European Offshore Wind Deployment Centre

Environmental Statement

Appendix 8.2: Coastal Processes EIA Technical Report

A project part-funded by the European Union under the European Economic Plan for Recovery in the field of Energy

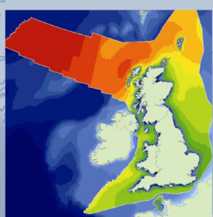
Aberdeen Offshore Wind Farm Limited

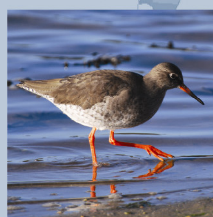
European Offshore Wind Deployment Centre: Coastal Processes Assessment Report

Report R.1789

June 2011

Creating sustainable solutions for the marine environment

Aberdeen Offshore Wind Farm Limited

European Offshore Wind Deployment Centre: Coastal Processes Assessment Report

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Summary

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by Aberdeen Offshore Wind Farm Limited (AOWFL) to undertake a coastal process study for the proposed European Offshore Wind Deployment Centre (EOWDC). The proposed EOWDC site, consisting of 11 turbines, is within Aberdeen Bay.

This report follows the baseline assessment report (ABPmer, 2011) and provides an assessment of the potential impacts of the proposed EOWDC development upon existing coastal processes. In order to assess the potential effects relative to the baseline (existing) coastal environment, a combination of qualitative assessment of site data, empirical evaluation and detailed numerical modelling has been used to establish the potential magnitude and significance of the predicted changes. These effects have been assessed using the 'worst-case' characteristics of the proposed development as provided by AOWFL.

Considerations of the proposed impacts upon the tide and wave regimes have been made and the subsequent effects upon a series of receptors determined. These receptors include the offshore sediment transport pathways, offshore seabed morphology and littoral sediment transport pathways. Comment has also been made to address relevant concerns raised by consultees. It is shown that the majority of potential impacts can be considered to be of negligible significance. Exceptions are scour development, short-term changes to suspended sediment concentrations and subsequent localised deposition, and slight changes in the coastal response to naturally occurring storm events, which are all considered to be of minor significance.

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1. Introduction

The European Offshore Wind Deployment Centre (EOWDC) is located within Aberdeen Bay and has an associated Lease Boundary area of 20km^2. The development comprises 11 turbines, with an installed capacity of between 4 and 10MW per turbine. There is also the potential for an Ocean Laboratory to be installed on the site, however this would be subject to a separate planning application. The project site has a relatively uniform seabed profile ranging in depth from, approximately, 10m to 35m Chart Datum (CD).

An integral part in the determination of the potential impact of the proposed project upon the existing environment is the assessment of its interaction with the coastal process regime. The purpose of the coastal processes study is to demonstrate a sufficiently robust understanding of the potential interaction of the wind farm development on wave, tidal and sediment regimes, to assess any direct, indirect and cumulative impacts. It also makes suggestions for mitigation and monitoring requirements where appropriate. This report follows the baseline assessment (ABPmer, 2011) and provides an assessment of the potential impacts of the EOWDC development upon existing coastal processes. The baseline assessment and impact assessment reports together form the coastal processes study and the findings of this work have been summarised in the Environmental Statement (ES) chapter. It should be noted that this study is not intended to directly inform the engineering or design of the project structures.

1.1 Information for the Non-Technical Summary

This report follows the baseline assessment report (ABPmer, 2011) and provides an assessment of the potential impacts of the proposed EOWDC development within Aberdeen Bay upon existing coastal processes. In order to assess the potential effects of EOWDC relative to the baseline (existing) coastal environment, a combination of qualitative assessment of site data, empirical evaluation and detailed numerical modelling has been used to establish the potential magnitude and extent of the predicted changes. These effects have been assessed using the 'worst-case' characteristics of the proposed development, as provided by the project.

Considerations of the proposed impacts upon the tide and wave regimes have been made and the subsequent effects upon a series of receptors determined. These receptors include the offshore sediment transport pathways, offshore seabed morphology and littoral sediment transport pathways. Comment has also been made to address relevant concerns raised by consultees. It is shown that the majority of potential impacts can be considered of negligible significance. Exceptions are scour development, short-term changes to suspended sediment concentrations and subsequent localised deposition, and slight changes in the coastal response to naturally occurring storm events, which are all considered to be of minor significance.

1.2 Methodology Consultation

The scope of coastal process investigations responds to the issues raised as a result of the consultation of the Environmental Impact Assessment (EIA) Scoping Report (AOWFL, 2010). Currently, responses from four organisations have been provided to ABPmer, of which all have concerns relevant to coastal process issues. These are presented in full in ABPmer, 2011. In addition to the responses received for the EOWDC, scoping opinions were also supplied as part of the original proposed Aberdeen Offshore Wind Farm (AOWF) development in response to the scoping report published in 2005 (AOWFL, 2005). Six organisations had concerns relevant to coastal process issues. The full list of organisations whom submitted responses relevant to the current development in response to the 2010 Scoping Document (AOWFL, 2010) is:

- Aberdeen Harbour Board;
- Scottish Natural Heritage (SNH);
- Scottish Environmental Protection Agency (SEPA); and
- Marine Scotland.

1.3 Key Guidance Documents

Guidance on the generic requirements, including spatial and temporal scales for coastal process studies is provided in six main documents:

- 'Offshore wind farms: guidance note for Environmental Impact Assessment in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) requirements: Version 2' (Department for Environment, Food and Rural Affairs (Defra), Centre for Environment, Fisheries and Aquaculture Science (Cefas) and Department for Transport (DfT), 2004);

- 'Guidance on Environmental Impact Assessment in Relation to Dredging Applications' (Office of the Deputy Prime Minister, 2001);

- 'Nature Conservation Guidance on Offshore Wind Farm Development' (Defra, 2005);

- 'Marine Renewable Energy and the Natural Heritage: An Overview and Policy Statement' (Scottish Natural Heritage, 2003);

- 'Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment' (COWRIE, 2009); and

- Consenting, EIA and HRA Guidance for Marine Renewable Energy Deployments in Scotland' (EMEC & Xodus AURORA, 2010).

1.4 Data, Information and Sources

A large amount of data has been considered as part of the EIA process, the main sources of data and information are summarised as follows, for further details on these data sources the reader is referred to the baseline document (ABPmer, 2011).

Data Sources:

- Five months of metocean survey between 12 September and 13 February 2008 (Emu, 2008a);

- Geophysical surveys covering the original study area (Emu, 2008b) and the EOWDC site (Osiris, 2010);

- Geotechnical review of existing borehole information (Setech, 2009);

- Grab samples of surficial sediments covering the previous site collected by the Fisheries Research Services (FRS) (Titan, 2008), covering the EOWDC site collected in 2010 by the Centre for Marine and Coastal Studies (CMACS Ltd) and covering the intertidal are adjacent to the EOWDC (ABPmer, 2011);

- Beach profiles collected by ABPmer (ABPmer, 2011); and

- Water level data collected in Aberdeen Harbour by the British Oceanographic Data Centre's (BODC) National Tide and Sea Level Facility (NTSLF) between 1980 and 2005.

Reports from other previous work have also been compiled that describe various aspects of the study area, the principal studies are summarised below:

- Aberdeen Bay Coastal Protection Study (Halcrow Crouch Ltd, 1999);
- Coastal Cells in Scotland, Cell 2 (HR Wallingford, 2000);
- Coastal processes and management of Scottish estuaries, The Dee, Don and Ythan Estuaries (Stapleton & Pethick, 1996);
- Beaches of Northeast Scotland (Ritchie *et al*, 1977); and
- SEA 5 (DTI, 2005).

1.5 Coastal Process Regimes

The coastal process regimes considered as part of the Environmental Statement (ES) are:

- *Hydrodynamic regime:* tides, waves and currents;
- *Sediment regime:* seabed sediment distribution, bedload and suspended load transport; and
- *Morphodynamic regime:* form and function of both the coast and offshore, the morphodynamic regime is defined as a response to both the hydrodynamic and sediment regime.

These regimes can be considered in the context of the source–pathway–receptor model as the:

- Foundation structure and support column being considered as the *source* of a potential effect on the waves or tides;
- Interaction of the waves and tides acting as the *pathway* for transporting sediment; and
- *Receptor* being a feature identified as being potentially sensitive to any change in sediment movements, for example the coast.

Therefore, significance levels have only been assigned to potential changes to the receptors. In order to provide some distinction within this document, changes to the pathways are classified as 'effects' and changes to the receptors as 'impacts'.

1.6 Spatial Scales

A consideration of these regimes is required over the following spatial scales:

- Near-field (i.e. the area within the immediate vicinity of the turbine grid and along the indicative cable route); and
- Far-field (i.e. the wider coastal environment over which effects could potentially occur).

1.7 Temporal Scales

There are four main phases of development that require consideration in the coastal process assessment. These are:

- Baseline (including pre-construction);
- Construction phase;
- Operation; and
- Decommissioning.

A brief description of each phase is summarised in the following sub-sections.

1.7.1 Baseline

The baseline, or pre-construction, phase considers the coastal processes prior to any construction works. The investigation of this phase is relevant as it provides a condition to which the coastal processes during all other phases can be compared. It should be noted that any changes to the coastal processes within the lifetime of the array due to natural variability (i.e. storm events) and climate change (i.e. sea level rise) will also be compared to this phase.

The pre-construction phase forms the baseline which has been discussed within the Baseline Technical Report (ABPmer, 2011).

1.7.2 Construction

Tidal and Wave Regimes

Impacts upon the hydrodynamic regime, as a consequence of the construction phase, are typically most likely to be associated with the presence of engineering equipment, for example, jack-up barges placed temporarily on site to install the turbine structures. As it is likely that such equipment will be positioned at one site at a time for a relatively short duration (of the order of days), the consequential effects upon the hydrodynamic regime is deemed to be small in magnitude and localised over both temporal and spatial scales.

In addition, it is likely that operations will be undertaken during relatively benign metocean conditions.

Sedimentological Regime

It is during the construction phase that there is the potential for the greatest impact upon suspended sediment concentrations (SSC) and consequential sediment deposition is anticipated. However, it is expected that this impact will be short-lived (order of days) during the construction period for each foundation. The effects could be as a consequence of material released during the:

- Installation of the structures; and/or
- Cable laying process.

To further investigate the potential impacts due to these activities, a plume dispersion model has been used. This model is able to simulate the spatial and temporal distribution of suspended substances discharged into coastal areas or open seas, using the flow conditions provided by the hydrodynamic model.

Effects may also result from the positioning of construction equipment, such as jack-up rigs and barges. These will only be temporary in position for each foundation during the construction period. The effects are most likely to be observed as seabed indentations. Subsequent seabed recovery will be primarily dependent upon sediment availability for the infilling of these indentations.

1.7.3 Operation

The lease area covers an area of approximately 20km^2 within which it is currently planned to construct 11 turbines.

Tidal Regime

It is the effects during the operational phase that have the potential to be both larger in magnitude and may exist over the extent of the array over both the near and far-fields. In addition, the effects could last over greater temporal scales. Potential changes may occur to the water levels, current speeds and directions. Impacts during this phase have been investigated further with numerical modelling techniques.

Wave Regime

It is the effects during the operational phase that are likely to have greater effects upon the wave regime, both in the near and far-fields. The parameters of the wave climate that may undergo change are the wave heights, periods and directions. The potential effects during this phase have been assessed using numerical modelling techniques.

Sedimentological Regime

Effects upon the sediment regime during the operational phase may occur through:

- The alteration of suspended and/or bed load sediment transport pathways within both the near and far-fields;
- As scour around the turbine foundations and/or the cables, with the potential for material to be transported away from the development location; and
- Changes to the littoral drift processes along the coastline.

The potential effects during this phase have been assessed using parametric and numerical modelling techniques.

1.7.4 Decommissioning

Specific details of the decommissioning phase are to be presented in the decommissioning plan. It is expected that on expiry of the lease the developer will remove turbine structures and return the seabed to a usable state, in accordance with Department of Energy and Climate Change decommissioning guidelines (DECC, 2011).

Tidal and Wave Regimes

It is assumed that the decommissioning phase will involve the removal of any structures related to the wind farm development. Therefore, impacts upon the tidal and wave regimes as a consequence of this phase will be comparable to those identified for the construction phase, and thus no significant post-decommissioning impacts are anticipated.

Sedimentological Regime

The effects upon the sedimentological regime during the decommissioning phase are anticipated to be comparable to those of the commissioning phase.

1.8 Impact Methodology

Numerical models from the Danish Hydraulics Institute (DHI) have been applied to assess the effects of the potential development upon the existing coastal processes over two spatial scales identified in ABPmer (2011), allowing the following different effects to be determined:

- Near-field. The model has been used to determine the potential effects of the entire development upon the existing coastal processes within the wind turbine array, with the objective of illustrating that multiple devices act independently to each other; and

- Far-field. The model was used to illustrate any consequences to the physical environment that exist outside the development site, including any potential impacts upon the shoreline. Cumulative and in-combination effects, as summarised in Section 1.5, have also been assessed at this scale.

The selection of modules used is used to simulate each regime is as follows:

- Mike FM HD: Hydrodynamics;
- Mike FM SW: Spectral Waves;
- Mike 21 PT: Particle Tracking; and
- Mike 21 ST: Sand Transport.

In addition, the software programme XBeach has been used to determine potential changes to the beach morphology and nearshore (littoral) regime.

To assess the potential for localised scour around the turbine foundations, a combination of site information and model outputs have been used to derive inputs to suitable empirical methods.

1.8.1 Assessment of Significance

When assigning significance to an impact, the methodology can be summarised as follows:

- The **magnitude of the effect** (Table 1) is based on a combination of the spatial extent, the duration and the scale of the effect;

- The **sensitivity of the receptor** is based on a combination of the recoverability of the receptor and the importance of the receptor and based on this is given a value of very high, high, medium or low.

This document presents the impacts upon both pathways (tidal and wave regimes), in addition to receptors (for example the coastal environment).

Using a combination of these criteria (Table 2), impacts can be assigned a rating of major, moderate, minor or negligible. It is important to note that this approach assumes a negative impact and that some impacts might have positive implications.

Table 1. Outline criteria for assessing the magnitude of the effect

Rating	Spatial Extent Criteria	Duration Criteria	Scale Criteria
Very High	National/International	>10 years	Very high level of change compared to background
High	Regional	5–10 years	High level of change compared to background
Medium	Local (<5km)	1–5 years	Medium level of change compared to background
Low	Site specific	<1 year	Low level of change compared to background
Negligible	Restricted to the immediate vicinity	Negligible	Negligible level of change compared to background

(Adapted from: AOWFL, 2010)

Table 2. Matrix used to assign level of significance

Magnitude of Effect (Based on Combination of Criteria in Table 1)	Sensitivity of Receptor			
	Very High	High	Medium	Low
Very High	Major	Major	Major	Moderate
High	Major	Major	Moderate	Minor
Medium	Major	Moderate	Moderate	Minor
Low	Moderate	Minor	Minor	Negligible
Negligible	Minor	Negligible	Negligible	Negligible

(Adapted from: AOWFL, 2010)

1.8.2 Implications of Significance

Where the significance (as determined using the methodology detailed above) is classed as moderate to major or major this is considered to be a potentially significant effect. It should be noted that significant effects may not be unacceptable or reversible and suitable mitigation methods could be considered to lessen the impact.

1.9 Cumulative and In-combination Impact Assessment Methodology

For the purposes of this assessment cumulative and in-combination impacts are defined as follows (AOWFL, 2010):

- The cumulative assessment will address where predicted impacts of construction and operation could interact with impacts from other industry sectors within the same region and impact sensitive receptors; and
- The term in-combination refers to impacts of the proposals with other plans or projects on European sites.

The potential for cumulative and in-combination impacts was assessed in detail in the baseline report (ABPmer, 2011) and is summarised in the following sections.

1.10 Worst-case

The development scenario considered during the impact assessment has been developed based on a 'worst-case' as opposed to the 'realistic worst-case'.

It is proposed that the EOWDC will be developed with 11 turbine structures. The required infrastructure presently includes seabed installation of the items listed below:

- Foundation units;
- Turbine support columns; and
- Cabling (inter-array network of cables and main export cable(s) to shore).

1.10.1 Foundation Type

The definition of a 'worst-case' will vary depending on the element of the coastal processes regime being considered. For example the greatest impact on hydrodynamics will occur as a result of the greatest blocking effect (the largest foundation type) and the greatest impact on sediment dispersal will depend on the amount of seabed preparation required. A number of different foundation options are being considered at the EOWDC, these are summarised in Table 3 based on information supplied by the project. Based on these descriptions it is then possible to determine the 'worst-case' scenario with respect to each physical process, these conclusions are summarised for each foundation scenario in Table 3 and show that:

- The monopile disturbs the greatest sediment volume and therefore represents the 'worst-case' in terms of the mobilisation of sediment plumes; and
- The gravity base has the largest footprint and area and therefore represents the 'worst-case' in terms of blockage on hydrodynamics (waves and tides) and any consequential impacts on sediment transport and morphology.

Table 3. Summary of foundation types considered at EOWDC

Type	Description	Resultant Volume of Sediment Disturbed During Installation (m^3)	Resultant Footprint of Foundation in Contact with Seabed (m^2)	Summary
Monopile	Single pile driven/drilled into seabed with a diameter of 8.5m and a maximum depth of 37m.	2,100	57	Worst case in terms of sediment disturbance. Turbine type considered in the sediment spill analysis during foundation installation.
Jacket on Piles	Typically a lattice structure comprising tubular sections of maximum diameter 1.2m. Four piles with a diameter of 2.5m each hold the structure in place which are driven/drilled to a depth of 35m. The foundation will measure 25 x 25m at its base.	687	20	Moderate sediment volume released and moderate footprint size, therefore not considered in modelling assessments.
Tripod on Piles	Main column (diameter of 5.5m) with three diagonal braces (maximum diameter of 4m each). Structure is held in place by Three piles (or suction caissons) measuring 2.5m in diameter which are driven/drilled up to 35m into the seabed. The total foundation diameter is 25m.	515	15	Moderate sediment volume released and moderate footprint size, therefore not considered in modelling assessments.
Gravity Base	Foundation rests on seabed which involves some preparation to flatten the bed down to an estimated depth of 0.5m. Maximum diameter is 6.5m until 10m below Lowest Astronomical Tide (LAT). The base of the foundation has a diameter of 40m.	628	1,257	Largest footprint and therefore represents greatest blocking affect on hydrodynamics so considered during the wave and tidal assessments.
Suction Caisson/Bucket	Watertight hollow foundation which is placed on the seabed, water is then pumped out of the foundation creating a pressure differential causing further penetration into the seabed up to a depth of 18m depending on the soil conditions. The tower section has a diameter of 6.5m and the base of the foundation has a maximum diameter of 20m.	N/A	314	Relatively small footprint and limited potential for sediment disturbance, therefore not considered in modelling assessments.

(As supplied by the project)

1.10.2 Turbine Layout

The turbine layout being considered is shown in Figure 1 and comprises 11 turbines, and will remain the same regardless of foundation choice or size of turbine.

1.10.3 Seabed Preparation

As described in Table 3, the 'worst-case' scenario in terms of seabed preparation and the subsequent volume released into the water column is provided by the monopile foundation. Based on evidence presented in the baseline assessment (ABPmer, 2011) the sediment layers likely to be disturbed during the installation process (and therefore considered within the numerical modelling study of sediment plumes) are summarised in Table 4. It should be noted that the sediment depths are based on geophysical interpretation and therefore:

- The depths inferred are based on remotely collected data and are not ground truthed;
- The geophysical survey (Emu, 2008b) did not locate any till in the vicinity of Turbines 1, 2, 4 and 5, it is unclear whether this is due to the absence of this strata; and
- The sediment sizes are based on generic descriptions of sediment encountered in other boreholes outside of the study area and therefore the sediment descriptions have not been ground-truthed.

