DOGGER BANK
TEESSIDE A & B

October
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Draft Environmental Statement
Chapter 9 Marine Physical Processes

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	Marine Physical Processes
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Drafted by		Royal HaskoningDHV (David Brew)	
Checked by		Angela Lowe	
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Approved by		Rufus Howard	
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Prepared by: Royal HaskoningDHV (David Brew)		Checked by: Angela Lowe	
Approved by: Rufus Howard	Signature / Approval (Forewind) Gareth Lewis		Approval Date: 27 September 2013

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1 Introduction

1.1.1 This chapter of the draft Environmental Statement (ES) describes the existing environment with regard to marine physical processes and assesses the potential effects of Dogger Bank Teesside A & B during the construction, operation and decommissioning phases. This chapter also includes an assessment of the landfall site between the coastal towns of Redcar and Marske-by-the-Sea on the Borough of Redcar and Cleveland coast. It includes site-specific information related to bathymetry and topography, physical processes (wave and tidal regimes), sedimentary processes (sediment transport, erosion and deposition) and geomorphology.

2 Guidance and Consultation

2.1 Legislation, policy and guidance

2.1.1 The assessment of potential effects upon marine physical processes has been made with specific reference to the relevant National Policy Statements (NPS). These are the principal decision making documents for Nationally Significant Infrastructure Projects (NSIP). Those relevant to Dogger Bank Teesside A & B are:

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

2.1.2 The specific assessment requirements for marine physical processes as detailed in the NPS are summarised in **Table 2.1**, together with an indication of the paragraph numbers of the draft ES chapter where each is addressed. Where any part of the NPS has not been followed within the assessment an explanation as to why the requirement was not deemed relevant, or has been met in another manner, is provided.

Table 2.1 NPS assessment requirements

NPS requirement	NPS reference	ES reference
The construction, operation and decommissioning of offshore energy infrastructure can affect the following elements of the physical offshore environment: • Waves and tides: the presence of the turbines can cause indirect effects on flood defences, marine ecology and biodiversity, marine archaeology and potentially, coastal recreation activities; • Scour effect: the presence of wind turbines and other infrastructure can result in a change in the water movements within the immediate vicinity of the infrastructure, resulting in scour (localised seabed erosion) around the structures. This can indirectly affect navigation channels for marine vessels and marine archaeology; • Sediment transport: the resultant movement of sediments, such as sand across the seabed or in the water column, can indirectly affect navigation channels for marine vessels; and • Suspended solids: the release of sediment during construction and decommissioning can cause indirect effects on marine ecology and biodiversity.	EN-3 Paragraph 2.6.189	Section 6.2 (construction sediment transport effects) Section 7.2 (operational tidal current effects) Section 7.3 (operational wave effects) Section 7.4 (operational sediment transport effects)
The Environment Agency (EA) regulates emissions to land, air and water out to 3nm. Where any element of the wind farm or any associated development included in the application to the IPC is located within 3nm of the coast, the EA should be consulted at the pre-application stage on the assessment methodology for impacts on the physical environment.	EN-3 Paragraph 2.6.191	Sections 3.3 and 5 (Dogger Bank Teesside A & B Export Cable Corridor and landfall assessment methodologies and worst case scenarios)

NPS requirement	NPS reference	ES reference
Beyond 3nm, the Marine Management Organisation (MMO) is the regulator. The applicant should consult the MMO and Centre for Environment, Fisheries and Aquaculture Science (Cefas) on the assessment methodology for impacts on the physical environment at the pre-application stage.	EN-3 Paragraph 2.6.192	Sections 3.3 and 5 (wind farm and Dogger Bank Teesside A & B Export Cable Corridor assessment methodologies)
The assessment should include predictions of the physical effect that will result from the construction and operation of the required infrastructure and include effects such as the scouring that may result from the proposed development.	EN-3 Paragraph 2.6.194	Section 6 (construction effects) and Section 7 (operational effects)
As set out above, the direct effects on the physical environment can have indirect effects on a number of other receptors. Where indirect effects are predicted, the IPC should refer to relevant sections of this NPS and EN-1.	EN-3 Paragraph 2.6.195	The effects on other receptors are considered separately in **Chapter 10 Marine Water and Sediment Quality**, **Chapter 12 Marine and Intertidal Ecology**, **Chapter 13 Fish and Shellfish** and **Chapter 18 Marine and Coastal Archaeology.**
An assessment of the effects of installing cable across the intertidal zone should include information, where relevant, about increased suspended sediment loads in the intertidal zone during installation.	EN-3 Paragraph 2.6.81 (intertidal impacts)	Section 6 (construction effects) and Section 7 (operational effects). The effects of suspended sediment on intertidal habitat are considered separately in **Chapter 12 Marine and Intertidal Ecology.**
Where necessary, assessment of the effects on the subtidal environment should include: • Loss of habitat due to foundation type including associated seabed preparation, predicted scour, scour protection and altered sedimentary processes; and • Increased suspended sediment loads during construction.	EN-3 Paragraph 2.6.113 (subtidal impacts)	The effects of scour and changes to sedimentary processes on subtidal habitat are considered separately in **Chapter 12 Marine and Intertidal Ecology.** The effects of suspended sediment on subtidal habitat are considered separately in **Chapter 12 Marine and Intertidal Ecology.**
Heritage assets can be affected by offshore wind farm development in two principal ways [only one is relevant to the physical environment]: • From indirect changes to the physical marine environment (such as scour, coastal erosion or sediment deposition) caused by the proposed infrastructure itself or its construction.	EN-3 Paragraph 2.6.139 (historic environment)	The effects of scour and changes to sedimentary processes on the historic environment are considered separately in **Chapter 18 Marine and Coastal Archaeology.**

NPS requirement	NPS reference	ES reference
Where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures.	EN-1 Paragraph 5.5.6	Sections 6.3 and 6.4 (expert geomorphological assessment of landfall effects)
The ES should include an assessment of the effects on the coast. In particular, applicants should assess: • The impact of the proposed project on coastal processes and geomorphology, including by taking account of potential impacts from climate change. If the development will have an impact on coastal processes the applicant must demonstrate how the impacts will be managed to minimise adverse impacts on other parts of the coast; • The implications of the proposed project on strategies for managing the coast as set out in Shoreline Management Plans (SMPs) (which provide a large-scale assessment of the physical risks associated with coastal processes and present a long term policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner), any relevant Marine Plans, River Basin Management Plans and capital programmes for maintaining flood and coastal defences; and • The vulnerability of the proposed development to coastal change, taking account of climate change, during the project's operational life and any decommissioning period	EN-1 Paragraph 5.5.7	Sections 6.3 and 6.4 (expert geomorphological assessment of landfall effects)
The applicant should be particularly careful to identify any effects of physical changes on the integrity and special features of Marine Conservation Zones, candidate marine Special Areas of Conservation (SACs), coastal SACs and candidate coastal SACs, coastal Special Protection Areas (SPAs) and potential coastal SPAs, Ramsar sites, Sites of Community Importance (SCIs) and potential SCIs and Sites of Special Scientific Interest (SSSI).	EN-1 Paragraph 5.5.9	The extent of physical process related change is discussed throughout this chapter. Potential impacts on designated sites, as a result of any such change, are addressed in **Chapter 8 Designated Sites**.

2.1.3 Discussion of the effects of Dogger Bank Teesside A & B on the elements described in EN-3 (offshore) and EN-1 (coastal) are provided in Section 6 (construction), Section 7 (operation) and Section 8 (decommissioning) of this chapter.

2.1.4 The principal guidance documents used to inform the assessment of potential effects on marine physical processes are as follows:

- Cefas. 2004. Guidance Note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements. Report to the Marine Consents and Environment Unit (MCEU), June 2004.
- Lambkin, D.O., Harris, J.M., Cooper, W.S. and Coates, T. 2009. Coastal process modelling for offshore wind farm environmental impact

assessment: best practice guide. COWRIE COAST-07-08, September 2009.

2.2 Consultation

2.2.1 As part of the development of Dogger Bank Teesside A & B, Forewind has undertaken a thorough pre-application consultation process, which has included the following key stages:

- First stage of statutory consultation (in accordance with sections 42 and 47 of the Planning Act 2008) on Preliminary Environmental Information (PEI) 1 including the Scoping Report submitted to the Planning Inspectorate (May 2012); and
- Scoping Opinion received from the Planning Inspectorate (June 2012).

2.2.2 Forewind has also consulted specific groups of stakeholders on a non-statutory basis to ensure that they had an opportunity to inform and influence the development proposals. Consultation undertaken throughout the pre-application development phase has informed Forewind's design decision making and the information presented in this document. Further information detailing the consultation process is presented in **Chapter 7 Consultation**. A Consultation Report will be provided as part of the overall planning submission.

2.2.3 A summary of the consultation carried out at key stages throughout the project, of particular relevance to marine physical processes is presented in **Table 2.2**. This table only includes the key items of consultation that have defined the assessment. A considerable number of comments, issues and concerns raised during consultation have been addressed in meetings with consultees and hence have not resulted in changes to the content of the draft ES. In these cases, the issue in question has not been captured in **Table 2.2**. A full explanation of how the consultation process has shaped the draft ES, as well as tables of all responses received during the statutory consultation periods, is provided in the Consultation Report to be submitted with the final application.

Table 2.2 Summary of consultation and issues raised by consultees

Date	Consultee	Summary of issue	ES reference
June 2012 (Scoping)	Secretary of State	The existing environment is described in this section outlines the further survey work that will be undertaken and the timescale for its completion. The purpose of each survey is noted but there are no proposed methodologies. The methodologies should be developed in consultation with JNCC, Natural England and the MMO.	Section 3 (methodology)
June 2012 (Scoping)	Secretary of State	The applicant states that the onshore and offshore cables may be left in situ as part of the decommissioning of the development. The EIA should assess the impacts of this option including the potential for cable exposure as a result of coastal changes and hydrological processes, including a monitoring plan and suitable mitigation measures.	Section 8 (decommissioning effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 6.2.2, Effects on geology, proposes to scope out the effect on underlying offshore geology. As highlighted in section 28.3.3 of the Scoping Report any topics to be scoped out must be properly justified. This should include specification of what is being considered the "underlying geology" and explanation of why and how this won't be affected, including depth below shallower geology and sediments. Should any effects upon geology be identified further information on the secondary effect upon other marine processes or ecology should be outlined.	Section 7 (operational effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 6.2.3, Effects on hydrodynamic processes, proposes to scope out the effect of construction infrastructure upon the hydrodynamic regime. As highlighted in Section 28.3.3 of the Scoping Report any topics to be scoped out must be properly addressed and justified and this should include detail of the construction infrastructure including dimensions, location, length of time that it will be left in place and movements, as well as any associated infrastructure such as moorings. Interaction between the infrastructure and hydrodynamic regime should be provided with an explanation of why the regime isn't affected.	Section 6 (construction effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 6.2.6, Effects on hydrodynamic processes and 6.2.7 Effects on sediment transport processes propose to assess the operational effects on the hydrodynamic and sediment transport processes. We are encouraged that the EIA will consider both near-field and far-field effects on hydrodynamic conditions. This assessment should be informed by appropriate hydrodynamic information for the development area and modelling studies. In-combination effects need also be considered, especially given the large number of turbines proposed and the overlap of the project with the Annex I sandbank habitat of the Dogger Bank cSAC. JNCC also advise that screening for an Appropriate Assessment in relation to potential effects on hydrodynamic and sedimentary processes will be required.	Section 7 (operational effects)

Date	Consultee	Summary of issue	ES reference
June 2012 (Scoping)	JNCC/Natural England	The assessment on hydrodynamic processes should also consider the potential effects of the development proposal upon the coastline, coastal processes and designated sites by impediment to sediment transport; and the interaction of turbines and their effect upon hydrodynamic and sediment processes as a group, as well as individually.	Sections 6.3 and 6.4 (expert geomorphological assessment of landfall effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 6.2.9 states that decommissioning and construction impacts will be similar and therefore proposes to scope out geology and hydrodynamic processes out of the EIA. The decommissioning effects must be addressed, particularly as this will include the removal of structures with a resultant change to the marine environment, hydrodynamic and sediment processes and potentially the remobilisation of sediments which have built up around infrastructure.	Section 8 (decommissioning effects)
June 2012 (Scoping)	JNCC/Natural England	As stated earlier in this letter, the effect of Spoils (Scoping Report, 2.3.13) should be addressed in the EIA for the effect upon benthic habitats and communities; turbidity and general water quality; and the potential for increasing or inhibiting sediment transport. Particular thought should be given to the impact of arisings from drilling into chalk as these have been seen to persist in the marine environment at other sites.	Section 6 (construction effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 6.5.1 states that there is an aggregate extraction licence area located on the south western edge of Tranche A. The aggregate area referred to is still in the application process (i.e. not licensed), but as Forewind pointed out that does not mean that extraction activities will not occur at this site in the future. Potential future extraction activities within Tranche A should be assessed within the cumulative impact assessment.	Section 10 (cumulative effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, Chapter 6, Marine Physical Processes, contains limited, to no scope for the assessment of the export cable and landfall effects. As such we would welcome early consultation. Provided below is an outline of issues that should be addressed along with the general comments provided at the beginning of this letter, as well as the comments under Intertidal and Subtidal Ecology Chapter 9. However this is not exhaustive and further consultation is required.	Section 6 (construction effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report must consider construction and operation impacts upon short and long-term coastal management, the shoreline management plans, potential changes in the coastline and associated requirements for coastal defences. The effects of any such requirements must be included and assessed by the EIA.	Sections 6 and 7 (construction and operational effects)
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 9.2.17, Potential Impacts during Decommissioning, Disturbance to intertidal habitats, identifies the intention to leave cables in situ in the intertidal. This proposal should be considered in detail within the ES and encompass on-going coastal changes, coastal retreat and beach/seabed lowering. The potential for exposure of the cables and effects upon coastal processes as well as the requirement for later protection or removal of the cables should be	Section 8 (decommissioning effects)

Date	Consultee	Summary of issue	ES reference
		included. The ES must consider the potential need for a monitoring plan for exposure, or effects upon the coastal processes caused by cables, over the lifetime of the project and if left permanently in situ.	
June 2012 (Scoping)	JNCC/Natural England	Scoping Report, 9.2.18, Impacts upon Subtidal ecology, (Decommissioning) identifies that decommissioning impacts on the subtidal will be similar to the construction phase. As with the intertidal, any intention to leave infrastructure in situ must be clearly outlined and assessed in the ES. Additionally, specific consideration of the decommissioning will be required particularly related to coastal changes which are expected to occur during the operational phase.	Section 8 (decommissioning effects)
June 2012 (Scoping)	MMO	It is noted from the project description that scour protection may be needed and could consist of protective aprons, mattresses, frond devices and rock and gravel dumping. This description also indicates that a detailed cable burial and protection assessment will be carried out to identify the target burial depth in each area and that specifications regarding landfall cable burial will take future coastal erosion into account.	Sections 6.3 and 6.4 (expert geomorphological assessment of landfall effects)
June 2012 (Scoping)	MMO	The approach to adopt a precautionary approach to impact assessment where uncertainty exists (Section 3.3.17, page 39) has been noted.	Section 5 (worst case scenarios)
June 2012 (Scoping)	MMO	It is acknowledged that mitigation and monitoring measures are outside the remit of this document (Section 3.8.2 and 3.8.3, page 44).	N/A
June 2012 (Scoping)	MMO	We consider that the existing environment is accurately described in section 6.1 (pages 69 to 73) with regard to geology, hydrodynamics, meteorology and geomorphology.	N/A
June 2012 (Scoping)	MMO	No impacts to the underlying geology of the development area are predicted and this issue may be scoped out of the EIA (as suggested in 6.2.2, page 73) provided foundation penetration is restricted to the surface sediment layers.	N/A
June 2012 (Scoping)	MMO	The potential impacts during construction are listed as temporary influences on hydrodynamics, disturbance to the seabed and an increase in suspended sediment (Sections 6.2.3 and 6.2.4, page 73).The temporary, localised impacts of construction infrastructure can be scoped out of the EIA as suggested.	Section 6 (construction effects)
June 2012 (Scoping)	MMO	Operational impacts on hydrodynamic processes are suitably described (Section 6.2.6, page 75) as localised scour and (potentially) far-field effects on the wave and tidal regime. We concur that these far-field effects need to be tested thoroughly through a modelling study. Such testing is important because of its implications for the future cumulative impacts of the wider proposed Dogger Bank zone.	Section 7 (operational effects)
June 2012 (Scoping)	MMO	Operational effects on sediment transport processes are predicted to be restricted to scour (Section 6.2.7, page 75). Although the report is correct to state that tidal will therefore be of key importance in assessing impacts to the sediment transport regime.	Section 7 (operational effects)

Date	Consultee	Summary of issue	ES reference
June 2012 (Scoping)	MMO	We concur that decommissioning impacts are to be similar to construction impacts (Section 6.2.9, page 75).	Section 8 (decommissioning effects)
June 2012 (Scoping)	MMO	We approve of the focus on the cumulative effects of this and other activities on physical processes (during operation) and sediment transport (during all project phases) (Section 6.5.1, page 75).	Section 10 (cumulative effects)
June 2012 (Scoping)	MMO	Potential construction impacts on water and sediment quality are expected to be restricted to the accidental release of chemicals and discrete short-term seabed disturbance leading to the re-suspension of sediments that may contain contaminants (Section 7.2.2 and 7.2.3, page 80).	The water and sediment quality impacts are considered separately in **Chapter 10 Marine Water and Sediment Quality**
June 2012 (Scoping)	MMO	During operation, potential impacts are expected to be indirect and the result of the disturbance and re-suspension of contaminated sediments. These impacts are expected to be localised and associated with scour around foundation structures (section 7.2.6, page 80).	The water and sediment quality impacts are considered separately in **Chapter 10 Marine Water and Sediment Quality**
June 2012 (Scoping)	MMO	Section 28.3.2 (page 232) includes a list of aspects that are proposed to be scoped out of the EIA. Of relevance to coastal processes are the following aspects: • Impacts on offshore geology • Impacts of the presence of construction plant on offshore geology and hydrodynamic regime. • Impacts of the decommissioning process on offshore geology and hydrodynamic regime. Scoping out these aspects is appropriate provided the foundation structures used do not penetrate the overlying sediment layer and intrude into the underlying geological formations, in which case the first aspect should be included in the ES.	Section 7 (operational effects)

3 Methodology

3.1 Study area

3.1.1 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 south western part of the Dogger Bank Zone (**Figure 3.1**) 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 of up to 2.4GW (up to 1.2GW in each). Following the identification of Tranche A in 2010, Tranche B (approximately 1,520km^2) was identified in 2011 as the second area for development.

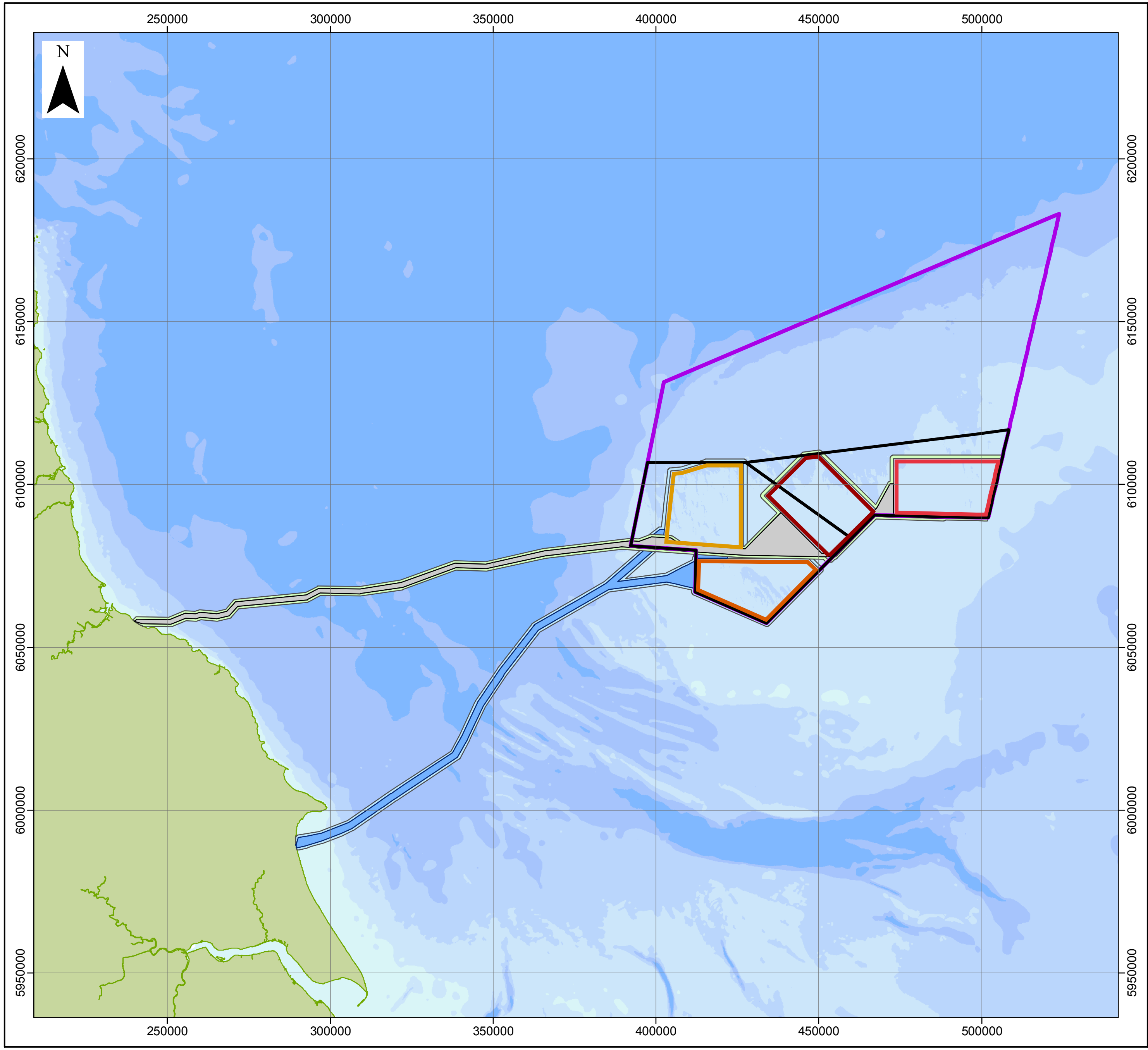
3.1.2 The second application by Forewind will cover two further project areas; Dogger Bank Teesside A & B (**Figure 3.1**). These two projects are also anticipated to have a combined installed capacity of up to 2.4GW. The entirety of Dogger Bank Teesside A is located in Tranche B, whereas Dogger Bank Teesside B straddles both tranches A and B. Two further projects have been identified within Tranche C of the Dogger Bank Zone, which lies north of Tranche A, are also planned (Dogger Bank Teesside C & D).

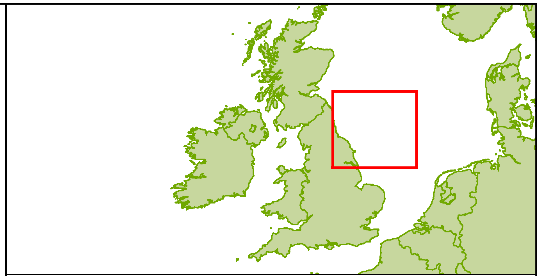
3.1.3 Electricity from Dogger Bank Teesside A & B will be transferred to shore by export cables, which will be routed to a landfall site between the coastal towns of Redcar and Marske-by-the-Sea. The proposed works to install the cables will be both offshore and onshore, as the cables extend from the wind farms to the coast. A 1,500-m wide export cable corridor has been delineated with the flexibility to place the cables anywhere within the corridor. The Dogger Bank Teesside A & B Export Cable Corridor will consist of two portions, an in-Zone cable corridor linking the project boundaries to the zone exit point and an export cable corridor linking the zone exit point to the cable landfall (**Figure 3.1**). The corridor is 157km long from the zone exit point to the beach at Redcar/Marske-by-the-Sea and 220km from the western boundary of Dogger Bank Teesside B to the beach.

3.1.4 The receptors to potential changes in physical and sedimentary processes occur both locally and regionally to Dogger Bank Teesside A & B. Hence, the physical environment study area encompasses the Dogger Bank Zone, the area of seabed between Dogger Bank and Redcar/Marske-by-the-Sea, and the Redcar and Cleveland coast. Assessment of the physical environment is considered over two spatial scales:

- Far-field: the southern North Sea area surrounding the development site, Export Cable Corridor and landfall, over which remote effects may occur and interact with other activities; and

- Near-field: the footprint of the development that resides in the marine and coastal environments, including the wind turbine foundations, export cable corridor and landfall.





LEGEND

- Dogger Bank Zone
- Tranche 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 Teesside A & B temporary works area
- Dogger Bank Creyke Beck export cable corridor
- Dogger Bank Creyke Beck temporary works area

0 20 40
Kilometres

Data Source:
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 3.1 Location of Dogger Bank Teesside A & B

VER	DATE	REMARKS	Drawn	Checked
1	21/02/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-410**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

3.2 Characterisation of existing environment - methodology

3.2.1 Three conceptual models were completed by Royal HaskoningDHV to support the characterisation of the Dogger Bank Zone (including the in-Zone cable corridor), the Dogger Bank Teesside A & B Export Cable Corridor and the landfall site (**Appendix 9A**). Numerical modelling to support both the baseline understanding and the assessment has been carried out by the Danish Hydraulic Institute (DHI) – see Section 3.3 for more details on modelling techniques adopted to characterise the existing environment.

3.2.2 Project-specific data was collected for Dogger Bank Teesside A & B across the Dogger Bank Zone and along the Dogger Bank Teesside A & B Export Cable Corridor. These data were input to the conceptual models as appropriate. Due to sufficient existing data, no new data was collected along the Redcar/Marske-by-the-Sea coastline (**Appendix 9A**). A summary of the data that has been used to inform this chapter is discussed in the following paragraphs.

Geophysical data

3.2.3 Geophysical data was collected during four main survey campaigns completed for different purposes at different stages of the project:

- Zonal characterisation of the Dogger Bank Zone at a wide 2.5km transect spacing;
- Detailed survey of Tranche A at a narrow 100m transect spacing (only the north eastern part of this tranche is relevant where some of Dogger Bank Teesside B is located);
- Detailed survey of Tranche B at a narrow 100m transect spacing; and
- Detailed survey of the Dogger Bank Teesside A & B Export Cable Corridor between the Dogger Bank Zone and the landfall.

3.2.4 Full details of the methods of these surveys, along with charts of the geophysical survey transect lines and outputs are provided in **Appendix 9A**.

3.2.5 Gardline (2011a) collected geophysical data across the entire Dogger Bank Zone to provide a broad characterisation of the potential development area and to inform the zone characterisation process. This survey was carried out between May 2010 and August 2010 and deployed single and multibeam echo sounder, side-scan sonar, and sub-bottom profilers (pinger, sparker and mini airgun). The survey was run in a square grid pattern with transect lines 2.5km apart, meaning that around 15% of the Dogger Bank Zone's surface was covered by side scan and bathymetry (200m swathe along each transect).

3.2.6 GEMS (2011) carried out a geophysical survey of Tranche A to support development of projects within this area. The survey was carried out between July 2010 and December 2010 and included collection of side-scan sonar, sub-bottom profiling (pinger and sparker), bathymetry (single and multibeam echosounder) and acoustic ground discrimination (AGDS). The main geophysical lines were run 100m apart with 500m spaced cross lines, achieving 100% coverage of Tranche A with side scan and bathymetry.

3.2.7 Gardline (2013a) carried out a geophysical survey of Tranche B between June 2011 and October 2011, and between March 2012 and May 2012. The main geophysical lines were run at 100m apart with 500m or 1,000m spaced cross lines, achieving 100% coverage of side scan and bathymetry. The Tranche B data includes seabed characterisation (side-scan sonar, AGDS), sub-bottom profiling (pinger, sparker and mini airgun), and bathymetry (single and multibeam echosounder).

3.2.8 Gardline (2013b) collected geophysical data along two 500-m wide sections of the Dogger Bank Teesside A & B Export Cable Corridor between May 2012 and July 2012. Data collection included bathymetry (multi-beam echosounder), seabed features (side-scan sonar) and sub-bottom profiling. The main geophysical lines were run approximately 100m apart along the majority of the length of the sections of export cable achieving 100% coverage of side scan and bathymetry. For the Dogger Bank Teesside A & B Export Cable Corridor nearer to the coast, geophysical survey lines were approximately 25m apart up to 5km from the coast and then approximately 50m apart up to 16km from the coast.

Geotechnical data

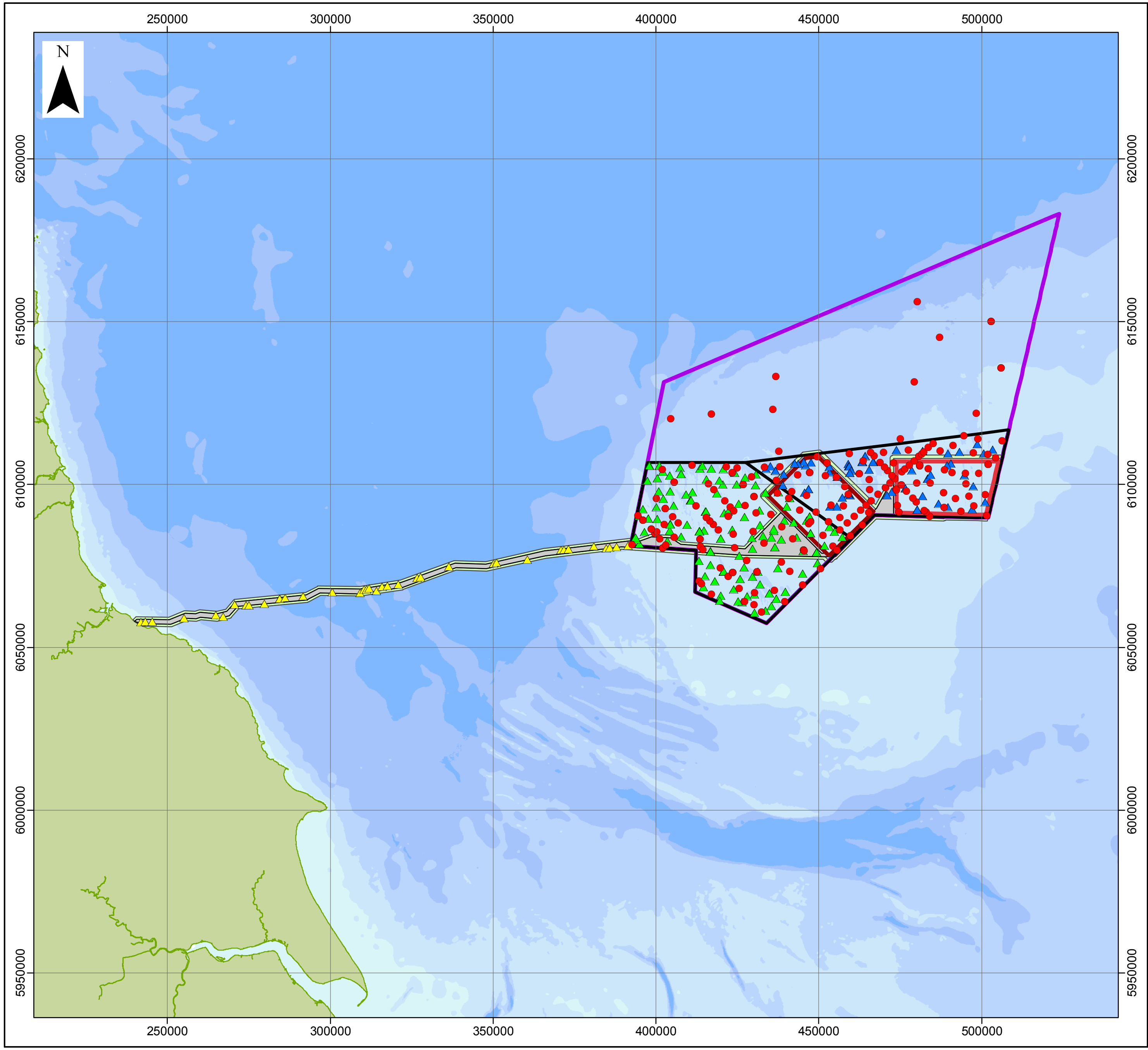
3.2.9 Fugro (2011) collected 56 boreholes and wireline logs (45 in Tranche A) and 96 cone penetration tests (CPTs) across the Dogger Bank Zone between October 2010 and December 2010. The distribution of these is shown in **Figure 3.2**, but note that at each location (114 locations), one or more of the different types of geotechnical data collection has been undertaken. The boreholes were logged and various geotechnical tests were performed *in situ* and in the laboratory.

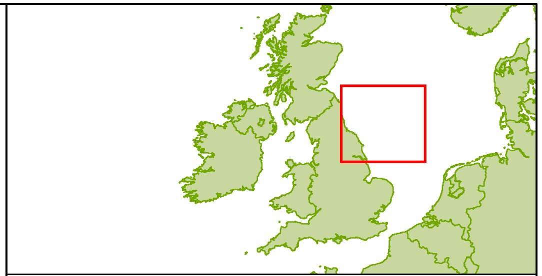
3.2.10 In addition, Fugro (2012) carried out a geotechnical survey in Tranche B in August 2012, collecting 17 borehole logs with combined CPTs and GEO (Danish Geotechnical Institute) (2012) collected 80 CPTs across Tranche B and eight CPTs in Tranche A between May and June 2012.

Benthic data

3.2.11 Gardline (2011b) collected 103 seabed sediment grab samples across Tranche A (**Figure 3.2**) as part of the wider benthic survey campaign undertaken between May 2011 and August 2011. All of these samples were analysed for particle size distribution.

