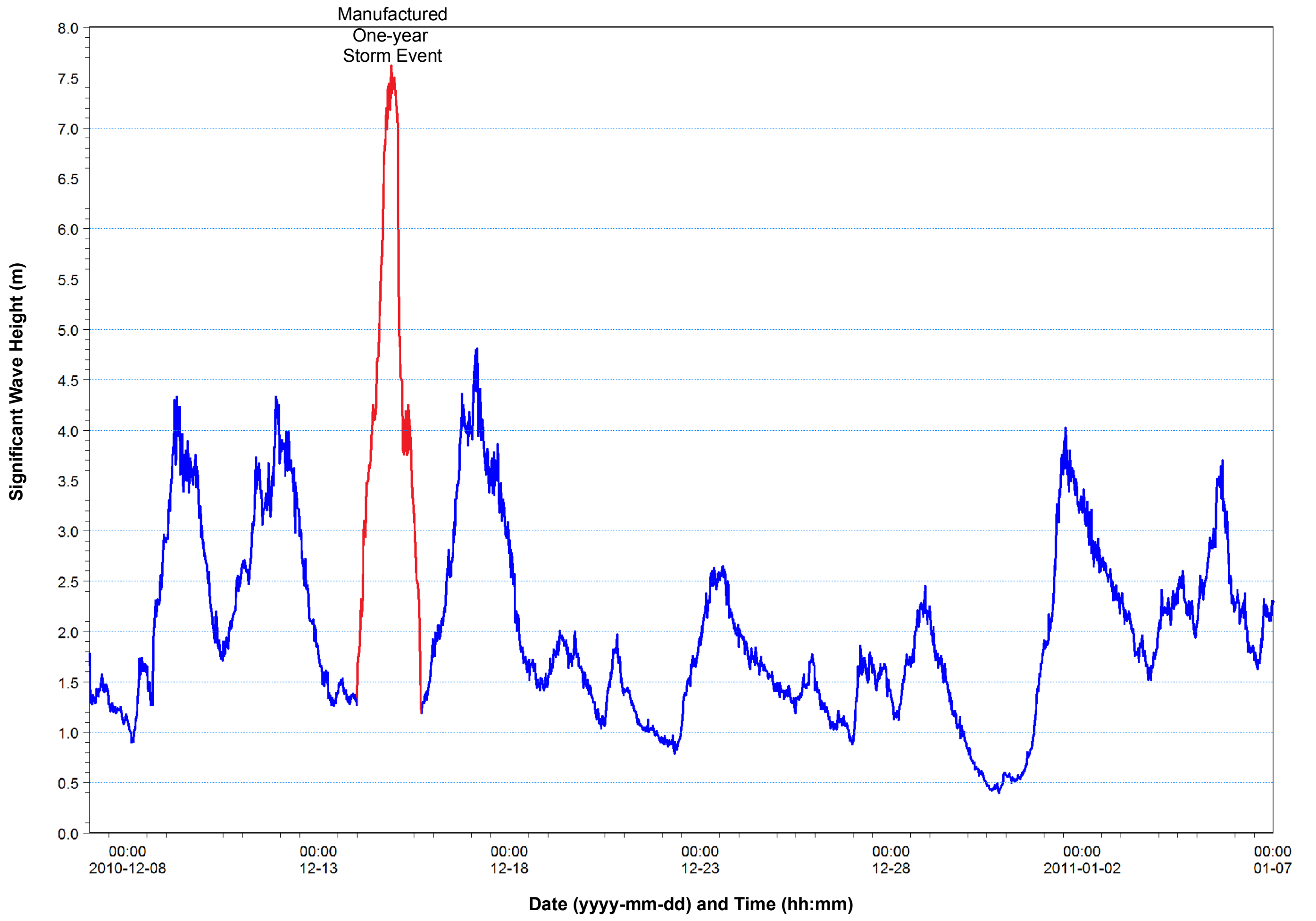
Figure 2.9 Worst Case Location of Foundations for the Construction Phase Relative to Sensitive Habitats