Table 4. Summary of sediment types disturbed during the monopile installation

Sediment Type	Sediment Description	Envelope of Sediment Depth Below Seabed at Turbine Locations (m)		Representative Grain Size (µm)	Comments
		Top of Unit	Base of Unit		
Holocene seabed sediments	Predominantly sands with some fines and gravels. Well described by grab samples by CMACS and FRS.	0	1-9	60 and 150µm	Sand sized sediments (150µm) are likely to fall out of suspension rather than becoming transported, joining the background bedload transport regime and therefore do not require further consideration.
Forth Formation	No borehole evidence so sediment composition inferred from other studies. Likely to consist of fine to coarse sands.	1-9	13-24	150µm (typical fine sand based on sediment description no specific particle size data available)	Sand sized sediments (150µm) are likely to fall out of suspension and join the background bedload transport regime and therefore do not require further consideration.
Wee Bankie Formation (till)	No site specific borehole evidence so sediment composition inferred from other studies. Likely to be a mixed sediment consisting clays, coarse gravels and sands	13-24	23-31	20µm (representative of fine component of till based on sediment description no specific particle size data available)	Fine sediment is likely to go into suspension so will be modelled.
Bedrock (Old Red Sandstone and some other coarse grained igneous rocks)	No borehole evidence and very limited information. Behaviour of rock uncertain when piled or drilled.	23-31	>37	20µm (conservative representation of sediment after drilling/piling no actual sediment size data available)	Fine sediment is likely to go into suspension so will be modelled.

1.10.4 Disposal of Seabed Preparation Material

At the present time it is anticipated that the sediment disturbed during the foundation installation procedure (as summarised in Table 4) will be released in-situ immediately adjacent to the turbine (pers. comm., 2011) and the modelling of sediment plumes will be undertaken based on this assumption.

1.10.5 Turbine Installation

The precise sequence and timing of turbine installation is not fully defined at this stage, but for the purposes of this study a 'worst-case' scenario has been used whereby for monopiles:

- All turbines are installed in 2013; and
- Each turbine takes 5 days to install.

1.10.6 Export Cable Route

The precise export cable route has not been finalised at this stage but an indicative export cable corridor has been defined. An indicative cable route has been chosen within this corridor for the purposes of the sediment plume assessment. It should be noted that this does not represent the location of the final export cable corridor. The following characteristics of the cable route are included within this assessment:

- Total of four cables installed within the corridor; and
- Corridor length of, approximately, 26km.

1.10.7 Export Cable Installation Method

The following techniques are being considered for the installation of the export cable:

- Ploughing;
- Jetting; and
- Mass excavation tools.

In terms of sediment plume generation, the maximum amount of dispersed sediment is likely to be caused by the mass evacuation tool. The estimated installation rates applicable to this method are 500m/hr in water depths greater than 2m, and 5m/hr in less than 2m water depth.

The trench characteristics applicable to the use of the mass excavation tool are:

- Maximum depth of trench 3m;
- Maximum width of trench 10.38m; and
- Shape of trench: v-shaped.

For the purposes of the sediment plume investigations, it has therefore been assumed that a total volume of 405,000m^3 will be displaced along the 26km cable route using the mass excavation method of cable installation.

Based on the evidence presented in the baseline assessment (ABPmer, 2011) the sediment layers likely to be disturbed during the cable installation process (and therefore considered within the numerical modelling study of sediment plumes) are discussed below.

Project details indicate that the maximum depth during cable installation is expected to be 3m. The depth of the surficial Holocene sediments ranges between <1m and 9m, below the seabed surface. In general the sediment depths are greater further offshore (with the exception of the shore-parallel ridge). This means that there is potential for the cable laying operation to disturb the sediment layers located below.

The geophysical survey (Emu, 2008b) described these sediments as "possibly coarser glacial till". The Osiris report (Osiris, 2010) provided further detail based on other sources of geological data and further sub-divided this unit into the Forth Formation and the Wee Bankie Formation. These are described as:

- Forth Formation: This unit is expected to comprise shelly sands (St Andrews Member) in places underlain by intermittent silty clays and gravely clays (Largo Bay Member); and

- Wee Bankie Formation: This unit is a glacial till deposit and is expected to comprise of soft to stiff generally sandy, gravelly clay with coarser sand and gravel deposits.

Based on available evidence, it is not possible to differentiate precisely where these two sediment horizons will be encountered during the cable route installation. It is known that the Wee Bankie formation is situated directly beneath the Holocene sediments and in places outcrop on the seabed so it is possible that both strata could be disturbed. However, as these formations comprise mainly sands and clays, it is considered that representative particle sizes of 20 and 150µm will adequately describe the sediments likely to be disturbed during the cable works.

It should be noted that the sediment depths are based on geophysical interpretation and therefore:

- The depths inferred are based on remotely collected data and are not ground truthed; and

- The sediment sizes are based on generic descriptions of sediment encountered in other boreholes outside of the study area and therefore the sediment descriptions have not been ground truthed.

1.10.8 Cumulative and In-combination Impacts

The Ocean Laboratory is to be considered as a cumulative impact with the proposed EOWDC. Its location is shown in Figure 1 and it is to be represented as a gravity-base structure with characteristics matching those of the turbine structures (Section 1.10.1 and Table 3).

2. Impact Assessment

2.1 Potential Impact: Changes to Processes Acting Within Aberdeen Bay

Changes to the tide and wave regimes within Aberdeen Bay may result in changes to the offshore sediment transport regime and hence the seabed morphology. The processes of tides and waves should be considered as pathways to the receptor of seabed form. Significance levels have been presented for the potential impacts determined for the receptors.

2.1.1 Construction Phase

Potential Impacts

Whilst there will be effects during the construction phase, as a result of the temporary presence of engineering equipment such as jack-up barges it is considered that the effect on the tide and wave regimes and consequently upon seabed morphology will be small in magnitude, short-lived and localised. Therefore, potential impacts on the coastal sediment transport regime during the construction phase have not been considered further.

The offshore seabed form should be considered to be of low importance as it does not have any designated features and is considered to be of medium recoverability due to the weak tidal conditions.

The potential impact has been assessed of negligible magnitude, low sensitivity and therefore of negligible significance.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.1.2 Operational Phase

Potential Effect: Changes to the Tidal Regime as a Result of the Presence of the Turbine Foundations

The presence of the turbines has the potential to impact on the tidal regime as flows interact with the structures. Any changes to the tidal regime may have a resultant impact on the sediment regime (offshore and coastal morphology) and therefore requires careful consideration. The turbines have the potential to impact on the following tidal characteristics:

- Tidal speeds (currents);
- Tidal directions; and
- Tidal heights (water levels).

To quantify the likely magnitude and extent of interaction between the operational scheme and the tidal regime, the numerical model was run over a typical spring-neap tidal cycle. It should be noted that within Aberdeen Bay, slack water does not coincide with high and low water but instead occurs around 1.75hrs after low tide and 2.25hrs after high tide (see ABPmer, 2011 for further details).

This analysis showed the following main points with respect to tidal currents:

- The aggregate impact of all the structures in the array is to increase tidal speeds by no more than 0.01m/s and to reduce tidal speeds by less than 0.05m/s. It is noteworthy that these changes do not occur at a time of peak flow. Further, the greatest changes in current speed are restricted to the immediate vicinity of the turbines;

- The increase in tidal speed occurs both during the ebb (to the south of the array) and during the flood (to the north of the array) immediately after slack water. This is due to a slight change in the timing of slack water and is very small in magnitude (<0.01m/s) and duration (<45 mins); and

- The local decrease in tidal speed is greater in magnitude and occurs just after peak flow on both the ebb and flood. The decrease in current speed occurs in the lee of the structure, depending on the direction of the tidal current and is a direct result of drag around the turbine structures and a resultant decrease in current speed ‘downstream’ of the turbine. Therefore, during the flood the reduction initially occurs to the north-northeast of the structures (during the north-northeasterly directed tidal flow) and then to the south-southwest (during the south-southwesterly directed tidal flow) in the later stages of the flood tide after the tidal current has reversed direction. During the ebb the pattern is reversed with the reduction occurring to the south of the array during the initial stages of the ebb and to the north of the array during the later stages. The magnitude of these changes is very small and does not exceed -0.05m/s. The maximum extent of this impact is shown in Figure 2 for a flood and an ebb mean spring tide.

With respect to water levels, the analysis showed no measurable increases or decreases in water levels.

The consequential impacts of these changes to the tidal regime on sediment transport and morphology are discussed in later sections.

Potential Effect: Changes to the Wave Regime as a Result of the Presence of the Turbine Foundations

The wind turbines have a potential to impact on the wave regime as the waves pass through the structures, as for the tidal regime any changes to the wave regime can have important implications for resultant sediment transport pathways and hence the morphology of the seabed and adjacent coast. The baseline assessment (ABPmer, 2011) identified the wave climate as an important control on sediment transport within the study area; especially with regards to the adjacent shoreline where wave induced littoral transport processes predominate.

To investigate any potential impacts on the wave regime, a wide range of wave events were simulated which represent those currently experienced within the study area (ABPmer, 2011). Metocean records show that the most frequent wave direction is from the south-east and the largest waves from the east. Therefore the numerical model was used to simulate the wind coming from the 60, 90, 120 and 150°N sectors for an 8, 12 and 16m/s wind. This approach lends to the identification of the most significant event in terms of littoral processes (see Section 2.6 for further analysis of the impacts of littoral processes) which represents an important coastal processes receptor. The potential changes to significant wave height (Hs), peak wave period (Tp) and wave direction approximately 500m shoreward of the array are summarised in Table 5.

The information presented in Table 5 shows that the turbine structures result in a negligible change to wave direction, a very small change to wave period (<1%) and small changes to significant wave height (<2.8%). This shows that the main impact on the wave climate is a reduction in wave heights due to the sheltering effect of the turbines, in turn reducing the amount of wave energy propagating through the proposed development area. Impacts on wave direction due to refraction from the turbines are insignificant, with no change amounting to more than 1°.

Table 5. Modelled changes to the wave climate as a result of the EOWDC development

Boundary Wind Direction (°N)	Boundary Wind Speed (m/s)	Baseline Hs (m)*	Scheme Hs (m)*	% Hs Change	Baseline Tp (s)*	Scheme Tp (s)*	% Tp Change	Baseline Dir (°N)*	Scheme Dir (°N)*	Dir Difference (°)
60	8	1.80	1.75	-2.8	7.6	7.6	0.0	76	76	0.0
	12	4.20	4.1	-2.4	11.9	11.9	0.0	82	82	0.0
	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90	8	2.00	1.95	-2.5	7.6	7.6	0.0	94	94	0.0
	12	4.04	3.96	-2.0	11.3	11.3	0.0	96	97	1.0
	16	5.81	5.65	-2.8	12.4	12.4	0.0	97	97	0.0
120	8	2.00	1.96	-2.0	7.6	7.6	0.0	115	115	0.0
	12	4.10	3.99	-2.7	11.3	11.3	0.0	112	111	-0.9
	16	5.83	5.68	-2.6	12.2	12.1	0.8	111	110	-0.9
150	8	2.27	2.21	-2.6	8.5	8.5	0.0	133	133	0.0
	12	3.83	3.73	-2.6	11.2	11.2	0.0	126	126	0.0
	16	5.06	4.93	-2.6	11.9	11.9	0.0	125	124	-0.8

* Taken at a point approximately 500m shoreward of the turbine array

To illustrate the spatial extent of changes to the wave climate a number of scenarios have been modelled during a mean tidal level, three of these scenarios are presented in Figure 4. It is shown that:

- Under the most common conditions (ABPmer, 2011) (60°N sector, Hs 0.5m and 1.0m), the magnitude of changes to the waves due to the turbines is very low and almost indiscernible. Under the 0.5m event no reductions in significant wave height greater than -0.05m are observed, whilst discrete reductions of -0.1m are observed in the immediate lee of the turbines (Figure 4a);

- Under the 'worst-case' impact (in terms of changes to the magnitude of significant wave height) as identified in Table 5 (90°N sector, Hs 5.8m) the extent of the impact is more extensive (as expected), but the largest changes are restricted to the immediate vicinity of the turbines (Figure 4b). Changes to the significant wave height at the coast amount to no more than -0.01m; and

- For all wave directions, the greatest spatial impact (i.e. largest footprint) of effect occurs during the moderate sized wave events of between 1 and 2.5m (Figure 4b). This is because the larger wave events tend to shoal and break in deeper water resulting in a reduction in the extent of impact. The magnitude of these impacts at the coastline is low and does not exceed -0.05m and commonly does not exceed -0.01m.

Potential Impacts: Changes to the Seabed Form

The sediment transport pathways within Aberdeen Bay are controlled by both the tidal and wave regime, with the latter shown to exert a sizeable, relative, contribution to the mobilisation of seabed sediments. It has been previously surmised that the lack of significantly sized bedforms within the area is probably due to a combination of weak tidal currents not creating bedforms and wave events flattening the seabed during storm events.

The analysis of impacts on both the tide and wave regime have shown no significant impacts; whilst a reduction in tidal currents has been simulated (<0.05m/s) this does not occur at the time of peak flow. Further, there is only a slight reduction in wave heights (< 0.01m) for both frequent, low energy and in-frequent, high energy events which is restricted to within the turbine's immediate lee.

It can therefore be inferred that no significant impacts on the sediment regime will result from the proposed development. It is not expected that the combined changes to these regimes will have any consequential significant impacts upon the offshore sediment transport regime.

In terms of coastal processes, the offshore seabed form should be considered to be of low importance as it does not have any designated features and be of medium recoverability due to the weak tidal conditions.

The potential impact has been assessed of negligible magnitude, low sensitivity and therefore of negligible significance.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

As with the wind farm array, the presence of the Ocean Laboratory has the potential to impact on the tidal regime as it interacts with the structure. Any changes to the tidal regime may have a resultant impact on the sediment regime (offshore and coastal morphology) and therefore requires careful consideration. The Ocean Laboratory has the potential to impact on the following tidal characteristics:

- Tidal speeds (currents);
- Tidal directions; and
- Tidal heights (water levels).

A comparison of Figures 2 and 3 indicates that the cumulative impacts of the Ocean Laboratory and the EOWDC does not induce a greater magnitude of change to the tidal regime beyond that predicted by the EOWDC alone. Flow speed changes are predicted in the immediate vicinity of the Ocean Laboratory structure, but these are no greater than those predicted in the immediate vicinity of each of the array turbines.

Further, the Ocean Laboratory has a potential to impact on the wave regime as the waves moves past the structure, as for the tidal regime any changes to the wave regime can have important implications for resultant sediment transport pathways and hence the morphology of the seabed and adjacent coast. The baseline assessment (ABPmer, 2011) identified the wave climate as an important control on sediment transport within the study area; especially with regards to the adjacent shoreline where wave induced littoral transport processes predominate.

A comparison of Figures 4 and 5 indicates that the cumulative impacts of the Ocean Laboratory and the EOWDC does not induce a greater magnitude of change to the wave regime beyond that predicted by the EOWDC alone.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.1.3 Decommissioning Phase

The scope of decommissioning impacts will be assessed in detail in the decommissioning plan, but these are expected to be within the envelope of constructional and operational impacts already discussed

Potential Impacts

Impacts predicted to be the same as or construction.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.2 Potential Impact: Seabed Changes as a Result of the Presence of Construction Equipment and Turbine Foundations (e.g. scour)

2.2.1 Construction Phase

Potential Impacts

During the construction phase of the wind farm, there is the potential for indentations on the seabed due to the positioning of construction equipment such as jack-up rigs. Project details indicate that the maximum footprint of the construction equipment will result from the use of one 6-legged jack and one 6-legged barge per turbine installation with a total maximum footprint of 4,200m^2. This amounts to 0.021% of the development area.

The relative seabed immobility, as inferred from the geophysical campaign (Osiris, 2010) and discussed in ABPmer (2011) may mean that the indentations may persist over the short-term. However, due to the small area of the potential indentations this impact has not been considered further.

The potential impact has been assessed of negligible magnitude, low sensitivity and therefore of negligible significance.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.2.2 Operational Phase

Potential Impacts

As the hydrodynamic flow passes around the base of the foundation, flows accelerate close to the seabed resulting in increased bed shear stress and increased potential for sediment mobilisation in the immediate vicinity of the foundation. This results in scour whereby a depression in the seabed is formed around the base of the turbine. The rate of scour development is generally rapid enough for equilibrium conditions to form over a period of a few tides. Using a series of empirical equations, the equilibrium scour depth for each foundation type resulting from a combination of both waves and currents has been calculated and summarised in Table 6. Appendix B provides further detail on the scour assessment summarised in this section.

For the jacket and tripod structures the term “local scour” refers to scour caused by the individual structures which make up the foundation whereas “group scour” refers to a region of shallower but potentially more extensive scour resulting from:

- The change in flow velocity in the gaps between the members of the jacket structure; and
- The turbulence shed by the structure as a whole.

Global scour relates to scour on the array scale.

In addition, the potential scour footprint has also been calculated based on currents alone. In all cases, these equations are applied assuming a uniform and erodible sub-surface geology.

Table 6. Summary of predicted maximum scour depth assuming uniform erodible sediment

Parameter	Foundation Option				
	Monopile	Jacket*	Tripod	Gravity Base	Suction Caisson
Equilibrium Scour Depth (m)					
Steady Current	11.05	3.25	3.25	7.2	3.6
Waves	Negligible	0.5	2.2	1.6	0.8
Waves and current	≤ 11.05	≤ 3.25	≤ 3.25	18	9
Group Scour	N/A	~1	~1	N/A	N/A
Scour Extent#					
Scour extent from foundation ** (m)	18	5	5	12	6
Scour footprint ** (m^2)	1,445	1,472	1,101	1,865	466
Foundation footprint (m^2)	*57*	*20*	*15*	*1,257*	*314*
Scour Volume**					
Scour volume (m^3)	6,228	749	884	6,214	777

* Bed prep volume negligible if corner piles are inserted without drilling

** Extent and area excluding the foundation. Values based upon the scour depth for steady currents. Footprint and volume values per foundation.

Whilst these calculations assume uniform erodible sediment, the presence of the Wee Bankie formation at, approximately, 10m to 20m below the seabed is likely to restrict the scour depth.

Overall, in terms of scour depth the gravity base structure causes the largest impact with a depth of, approximately, 18m local to the structure. This is due to the large size, volume and surface area of the foundation. In reality, this depth is unlikely to be attained due to potential constraints arising from the sub-surface geology with a till surface (termed the Wee Bankie Formation) at, approximately, 10m to 20m below the seabed (Osiris, 2010). This layer can be described as a soft to very stiff very stiff clays with occasional sand and gravel lenses (SEtech, 2009) and therefore based on available evidence is likely to be cohesive and largely resistant to erosion. It is important to note that this interpretation is based on remotely sensed and inferred data rather than actual boreholes and subsequent testing of sub-surface sediment properties may revise this hypothesis. Therefore, it may also be possible that the presence of this layer may act to slow scour rather than halt it. Group scour is expected to be minimal and the risk for global scour negligible.

The extent of scour from the edge of each foundation is also shown in Table 6. This is calculated assuming the profile of the scour pit is an inverted cone with slopes at the angle of repose for sand (32°). The footprint or area of the scour pit (excluding the foundation) is also provided, together with the footprint of the foundation for comparison. The gravity base foundation will result in the greatest total scour footprint; the suction caisson will produce the least. Table 7 summarises the total foundation and scour footprints and as a proportion of the lease area.