3.2.12 Gardline (2012) also investigated 55 sites across Tranche B at which seabed sediment grab samples were taken from 51. The remaining four sites were not sampled due to the presence of hard substrate unsuitable for grab sampling. Particle size analysis and faunal analyses were carried out on all 51 samples. Gardline (2013b) collected 39 seabed sediment grab samples along the Dogger Bank Teesside A & B Export Cable Corridor (**Figure 3.2**). All of these samples were analysed for particle size distribution.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Geotechnical sample location
- Tranche A seabed sediment sample location
- Tranche B seabed sediment sample location
- Export cable corridor seabed sediment sample location

0 20 40
Kilometres

Data Source:
Dogger Bank geotechnical sample locations from Fugro (2010)
Tranche A & B geotechnical sample locations from GEO (2012)
Tranche A seabed sediment sample locations from Gardline Environmental Limited survey (2011)
Teesside Export Cable Corridor & Tranche B seabed sediment sample locations from Gardline Environmental Limited survey (2012)
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 3.2 Seabed sediment sample locations

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-411**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

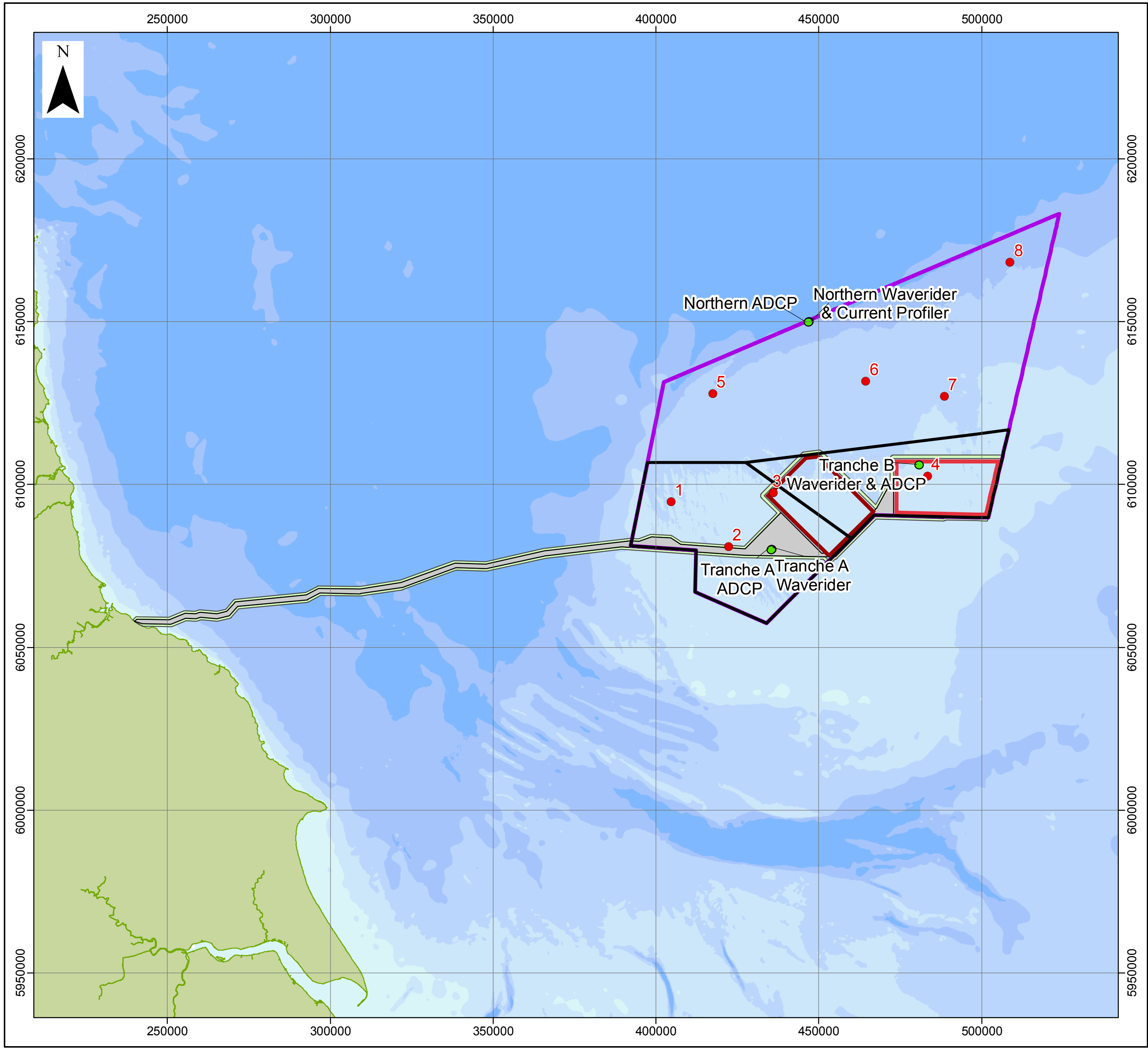
Meteorology and oceanography (metocean) data

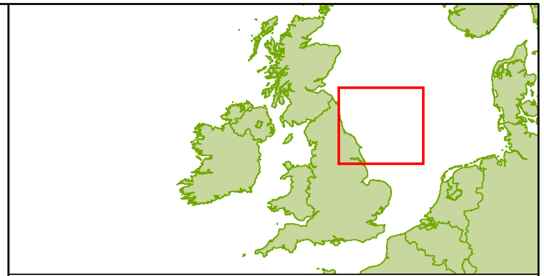
3.2.13 Currently, there are three locations where Forewind has deployed instruments to collect time series metocean data; the northern limit of the Dogger Bank Zone, inside Tranche A and inside Tranche B (**Figure 3.3**). At all these locations, wave and tidal current data have been collected using wave-riders and Acoustic Doppler Current Profilers (ADCPs). The time series of data that has been collected is listed in **Table 3.1**.

Table 3.1 Metocean data available from the deployments in the Dogger Bank Zone

Location	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	-	-

3.2.14 In addition to the new data collection, Mathiesen and Nygaard (2010) and Mathiesen *et al*., (2011) provided modelled metocean data for eight locations within the Dogger Bank Zone (**Figure 3.3**).





LEGEND

- Dogger Bank Zone
- Tranche Boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Forewind metocean deployment
- Modelled metocean location

0 20 40
Kilometres

Data Source:
Metocean Bouys © Gardline Environmental Ltd, 2012
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 3.3 Metocean data points in the Dogger Bank Zone

VER	DATE	REMARKS	Drawn	Checked
1	21/02/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-412**

SCALE 1:1,800,000 | PLOT SIZE A4 | DATUM WGS84 | PROJECTION UTM31N

FOREWIND

3.3 Assessment of effects – methodology

Effects and impacts

3.3.1 The assessment methodology adopted to understand changes to the physical environment caused by Dogger Bank Teesside A & B is different to those adopted in other chapters of this draft ES. This is because the development will have effects on the hydrodynamic and sedimentary processes, but these effects in themselves are not considered to be impacts. The impacts will manifest upon other receptors such as marine ecology, fish and shellfish resources, marine water and sediment quality, and the historic environment. Hence, the assessment in this chapter focuses on describing the changes/effects against the existing environment, rather than defining the impact. Where an effect is identified, the assessment considers the magnitude of the degree of change relative to baseline conditions.

3.3.2 Potential impacts on receptors caused by changes in the physical environment are described in **Chapter 10 Marine Water and Sediment Quality**, **Chapter 12 Marine and Intertidal Ecology**, **Chapter 13 Fish and Shellfish Ecology** and **Chapter 18 Marine and Coastal Archaeology**. The assessments presented in these chapters draw on the outputs of the marine physical processes studies.

Modelling techniques

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

Tidal current (hydrodynamic modelling)

3.3.4 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 project-specific hydrodynamic model was developed and run.

3.3.5 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. 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 in the developable area.

3.3.6 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

3.3.7 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.

3.3.8 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 wind turbines are proposed.

3.3.9 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 3.3**) (Gardline 2011c). The data used in the model 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.

Dispersion modelling

3.3.10 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 has 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.

3.3.11 Particle size inputs to the dispersion models were calculated from two sources:

- For surface sediment as an average from analyses of the seabed sediment samples collected across Tranche B and the Dogger Bank Teesside A & B Export Cable Corridor; and
- For sub-surface sediments as an estimate from borehole data collected across Tranche B.

Conceptual modelling

3.3.12 Expert geomorphological assessment, using the landfall conceptual model (**Appendix 9A**) as a basis, has been used to assess the effects of the landfall works on existing physical processes and future evolution of the coastline. The landfall conceptual model provides a baseline understanding of the physical and sedimentary processes operating along Redcar/Marske-by-the-Sea coast and, more specifically, in the vicinity of the landfall. The conceptual model was compiled almost entirely from existing data including wave conditions, sediment transport and coastal change. 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.

4 Existing Environment

4.1 Bathymetry

4.1.1 The Dogger Bank is a large and isolated positive bathymetric feature which is approximately 300km long and elongate in an east-north east to west-south west direction. Within the Dogger Bank Zone, water depths range from approximately 78m below lowest astronomical tide (LAT) along the northern edge to just less than 20m below LAT in the south west (Tranche A).

4.1.2 A proportion (about one third) of the Dogger Bank Teesside B project area is located within the north eastern part of Tranche A and falls within the 20-30m bathymetry zone. The remaining two thirds is located in the western part of Tranche B. All of Dogger Bank Teesside A is located in Tranche B.

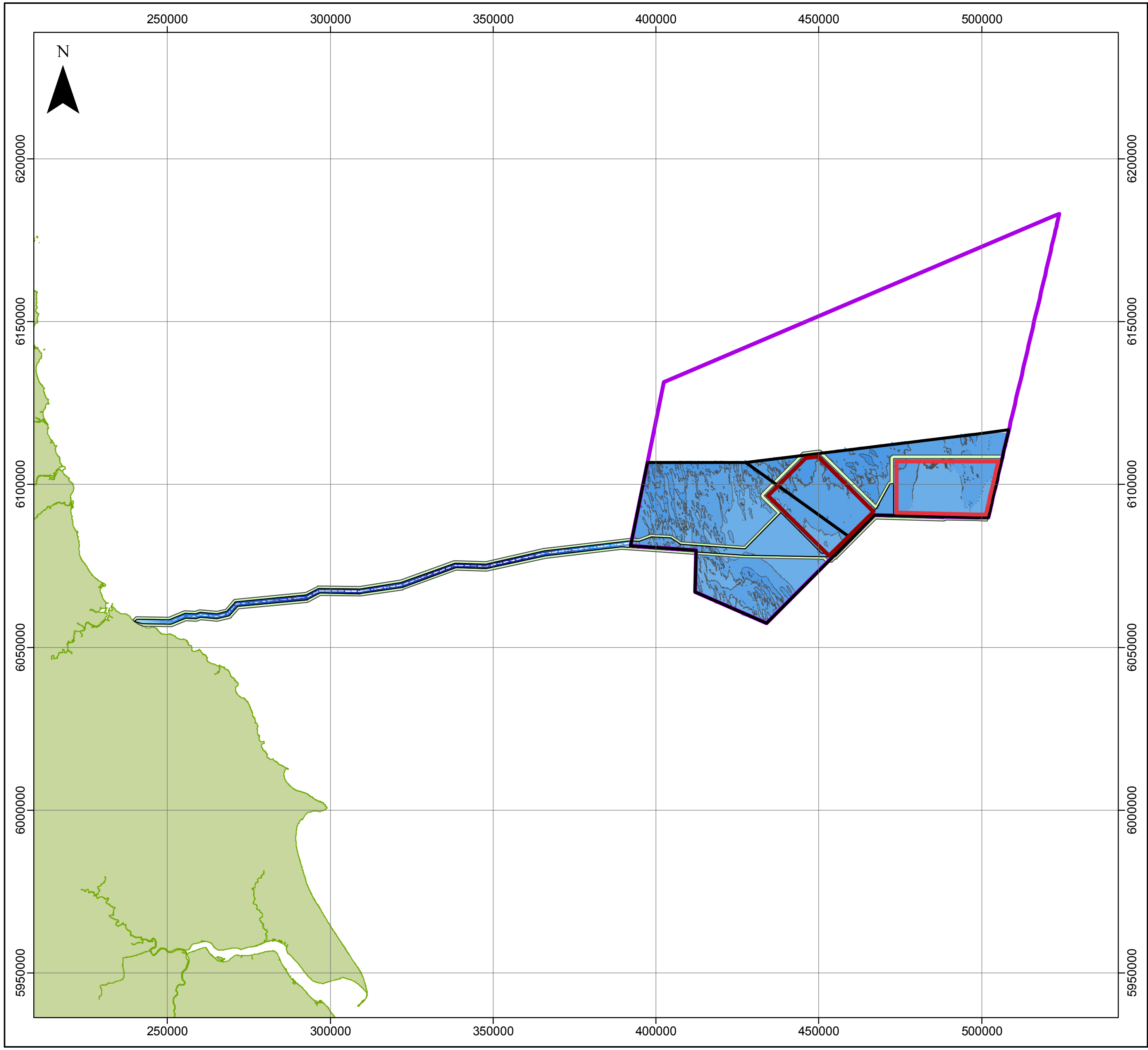
4.1.3 Gardline (2013a) and GEMS (2011) mapped the bathymetry of Tranche B and north east Tranche A, respectively, in more detail than the Dogger Bank Zone (**Figure 4.1**). Tranche B was divided into three main zones:

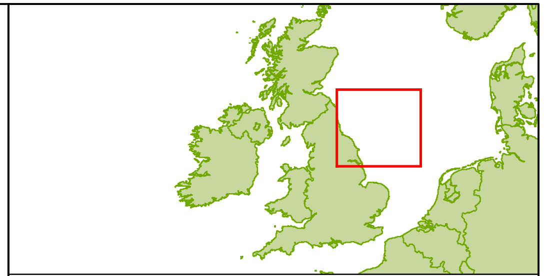
- Areas less than 25m below LAT; predominantly in the form of a plateau in the south east of Tranche B;
- Areas between 25 and 35m below LAT; these depths dominate most of Tranche B; the seabed here is generally low relief, with gradients of less than three degrees; and
- Areas greater than 35m below LAT; these depths occur in the north of Tranche B in the form of north west to south east elongated gullies up to 6m deep with gradients up to six degrees along their sides.

4.1.4 The part of Tranche A occupied by Dogger Bank Teesside B comprises an area between 20m and 30m below LAT; these depths dominate much of Tranche A where the seabed is generally low relief compared to deeper areas.

4.1.5 Gardline (2013b) mapped the bathymetry of the Dogger Bank Teesside A & B Export Cable Corridor (**Figure 4.1**). Water depths range from just above LAT near the coast to approximately 80m below LAT with the deepest point about 90km offshore.

4.1.6 At the landfall site, the seabed can be separated into two zones; a nearshore zone that extends 2.5km from the coast to 20m depth with a mean gradient of 0.4^{o} and an offshore zone that extends from 2.5km to 4km offshore, characterised by a mean gradient of 0.1^{o}.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Bathymetry contours (m below LAT)

Bathymetry (m below LAT)

- Above 0
- 0 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- 45 - 50
- 50 - 55
- 55 - 60
- 60 - 65
- 65 - 70
- 70 - 75
- 75 - 80
- 80 - 85
- 85 - 90

Data Source:
Tranche A bathymetry from GEMS (2010),
Tranche B bathymetry from Gardline (2011),
Cable corridor bathymetry from Gardline (2013),
Round 3 offshore wind farm boundary © Crown Copyright, 2013

0 20 40
Kilometres

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.1 Bathymetry of tranches A & B and the Dogger Bank Teesside A & B export cable corridor

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-413**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

4.2 Offshore geology

Pleistocene and older

4.2.1 The top 200m of the geology of Dogger Bank is dominated by sediments deposited during the Quaternary (Pleistocene followed by Holocene). The deeper Pleistocene formations preserved beneath tranches A & B of Dogger Bank comprise a variety of sedimentary units including marine, non-marine and intertidal sediments and till (**Table 4.1**). Some units may be incised glacial sediments deposited in sub-glacial valleys. It is likely that some of these units approach within 50m of the seabed beneath tranches A & B.

Table 4.1 Stratigraphic summary of formations observed or believed to be present across tranches A and B

Age	Formation name	Composition / Sediment type	Environment
Holocene	Bligh Bank	Medium to fine sand	Marine
	Indefatigable Grounds	Gravelly sand and sandy gravel	Marine
	Nieuw Zeeland Gronden – Terschellinger Bank Member	Fine sand with shell fragments	Marine
	Well Hole	Fine sand and sandy mud	Shallow Marine
	Elbow	Peat followed by clay followed by muddy fine sand	Fluvial to Intertidal
	Transitional	Various	Sub-glacial to pro-glacial
	Botney Cut	Mud with cobble patches	Sub-glacial
Pleistocene	Dogger Bank	Clay diamicton	Sub-glacial and pro-glacial
	Eem	Shelly sand and muddy sand	Marine
	Tea Kettle Hole	Fine sand with organics	Periglacial and aeolian
	Cleaver Bank	Laminated clay and fine sand	Marine to pro-glacial
	Egmond Ground	Gravelly sand with interbeds of clay and silt	Marine
	Swarte Bank	Diamicton followed by mud then clay	Sub-glacial to pro-glacial
	Yarmouth Roads	Fine to medium sand	Fluvial to intertidal to shallow marine

4.2.2 The shallower Pleistocene units are dominated by the Dogger Bank Formation, which rests unconformably on the underlying formations. It comprises two main units; Older Dogger Bank and Younger Dogger Bank, both of which are clay-rich formations with multiple sand-rich layers of glacial origin (**Table 4.1**). The Dogger Bank Formation is present at or near the seabed, underlying Holocene sands, and in some areas underlying Botney Cut Formation channel infills.

4.2.3 In Tranche B, the Older Dogger Bank unit comprises a series of pro-glacial morainic ridges in the west, oriented approximately northeast-southwest. The unit then thins across the central part of Tranche B before thickening again to the eastern side. The overlying Botney Cut Formation is composed of pro-glacial lake deposits that infill a basin in the Younger Dogger Bank unit. These sediments are thinly laminated clays with laminae of silts and fine sand.

4.2.4 To the south and west of Dogger Bank (and along the Dogger Bank Teesside A & B Export Cable Corridor), the Dogger Bank Formation passes laterally into the Bolders Bank Formation (Cameron et al., 1992). The Bolders Bank Formation is a sub-glacial to pro-glacial diamicton laid down during the late Pleistocene glaciation (Cameron et al., 1992).

Holocene

4.2.5 The Dogger Bank is formed mostly from a core of Pleistocene sediment, but is surrounded and covered by a veneer of Holocene sediments that reach 10m in thickness around its margins and greater than 25m thickness in infilled channels on Dogger Bank itself. The Bligh Bank and Indefatigable Grounds Formations and the Terschellinger Bank Member of the Nieuw Zeeland Gronden Formation (**Table 4.1**) are marine sands. There are also two older Holocene units (Well Hole and Elbow Formations) which were deposited in terrestrial tundra through to estuarine and intertidal environments.

4.2.6 The nature of the shallow geology (top 3m) along the Dogger Bank Teesside A & B Export Cable Corridor is mainly governed by the distribution and thickness of Holocene sands. The sand ranges in thickness from absent to greater than 20m at the eastern extent of the cable (Gardline, 2013b). Where the sand is thin or absent, the outcrop at the seabed and in the shallow sub-seabed is composed predominantly of Pleistocene Bolders Bank Formation (Cameron *et al*. 1992; Stoker *et al*. 2011) or bedrock.

4.3 Coastal geology

4.3.1 The coastline between Redcar and Marske-by-the-Sea is backed by undefended and initially (Redcar) low, vegetated till cliffs rising to the higher coastal till slopes at Marske-by-the-Sea (**Figure 4.2**). The backshore and toe of the coastal slope is composed of a high, dry sandy backshore. Along some of the coastal slopes there are substantial shingle berms present at their toes.

4.3.2 The geological layers of interest for the construction of Dogger Bank Teesside A & B Export Cable and landfall are:

- Till slopes between Redcar and Marske-by-the-Sea;
- Sand beaches that front the slopes; and
- Occasional outcrops of underlying bedrock and patches of shingle berms at the toe of the slopes.

N

LEGEND

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.2 Till cliffs and beach at Marske-by-the-Sea

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-414**

SCALE	Not to scale	PLOT SIZE	A4	DATUM		PROJECTION	

FOREWIND

4.4 Wave climate

4.4.1 Gardline (2011c) presented wave roses for the Tranche A waverider buoy for time series between 23 September 2010 and 19 May 2011 and, for the northern buoy, between 6 November 2010 and 31 October 2011 (**Figure 4.3**). The results show that most waves approach the site from the northern sector. For the Tranche A buoy, the mean significant wave height for the time series period was 1.7m and the maximum value was 6.0m.

4.4.2 No new wave data has been collected along the Dogger Bank Teesside A & B Export Cable Corridor, and so the characterisation of the wave climate relies on existing information. At the offshore end of the Dogger Bank Teesside A & B Export Cable Corridor, BERR (2008) described annual mean significant wave heights of 1.75-2.0m, whereas close to the landfall site the annual mean significant wave height decreases to less than 1.0m. Across Dogger Bank, BERR (2008) described annual mean significant wave heights of 1.75-2.0m, which corresponds broadly to the mean significant wave height of 1.7m recorded from the Tranche A waverider buoy.

4.4.3 As offshore waves propagate towards the shore, they are influenced by the seabed and shoreline features and so wave transformation processes occur, resulting in a nearshore wave climate. Generally, nearshore waves approach the landfall from the north-north east and north east due to these transformation processes. The north-north east-approaching waves drive sediment transport to the south east along the Redcar/Marske-by-the-Sea coastline.

4.5 Astronomical tidal range

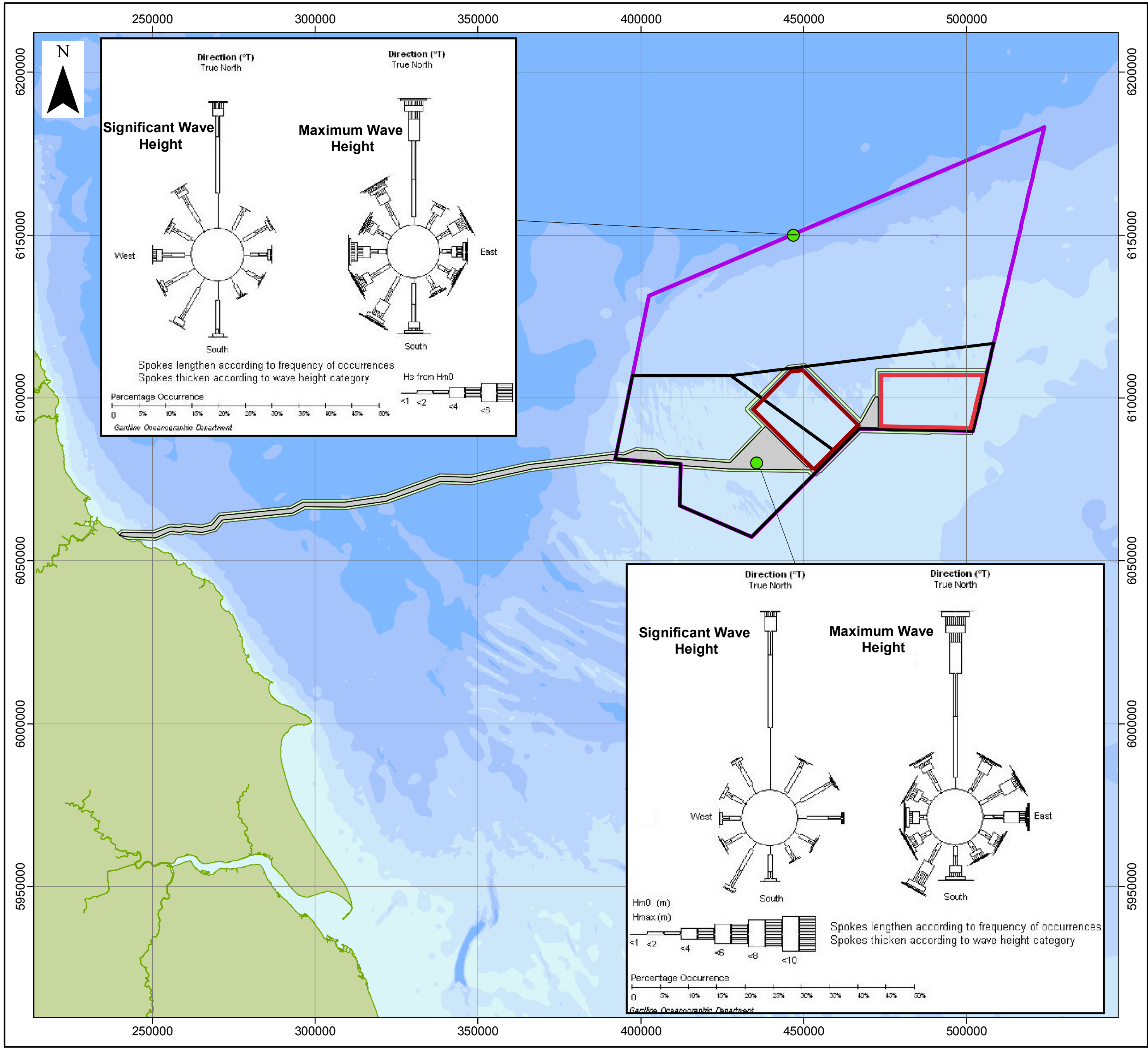
4.5.1 The tidal regime at the landfall site is semi-diurnal; the water level rises and falls twice a day. The tide levels for the landfall site have been estimated using the tide levels for the River Tees, obtained from 2013 Admiralty Tide Tables. **Table 4.2** shows that the tidal range, the difference between high and low water level, is 4.6m on a spring tide and 2.3m on a neap tide. These are astronomical levels and do not account for meteorological surges.

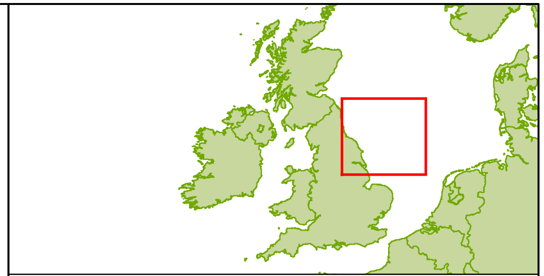
Table 4.2 Tidal levels at the River Tees (from the 2013 Admiralty Tide Tables)

Datum	m LAT	m ODN
Mean High Water Spring	5.5	2.65
Mean High Water Neap	4.3	1.45
Mean Sea Level	3.2	0.35
Mean Low Water Neap	2.0	-0.85
Mean Low Water Spring	0.9	-1.95

Note: Ordnance Datum Newlyn (ODN) is 2.85m above Lowest Astronomical Tide (LAT)

4.5.2 Mathiesen *et al*., (2011) showed that mean high water spring at Dogger Bank Teesside A is 0.65m above mean sea level (at Location 4, **Figure 3.3**) and 0.95m above mean sea level at Dogger Bank Teesside B (at Location 3, **Figure 3.3**) Mean low water spring tide was not presented in their analysis.





Data Source:
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from TCarta data © 2009
Buoys and wave roses data from Gardline Environmental Limited, MetOcean Operations Report (2013)

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.3 Wave roses at the Tranche A Waverider and the Northern Waverider

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: F-OFL-MA-415

SCALE 1:1,800,000 | PLOT SIZE A4 | DATUM WGS84 | PROJECTION UTM31N

FOREWIND

4.6 Extreme water levels

4.6.1 Water levels on the east coast are strongly influenced by tidal surges, which are driven by low pressure weather systems moving down the North Sea. These have the effect of raising extreme water surfaces above levels that would be caused by astronomical effects alone. The resulting water levels have been quantified, for different return periods, in the River Tyne to Flamborough Head Shoreline Management Plan (Royal Haskoning, 2007), and the results for the River Tees are shown in **Table 4.3**. The 50-year extreme water level is 3.68m ODN; an increase above the predicted astronomical spring tide level of about 1m.

Table 4.3 Extreme water levels at the River Tees (Royal Haskoning, 2007)

Return period (years)	Water level (m ODN)
1	3.20
10	3.48
50	3.68
100	3.80
200	3.87

4.7 Sea-level rise

4.7.1 Global sea level is primarily controlled by three factors; thermal expansion of the ocean, melting of glaciers and change in the volume of the ice caps of Antarctica and Greenland. The Intergovernmental Panel on Climate Change (IPCC 2007) estimated a global average sea-level rise over the 20th century of 1.2-2.2mm/yr with an average value of 1.7mm/yr. From 1961 to 2003, the rate was estimated at 1.8mm/yr (1.3-2.3mm/yr) rising to 3.1mm/yr (2.4-3.8mm/yr) between 1993 and 2003.

4.7.2 Woodworth *et al.* (2002) undertook an analysis of measured tide gauge data for UK sites with more than 15 years data record. The gauge at North Shields provides the longest available record of historic sea levels at a location relatively close to the envelope of the two cable landfall corridors. Between the years 1901 and 1996, relative sea level rise was measured to be 1.86mmyr^{-1}.

4.7.3 For Redcar to Marske-by-the-Sea, UKCP09 projected a 0.20m rise in sea level by 2050 (‘most likely’ value under the medium greenhouse gas emissions scenario) (UKCIP 2009). For the longer term, UKCP09 provides lower and upper bounds projections by 2100 of between 0.18m (low emissions) and 0.86m (high emissions), respectively. Since these potential changes in sea level will occur over the expected life time of Dogger Bank Teesside A & B, it is necessary to anticipate these increased water depths.

4.8 Storm surges

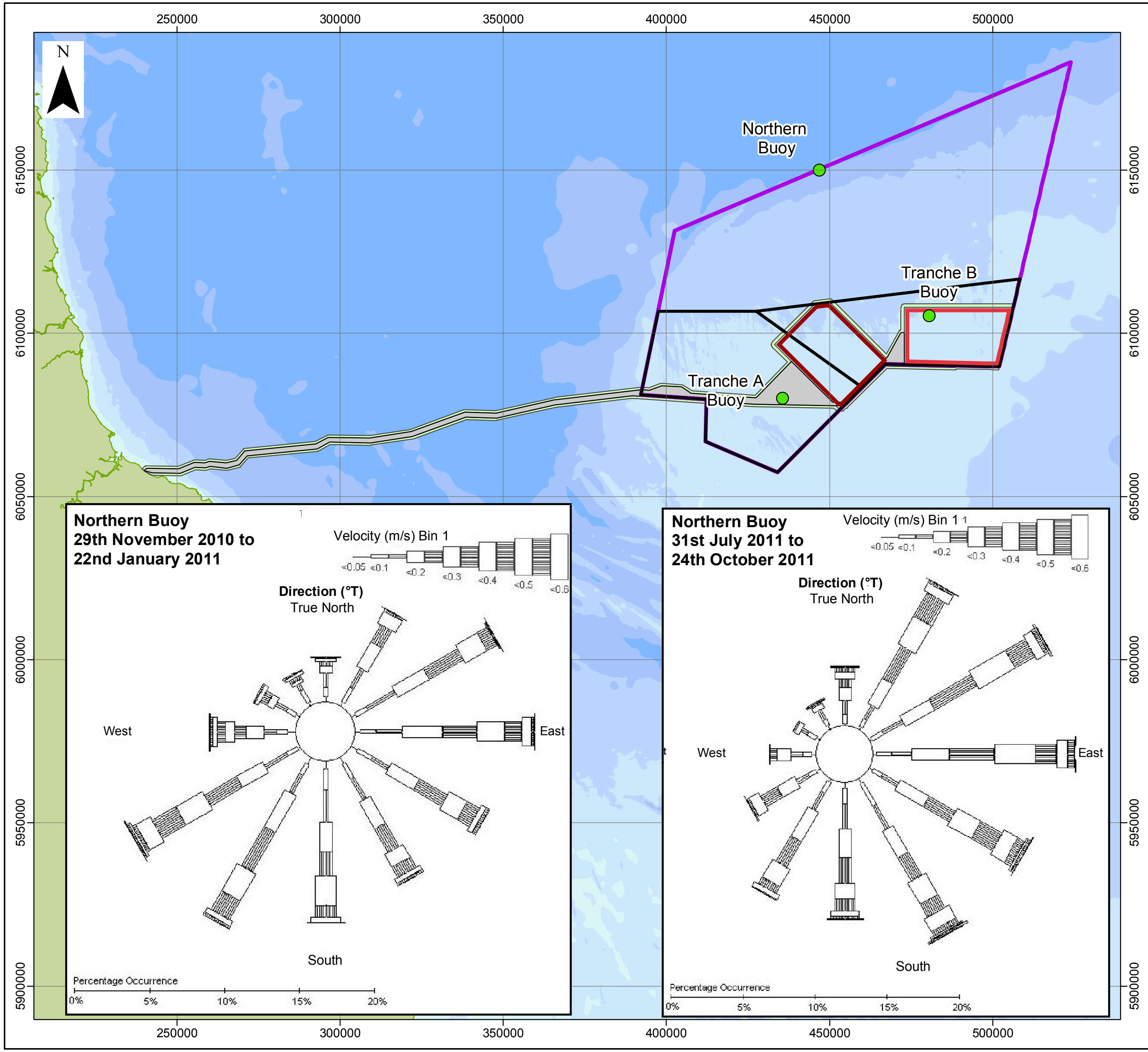
4.8.1 The occurrence of storm surge events may be altered in the future by changes in storminess (the number, location or strength of storms), though there is no scientific consensus on this at present. UKCIP (2009) indicated that the projected future trends in 50-year storm surges are less than 40mm above current average storm surge levels by 2050, not including sea-level rise. This magnitude of change is within what might be expected through existing natural variation.

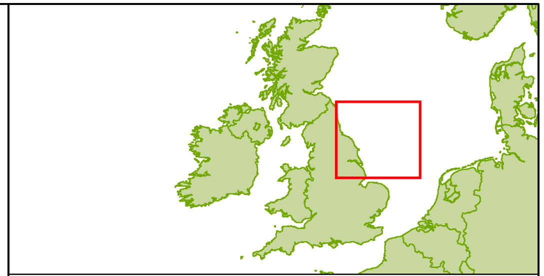
4.9 Tidal currents

4.9.1 Gardline (2011c) provided summary statistics of the data series for the Forewind current profiler at the northern limit of the Dogger Bank Zone (**Figure 3.3**) for its first (7 November 2010 to 21 January 2011) and third (31 July 2011 to 24 October 2011) periods of operation. Gardline (2011c) provided surface current roses for the two periods which are shown in **Figure 4.4**. Dominant tidal current directions over this period are from a broad range of directions from the north east sector through the south east sector to the south west sector. Current velocities are mainly less than 0.4m/s.

4.9.2 No new tidal current data has been collected along the Dogger Bank Teesside A & B Export Cable Corridor, and so the characterisation of the tidal currents relies on existing information. BERR (2008) modeled mid-depth peak flows for mean spring tides of approximately 0.4m/s at the offshore end of the Dogger Bank Teesside A & B Export Cable Corridor to between 0.20m/s and 0.60m/s off the coast at Redcar. The corresponding mid-depth peak flows for mean neap tides are about 0.2m/s and between 0.10m/s and 0.30m/s for the offshore and nearshore, respectively.

4.9.3 Mathiesen and Nygaard (2010) estimated extreme tidal current velocities at eight locations across Dogger Bank (**Figure 3.3**). The maximum extreme velocities for return periods of one, ten and 100 years were 0.88m/s, 0.98m/s and 1.11m/s, respectively. More details of extreme flows are provided in **Appendix 9A**.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Forewind operating buoy

0 20 40
Kilometres

Data Source:
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from TCarta data © 2009
Buoys and wave roses data from Gardline Environmental Limited, MetOcean Operations Report (2013)

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.4 Surface Current Roses at the Northern Buoy

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-416**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

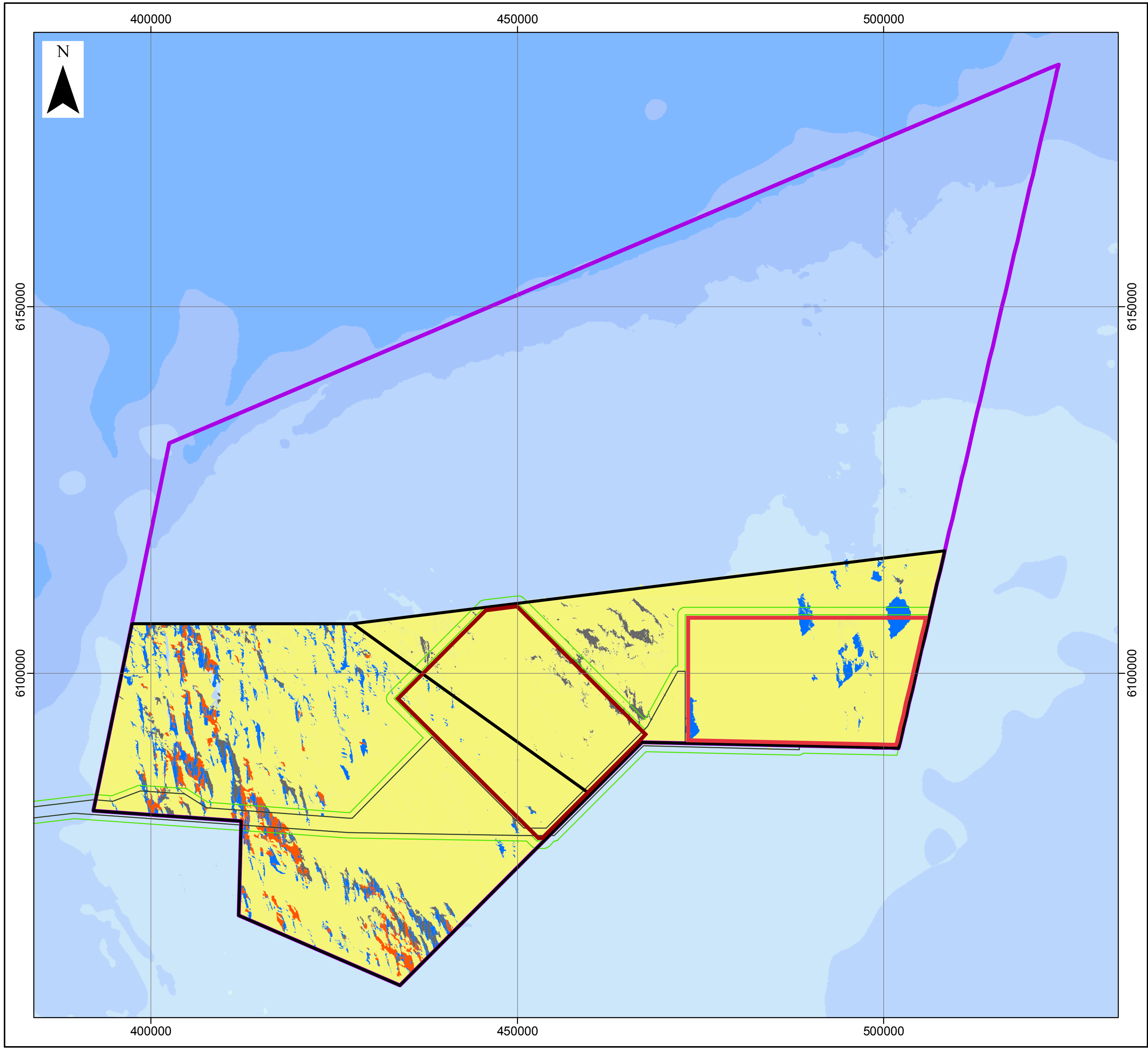
4.10 Seabed sediment distribution

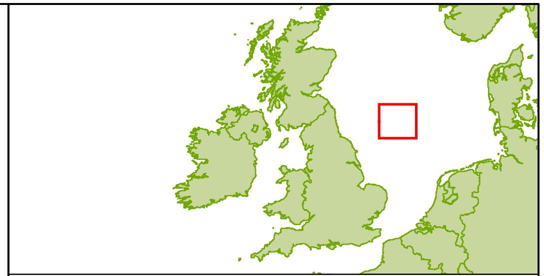
4.10.1 GEMS (2011) and Gardline (2013a), using geophysical data, showed that the majority of seabed sediments across Tranche B and north east Tranche A are sandy (on the Udden-Wentworth scale) (**Figure 4.5**). Particle size analyses (Gardline 2011b, 2012) show that the medium particle diameter (d_{50}) for tranches A and B fall predominantly between 0.15mm and 0.22mm (fine sand) and 0.16mm and 0.19mm (fine sand), respectively, with a few samples in the medium to coarse sand categories. Most of the seabed sand samples contain less than 5% gravel and less than 5% mud, and can be categorised as slightly gravelly sand. Details of the particle size distributions of the seabed sand (and gravel) samples are provided in **Appendix 9A**.