VER	DATE	REMARKS	Drawn	Checked
1	19/02/2013	Draft	FK	DB
2	15/10/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/61**

SCALE 1:700,000 | PLOT SIZE A4 | DATUM WGS84 | PROJECTION UTM31N

FOREWIND



Data Source:
Image supplied by Gardline

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

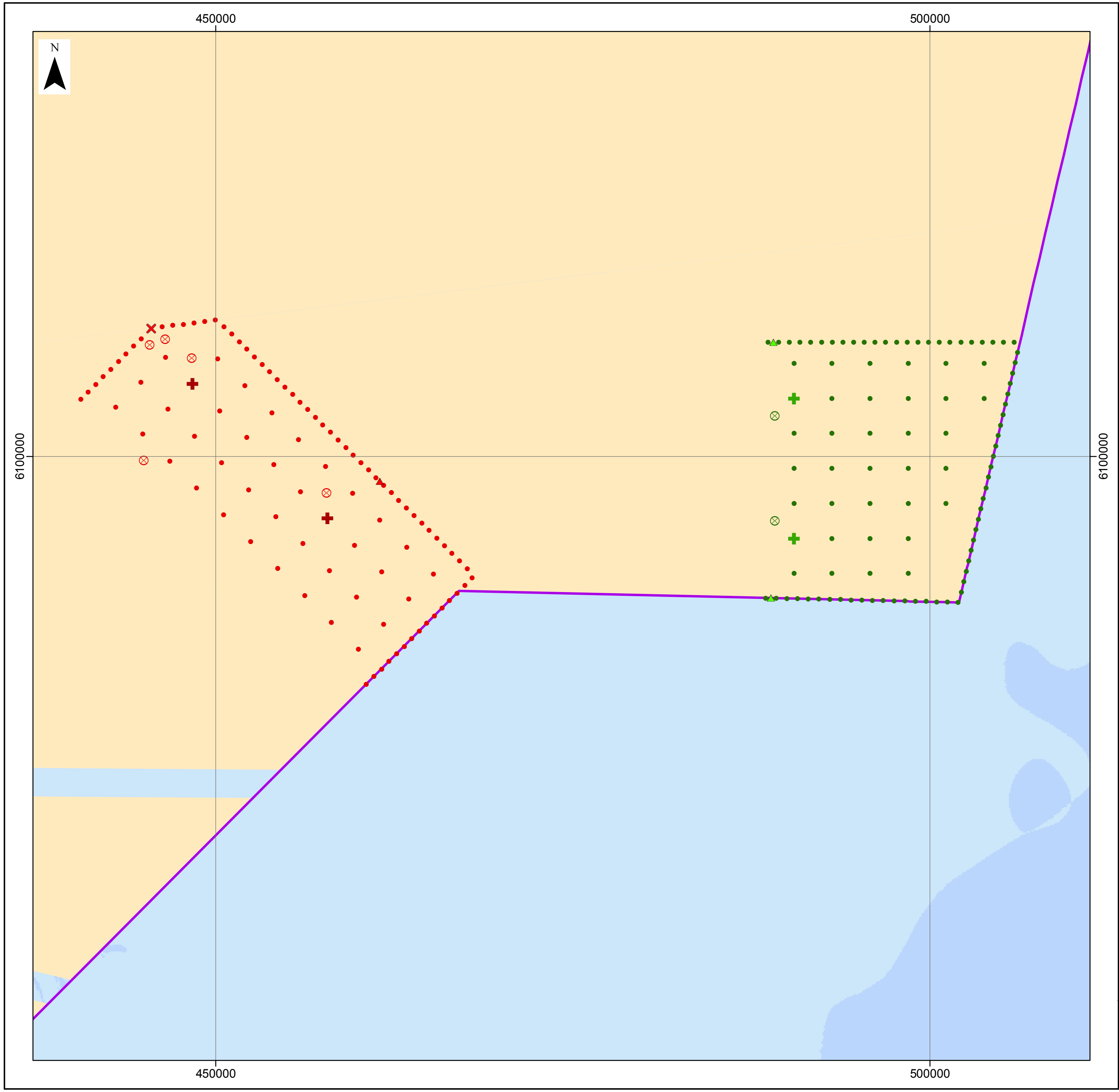
Figure 2.10 Wave Time Series Applied in the Construction Phase Plume Dispersion Simulation