Table 7. Summary of predicted scour as a proportion of the lease area

Parameter	Foundation Option				
	Monopile	Jacket	Tripod	Gravity Base	Suction Caisson
Footprint on seabed of all devices (m^2)	624	216	162	13,823	3,456
Proportion of total site area (%)	*0.003*	*0.001*	*0.001*	*0.069*	*0.017*
Footprint on seabed of all devices + scour (m^2)	16,625	7,354	12,269	34,339	8,585
Proportion of total site area (%)	*0.083*	*0.037*	*0.061*	*0.172*	*0.043*

This greatest volume of scoured material results from the monopile structure with a scoured volume of 6,228m^3 per turbine. As already mentioned, this full volume may not be attained due to geological conditions in the site.

The time required for the majority of scour pit development around all foundations within the EOWDC is estimated to be within the order of 6 to 12 hours, under flow conditions sufficient to induce scour. This takes the assumption of a mobile uniform non-cohesive sediment substrate. Symmetrical scour will only develop following exposure to both flood and ebb tidal directions. Waves do not typically cause rapid initial scour directly, but can increase the rate of initial scour development.

The potential impact has been assessed of medium magnitude, low sensitivity and therefore of minor significance.

Mitigation

The above assessments have been based on a 'worst-case' scenario that no scour protection is provided. The results presented above suggest that scour protection need not be considered essential. As a matter of good practise, the project's detailed design will consider whether scour protection can reasonably be provided to further reduce this impact. Scour protection could be provided by rock dumping, the placement of marine mattresses or fronds. The design of scour protection will need to take into account the transition from the scour protection to the natural seabed with the edge of the protection far enough away from the foundation so as to remove any edge effects. Also the edge of the scour protection should be profiled in such a way as to reduce any scouring due to flow disturbance.

Residual Impacts

None anticipated.

Cumulative Impacts

None anticipated.

As with the turbine foundations, the Ocean Laboratory has the potential to create scour around its base. The Ocean Laboratory is located, approximately, 300m from the nearest turbine and is considered here to be mounted on a substructure similar to those previously considered.

The scour extents calculated for the range of substructures considered in pre-ceding sections indicates that scour is unlikely to extend more than 30m from the centroid location of any structure. It is therefore not anticipated that there would be any interaction of scour between the foundations of the Ocean Laboratory and other turbines.

Further, the foundations are located within a staggered grid such that the rows are not tidally aligned; this also makes it unlikely that there will be any interaction between the tidal wake of one foundation and another one downstream.

In-combination Impacts

None anticipated.

Monitoring

The extent of scour development is typically limited to less than 30m from the centroid location of any structure. Whilst it would not be considered essential to include scour monitoring as an integral aspect of the post-construction monitoring, it could be included as an additional aspect of the EOWDC. Visual or bathymetric surveys could be undertaken at selected locations and these surveys compared to assess the magnitude (area, depth and volume of sediment displaced) of scour and the effectiveness of any scour protection.

Subsequent surveys can then be planned depending on the results of this initial monitoring schedule. Due to the status of this development as a test centre, it may be of interest to monitor scour development at an in-situ point over a set temporal period (i.e. two spring-neap tidal cycles).

2.2.3 Decommissioning Phase

The scope of decommissioning impacts will be assessed in detail in the decommissioning plan, but these are expected to be within the envelope of constructional and operational impacts already discussed

As construction

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.3 Potential Impact: Increase in Suspended Sediment Concentrations

2.3.1 Construction Phase

Potential Impacts

During the installation of the foundation structures and cables, there is the potential for sediment re-suspension and dispersal of these sediments. The scoping exercise identified sensitive receptors within designated sites and also concerns regarding deposition within the harbour causing siltation of navigable channels.

Sediment re-suspension and dispersal has been considered using numerical modelling techniques. Here, sediment representative of the site conditions (as reported in project specific surveys (Emu, 2008b and Osiris, 2010) is released to mimic that likely to be released during the works for structure and cable installation. Project details provide parameters which define a 'worst-case' scenario are used, as described in Section 1.10 for the foundation and cable installations.

Foundation Installation

The installation of 11 monopile foundations, as specified in Table 3, is shown to result in the release of silts and fine sands which become suspended immediately following mobilisation by the works. Whilst this material does undergo deposition on the bed when the tidal flow is insufficient to maintain suspension, it does not remain on the seabed long-term such that it becomes re-suspended. Of note is that the displaced sediment will not act in the same manner as the surficial seabed sediments which are not as easily suspended by the hydrodynamic regime. The 'natural' state of the seabed is characterised by the presence of sands and muds which act in a consolidated manner to provide some armouring against mobilisation by the hydrodynamic regime.

As the volume of material released by the works increases as a function of the number of turbines installed, the SSC plume increases in spatial extent but importantly the magnitude of this plume does not increase over its extent. Thus, as more material is released the plume grows larger but not more concentrated.

As shown in Figure 6, following the complete installation of the first three turbines, a (depth-averaged) sediment plume extends from Aberdeen Harbour to, approximately, 5km south of the River Ythan. The plume remains shore-parallel at the position of the shoreward three turbines. Within the plume the wider concentrations are of the order of 8mg/l, with maximum concentrations reaching 100mg/l in localised areas. A further, similar, localised high concentration is located seaward of the Aberdeen Harbour. Project specific surveys indicated a maximum SSC of 43mg/l (ABPmer, 2011) within the array boundary. Thus foundation installation activities have the potential to elevate SSC levels beyond natural background levels. However, it is important to consider that after the complete installation of all 11 turbines the concentrations are much reduced, as discussed further below.

After the complete installation of all 11 turbines, concentrations formed by disturbed sediments are much reduced. The main area of SSC changes lies between Aberdeen Harbour and, approximately, 5km south of the River Ythan. Here SSC levels show a change of 20mg/l above the natural background levels. A localised area of SSC changes of less than 60mg/l, above natural background levels, is shown seaward of the Aberdeen Harbour. More widespread localised SSC levels are shown to both the north (along the Collieston coast) and south (to Stonehaven) of the order of less than 8mg/l, above natural background levels. The results described above, and as illustrated in Figure 6, clearly show the widespread dispersion of the sediment mobilised by foundation works beyond Aberdeen Bay.

Concern has been raised by the Aberdeen Harbour Board regarding the increase in SSC levels which may lead to sedimentation within the harbour and along the Aberdeen Beach frontage. The results presented here indicate that the mobilised material is transported to both the north and south of the development with the greatest extent being to the south. As such, the transport direction follows the orientation of the coastline. The fine nature of the sediment is such that it is more likely that widespread dispersal beyond Aberdeen Bay occurs, as indicated by the numerical modelling, and not deposition within the bay. Foundation installation activities are usually scheduled to occur during benign wave conditions. It should be considered that a continual 55 day window for installation may not occur and therefore there will be a smaller sediment plume which will be widely dispersed prior to any further sediment release into the water column.

A very small proportion of the total volume of sediments suspended may be entrained into Aberdeen Harbour by normal tidal exchange and as a consequence of the one-off foundation installation activity. The largest total volume of silt sized sediment potentially resuspended by the installation of foundations would result from 11 gravity bases and is equivalent to a maximum of 0.2m unconsolidated sediment thickness, if deposited directly and evenly over an area equivalent to that of Aberdeen Harbour. Naturally occurring processes of advection, dispersion and sediment settlement in the coastal environment make it highly unlikely that any significant proportion of the total sediment volume disturbed would actually enter and subsequently settle inside the harbour. It is also unlikely that all foundations will be gravity bases, given the nature of the EOWDC development, further reducing the total sediment volume and the potential for its accumulation elsewhere.

It is important to note here that once all 11 turbines are installed the sediment source for the SSC plume is removed and the tidal regime then acts to further reduce the SSC levels back to the background concentrations by continual dispersion. This potential impact therefore represents a temporary effect.

Alongside a consideration of the production of a sediment plume resulting from foundation installation is that of the resultant change in bed level. This is considered here as a change in the bed thickness. It is notable that there are no predicted changes greater than 1mm over the whole extent and represents a non-significant bed level change. Placing this in context 1mm is the diameter of one grain of coarse sand. This supports the predictions that the material is continually suspended and dispersed over the far-field.

The potential impact within the Aberdeen Harbour has been assessed of low magnitude, medium sensitivity and therefore of minor significance.

As shown in ABPmer (2011), European designated sites are present within the wider study area:

- Special Areas of Conservation (SAC) : River Ythan, shoreline immediately north of the River Ythan, River Dee; and
- Special Protection Area (SPA) : River Ythan, Buchan Ness to Colliston coast.

The suspended sediment plume predicted by the numerical modelling suggests that there will changes to SSC levels along the Collieston coast, within the area designated as a SPA. Only very localised, temporary changes to SSC levels are shown to occur (Figure 6). It is considered that only under very extreme wave conditions will the plume result in deposition within the dune system (shoreline classified SAC).

The potential impact within designated sites has been assessed of low magnitude, high sensitivity and therefore of minor significance.

Cable Installation

The installation of the export cable along a notional route is shown to result in the release of silts and fine sands which become suspended immediately following mobilisation by the works. Whilst this material does undergo deposition on the bed when the tidal flow is insufficient to maintain suspension, it does not remain on the seabed long-term such that it becomes re-suspended. Of note is that the displaced sediment will not act in the same manner as the surficial seabed sediments which are not as easily suspended by the hydrodynamic regime. The 'natural' state of the seabed is characterised by the presence of sands and muds which act in a consolidated manner to provide some armouring against mobilisation by the hydrodynamic regime.

As the volume of material released by the works increases as a function of the length of cable installed, the SSC plume increases in spatial extent but importantly the magnitude of this plume does not increase over its extent. Thus, as more material is released the plume grows larger but not more concentrated.

Following the complete installation (after 52 hours) of the 26km of cable, it is possible to observe an increase in SSC within Aberdeen Bay. Here, changes to the depth-averaged suspended sediment concentrations are clearly present along the cable extent and localised to the works (Figure 7). The greater concentrations are observed where the installation works are the most intent and are typically less than 70mg/l, with very localised concentrations of 90mg/l occurring. Wider concentrations within Aberdeen Bay less than 40mg/l above natural background levels. Project specific surveys indicated a maximum SSC of 43mg/l (ABPmer, 2011) within the array boundary.

A very small proportion of the total volume of sediments suspended may be entrained into Aberdeen Harbour by normal tidal exchange and as a consequence of the one-off short-term (52 hour) cable installation activity. It is however considered that, given the short-term duration of the installation works combined with the naturally occurring processes of advection, dispersion and sediment settlement in the coastal environment, it is highly unlikely that any significant proportion of the total sediment volume disturbed would actually enter and subsequently settle inside the harbour. Should the mass excavator tool not be used, the total sediment volume will be further reduced as will the potential for its accumulation elsewhere.

As observed with the foundation installation works, it is anticipated that the suspended sediments will further disperse following completion of the works such that natural background levels will become restored.

The results presented here indicate that the predominant fate of the mobilised material would be to the south, following the coastal orientation. The fine nature of the sediment is such that it is more likely that widespread dispersal beyond Aberdeen Bay occurs, as indicated by the numerical modelling, and not deposition within the bay. This is confirmed by further modelling results which show that there are insignificant bed levels changes within Aberdeen Bay.

It is important to note here that once the cables are installed, the sediment source for the SSC plume is removed and the tidal regime then acts to further reduce the SSC levels back to the background concentrations by continual dispersion. This potential impact therefore represents a temporary effect.

When compared to the suspended sediment levels resulting from the foundation installation, it is possible to conclude that those resulting from the cable installation will be higher than natural background levels:

- For a much shorter time period as a consequence of the duration of the works (52 hours as compared to 55 days);
- Over a smaller spatial extent as a consequence of the duration of the works; and
- Of higher concentrations as a consequence of the larger volume of material dispersed over the shorter duration of works.

The potential impact has been assessed of medium magnitude, low sensitivity and therefore of minor significance.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

The precise installation techniques have yet to be determined but AOWFL will implement appropriate research studies to investigate changes in suspended sediment concentration should any novel techniques be used for which there is an absence of any previous research. An example of a potential study is the monitoring of suspended sediment levels should the mass excavator tool be used for the cable installation works. This and any other studies designed to test and validate assumptions made within the Environmental Statement would add to the existing evidence base on coastal impacts of offshore wind farm developments. To date there is no evidence regarding the use of mass excavation tools during the installation of offshore wind farm infrastructure.

2.3.2 Operational Phase

Potential Impacts

None anticipated.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.3.3 Decommissioning Phase

As construction

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.4 Potential Impact: Changes to Processes Acting to Maintain the Aberdeen Bay Coastline

Changes to the tide and wave regimes may result in changes to the sediment transport regime and hence changes to the shoreline morphology in the region of the wind farm. The littoral regime represents a receptor identified by stakeholders with some importance and should therefore be considered to be of medium sensitivity. Those concerns of relevance here submitted in response to the EOWDC Scoping Document (AOWFL, 2010) are presented in ABPmer (2011). The coastal processes baseline report (ABPmer, 2011) identified that the main control on the nearshore sediment transport (littoral) regime is wave processes and therefore the impact assessment is focussed upon this aspect. A consideration of the EOWDC effects upon the wave regime has been presented in full in earlier sections (Section 2.1).

2.4.1 Construction Phase

Potential Impacts

Whilst there will be effects during the construction phase, as a result of the temporary presence of engineering equipment such as jack-up barges it is considered that the effect on the wave regime will be small in magnitude, short-lived and localised. Therefore, potential impacts on the coastal sediment transport regime during the construction phase have not been considered further.

The potential impact has been assessed of negligible magnitude, medium sensitivity and therefore of negligible significance.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.4.2 Operational Phase

Potential Impacts

The potential impacts on the littoral regime immediately shoreward of the proposed EOWDC have been assessed using the XBeach numerical model. This numerical scheme allows for the shoreline impacts of the EOWDC on both the alongshore and cross-shore sediment transport and associated changes in beach morphology to be determined.

To investigate any potential impacts on the shoreline, a wide range of wave events were simulated which represent those currently experienced within the study area (ABPmer, 2011). Metocean records show that the most frequent wave direction is from the south-east and the largest waves from the east. Therefore a range of representative wave events and directions with the wind (and waves) approaching from, at the offshore boundary, of either the northeast

(60°N), east (90°N), southeast (120°N) and south-southeast (150°N) at speeds of either 8, 12 or 16m/s at the model boundary. These wave events were subsequently transformed as they refracted across the study area and the nearshore bathymetry (thus resulting in wave height, period and direction). The relative amount of shoreline change over a single spring tide was calculated by comparing pre- and post-development scenarios. This was done by initially examining three cross-shore profiles (1D aspect) to determine the 'natural' behaviour of the beach. Subsequently, a longshore area extending 3km in the development's lee (2D aspect) was used to determine the potential impacts of the proposed EOWDC upon the beach's morphological behaviour.

Prior to determining the effect of the EOWDC upon the beach's morphological behaviour, it is important to firstly consider the pre-development, or baseline behaviour. When examining 'natural' cross-shore changes, it is shown that the predicted response of the beach to different wave conditions, at these locations, is variable and ultimately dependent upon the initial morphology. As would be expected, the beach change increases with increasing wave height, such that absolute beach elevation changes are less than 0.2m when the significant wave height (Hs) is less than 1m (Figure 8). In order to observe a large change in beach morphology (±0.5m), the Hs should be greater than 3m with a peak wave period (Tp) greater than 10s (Figure 8). It is noted that more than 45% of wave heights recorded by the project specific metocean campaign are between 0.5 and 1.0m. It has been further shown that a 10 in 1 year return period wave condition at the AWAC site relates to the characteristics of 2.1m (Hs) and 7.3s (Tp) (ABPmer, 2011). The metocean survey therefore shows that the conditions required to result in a ±0.5m beach profile change can be considered as infrequent events.

When considering the potential impact of the development shoreward of the proposed EOWDC, it is evident that the morphological beach response is ultimately dependent upon the initial beach configuration. Further, it is the larger wave conditions that result in the greater beach changes. Changes to the more frequent wave conditions by the development lead to beach elevation changes of ±0.05m, with the more extreme wave conditions leading to greater changes of no more than ±0.2m. The largest cumulative erosion and accretion values are associated with a wave approach of, approximately, 68°N. This is thought to result from bathymetry effects that favour shoreward propagation of waves from this direction with less attenuation than waves from other directions tested (Figure 9).

When considering the magnitude of these changes to the beach morphology, it is important to take into account the following:

- Absolute changes in bed levels under similar wave conditions amount to one order of magnitude larger than the relative changes due to the wind farm;
- The resultant wave event at the shoreline for the 'worst-case' scenario (Hs of 5.68m and Dir of 110°N) has occurred during less than 0.05% of the 30 year record analysed as part of the baseline and therefore represents a rare event; and
- All indications are that the proposed development will result in a, slightly, reduced wave energy at the shoreline. It is therefore likely that the proposed EOWDC will result in a decrease in the natural variability of the beach, rather than an increase.

During the smaller, more frequent wave events from each sector (Hs of 2m) any identified changes to the beach morphology are less with changes limited spatially and generally not exceeding ± 0.05m in magnitude. It is important to emphasise that all wave events considered in this analysis are relatively extreme in that 61% of all wave events measure less than 1m in wave height. This assessment should be considered in this context.

Not only is the EOWDC is shown to result in small changes (±0.05m) under everyday events and slightly larger (±0.2m) under the less frequent events, but the development has also been shown to reduce the significant heights and thus may well result in less beach variability. It is also important to consider that these changes are within those occurring naturally and as such may be indistinguishable from the natural variability. Therefore, in comparison to existing variability, and considering that any changes are most likely to occur shoreward of the site, the changes that may be induced by the EOWDC could be considered to be of low magnitude

The potential impact has been assessed of low magnitude, medium sensitivity and therefore of minor significance.

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

2.4.3 Decommissioning Phase

As construction

Mitigation

No mitigation measures required.

Residual Impacts

As no mitigation is required, the residual impacts after mitigation are not relevant.

Cumulative Impacts

None anticipated.

In-combination Impacts

None anticipated.

Monitoring

No monitoring required.

3. Summary of Potential Impacts

An assessment of the potential impacts of EOWDC upon existing coastal processes has been undertaken. Stakeholder concerns and the location of various receptors have guided the assessment.

The potential impacts upon coastal processes have been determined using a range of techniques, including conceptual understanding and numerical modelling and have been assessed over a range of temporal and spatial scales (as detailed in guidelines for the development of offshore wind farms).

In addition to this, the changes that will occur naturally have been considered, i.e. shoreline changes, in addition to considering the overall context of the variability in the existing natural system.

This investigation has shown that there is relatively limited potential for a longer term, significant impact upon the existing tide, wave, sedimentary and morphological regimes, both within Aberdeen Bay and further afield.

3.1 Construction/Decommissioning Changes

Over the construction period there is the likelihood for discrete temporary seabed disturbances as devices are installed sequentially within the development site. These disturbances will be related to the installation of foundations and cables installation works with the potential to release seabed material into the water column. Subsequent sediment plumes may form. The decommissioning phase of an offshore wind farm is generally considered to be of similar or lesser impact than the initial construction phase.

The most measurable effects during the construction result from monopile foundation and cable installation works when temporary, small-scale increases in ambient suspended sediment concentrations occur. It is shown that tidal processes act to disperse the mobilised sediment such that concentrations return to background levels.

3.2 Operational Changes

It is during the operational stage for the proposed wind farm that the greatest potential changes to the tide and wave regime could occur. The installation of gravity base foundation structures has the greatest potential to cause change to the natural regime. Other foundation types are expected to have lesser effects upon the tide and wave regimes. The assessment undertaken here indicates there is little potential for significant changes to these regimes to occur.