4.10.2 Gardline (2013a) showed that patches of gravel occur across the east and south east of Tranche B (**Figure 4.5**). Median particle diameters (d_{50}) range from 1.8mm to 10.5mm, with gravel percentages between 49% and 93%. The mud content of the gravel areas is predominantly less than 5%. Seabed gravel is rare across north east Tranche A (Dogger Bank Teesside B) (GEMS, 2011).

4.10.3 Along the Dogger Bank Teesside A & B Export Cable Corridor, the seabed is dominated by sand (Gardline 2013b) **(Figure 4.6**). However, patches of gravel occur between 60km and 110km offshore along the Dogger Bank Teesside A & B Export Cable Corridor and where it connects to Tranche A. Along the in-zone cable corridor, the seabed is also mainly sand with patches of gravel, mixed sediment and outcrop along its western half (**Figure 4.5**). Between approximately 5km and 25km offshore, the Dogger Bank Teesside A & B Export Cable Corridor passes through mudstone with pockets of till at seabed (Gardline, 2013b). Where bedrock or till are near the seabed, cobbles and boulders are present.

4.10.4 Particle size analyses of samples from the Dogger Bank Teesside A & B Export Cable Corridor (Gardline 2013b) show that the medium particle diameter (d_{50}) falls predominantly between 0.15mm and 0.30mm (mainly fine sand with some occasional medium sand). Most of the seabed sand samples contain less than 1.5% gravel and less than 5% mud, and can be categorised as slightly gravelly sand. Several samples contain between 7% and 65% gravel. A breakdown of the particle size distributions of the Dogger Bank Teesside A & B Export Cable Corridor seabed samples is provided in **Appendix 9A**.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Sand
- Gravel
- Mixed sediment
- Outcrop

0 5 10
Kilometres

Data Source:
Tranche A sediment data from GEMS (2010),
Tranche B sediment data from Gardline (2011),
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

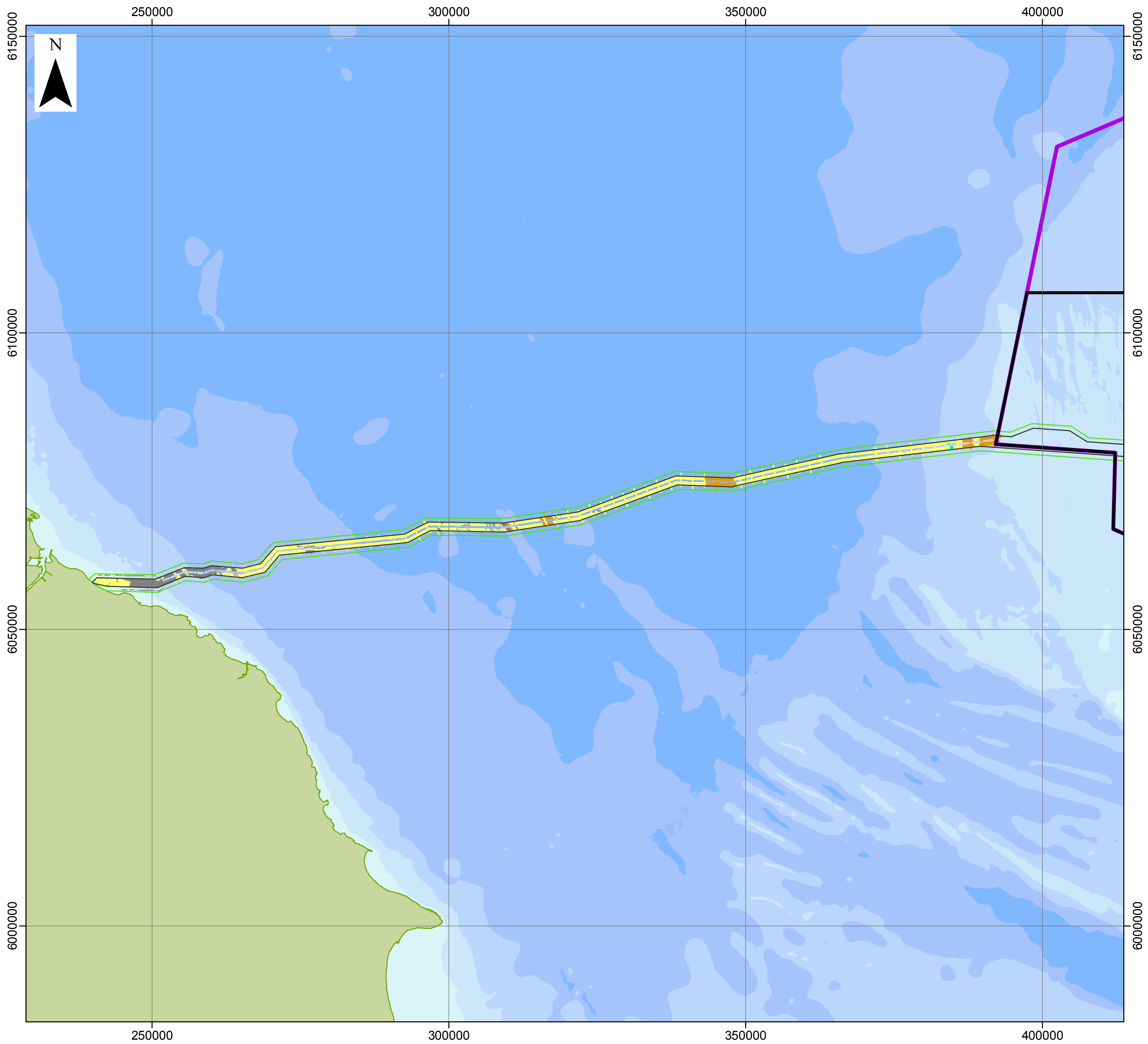
Figure 4.5 Distribution of seabed sediment across tranches A & B

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-417**

SCALE	1:800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND



LEGEND

- Dogger Bank Zone
- Tranche boundary
- Export cable corridor
- Temporary works area

Seabed sediment type

- Gravel
- Sand
- Rock
- Till

0 10 20
Kilometres

Data Source:
Seabed sediments data from Gardline (2012),
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from TCarta data © 2009

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.6 Dogger Bank Teesside A & B export cable corridor seabed sediment distribution

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-418**

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

FOREWIND

4.11 Bedforms and sediment movement

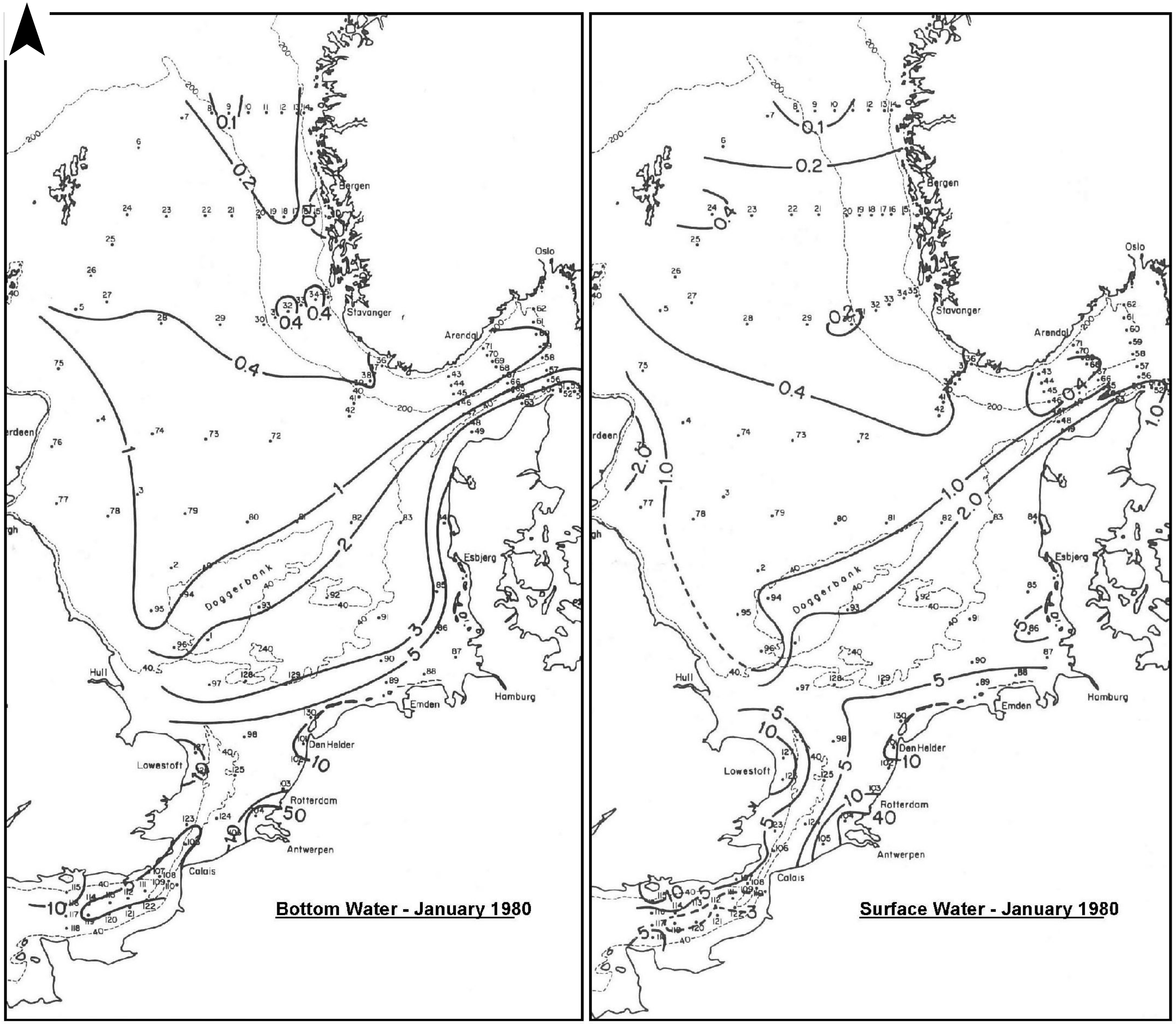
4.11.1 The Dogger Bank Zone seabed is largely benign and featureless because tidal current velocities are relatively weak at less than 0.4m/s. However, megaripples (wavelengths between 0.5 and 25m) sculpted into both gravel and sand substrates are present in patches across Dogger Bank Teesside A & B.

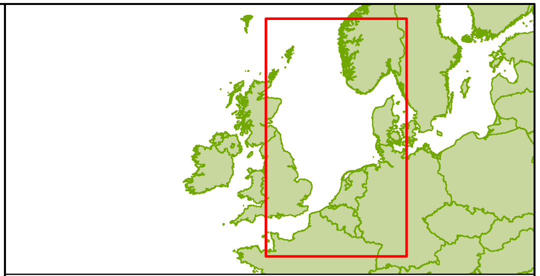
4.11.2 Gardline (2013a) observed megaripples within the gravelly sand areas of Dogger Bank Teesside A. The crests of the megaripples are aligned north-north west to south-south east and north to south, with amplitudes varying from 1.4m to 2.2m. Only limited bedforms occur in the north eastern part of Tranche A (Dogger Bank Teesside B) (GEMS, 2011). Details of the bedforms are provided in **Appendix 9A**.

4.11.3 Although there is widespread occurrence of Holocene sands along the Dogger Bank Teesside A & B Export Cable Corridor, there is only limited development of megaripples and sand waves. Both are present along a short section of the Dogger Bank Teesside A & B Export Cable Corridor, at approximately 25-35km offshore. The largest sand wave is up to 3m high and the bedform crests are generally aligned north east to south west. The megaripples and sand waves are predominantly asymmetric with their steeper sides facing to the south east indicating that they are migrating to the south east.

4.12 Suspended sediment

4.12.1 Eisma (1981) showed that the general distribution of suspended sediment in the southern North Sea is characterised by values lower than 2mg/l across Dogger Bank and along the Dogger Bank Teesside A & B Export Cable Corridor. Eisma and Kalf (1987) carried out a water sampling programme in January 1980 and differentiated general surface concentrations from bottom concentrations. They showed that across Dogger Bank, the concentrations were similar at both elevations, ranging from 1mg/l across south Dogger Bank to 2mg/l across north Dogger Bank (**Figure 4.7**). Data along the Dogger Bank Teesside A & B Export Cable Corridor is limited, but appears to show concentrations less than 2mg/l.





LEGEND

Data Source:
Eisma and Kalf (1987)

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.7 Concentration of suspended sediment in the North Sea

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-419**

SCALE	PLOT SIZE	DATUM	PROJECTION
Not to scale	A4		

FOREWIND

4.12.2 The main driving force for suspended sediment dynamics in the North Sea is turbulence induced by tidal currents and waves (Stanev *et al*. 2008). The fundamental mechanism controlling sediment re-suspension from the seabed is bed shear stress. Across Dogger Bank, Stanev *et al*. (2008) showed that during storm conditions, no clear correlation exists between Dogger Bank bed shear stress and suspended sediment concentrations. They concluded that the availability of re-suspendable sediment at the bed across Dogger Bank is limited.

4.12.3 Site measurements of suspended sediment were not undertaken at Dogger Bank because the data from previous studies (Eisma, 1981; Eisma and Kalf, 1987) were deemed to be robust enough as a baseline. The concentrations are low (2mg/l) meaning that the effects compared to this baseline will be very conservative.

4.13 Coastal sediment sources, transport and sinks

4.13.1 The coastline of the landfall site, between Redcar and Saltburn-by-the-Sea comprises a wide (300-400m) sand beach held in place by Saltburn Scar (a rock headland) to the east. Along its western end the beach is backed by a rock revetment built on to the face of a narrow strip of sand dune fronting a till hinterland (British Geological Survey, 1998). Here the beach is controlled by groynes. The eastern half is mainly undefended and the beach is backed by a narrow strip of dunes in front of till slopes, apart from a stretch of sea wall in front of Saltburn-by-the-Sea at the eastern extremity. Prior to defences, the dunes and till cliffs appear to have been eroding at a fairly constant rate to form a gently curving bay between Redcar and Saltburn Scar.

4.13.2 The dunes are in poor health and are actively eroding, forming a ‘veneer’ in front of the till hinterland. In places, the dunes are absent and till is exposed at the coast. In front of the till, the beach is composite with pebbles forming an upper storm beach with a wide sandy lower beach. This structure indicates that the pebbles are supplied locally through erosion of the till. In front of the dunes, the upper pebble beach breaks down and there are patches of shingle sometimes shaped into cusps on the beach surface, which is mainly sand.

4.13.3 Net longshore sediment transport is to the east (Babtie, 1997, 1999) but only small sediment build-up on the west side of the Redcar groynes indicates that actual longshore sediment transport is low in this area. In addition, the presence of Saltburn Scar does not allow much loss of sediment to the east.

4.13.4 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 north west to south east, onshore to offshore movement occurs during storms.

4.13.5 Houston (1995) provided a simple formula based on a mean annual significant wave height ($\dot{H}_s$):

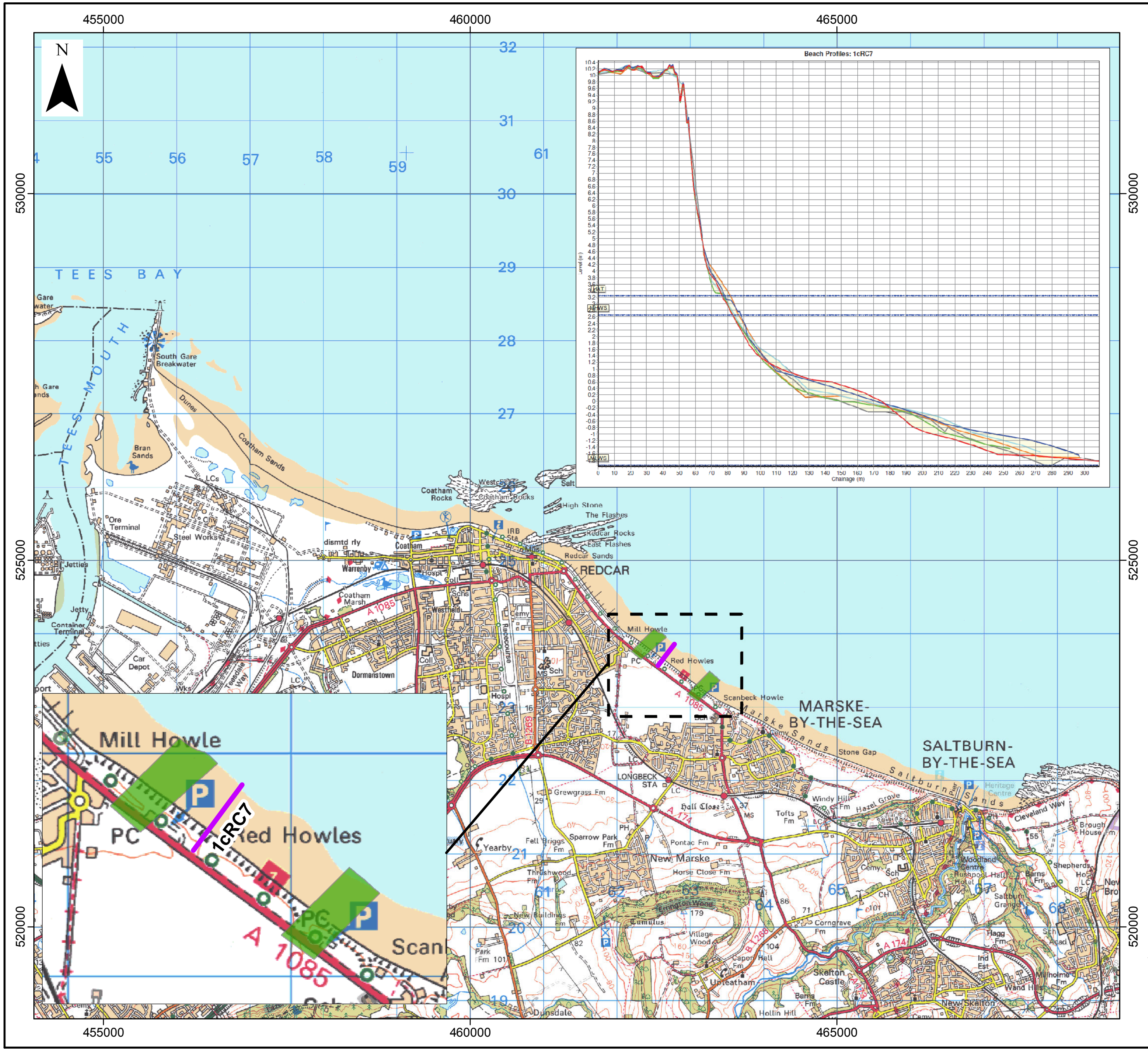
$$h_{in} = 6.75\ \dot{H}_s$$

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

4.13.6 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 9A**). 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.

4.13.7 Babtie (1999) showed that over the long-term (1858-1990), the mean high water and mean low water marks have retreated by up to $0.8myr^{-1}$) but with local accretion at Marske-by-the-Sea ($0.01myr^{-1}$). Overall, Babtie (1999) estimated that the erosion rate for undefended land has been $0.4myr^{-1}$ with localised erosion of $0.6\text{-}0.7myr^{-1}$ closer to Redcar.

4.13.8 Since 2008, Redcar and Cleveland Borough Council has been monitoring beach morphological change as part of the wider Cell 1 (North East) Regional Coastal Monitoring Programme (Cooper et al., 2009). Beach profile RC7 is located within the envelope of the two cable landfall corridors. **Figure 4.8** shows the variations in beach and coastal slope profile over time between November 2008 and April 2011. The profiles describe changes to foreshore levels of up to 0.6m over this short period.



LEGEND

- Dogger Bank Teesside A & B cable landfall envelope
- Bi-annual topographic profile

0 0.5 1
Kilometres

Data Source:
North East Coastal Observatory

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 4.8 Location of beach profile RC7 (Cell 1 Regional Coastal Monitoring Programme)

VER	DATE	REMARKS	Drawn	Checked
1	25/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-420**

SCALE	1:80,000	PLOT SIZE	A4	DATUM	OSGB36	PROJECTION	BNG

FOREWIND

5 Assessment of Effects – Worst Case Definition

5.1 General

5.1.1 This section establishes the realistic worst case scenario for each category of effect as a basis for the subsequent impact assessment. For the assessment, this involves both a consideration of the construction scenarios (i.e. the manner in which Dogger Bank Teesside A & B will be built out), as well as the particular design details of each project (such as the maximum construction footprint at the landfall) that define the Rochdale[1] envelope.

5.1.2 Full details of the range of development options being considered by Forewind are provided within **Chapter 5 Project Description**. For the purpose of the marine physical processes assessment, the realistic worst case scenarios, taking these options into consideration, are set out in **Table 5.1**.

5.1.3 Only those design parameters with the potential to influence the level of effect are identified. Therefore, if the design parameter is not described, it is not considered to have a material bearing on the outcome of the assessment.

5.1.4 The realistic worst case scenarios identified here are also applied to the cumulative assessment. When the worst case scenarios for the project in isolation do not result in the worst case for the cumulative assessment, this is addressed within the cumulative section of this chapter (see Section 10) and summarised in **Chapter 33 Cumulative Impact Assessment**.

5.2 Construction scenarios

5.2.1 There are a number of key principles relating to how the projects will be built, and that form the basis of the Rochdale Envelope (see **Chapter 5**). These are:

- The two projects may be constructed at the same time, or at different times;
- If built at different times, either project could be built first;
- Offshore construction will commence no sooner than 18 months post consent, but must start within seven years of consent (as an anticipated condition of the development consent order); and
- Assuming a maximum construction period per project of six years, and taking the above into account, the maximum construction period over which the construction of Dogger Bank Teesside A & B could take place is 11 years and six months.

5.2.2 As explained in Section 3.3, the marine physical processes assessment focuses on describing the changes/effects in hydrodynamic and sedimentary processes

[1]As described in **Chapter 5** the term 'Rochdale Envelope' refers to case law (R.V. Rochdale MBC Ex Part C Tew 1999 "the Rochdale case"). The 'Rochdale Envelope' for a project outlines the realistic worst case scenario or option for each individual impact, so that it can be safely assumed that all lesser options will have less impact.

against the existing environment. In order to do this, a variety of numerical modelling tools and conceptual techniques have been used. The spatial and temporal scale at which these tools and techniques have been implemented has been used to ensure that the Rochdale Envelope incorporates all of the possible construction scenarios as outlined in **Chapter 5** (details provided in **Table 5.1** below).

5.3 Operation scenarios

5.3.1 **Chapter 5** provides details of the operation scenarios for Dogger Bank Teesside A & B. Flexibility is required to allow for the following three scenarios:

- Dogger Bank Teesside A to operate on its own;
- Dogger Bank Teesside B to operate on its own, and
- For the two projects to operate concurrently.

5.3.2 As above, the numerical modelling tools and conceptual techniques used in this assessment have been implemented at a spatial and temporal scale to ensure that the worst case of all three operation scenarios has been assessed (details provided in **Table 5.1** below).

5.4 Decommissioning scenarios

5.4.1 **Chapter 5** provides details of the decommissioning scenarios for Dogger Bank Teesside A & B. Exact decommissioning arrangements will be detailed in a Decommissioning Plan (which will be drawn up and agreed with DECC prior to construction); however, for the purpose of this assessment it is assumed that decommissioning of Dogger Bank Teesside A & B could be conducted separately, or at the same time.

5.5 Realistic worst case scenarios

5.5.1 **Table 5.1** identifies the key design parameters for the assessment of effects. In order to identify the realistic worst case scenarios, a detailed iterative process was carried out (described in **Appendix 9A**), including consultation with stakeholders.

Table 5.1 Key design parameters forming the realistic worst case scenarios for the assessment of effects on marine physical processes

Effect	Realistic worst case scenario	Rationale
Construction		
Offshore Increase in suspended sediment concentrations due to installation of foundations and cables	The worst case installation process for effects on sediment transport that was modelled is 24 12m-diameter drilled monopole foundations, a set of inter-array cables connecting them and one export cable (within 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; • 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 a plume	An installation process was developed that would be realistic, but that would also be very conservative in terms of numbers of foundations and installation over a relatively short period.
	A worst case drill arisings volume of 6,220m^3 is applied for installation of a 12m piled 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. The depth of drill penetration is above the level of the top of the chalk and so particles from the chalk do not contribute to the sediment in the arisings
	The worst case equilibrium scour volume for 12m monopole foundations is estimated to range from 365m^3 to 756m^3	The scour volumes for the monopole foundation were predicted using empirical methods from existing literature and knowledge using the

Effect	Realistic worst case scenario	Rationale
	depending on applied wave climate and water depth.	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 because there is the potential for any one set of 24 foundations to be located where the sand thickness is greater than the equilibrium scour depth.
	The inter-array cables will release approximately 3,750m^3 of sediment per km length excavated.	The inter-array cable volume released is based on cables that are excavated up to 3m deep and 1.5m wide in an approximate 'U' shape.
	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 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 drilled monopole 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.
Offshore Fate of sediment that is not suspended during foundation installation	The worst case scenario is for 12m-diameter drilled monopole foundations and 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 Interruption of sediment transport due to construction activities	The worst case landfall construction would be in the intertidal zone. The worst case scenario is four small cofferdams measuring 10m by 10m by 3m 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. 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

Effect	Realistic worst case scenario	Rationale
		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.
Operation		
Offshore Changes in waves and tidal currents due to operation	Conical gravity base 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.
	Conical gravity base 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 to reach this conclusion: • Grid of 6MW foundations across Dogger Bank Teesside A & B; and • Grid of 10MW foundations across Dogger Bank Teesside A & B
Offshore Increase in suspended sediment concentrations due to operation	An array of 400 6MW conical gravity base 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 worst case scenario layout is considered to be a grid of foundations that fills each project area 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

Effect	Realistic worst case scenario	Rationale
	The foundations would be installed over a (minimum) two year construction period.	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.
	The worst case operational scour volumes for the conical gravity base 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.

Effect	Realistic worst case scenario	Rationale
Offshore Interruption of sediment transport due to linear cable protection	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 approximately 1.3m above the surrounding seabed.	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.
Decommissioning		
Offshore	Expected to be less than construction	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	Similar to construction	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.

6 Assessment of Effects during Construction

6.1 Introduction

6.1.1 The construction phases of Dogger Bank Teesside A & B have the potential to affect marine physical processes both in the near-field and far-field environments. Construction activities include installation of the foundations, laying of inter-array and export cables, and installation of landfall infrastructure, all of which may affect the tidal current regime, wave climate and sediment transport processes. Specific effects related to these processes are described below.

6.2 Increase in suspended sediment concentrations and sediment deposition as a result of combined drilled 12m monopole foundation and cable installation activities

6.2.1 Sediment dispersion modelling was undertaken using the MIKE3-FM MT model, integrated with the MIKE3-FM HD model (see Section 3.3). The modelling scenario used was as outlined in **Table 5.1**.

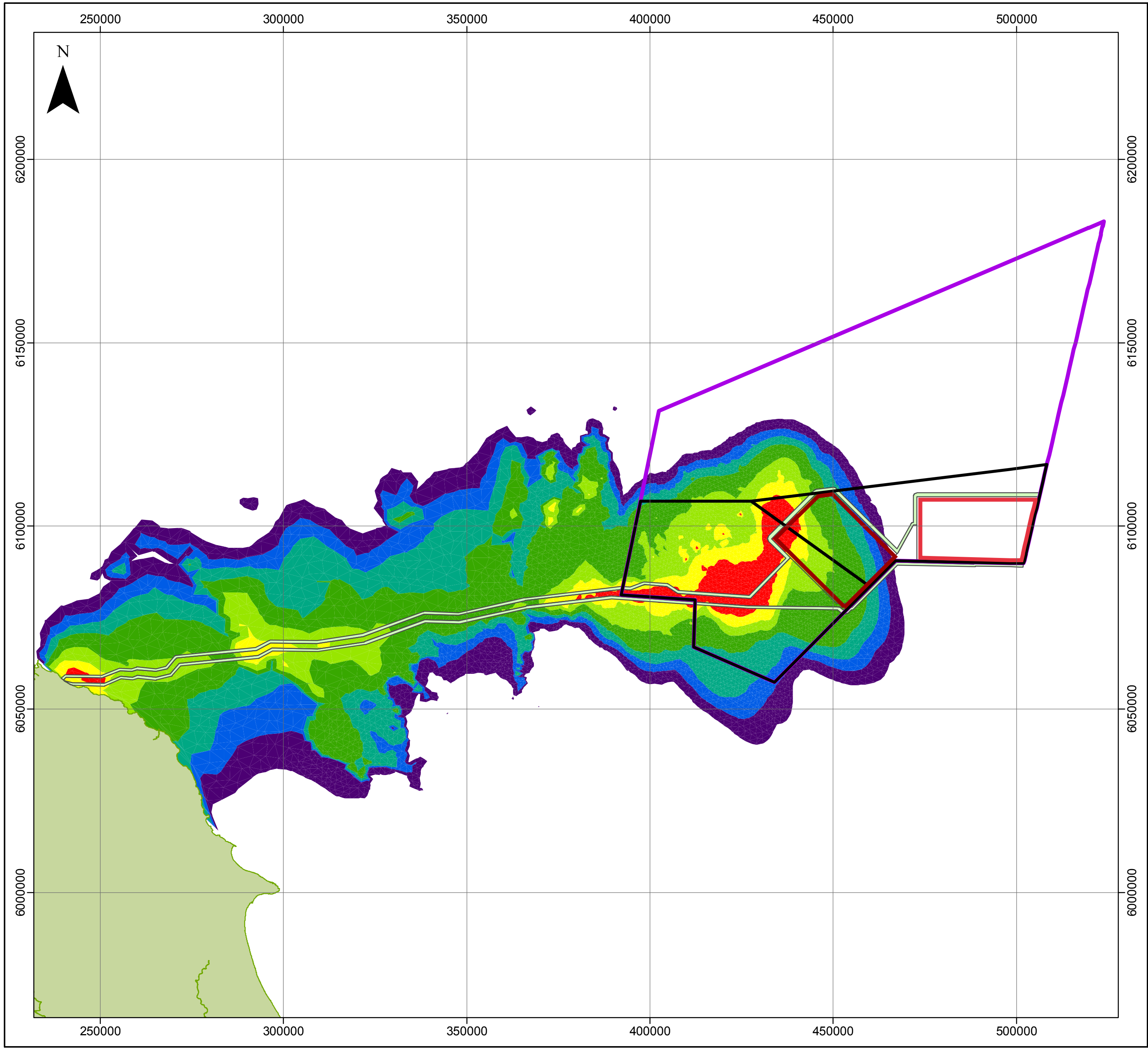
6.2.2 The results of the sediment dispersion modelling are presented as a series of maps showing suspended sediment concentration in the bottom layer (corresponding to the lower 5m of the water column) and sediment deposition on the seabed from the plume, using the following statistical measures:

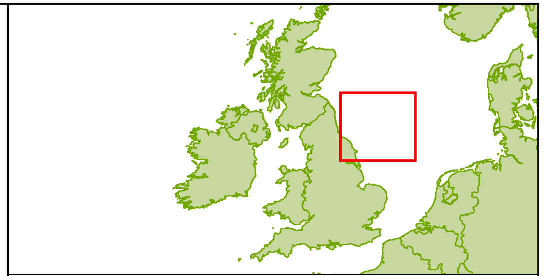
- The maximum values of suspended sediment concentration above a background of 2mg/l and thickness of deposited sediment over the 30-day simulation period;
- The average values of suspended sediment concentration above a background of 2mg/l and thickness of deposited sediment over the 30-day simulation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

6.2.3 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

6.2.4 **Figures 6.1** to **6.3** show maps of predicted suspended sediment concentration in the bottom layer. The concentrations are presented as excesses over the natural background concentration (2mg/l).