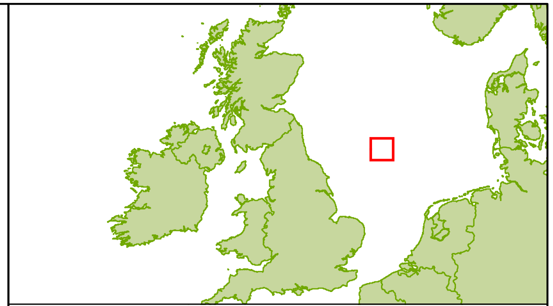
VER	DATE	REMARKS	Drawn	Checked
1	20/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/62**

SCALE	PLOT SIZE A4	DATUM	PROJECTION

FOREWIND





LEGEND

- Dogger Bank Zone
- Dogger Bank Developable Area

Dogger Bank Teesside A Layout

- Accomodation Platform
- Collector Platform
- Converter Platform
- Met Mast
- Mooring
- Turbine

Dogger Bank Teesside B Layout

- Accomodation Platform
- Collector Platform
- Converter Platform
- Met Mast
- Mooring
- Turbine

0 10
Kilometres

Data Source:
© UKDeal
Round 3 © TCE, 2010.
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

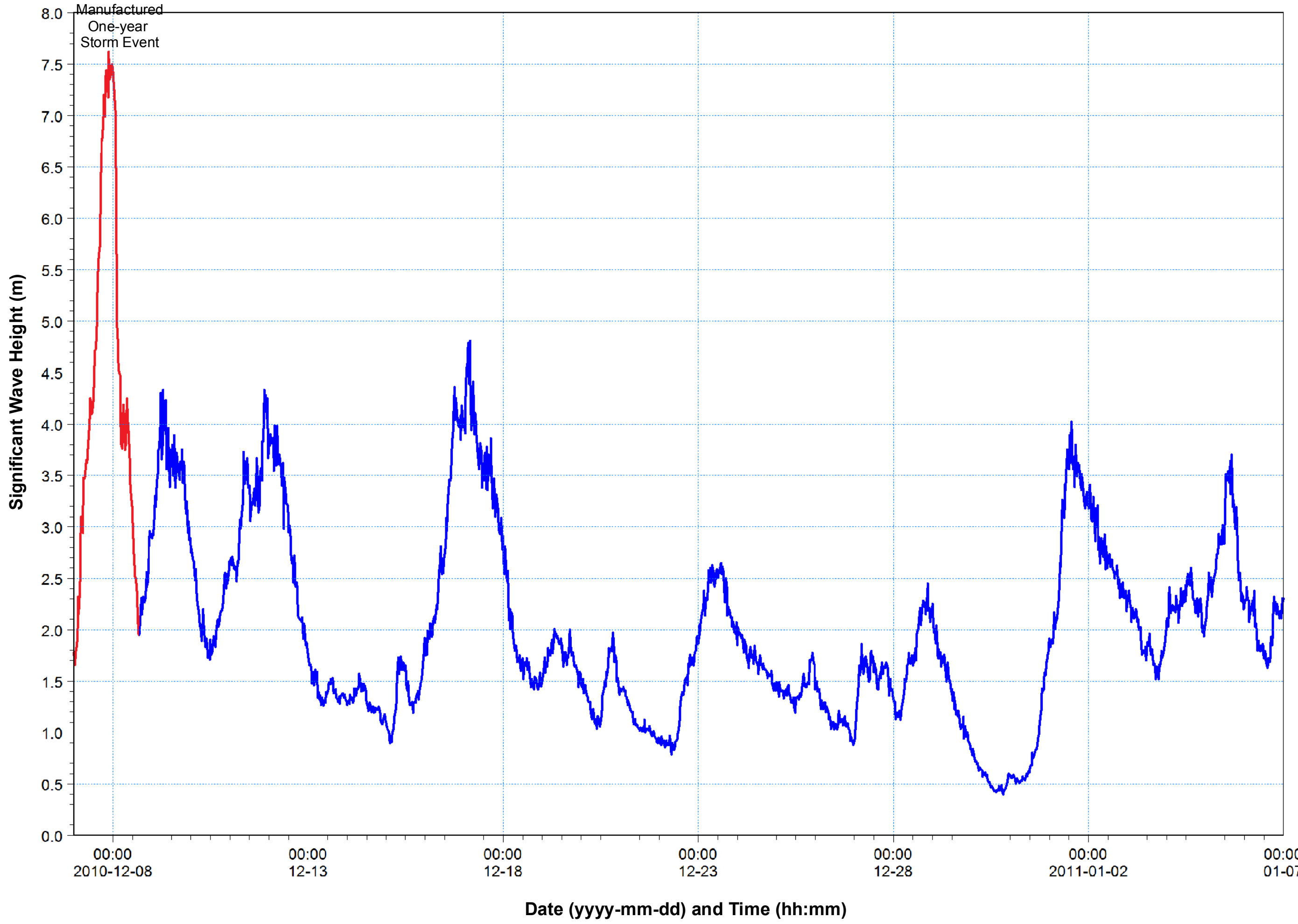
Figure 2.11 Dogger Bank Teesside A and Teesside B 6MW Layouts after One Year of Operation