Potential impacts on the adjacent shoreline, as a result of changes to the wave regime and corresponding rates of cross-shore and longshore littoral sediment transport, were also considered. It was found that the presence of the wind farm may slightly modify the response of the adjacent beach to naturally occurring storm events; however, it is also shown that the contribution of the EOWDC is small relative to the absolute beach response and relative to the observed natural variability in beach processes.

Scour effects are shown to occur localised to the foundation structures. It is not anticipated that the scour features associated with the individual structures will combine to cause group scour, at the scale of the EOWDC.

Cumulative effects from the EOWDC and Ocean Laboratory were also considered. It is suggested that there is little chance of substantial interaction between the two developments.

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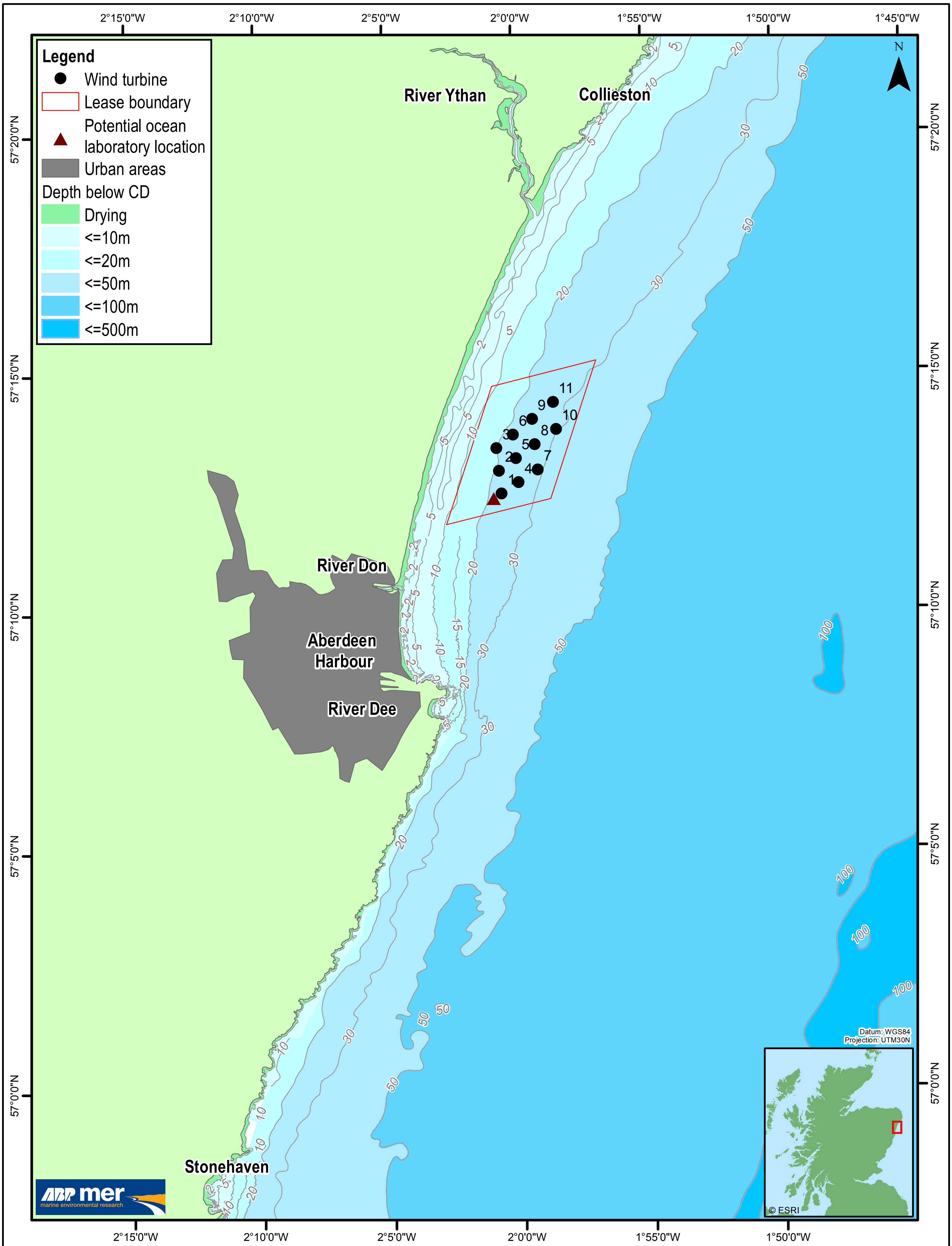
Figures



0 1 2 km

0 0.5 1 nm

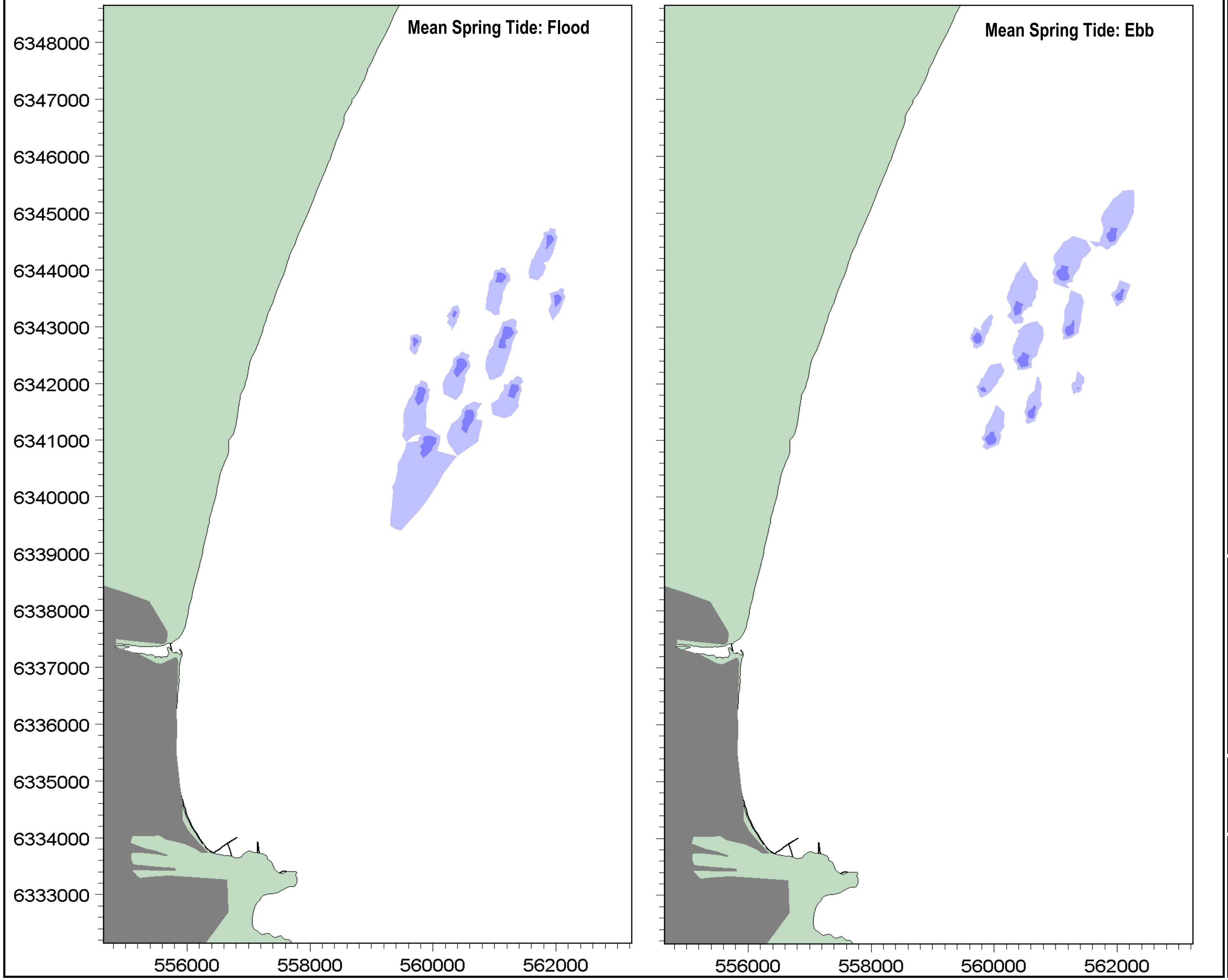
Original A4 Plot Scale 1:200,000

European Offshore Wind Deployment Centre

Overview of EOWDC project

Layout	By	Date	Rev	Dwg No.
LABER039	NJG	08/04/2011	B	6129-530-PM-006

Figure 1



Current Speed difference (m/s)

- Above 0.10
- 0.05 - 0.10
- 0.02 - 0.05
- 0.01 - 0.02
- -0.01 - 0.01
- -0.02 - -0.01
- -0.05 - -0.02
- -0.10 - -0.05
- Below -0.10

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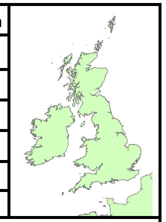

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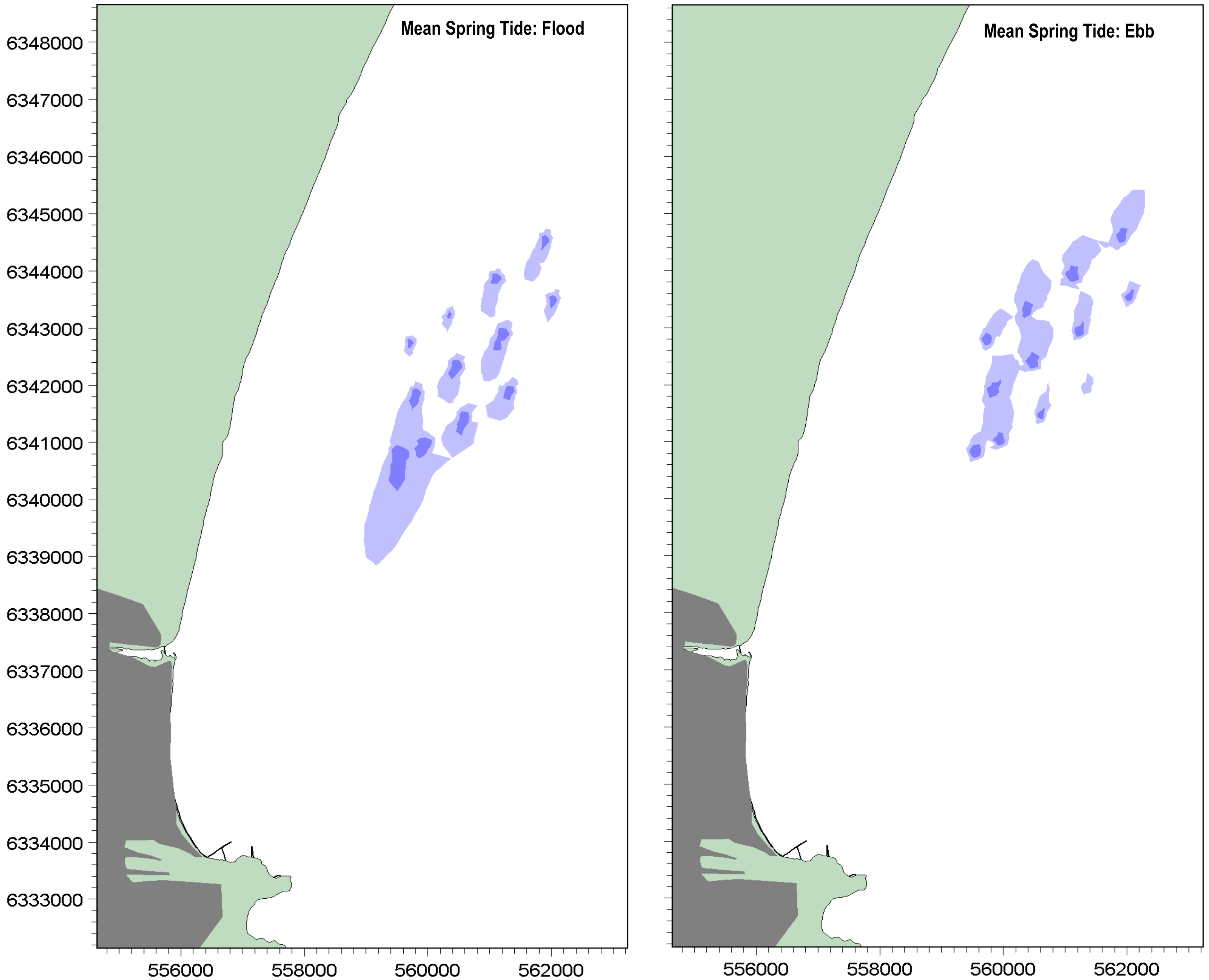
Modelled changes tidal currents

Figure 2



Current Speed difference (m/s)

Above	0.10
0.05 -	0.10
0.02 -	0.05
0.01 -	0.02
-0.01 -	0.01
-0.02 -	-0.01
-0.05 -	-0.02
-0.10 -	-0.05
Below	-0.10

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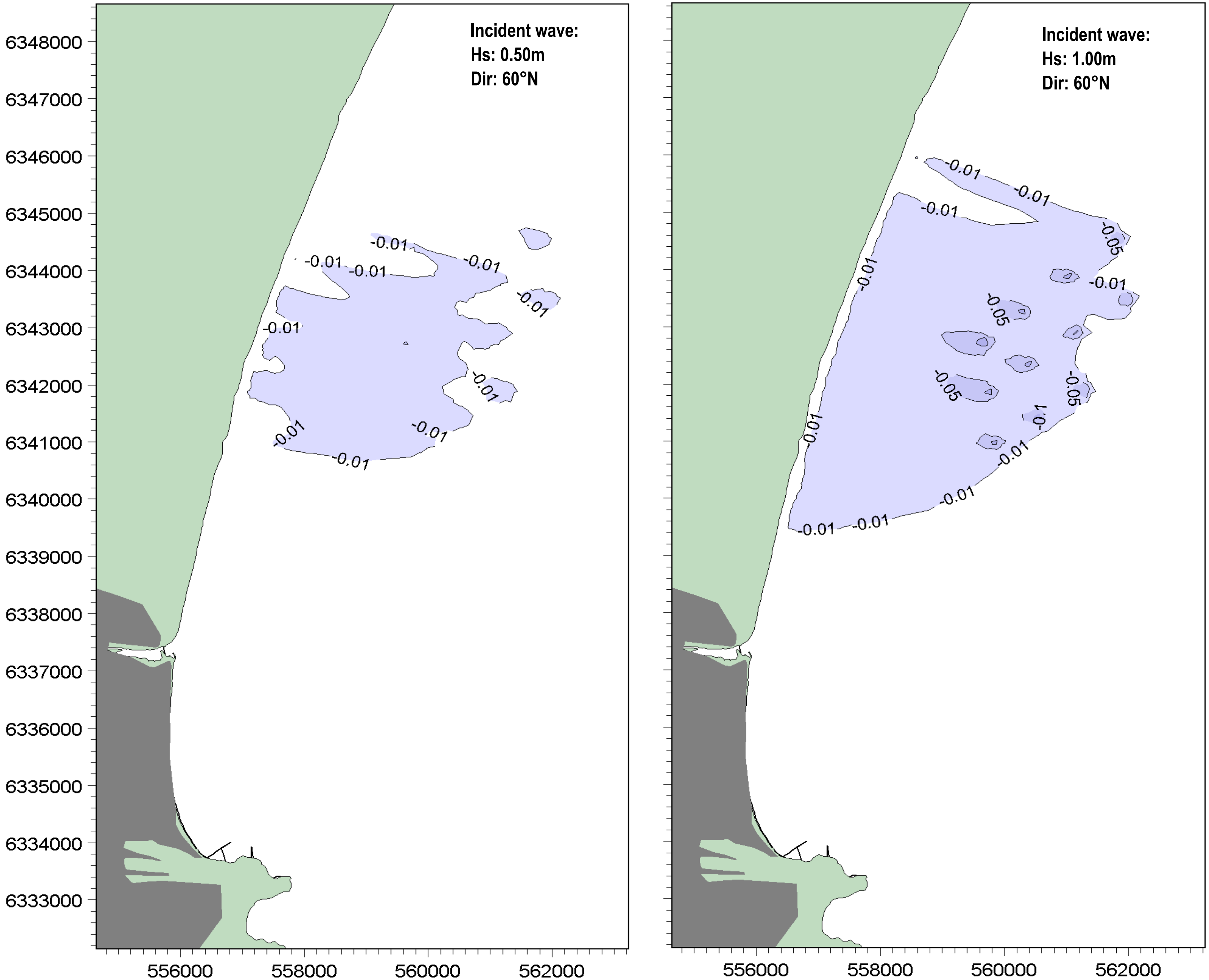
Modelled changes tidal currents (+OceanLab)

Figure 3



Hs difference (m)

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	-0.05 - -0.01
	-0.10 - -0.05
	-0.15 - -0.10
	-0.20 - -0.15
	-0.25 - -0.20
	-0.30 - -0.25
	-0.35 - -0.30
	-0.40 - -0.35
	Below -0.40

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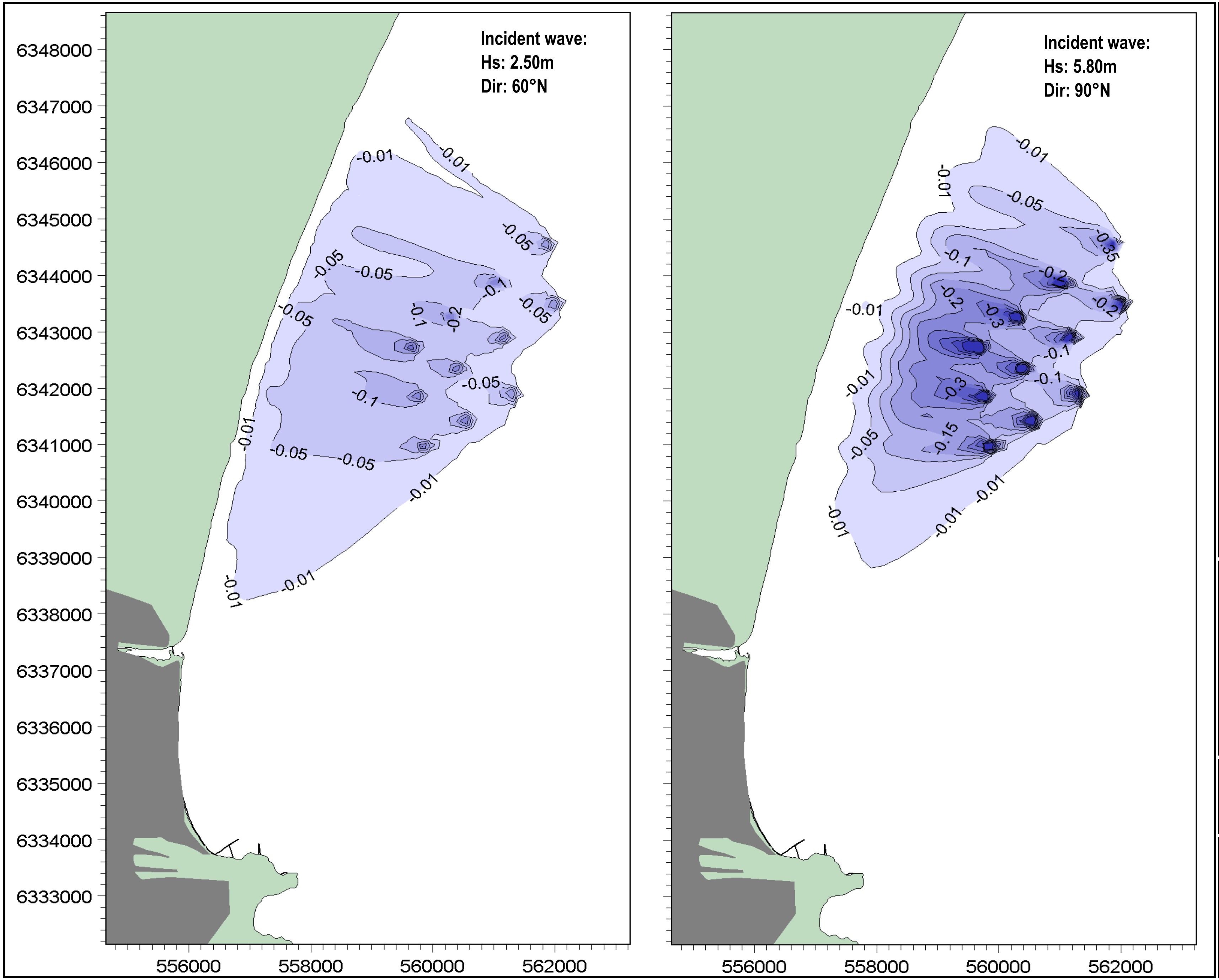
Modelled changes to significant wave height (frequent conditions)