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE
DOGGER BANK TEESSIDE A & B

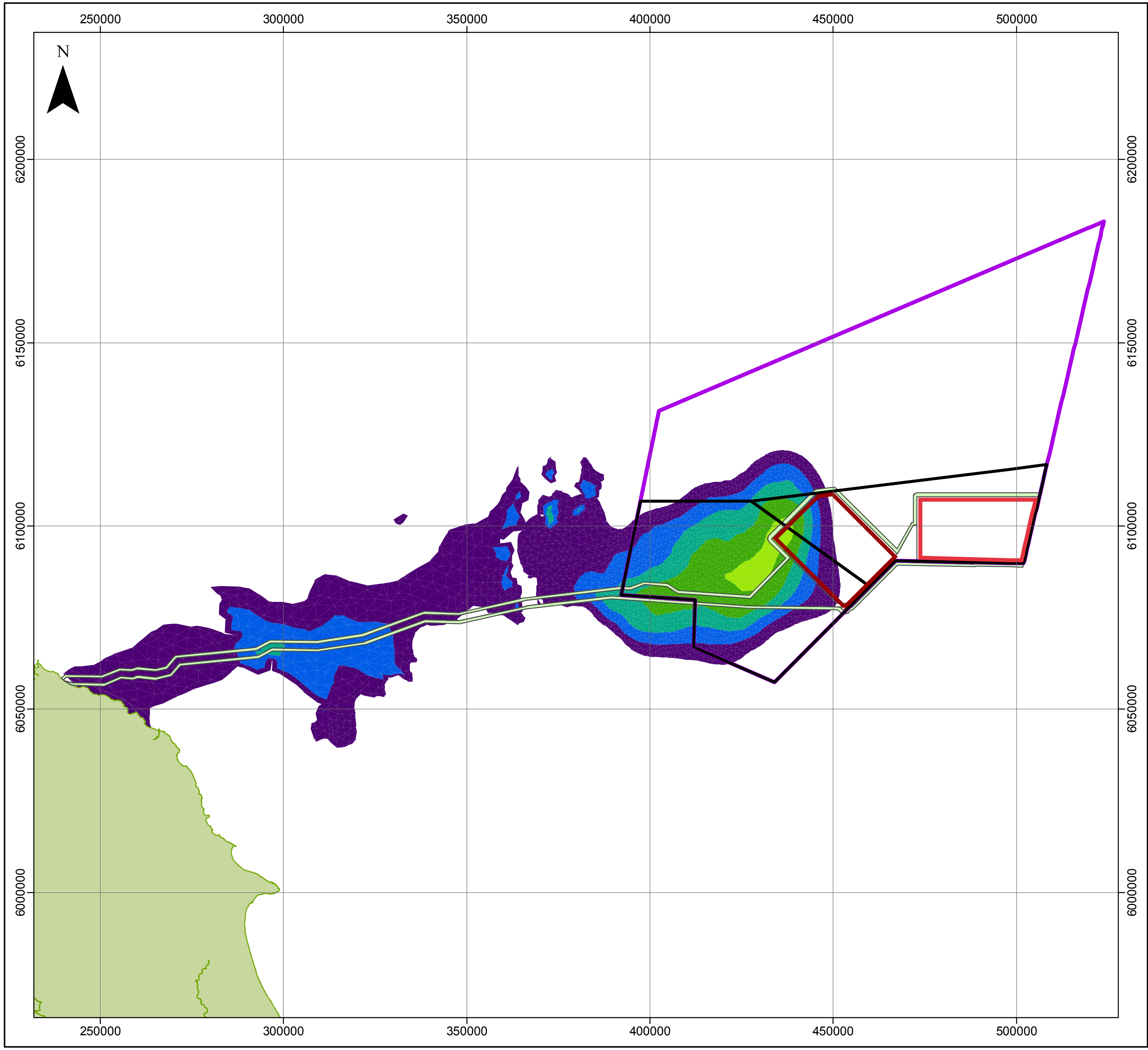
DRAWING TITLE
Figure 6.1 Maximum SSC in the bottom layer predicted over the simulation period for the construction phase for 12m monopoles using the re-suspension of fractions 1 and 2 method

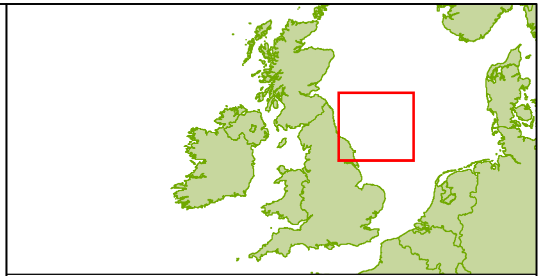
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-421**

SCALE	1:1,600,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

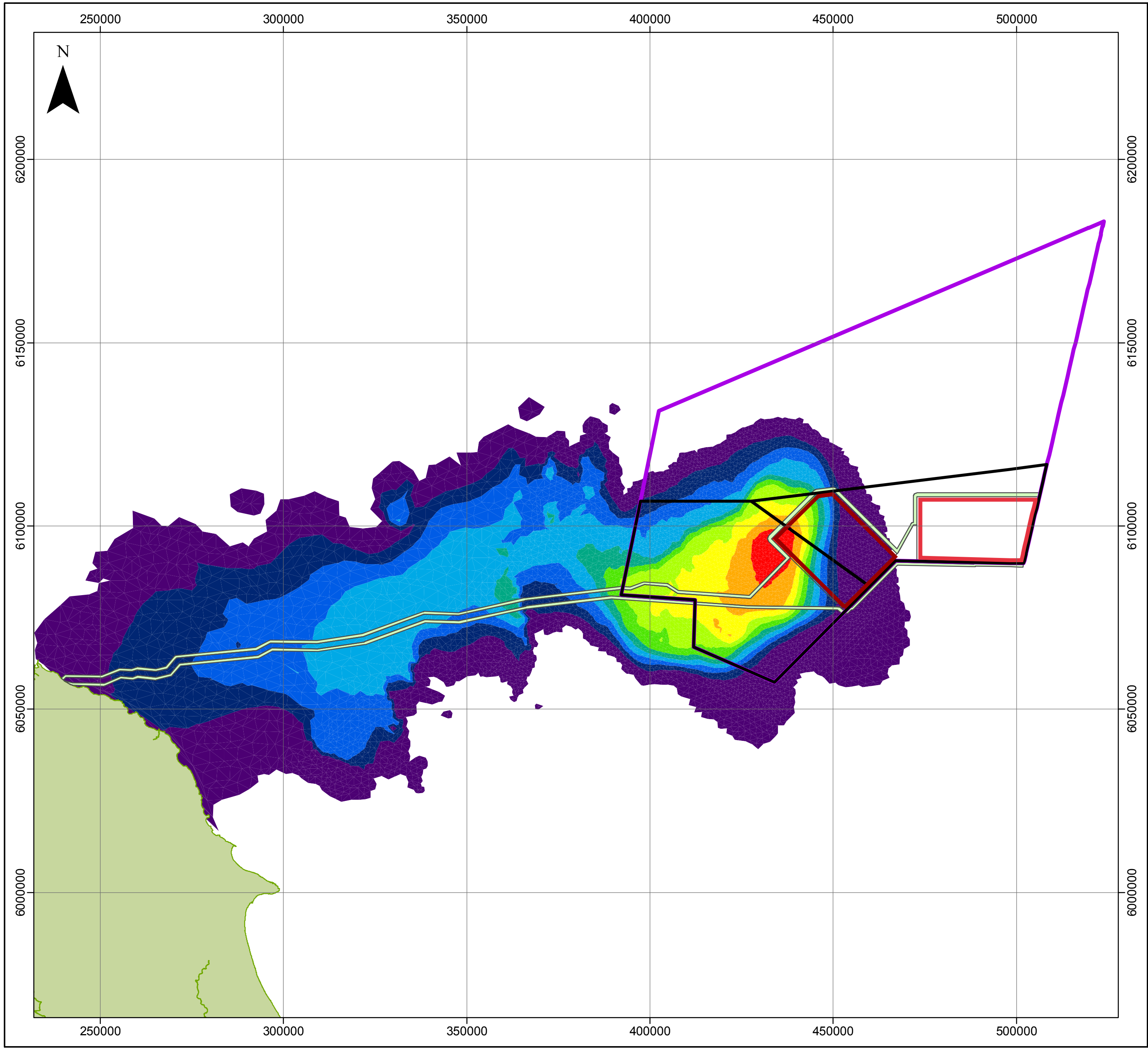
Figure 6.2 Average SSC in the bottom layer predicted over the simulation period for the construction phase for 12m monopoles using the re-suspension of fractions 1 and 2 method

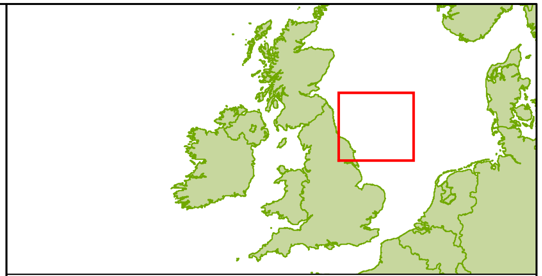
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-422**

SCALE	1:1,600,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Exceedance of 2 mg/l (%)

- Above 90
- 80 - 90
- 70 - 80
- 60 - 70
- 50 - 60
- 40 - 50
- 30- 40
- 20 - 30
- 10 - 20
- 0 - 10
- Below 0

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 6.3 Percentage of time predicted over the simulation period where SSC of 2mg/l is exceeded in the bottom layer for the construction phase for 12m monopoles using the re-suspension of fractions 1 and 2 method

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-423**

SCALE	1:1,600,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

6.2.5 **Figure 6.1** shows the maximum concentration 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 export cable route within the Dogger Bank Zone and between approximately 1km and 11km either side of the route. Maximum concentrations gradually reduce with distance from the foundations and the export cable route within the Dogger Bank Zone until they are at the background of 2mg/l, up to 40km to the north and up to 40km south.

6.2.6 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 and about 50km offshore (**Figure 6.1**). 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.

6.2.7 The average suspended sediment concentration in the bottom layer predicted over the simulation period is presented in **Figure 6.2**. The results show that within the confines of the 24 foundations and up to approximately 20km along the export cable route within the Dogger Bankzone (a band up to 9km 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 export cable route within the Dogger Bank Zone. 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.

6.2.8 **Figure 6.3** presents the exceedance time during the simulation of the predicted suspended sediment concentration above the baseline of 2mg/l. The map shows that 2mg/l is exceeded over 90% of the 30-day simulation period up to 15km south west of the centre of the foundations, along the export cable route within the Dogger Bank Zone. 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. 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

6.2.9 **Figure 6.4** 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 export cable route within the Dogger Bank Zone and 25km north of the Dogger Bank Teesside A & B Export Cable Corridor outside the Dogger Bank Zone.

6.2.10 **Figure 6.5** 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.

6.2.11 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 6.6**) describes the persistency of sediment thickness on the seabed. **Table 6.1** describes the maximum lengths of time that sediment maintains predicted thicknesses greater than 10mm, 7mm, 3mm and 1mm over the 30-day simulation period.

Table 6.1 Maximum persistency of sediment thickness over the 30-day simulation period for construction of a 12m monopole

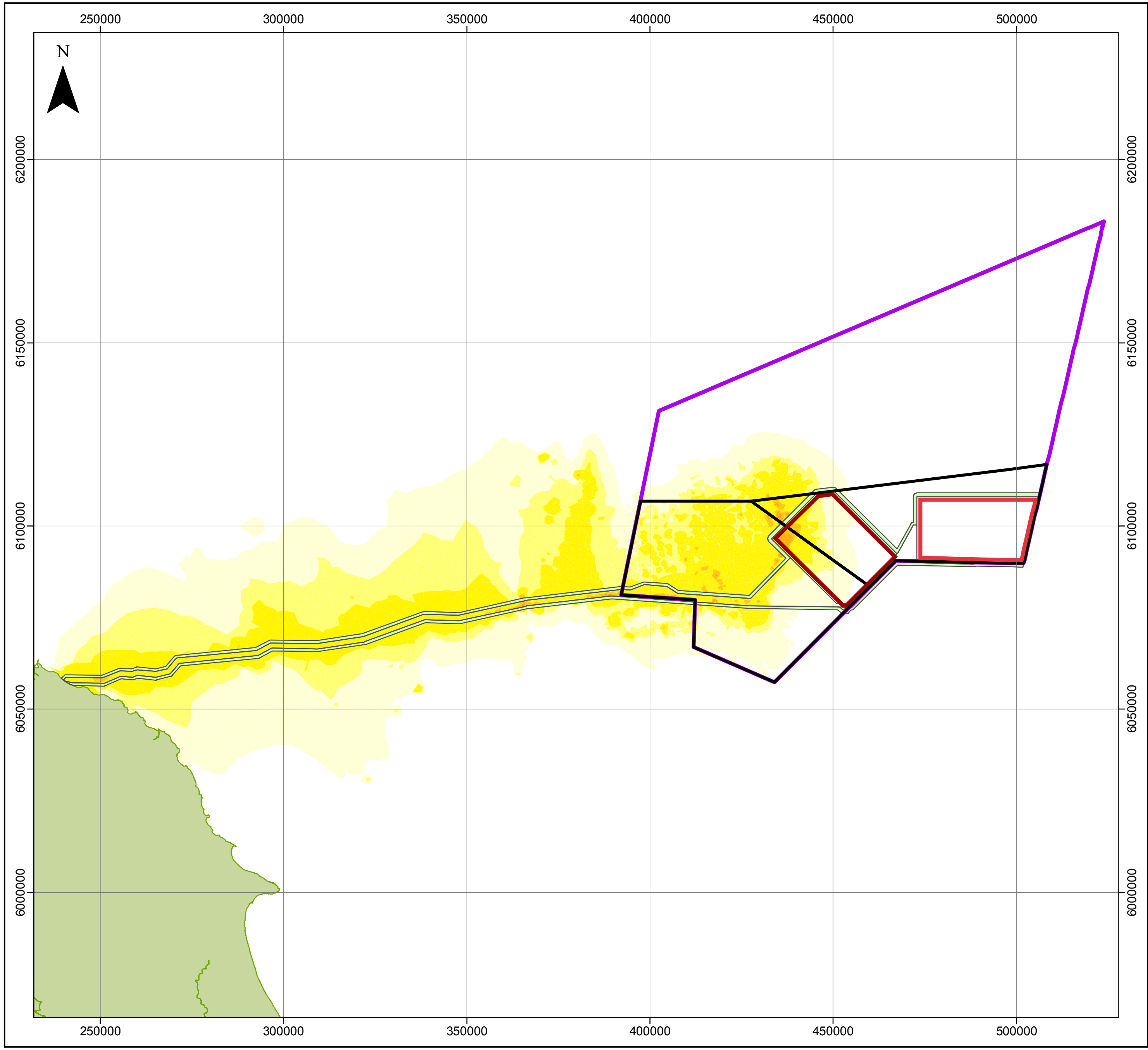
Point	Maximum thickness (mm)	Maximum continuous time of sediment thickness (hours with days in brackets)				Thickness at end of simulation (mm)
		>10mm	>7mm	>3mm	>1mm	
P1	13.71	32 (1.33)	38 (1.58)	80 (3.33)	174 (7.25)	<0.1
P2	3.19	0	0	10	22	<0.1
P3	1.35	0	0	0	6	<0.1
P4	1.26	0	0	0	2	<0.1
P5	1.00	0	0	0	2	<0.1

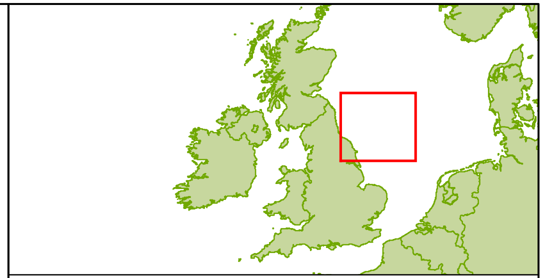
6.2.12 **Table 6.1** demonstrates that within the foundation layout (Point P1), sediment thicknesses predicted to be greater than 10mm and 7mm persist for maximum continuous periods of 32 hours (1.33 days) and 38 hours (1.58 days), respectively. Thicknesses greater than 3mm and 1mm occur continuously for a maximum of 80 hours (3.33 days) and 174 hours (7.25 days), respectively. Approximately 20km west-south west of the foundation layout (Point P2, **Figure 6.6**), sediment thicknesses greater than 3mm only persist for a maximum continuous period of ten hours (0.42 days), whereas 1mm thick sediment persists for a maximum continuous period of 22 hours (0.92 days).

6.2.13 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. 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 two hours (0.08 days). At Point P5, about 20km from the coast, total deposition from the plume never exceeds 1mm.

6.2.14 **Table 6.1** shows that at the end of the simulation the predicted thickness of sediment resting on the seabed is mainly 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.

6.2.15 There is no discernible difference in deposition 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).





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Sediment thickness (m)

- Above 0.1000
- 0.0500 - 0.1000
- 0.0100 - 0.0500
- 0.0050 - 0.0100
- 0.0010 - 0.0050
- 0.0005 - 0.0010
- 0.0001 - 0.0005
- Below 0.0001

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

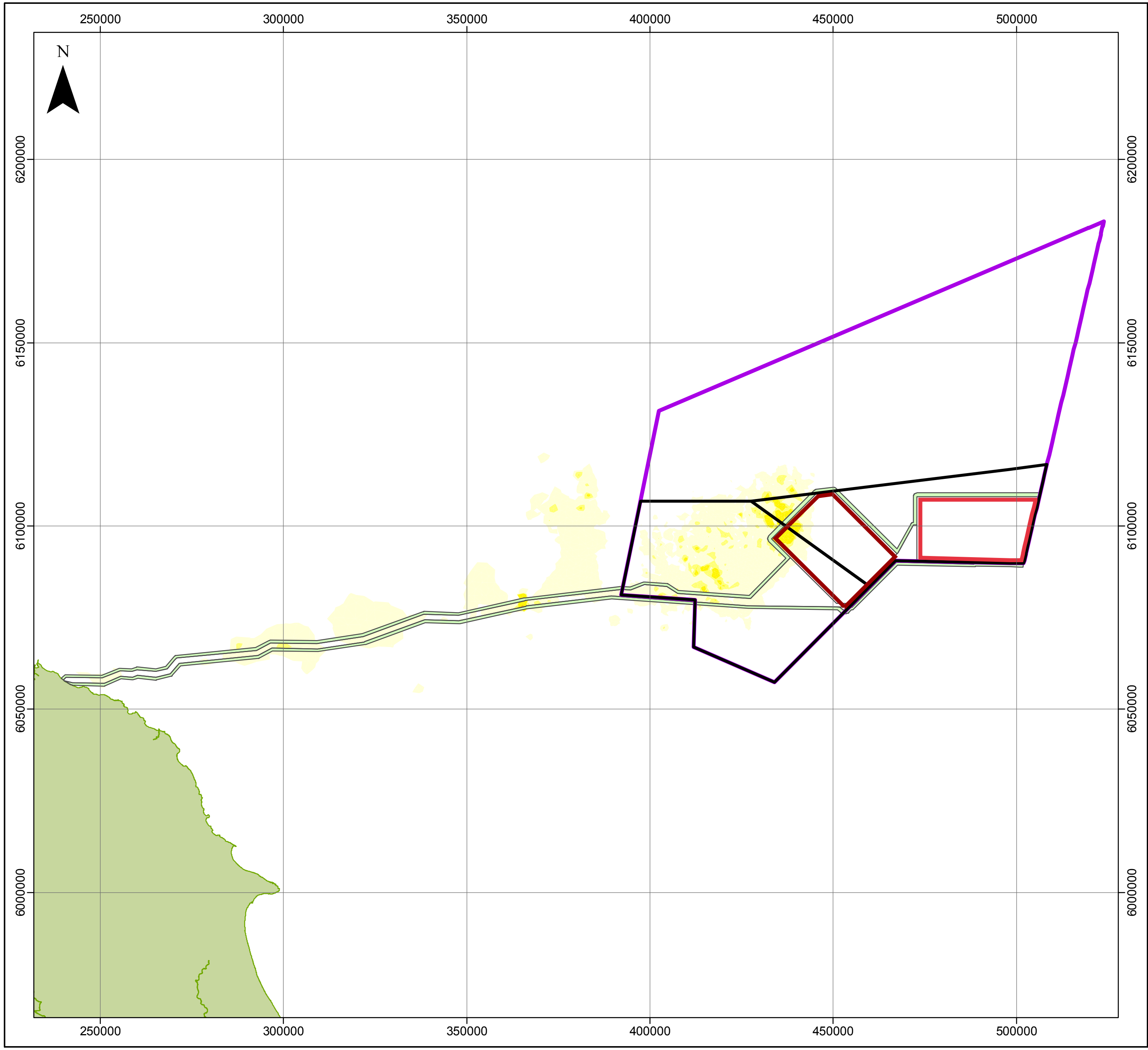
Figure 6.4 Maximum deposition predicted over the simulation period for the construction phase for 12m monopoles using the re-suspension of fractions 1 and 2 method

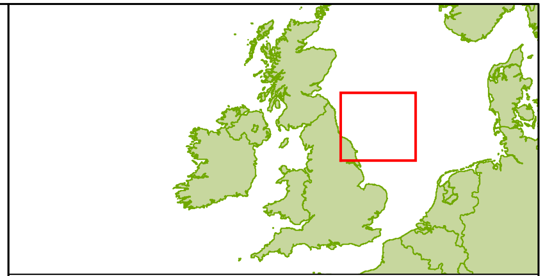
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-424**

SCALE	1:1,600,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Sediment thickness (m)

- Above 0.1000
- 0.0500 - 0.1000
- 0.0100 - 0.0500
- 0.0050 - 0.0100
- 0.0010 - 0.0050
- 0.0005 - 0.0010
- 0.0001 - 0.0005
- Below 0.0001

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

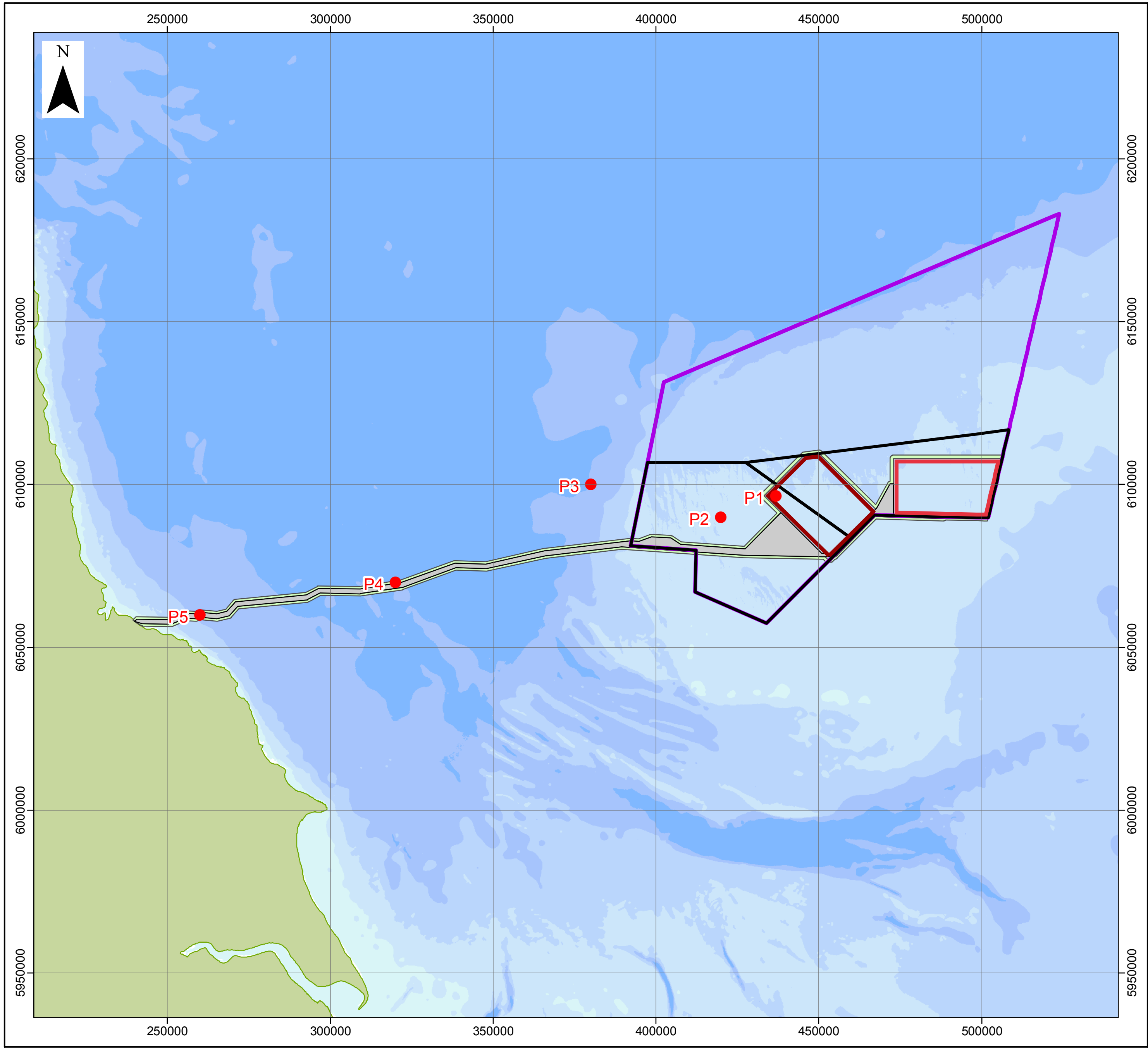
Figure 6.5 Average deposition predicted over the simulation period for the construction phase for 12m monopoles using the re-suspension of fractions 1 and 2 method

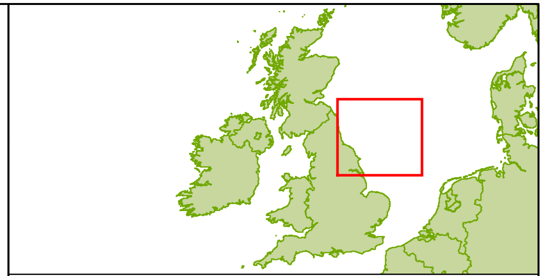
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-425**

SCALE	1:1,600,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Sediment thickness time series analysis point

0 20 40
Kilometres

Data Source:
Sediment data from Danish Hydraulic Institute, 2012
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from © TCarta data 2009.

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 6.6 Location of points for sediment thickness time series analysis for the construction phase using the re-suspension of fractions 1 and 2 method

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-426**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

Predicted suspended sediment concentrations in the surface layer

6.2.16 **Figure 6.7** shows the maximum suspended sediment concentration in the sea surface layer predicted for construction of 12m monopole foundations. **Figure 6.8** 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.

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

6.3.1 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 (**Appendix 9A**). Sediment particles larger than 0.18mm are assumed to deposit at the source position.

6.3.2 For installation of a conical GBS, a worst case volume of 3,675m^3 is assumed for the side cast seabed preparation sediment (**Table 5.1**). 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 0.177mm remains (1,396m^3) at the source position as a residual side cast mound.

6.3.3 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.

6.3.4 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 (**Appendix 9A**). Immediately beneath the loose upper layer, the friction angle quickly rises indicatively to 45-50°.

6.3.5 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.

6.3.6 The predominant tidal current directions are north and south, and the predominant wave direction is from the north, and so the sediment pile will be redistributed mainly in those directions to form a 31m wide (assuming little transport in other directions) sand wave. Natural sand waves across Tranche A have an average wavelength of 100m (range 50-150m) and average crest height of 0.5m (maximum 2m).

6.3.7 For 12m monopole foundations, if a sand wave is assumed to form from 2,301m^3 of sediment, that is 100m wavelength and 31m wide, it will have a crest height of about 1.5m. The sand wave footprint will be about 3,100m^2.

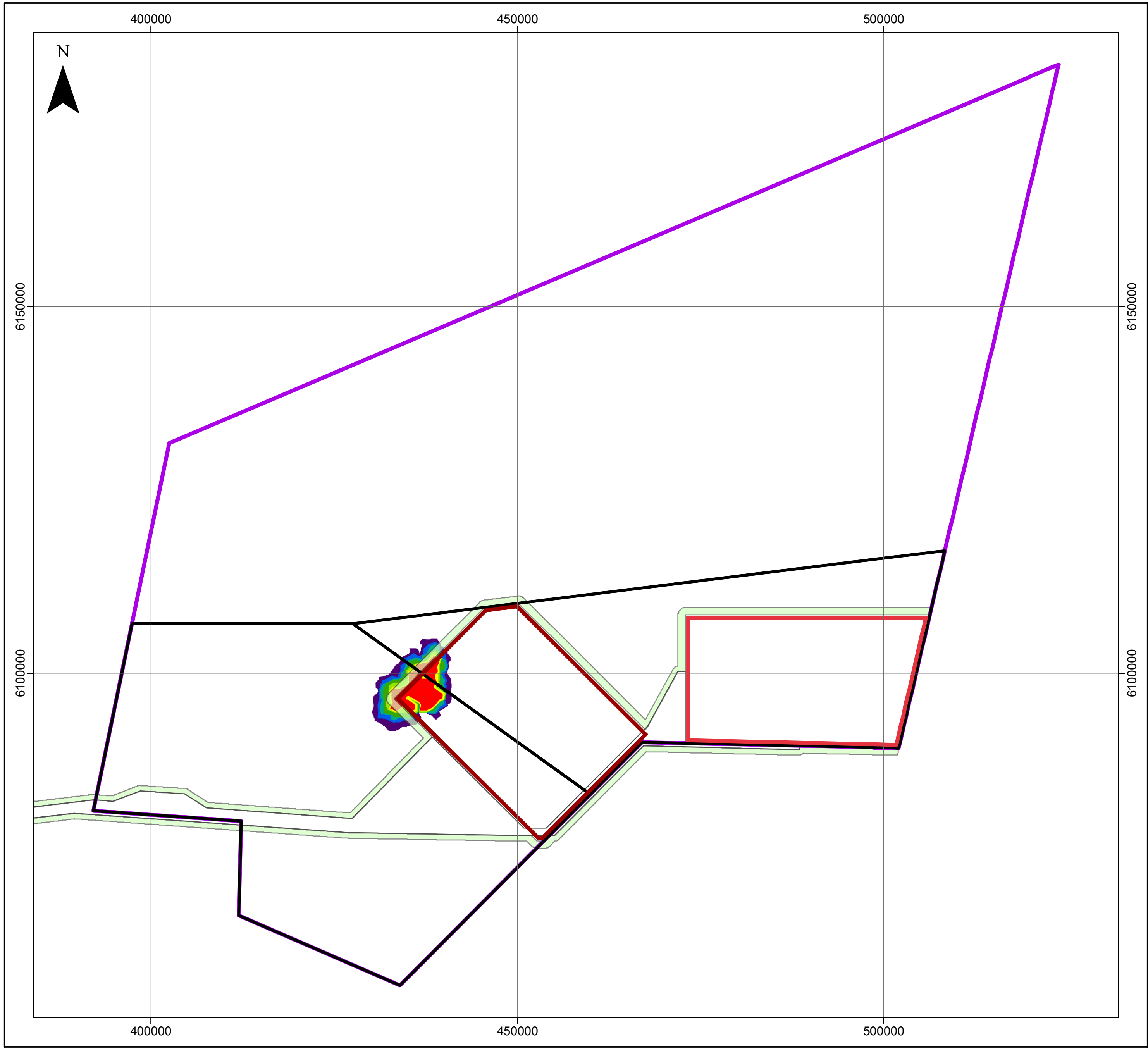
6.4 Interruption of sediment transport as a result of landfall construction activities

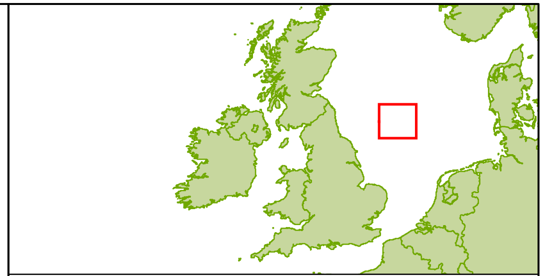
6.4.1 The consideration of the assessment of effects at the landfall site uses the conceptual understanding (**Appendix 9A**) as a baseline against which the potential effects and sensitivities of sediment transport to changes in the system are determined. Sediment transport across the intertidal area has the potential to be affected by the installation and operation of a worst case scenario of four temporary cofferdams, which would protect excavated trenches within which the export cables will be placed. Each cofferdam comprises a 10m-long cross-shore obstruction to sediment transport stretching seaward from the HDD exit hole.

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

6.4.3 For a single small cofferdam, the worst case scenario is that there would be an obstacle of only 10m 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, four 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.

6.4.4 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 9A**). 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.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

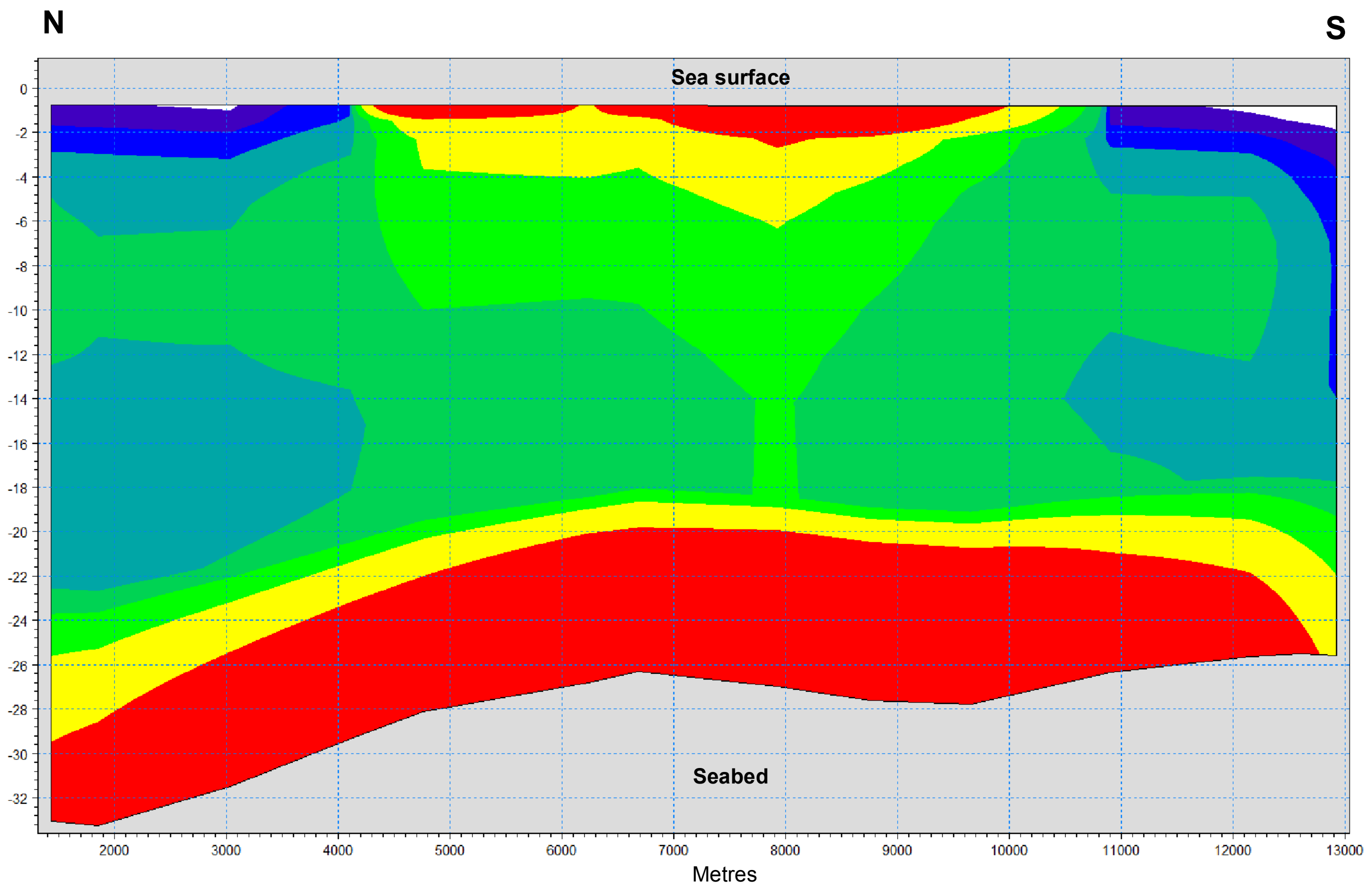
Figure 6.7 Maximum SSC in the surface layer predicted over the simulation period for a 12m monopole using the re-suspension of fractions 1 and 2 method

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-427**

SCALE	1:800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND



LEGEND

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10
Kilometres

Data Source:
Image supplied by Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 6.8 North-south cross-section of maximum SSC for a 12m monopole

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-428**

SCALE Taken from image	PLOT SIZE A4	DATUM	PROJECTION

FOREWIND

6.5 Increased turbidity as a result of landfall construction activities

6.5.1 With respect to turbidity, part of the works in the intertidal area 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.

6.5.2 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.

6.5.3 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.

7 Assessment of Effects during Operation

7.1 Introduction

7.1.1 The operational phase of 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.

7.1.2 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 area 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.

7.2 Effects of foundation structures on tidal currents

7.2.1 As outlined in **Table 5.1**, the worst-case foundation scenario for potential effects on tidal currents is 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.