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	15/10/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/63**

SCALE	1:400,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND



Data Source:
Image supplied by Gardline

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

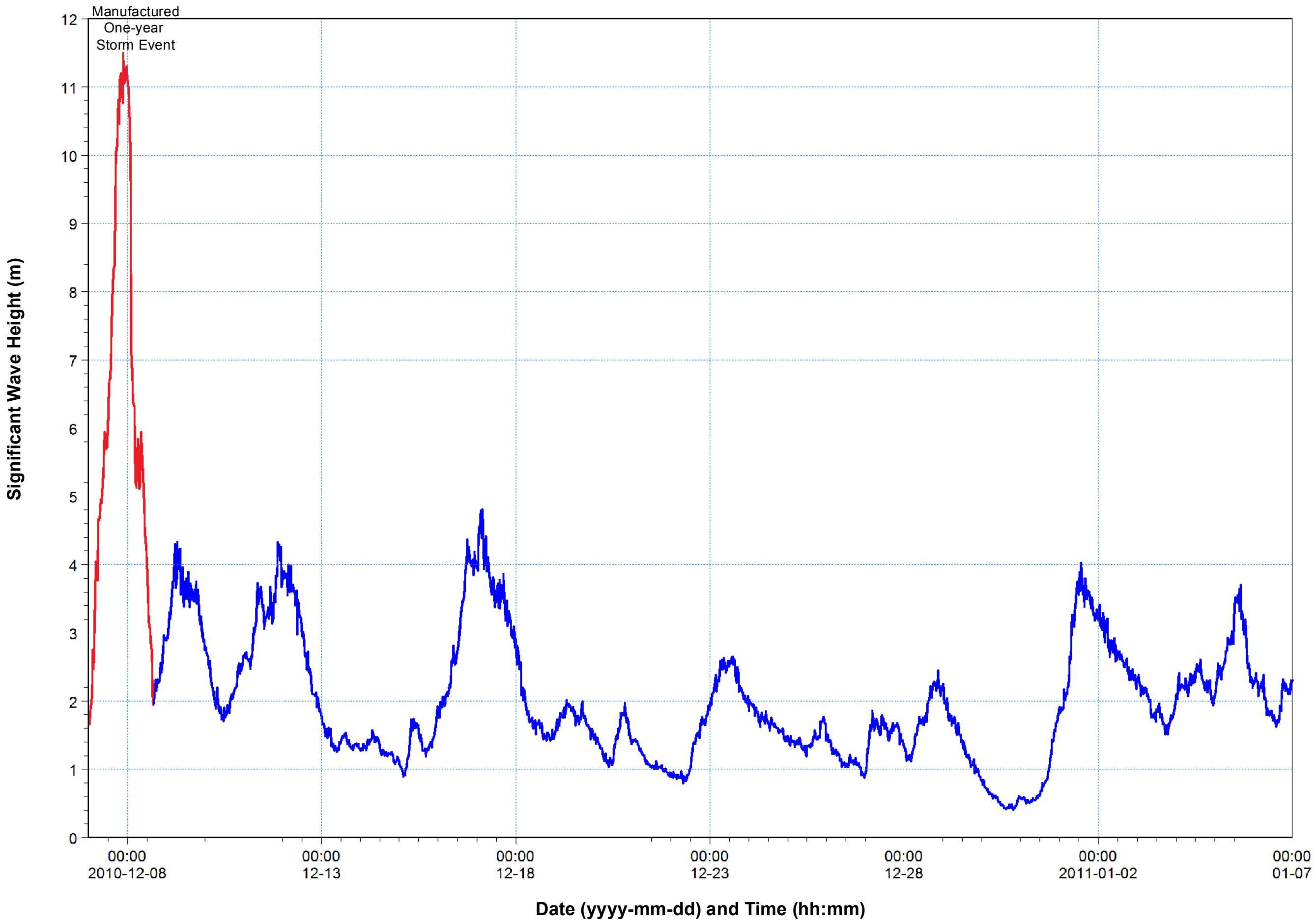
Figure 2.12 Wave Time Series Applied in the Operational Plume Dispersion Simulation after One Year of Operation