Figure 4a



Hs difference (m)

	-0.01 - 0.01
	-0.05 - -0.01
	-0.10 - -0.05
	-0.15 - -0.10
	-0.20 - -0.15
	-0.25 - -0.20
	-0.30 - -0.25
	-0.35 - -0.30
	-0.40 - -0.35
	Below -0.40

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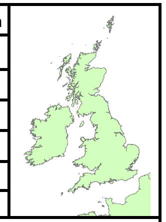

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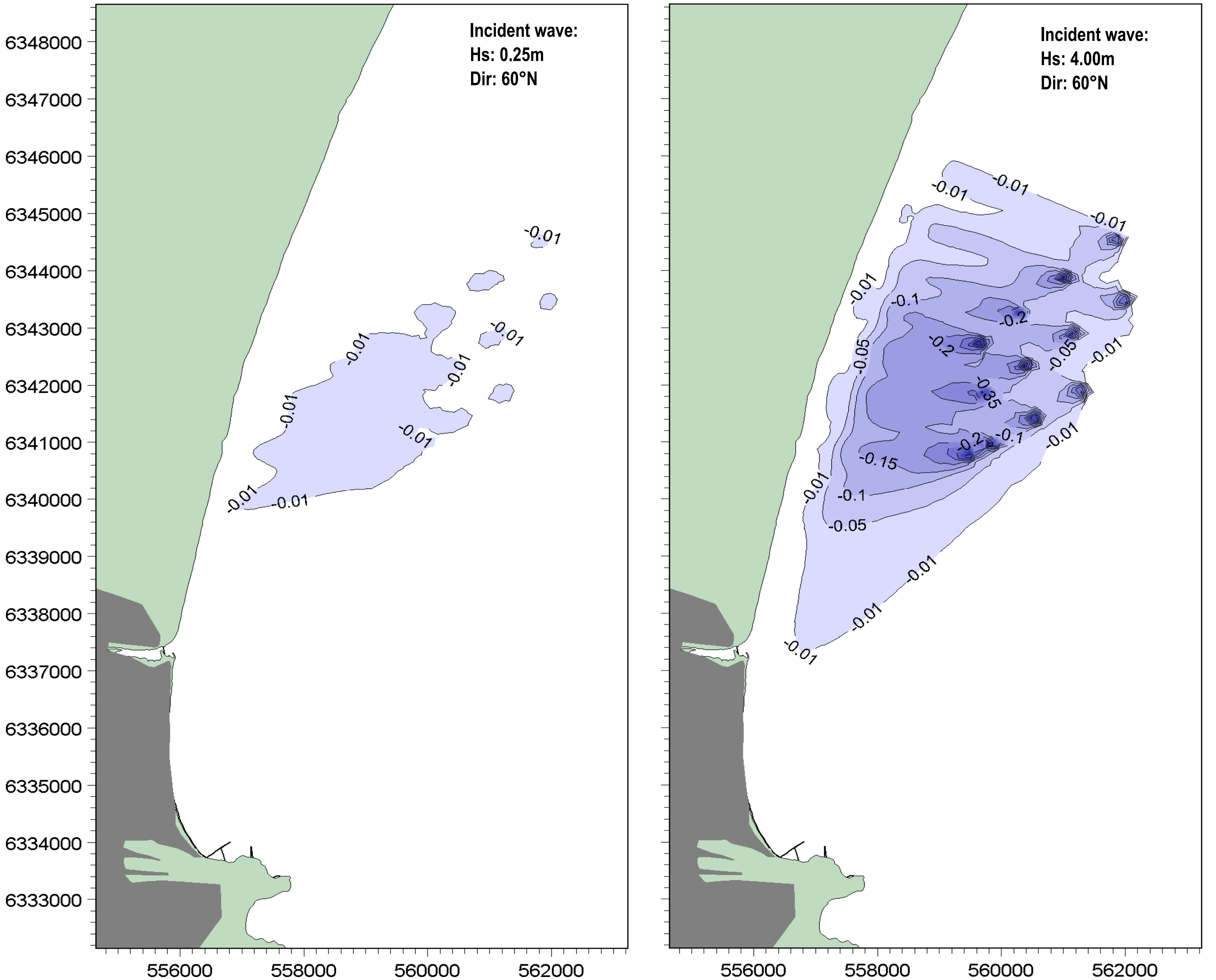
Modelled changes to significant wave height (infrequent conditions)

Figure 4b



Hs difference (m)

	-0.01 - 0.01
	-0.05 - -0.01
	-0.10 - -0.05
	-0.15 - -0.10
	-0.20 - -0.15
	-0.25 - -0.20
	-0.30 - -0.25
	-0.35 - -0.30
	-0.40 - -0.35
	Below -0.40

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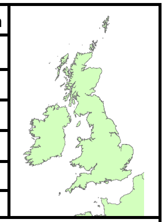

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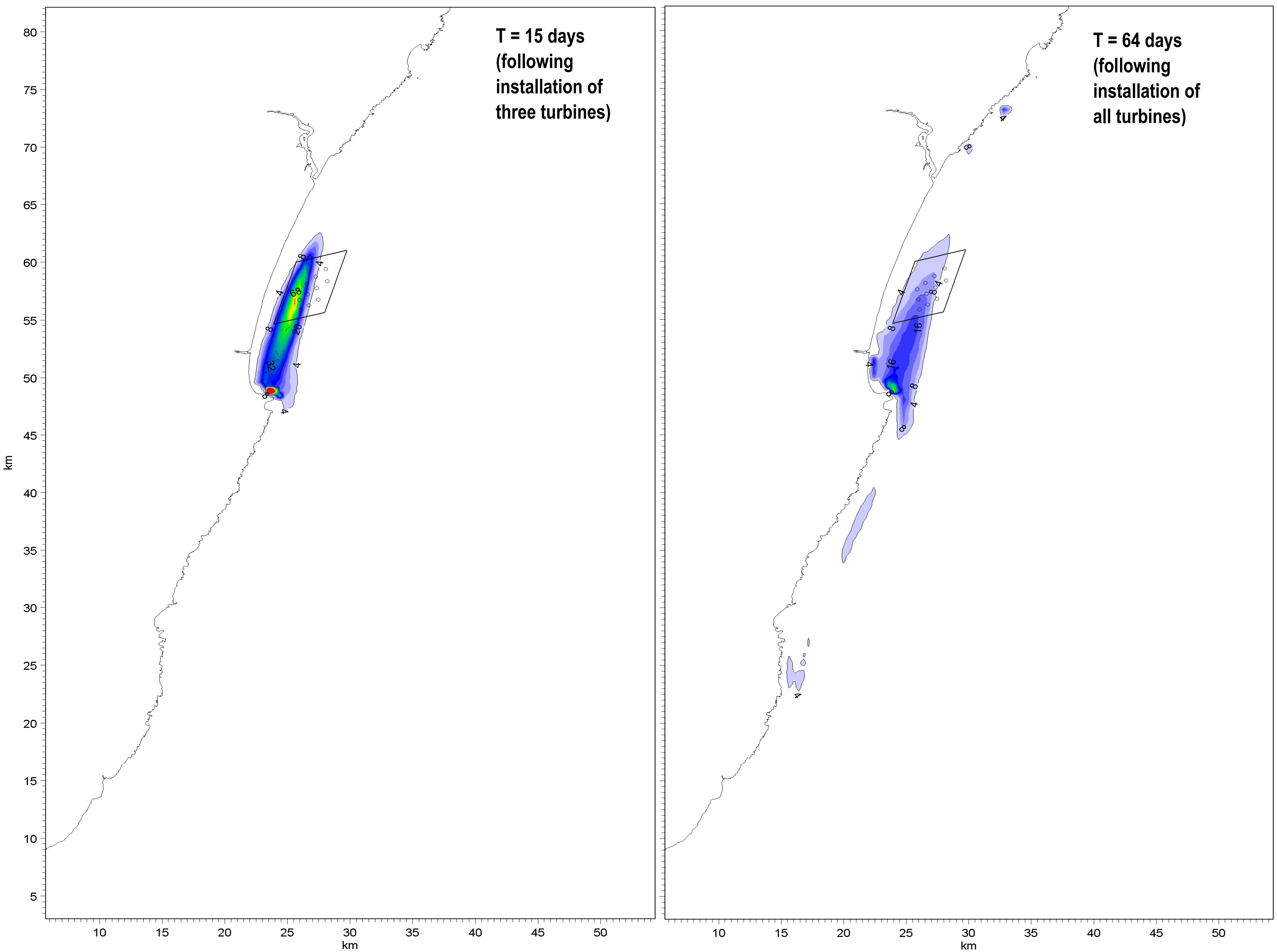
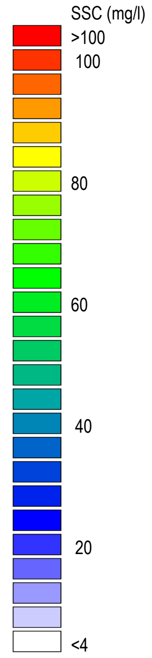
Modelled changes to significant wave height (+OceanLab)

Figure 5





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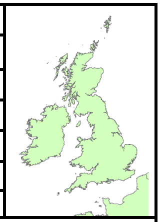

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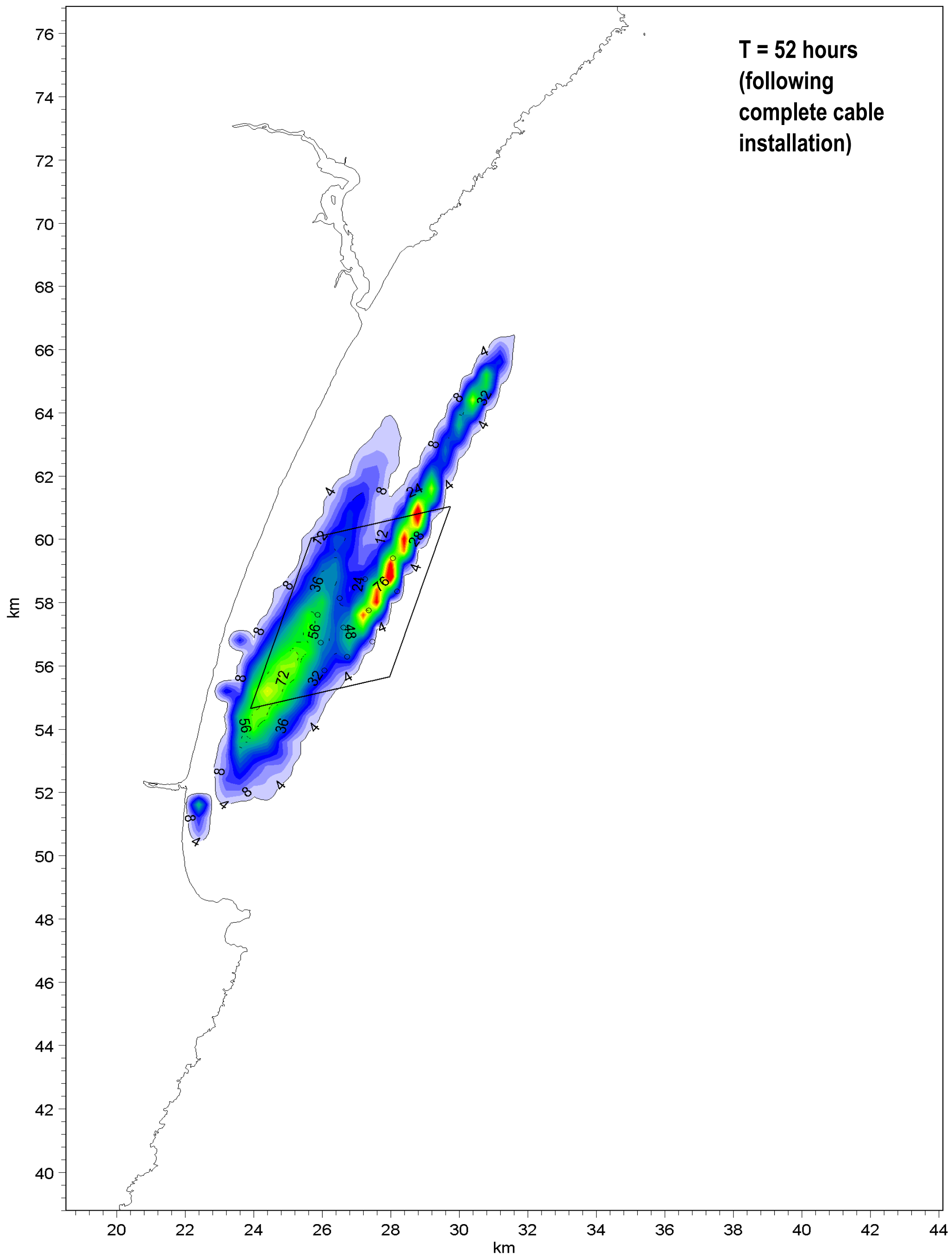
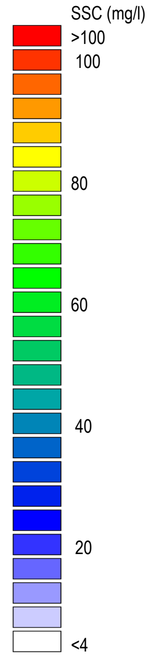
Suspended sediment concentrations resulting from foundation installation works

Figure 6





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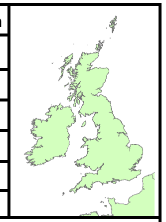

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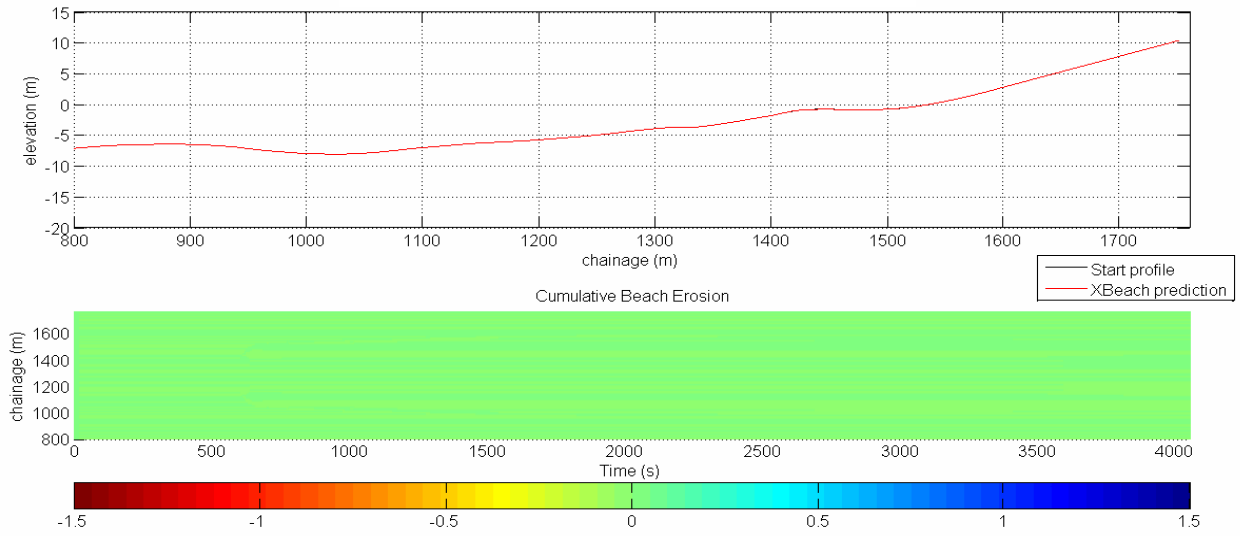
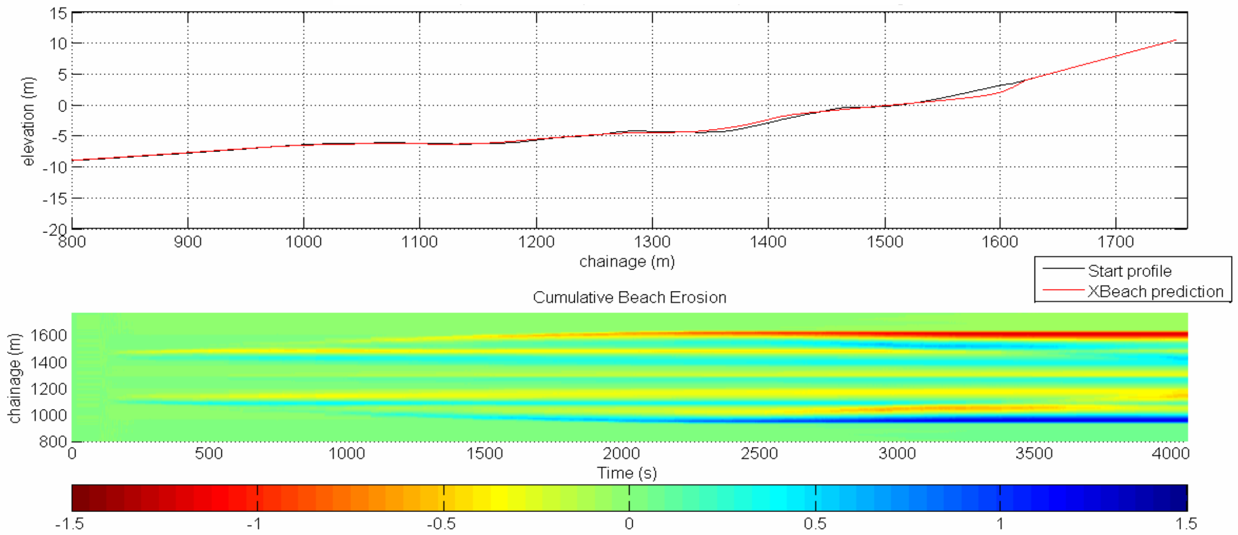
Suspended sediment concentrations resulting from cable installation works

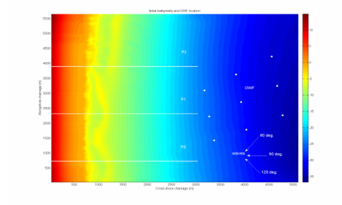
Figure 7



Aberdeen Beach, Profile 1: Predicted profile changes and cumulative beach erosion/accretion, Ws = 4m/s, Hs = 0.4m, Tp = 4.3s, Dir = 90°N.



Aberdeen Beach, Profile 3: Predicted profile changes and cumulative beach erosion/accretion, Ws = 12m/s, Hs = 4.0m, Tp = 11.3s, Dir = 90°N.