7.2.2 The effects on tidal currents of the conical gravity base foundations can be divided into two types:

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

7.2.3 The regional effects on tidal currents of the foundations have been predicted as changes to depth-averaged current velocity relative to the baseline. The changes were estimated at 30-minute intervals over the 30-day simulation period.

7.2.4 **Figure 7.1** shows the maximum absolute change (increase or decrease) in depth-averaged tidal current velocity, predicted for the 6MW conical gravity base foundation layout. The strongest effect occurs along the project boundaries where the density of the foundations is highest. The maximum change is up to 0.008m/s along the project boundaries reducing to below 0.002m/s up to approximately 8km either side of the boundary. These absolute changes are so small that they are unlikely to affect the form of recent sediments over and above the natural tidal processes.

7.2.5 The maximum change in current velocity is less than 2%, restricted to narrow (up to 3km wide) bands along the boundaries of Dogger Bank Teesside A & B (**Figure 7.2**). This maximum percentage change is within the natural variation of tidal current velocity across Dogger Bank and surrounding sea areas.

7.3 Effects of foundation structures on waves

7.3.1 The simulation for the worst-case foundation layout was run using four different wave conditions, which were commonest directions of approach across Dogger Bank:

- One-year return period waves approaching from the north;
- One-year return period waves approaching from the north east;
- 50-year return period waves approaching from the north; and
- 50-year return period waves approaching from the north east.

7.3.2 The wave model boundary is defined by the rectangle in **Figures 7.3** to **7.5**, 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.

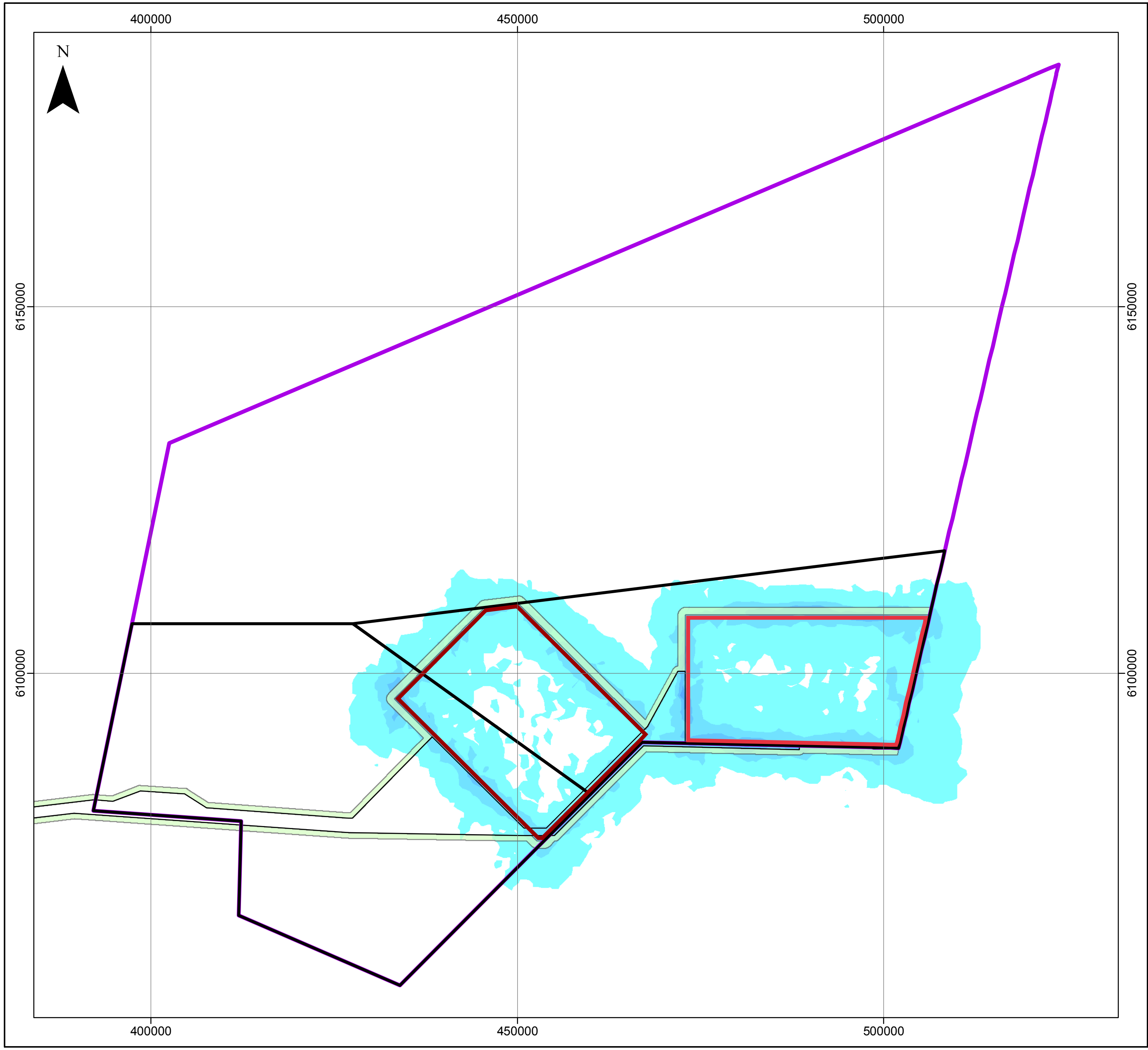
7.3.3 As outlined in **Table 5.1**, the worst-case foundation scenario for potential effects on waves is an array of 400 6MW conical GBS$^{\#}$1 foundations across Dogger Bank Teesside A & B, spaced 750m apart around their perimeters with a wider internal spacing.

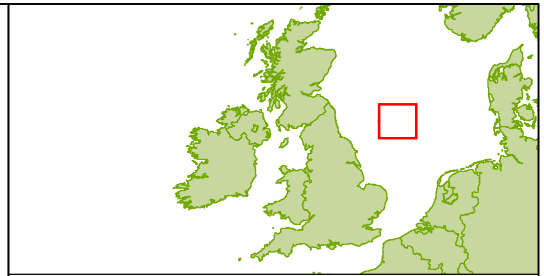
7.3.4 **Figures 7.3** to **7.5** show the difference in significant wave height between the baseline condition and the layout in place. Changes in significant wave height vary depending on the scenario that was modelled. The differences in wave height under the 50-year return period condition are less than for the one-year return period. This trend is explained in **Appendix 9A**.

7.3.5 Maximum changes in significant wave height are for one-year waves from the north and north east (**Figures 7.3** and **7.4**). The changes are up to +/-0.04m at the southern/south western and northern/north eastern boundaries of Dogger Bank Teesside A & B reducing to less than +/-0.02m up to approximately 22km (waves from the north) and 17km (waves from the north east) from the boundaries. Significant wave height reduces to less than +/-0.01m up to 75km north of Dogger Bank Teesside A & B for waves from the north.

7.3.6 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 7.3** to **7.4**).

7.3.7 By comparing the change in significant wave height to the baseline condition for the worst case one-year waves, the percentage change has been calculated. **Figure 7.5** shows that the maximum relative change in wave height results from waves from the north and north east.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Change in velocity (m/s)

- Above 0.020
- 0.018 - 0.020
- 0.016 - 0.018
- 0.014 - 0.016
- 0.012 - 0.014
- 0.010 - 0.012
- 0.008 - 0.010
- 0.006 - 0.008
- 0.004 - 0.006
- 0.002 - 0.004
- Below 0.002

0 5 10
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

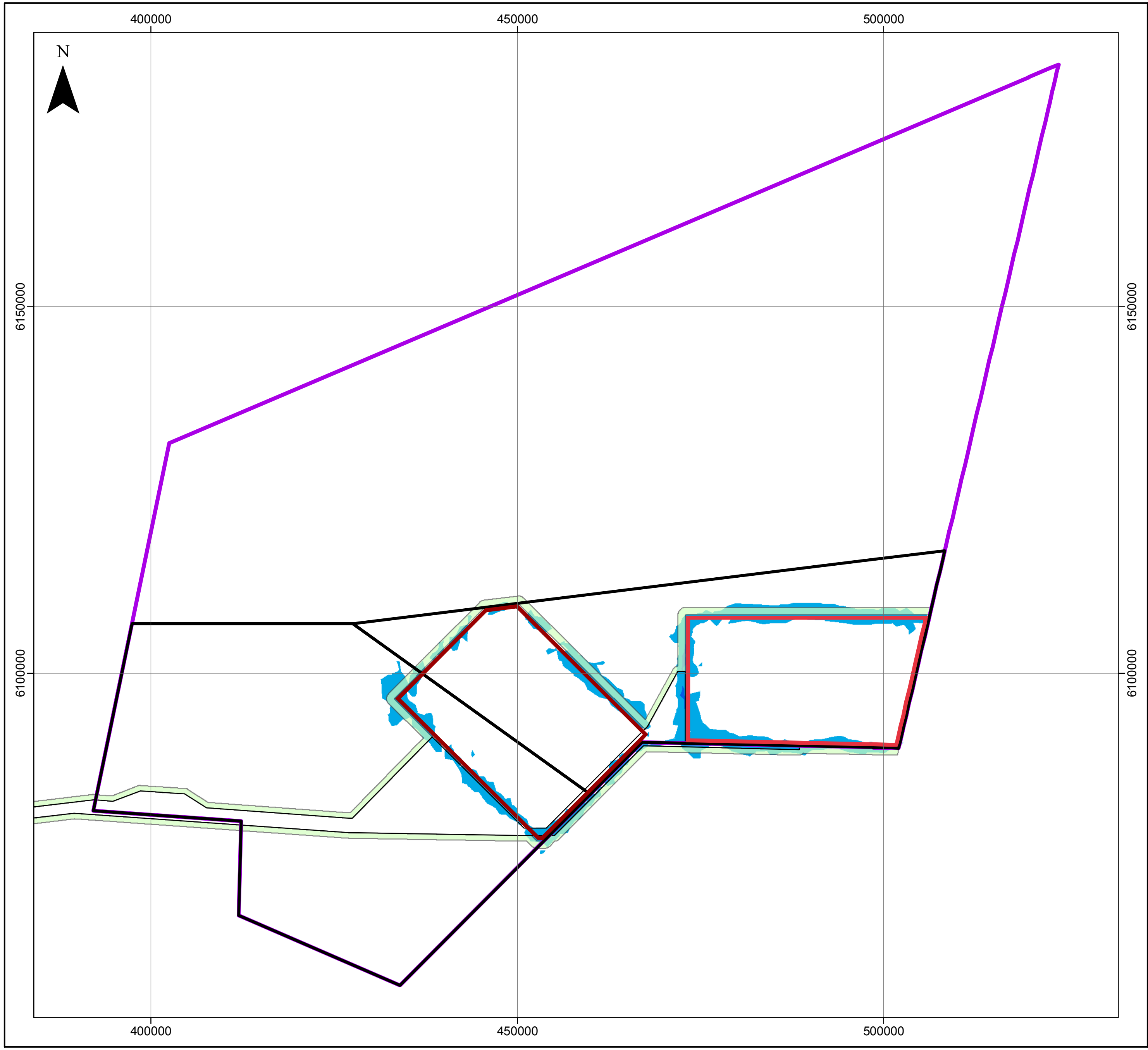
Figure 7.1 Maximum predicted change in depth-averaged tidal current velocity caused by 6MW conical GBS#1 foundations

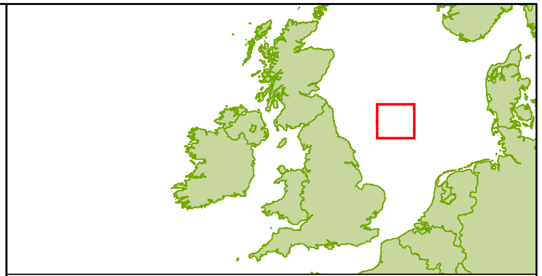
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-429**

SCALE	1:800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Change in velocity (%)

- Above 5
- 4 - 5
- 3 - 4
- 2 - 3
- 1 - 2
- Below 1

Data Source:
Modelling © Danish Hydraulic Institute, 2013

0 5 10
Kilometres

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

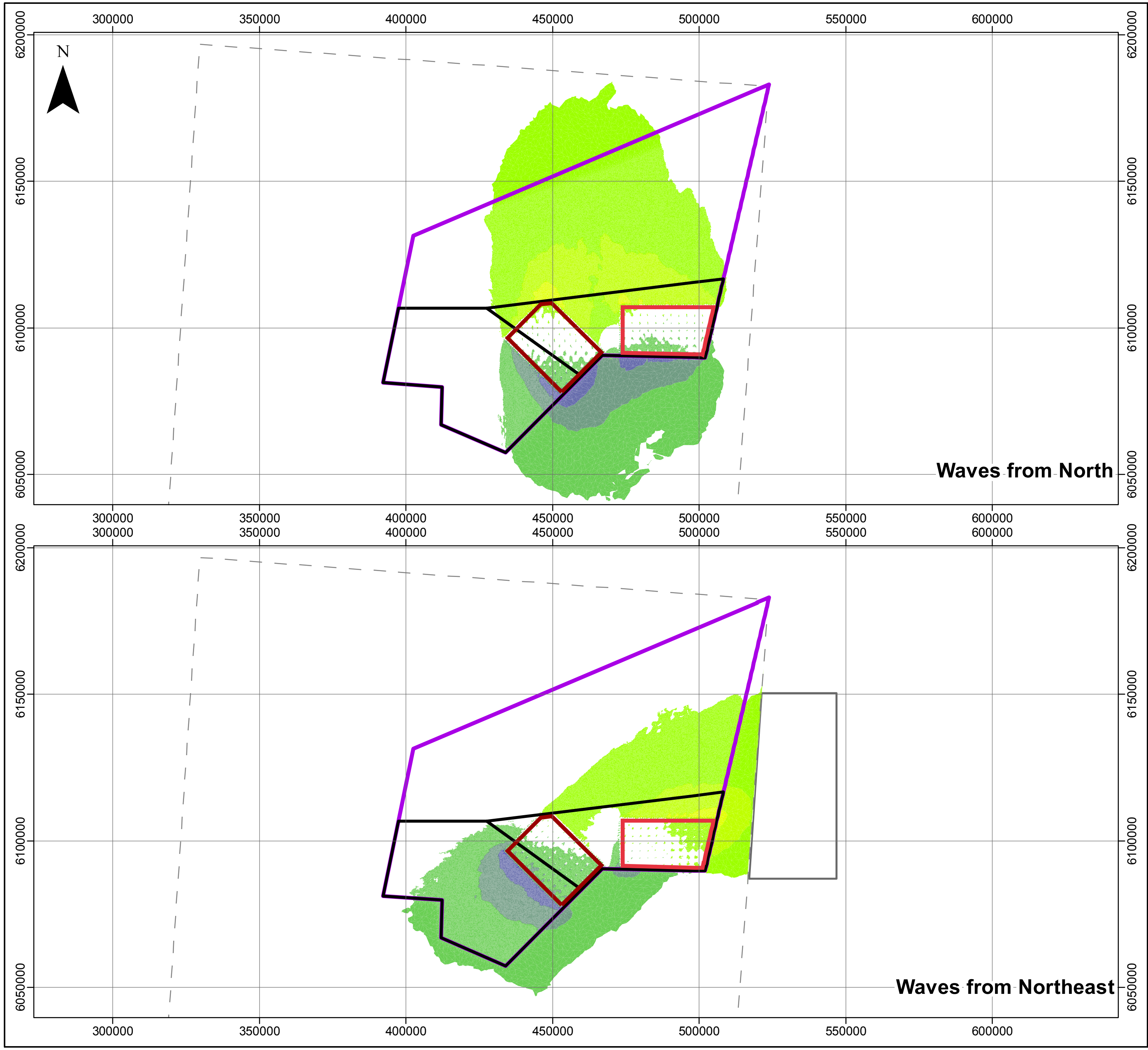
Figure 7.2 Maximum percentage change in depth-averaged tidal current velocity caused by 6MW conical GBS#1 foundations

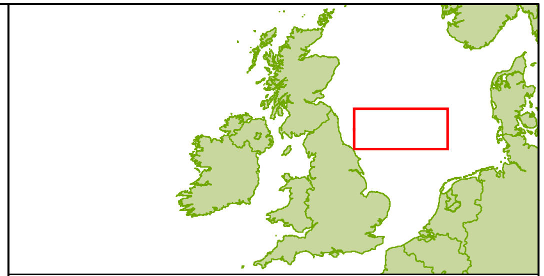
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-430**

SCALE	1:800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Model boundary
- Potential extent of wave effects into international waters

Change in significant wave height (m)

- Above 0.09
- 0.08 - 0.09
- 0.07 - 0.08
- 0.06 - 0.07
- 0.05 - 0.06
- 0.04 - 0.05
- 0.03 - 0.04
- 0.02 - 0.03
- 0.01 - 0.02
- 0.00 - 0.01
- -0.01 - 0.00
- -0.02 - -0.01
- -0.03 - -0.02
- -0.04 - -0.03
- -0.05 - -0.04
- -0.06 - -0.05
- -0.07 - -0.06
- -0.08 - -0.07
- -0.09 - -0.08
- Below -0.09

0 20 40
Kilometres

Data Source:
Wave height © Royal HaskoningDHV, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

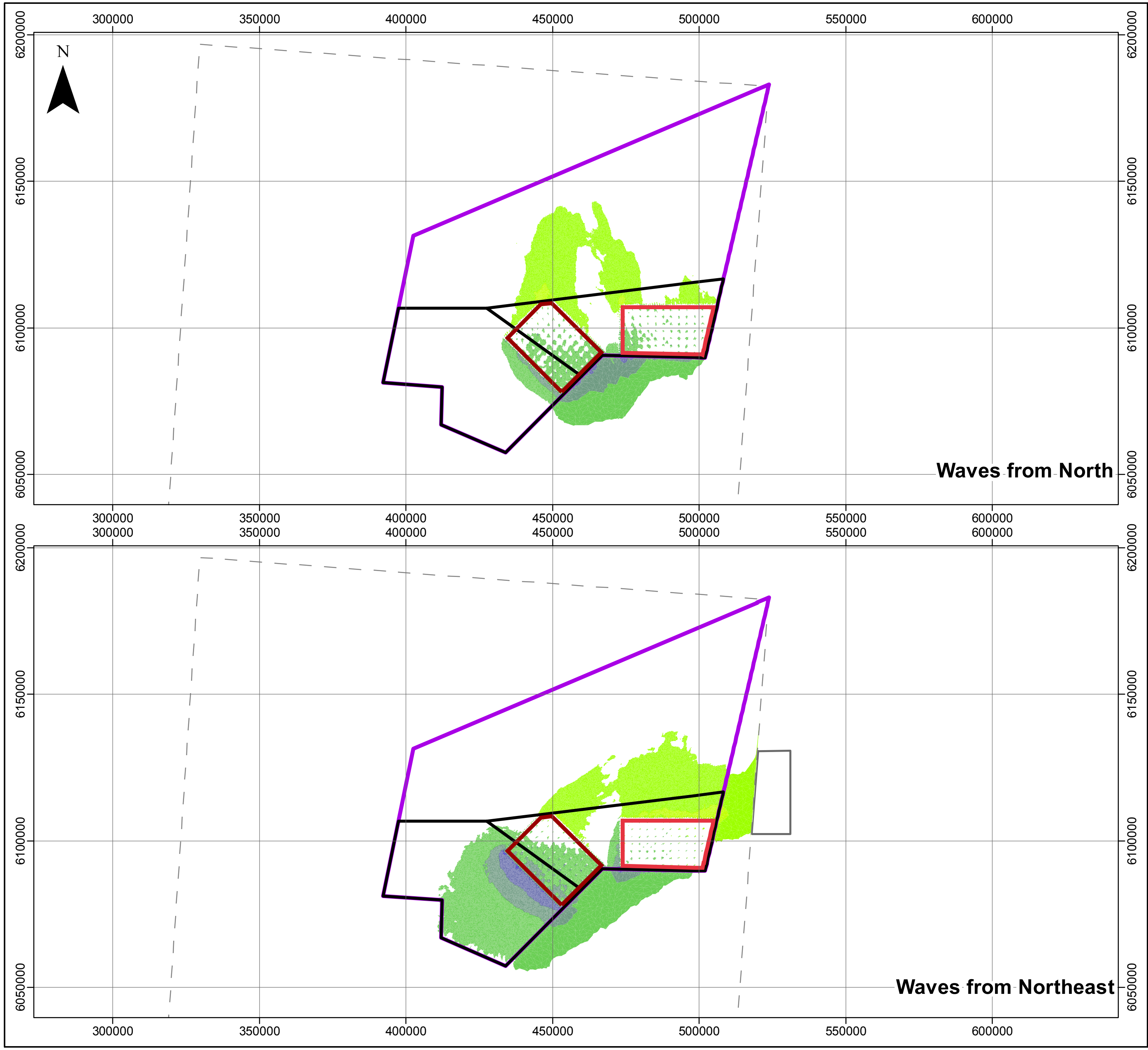
Figure 7.3 Changes to significant wave height for one-year waves from the north and northeast caused by 6MW conical GBS#1 foundations

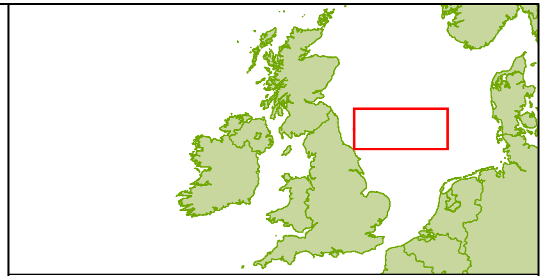
VER	DATE	REMARKS	Drawn	Checked
1	02/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-431**

SCALE	1:2,000,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

Dogger Bank Zone
Tranche boundary
Dogger Bank Teesside A
Dogger Bank Teesside B
Model boundary
Potential extent of wave effects into international waters

Change in significant wave height (m)

- Above 0.09
- 0.08 - 0.09
- 0.07 - 0.08
- 0.06 - 0.07
- 0.05 - 0.06
- 0.04 - 0.05
- 0.03 - 0.04
- 0.02 - 0.03
- 0.01 - 0.02
- 0.00 - 0.01
- -0.01 - 0.00
- -0.02 - -0.01
- -0.03 - -0.02
- -0.04 - -0.03
- -0.05 - -0.04
- -0.06 - -0.05
- -0.07 - -0.06
- -0.08 - -0.07
- -0.09 - -0.08
- Below -0.09

0 20 40
Kilometres

Data Source:
Wave height © Royal HaskoningDHV, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

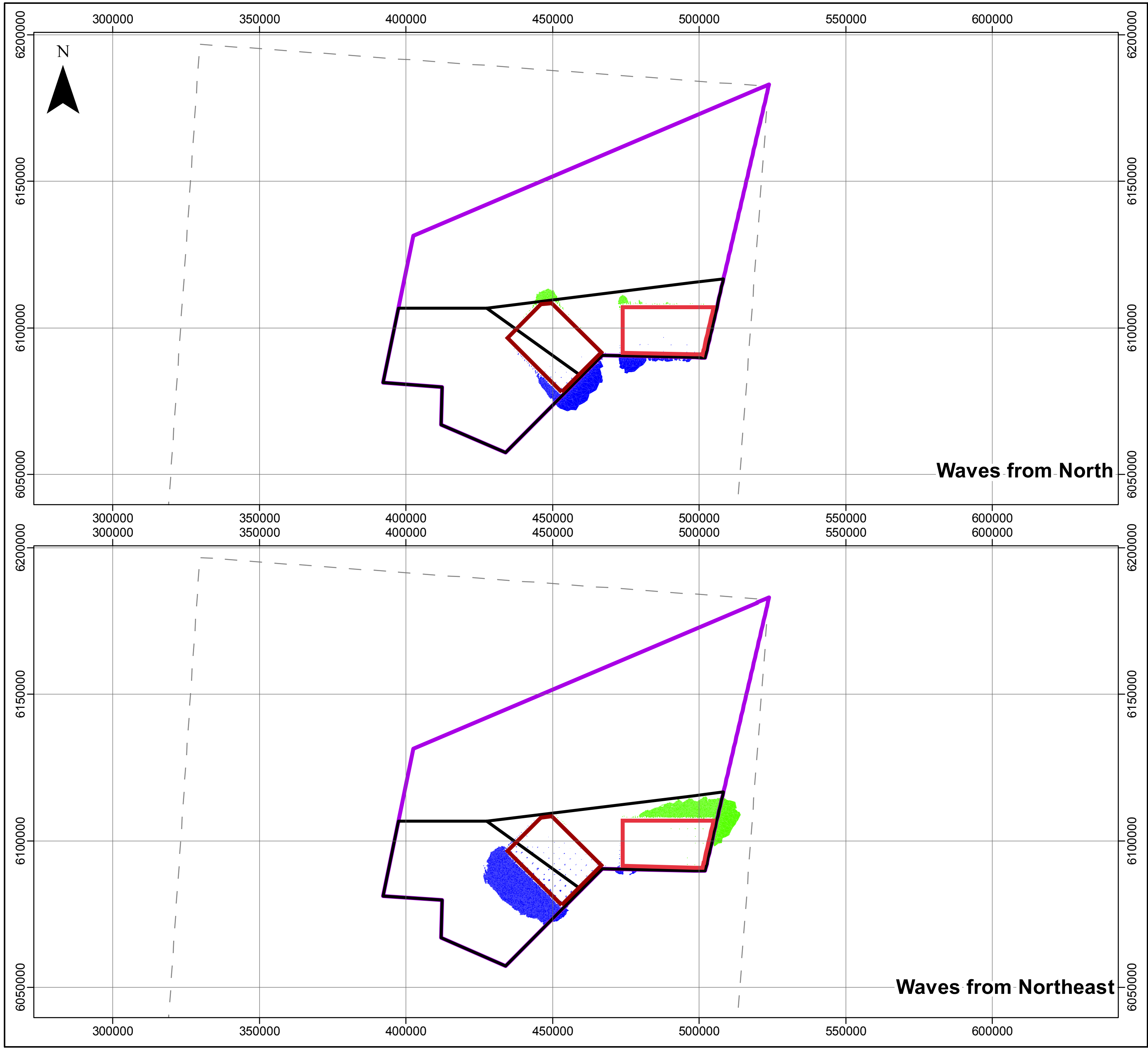
Figure 7.4 Changes to significant wave height for 50-year waves from the north and northeast caused by 6MW conical GBS[#1] foundations

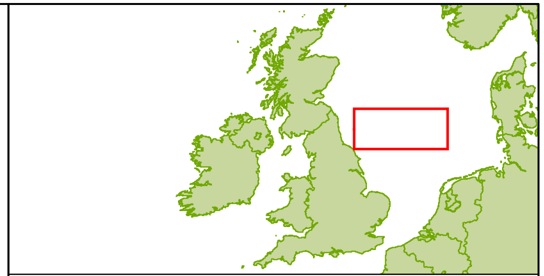
VER	DATE	REMARKS	Drawn	Checked
1	02/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-432**

SCALE	1:2,000,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Model boundary

Wave height difference (%)

- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1.0 - -0.5
- -1.5 - -1.0
- Below - 1.5

0 20 40
Kilometres

Data Source:
Wave height © Royal HaskoningDHV, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 7.5 Percentage change to significant wave height for one-year waves from the north and northeast caused by 6MW conical GBS#1 foundations

VER	DATE	REMARKS	Drawn	Checked
1	02/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-433**

SCALE	1:2,000,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

7.3.8 **Figure 7.5** shows that the maximum change in significant wave height for the 6MW conical gravity base foundations is approximately 1% along the southern/south western boundary of Dogger Bank Teesside B (in a band about 12km wide) and the northern boundary of Dogger Bank Teesside A. 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.

7.4 Increase in suspended sediment concentrations as a result of foundations

7.4.1 During the operational phase, scour will occur around the base of the foundations across the project areas, resulting in the liberation of sediment to the water column and formation of sediment plumes. Details of the methodology adopted for the worst case operational scenario are provided in **Appendix 9A**.

7.4.2 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 worst case results are presented for a run of the model during which all 400 foundations (across Dogger Bank Teesside A & B) (and related infrastructure) are struck by a 50-year storm. The following statistical measures were used:

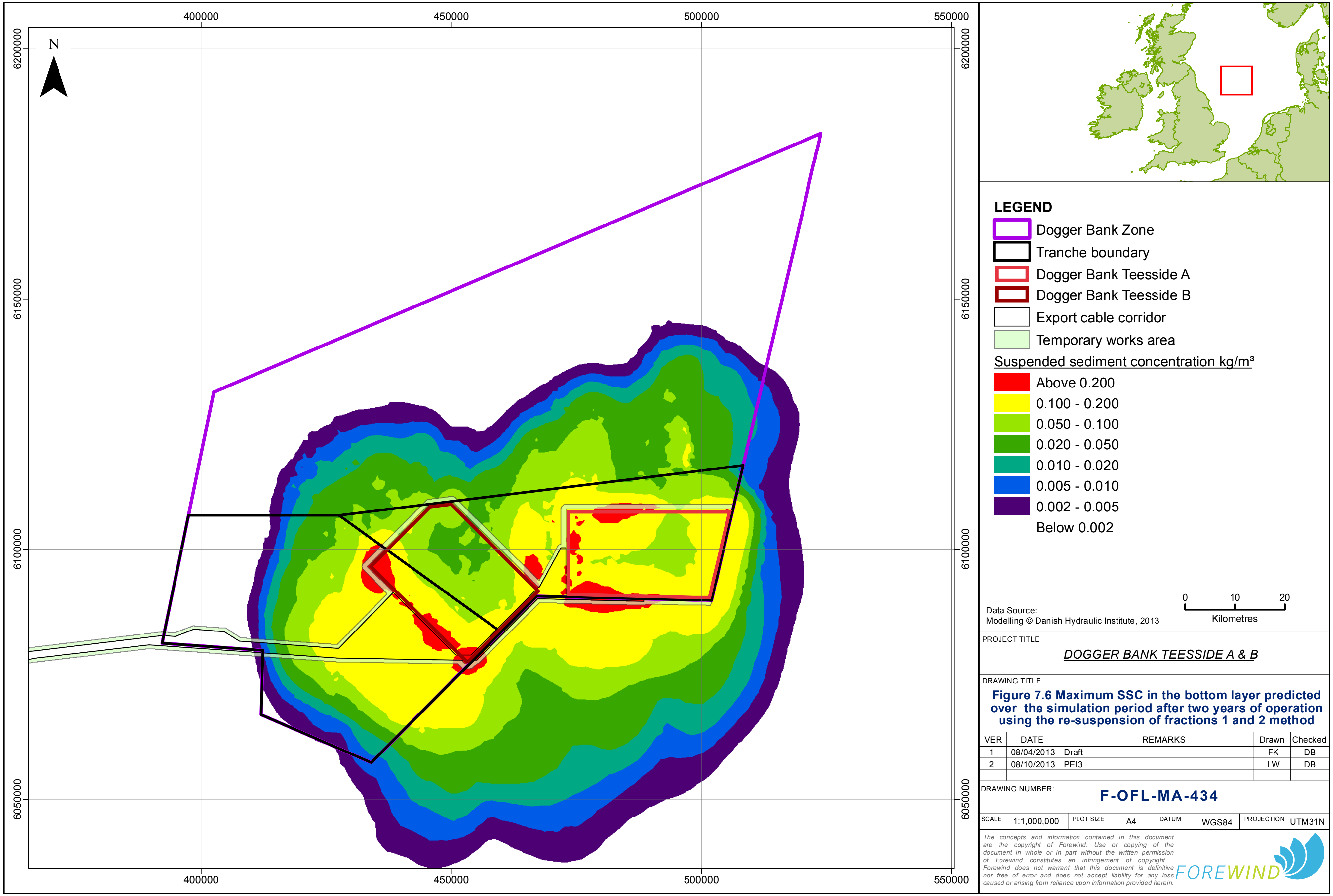
- The maximum values over the 30-day simulation period;
- The average values over the 30-day simulation period; and
- The time over which suspended sediment concentration exceeds 2mg/l.

7.4.3 Once the foundations have been scoured to their equilibrium depth, they are unlikely to refill (either partially or fully). Hence, once the scour has reached its equilibrium value for typical conditions (which may take place over a short period of time), then there will be an absence of sediment for further scouring under typical conditions in the future.

Predicted suspended sediment concentrations in the bottom layer

7.4.4 **Figures 7.6** to **7.8** 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).

7.4.5 **Figure 7.6** shows that 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 boundaries of Dogger Bank Teesside A and the south western boundary 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.



Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

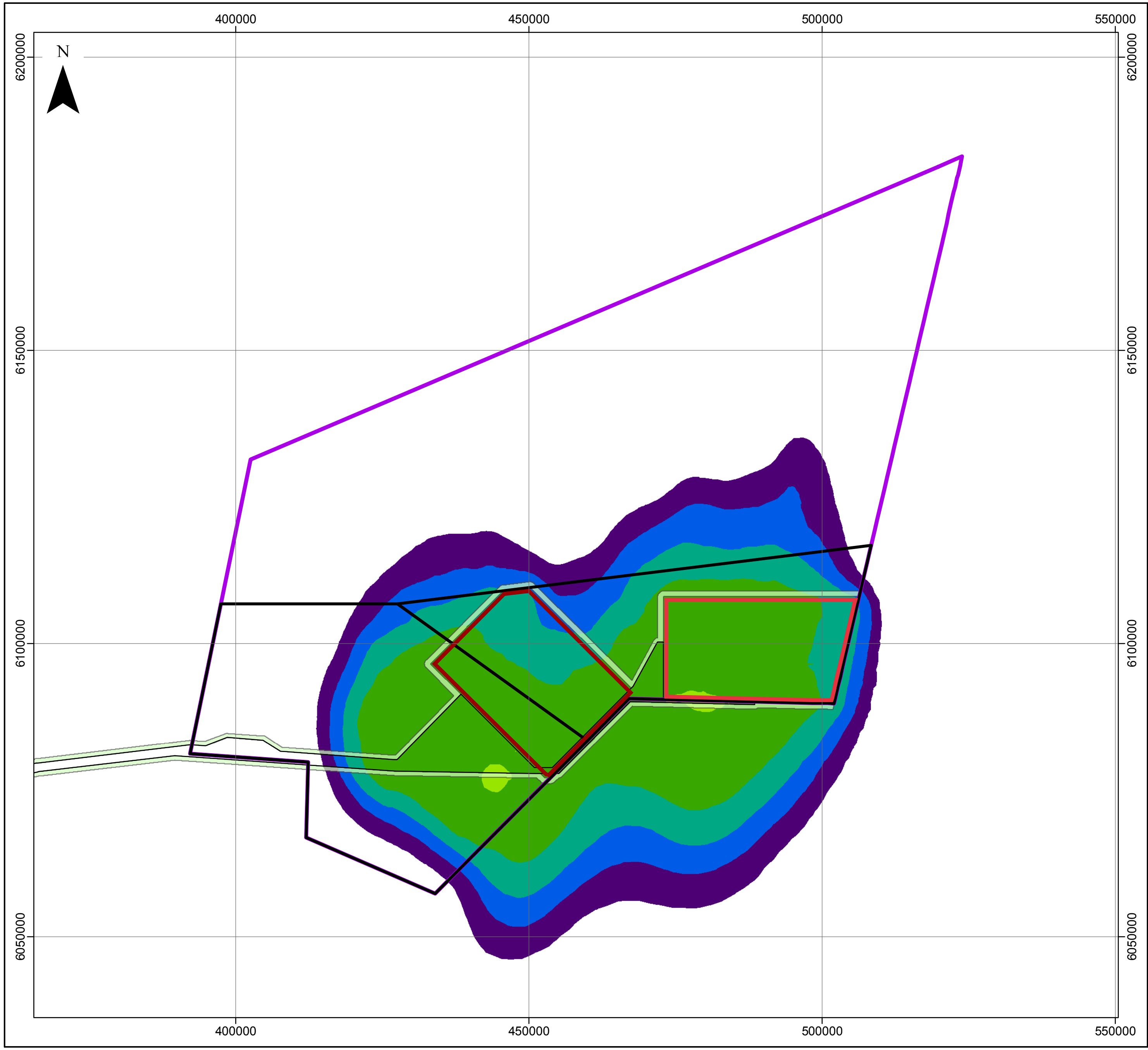
Figure 7.6 Maximum SSC in the bottom layer predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

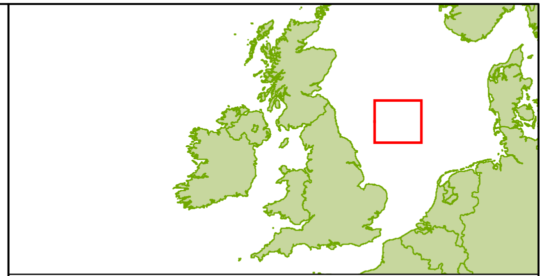
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-434**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

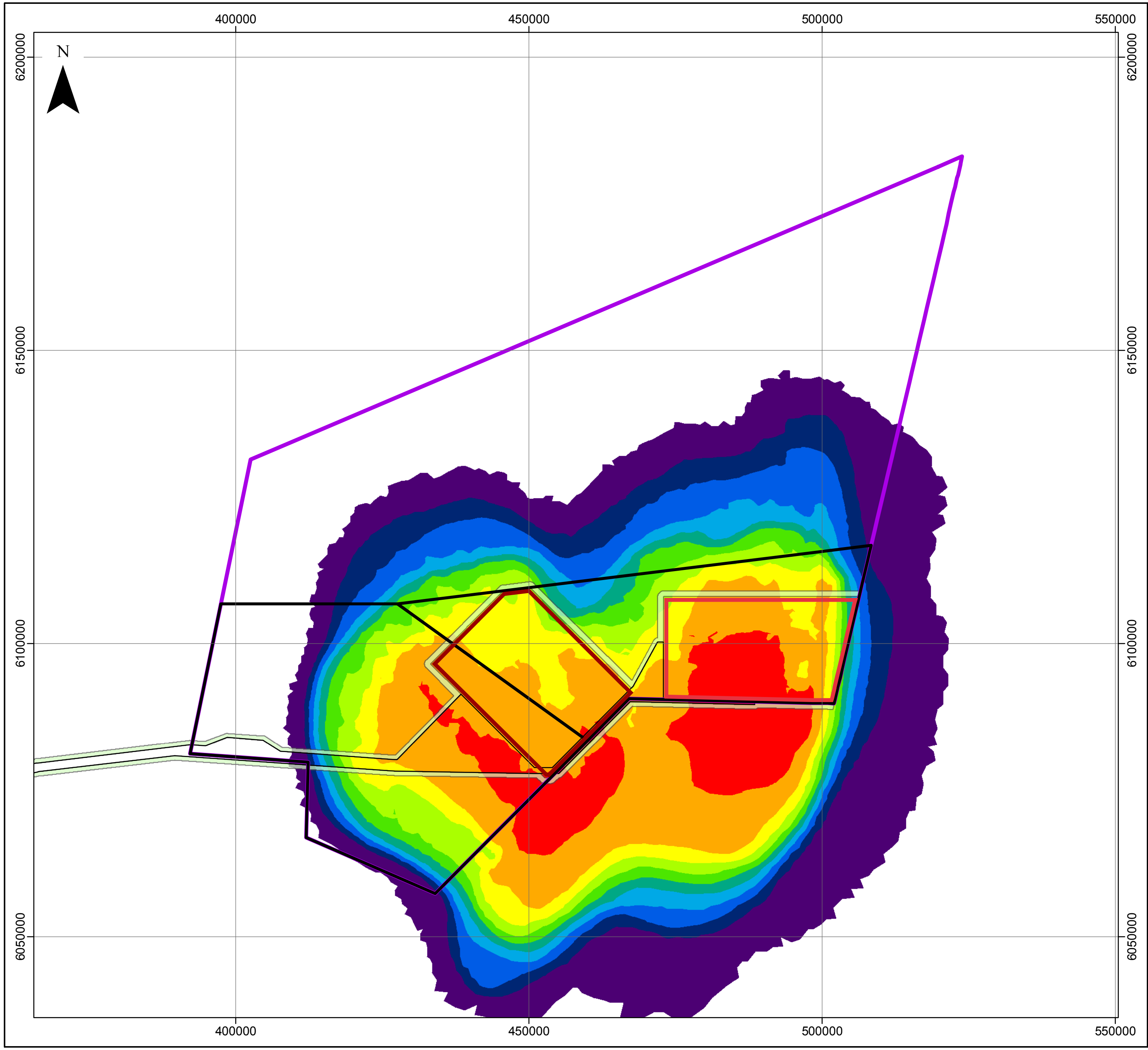
Figure 7.7 Average SSC in the bottom layer predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

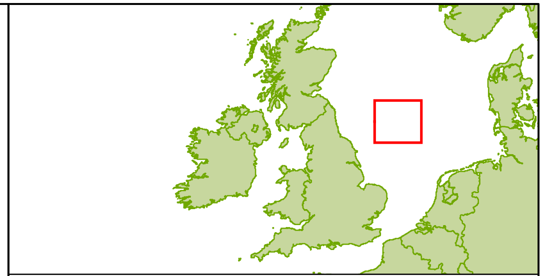
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-435**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Exceedance of 2 mg/l (%)

- Above 90
- 80 - 90
- 70 - 80
- 60 - 70
- 50 - 60
- 40 - 50
- 30- 40
- 20 - 30
- 10 - 20
- 0 - 10
- Below 0

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 7.8 Percentage of time predicted over the simulation period where SSC of 2mg/l is exceeded in the bottom layer after two years of operation using the re-suspension of fractions 1 and 2 method

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-436**

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

FOREWIND

7.4.6 The average suspended sediment concentration in the bottom layer predicted over the simulation period is presented in **Figure 7.7**. 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.

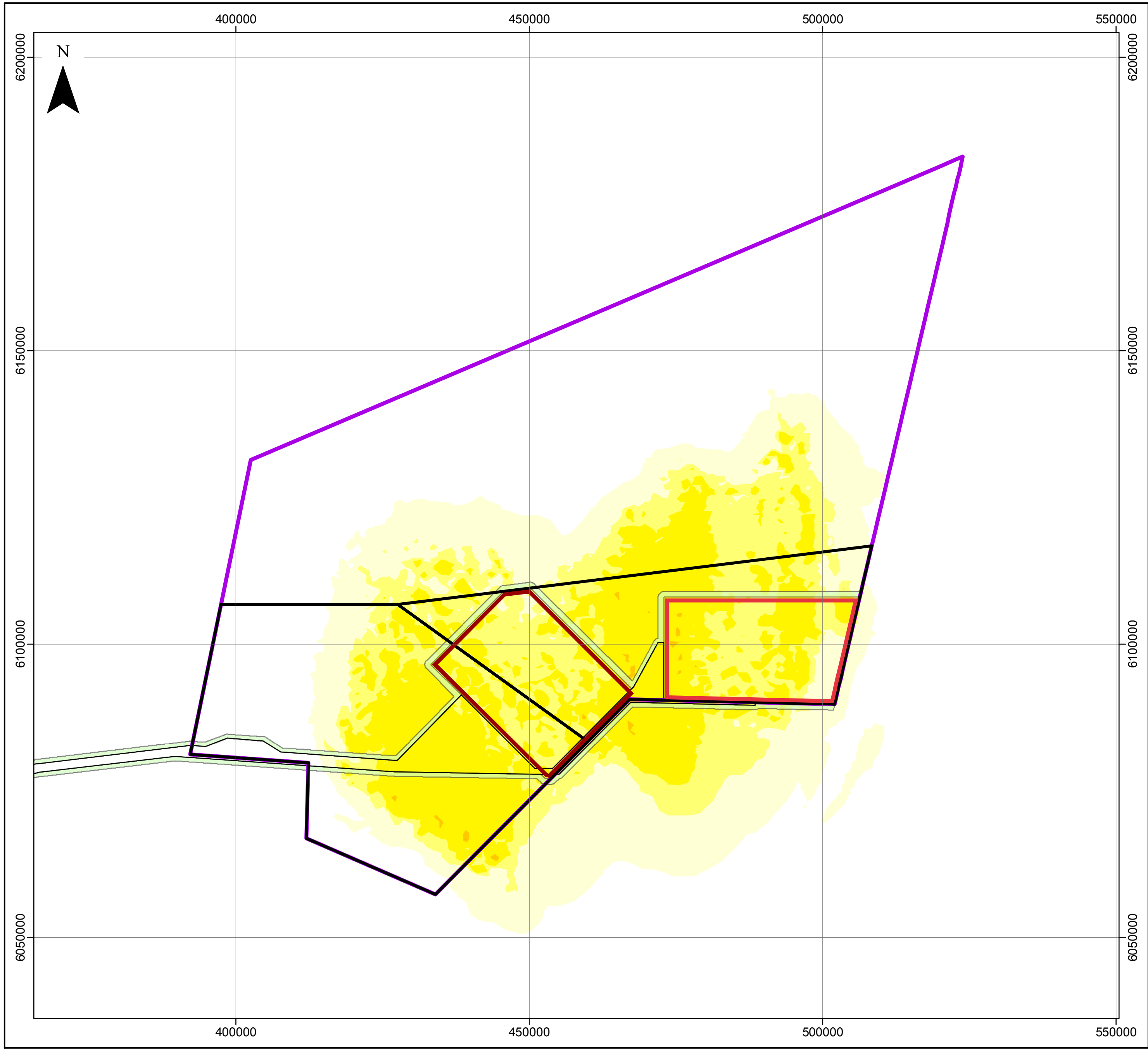
7.4.7 **Figure 7.8** presents the exceedance time during the simulation of the predicted suspended sediment concentration above a chosen limit of 2mg/l. The map shows that 2mg/l is exceeded greater than 90% of the 30-day simulation period in two patches, one to the south of Dogger Bank Teesside B and 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.

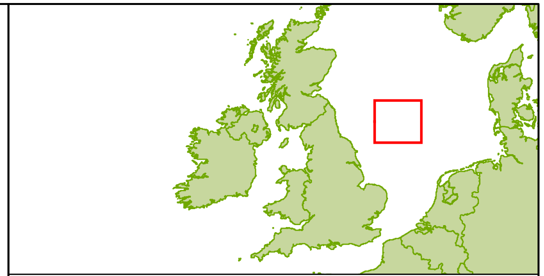
Predicted deposition and re-suspension of dispersed sediment

7.4.8 **Figure 7.9** shows the maximum change in deposition predicted at any time over the 30-day simulation period. 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.

7.4.9 Average deposition is predicted to be between 0.5mm and 5mm in a 32km long, 14km wide area located between the two projects (**Figure 7.10**). Elsewhere the maximum average deposition is less than 0.5mm reducing to less than 0.1mm approximately 23km south west of Dogger Bank Teesside B and 19km north of Dogger Bank Teesside A.

7.4.10 **Table 7.1** 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 seven selected points (Points R1 to R7 in **Figure 7.11**). **Table 7.1** 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.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Sediment thickness (m)

- Above 0.1000
- 0.0500 - 0.1000
- 0.0100 - 0.0500
- 0.0050 - 0.0100
- 0.0010 - 0.0050
- 0.0005 - 0.0010
- 0.0001 - 0.0005
- Below 0.0001

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

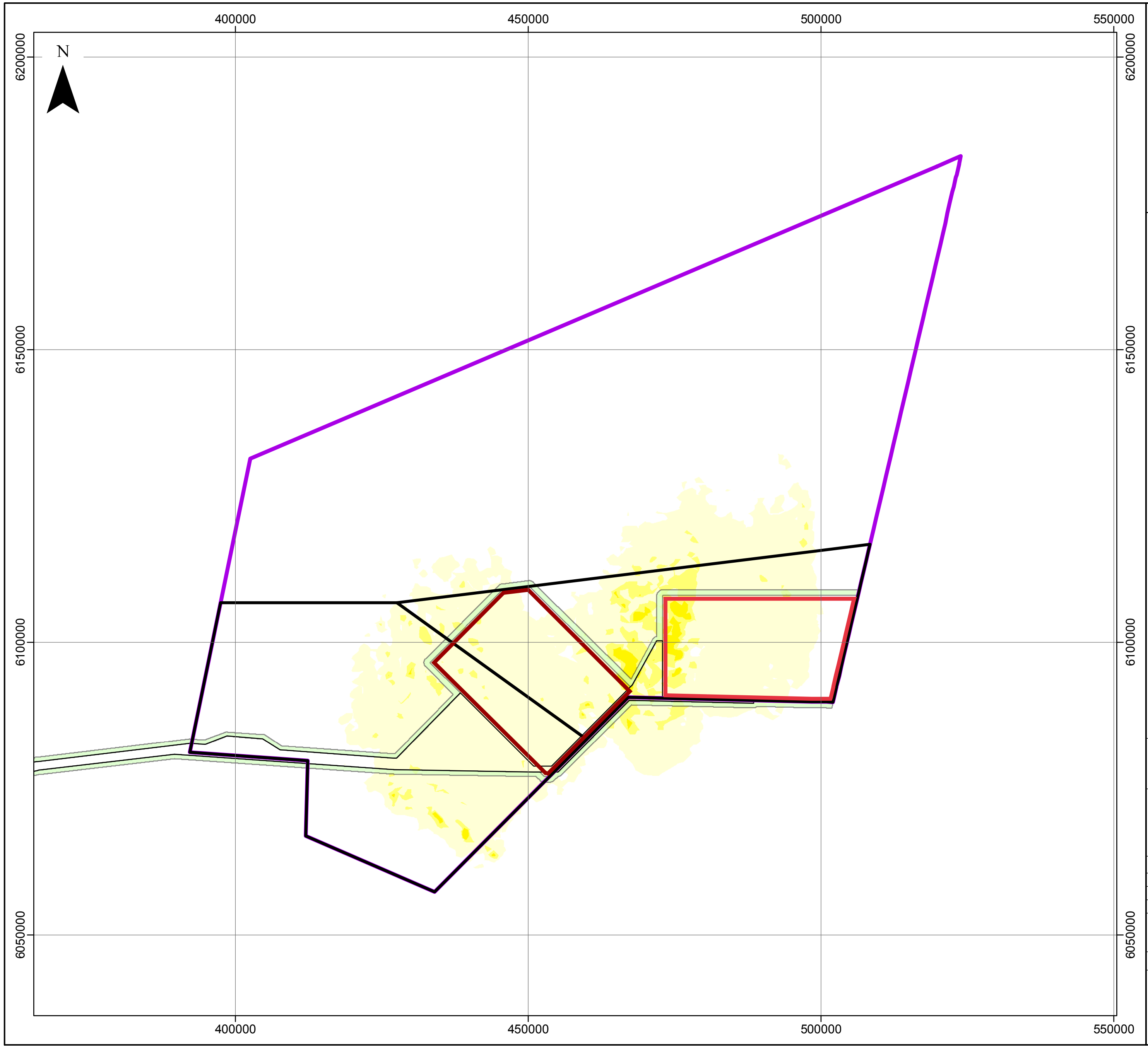
Figure 7.9 Maximum deposition predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

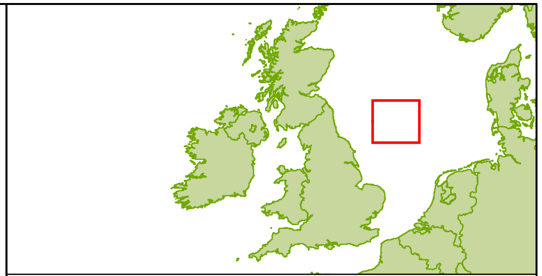
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-437**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area

Sediment thickness (m)

- Above 0.1000
- 0.0500 - 0.1000
- 0.0100 - 0.0500
- 0.0050 - 0.0100
- 0.0010 - 0.0050
- 0.0005 - 0.0010
- 0.0001 - 0.0005
- Below 0.0001

Data Source:
Modelling © Danish Hydraulic Institute, 2013

0 10 20
Kilometres

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

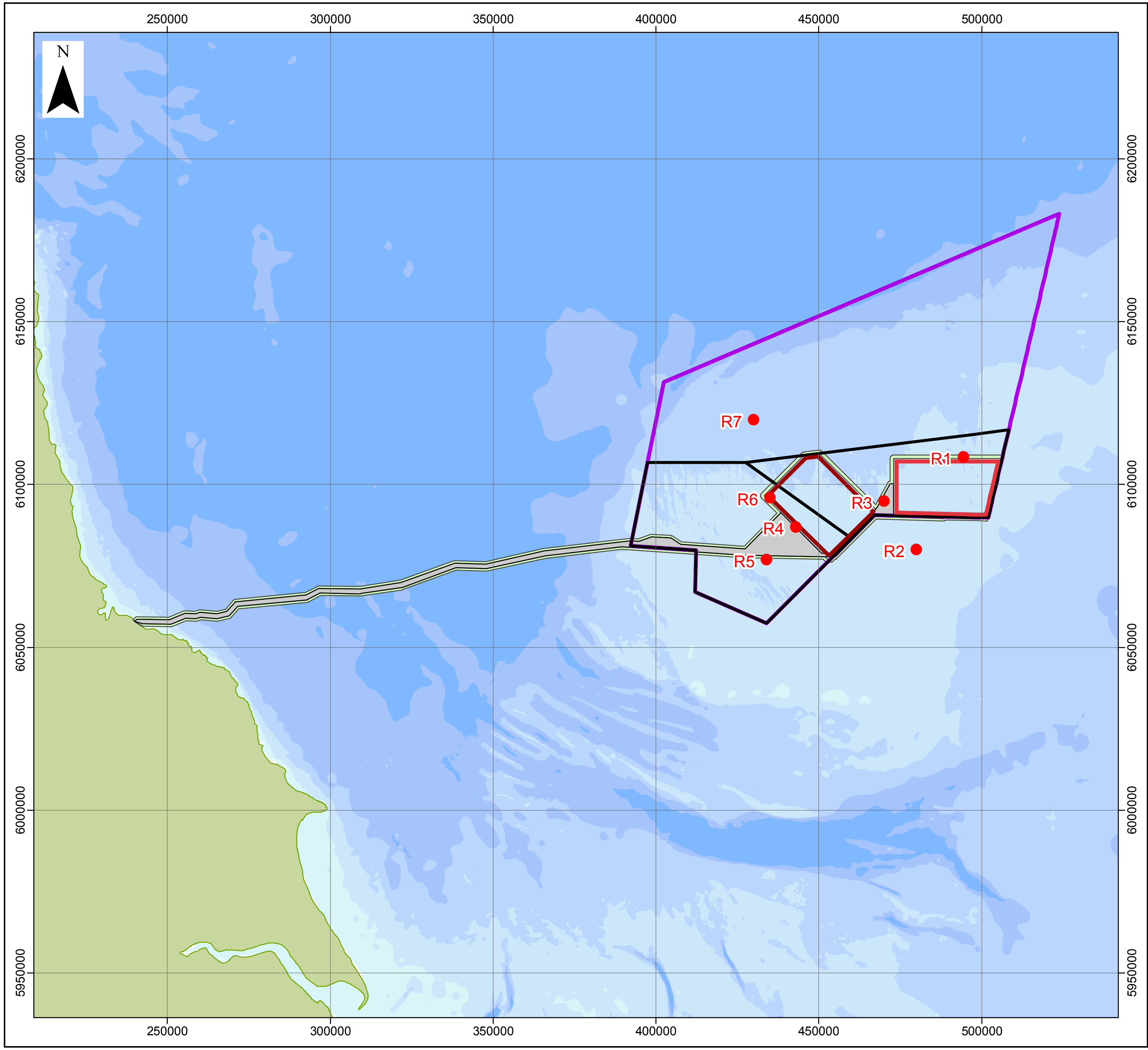
Figure 7.10 Average deposition predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

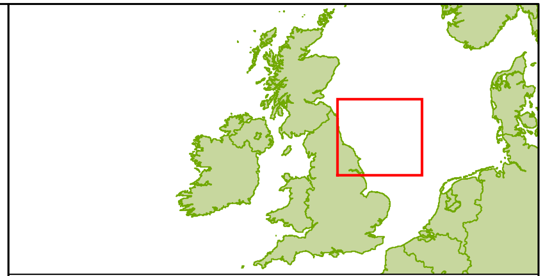
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-438**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche Boundary
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Export cable corridor
- Temporary works area
- Sediment thickness time series analysis point

0 20 40
Kilometres

Data Source:
Sediment data from Danish Hydraulic Institute, 2012
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from © TCarta data 2009.

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 7.11 Location of points for sediment thickness time series analysis for the operational phase

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **#-###-####-##**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

Table 7.1 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

7.4.11 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 50-year storm across Dogger Bank without foundations in place.

7.4.12 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 700m x 700m (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.

7.4.13 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 7.2** shows the results of the predictions.

Table 7.2 Natural suspended and GBS scour volumes released during a 50-year storm condition

Storm	Naturally suspended volume (m^3)	Maximum scour volume from GBS (m^3)	Equivalent bed depth released in suspension (mm)
50 year	16,254	2,843	29

7.4.14 **Table 7.2** shows that under a 50-year storm condition, 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. There is more than sufficient naturally occurring sediment to sustain the predicted suspended volume at the 50-year return period.

7.5 Effect on nearshore sediment transport of seabed cable protection

7.5.1 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 the cables will be on the surface and protected by rock armour (or some other form of remedial protection), which could potentially create a partial barrier to sediment transport.

7.5.2 The main reason for the cables to be surface laid is the absence of surface sand and the proximity of bedrock to the seabed.

7.5.3 At this stage an assumption is made that there is no restriction on the length of cable protection in the nearshore. Therefore, the worst case scenario for this assessment is for remedial protection across the whole of the nearshore subtidal zone to an unspecified distance offshore. Remedial protection is anticipated to be up to about 15m wide and stand 1.3m above the surrounding seabed. There is the potential for up to four cables requiring protection, and hence, four 15m wide, 1.3m high structures have been assessed as the worst case scenario.

7.5.4 With regard to effects on bedload sediment transport, the key factors in determining the magnitude of the potential effect 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. 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 9A**):

- 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.

7.5.5 The placement of cables on the seabed in areas where burial cannot be achieved, and the potential protection of these lengths in the form or rock armour or other remedial protection, 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.

7.5.6 To investigate the potential effect of remedial protection on the longshore sediment transport regime, it is necessary to define the active littoral zone. Using the Houston formula the active zone is about approximately 2km wide offshore from mean low water spring along the cable route (to about the 10m water depth contour). Consequently, any remedial protection seaward of 2km offshore would have no effect on longshore sediment transport processes.

7.5.7 The presence of remedial protection on the seabed inshore of 2km along the cable route would provide a physical barrier to water flow and sand transport on, and close to, the seabed. 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.

7.5.8 With regard to effects on bedload sediment transport, the existing tidal currents and waves are capable of mobilising sand landward of the 10m water depth (up to 2km offshore along the cable route from mean low water spring). Longshore sediment transport is generally to the southeast within the envelope of the Dogger Bank Teesside A & B Export Cable Corridor, but rates are relatively low. This is manifest in only small sediment build-up on the west side of the Redcar groynes (northwest of the cable corridor). In addition, the presence of Saltburn Scar to the southeast of the cable corridor does not allow much loss of sediment to the east.

7.5.9 Although some trapping of sediment would occur on the ‘updrift’ side of the remedial protection, because the longshore transport rates are low, it is anticipated that the volumes will be small. In addition, only small volumes of sediment are transported beyond Saltburn Scar to the southeast. These two factors combined means that the magnitude of changes at locations ‘downdrift’ of the cable corridor, both locally and further down the sediment transport pathway, are likely to be 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.

7.5.10 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.

7.5.11 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.

7.5.12 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 south east. 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.

8 Assessment of Effects during Decommissioning

8.1 Removal of foundations and cables

8.1.1 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 (Section 6). 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.

8.2 Removal of landfall infrastructure

8.2.1 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. 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 (Section 6).

9 Inter-relationships

9.1.1 In order to address the environmental impact of the proposed development as a whole, this section establishes the inter-relationships between marine physical processes and other physical, environmental and human receptors. The objective is to identify where the accumulation of residual effects on a single receptor, and the relationship between those effects, gives rise to a need for additional mitigation.

9.1.2 **Table 9.1** summarises the inter-relationships that are considered of relevance to marine physical processes and identifies where they have been considered within the draft ES.

9.1.3 Although the effects assessed on marine physical processes have the potential to impact a number of other receptors, no inter-relationships have been identified where an accumulation of residual effects on marine physical processes and the relationship between those effects gives rise to a need for additional mitigation.

Table 9.1 Inter-relationships relevant to the assessment of marine physical processes

Inter-relationship	Section where addressed	Linked chapter
Construction and decommissioning		
Re-suspension of seabed sediments through seabed preparation, drill arisings and scour has the potential to affect water and sediment quality.	Section 6.2 (construction effects on sediment transport)	**Chapter 10 Marine Water and Sediment Quality**
Suspended sediments have the potential to affect other ecological receptors including marine ecology, marine mammals and fish.	Section 6.2 (construction effects on sediment transport)	**Chapter 12 Marine and Intertidal Ecology** **Chapter 13 Fish and Shellfish** **Chapter 14 Marine Mammals**
Suspended sediments have the potential to affect tourism and recreation.	Section 6.2 (construction effects on sediment transport)	**Chapter 23 Tourism and Recreation**
Re-suspension of seabed sediments through seabed preparation, drill arisings and scour has the potential to affect other marine users.	Section 6.2 (construction effects on sediment transport)	**Chapter 17 Other Marine Users**
Re-suspension of seabed sediments through seabed preparation, drill arisings and scour has the potential to affect marine archaeological resources.	Section 6.2 (construction effects on sediment transport)	**Chapter 18 Marine and Coastal Archaeology**
Changes in coastal processes have the potential to affect ecological receptors.	Section 6.3 (construction effects at the landfall)	**Chapter 12 Marine and Intertidal Ecology**
Changes to coastal	Section 6.3 (construction effects at	**Chapter 20 Seascape and Visual**

Inter-relationship	Section where addressed	Linked chapter
processes and the physical composition of the coast can affect seascape and visual character.	the landfall)	**Character**
Scour of the seabed has the potential to result in a change of habitat.	Section 5 (realistic worst case scenario)	**Chapter 12 Marine and Intertidal Ecology**
Operation		
Re-suspension of seabed sediments through scour has the potential to affect water and sediment quality.	Section 7.4 (operational effects on sediment transport)	**Chapter 10 Marine Water and Sediment Quality**
Re-suspension of seabed sediments through scour has the potential to affect other marine users.	Section 7.4 (operational effects on sediment transport)	**Chapter 17 Other Marine Users**
Re-suspension of seabed sediments through scour has the potential to affect marine archaeological resources.	Section 7.4 (operational effects on sediment transport)	**Chapter 18 Marine and Coastal Archaeology**
Suspended sediments and changes in wave and tidal current regime have the potential to affect other ecological receptors including marine ecology and fish.	Sections 7.2 and 7.3 (operational effects on tidal currents and waves, respectively) and Section 7.4 (operational effects on sediment transport)	**Chapter 12 Marine and Intertidal Ecology** **Chapter 13 Fish and Shellfish**
Changes to far-field wave and hydrodynamic conditions have the potential to affect designated habitats.	Sections 7.2 and 7.3 (operational effects on tidal currents and waves, respectively)	**Chapter 8 Designated Sites**

9.1.4 **Chapter 31 Inter-relationships** provides a holistic overview of all of the inter-relationships associated within the proposed development.

10 Cumulative Effects

10.1 Cumulative impact assessment strategy and screening

10.1.1 This section describes the cumulative assessment for marine physical processes, taking into consideration other plans, projects and activities. A summary of the cumulative impact assessment (CIA) is presented in **Chapter 33**.

10.1.2 Forewind has developed a strategy (the 'CIA Strategy') for the assessment of cumulative impacts in consultation with statutory stakeholders including the Marine Management Organisation (MMO), Joint Nature Conservation Committee (JNCC), Natural England and Centre for Environment, Fisheries and Aquaculture Science (Cefas). Details of the approach to CIA adopted for this draft ES are provided in **Chapter 4 EIA Process**. Although the marine physical processes assessment focusses on describing the effects against the existing environment, rather than defining the impact (see Section 3.3), the general approach taken to the cumulative assessment is the same.

10.1.3 In its simplest form the CIA Strategy involves consideration of:

- Whether impacts on a receptor (or effects) can occur on a cumulative basis between the wind farm project(s) subject to the application(s) and other wind farm projects, activities and plans in the Dogger Bank Zone (either consented or forthcoming); and
- Whether impacts on a receptor (or effects) can occur on a cumulative basis with other activities, projects and plans outwith the Dogger Bank Zone (e.g. other offshore wind farm developments), for which sufficient information regarding location and scale exist.

10.1.4 In this manner, the assessment considers (where relevant) the potential for cumulative impacts in the following sequence:

- With the third phase of development in the Dogger Bank Zone, known as Dogger Bank Teesside C & D;
- With the above, plus any other activities, projects and plans in the Dogger Bank Zone; and
- With all of the above, in addition to any other activities, projects and plans outwith the Dogger Bank Zone.

10.1.5 The strategy recognises that data and information sufficient to undertake an assessment will not be available for all potential projects, activities, plans and/or parameters, and seeks to establish the 'confidence' we can have in the data and information available.

10.1.6 There are two key steps to the Forewind 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.

10.1.7 The first step in the cumulative assessment for marine physical processes involved an appraisal of the key effects identified in the assessment of Dogger Bank Teesside A & B (**Table 10.1**). The potential for effects to occur on a cumulative basis has been identified, both within and beyond the Dogger Bank Zone and the confidence in the data and information available to inform the assessment has been appraised (following the methodology set out in **Chapter 4**).

10.1.8 This also identifies where cumulative effects are not anticipated, thereby screening them out from further assessment.

10.1.9 For the purposes of marine physical processes, the effects identified during the construction (Section 6), operation (Section 7) and decommissioning phases (Section 8) of Dogger Bank Teesside A & B that have the potential to result in a cumulative effect, are identified in **Table 10.1**.

10.1.10 On this basis, the potential for any other cumulative effects is screened out from further consideration in the process.

Table 10.1 Potential cumulative effects

Effect	**Dogger Bank Zone and Dogger Bank Teesside A & B Export Cable Corridor (within 1km)**		**Beyond 1km from the Dogger Bank Zone and Dogger Bank Teesside A & B Export Cable Corridor**		**Rationale for where no cumulative effect is expected**
	Potential for cumulative effect	**Data confidence**	**Potential for cumulative effect**	**Data confidence**	
Increase in suspended sediment concentrations and sediment deposition during construction and decommissioning.	Yes	High	Yes	Medium	The nearest development outside the Dogger Bank Zone is approximately 25km away. Construction plumes are unlikely to interact over this distance, although these are screened in to the assessment on a precautionary basis.
Interruption of sediment transport as a result of landfall construction and decommissioning activities.	No	High	No	Medium	No other projects have been identified that would cumulatively effect sediment transport at the landfall site.
Increased turbidity as a result of landfall construction and decommissioning activities.	No	High	No	Medium	No other projects have been identified that would cumulatively effect turbidity (suspended sediment concentration) at the landfall site.
Effects of foundation structures on tidal currents during operation.	No	High	No	Medium	The cumulative effects on tidal currents within the Dogger Bank Zone have been investigated by filling Dogger Bank Teesside A & B, Dogger

Effect	Dogger Bank Zone and Dogger Bank Teesside A & B Export Cable Corridor (within 1km)		Beyond 1km from the Dogger Bank Zone and Dogger Bank Teesside A & B Export Cable Corridor		Rationale for where no cumulative effect is expected
	Potential for cumulative effect	Data confidence	Potential for cumulative effect	Data confidence	
					Bank Creyke Beck and Dogger Bank Teesside C & D with foundations. The results show that the absolute changes are within the natural variation of tidal current velocity; Outside the Dogger Bank Zone the nearest development with the potential to have operational tidal current effects is 65km away (Hornsea Projects One and Two) and tidal currents will not interact over this distance.
Effect of foundation structures on waves during operation.	No	High	No	Medium	The cumulative effects on waves within the Dogger Bank Zone have been investigated by filling Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D with foundations. The results show that the absolute changes are within the natural variation of wave height; Outside the Dogger Bank Zone the nearest development with the potential to have operational wave effects is 65km away (Hornsea Projects One and Two) and waves will not interact over this distance.
Increase in suspended sediment concentrations as a result of scour at foundations during operation.	Yes	High	Yes	Medium	Operational plumes (via release of sediments via scour) from developments outside the Dogger Bank Zone would either be short-lived and relatively small compared to those associated with Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank

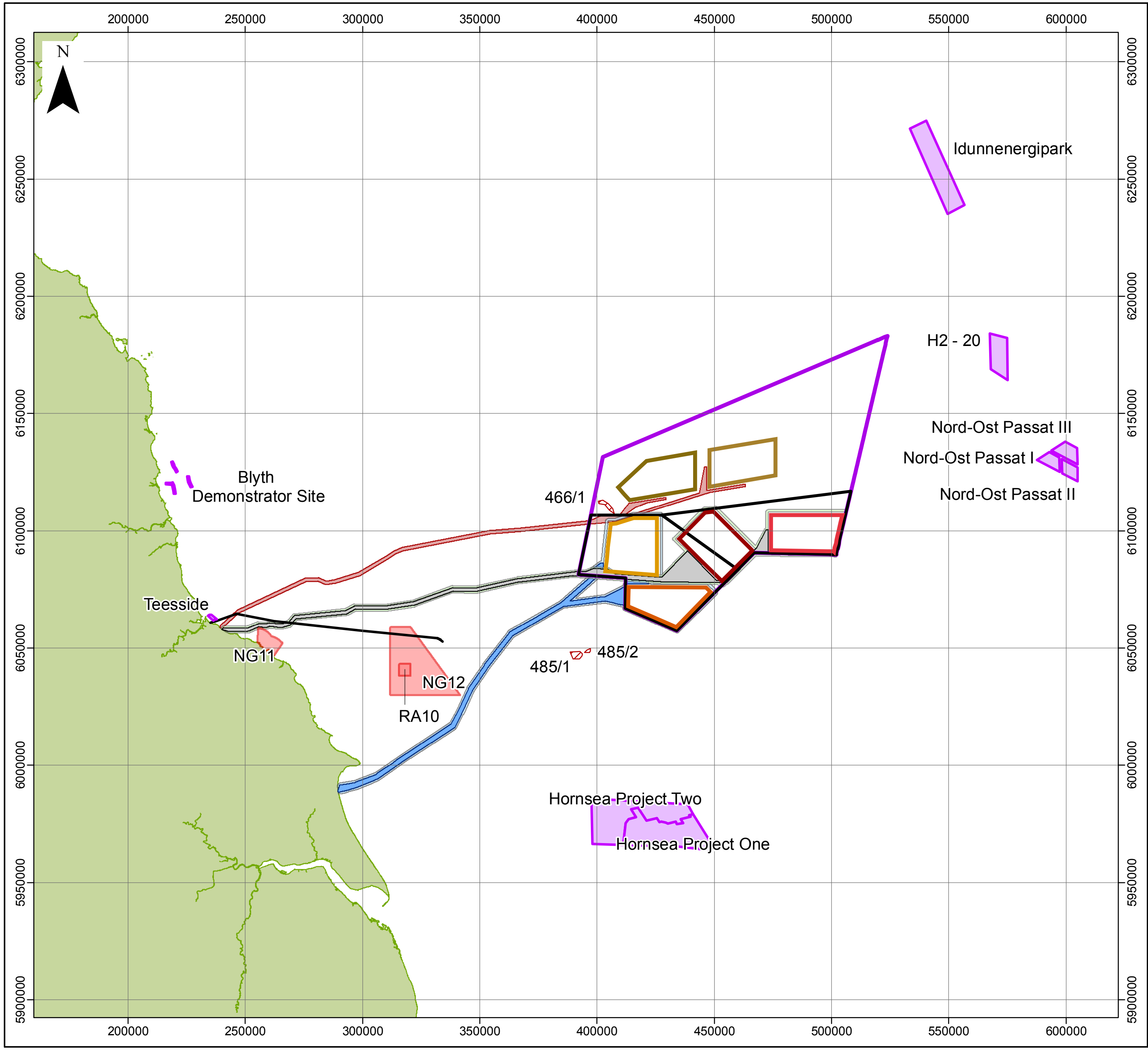
Effect	Dogger Bank Zone and Dogger Bank Teesside A & B Export Cable Corridor (within 1km)		Beyond 1km from the Dogger Bank Zone and Dogger Bank Teesside A & B Export Cable Corridor		Rationale for where no cumulative effect is expected
	Potential for cumulative effect	Data confidence	Potential for cumulative effect	Data confidence	
					Teesside C & D, or would be at such a large distance that interaction would be unlikely. However, as with construction, these are screened in to the assessment on a precautionary basis.
Effect on nearshore sediment transport of seabed rock armouring during operation.	No	High	No	Medium	No other projects have been identified that would cumulatively effect sediment transport due to rock armouring the export cable.