VER	DATE	REMARKS	Drawn	Checked
1	20/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/64**

SCALE	PLOT SIZE A4	DATUM	PROJECTION

FOREWIND



Data Source:
Image supplied by Gardline

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

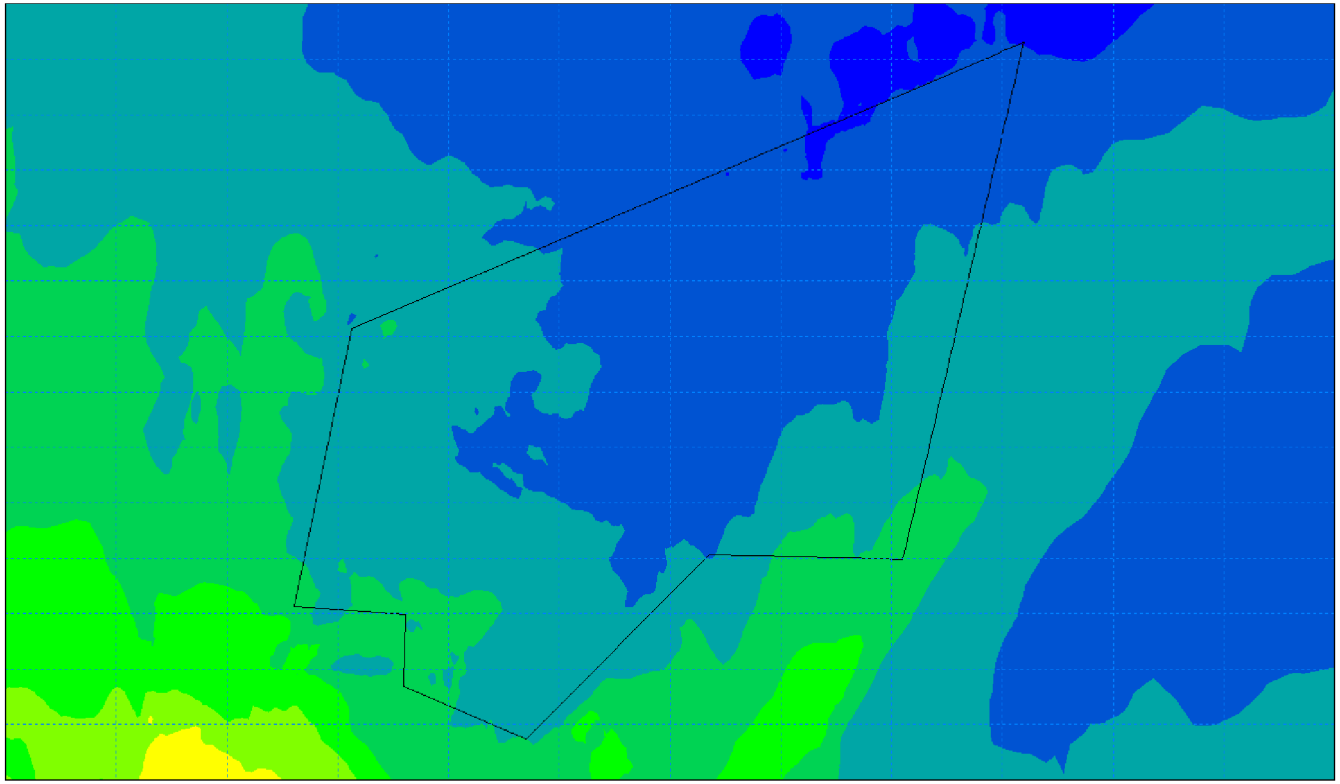
Figure 2.13 Wave Time Series Applied in the Operational Plume Dispersion Simulation after Two Years of Operation