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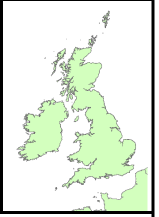

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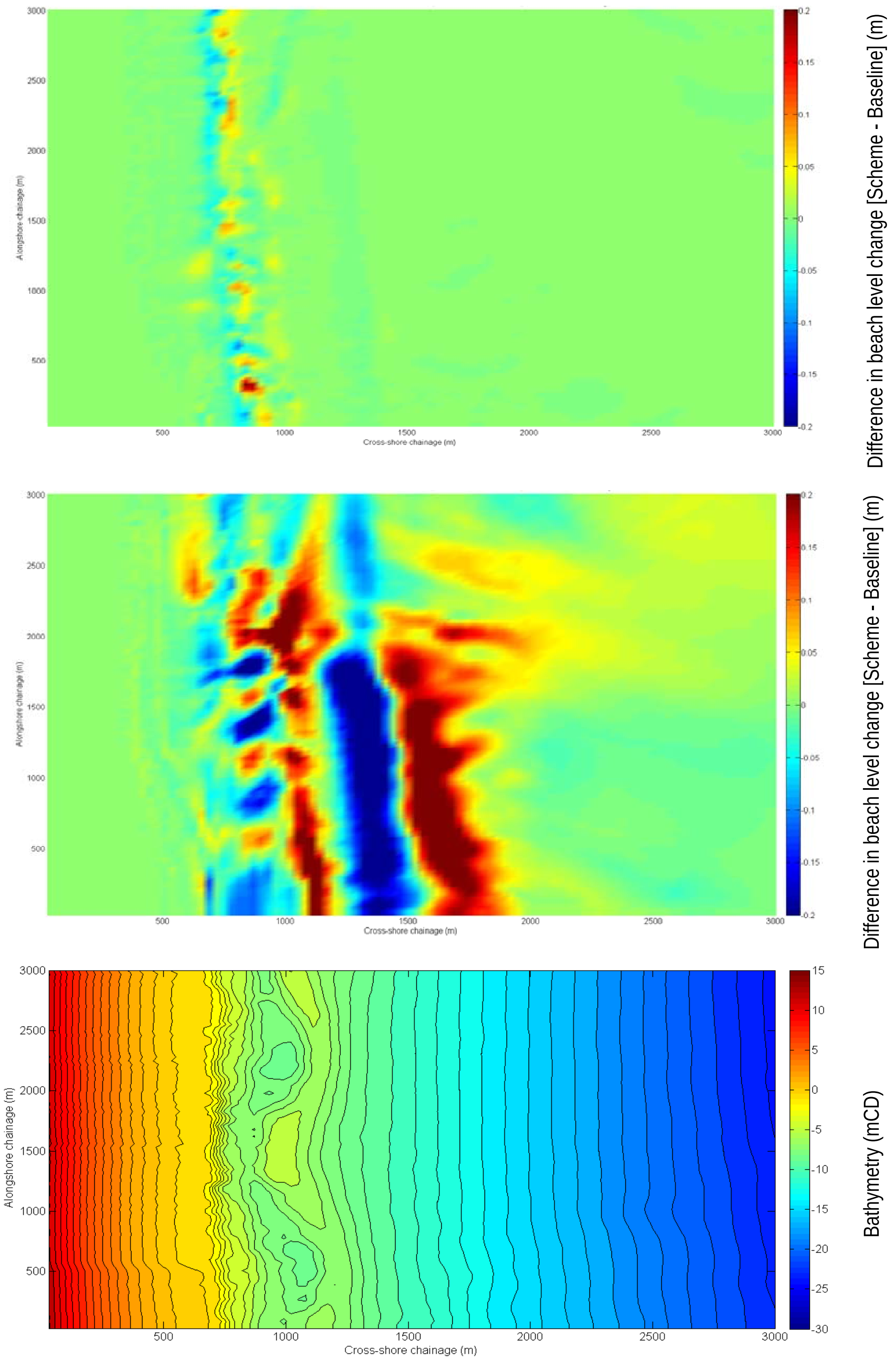
Beach profile changes in response to differing wave conditions

Figure 8



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Top: Baseline conditions: Ws = 8m/s, Hs = 1.8m, Tp = 7.6, Dir = 68.3°N;
Corresponding OWF scheme conditions: Ws = 8m/s, Hs = 1.66m, Tp = 7.56, Dir = 68.3°N;
Middle: Baseline conditions: Ws = 12m/s, Hs = 4.2m, Tp = 11.9, Dir = 68.3°N;
Corresponding OWF scheme conditions: Ws = 12m/s, Hs = 3.87m, Tp = 11.81, Dir = 68.3°N;
Bottom: Detail of initial nearshore bathymetry (mCD) used in the 2D XBeach simulations.

Ws = Wind speed; Hs = significant wave height; Tp = Peak wave period; Dir = incoming direction

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Beach morphology changes in response to the installed EOWDC

Figure 9

Appendices

Appendix A

European Offshore Wind Deployment Centre - Model Calibration and Validation Report

Appendix A. European Offshore Wind Deployment Centre – Model Calibration and Validation Report

A1. Introduction

Several numerical models have been developed to enable the quantification of tide, wave and sedimentary processes in the vicinity of the proposed European Offshore Wind Deployment Centre.

The modelling systems included the MIKE21FM (Flexible Mesh) marine model suite by the Danish Hydraulic Institute (DHI) for waves, tides and dispersion studies for resuspended sediments. The XBeach modelling suite was also used to undertake higher resolution studies of the morphological response of the adjacent beach and coastline to the modified incoming wave climate.

Only the tidal and wave models are suitable for calibration and validation, using the available observed data. The accuracy of the other (sediment transport and morphological) models are inherently controlled by the accuracy of the input waves and tides as they provide the driving conditions. Quantitative calibration and validation of sediment transport and morphological models are not possible as it is not practicable to collect sufficient measurements of sediment transport rates and morphological change at the temporal and spatial scales, accuracy and detail required. These models are however based upon the current best available research regarding sediment transport and morphological response and results are qualitatively validated before further use by experienced and highly-qualified members of staff.

A2. Model Domains

Two separate model domains form the basis of the tide and wave models, the extent of these domains is shown in Figure A1. The extent of the tidal model is determined by the location of tidal amphidromes and the performance of the harmonic boundaries, while the wave model extents are determined by the need to include the relevant fetch lengths over which winds can generate the waves. For both models, the resolution in the vicinity of the proposed wind farm boundary is in the order of 200m. In the vicinity of the beach and nearshore zone this resolution increases to around 40m. This variable resolution approach ensures that the numerical models are able to adequately capture the features of the high resolution inshore bathymetry surveys.

Each model domain (tide and wave) is based upon the same bathymetry data, which include:

- Etopo2 (far-field areas);
- EMU geophysical surveys from 2007 (near-field areas);
- Osiris bathymetry surveys 2010 (near-field areas); and
- ABPmer beach profile surveys 2010 (intertidal beach region only).

A3. Tidal Model

The tidal model (Figure A1) is driven at its offshore boundaries by water levels calculated from tidal constituents derived from satellite observation of the ocean's surface. This is available as part of the modelling suite that comprises MIKE21 (the 'KMS' tide model).

A process of model calibration and validation was undertaken and is described in more detail in the following sections. Calibration is a process which requires the adjustment of available model parameters to achieve the best model performance. Validation is defined as seeking to quantify or characterise the level of agreement between model predictions and field observations. Validation is achieved by running the numerical model and comparing the results with data from an alternative period (to that used for calibration) and without making any further adjustments to the model setup. ABPmer's standard modelling guidelines (ABPmer, 2011) for tidal processes determine that a model becomes fit for purpose when it performs within the following limits:

- Speed to within 20% of observed speed;
- Water levels to within 10% of spring tidal ranges;
- Directions to within 10°; and
- Timing of high water to within 15 minutes.

For the purposes of model calibration, six days of spring tides in November 2007 are used to test the tidal model's performance against measured AWAC records originating from the EMU survey campaign from November to December 2007 (reported in EMU 2008a). For the purposes of model validation, six days of neap tides during December 2007 were used, with field data originating again from the EMU 2007 November to December 2007 survey.

The calibration performance of the tidal model is presented visually in Figure A2, whilst the summary statistics of water levels and current speed and directions are presented in Table A1 and Table A2 respectively.

Table A1. Tidal model water level calibration performance

Parameter		Value
Water Level	Mean high water difference (modelled - observed)	-0.23m
	Mean low water difference (modelled - observed)	-0.02m
	Standard deviation of high water difference	0.16m
	Standard deviation of low water difference	0.18m
	Mean high water difference as percentage of spring tidal range	-6.4%
	Mean low water difference as percentage of spring tidal range	-0.5%
Phase	Mean high water difference	-11.0 min
	Mean low water difference	9.4 min
	Standard deviation of high water difference	8.4 min
	Standard deviation of low water difference	9.1 min

Table A2. Tidal model current calibration performance

Parameter		Value
Speed	Mean ebb difference (modelled - observed)	-0.17m/s
	Mean flood difference (modelled - observed)	-0.06m/s
	Standard deviation of ebb difference (modelled - observed)	0.11m/s
	Standard deviation of flood difference (modelled - observed)	0.07m/s
	Mean ebb difference (modelled - observed) as % of max observed speed	-15.9%
	Mean flood difference (modelled - observed) as % of max observed speed	-7.9%
Direction	Mean ebb difference (modelled - observed)	0.7°
	Mean flood difference (modelled - observed)	6.8°
	Standard deviation of ebb difference (modelled - observed)	7.6°
	Standard deviation of flood difference in flood direction (modelled - observed)	4.8°

The validation performance of the tidal model is presented visually in Figure A3, whilst the summary statistics of water levels and current speed and directions are presented in Table A3 and Table A4 respectively.

Table A3. Tidal model water level validation performance

Parameter		Value
Water Level	Mean high water difference (modelled - observed)	-0.15m
	Mean low water difference (modelled - observed)	-0.08m
	Standard deviation of high water difference	0.15m
	Standard deviation of low water difference	0.18m
	Mean high water difference as percentage of spring tidal range	-7.5%
	Mean low water difference as percentage of spring tidal range	-3.8%
Phase	Mean high water difference	-23.3 min
	Mean low water difference	-9.5 min
	Standard deviation of high water difference	14.7 min
	Standard deviation of low water difference	9.0 min

Table A4. Tidal model current validation performance

Parameter		Value
Speed	Mean ebb difference (modelled - observed)	-0.16m/s
	Mean flood difference (modelled - observed)	-0.04m/s
	Standard deviation of ebb difference (modelled - observed)	0.11m/s
	Standard deviation of flood difference (modelled - observed)	0.06m/s
	Mean ebb difference (modelled - observed) as % of max observed speed	-24.8%
	Mean flood difference (modelled - observed) as % of max observed speed	-9.6%
Direction	Mean ebb difference (modelled - observed)	4.9°
	Mean flood difference (modelled - observed)	7.1°
	Standard deviation of ebb difference (modelled - observed)	9.8°
	Standard deviation of flood difference in flood direction (modelled - observed)	13.3°

For the purposes of assessing the performance of a numerical model (reproducing only the astronomical tide) it is common practice to compare the model result with only the astronomic component of the measured time series. This is achieved by using harmonic analysis to remove the effects of meteorology from the measured data. In the present study, the resulting astronomical measured water levels provided a reasonable representation of the original data. However, when the analysis was applied to currents, the resulting astronomical measured speeds contained a persistent repetitive peak during the ebb current phase that was not apparent in the original data. This anomaly is caused by the presence of meteorological events that persisted for a significant enough proportion of the total data set and masked too much of the underlying astronomical signal in the analysis for an accurate result. An example of such an event can been seen in the current speeds between 4 and 6 December 2007, in Figure A3. As a result, the calibration and validation of the tidal model is undertaken against the field data 'as is'. Therefore, the influence of meteorological effects on the measured data has been considered when reviewing the tide model's performance and assessing the performance criteria outlined at the beginning of this section.

In cases where meteorological events are apparent in the measured water levels, the tidal elevation is seen to typically increase above the predicted (astronomical) water level. Two such events appear in the field data periods used for calibration and validation, notably those centred upon 25 November (Figure A2) and 6 December 2007 (Figure A3).

Tidal currents are generally well represented, although the modelled data are closer in matching measured peak flood (-0.04 to -0.06m/s) than peak ebb current speeds (-0.16 to -0.17m/s). This disparity in the flood and ebb difference is attributed in part to the effect on the measured data of the wind blowing predominantly from the south and southwest during the survey period. Such wind directions will act to lessen observed flood currents and strengthen ebb currents in the study area.

The differences in tidal directions at the time of peak flow speeds are in the range of 0.7 to 7.1°. These are found to be largely due to relatively small phase differences between the modelled (astronomic only) and field (also including meteorology) data. Overall, the orientation of the tidal axis is well represented with the difference between that modelled and observed being in the order of 1° (Figure A4).

It is noted that the influence of meteorology on the field recorded data is considerable and the difficulty in extracting the pure astronomical signal in this case prevents a fair direct quantification of model performance. Under these circumstances the model's performance has been considered with the meteorological signal included in the field data. As a result, model performance for current speed, at -24%, is just outside (below) the target performance of 20%. This is however considered acceptable as the meteorological influence in the field data tends to increase field recorded current speeds.

Water levels are reproduced to within the required 10% of spring tidal ranges.

The timing of modelled high and low waters is typically within 10 minutes of that measured. However, the time of modelled high waters during neap conditions was approximately 23 minutes earlier than measured. This is again at least partly explained by the persistent south westerly winds present during the observation period, which have the effect of slowing the flooding tide and delaying high water in the study area. Overall, modelled water levels were considered to compare well with the observed data.

Considering the influence of meteorology and the variability that it introduces into the field records, the tidal model is viewed as meeting the standard performance required to be deemed fit for purpose.

The validation exercise shows that the model is providing a close representation of the naturally occurring processes, within the range of natural variability. It is accepted that such a model will not always provide an exact replication of the measured data, due to the additional complexities and processes contributing to the naturally occurring signal and which are not possible to included or resolve in the type of model used. This is typically due to an inevitable lack of fully detailed data regarding the natural environment, and limitations in the mathematics of our understanding of natural processes which comprise the model.

In the present study, residual errors in the performance of the model have been minimised by the process of calibration and the remaining residual error has been quantified by the process of validation. Model results reported directly in the baseline description are subject to these estimates of error or uncertainty. For the impact assessment, residual uncertainty has been further minimised by using an analysis of relative difference ([scheme] – [baseline]) in the results. Because the same absolute errors are present in both data sets, they cancel out to a large extent, leaving only the signal/effect of the wind farm or operation being considered. The accuracy of the reported differences and so the results informing the impact assessment, are therefore better than the absolute accuracy of the baseline model.

A4. Wave Model

The wave model is driven by surface winds obtained from the Climate Forecast System Reanalysis (CFSR), developed by NOAA's (the National Oceanographic and Atmospheric Administration) National Centres for Environmental Prediction (NCEP) (Saha *et al*, 2010). As such, the wave model includes a spatially varying wind field and relies upon the development of waves over the fetches incorporated into its domain (Figure A1).

ABPmer's standard modelling guidelines for wave processes determine that a model becomes fit for purpose when it performs within the following limits:

- Wave heights and periods are within 15% of field observations; and
- Wave directions are within 20° of field observations.

Model calibration was undertaken using the largest observed event from the survey reported in EMU (2008a). This event lasted for five days and achieved a peak significant wave height (Hs) of 5.5m; two further minor peaks in wave height (4.5m and 1.5m) also occur after the initial five days. The graphical comparison of the model's performance against the observed records is shown in Figure A5 and summarised in Table A5.

Model validation used two other events observed during the survey campaign reported in EMU (2008a). 'Observed Event 1' is the second largest storm in the available data record; 'Observed Event 2' is a period of typical background wave conditions where Hs is less than 1m for several consecutive days. These events are shown graphically in Figure A6 and summarised in Table A6.

Table A5. Wave model calibration performance

Description	Wave Characteristic		
	Event Peak Hs (Model Difference)	Event Mean Tp (Model Difference)	Event Mean Direction Difference
Largest observed event >5 days duration	5.5m (-1.3%)	8.4s (12.9%)	14.5°
Accompanying note: Hs = Significant wave height			

Table A6. Wave model validation performance

Description	Wave Characteristic		
	Event Peak Hs (Model Difference)	Event Mean Tp (Model Difference)	Event Mean Direction Difference
Observed Event 1 (storm) 10 day duration	4.1m (-13.2%)	8.6s (5.3%)	19.3°
Observed Event 2 (background conditions) 6 days	0.6m* (-1.1%)	8.4s (-8.2%)	N/A **
Accompanying note: Hs = Significant wave height * Hs values for Event 2 are mean, not peak ** Measured background condition directions are highly variable (±45°) making direct comparison unsuitable			

Overall, the wave model reproduces storm wave heights well. In particular, the predicted values of Hs are met on the majority of occasions, with the wave predictions typically within 15% of that observed. Peak values are met and the rate of growth and decay of storm events is comparable. Minor differences in the detail of the two signals are apparent but are distributed above and below the measured signal. The model is also shown to be capable of providing a consistent representation of the more frequent low wave height background conditions.

Peak wave periods (Tp) are reproduced well during the observed events, with mean differences no greater than 15.5% and generally less in most cases.

On average, event directionality is represented well with overall directions being reproduced to within 20°. Observed wave directions during background conditions (Observed Event 2) are inherently variable, resulting in a greater degree of difference between the modelled and observed data.

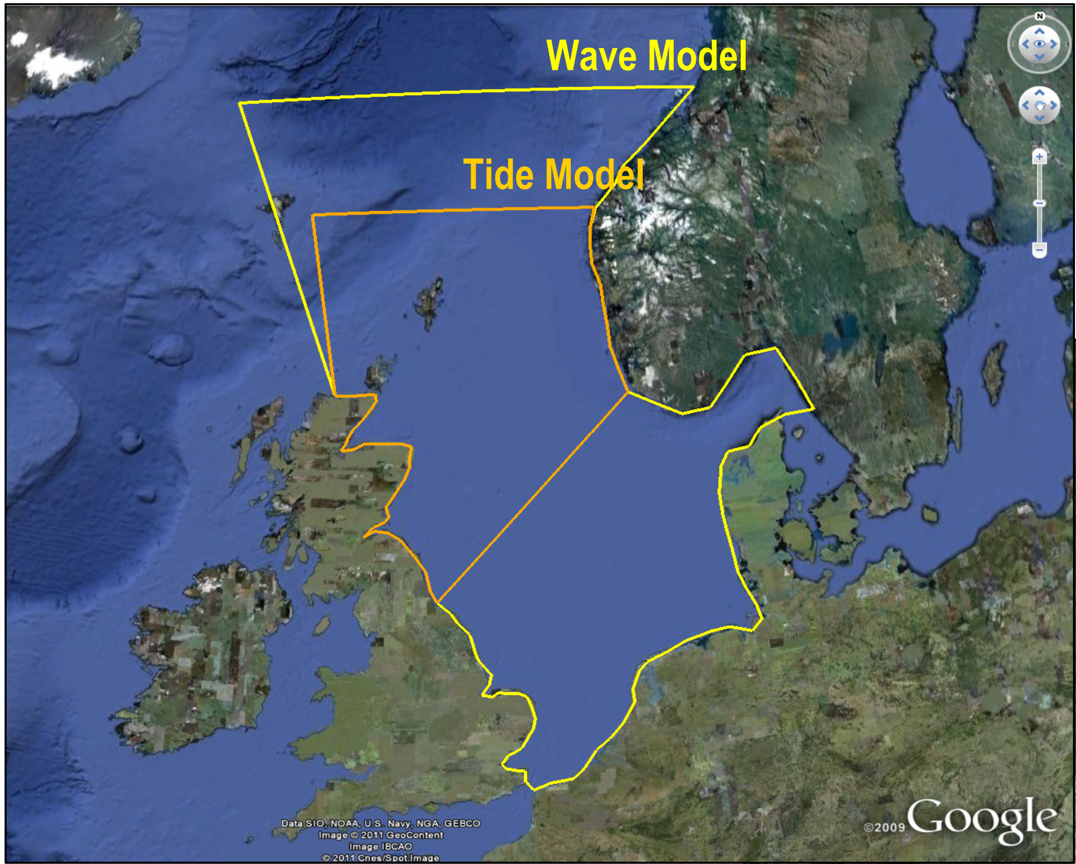
In summary, the wave model is capable of reproducing conditions at the site of interest, with all parameters falling on or within the prescribed limits of 15% Hs and Tp, and 20° wave direction.