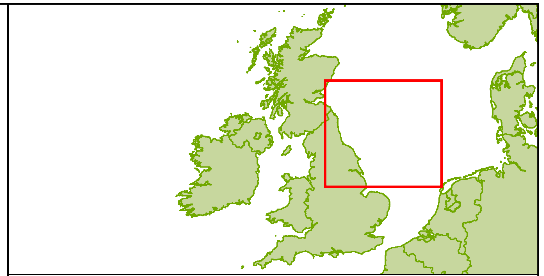
10.1.11 Where the first step has indicated the potential for cumulative effects, the second step in the cumulative assessment for marine physical processes involved the identification of the actual individual plans, projects and activities within those broad industry levels for inclusion in the detailed assessment. 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 'CIA Project List', see **Chapter 4**). The 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.

10.1.12 The plans, projects and activities relevant to marine physical processes are presented in **Table 10.2** and **Figure 10.1**, along with the results of a further screening exercise that identifies whether there is sufficient confidence to take these forward in a detailed cumulative assessment, or whether they can be screened out on account of distance to (i.e. no interaction with) the receptor in question.

10.1.13 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; and
- Existing projects, activities and plans are considered to be a part of the established baseline and are therefore not included in the cumulative assessment.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area
- Dogger Bank Creyke Beck export cable corridor
- Dogger Bank Creyke Beck temporary works area
- Dogger Bank Teesside C & D export cable corridor
- Aggregate application area
- Offshore wind farm
- Breagh pipeline
- Recommended Marine Conservation Zone (NG) & Recommended Reference Area (NG RA)

0 20 40
Kilometres

Data Source:
Breagh pipeline data provided by RWE Dea UK
Designation © Natural England, 2012
UK offshore wind farm & Aggregate areas © The Crown Estate, 2013
European wind farm boundary data supplied by MarineFind, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 10.1 Cumulative effects considered for marine physical processes

VER	DATE	REMARKS	Drawn	Checked
1	21/02/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-440**

SCALE 1:2,500,000 | PLOT SIZE A4 | DATUM WGS84 | PROJECTION UTM31N

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Table 10.2 Cumulative assessment screening for marine physical processes

Type of project	Project title	Project status	Predicted construction and development period	Distance from Dogger Bank Teesside A & B	Confidence in project details	Confidence in project data	Carried forward to cumulative assessment?
Offshore Wind Farm	Dogger Bank Creyke Beck A & B	Pre-application	2016-2027	5km south west of Dogger Bank Teesside B	High	High	Yes
Offshore Wind Farm	Dogger Bank Teesside C & D	Pre-application	2018/19-2029	5km north of Dogger Bank Teesside B	High	Medium	Yes
Offshore Wind Farm	Project One of the Hornsea Zone	Pre-application	2015 on	100km south of Dogger Bank Teesside B	Medium	Medium	Yes
Offshore Wind Farm	Project Two of the Hornsea Zone	Pre-application	2015 on	100km south of Dogger Bank Teesside B	Medium	Medium	Yes
Offshore Wind Farm	Teesside Offshore Windfarm	Construction	2013	4km north of Dogger Bank Teesside A & B Export Cable Corridor	High	High	Yes
Offshore Wind Farm	Blyth Demonstration	Application submitted	2014 on	60km north-north west of Dogger Bank Teesside A & B Export Cable Corridor	High	High	Yes
Offshore Wind Farm	H2-20	Application submitted	Not confirmed	90km north east of Dogger Bank Teesside A	Medium	Medium	Yes
Offshore Wind Farm	Idunn Energipark	Concept / early planning	Not confirmed	140km north-north east of Dogger Bank Teesside A	Medium	Medium	Yes
Offshore Wind Farm	Nord-Ost Passat I, II and III	Concept / early planning	Not confirmed	85km east of Dogger Bank Teesside A	Medium	Medium	Yes
Aggregate License Area	Area 466	Application	Not confirmed	30km west-north west of Dogger Bank Teesside B	High	High	Yes
Aggregate License Area	Area 485 (1 and 2)	Application	Not confirmed	60km south west of Dogger Bank Teesside B	High	High	Yes
Potash Mining	Cleveland Potash	Operational	Ongoing	3km south east of Dogger Bank Teesside A & B Export Cable Corridor	High	High	Yes

10.1.14 Forewind currently has plans to develop four further projects within the Dogger Bank Zone; Dogger Bank Creyke Beck A & B and Dogger Bank Teesside C & D. Project information and boundaries are available for these, shown in **Figure 10.1**.

10.1.15 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 maximum construction period for each project is six years. The worst case scenario from a physical processes perspective would be for all projects to be constructed at the same time. This would provide the greatest opportunity for interaction of waves, tidal currents and sediment transport during construction and operation of all projects.

10.2 Cumulative effects of construction of Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D

10.2.1 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.

10.2.2 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 6. 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 draft 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.

10.2.3 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.

10.3 Cumulative effects of operation of Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D

10.3.1 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.

10.3.2 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.

Predicted cumulative effects of operation of projects on tidal currents

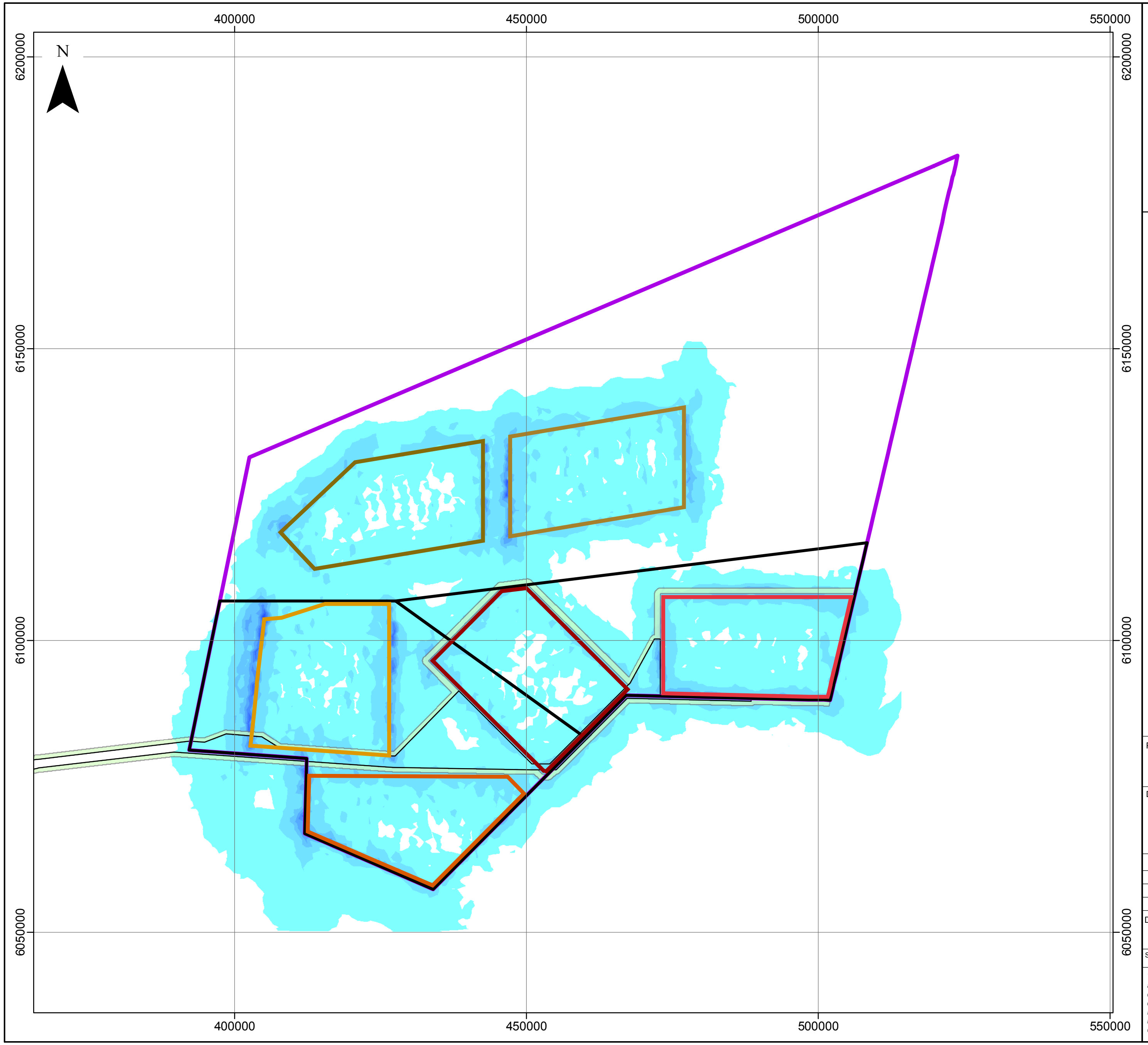
10.3.3 **Figure 10.2** shows the maximum absolute change (increase or decrease) in depth-averaged tidal current velocity over the 30-day simulation period. The strongest effect occurs along the project boundaries where the density of the foundations is highest. The greatest effect is predicted along 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.

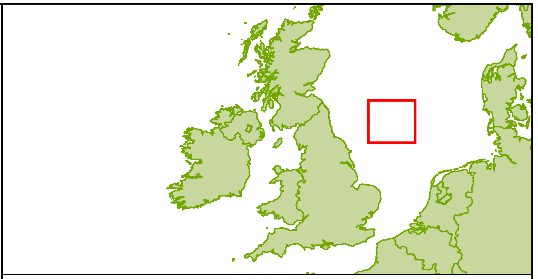
10.3.4 The maximum relative effect is up to approximately 3%, restricted to narrow (up to 2km wide) patches along the western boundaries of Dogger Bank Creyke Beck B and Dogger Bank Teesside D (**Figure 10.3**). This predicted change in tidal current velocities is so small that it is unlikely to affect 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

10.3.5 The same four wave conditions that were used to model Dogger Bank Teesside A & B only (Section 7.3) have been applied in the cumulative wave model runs and their description is not repeated here. Maximum changes in significant wave height are for one-year waves from the north and north east (**Figures 10.4**). For one-year waves from the north the changes are up to +/-0.06m at the southern and northern boundaries 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 north east, changes are up to +/-0.05m at the south western and north eastern boundaries of the projects apart from

Dogger Bank Teesside B and Dogger Bank Teesside C reducing to less than +/- 0.02m up to approximately 65km south west of the Dogger Bank Creyke Beck south west boundaries and north east of the Dogger Bank Teesside D boundary.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area

Change in velocity (m/s)

- Above 0.020
- 0.018 - 0.020
- 0.016 - 0.018
- 0.014 - 0.016
- 0.012 - 0.014
- 0.010 - 0.012
- 0.008 - 0.010
- 0.006 - 0.008
- 0.004 - 0.006
- 0.002 - 0.004
- Below 0.002

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 10.2 Maximum predicted cumulative change in depth-averaged tidal current velocity caused by 6MW conical GBS#1 foundations

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-441**

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

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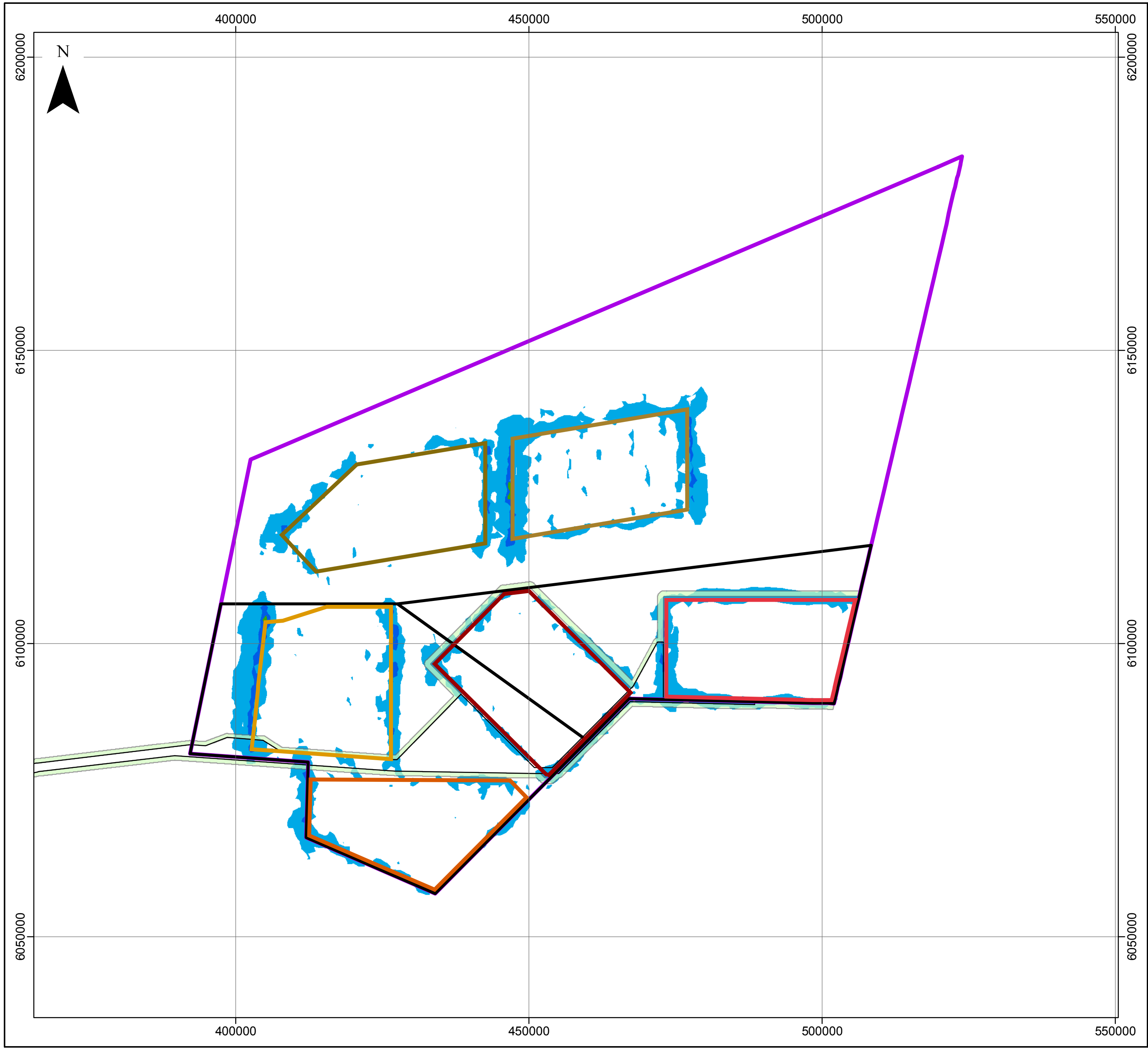
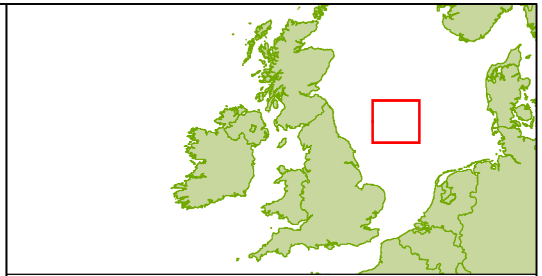




LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area

Change in velocity (%)

- Above 5
- 4 - 5
- 3 - 4
- 2 - 3
- 1 - 2
- Below 1

Data Source:
Modelling © Danish Hydraulic Institute, 2013

0 10 20
Kilometres

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

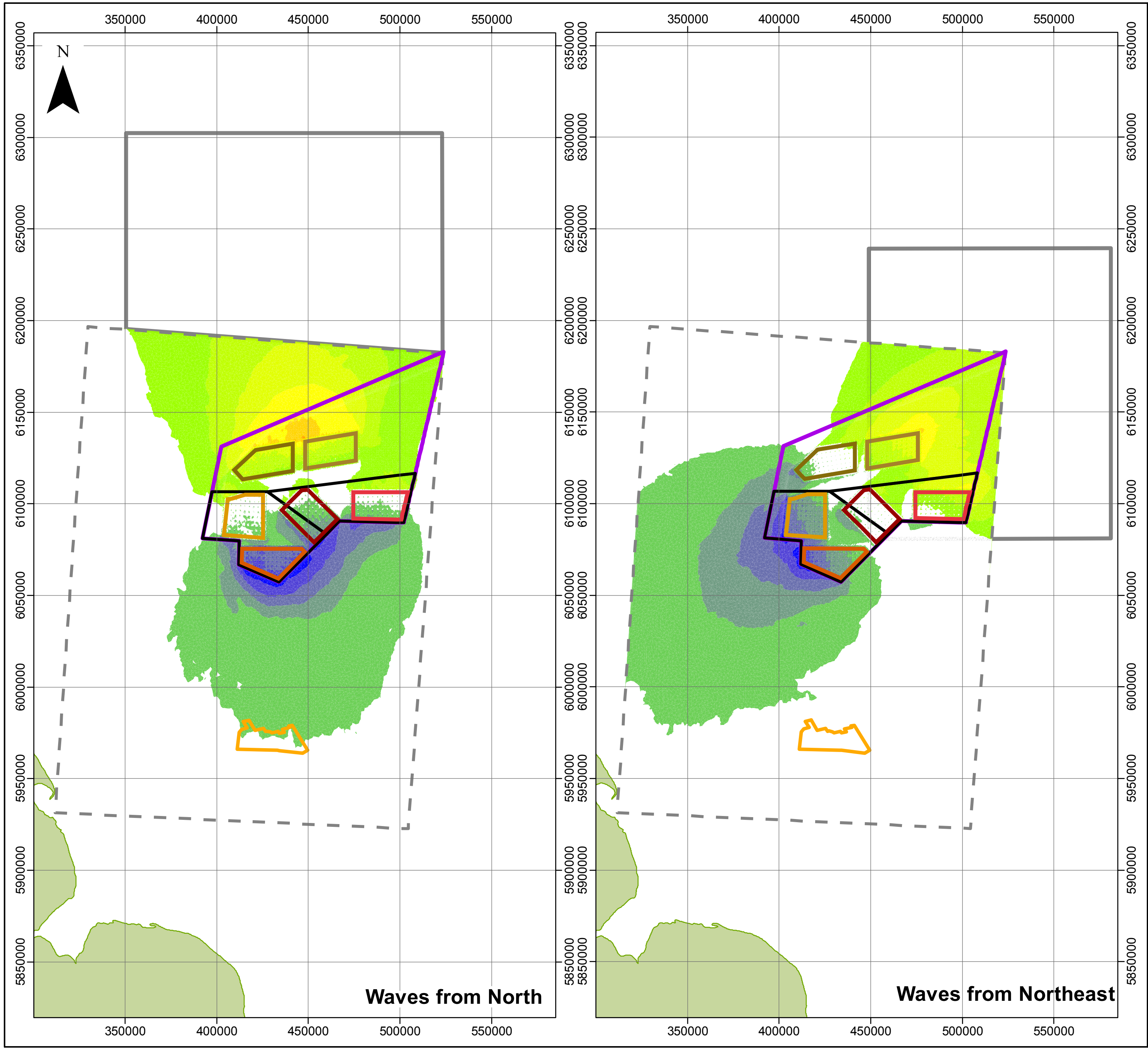
Figure 10.3 Maximum percentage cumulative change in depth-averaged tidal current velocity caused by 6MW conical GBS#1 foundations

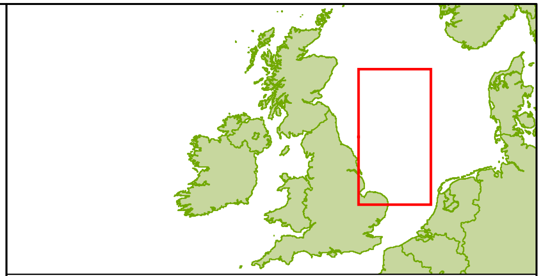
VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-442**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Hornsea Project One
- Model boundary
- Potential extent of wave effects into international waters

Change in significant wave height (m)

- Above 0.09
- 0.08 - 0.09
- 0.07 - 0.08
- 0.06 - 0.07
- 0.05 - 0.06
- 0.04 - 0.05
- 0.03 - 0.04
- 0.02 - 0.03
- 0.01 - 0.02
- 0.00 - 0.01
- -0.01 - 0.00
- -0.02 - -0.01
- -0.03 - -0.02
- -0.04 - -0.03
- -0.05 - -0.04
- -0.06 - -0.05
- -0.07 - -0.06
- -0.08 - -0.07
- -0.09 - -0.08
- Below -0.09

0 30 60
Kilometres

Data Source:
Wave height © Royal HaskoningDHV, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 10.4 Cumulative changes to significant wave height for one-year waves from the north and northeast caused by 6MW conical GBS#1 foundations

VER	DATE	REMARKS	Drawn	Checked
1	26/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-443**

SCALE	1:3,200,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

10.3.6 **Figure 10.5** shows the maximum relative change in wave height for one-year waves from the north and north east directions. The maximum change in significant wave height is approximately up to 1.5% along the southern and south western boundaries of Dogger Bank Creyke Beck A (a band up to 4km or 13km wide, depending on wave direction). Along the northern and north eastern 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.

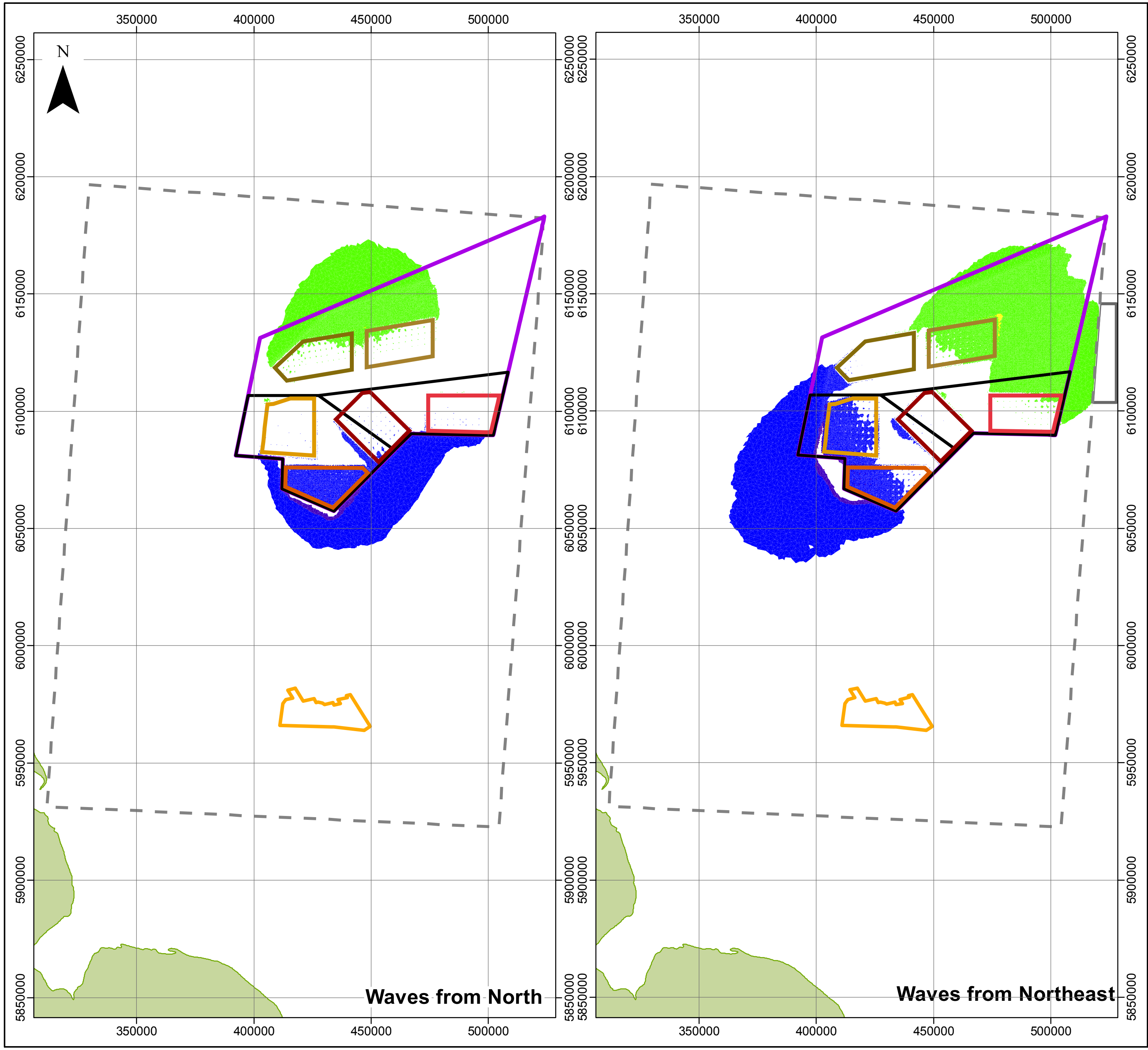
Predicted cumulative suspended sediment concentrations in the bottom layer

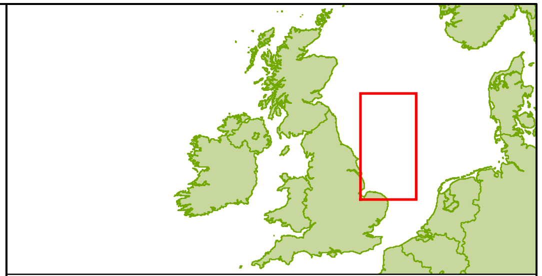
10.3.7 The results of the cumulative plume dispersion modelling of the operational phase are presented as maximum and average changes in suspended sediment concentration in the bottom layer and sediment thickness deposited from the plume. The worst case results are presented for a run of the model during which all foundations (across Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D) (and related infrastructure) are struck by a 50-year storm. **Figures 10.6** to **10.8** show maps of predicted suspended sediment concentration in the bottom layer. The concentrations are presented as excesses over the natural background concentration (2mg/l).

10.3.8 **Figure 10.6** 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 greater than 200mg/l in up to 22km long, 7km wide patches along the boundaries 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.

10.3.9 Predicted average suspended sediment concentrations are between 50mg/l and 100mg/l across the adjacent boundaries of Dogger Bank Creyke Beck A & B (**Figure 10.7**). 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.

10.3.10 **Figure 10.8** 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 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.





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Hornsea Project One
- Model boundary

Wave height difference (%)

- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1.0 - -0.5
- -1.5 - -1.0
- Below - 1.5

0 30 60
Kilometres

Data Source:
Wave height © Royal HaskoningDHV, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

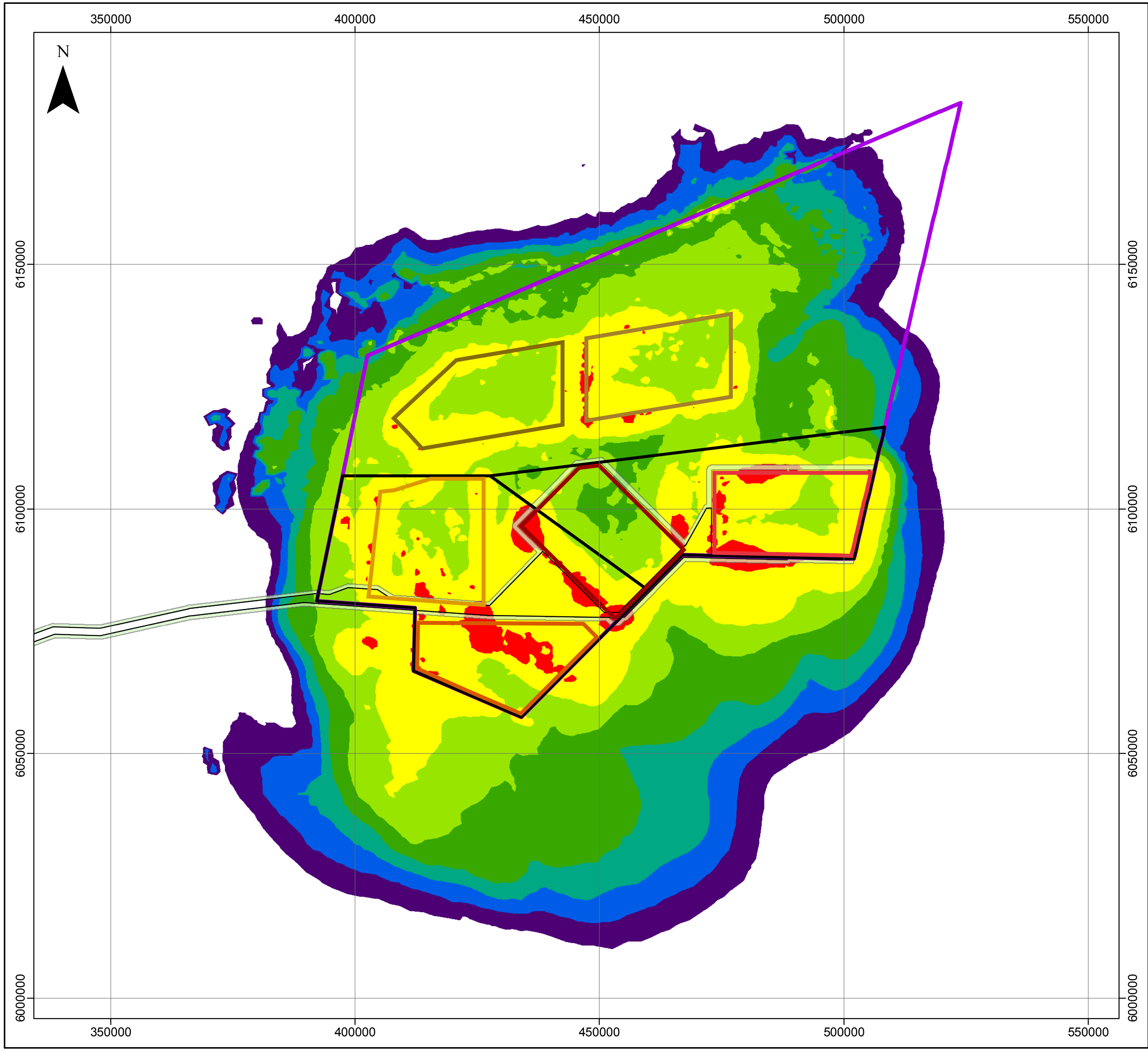
Figure 10.5 Cumulative percentage change to significant wave height for one-year waves from the north and northeast caused by 6MW conical GBS#1 foundations

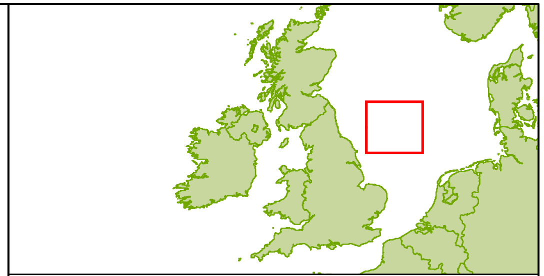
VER	DATE	REMARKS	Drawn	Checked
1	26/06/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-444**

SCALE	1:2,500,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECTION TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

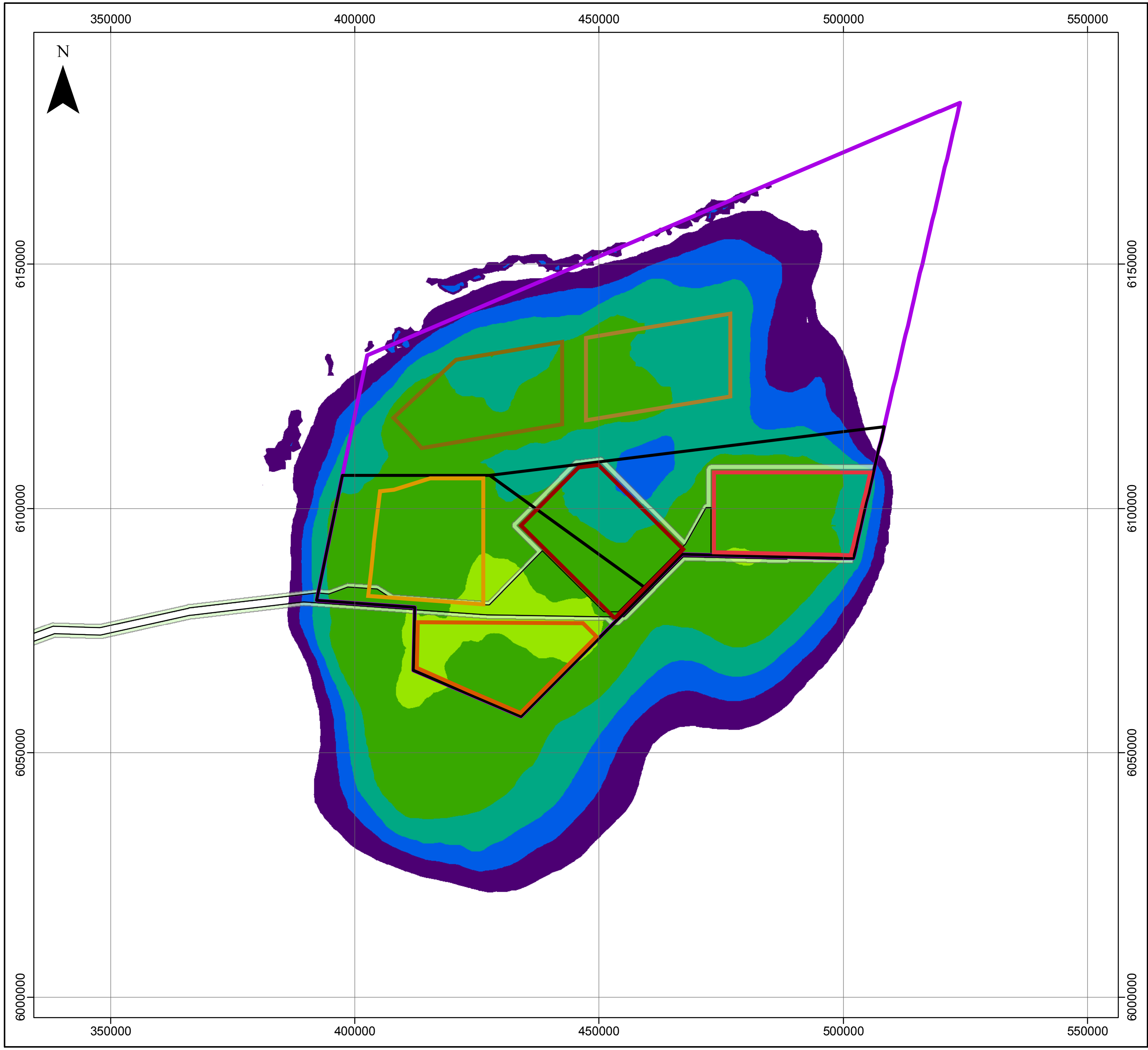
Figure 10.6 Maximum SSC in the bottom layer predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