VER	DATE	REMARKS	Drawn	Checked
1	20/02/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/65**

SCALE	PLOT SIZE	DATUM	PROJECTION
	A4		

FOREWIND



LEGEND

Maximum Current Velocity (m/s)

- Above 1.0
- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- Below 0.1
- Undefined Value

0 20

Kilometres

Data Source:
Image supplied by Danish Hydraulic Institute

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

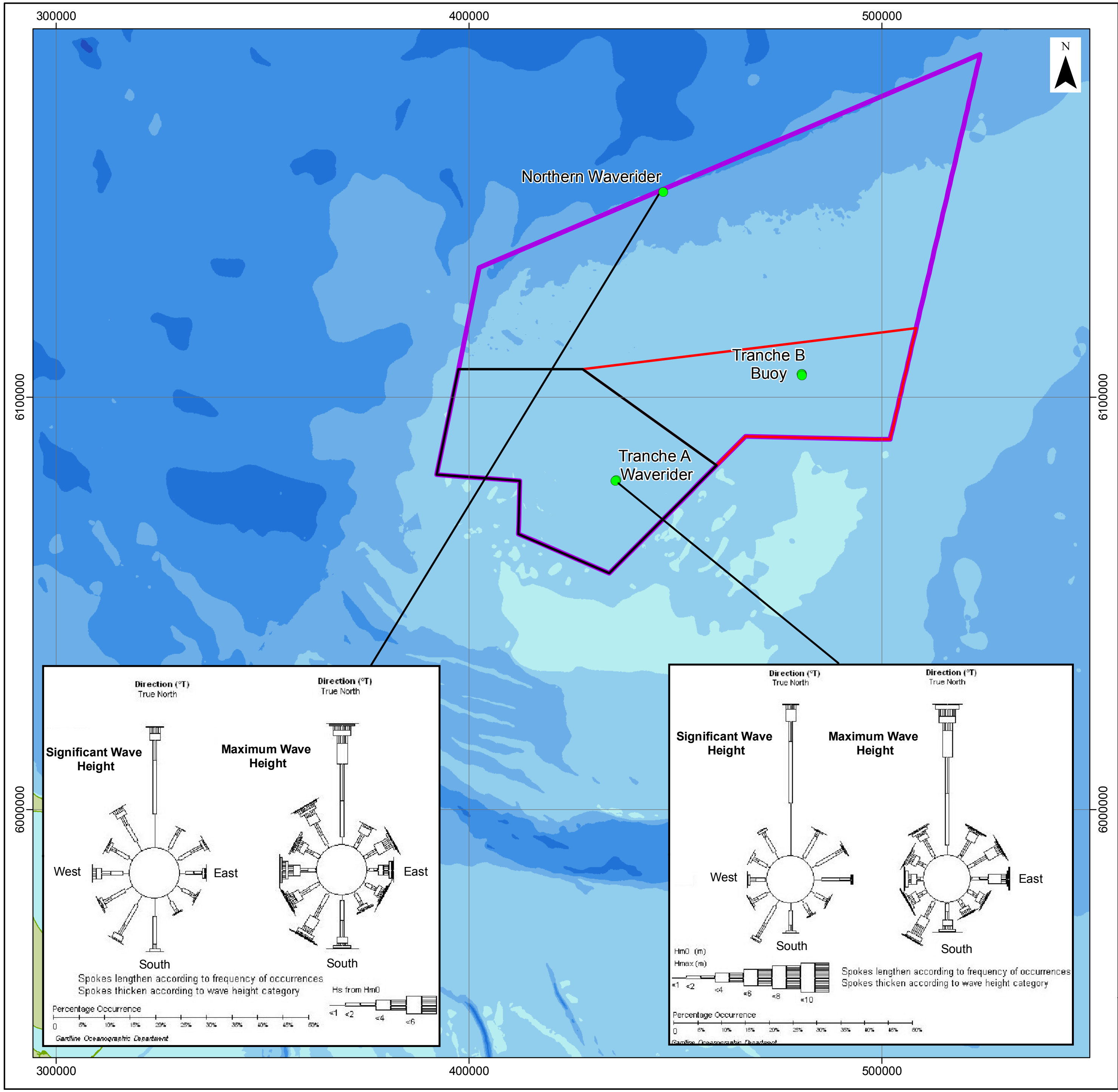
Figure 3.1 Maximum Depth-averaged Tidal Current Velocities over the 30-day Simulation Period