The same comments made at the end of the previous section, regarding the accuracy of the tidal model results in their use for understanding the baseline and providing scheme assessment are also valid here.

A5. References

ABPmer 2011 Numerical Model Calibration and Validation Guidance. ABP Marine Environmental Research Ltd, Project File: R.1400/112, April 2011

Saha S., Moorthi S., Pan H.L., Wu X., Wang Ji., Nadiga S., Tripp P., Kistler R., Woollen J., Behringer D., Liu H., Stokes D., Grumbine R., Gayno G., Wang Ju., Hou Y.T., Chuang H.Y., Juang H.M.H, Sela J., Iredell M., Treadon R., Kleist D., Van Delst P., Keyser D., Derber J., Ek M., Meng J., Wei H., Yang R., Lord S., Van Den Dool H., Kumar A., Wang W., Long C., Chelliah M., Xue Y., Huang B., Schemm J.K., Ebisuzaki W., Lin R., Xie P, Chen M., Zhou S., Higgins W., Zou C.Z., Liu Q., Chen Y., Han Y., Cucurull L, Reynolds R.W., Rutledge G. & Goldberg M. 2010. The NCEP Climate Forecast System Reanalysis. Bull. Amer. Meteor. Soc., Submitted.



Bathymetry

5m
0m
-5m
-10m
-15m
-20m
-25m
-30m
-35m

Date	By	Size	Version
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Scale		n/a	
QA		APW	
3890-Figure-control_110411.xls			
Produced by ABPmer Ltd.			

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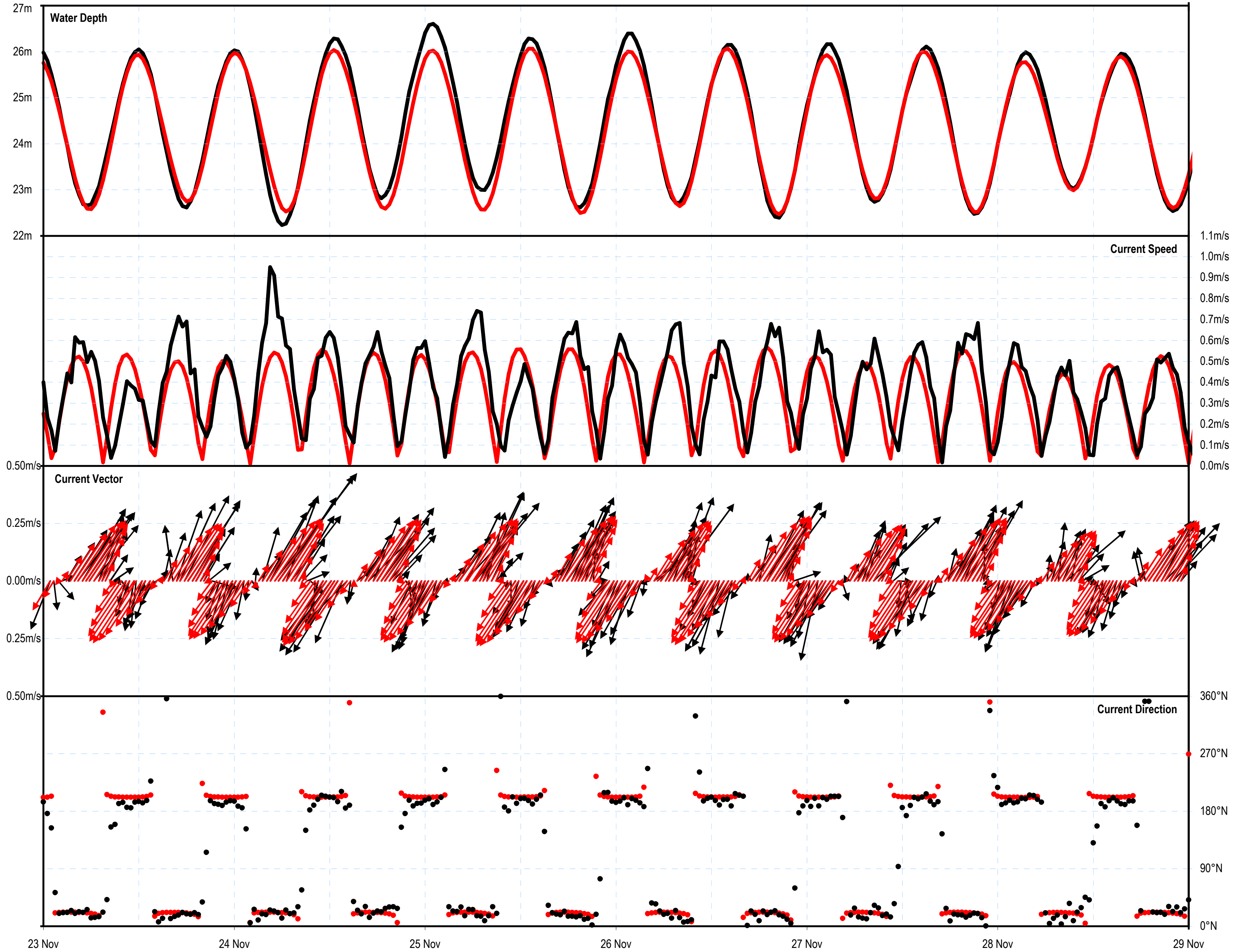
Tide and wave model domain extents

Figure A1



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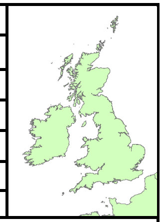

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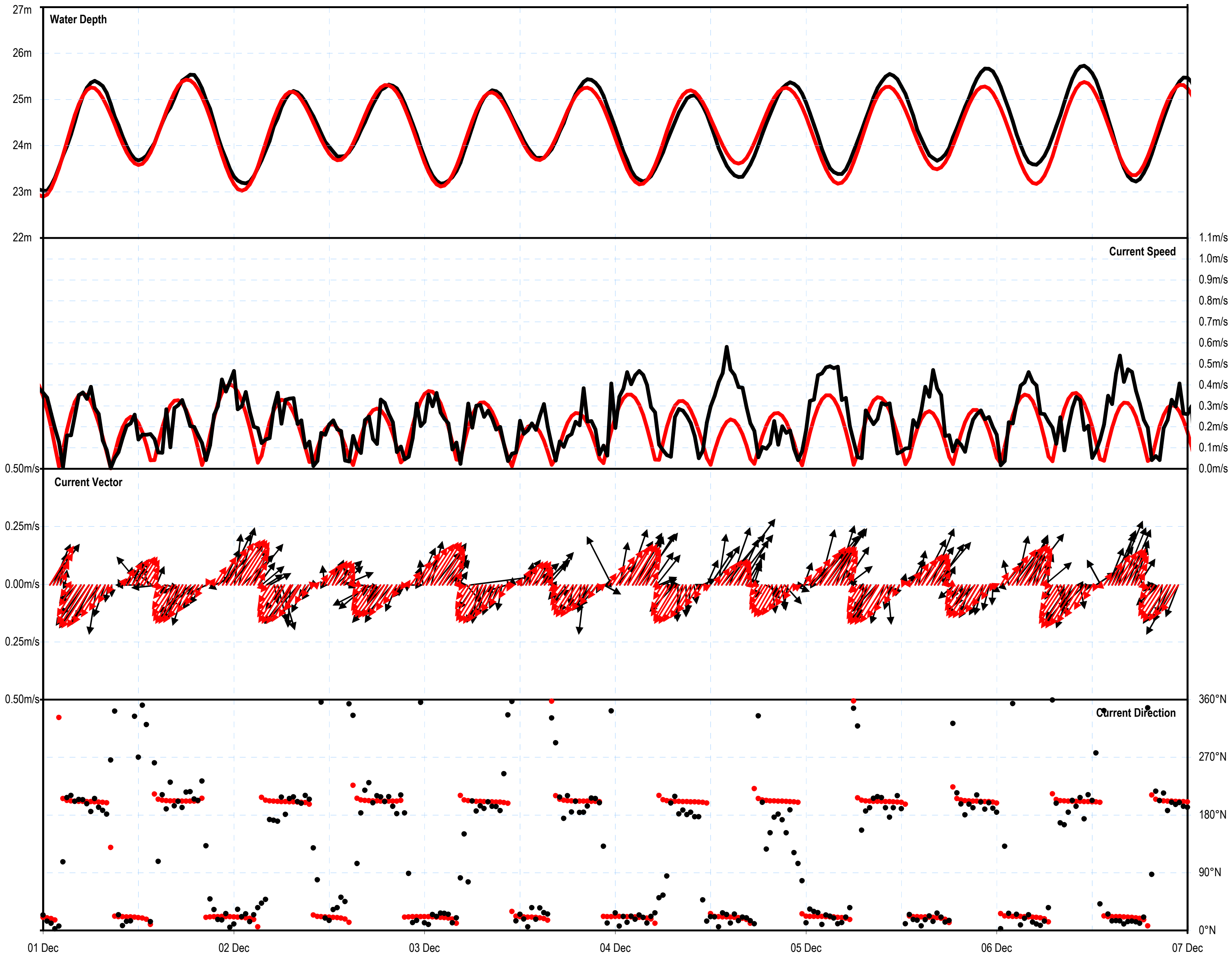
Tidal model calibration performance (Spring Tides)

Figure A2



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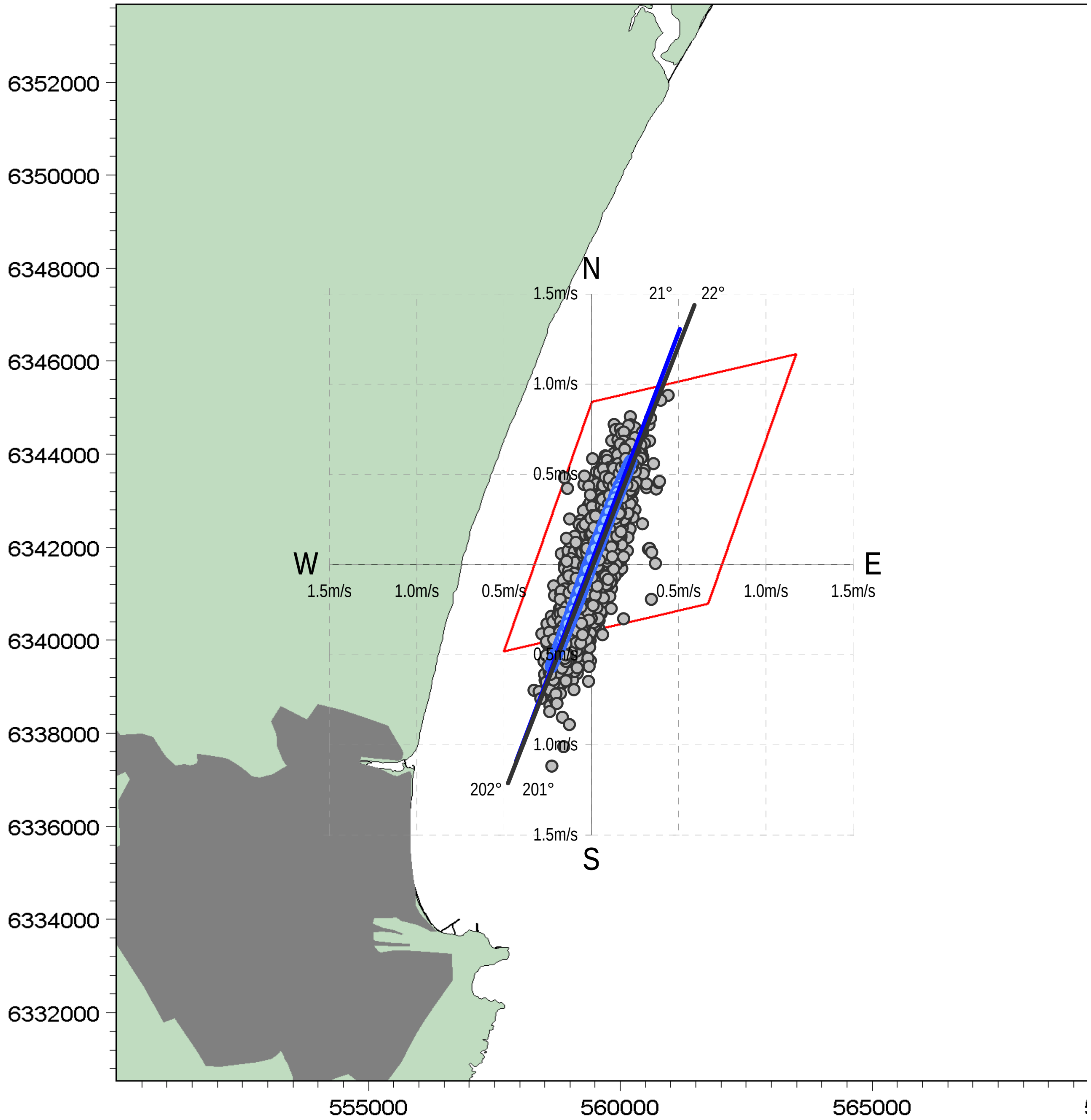
Tidal model validation performance (Neap Tides)

Figure A3



Lease boundary
AWAC current
Model current
AWAC tidal current axis
Model tidal current axis

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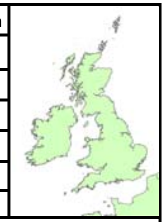

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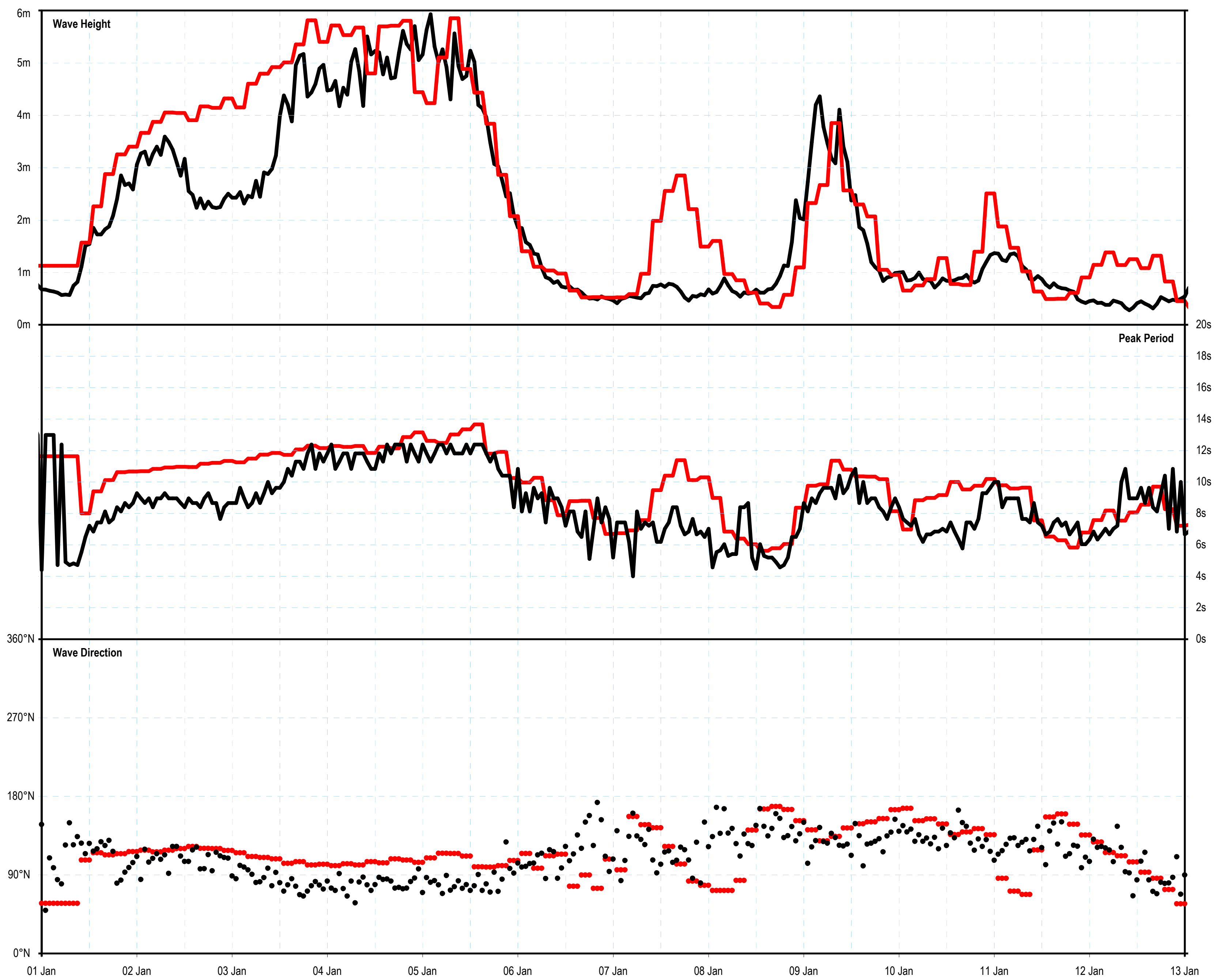
Comparison of tidal axes (all tides)

Figure A4



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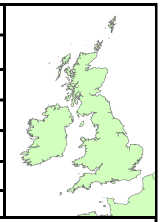

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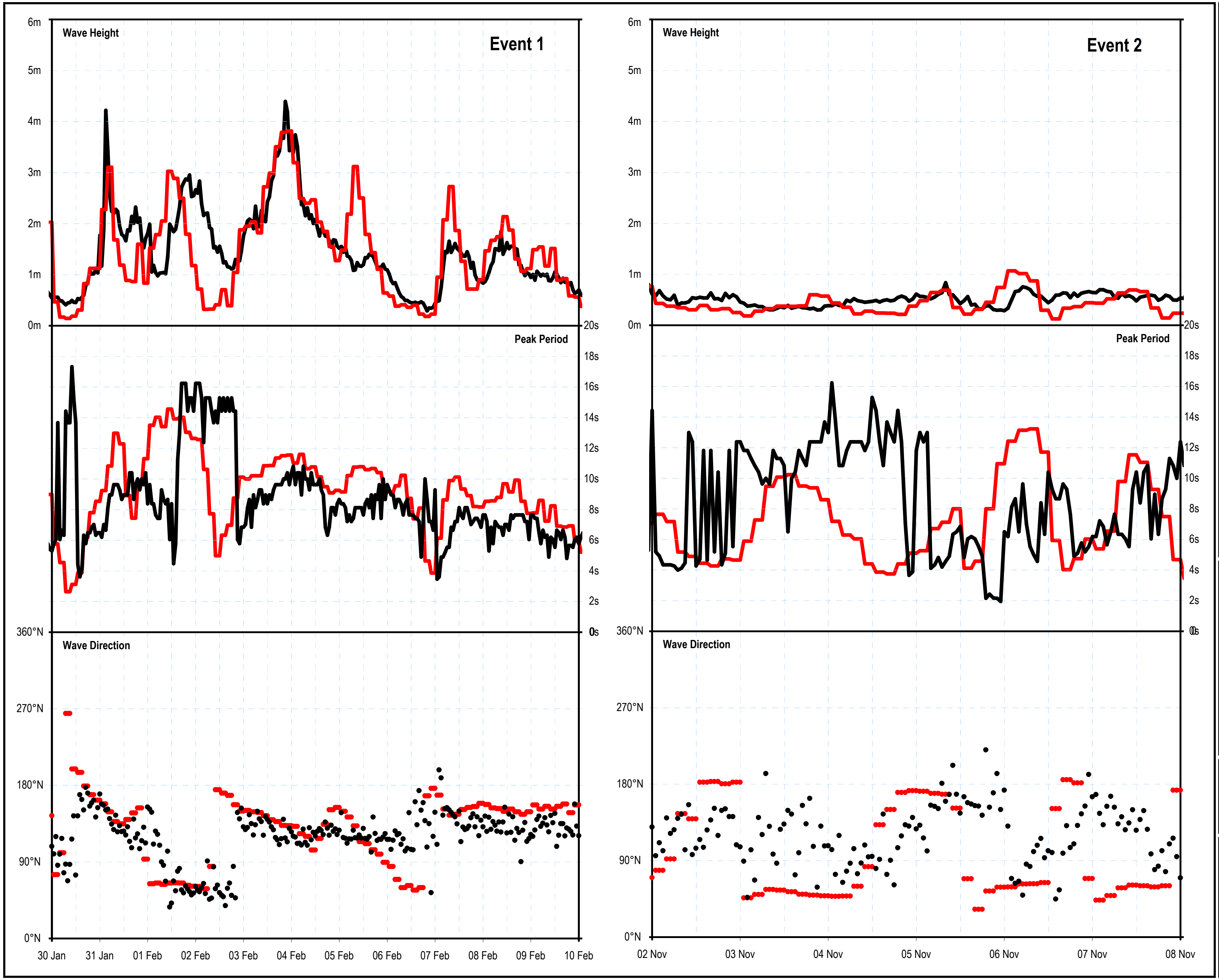
Wave model calibration performance

Figure A5



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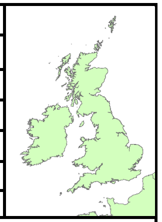

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Wave model validation performance (two conditions)

Figure A6

Appendix B

Scour Issues

Appendix B. Scour Issues

B1. Introduction

The term scour refers here to the natural development of pits, troughs or other depressions in the seabed sediments around the base of the turbine foundations. Net sediment removal over time results from complex three-dimensional interaction between the obstacle and ambient flows (currents and/or waves) producing local patterns of mean flow acceleration or increases in levels of turbulence that enhance sediment transport potential. The resulting dimensions and rate of scour are, generally, dependent upon:

- The characteristics of the obstacle (dimensions, shape and orientation);
- The characteristics of the ambient flow (depth, magnitude, orientation and variation including tidal currents, waves, or combined conditions); and
- The characteristics of the seabed sediment (geotextural and geotechnical properties).

Based on the existing literature and knowledge base, an equilibrium depth and pattern of scour can be empirically predicted for given combinations of the above parameters with varying levels of confidence. Natural variability in the above parameters means that the equilibrium scour condition may also vary over time; the time required to initially achieve a near equilibrium scour condition is also dependant on these parameters and may vary from hours to years.

Scour assessment for the purposes of Environmental Impact Assessment (EIA) is considered below for five foundation types: monopile; jacket; tripod; gravity base; and, suction caisson structures as given by the project. The potential concern being addressed is the additional area of seabed being modified from its natural state (and impacting sensitive receptors) and the volume and rate of additional sediment resuspension and redistribution as a result of scour. This assessment is an overview of scour potential for these purposes in an EIA and is not intended for use in engineering design or when considering the installation specifications of the structures being assessed.

B2. Equilibrium Scour Depths

The following first-order scour assessment for the European Offshore Wind Development Centre (EOWDC) site is made using the basic assumption that the seabed sediments are composed of uniform non-cohesive sediment that is mobile under the ambient wave or current conditions. This is consistent with the baseline understanding where surveys indicate that surficial seabed sediments comprise a layer of shelly, silty, gravelly sand 1-8m in thickness, overlying further layers of coarse shelly sand extending up to 36m below the present seabed surface. Surficial sediments were observed to be mobile in response to both tidal and wave driven processes.

Scheme, foundation and other details are consistent with the main body of the environmental baseline and scheme impact assessment reports and/or have been obtained from the project.

B2.1 Monopiles

Compared to other more complex foundation types, scour around upright slender monopile structures in steady currents is relatively well understood in the literature and is supported by a relatively large empirical evidence base from the laboratory and from the field. The maximum equilibrium scour depth, adjacent to the structure, below the mean seabed level (Sc), is typically proportional to the diameter of the monopile and is therefore expressed in units of monopile diameter (D).

B2.1.1 Under steady currents

Breusers *et al* (1977) presented a simple expression for scour depth under live-bed scour (i.e. scour occurring in a dynamic sediment environment) which was extended by Sumer *et al* (1992) who assessed the statistics of the original data to show that:

$$\frac{S_c}{D} = 1.3 \pm \sigma_{Sc/D} \quad \text{(B1)}$$

Where σSc/D is the standard deviation of observed Sc /D. Based on the experimental data, σSc/D is taken to be 0.7, hence, 95 % of observed scour falls in the range 0 < Sc/D < 2.7. Based on the central value Sc = 1.3 D (as also recommended in DNV, 2004), the maximum equilibrium depth of scour for an 8.5 m diameter monopile is estimated to be 11.05 m.

Observations of scour under uni-directional current conditions show that the upstream slope of the hole is typically equal to the angle of internal friction for the exposed sediment (typically 32º from horizontal in sands); the downstream slope is typically less steep. In reversing (tidal) current conditions, both slopes will develop under alternating upstream and downstream forcing and so will tend towards the less steep or an intermediate condition.

B2.1.2 Under waves and combined wave-current forcing

The mechanisms of scour associated with wave action are limited when the oscillatory displacement of water at the seabed is less than the length or size of the structure around which it is flowing. This ratio is typically parameterised using the Keulegan-Carpenter (KC) number:

$$KC = \frac{U_{0m} T}{D} \quad \text{(B2)}$$

Where U_{0m} is the peak orbital velocity at the seabed and T is the corresponding wave period. Sumer & Fredsøe (2001) found that for KC < 6, wave action is insufficient to cause significant scour in both wave alone and combined wave-current scenarios. Using relationships from Soulsby (1997) to derive wave parameters and KC from the extreme wave conditions at the EOWDC site (reported in the baseline report and used in this assessment report), typical values of KC for an 8.5m diameter monopile are < 6 and so no additional scour is predicted as a result of the contribution of waves, either alone or in combination with currents.

B2.2 Jackets

The substructure comprises a lattice of diagonal cross-member bracing, typically 1.2m in diameter; horizontal cross-member bracing is also present at the base, and this is assumed to be located 1m above the initial seabed level. The jacket frame will have a nominally square cross-section with base dimensions of approximately 25m x 25m. The frame is anchored to the seabed at each corner by a circular pile, typically 2.5m in diameter.

Such a structure may result in the occurrence of both local and global scour. The local scour is the local response to individual structure members, via the scour mechanisms described previously for monopiles. Global scour refers to a region of shallower but potentially more extensive scour resulting from:

- The change in flow velocity in the gaps between the members of the jacket structure; and
- The turbulence shed by the structure as a whole.

B2.2.1 Under steady currents

Under currents alone, the equilibrium scour depth around the vertical members of the structure base can be assessed using the same methods as were used for monopiles, unless significant interaction between individual members occurs. In the case of currents, inter-member interaction has been shown to be a factor when the gap (G) to pile diameter ratio (G/D) is less than 3; limited experiments by Gormsen & Larson (1984) have shown that, in this case, the scour depth might increase by between 5-15%. The gap ratio for members at the base of this jacket structure is much greater than 3, and so no significant in-combination effect is expected and the same empirical relationships used for monopiles can be used again here. Using equation B1 yields an equilibrium scour depth under steady currents of approximately 3.25m around the corner piles.

Horizontal cross-members suspended above the seabed between the corner piles also induce some degree of scour due to turbulence shedding and localised flow contraction. The depth of the resulting scour is a function of both the member diameter and the gap between it and the seabed and can be estimated using the following first-order empirical approach by Hansen *et al* (1986) for pipelines of diameter (D_p), with clearance above the bed (e):

$$\frac{Sc}{D} = 0.625\, e^{-0.6(gap/D)} \qquad \text{(B3)}$$

Yielding a scour depth of approximately 0.45m.

Empirical relationships presented in Sumer & Fredsoe (2002) indicate that global scour (measured from the initial sediment surface to the new sediment surface surrounding local scour holes) for an array of piles similar to a jacket (2 x 2) is approximated as 0.4D (i.e approximately 1m based on 2.5m corner pile diameter).

B2.2.2 Under waves and combined wave-current forcing

Under waves alone, the diameter of individual members is smaller than that of the monopile structure and as a result, the value of KC increases (equation B2). Using relationships from Soulsby (1997) to derive wave parameters and KC from the extreme wave conditions used in this assessment report, typical values of KC at the EOWDC site for the tripod foundation corner piles and cross-member bracing. The scour depth predicted to result from wave action is of the order 0.5m, i.e. much less than that predicted under steady currents (3.25m). As a result, it is considered likely that little significant additional scour will result from the contribution of waves, either alone or in combination with currents, during large storm events.

Under dominantly wave forcing, the equilibrium scour depth underneath horizontal members can be estimated using the following first-order empirical approach by Hansen *et al* (1986):

$$\frac{Sc}{D} = 0.1\sqrt{KC}\; e^{-0.6(gap/D)} \qquad \text{(B4)}$$

Yielding cross-member scour depths of 0.2 to 0.43m for the range of extreme wave conditions that are likely to be experienced during the lifetime of the development.

In conjunction, the predicted local scour at the corner piles (3.25m), the cross-member scour (0.45m) and the global scour (1m) is conservatively consistent with evidence from the field reported in Whitehouse (1998), summarising another report that scour depths of between 0.6 and 3.6m were observed below jacket structures in the Gulf of Mexico.

B2.3 Tripods

The substructure comprises a framework of cross-member bracing, typically 4m in diameter; horizontal cross-member bracing is present at the base, and this is assumed to be located 1 m above the initial seabed level. The tripod frame will have a nominally equilateral triangular base cross-section with a base edge length scale of approximately 35m. The frame is anchored to the seabed at each corner by a circular pile, typically 2.5m in diameter.

Such a structure may also result in the occurrence of both local and global scour (as described in the previous section). Empirical results are only available for a square array of piles, so the relationship used for the jacket (for a 2 x 2 array) is conservatively applied here also, yielding approximately 1m of global scour based on a 2.5m diameter corner pile.

B2.3.1 Under steady currents

The gap ratio for members at the base of this jacket structure is again greater than 3, and so no significant in-combination effect is expected and the same empirical relationships used for monopiles can be used again here. Using equation B1 yields an equilibrium scour depth under steady currents of approximately 3.25m around the corner piles.

Horizontal cross-members suspended above the seabed between the corner piles are larger that previously considered for jackets. Using equation B3, the equilibrium scour depth under currents is estimated as 2.15m.

B2.3.2 Under waves and combined wave-current forcing

Typical values of KC at the EOWDC site for the tripod foundation corner piles and cross-member bracing are > 6. The scour depth predicted to result from wave action is of the order 2.2m, i.e. similar to but less than that predicted under steady currents (3.25m). As a result, it is considered possible that some additional scour may result from the contribution of waves, either alone or in combination with currents, during large storm events. Any additional scour beyond the equilibrium value for currents will likely be infilled by natural processes over a relatively short period of time (order of a few tidal cycles).

Using equation B4, the equilibrium scour depths under waves are estimated to be 0.5 to 2.25m under the range of expected extreme conditions.

B2.4 Gravity Base

The foundation is a broad round base, tapering upwards to a monopile like section in the middle or upper water column. The base diameter for the present study is approximately 40m.

The knowledge base for scour associated with gravity base structures is relatively limited in comparison to that for monopiles and tends to refer to oil and gas platforms which have a diverse range of shapes and designs. Attempts to produce empirical relationships are complicated by this diversity of 'gravity base' structures.

Empirical results from physical model testing by Whitehouse (2004) suggest that the maximum scour depth around a conical top gravity base (broadly similar to that proposed at the EOWDC site) under combined wave-current conditions was 0.45Dc, where Dc is the maximum diameter of the gravity base structure. This would yield maximum scour depths of 18m for the 40m gravity base unit. This is considered to be a very worst case scenario.

Observations using the conical top shape for current alone or waves alone were not made, however, observations were made for a 'girder top' structure, resulting in equilibrium scour depths of 0.18Dc and 0.04Dc, respectively. This would yield somewhat smaller maximum scour depths of 7.2m for currents alone, or 1.6m for waves alone, for the 40m gravity base units. Whitehouse concluded that the scour depth was controlled in part by both the height and diameter of the foundation, which may vary depending upon the final design chosen for the EOWDC site.

The pattern and extent of scouring and the location of the point of maximum scouring may vary depending upon the size and shape of the gravity base. For the purposes of the present assessment, scour is assumed to be present at the predicted depth around the perimeter of the gravity base structure, rising with distance from the base edge to the ambient bed level at the angle of internal friction for the sediment.

B2.5 Suction Caisson

The foundation is similar to the gravity base unit, comprising a broad round base, tapering upwards to a monopile like section in the middle or upper water column. The base diameter for the present study is approximately 20m. A skirt at the outer diameter of the base extends up to 18m below the sediment surface. The part of the base above the sediment surface is shown as having a ribbed or otherwise textured surface which may affect the hydrodynamic properties of the structure, and therefore its potential to scour.

Using Whitehouse (2004) to estimate equilibrium scour depth under combined wave-current conditions yields maximum scour depths of 9m. This is again considered to be a very worst case scenario.

Equilibrium scour depths for 'girder top' structures yield 7.2m for waves alone and 1.6m for currents alone. Again, actual depths may vary depending upon the final design chosen for the EOWDC site, including for example the presence of a smooth or ribbed surface.

For the purposes of the present assessment, the scour is assumed to be present at the predicted depth around the perimeter of the suction caisson structure, rising with distance from the edge of the skirt to the ambient bed level at the angle of internal friction for the sediment.

B3. Factors Affecting Equilibrium Scour Depth

As summarised in Whitehouse (1998), a number of factors are known to influence equilibrium scour depth for monopiles, contributing to the range of observed equilibrium scour depths. These factors include:

- The ratio of monopile diameter to water depth;
- The ratio of monopile diameter to peak flow speed;
- The ratio of monopile diameter to sediment grain size; and
- The sediment grain size, gradation and geotechnical properties of the soil.

These factors have been considered in the context of the EOWDC site and were not found to significantly affect the predicted value for the purposes of EIA. The effect of these factors where they do apply is to reduce the depth, extent and volume of the predicted scour, hence providing a less conservative estimate.

B4. Time for Scour to Develop Around the Foundation Options

Using empirical relationships from Whitehouse (1998) and making the assumption of a mobile uniform non-cohesive sediment substrate, the time required for the majority of scour pit development around all foundations is estimated to be within the order of 6 to 12 hours under flow conditions sufficient to induce scour. Symmetrical scour will only develop following exposure to both flood and ebb tidal directions. Waves typically do not cause rapid initial scour directly but can increase the rate of initial scour development.

B5. Summary of Results

Based on the analysis undertaken above for the five foundation options, Table B1 summarizes the key results of the first order scour assessment, conservatively assuming maximum equilibrium scour depths are symmetrically present around the perimeter of the structure or jacket members in a uniform and potentially mobile sedimentary environment. Derivative calculations of scour extent, footprint and volume assume an angle of internal friction = 32°. As shown, scour extent is measured from the edge of the structure. Scour pit volumes for monopile, gravity base and suction caisson foundations are calculated as the volume of a truncated cone, minus the volume of the structure itself; scour pit volume for the jacket and tripod foundations are calculated as the sum of the scour predicted for corner piles (as for monopiles) and for cross-members near to the bed.

Table B1. Summary of predicted maximum scour depth assuming a uniform, erodible sediment

Parameter	Foundation Option				
	Monopile	Jacket*	Tripod	Gravity Base	Suction Caisson
Equilibrium Scour Depth (m)					
Steady current	11.05	3.25	3.25	7.2	3.6
Waves	Negligible	0.5	2.2	1.6	0.8
Waves and current	≤ 11.05	≤ 3.25	≤ 3.25	18	9
Global scour	N/A	~1	~1	N/A	N/A
Scour extent from foundation** (m)	18	5	5	12	6
Scour footprint** (m^2)	1,455	1,472	1,101	1,865	466
Structure footprint (m^2)	*(57)*	*(20)*	*(15)*	*(1,257)*	*(314)*
Scour volume** (m^3)	6,228	669	1,292	6,214	777
Bed prep. volume (m^3)	*(1,702)*	*(687)*	*(515)*	*(2,513)*	*(0)*

* Bed prep volume negligible if corner piles are inserted without drilling.
** Based upon the scour depth for steady currents. Footprint and volume values per foundation.

Table B1 shows that a greater total volume of sediment can potentially be mobilised by scour than by construction operations such as drill drive installation or gravity base bed preparation.

For comparison, the footprint of contact with the bed and the corresponding volume of sediment involved in bed preparation or drilling operations is also shown for each structure type in Table B1. These values are scaled up in Table B2 by the number of turbines in the site (11) to summarise the total area of seabed directly affected by the each foundation type, with and without the presence of scour; values are also shown as a proportion of the total EOWDC site.

Table B2. Total footprint of the different foundation types with and without scour

Parameter	Foundation Option				
	Monopile	Jacket	Tripod	Gravity Base	Suction Caisson
Footprint on seabed of all devices (m^2)	624	216	162	13,823	3,456
Proportion of total site area (%)	*0.003*	*0.001*	*0.001*	*0.069*	*0.017*
Footprint on seabed of all devices + scour (m^2)	16,625	7,354	12,269	34,339	8,585
Proportion of total site area (%)	*0.083*	*0.037*	*0.061*	*0.172*	*0.043*

Table B2 shows that there is the potential for scour to slightly increase the total footprint of the impact of the foundations on the seabed within the site boundary. However, the area of effect as a proportion of the wind farm site as a whole remains relatively small and is a much smaller proportion again of all the available seabed area of this type in the regional area.

B6. Concluding Remark

The gravity base structure has the potential to cause the largest impact due to the large size, volume and surface area of the foundation. However, this depth is unlikely to be attained due to the sub-surface geology with a till surface (termed the Wee Bankie Formation) at, approximately, 10m to 20m below the seabed (Osiris, 2010). This layer can be described as a soft to very stiff very stiff clays with occasional sand and gravel lenses (SEtech, 2009) and therefore based on available evidence is likely to be cohesive and largely erosion resistant. It may also be possible that the presence of this layer may act to slow scour rather than halt it. Group scour is expected to be minimal and the risk for global scour negligible.

The time required for the majority of scour pit development around all foundations within the EOWDC is estimated to be within the order of 6 to 12 hours, under flow conditions sufficient to induce scour. This takes the assumption of a mobile uniform non-cohesive sediment substrate. Symmetrical scour will only develop following exposure to both flood and ebb tidal directions. Waves do not typically cause rapid initial scour directly, but can increase the rate of initial scour development.

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