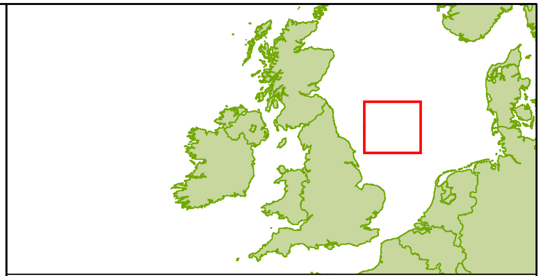
VER	DATE	REMARKS		Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-445**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area

Suspended sediment concentration kg/m³

- Above 0.200
- 0.100 - 0.200
- 0.050 - 0.100
- 0.020 - 0.050
- 0.010 - 0.020
- 0.005 - 0.010
- 0.002 - 0.005
- Below 0.002

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

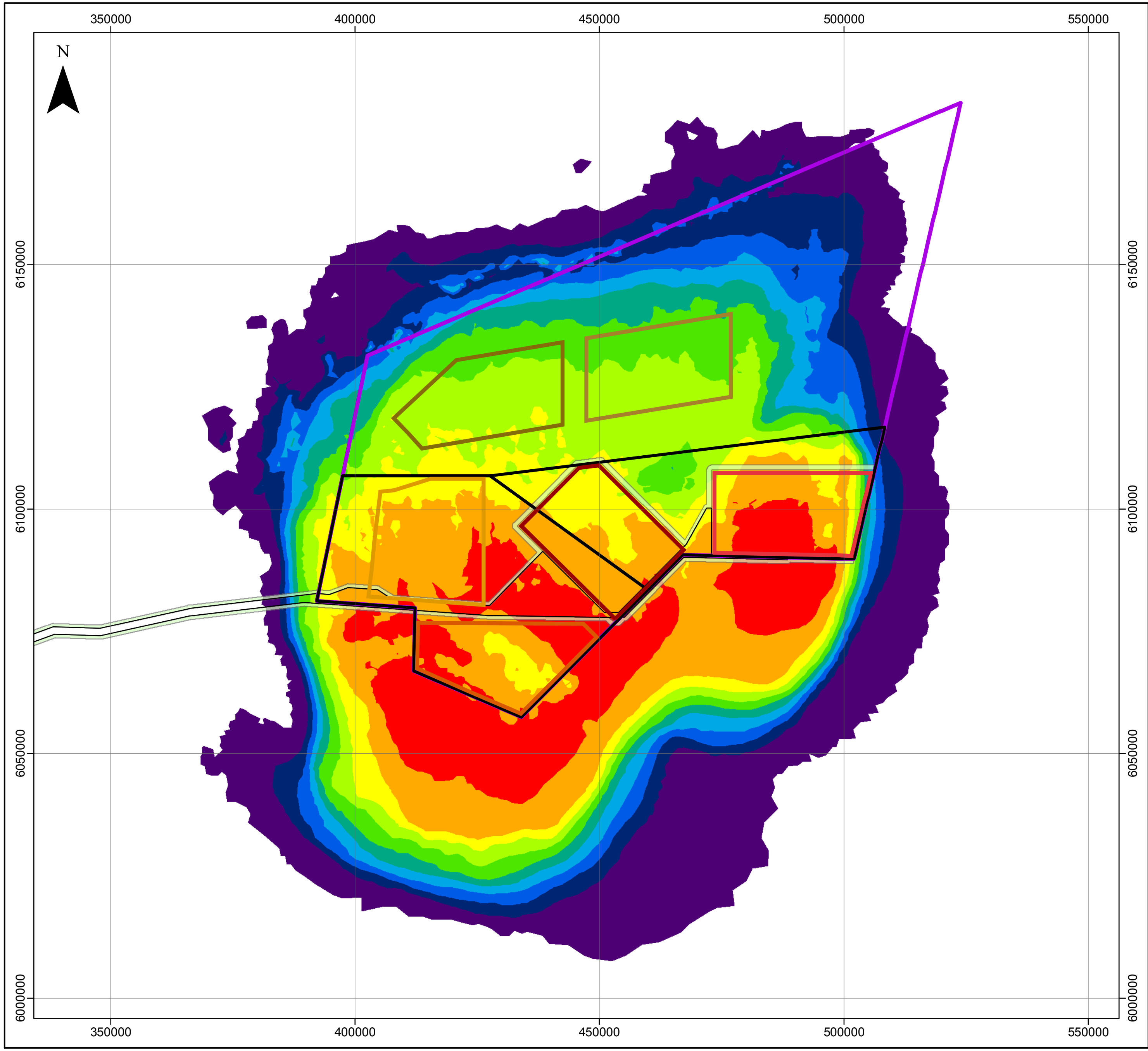
Figure 10.7 Average SSC in the bottom layer predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

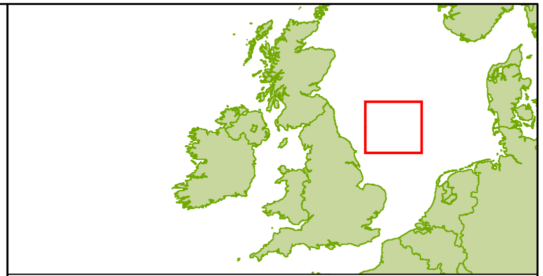
VER	DATE	REMARKS		Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-446**

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

FOREWIND





Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 10.8 Percentage of time predicted over the simulation period where SSC of 2mg/l is exceeded in the bottom layer after two years of operation using the re-suspension of fractions 1 and 2 method

VER	DATE	REMARKS		Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-447**

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

FOREWIND

Predicted cumulative deposition and re-suspension of dispersed sediment

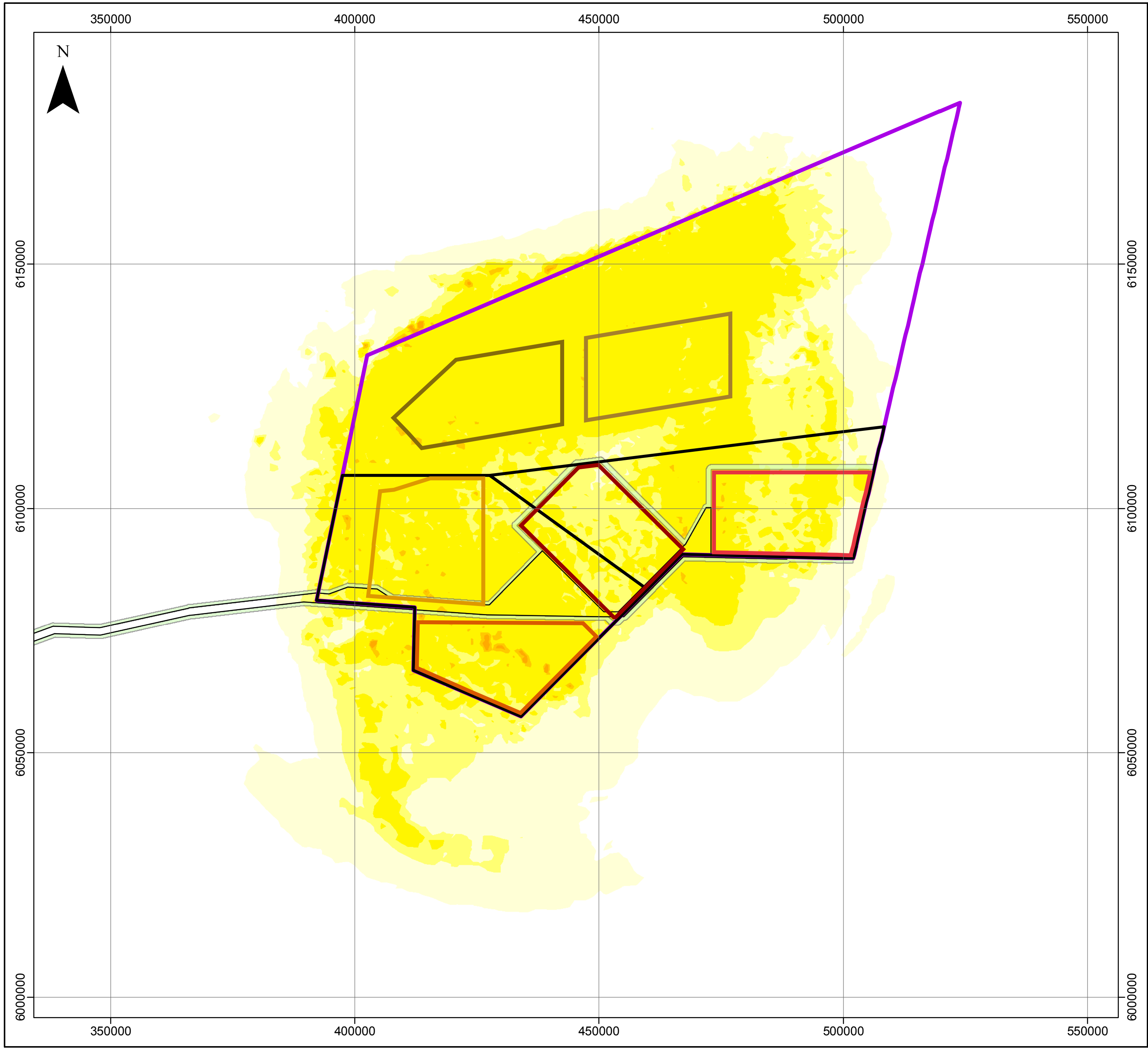
10.3.11 **Figure 10.9** shows the maximum change in deposition predicted at any time over the 30-day simulation period. The majority of the project areas are predicted to have maximum thickness of sediment over the simulation period of 5mm, reducing to 0.1mm about 31-43km from the southern boundaries of the projects and 23-33km from the northern boundaries.

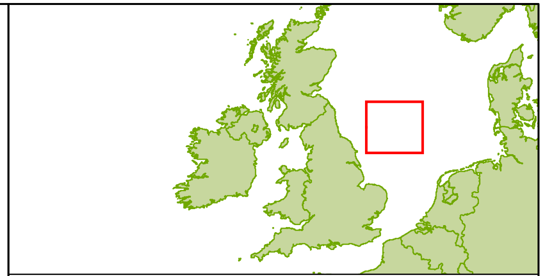
10.3.12 Average deposition is predicted to be 0.1-0.5mm in numerous patches across and outside most of the projects (**Figure 10.10**). The largest patch is up to 22km long and up to 12km wide. Average deposition is generally higher across Dogger Bank Teesside C & D than across the other projects. Average deposition is predicted to reduce to 0.1mm close to the southern boundaries and approximately 12-32km north of the northern boundaries.

10.3.13 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 10.11**) describes the persistency of sediment thickness on the seabed. **Table 10.3** 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 10.3 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)	322 (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





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area

Sediment thickness (m)

- Above 0.1000
- 0.0500 - 0.1000
- 0.0100 - 0.0500
- 0.0050 - 0.0100
- 0.0010 - 0.0050
- 0.0005 - 0.0010
- 0.0001 - 0.0005
- Below 0.0001

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

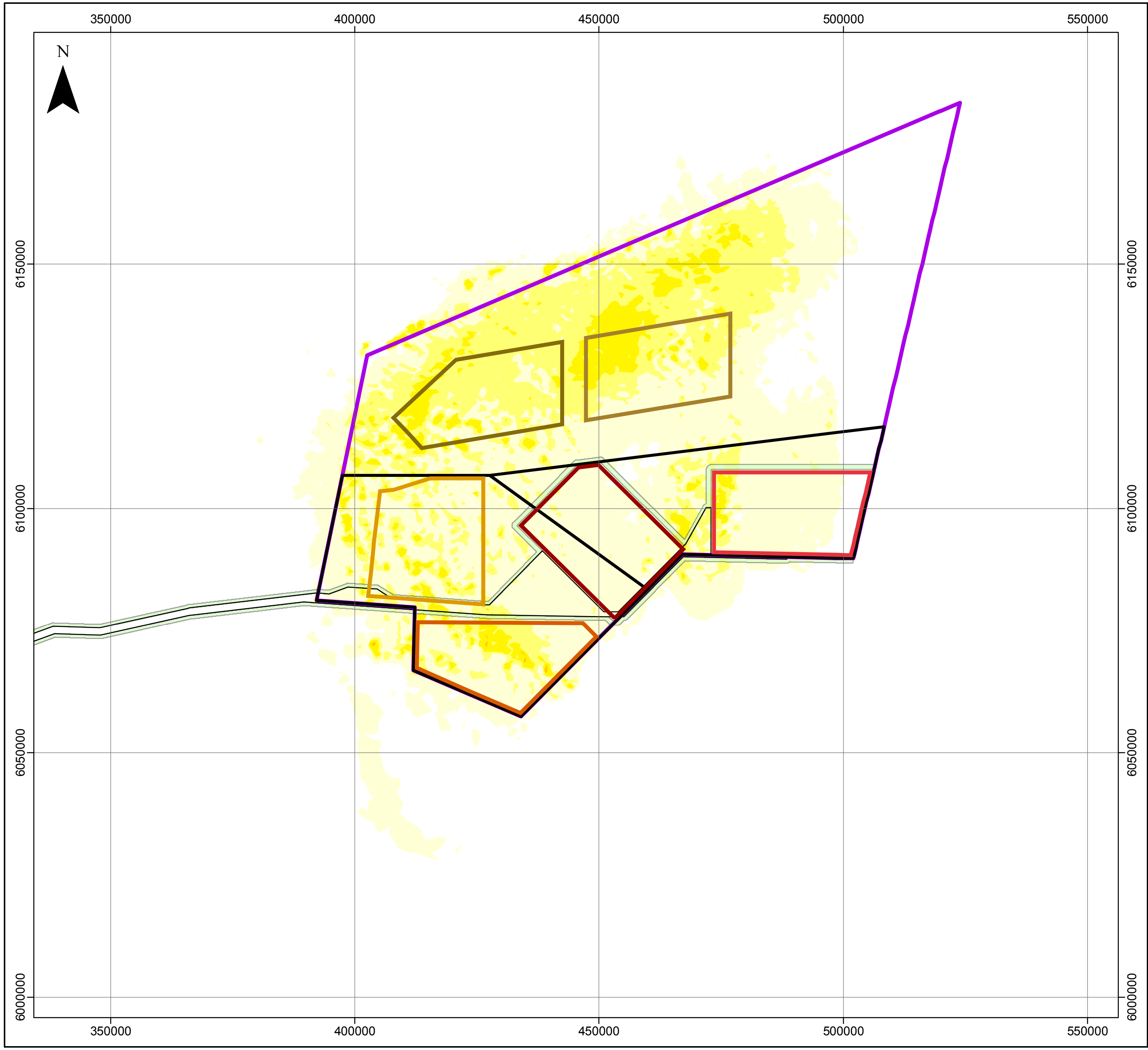
Figure 10.9 Maximum deposition predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

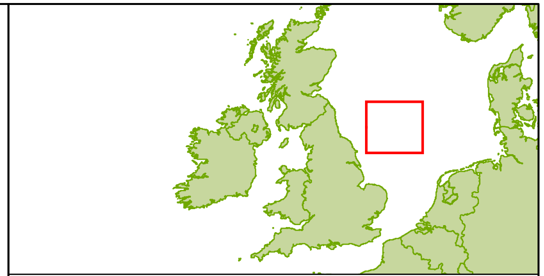
VER	DATE	REMARKS		Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-448**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside A
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area

Sediment thickness (m)

- Above 0.1000
- 0.0500 - 0.1000
- 0.0100 - 0.0500
- 0.0050 - 0.0100
- 0.0010 - 0.0050
- 0.0005 - 0.0010
- 0.0001 - 0.0005
- Below 0.0001

0 10 20
Kilometres

Data Source:
Modelling © Danish Hydraulic Institute, 2013

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

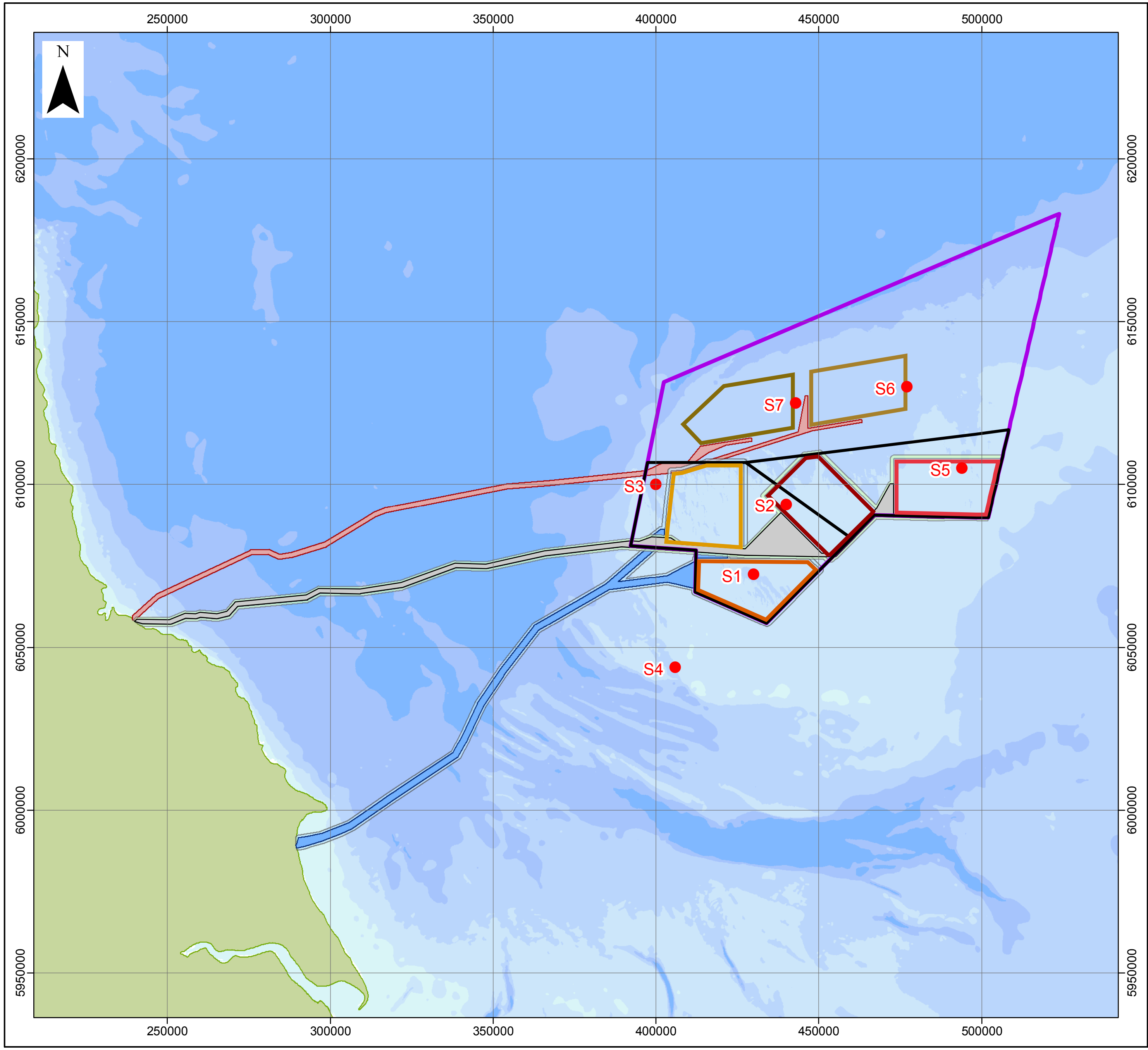
Figure 10.10 Average deposition predicted over the simulation period after two years of operation using the re-suspension of fractions 1 and 2 method

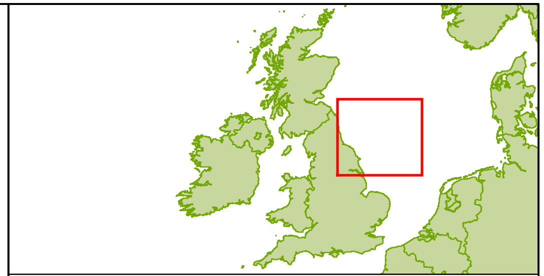
VER	DATE	REMARKS		Checked
1	08/04/2013	Draft	FK	DB
2	08/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-449**

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

FOREWIND





LEGEND

- Dogger Bank Zone
- Tranche boundary
- Dogger Bank Creyke Beck A
- Dogger Bank Creyke Beck B
- Dogger Bank Teesside
- Dogger Bank Teesside B
- Dogger Bank Teesside C
- Dogger Bank Teesside D
- Dogger Bank Teesside A & B export cable corridor
- Dogger Bank Teesside A & B temporary works area
- Dogger Bank Creyke Beck export cable corridor
- Dogger Bank Creyke Beck temporary works area
- Dogger Bank Teesside C & D export cable corridor
- Sediment thickness time series analysis point

0 20 40
Kilometres

Data Source:
Sediment data from Danish Hydraulic Institute, 2012
Round 3 offshore wind farm boundary © Crown Copyright, 2013
Background bathymetry image derived in part from © TCarta data 2009.

PROJECT TITLE

DOGGER BANK TEESSIDE A & B

DRAWING TITLE

Figure 10.11 Location of points for sediment thickness time series analysis for the cumulative operational phase

VER	DATE	REMARKS	Drawn	Checked
1	08/04/2013	Draft	FK	DB
2	07/10/2013	PEI3	LW	DB

DRAWING NUMBER: **F-OFL-MA-450**

SCALE	1:1,800,000	PLOT SIZE	A4	DATUM	WGS84	PROJECTION	UTM31N

FOREWIND

10.4 Cumulative effects with Project One of Hornsea Offshore Wind Farm

10.4.1 The northern boundary of the Hornsea Round 3 Zone is located approximately 75km south of the southern boundary of the Dogger Bank Zone (**Figure 10.1**). 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 Round 3 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.

10.4.2 Smart Wind has recently completed 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.

10.4.3 The offshore cable route will extend from a proposed landfall at Horseshoe Point in Lincolnshire, offshore in a north east 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.

10.4.4 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.

10.4.5 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.

10.4.6 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 with combined Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D construction plume

10.4.7 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 Teesside C & D and Dogger Bank Creyke Beck will overlap with construction of Project One of Hornsea.

Interaction with combined Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D operational plume

10.4.8 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.

10.5 Cumulative effects with Project Two of Hornsea Offshore Wind Farm

10.5.1 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, 2012a) 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.

10.5.2 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.

10.6 Cumulative effects with other UK offshore wind farms

10.6.1 Teesside Offshore Windfarm (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 10.1**) 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.

10.6.2 The construction of the Teesside Offshore Windfarm will be completed before construction/operation of the Dogger Bank projects. Hence, the only cumulative effects would arise from operation of the Teesside Offshore Windfarm. 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.

10.6.3 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 10.1**), each containing five turbines. The turbines would be 1km apart with over 5km spacing between each array.

10.6.4 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 Offshore Windfarm, 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.

10.7 Cumulative effects with German and Norwegian offshore wind farms

10.7.1 H2-20 and Nord-Ost Passat I, II and III offshore wind farms are in the German sector of the North Sea (**Figure 10.1**). 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-north east 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 10.1**) 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.

10.7.2 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.

10.7.3 The worst case cumulative operation plume for Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck A & B is predicted to be mainly confined to UK waters (**Figure 10.6**). 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.

10.8 Cumulative effects with Aggregates Area 466

10.8.1 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 10.1**) 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.

10.8.2 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.

10.8.3 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.

10.8.4 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.

10.8.5 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.

10.8.6 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-south east 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.

10.8.7 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 of Area 466 with combined Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D construction plume

10.8.8 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 north western 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.

10.8.9 The predicted worst case dispersion for a set of 24 foundations in the north west 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 north west over Area 466 (**Figures 6.1** and **6.4**). 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 draft 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.

10.8.10 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.

10.8.11 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 6.1**). 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 of Area 466 with combined Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D operational plume

10.8.12 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 A & B. 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.

10.9 Cumulative effects with Aggregates Area 485

10.9.1 There is also an application for a licence for Area 485 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 10.1**) 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.

10.9.2 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.

10.9.3 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-north west and up to 3km south-south east of the sub-area. At these distances the predicted increases in suspended sediment concentration were approximately 10mg/l or less.

10.9.4 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-north west and up to 4.5km south-south east 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.

10.9.5 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 of Area 485 with combined Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D construction plume

10.9.6 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.

10.9.7 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 of Area 485 with combined Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D operational plume

10.9.8 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.

10.10 Cumulative effects with Potash Mining Outfall Dredge Disposal

10.10.1 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**).

10.10.2 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.

10.10.3 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.

10.10.4 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 Dogger Bank Teesside A & B 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.

10.10.5 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 6.1**). However, this high concentration only translates into deposition on the seabed of less than 5mm (**Figure 6.4**). This is because the exceedance time for concentrations greater than 2mg/l in this area is less than 10% of the simulation period (**Figure 6.3**). 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.

11 Transboundary Effects

11.1.1 This chapter has considered the potential for transboundary effects (effects across international boundaries) to occur on marine physical processes as a result of the construction, operation or decommissioning of Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D.

11.1.2 A summary of the likely transboundary effects of Dogger Bank Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D is provided in **Chapter 32 Transboundary Effects**.

11.1.3 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.

11.1.4 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 10.2** and **10.3**). The effects on waves enter all adjacent international waters (**Figure 10.4**). However, the results show that predicted changes to waves would be of small magnitude in international waters (**Figure 10.5**) with limited secondary effects on sediment transport or seabed morphology.

11.1.5 Cumulative sediment plumes predicted for operation of Dogger Bank Teesside A & B, Dogger Bank Teesside C & D 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.

12 Summary

12.1 Baseline physical processes

12.1.1 This chapter of the draft ES has provided a characterisation of the existing marine physical processes based on both existing and site specific survey data, which has established the following:

- Water depths range from approximately 20m to 78m below LAT within the Dogger Bank Zone, with 25-35m common in Tranche B. Water depths vary along the Dogger Bank Teesside A & B Export Cable Corridor from just above LAT near the coast to 80m at the deepest point. The predominant seabed sediment type across tranches A and B is sand with smaller patches of gravel and areas where the underlying geology is exposed at the seabed. The seabed along the Dogger Bank Teesside A & B Export Cable Corridor is covered mainly by sand.

  Only small proportions of mud in the surface sediments (less than 5%) indicate that the availability of sediment that can be suspended into the water column from the bed is limited. This is supported by regional data suggesting that suspended sediment concentrations across Dogger Bank and along the Dogger Bank Teesside A & B Export Cable Corridor are very low (less than 2mg/l).

- Tidal currents flowing across Dogger Bank are mainly directed north to south and south to north with mean velocities reaching a maximum of 0.40m/s. In places, these relatively weak currents have moulded the surface sediments into sand waves and megaripples. The geometry of these bedforms indicates that they have limited migration leading to the overall conclusion that sediment transport across tranches A and B is small. Measured waves in Tranche A have a mean significant wave height (the average of the highest one third of waves) of 1.7m with a maximum value of 6m.

- Tidal currents flowing across the Dogger Bank Teesside A & B Export Cable Corridor vary from 0.4m/s at the offshore end to 0.20-0.60m/s off the coast at Redcar. There is limited development of sand waves and megaripples along the Dogger Bank Teesside A & B Export Cable Corridor. Where they are present, their crests are oriented north east-south west and their geometry indicates migration and hence sediment transport to the south east. Waves at the offshore end of the corridor have a mean significant wave height of 1.75-2.0m decreasing to less than 1.0m towards the landfall site.

12.2 Assessment of effects

12.2.1 In order to assess the potential effects of the wind farm (including all associated infrastructure), the export cables and the landfall site, relative to baseline (existing) conditions, a combination of detailed numerical modelling, expert geomorphological assessment and empirical evaluation 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, in **Chapter 5**. 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 (**Table 12.1**).

12.2.2 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, inter-platform 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.

12.2.3 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.

12.2.4 For the worst case sediment plume (12m drilled monopoles), 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 export cable route within the Dogger Bank Zone and between approximately 1km and 11km either side of the route. The maximum concentration reduces to background levels up to 40km to the north and up to 40km south of the export cable route within the Dogger Bank Zone. The highest average suspended sediment concentration is predicted to be 50-100mg/l within the confines of the 24 foundations and up to approximately 20km along the export cable route within the Dogger Bank Zone.

12.2.5 Maximum sediment deposition from the plume throughout the 30-day simulation period was predicted to be 10-50mm within a small part of the foundation layout reducing to less than 0.5mm up to a maximum of 35km away from the export cable route within the Dogger Bank Zone. 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 Dogger Bank Teesside A & B Export Cable Corridor, and is effectively zero in places.

12.2.6 Time series of deposition from the plume 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). To the west of the layout (in the vicinity of the sand eel habitat), deposition at any one time throughout the 30-day simulation period rarely exceeds 1mm. The predicted deposition from the plume at the end of the 30-day simulation was less than 0.1mm across the whole of the footprint.

12.2.7 The excavation of the export cable could potentially create maximum suspended sediment concentrations of 100-200mg/l near the coast and about 50km offshore, although the predicted concentrations elsewhere along the cable are generally less than 100mg/l. Maximum concentrations reduce to the background of 2mg/l, up to 50km either side of the corridor. Maximum deposition from the plume along the export cable is predicted not to exceed 0.5mm.

12.2.8 At the coastal landfall site, physical processes have the potential to be affected by the temporary construction of infrastructure. The worst case scenario is considered to be construction, over a continuous period of 14 weeks, of four 10m-long cofferdams across the intertidal (beach) area. These structures offer partial barriers to alongshore sediment transport. The results of expert geomorphological assessment showed that potential alongshore sediment transport rates at Marske-by-the-Sea are low and directed to the south east. Although the coastline to the south east may be affected by cofferdam construction, the change is likely to be low magnitude 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.

12.2.9 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 arrays of foundations spaced 750m apart around their perimeters with a wider internal spacing 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.

12.2.10 The results show predicted changes to both waves and tidal currents would be relatively small. Predicted maximum changes (worst case) in significant wave height were for one-year waves from the north and north east. Significant wave heights change by up to +/-0.04m at the southern, south western, northern and north eastern boundaries of the projects. The predicted pattern is a maximum increase in wave height of 1% along the southern and south western boundaries of Dogger Bank Teesside B. The maximum change to depth-averaged current velocity is predicted to be +/-0.008m/s with the greatest effect occurring at the boundaries of the projects. The maximum change in current velocity is less than 2% along the boundaries of Dogger Bank Teesside A & B. 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.

12.2.11 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 layouts across Dogger Bank Teesside A & B that were used for wave and tidal current modelling. The worst case for plume dispersion would occur when all the foundations are operational and subject to a 30-day simulation including a larger 50-year storm.

12.2.12 The maximum concentration was predicted to increase to greater than 200mg/l in patches along the northern and southern boundaries of Dogger Bank Teesside A and the south western boundary of Dogger Bank Teesside B. 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 projects southern boundaries. The highest average concentrations were 10-50mg/l within the projects and up to 19km to their south.

12.2.13 Maximum deposition of 5mm occurs, but more generally across each project, maximum deposition was 0.5-5mm. Thicknesses reduce to below 0.1mm up to a maximum of 35km from the project boundaries. Average deposition is predicted to be 0.5-5mm between the projects. Average deposition reduces to less than 0.1mm approximately 23km south west of Dogger Bank Teesside B and 19km north of Dogger Bank Teesside A.

12.2.14 Time series of deposition from the plume at several points show that the thickness may exceed 1mm continuously for up to 72 hours (3.00 days) and never exceeds 3mm. The predicted deposition from the plume at the end of the 30-day simulation period was less than 0.1mm across all of the depositional area.

12.2.15 A comparison of operational scour volumes with naturally occurring release of sediment during a 50-year storm shows that predicted scour volumes are about a sixth of the volume that would be suspended during a 50-year storm without the foundations in place.

12.2.16 In the nearshore, remedial protection is anticipated to be up to about 15m wide and stand 1.3m 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.

12.2.17 The cumulative effect of operation of Dogger Bank Teesside A & B, Dogger Bank Teesside C & D and Dogger Bank Creyke Beck on tidal currents, waves and/or sediment transport have been assessed. The worst case scenario was determined to be arrays of foundations spaced 750m apart around their perimeters with a wider internal spacing including platforms, meteorological masts and vessel moorings.

12.2.18 The results show predicted cumulative changes to both waves and tidal currents would be relatively small. Significant wave heights change by up to +/-0.06m at the southern, south western, northern and north eastern boundaries of the projects. The predicted pattern is a maximum increase in wave height of 1.5% along the southern and south western boundaries of Dogger Bank Creyke Beck A. Along the northern and north eastern boundaries, predicted changes are mainly up to 1%. The maximum change to depth-averaged current velocity is predicted to be +/-0.01m/s with the greatest effect along the western boundaries of Dogger Bank Creyke Beck B and Dogger Bank Teesside D. The maximum change in current velocity is approximately 3% along the western boundaries of Dogger Bank Creyke Beck B and Dogger Bank Teesside D. These percentage changes are within the natural variation of wave height and tidal current velocity across Dogger Bank and surrounding sea areas and are unlikely to affect the form of recent sediments over and above the natural processes.

12.2.19 The maximum cumulative suspended sediment concentration was predicted to be greater than 200mg/l along the boundaries of the projects (apart from the boundary of Dogger Bank Teesside C). Across all projects, maximum suspended sediment concentrations were greater than 50mg/l reducing to background levels up to approximately 55km from the projects southern boundaries. The highest average concentrations were 50-100mg/l across the boundaries of Dogger Bank Creyke Beck A & B.

12.2.20 Maximum deposition of 5mm occurs reducing to 0.1mm up to a maximum of 43km from the project boundaries. Average deposition is predicted to be 0.1-0.5mm and is generally higher across Dogger Bank Teesside C & D than across the other projects.

12.2.21 Time series of deposition from the plume at several points show that the thickness may exceed 3mm continuously for up to 244 hours (10.17 days) at isolated points. In general, thicknesses rarely exceed 2mm and persist at greater than 1mm between 2 hours (0.08 days) and 80 hours (3.33 days). The predicted deposition from the plume at the end of the 30-day simulation period was less than 0.1mm across most of the depositional area.

12.2.22 Cumulative effects 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 Teesside A & B, Dogger Bank Creyke Beck and Dogger Bank Teesside C & D plumes. Plumes from aggregate dredging areas and potash mining dredge disposal would be small and short-lived in comparison and no cumulative effects are anticipated.

Table 12.1 Summary of predicted effects of Dogger Bank Teesside A & B on marine physical processes

Effect	Metric	Value	Key distance
Construction			
Increased suspended sediment concentrations	Maximum suspended sediment concentration	>200mg/l	Up to 11km from source of sediment plume
		2mg/l (baseline)	Up to 40km from source of sediment plume
	Average suspended sediment concentration	50-100mg/l	Up to 9km from source of sediment plume
		2mg/l (baseline)	Up to 32km from source of sediment plume
Sediment deposition from plume	Maximum deposition	10-50mm	Within worst case foundation layout
		<0.5mm	Up to 35km from source of sediment plume
	Average deposition	1-5mm	Up to 10km from source of sediment plume
		0.5mm	Up to 30km from source of sediment plume
Operation			
Changes to waves	Wave Height	+/-0.04m	At the boundaries of the projects
Changes to tidal currents	Current Velocity	+/-0.008m/s	At the boundaries of the projects
Increased suspended sediment concentrations	Maximum suspended sediment concentration	>200mg/l	At the boundaries of the projects
		2mg/l (baseline)	Up to 54km from source of sediment plume (measured from project boundary)
	Average suspended sediment concentration	10-50mg/l	Up to 19km from source of sediment plume (measured from project boundary)
		2mg/l (baseline)	Up to 36km from source of sediment plume (measured from project boundary)
Sediment deposition from plume	Maximum deposition	0.5-5mm	Within the boundaries of the projects
		0.1mm	Up to 35km from source of sediment plume (measured from project boundary)
	Average deposition	0.5-5mm	Between the projects
		0.1mm	Up to 23km from source of sediment plume (measured from project boundary)

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