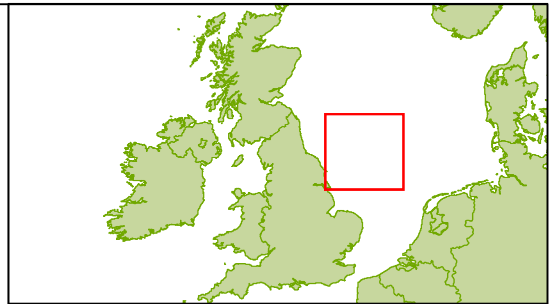
VER	DATE	REMARKS	Drawn	Checked
1	02/04/2013	Draft	FK	DB
2	26/09/2013	Final	LW	DB

DRAWING NUMBER: **5X5889/04/66**

SCALE	PLOT SIZE	DATUM	PROJECTION
Taken from image	A4	WGS84	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche A Boundary
- Tranche B Boundary
- Forewind Operating Buoy

0 20 40
Kilometres

Data Source:
Round 3 © TCE, 2010,
Current Roses © Gardline, 2011,
Forewind Operating Buoys © Gardline, 2012,
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

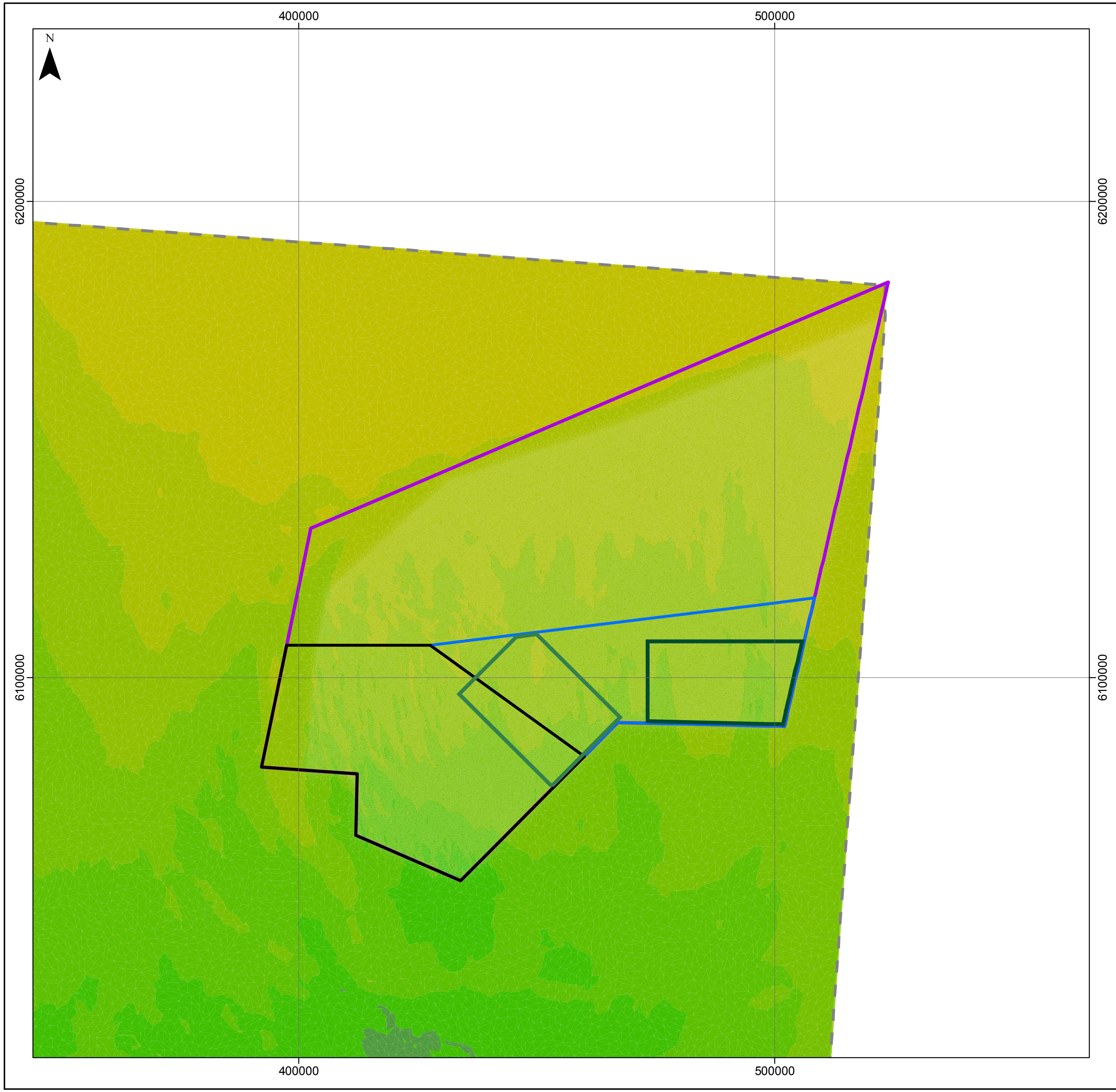
Figure 3.2 Wave Roses at the Tranche A Waverider and the Northern Waverider

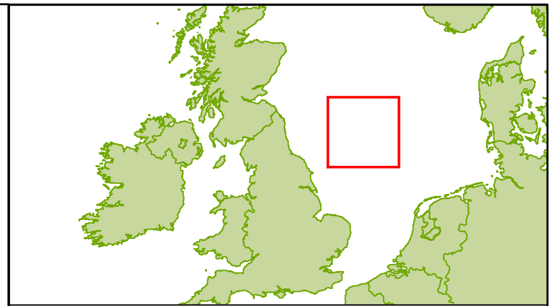
VER	DATE	REMARKS	Drawn	Checked
1	02/04/2013	Draft	FK	DB
2	16/09/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/67**

SCALE	1:1,387,837	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

Significant Wave Height (m)

- Above 9.5
- 9 - 9.5
- 8.5 - 9
- 8 - 8.5
- 7.5 - 8
- 7 - 7.5
- 6.5 - 7
- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- Below 0.0
- Model Boundary

- Dogger Bank Zone
- Tranche A Boundary
- Tranche B Boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B

0 40
Kilometres

Data Source:
© UKDeal
Wave Heights © Danish Hydraulic Institute, 2012,
Round 3 © TCE, 2013.

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 3.3 Baseline Significant Wave Height; One-year Waves from the North

VER	DATE	REMARKS	Drawn	Checked
1	02/04/2013	Draft	FK	DB
2	16/09/2013	Final	LW	DB

DRAWING NUMBER: **9X5889/04/68**

SCALE	1:1,200,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND