9 WIND FARM PHYSICAL PROCESSES AND GEOMORPHOLOGY

9.1 INTRODUCTION

1. This Section of the ES evaluates the likely significant effects of the Beatrice Offshore Wind Farm on physical processes in the marine environment and includes effects on water levels, currents, waves, sediment transport and geomorphology. The assessment has been undertaken by ABP Marine Environmental Research Ltd (ABPmer) and includes an assessment of cumulative effects.

2. This Section of the ES is supported by the following documents:

- Annex 9A: Baseline Characterisation;
- Annex 9B: Model Calibration and Validation;
- Annex 9C: Scour Assessment. ; and
- Annex 9D: Landfall Assessment.

3. This Section includes the following elements:

- Assessment Methodology and Significance Criteria;
- Baseline Description;
- Development Design Mitigation;
- Assessment of Potential Effects;
- Mitigation Measures and Residual Effects;
- Summary of Effects ;
- Assessment of Cumulative Effects;
- Statement of Significance; and
- References.

9.1.1 POLICY AND PLANS

4. The following policy, guidance and best practice documents have been considered in the preparation of this physical processes baseline and impact assessment.

- 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);
- Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects (CEFAS, final draft, 2011);
- 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: Best Practice Guidance (COWRIE, 2009);

- Consenting, EIA and HRA Guidance for Marine Renewable Energy Deployments in Scotland. Report commissioned for Marine Scotland' (EMEC & Xodus AURORA, 2010); and
- Overarching National Policy Statement for Energy (EN-1) (Department of Energy and Climate Change, 2011).

9.2 *ASSESSMENT METHODOLOGY AND SIGNIFICANCE CRITERIA*

9.2.1 CONSULTATION

5. A proposed assessment methodology was provided to Marine Scotland for comment (ABPmer, 2010). Subsequent telephone discussions and written responses confirmed that the proposed methodology was considered appropriate and fit for purpose. The importance of considering cumulative effects was reaffirmed. Table 9.1 provides a summary of consultation undertaken as part of the EIA.

Table 9.1 Summary of Consultation Undertaken

Consultee	Summary of Consultation Response	Project Response
Marine Scotland	The effect of the cabling infrastructure on local (inc. intertidal mudflat) habitats. However, temporary and localised nature of any effect is acknowledged.	Effects on designated coastal sites are set out in Sections 9.5.5.2, 9.5.6.2 and 9.5.7.2.
Scottish Natural Heritage (SNH), JNCC, RSPB	The effect of the wind farm on the extent, distribution, function or structure of designated marine and coastal habitats (SACs and SPAs).	Effects on designated coastal sites are set out in Sections 9.5.5.2, 9.5.6.2 and 9.5.7.2.
Maritime and Coastguard Agency (MCA)	Depth of cable burial requires consideration.	The depth of cable burial will be chosen as part of the cable route design. This chapter provides an assessment of the effects of cable burial and describes the resulting effects if it should become exposed.
Marine Scotland , SNH, JNCC, RSPB, MCA	Cumulative and in-combination effects of this and other developments	Cumulative and in-combination effects are set out in Section 9.8.

9.2.2 SCOPE OF ASSESSMENT

6. Consultation responses and other issues identified relating to the construction, operation and decommissioning of the Wind Farm were previously considered in the Scoping Report (BOWL, 2010) and Scoping Opinion response from Marine Scotland issued in 2010. The following potential issues or effects were identified.

9.2.2.1 *Hydrodynamics (waves and currents)*

- Effects upon the extent, distribution, function or structure of marine and coastal habitats (SACs and SPAs, especially the East Caithness Cliffs SPA); and
- Changes in the set and rate of the tidal stream.

9.2.2.2 *Sediment dynamics (changes to sediment transport pathways, suspended sediment concentrations and resulting sediment deposition)*

- Effects upon the extent, distribution, function or structure of marine and coastal habitats (SACs and SPAs);
- Effects upon sites of potential archaeological interest; and
- Potential for changes in sediment mobility that might affect navigable water depth.

9.2.2.3 *Footprint of seabed lost (footprint of foundations, of scour around foundations and of installation vessels)*

- Effects upon the extent, distribution, function or structure of marine and coastal habitats (SACs and SPAs).

9.2.2.4 *Cable burial*

- Concern regarding effects on local (including intertidal mudflat) habitats. However, temporary and localised nature of any effect is acknowledged; and
- MCA - Concerns regarding depth of cable burial.

7. The importance of considering cumulative effects was noted in relation to a wide range of issues.

9.2.3 GEOGRAPHICAL SCOPE

8. This study considers both near-field (i.e. onsite and local) and far-field (i.e. regional) effects of the Wind Farm. In the context of physical processes, near-field refers to the area within the Wind Farm site where structures or operations in the Wind Farm interact directly with the marine environment and cause the greatest magnitude of effect. Far-field refers to areas outside of the Wind Farm site where pathways exist for an effect to be translated to a distant sensitive receptor.

9. The geographical scope of the modelling tools used in the present study was also chosen to encompass a sufficiently large area that both the baseline environment and the full extent of any effects of the Wind Farm are adequately simulated and fully contained within the model domain.

10. The geographical scope of the study therefore includes both Inner and Outer parts of the Moray Firth and a large area of the northern North Sea (including the Pentland Firth for tides and the largest open fetches for waves).

9.2.4 PHYSICAL PROCESS RECEPTORS

11. A summary of the identified physical environment receptors is provided in Table 9.2 below and shown in Figure 9.1.

Table 9.2 Identified Physical and Coastal Process Receptors

Receptor	Designation	Description
Smith Bank	(None)	A submerged bathymetric high in the Outer Moray Firth, covered by a veneer of sands and gravels of variable thickness and proportion.
Loch of Strathbeg	SPA and Ramsar	Marshes, reedbeds, grassland and dunes.
Troup, Pennan and Lion's Heads	SPA	Seacliffs, occasionally punctuated small sand or shingle beaches.
The Moray and Nairn Coast	SPA and Ramsar	Intertidal flats, saltmarsh and sand dunes.
The Inner Moray Firth	SPA and Ramsar	Extensive intertidal flats and smaller areas of saltmarsh.
Cromarty Firth	SPA and Ramsar	Extensive intertidal flats and salt marsh.
The Dornoch Firth	SPA and Ramsar	Large estuary containing extensive sandflats and mudflats, backed by saltmarsh and sand dunes.
The East Caithness Cliffs	SPA	Old Red Sandstone cliffs, generally between 30 to 60 m high, rising to 150 m at Berriedale.
The Inner Moray Firth	SAC	Intertidal flats, saltmarsh and sand dunes.
Dornoch Firth	SAC	Extensive areas of mudflats and sandflats. Subtidally, the Firth supports rich biogenic reefs.
Berriedale and Langwell, Oykel, Morriston and Spey	SACs	(Riverine systems emptying into the Moray Firth).
Culbin Bar	SAC	Extensive dunes, vegetated shingle and salt meadows.
Buchan Front	(Tidal front)	Vertical stratification front.
Skirza Freswick Bay Lossiemouth Sandend Bay Banff Beach Fraserburgh St Combs to Inverallochy	(Surf beaches)	Sandy beaches (with particular wave climate).

Receptor	Designation	Description
Keiss Sinclair's Bay Ackergill Spey Bay Cullen Boyndie Bay Widemans Phingask West Point	(Surf beaches)	Sand/ shingle beaches (with particular wave climate).
Sunnyside Bay Pennan	(Surf beaches)	Rocky beaches (with particular wave climate).

9.2.5 BASELINE SURVEY METHODOLOGY

12. A detailed baseline study has been undertaken and is reported in Annex 9A: Baseline Characterisation (ABPmer 2011a).

9.2.5.1 Metocean Surveys

13. Two seabed frames were simultaneously deployed between February and June 2010, in the north eastern and south western ends of the Wind Farm site (Figure 9.2). Each frame contained an acoustic profiling instrument, an optical backscatter sensor and a sediment trap, collecting (typically) time series measurements of:

- Water levels;
- Current speed and direction profiles;
- Wave parameters (various heights, periods, directions);
- Temperature;
- Turbidity; and
- (samples of) sediment in suspension.

14. Four similar seabed frames were also deployed within the Moray Firth Round 3 Zone and these data were made available to BOWL for use. A number of previously collected single-point current meter data sets from other locations within the Moray Firth were also obtained from the British Oceanographic Data Centre. Coincident water level measurements from the nearby Wick tide gauge were also obtained from the National Tide and Sea Level Facility.

15. In addition to the wave data collected by the seabed frames, a directional wave buoy was also deployed at the north eastern end of the Wind Farm site between February 2010 and March 2011, collecting time-series measurements of:

- Wave parameters (various heights, periods, directions); and
- Temperature.

16. Three similar but separately managed wave buoys were also located nearby, namely: the Jacky Platform buoy, near to the south western end of the Wind Farm site; the Moray Firth WaveNet buoy, approximately 32 km further south west into the Moray Firth; and the buoy on the eastern margin of the Moray Firth Round 3

Zone. By providing coincident information, these data sets complement each other, quantifying the patterns of spatial variability in wave conditions within the Moray Firth in response to given wind conditions.

17. Measurements of wind speed and direction (important in driving the wave regime) were obtained from the Wick Airport meteorological station.

9.2.5.2 Geophysical and Geotechnical Surveys

18. High-resolution multi-beam echo sounder and sidescan sonar data were collected in April and May 2010. These data are used to identify surficial bathymetric features and seabed type distribution within the Wind Farm site.

19. At the same time, subsurface (seismic) geophysical measurements were also made and interpreted in conjunction with twenty-five boreholes in the Wind Farm site. The resulting maps infer, in three-dimensions, the shallow subsurface geological structure of Smith Bank in the vicinity of the Wind Farm site.

20. Surface and subsurface geophysical data (plus six boreholes) were collected from within the Moray Firth Round 3 Zone eastern development area. Similar data collection was also undertaken in the western development area but with less than 100% spatial coverage. These data were made available to the Wind Farm project team.

9.2.5.3 Sediment Grab Sample Surveys

21. Surveys of the benthic environment comprised approximately 100 grab samples from the Wind Farm site and its surroundings (Figure 9.3). Particle Size Analysis (PSA) of the sediments recovered, in conjunction with the geophysical survey data, informs a quantitative understanding of the distribution of surficial sediment.

9.2.5.4 Drop Down Camera Surveys

22. Drop down camera images were also collected as part of the benthic survey. These images provide additional qualitative information about fine scale (less than 1 m length scale) sediment type and bedforms within the Wind Farm site not resolved by the geophysical survey.

9.2.5.5 Previously Collected or Created Data

23. Previously collected data or other secondary data were obtained from external sources to inform the wider regional understanding of physical processes in the Moray Firth. In addition to those sources outlined in the previous Sections, these include the following:

- Regional scale bathymetry data from various sources (UK Hydrographic Office, TCARTA, and the General Bathymetric Chart of the Oceans GEBCO);
- Surge water level and current statistics (Proudman Oceanographic Laboratory);
- Hindcast wind and wave conditions in the general vicinity of the Wind Farm site (Met Office);
- Statistics of near-surface suspended sediment concentration (SSC) interpreted from MODIS satellite data archives (Dolphin et al, 2011);

- Assessments of the geological character and history of Smith Bank and the Moray Firth, including inferred patterns of sediment transport (Holmes et al 2004);
- Seabed PSA data (British Geological Survey (BGS) archives); and
- Maps of broad surficial sediment type distribution (BGS).

9.2.6 EFFECT ASSESSMENT METHODOLOGY

9.2.6.1 Worst Case Scenario

24. The complete range of options being considered for the Wind Farm is provided in Section 7: Project Description. In relation to physical processes, the worst case will vary depending upon the effect in question. The development parameters considered for each effect assessed in this Section are set out in Table 9.3.

Table 9.3 Worst Case Scenarios Tested

Potential Effect	**Worst Case Scenarios Assessed***
Wind Farm: Construction and Decommissioning Phases	
Increase in suspended sediment concentrations as a result of foundation installation activities Accumulation of sediment and change of sediment type at the seabed as a result of foundation installation activities	Dredging overspill (silts and clays) at 30 kgs^{-1} during GBS bed preparation, 95 m pit diameter, 5 m pit depth, 3.6 MW layout. Drill arisings (sands, silts and clays) at 26 kgs^{-1} during installation of pin piled jacket foundations, 4 pin piles, 3.0 m diameter, 60 m burial**, 3.6 MW layout.
Increase in suspended sediment concentrations and sediment deposition as a result of inter-array cable installation activities	Trenching by energetic means (e.g. jetting). Single trench with cross-section of disturbance 2.5 m deep by 3 m wide in 'V' shaped profile, 100% of material re-suspended.
Indentations left on the seabed by jack-up vessels and large anchors	Jack-up legs 30 m^2 footprint. Anchors 2 to 3 m length scale.
Wind Farm: Operational Phase	
Changes to the tidal regime due to the presence of the turbine foundations Changes to the wave regime due to the presence of the turbine foundations Changes to the sediment transport regime and geomorphology, due to the presence of the turbine foundations	GBS, 3.6 MW layout (277 turbines); Jacket, 3.6 MW layout (277 turbines).
Scour effects due to the presence of the turbine foundations	All foundation types and layouts
Scour effects due to the exposure of inter-array cables and cable protection measures	Inter-array cables and cable protection measures

* More than one worst case scenario has been assessed for certain potential effects in order to underpin and inform the assessments of other EIA topics within this ES.

** Dimensions of pin piles from an earlier stage in the project design. These values provide a more conservative (17% larger) assessed total sediment volume than the final values described elsewhere in this document.

9.2.6.2 Numerical Modelling

25. A number of calibrated regional scale numerical modelling tools were created to inform the present study and are described in more detail in a separate report (Annex 9B: Model Calibration and Validation, ABPmer 2011b). The modelling tool types developed include:

- MIKE 21 HD – Tidal model (water level, current speed and direction);
- MIKE 21 SW – Spectral wave model (wave height, period and direction); and
- MIKE 21 PA – Sediment plume dispersion.

26. The tidal and wave models utilise a flexible mesh approach (the domain is divided into a field of interlocking triangles of variable size) so that the near-field is resolved in much higher spatial detail (order 300 m), gradually decreasing with distance from the areas of most interest.

27. These models were developed and applied in accordance with the best practice guidance provided in COWRIE (2009). The design of the models and the levels of calibration and validation achieved are reported in Annex 9B: Model Calibration and Validation (ABPmer 2011b). The tidal and wave models achieved a good level of calibration and were validated satisfactorily against the available measured data. These models are therefore considered to be fit for purpose of describing spatial and temporal variability of the parameters of interest within the study area.

28. The tidal and wave model domains both include a large area of the northern North Sea. In the tidal model, this is needed in order to correctly resolve the progression of the tidal wave, especially through the Pentland Firth which has an important control on the tidal regime near to the Wind Farm site. In the wave model, this is needed in order to adequately account for the longest fetch lengths, over which the largest waves to affect the Wind Farm site are developed.

29. The plume dispersion model utilises the current speed and direction time-series map output from the tidal model to advect and disperse particles representative of discrete packages of sediment. Many (hundreds of thousands of) particles are introduced into the model according to the prescribed location, rate and duration of the release scenario. Particles are assigned settling and resuspension threshold characteristics that make them representative of the sediment fraction of interest. The resulting levels of SSC and deposition thicknesses are then inferred from the distribution of the particles in the model domain.

30. The effect of the presence of the Wind Farm structures (foundations) was also represented within the models. This was achieved (consistently with previous studies of this type) using a subgrid scale parameterisation of the foundation type and size. The tidal and wave models accept inputs of the locations and dimensions of the structures, and then introduce a proportional amount of additional friction or energy loss within the corresponding grid cell.

31. The ability of the numerical models to provide a completely accurate simulation of the hydrodynamic regimes is inherently limited by the quantity and quality of the input data, and the necessary simplifications and assumptions made by the model in comparison to the complete range of real-world complexity and detail. Uncertainty in estimating the effect of the Wind Farm foundations on water levels, waves and currents is initially reduced by calibrating and then quantified by validating the model. Uncertainty is minimised further by expressing the effect as the difference between the baseline and with scheme scenarios, so that the residual uncertainty in the underlying model is present in both and is therefore cancelled out. Best practice guidance in this respect is provided in COWRIE (2009) and has been followed in the present study.

32. A number of other numerical tools (spreadsheet based models) have also been applied in the present study to provide a conservative estimate of the thickness of sediment accumulation or levels of SSC where the effects are localised to a scale smaller than the resolution of the regional models (order 1 to 10s of metres and order of seconds to minutes of effect).

9.2.7 SIGNIFICANCE CRITERIA

33. The assessment of effects has been made in accordance with the terminology, methods and criteria presented in Section 4: Environmental Impact Assessment Process and Methodology.

34. The magnitude of any potential effects is (subjectively) assessed on a quantitative basis in terms of:

- Its magnitude relative to the range of baseline variability; and
- Its spatial and temporal scales.

35. Where the magnitude of an effect is not predicted to cause the range of baseline variability to be exceeded, the effect is considered to be of a small magnitude and therefore not significant, irrespective of the nature of the receptor.

36. Where the magnitude of an effect is predicted to exceed the range of baseline variability, the value, sensitivity or importance of each receptor within the spatial and temporal extent of the effect is also objectively considered, to obtain the corresponding level of significance. As set out in Section 4: Environmental Impact Assessment Process and Methodology, only those effects considered to be moderate or major significance are considered to be significant in terms of the EIA Regulations.

9.2.8 ASSESSMENT LIMITATIONS

37. Uncertainty and limitations in relation to the use of numerical modelling tools is discussed below.

38. The ability of the numerical models to provide a completely accurate simulation of the hydrodynamic regimes is inherently limited by the amount and quality of input data, and the necessary simplifications and assumptions made by the model in comparison to all real-world complexity and detail. Uncertainty in estimating the effect of the Wind Farm foundations on water levels, waves and currents is initially

reduced by calibrating and then quantified by validating the model. Uncertainty is reduced further by expressing the effect as the difference between the baseline and with scheme scenarios, so that the residual uncertainty in the underlying model is present in both and is therefore cancelled out. Best practice guidance in this respect is provided in COWRIE (2009) and has been followed in the present study.

39. The consequential effect on sediment transport however can only be inferred through the application of sediment transport relationships, which are known to be much less accurate (typically within one order of magnitude). The accuracy of any single relationship may be limited by the nature of the input data used to develop it, or, it may exclude the additional complex effect of specific other factors present in the field (e.g. bed armouring, bioturbation, biostabilisation). Assessment of overall or net effects will therefore not be explicitly modelled, but will be undertaken in a relative and qualitative sense, with reference to the magnitude and sign of any changes to the driving factors and the conceptual understanding of sediment pathways and processes.

40. In relation to sediment release scenarios, some uncertainty remains as to the actual machines or methods that might be employed to undertake dredging or drilling. The actual rate of the sediment release may vary accordingly (up or down), potentially affecting the resulting levels of SSC, but not outside of the range of values previously considered (and accepted) in relation to similar operations routinely undertaken elsewhere.

41. The nature of the dredging overspill or drill arisings is also uncertain. It is conservatively assumed here that the sediments are released as individual grains and so the values of SSC and the distance that material is transported is maximised. In practice, it is more likely that overspill will include coarser sediments and drill arisings will be more 'chunky' in nature, causing them to settle out of suspension faster and reducing levels of SSC. The accumulation thickness adjacent to the operation may however increase as a result. Monitoring review documents (e.g. ABPmer et al 2009) consistently find that the effects of drilling operations are generally not measurable in practice.

42. The actual rate and pattern of dispersion of sediments during cable burial is likely to be variable and dependant upon the actual machine used and the local soil properties. However, review documents (e.g. Royal Haskoning and BOMEL, 2008) consistently find that the effect of cable burial (considering a wide variety of situations) is only a localised and temporary effect.

9.3 BASELINE ENVIRONMENT

9.3.1 SMITH BANK AND THE WIND FARM SITE

43. Smith Bank is located in the immediate proximity of the Wind Farm site and will therefore be subject to any direct effects from the Wind Farm. The form and function of Smith Bank is not directly sensitive to differences in the absolute water level or speed or direction of the current if the modified condition remains consistent with the baseline range of natural variability. However, sufficiently large

and persistent changes to currents may have a net effect over time (in conjunction with the possibility of similar effects on the wave regime) on patterns of net sediment transport (rates and/or directions).

44. Smith Bank is a bathymetric high in the Outer Moray Firth. The main body of the bank is relict and stable, comprising bedrock overlain by poorly sorted stiff clay till sediments, with a variably thick veneer of (occasionally shelly) marine sands and gravels. Smith Bank is therefore not a true sand bank and its overall shape and minimum water depth, etc, will therefore have negligible sensitivity to changes in sediment transport pathways.

45. Sidescan sonar data indicate a predominance of granular surface sediments across the Wind Farm site, except in the shallowest parts near the crest of Smith Bank, where the underlying till is largely exposed with little sediment veneer. PSA data indicate that surface sediments are typically medium sands (250 to 500 μm diameter) with little (i.e. less than 5%) or no measurable content of fines (less than 63 μm). Typically, less than 3% of sediment volume is classed as gravel (greater than 2 mm). However, in 10% of locations, 10 to 20% of the sediment volume, and in a further 10% of locations, 20 to 30% of the sediment volume, may comprise gravels (Figure 9.3).

46. Smith Bank is exposed to semi-diurnal tidal forcing. The mean neap tidal range is 1.4 m, the mean spring tidal range is 2.8 m, and the maximum (astronomical) tidal range is 4 m (Figure 9.4). The tidal current axis is aligned approximately north by north east (ebb) by south by south west (flood). Peak tidal current speeds over Smith Bank are generally 0.25 ms^{-1} during mean neap tides and 0.50 ms^{-1} during mean spring tides. Instantaneous current speeds are generally slightly higher than average (by order of 5 to 10%) at the northern end of the Wind Farm site due to the influence of the Pentland Firth and deeper water, and correspondingly less than average at the southern end (Figure 9.4). Spatial gradients in tidal current speed result in a weak residual transport directed south west or south, into the Moray Firth.

47. Non-tidal surges are known to occur in the Moray Firth, caused by the influence of strong winds and atmospheric pressure gradients associated with storms over the North Sea. Non-tidal surges can cause instantaneous water levels to be up to 1 m above or below the predicted value. Tidal surges also induce a surge current, which will be directed into the Moray Firth. The magnitude of this current will vary depending upon the scale and timing of the surge, but an extreme event may modify normal tidal currents by the order of 1 ms^{-1}. In this area the magnitude of surge currents is predicted to decrease rapidly with distance into the Moray Firth and so the north eastern end of the Wind Farm site will experience the greatest effects.

48. Other non-tidal effects will include the potential for mean sea-level rise as a result of climate change, which is estimated to be 0.08 to 0.14 m over a 25 year period, based on a medium emissions scenario (UKCIP 2009).

49. Smith Bank is also exposed to wave action on a regular basis. Winds blowing from directions from south by south east, clockwise through to north, are only able to act upon the water surface over a relatively limited distance (termed the fetch) within the confines of the Moray Firth. Hence waves from these directions are typically more limited in height and period, in proportion to the distance from the coastline to the site of interest. Winds and hence waves (but of a limited height) most frequently occur from the south west.

50. Much larger waves are observed to come from other directions that have much longer fetches into the North Sea. Over such long distances, distant storms can also drive long period swell waves into the Moray Firth that do not necessarily rely on further local wind input. Key extreme significant wave height (Hs) statistics are provided in Table 9.4.

Table 9.4 Extreme Significant Wave Heights (Hs) for Location 58.25° N 2.86° W

Sector	**Coming Direction (°N)**	**Return Period Value of Hs(m)**			
		1 in 1 yr	**1 in 10 yr**	**1 in 50 yr**	**1 in 100 yr**
N	337.5 to 22.5	6.3	7.2	7.6	7.9
NE	22.5 to 67.5	6.7	8.0	8.9	9.2
E	67.5 to 112.5	6.7	7.5	8.0	8.2
SE	112.5 to 157.5	6.3	7.1	7.6	7.9
S	157.5 to 202.5	4.6	6.0	6.7	7.0
SW	202.5 to 247.5	4.9	5.8	6.4	6.6
W	247.5 to 292.5	4.7	5.6	6.2	6.4
NW	292.5 to 337.5	4.1	5.0	5.5	5.6
Maximum Hs (m)		6.7	8.0	8.9	9.2

51. Based on a theoretical assessment of sediment transport potential using relationships described in Soulsby (1997), tidal currents alone are largely insufficient to mobilise the main body of the marine (medium) sands, except around peak current periods on mean spring range tides or larger (current speeds greater than 0.45 to 0.5 ms^{-1}) (Figure 9.4). The predicted transport rates due to currents alone are in the order of 10-7 to 10-6 $m^3m^{-1}s^{-1}$. A small proportion of finer sands present may be relatively more mobile; gravels will however remain immobile under the full normal range of tidal currents. Evidence of weakly mobile (poorly defined), current induced (asymmetrically crested) bedforms was observed in some of the drop-down camera images and in the results of the multi-beam bathymetric survey (Figure 9.5); however, no consistent modulation in measured SSC (indicative of more energetic sand transport or resuspension of fines) was observed in correlation with semi-diurnal or spring-neap tidal cycles (Figure 9.8).

52. Evidence of wave induced (symmetrical and long crested) bedforms was also observed in some of the drop-down camera images and in the results of the multi-beam bathymetric survey. Modulation in measured SSC (indicative of more energetic sand transport or resuspension of fines) was observed to correlate with

frequently occurring storm events (approximately greater than 4 m Hs, i.e. more frequent than a 10 in 1 year event) (Figure 9.8). In the absence of currents, waves do not result in significant net sediment transport. In conjunction with the typical range of currents present, commonly occurring and extreme waves can theoretically increase the rate of potential sediment transport by one to three orders of magnitude (order of 10^{-6} to 10^{-4} $m^3m^{-1}s^{-1}$).

53. A conceptual model of sediment transport through the region is that sediments (mostly shelly carbonate material) are generally moving from the Pentland Firth into the Moray Firth, parallel to the Caithness coastline and along the coastal margins (Reid and McManus, 1987; Ramsey and Brampton, 2000, see Figure 9.6) . Most sediment transport likely occurs in pulses associated with (relatively frequent) storm events, although a very weak background transport rate may be associated with stronger (e.g. peak spring) tidal currents. In the absence of surge effects, the resulting direction of sediment transport is determined by the direction of the tidal current at the time (bi-directional aligned to the tidal axis but with a weak residual directed into the Moray Firth). During larger storms, surge effects will likely both increase the transport rate and cause the transport to be more consistently directed into the Moray Firth.

54. Measured levels of SSC are typically low (less than 4 mgl^{-1}) both nearbed and in the upper water column during periods of calm weather (i.e. due to tidal currents alone). However, more energetic resuspension of sediments during storms, as described above, is observed to increase levels of SSC up to the order of 100s to low 1000s of mgl^{-1} at approximately 1 m above the bed. This is in agreement with theoretical relationships predicting profiles of SSC, which also indicate levels in the order of 1000s of mgl^{-1} near to the bed and in the order of 10s of mgl^{-1} higher in the water column (more likely associated with finer sediment fractions).

55. The form and function of Smith Bank as a physical processes receptor is considered to have a low sensitivity to changes in instantaneous waves and tides that are within the range of baseline variability. Likewise, patterns of sediment transport resulting from the net effect of these regimes also have a low sensitivity to such changes.

9.3.2 SPA, SAC AND RAMSAR SITES

56. The form and function of designated coastal or submarine habitats elsewhere in the Moray Firth (identified in Table 9.2 and shown in Figure 9.1) may be variably sensitive to persistent changes in water level, current or wave regimes, and any consequential effects on sediment transport or supply, depending upon the balance of process important for maintaining the site in question. For example, tidal water levels might be important for the exposure characteristics of intertidal habitats and currents and waves might be jointly important for the mobility characteristics of certain sedimentary habitats.

57. Although not necessarily very sensitive to changes in physical processes, the designations and legal or statutory protection assigned to these sites leads to an assumption of high sensitivity for the purposes of EIA assessment.

9.3.3 SURFING BEACHES

58. Recreational surfing venues around the Moray Firth are socioeconomic receptors that are sensitive to effects, particularly reductions, in wave height (Hs), peak wave period (Tp) and wave direction (i.e. the quality and frequency of occurrence of certain surfing wave conditions).

59. Guidance provided by the surfing organisation Surfers Against Sewage (2009) provides a framework for the assessment of baseline and scheme effects in the form of categories of wave condition. The baseline conditions are first established (quantifying mean conditions or the frequency of certain categories of event). Subsequent effects of the Wind Farm are measured against the baseline.

60. Full details for each surf venue are provided in the supporting Baseline report (Annex 9A: Baseline Characterisation, ABPmer 2011a) and their locations are shown in relation to the Wind Farm in Figure 9.1. The following is a summary of the range of values for all of the identified sites.

- 'Small waves' [1 m Hs, 7 s Tp] typically occur between 30 to 40 days of each year;
- The 'annual mean' wave condition is typically between 0.6 and 1.2 m;
- Waves [2 m Hs, 10 s Tp] occur between 6 and 15 times each year;
- Waves [3 m Hs, 12 s Tp] occur between 1 and 6 times each year;
- Waves [4 m Hs, 14 s Tp] occur on average less than 1 time each year;
- 'Large Classic' waves [4 m Hs, 16 s Tp] do not normally occur at any site; and
- The 1:1 year extreme significant wave height (irrespective of period) is typically between 4 and 6.5 m.

61. Surfing venues naturally experience a wide range of wave conditions which may vary on short to long-term timescales. As physical processes receptors, surfing venues are therefore considered to have a low to medium sensitivity to changes in instantaneous waves and the wave regime, depending upon the actual or perceived quality of the wave resource at that location, which is presumed to correspond broadly to the value of the venue.

9.3.4 TIDAL FRONTS

62. The location, form or function of frontal systems in the outer Moray Firth may be sensitive to persistent changes in water depth and the tidal current regime outside of the baseline range of natural variability. The Buchan tidal front, located in the Outer Moray Firth has been shown in a limited number of studies to be associated with higher than average primary productivity (a normal characteristic of such physical features) (Figure 9.1). Fronts are essentially passive features that are a product of the physical environment (but do not influence it in return).

63. There are presently only limited quantitative details available about the baseline temporal or spatial variability in the physical properties of these features. However, the general properties of such features are generally well described by general oceanographic theory.

64. The processes important in regulating tidal front development operate on long timescales and in response to the full range of baseline variability. The location, form and function of frontal features as physical processes receptors are therefore considered to have a low sensitivity to changes in the tidal regime, provided that the range of baseline variability in these values (described above) is not exceeded.

9.4 DEVELOPMENT DESIGN/EMBEDDED MITIGATION

65. Of the options remaining in the Project Design Description (Section 7: Project Description), no specific embedded mitigation measures have been considered in this assessment chapter.

66. This chapter does however (realistically) assume the use of standard engineering practice in relation to activities such as dredging, drilling and cable burial.

9.5 ASSESSMENT OF POTENTIAL EFFECTS

67. This Section considers the effect of the Wind Farm on the identified physical process receptors during construction, operation and decommissioning phases of development.

9.5.1 CONSTRUCTION PHASE: INCREASE IN SUSPENDED SEDIMENT CONCENTRATIONS AS A RESULT OF FOUNDATION INSTALLATION ACTIVITIES

68. The release of sediment into the upper water column during either dredging or drilling works will lead to an increase in SSC. The resulting sediment plume will be advected with ambient tidal currents and will be subject to general processes of dispersion, deposition and resuspension over time.

69. To quantitatively estimate the likely magnitude and extent of the increase in SSC, currents from the numerical tidal model were used in conjunction with a plume dispersion model. Realistic sediment release types and rates were estimated (Table 9.3) based upon the available geotechnical and methodological information.

70. SSC is an additive quantity and so the calculated effect of the works indicates the predicted increase above ambient values.

71. The indicative layout of the worst case number of Wind Farm foundations tested in the present study illustrates how offset rows will inherently become apparent that align in multiple planes. Rows are aligned approximately to the major axis of the Wind Farm at 20° by 200°N and to the minor axis of the Wind Farm at 130° by 310°N. The tidal axis within the BOWL Wind Farm site varies from approximately 0° by 180° north in the north east to 30° by 210°N in the south west (with some degree of tidal rotation during each flood or ebb cycle). The rows aligned to the major axis of the site and also approximately to the tidal axis have the greatest potential for a cumulative effect to build from consecutive installation events. Foundations in the south western end of the site experience comparatively lower current speeds and so will also lead to the highest levels of SSC and thickness of subsequent deposition.

9.5.1.1 Smith Bank

Seabed Preparation for GBS

72. The plume model was used to consider:

- Nine consecutive GBS bed preparation events across a minor axis row from east to west in the south western end of the site; and
- Nine consecutive GBS bed preparation events along a major axis row, starting in the south western end of the site.

73. These locations were chosen as they represent the areas of slowest tidal flow in the site area, so leading to the least dispersion and the highest levels of SSC. The choice of nine foundations corresponds to the width of the Wind Farm.

74. At each foundation location, a conservatively high sediment release rate of 30 kgs^{-1} was introduced at the water surface (based on overspill rates recommended in CIRIA, 2000). A further conservative assumption is that the overspill material is all fine material, i.e. 15 kgs^{-1} silt (60 µm) and 15 kgs^{-1} clay (2 µm).

75. The realistic assumption regarding scheduling of the works is for 4 hours of sediment release (dredging) followed by 4 hours of no release (considered the minimum time for the vessel to dispose of dredged material). Seven cycles of dredging were applied for each foundation (total volume based on a 95 m diameter pit, 5 m deep, approximately equal to 35,000 m^3, in maximum dredger loads of 5,000 m^3).

76. An example image showing the distribution of SSC around the time of the ninth consecutive foundation to be installed (Figure 9.7) demonstrates the typical footprint of increase in SSC during active dredging. It also shows that the SSC signature of all preceding foundation installations is no longer evident.

77. Further analysis of the time series of information shows that the maximum localised increase in SSC is predicted to be 21 mgl^{-1}, contained within 50 to 100 m of the operation and only when sediment release is occurring. More than 100 to 200 m downstream, maximum SSC in the advected main plume (centred along the downstream tidal axis) is reduced to 10 mgl^{-1} or less.

78. The effects described above are only present during and up to 1 hour after the cessation of operations, after which time, SSC is reduced to less than 4 mgl^{-1} due to dispersion and deposition of sediment to the seabed.

79. In principle, the maximum length of the advected main plume is limited to the tidal excursion (7.1 km on spring tides, 3.6 km on neap tides) but will normally be less than this as each dredging (release) event lasts less than one half tidal cycle.

80. Material deposited to the seabed can be resuspended by stronger currents (greater than 0.3 to 0.4 ms^{-1}) during spring tides, or during storm events, leading to a dispersed low level increase in SSC of 1 to 4 mgl^{-1}.

81. Material put into suspension by the dredging or by subsequent remobilisation is redeposited to the seabed (resulting SSC less than 1 mgl^{-1}) when current speeds fall

below the locally critical value (i.e. typically during neap tides and around slack water periods during spring tides).

82. The dispersed small magnitude effects on SSC are advected in a south or south westerly direction outside of the site, i.e. the direction of residual transport by tidal currents.

83. Marine aggregate dredging is a relatively standard practice and so will be subject to a number of embedded mitigation measures in the design of the machinery and methodologies normally employed. This will likely limit levels of SSC resulting from the normal operation of such machines to levels that are generally acceptable according to a broad range of standards and in a variety of environment types.

84. The effects of dredging as part of bed preparation for GBS foundations are generally of a magnitude consistent with the natural range of variability (order 100s to 1000s mgl^{-1} near bed and order 10s to 100s mgl^{-1} higher in the water column). Local effects around the dredger more than a small distance above may however be potentially in excess of the natural range of variability but will be localised and temporary on short term time scales (order of hours to days).

85. A small magnitude of effect that may locally and temporarily exceed the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance.

Drilling to Facilitate Jacket Pin Pile Installation

86. The plume model was also used to consider:

- Nine consecutive jacket installation events across a minor axis row in the south western end of the site; and
- Nine consecutive jacket installation events along a major axis row, starting in the south western end of the site.

87. These locations were chosen for the reasons outlined in Section 9.2.6.

88. At each foundation location, a total sediment release rate of 26 kgs^{-1} was made at the water surface (based on a continuous rate of drilling, a 3 m diameter hole, 60 m deep, completing in 12 hours).

89. Based on information about subsurface soil composition from the geotechnical survey (Osiris, 2011), the proportional release of different sediment fractions was: [marine sediments: 83% sand (450 μm); 8% silt (60 μm) and 9% clay (2 μm)] and [underlying sediments: 50% sand (450 μm); 20% silt (60 μm) and 30% clay (2 μm)] – no chalk was found to be present.

90. Based on the thickness of the overlying marine sand units measured during the geophysical survey, the time over which the two sediment type releases are made was realistically applied for each nominal foundation location.

91. The realistic assumption regarding scheduling of the works was for 12 hours of sediment release (drilling) followed by 3 hours of no release (the minimum time for the vessel to reposition to the next pile), with four cycles (piles) for each foundation. A 12 hour period was allowed for repositioning between foundations.

92. The visual appearance of the SSC plume is similar to that shown previously for dredging in Figure 9.7.

93. Analysis of the time series of information shows that the maximum localised increase in SSC is predicted to be 25 mgl^{-1}, contained within 50 to 100 m of the operation and only when sediment release is occurring. More than 100 to 200 m downstream, maximum SSC in the advected main plume (centred along the downstream tidal axis) is reduced to 10 mgl^{-1} or less.

94. The effects described above are only present during and up to 1 hour after the cessation of operations, after which time, SSC is reduced to less than 4 mgl^{-1} due to dispersion and deposition of sediment to the seabed.

95. In principle, the maximum length of the advected main plume is limited to the tidal excursion (7.1 km on spring tides, 3.6 km on neap tides) but will normally be less than this as each dredging (release) event lasts less than one half tidal cycle.

96. Material deposited to the seabed can be resuspended by stronger currents (greater than 0.3 to 0.4 ms^{-1}) during spring tides, or during storm events, leading to a dispersed small magnitude increase in SSC of 1 to 4 mgl^{-1}.

97. Material put into suspension by the drilling or by subsequent remobilisation is redeposited to the seabed (resulting SSC less than 1 mgl^{-1}) when current speeds fall below the locally critical value (i.e. typically during neap tides and around slack water periods during spring tides).

98. The dispersed small magnitude effects on SSC are advected in a south or south westerly direction outside of the site, i.e. the direction of residual transport by tidal currents.

99. The effects of drilling to facilitate pin pile installation are generally of a magnitude consistent with the natural range of variability (order 100s to 1000s mgl^{-1} nearbed and order 10s to 100s mgl^{-1} higher in the water column). Local effects around the drilling vessel more than a small distance above the seabed may however be potentially in excess of the natural range of variability but will be both localised and temporary.

100. A small magnitude of change effect that may locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance and therefore not significant in terms of the EIA Regulations.

9.5.2 CONSTRUCTION PHASE: ACCUMULATION OF SEDIMENT AND CHANGE OF SEDIMENT TYPE AT THE SEABED AS A RESULT OF FOUNDATION INSTALLATION ACTIVITIES

101. Sediment released into the upper water column during either dredging or drilling works will be advected with ambient tidal currents and will be subject to general processes of dispersion, deposition and resuspension over time.

102. To quantify the likely magnitude and extent of the thickness of sediment deposition, currents simulated by the tidal model were used in conjunction with a plume dispersion model, as described in the previous Section. The resulting

thickness of sediment deposited is calculated as the equivalent sediment volume of particles deposited to the bed in each cell, divided by the grid cell area. The plume model only considers the ability of tidal currents to transport sediments. In practice, storm events will result in additional sediment resuspension and dispersion.

9.5.2.1 *Smith Bank*

Seabed Preparation for GBS

103. The sediment plume model was used to consider:

- Nine consecutive GBS bed preparation events across a minor axis row from east to west in the south western end of the site;
- Nine consecutive GBS bed preparation events along a major axis row, starting in the south western end of the site; and
- An instantaneous release of sediment at all foundation locations corresponding to the total volume of sediment overspill when installing one foundation (according to the details of release described in the previous Section).

104. These locations were chosen for the reasons outlined in Section 9.2.6.

105. The resulting spatial patterns of accumulation of fine material (silts and clays) are shown in Figure 9.8.

106. The results show that fine material will tend to be transported south by south west by residual currents and is predicted to accumulate in measurable thicknesses in the general area indicated in Figure 9.8, approximately 5 to 25 km outside of the Wind Farm site, near to or within the south western end of the Moray Firth Round 3 Zone western development area. This accumulation area is characterised by deeper water and lower peak current speeds (lower sediment mobility). Transport from the Wind Farm site to the accumulation area will occur on relatively short time scales (in the order of days to weeks).

107. Figure 9.8 shows that silts are transported a shorter distance than clays, due to the slight difference in grain size and mobility. In practice, the sediment released will contain a graded mixture of grain sizes in this range and so sediment will be more evenly deposited across the area indicated.

108. In the worst case that all fine material released from nine foundations should be very poorly sorted and accumulates in the discrete locations shown in Figure 9.8, the maximum local accumulation thickness could be 0.006 to 0.008 mm (but more typically 0.001 to 0.004 mm). In practice such a thickness would not be measurable in the field.

109. The results of the whole Wind Farm scenario can only be realistically used to demonstrate that the resulting spatial patterns of deposition in the short to medium term following release are consistent between the scenarios tested irrespective of the programme of operations (i.e. following the major or minor axis of the site), the proportion or part of the site (nine foundations or all, southern or northern end), or the state of the tide at the time of release.

110. In the unrealistic worst case that all fine material from all 277 foundations is released on a very short time scale and is very poorly sorted and accumulates only in the locations shown in Figure 9.8. The maximum local accumulation thickness is 0.5 to 0.6 mm (but more typically 0.01 to 0.10 mm). This thickness would accumulate at a rate in proportion to the duration of the construction period, i.e. given a three year construction period for the turbine foundations with a continuous rate of installation, the accumulation rate would be of the order 0.015 mm per month.

111. However the thickness will likely be less (approximately 0.03 mm total thickness on average, less than 0.001 mm per month) because the fine sediment fractions will be more evenly graded and therefore more evenly dispersed over the area indicated in Figure 9.8.

112. In addition this worst case scenario remains unrealistic because the fines would be subject to erosion and dispersion by storm events during the construction period, dispersing the sediment further as it progressively accumulates.

113. The effects of dredging as part of bed preparation for GBS foundations in terms of thickness of accumulation are generally of a magnitude consistent with the natural range of variability and so will not affect total water depths. The accumulation of a variable thickness of fine sediment to areas presently indicated to be mostly sands or sandy-gravels outside of the site may temporarily change the sediment surface texture in that area; however, these fine sediment accumulations are expected to be reworked and dispersed to background concentrations by storms on short to medium time-scales.

114. Natural variability in total water depth occurs in the form of: water depth (35 to 55 m below chart datum (CD)); tidal water levels (2 to 4 m); non-tidal influences (up to 1 m); and mean sea level rise over the lifetime of the Offshore Project (0.08 to 0.14 m).

115. Natural variability in seabed level occurs in the form of: active bed forms (within the order of 0.01 to 0.10 m); partial resuspension or fluidisation of the upper seabed during extreme storm events, followed by redeposition and consolidation (up to 0.3 m); local net sediment accumulation or erosion (potentially highly spatially and temporally variable).

116. The effects of dredging as part of bed preparation for GBS foundations in terms of thickness of accumulation are generally of a magnitude consistent with the natural range of variability. The accumulation of a variable thickness of fine sediment outside of the site may change the sediment surface type in that area. This sediment accumulation is expected to be reworked and dispersed to background concentrations by storms in short to medium time-scales.

117. A small to medium magnitude of change that may locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance.

Drilling to Facilitate Jacket Pin Pile Installation

118. The sediment plume model was used to consider:

- Nine consecutive jacket installation events across a minor axis row from east to west in the south western end of the site; and
- Nine consecutive jacket installation events along a major axis row, starting in the south western end of the site.

119. These locations were chosen for the reasons outlined in Section 9.2.6. An instantaneous release of sediment at all foundation locations (as assessed in relation to GBS ground preparation works in the previous Section) was not undertaken in relation to Jackets as the GBS scenario is relative worst case for fine sediment release.

120. The resulting spatial patterns of accumulation of fine material (silts and clays) are shown in Figure 9.8. Patterns are consistent between the jacket scenarios tested and with that observed for GBS bed preparation (see Figure 9.8), i.e. transport in a south by south westerly direction, accumulating in discrete sink areas outside of the Wind Farm site.

121. The results of the nine foundation (time series) scenarios show that sandy material will rapidly deposit to the seabed locally around the point of release (mainly within 50 to 100 m), resulting in a relatively thick deposit.

122. The localised thickness of sediment accumulation within 50 to 100 m of each foundation will be dependant upon the proportion of sand present in the underlying sediments but is conservatively predicted to be up to 5 m, accumulating at a rate of approximately 0.1 m per hour of drilling, due to the rapid local deposition of the sand fraction to the bed.

123. There will be spatial variability in the localised thickness of sand deposits depending upon many operational and environmental factors at the time of the operation. Once deposited to the seabed, sands will join the natural sedimentary environment. The resulting seabed surface will likely be uneven and predominantly sandy with little fine material content.

124. The results also show that fine material will be transported south by south west by residual currents and is predicted to accumulate in measurable thicknesses in the general area shown in Figure 9.8. i.e. approximately 5 to 25 km outside of the Wind Farm site, near to or within the south western end of the Moray Firth Round 3 Zone western development area. The maximum accumulation thickness of fine material as a result of installing nine foundations will be 0.004 to 0.006 m, but will more typically be 0.001 to 0.002 m. In practice such a thickness would not be measurable in the field.

125. On the basis of Figure 9.8 and assuming a proportional increase in the total volumes and thicknesses, the worst case that all fine material released from all 277 foundations should be very poorly sorted and accumulates in the two discrete locations shown in the figure, the maximum local accumulation thickness could be 0.7 to 0.9 mm (but more typically 0.01 to 0.15 mm). Given a three year construction

period with a continuous rate of installation, the accumulation rate would be of the order 0.025 mm per month.

126. It is more likely that the thickness will be less (approximately 0.05 mm on average, less than 0.0015 mm per month) because the fine sediment fractions will be more evenly graded and therefore more evenly dispersed over the area indicated in Figure 9.8.

127. In addition this worst case scenario remains unrealistic because the fines would be subject to erosion and dispersion by storm events during the construction period, dispersing the sediment further as it progressively accumulates.

128. The effects of drilling to facilitate pin pile installation are generally of a magnitude consistent with the natural range of variability. Local effects around the drilling vessel may however be potentially in excess of the natural range of variability but will be both localised and temporary.

129. A small to medium magnitude of change that may locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance which is therefore not significant in terms of the EIA Regulations.

9.5.3 CONSTRUCTION PHASE: INCREASE IN SUSPENDED SEDIMENT CONCENTRATIONS AND DEPOSITION OF SEDIMENT AS A RESULT OF INTER-ARRAY CABLE INSTALLATION ACTIVITIES

130. Three options or scenarios for cable installation are being considered:

- Bury all cables where seabed conditions allow, and where conditions do not allow, surface lay and protect with other means;
- Bury all cables where seabed conditions allow, and where conditions do not allow, surface lay but don't protect; and
- Surface lay cables and protect with other means where feasible.

131. The source of the potential effects considered in this Section is sediment resuspended into the lower water column by the machinery used to bury inter-array cables. Once resuspended, the sediment will be advected, dispersed and eventually redeposited as a function of the sediment properties, the manner of the initial release, and the properties of any local ambient flow.

132. A study of cabling methods and typical effects has been conducted by Royal Haskoning and BOMEL (2008). The report includes consideration of the different methods being proposed for cable installation in the present study. The report shows that the effect of cable burial operations mainly relates to a localised and temporary resuspension of sediments. Resulting increases in SSC may vary with the chosen method, burial depth and sediment type, but is also generally accepted to be only a local and a temporary effect.

133. Previously undertaken monitoring of SSC levels during similar cable installation works (e.g. ABPmer, HR Wallingford & CEFAS, 2010) have consistently validated this general assumption.

134. Sediment released into the water column during cable burial works will lead to an increase in SSC. It will also be advected with ambient tidal currents and will be subject to general processes of dispersion and deposition. Once deposited, sediments will effectively rejoin the local sedimentary environment.

9.5.3.1 Smith Bank

135. An increase in SSC may affect the form and function of Smith Bank or other identified coastal habitats if the modified condition falls outside of the baseline range of natural variability. The feature of the physical receptor at risk of modification is the level of SSC.

136. An accumulation of sediment may also affect the form and function of Smith Bank if the modified condition falls outside of the baseline range of natural variability. The features of the physical receptors at risk of modification are the short term rate of sediment deposition, the nature of sediment deposits and net changes in total water depth.

137. The effects of the expected increase in SSC and sediment accumulation have been assessed separately by other EIA topics in relation to other sensitive receptors e.g. benthic ecology (Section 10: Wind Farm Benthic Ecology), marine archaeology and cultural heritage (Section 15: Wind Farm Marine Archaeology and Cultural Heritage, and shipping and navigation (Section 18: Wind Farm Shipping and Navigation).

138. The following assessment presents a worst case scenario for energetic sediment release, expressed per metre of trench length.

139. The maximum subsurface trench dimensions for all proposed burial methods are 3 m wide by 2.5 m deep in a 'V' shaped profile, resulting in 3.75 m^3m^{-1} sediment disturbance. It is assumed that 100% of the wet material disturbed will be ejected from the trench. The porosity of the material is conservatively estimated as 20% void resulting in 3 m^3m^{-1} sediment release. The sediment is likely to be quartz mineral with a density of 2,650 kgm^{-3} resulting in 7950 kgm^{-1} sediment release.

140. The resulting levels of SSC depend upon the volume of water into which this sediment volume is mixed (which is in turn dependant upon the height of sediment ejection, the settling rate of the sediment and the ambient current speed). A range of possible outcomes are given in Table 9.5.

141. The resulting thickness of sediment deposition depends upon the area of seabed over which this sediment volume is deposited (also dependant upon the height of sediment ejection, the settling rate of the sediment and the ambient current speed). A range of possible outcomes are given in Table 9.5.

142. The elevation to which the sediment might be ejected is not known with certainty and may vary between burial methodologies, sediment types and the nature of the hydrodynamic regime at the time of the release. A lower height of ejection will result in a higher level of SSC and thickness of deposition but with a smaller footprint of effect, and visa versa.

143. Within the Wind Farm, the dominant grain sizes present that are susceptible to resuspension through cable installation are medium sands (250 to 500 µm diameter); a measureable proportion of finer sediments are generally not present in the upper sediments and any gravel content will deposit directly to the seabed locally. The settling velocity of such medium sands is approximately 0.05 ms^{-1}. The typical peak tidal current speed is 0.5 ms^{-1} on mean spring tides and 0.25 ms^{-1} on mean neap tides. The value 0.25 ms^{-1} is used here as a condition representative of most normal states of flow during individual tides and over the spring-neap cycle.

144. These values are applied in Table 9.5 below to quantify the total effect per metre of trench length dug. Table 9.5 assumes that the total mass of sediment (318 kg) is resuspended evenly up to a (variable) ejection height. The time required for sediment to settle (at 0.05 ms^{-1}) through the total height of ejection is calculated to yield the duration of the effect. The length scale of the effect is the furthest distance travelled by the plume (downstream), found as the product of the ambient current speed (0.25 ms^{-1}) and the duration of the effect. The estimate of mean SSC is found by dividing the total mass of sediment by the volume of the triangular wedge of water through which the sediment will settle ([ejection height x downstream distance] ÷ 2). The average thickness of any resulting seabed deposit is found by dividing the total volume of dewatered sediment (3 m^3) by the footprint (length scale of the effect x 1 m).

Table 9.5 Extent and Magnitude of Effect of Cable Trenching in Medium Sands

Ejection Height (m)	Duration of Effect (s)	Length Scale of Effect (m)	Indicative Mean SSC (mgl^{-1})	Average Thickness of Deposit (m)
1	20	5	3,180,000	0.600
5	100	25	127,200	0.120
10	200	50	31,800	0.060
25	500	125	5,088	0.024

145. The assessment shows that if the cable burial method used leads to a low height of ejection (1 to 5 m, the most likely scenario), resulting levels of SSC will be elevated above the natural range of variability, but only over a small distance or area (5 to 25 m downstream of the cable route), close to the seabed and lasting a very short time (less than 0.5 to 2 minutes).

146. The resulting thickness of deposition will also be small relative to natural variability in seabed level and contained within a localised area (12 cm over 25 m, or 2.4 cm over 125 m).

147. If the cable burial method used leads to a greater height of ejection (a less likely scenario), resulting levels of SSC will still be elevated, but only to the range of natural variability associated with storm events, and only over a small distance or area (50 to 125 m downstream of the cable route), in the lower half of the water column and lasting a very short time (less than 3 to 8 minutes).

148. An even greater height of ejection (e.g. equivalent to the full water depth, also an unrealistic scenario) would lead to a further reduction in SSC to a value that is

within the range of natural variability and the thickness of any resulting deposits would be of the order of 1 cm.

149. In all cases, the deposited sediment will be of the same type as that naturally present and so will not cause any change to the seabed sedimentary character. Once redeposited, the resuspended sediment will join the natural sedimentary environment and ceases to present any further effect.

150. The effect of cable burial on SSC is of a magnitude potentially in excess of the natural range of variability. However, the effect will be localised and temporary.

151. A small to medium magnitude of change locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance and therefore not significant in terms of the EIA Regulations.

Effect of Cable Protection Measures

152. Protection measures that might be deployed onto unburied sections of cable may take various forms including combinations of:

- Concrete mattresses; and
- Rock nets or Gabions.

153. Protection measures are used to mitigate the engineering risk posed by scour and exposure of the cable to external damage. Where used, the measures will prevent scour from developing around the cable; however, the area occupied by the scour protection might also be similarly considered as a modification to the sedimentary environment and may cause a more limited depth and area of secondary scour to develop.

154. There is insufficient information available to accurately quantify the effect of all possible types of protection measure, which may vary greatly in design and scale. On the basis of information contained in the PDS (BOWL, 2011) the maximum height of the protection will be 1 m. The total width of the protection material will be in the order of 6 m (3 m wide side slopes and a 1m long flat top).

155. Following installation and under favourable conditions, an initial period of sediment might accumulation (order of 0.25 to 0.5 m^3m^{-1}) between the individual rocks of the protection to create a smooth slope. Based on the typical rates of sediment transport through the site (10^{-6} to 10^{-5} $m^3m^{-1}s^{-1}$), this process may take place in the order of 7 to 140 hours of storm activity, i.e. a few months). The slope angle presented by sections of protected cable would be in the order of 18˚ from horizontal (a 1:3 slope) which is within the natural range of bed slope angles associated with bed forms and so will not affect patterns of sediment transport following the initial period of accumulation.

156. Alternatively, conditions may not be favourable for sediment accumulation. Where this is due to very low transport rates (e.g. in the central part of the Outer Moray Firth), the presence or absence of an obstacle will therefore not cause any further effect. Where this is due to a tendency for the protection material to create turbulence and secondary scour, the action of the (upstream) scour will be to

actively resuspend and transport sediment over the obstacle, again therefore not causing any further effect.

157. The effects of cable protection measures are considered to be of a small magnitude relative to the range of naturally occurring variability and will not have a measurable effect on sediment transport beyond a short to medium term period of initial adjustment. Effects on morphology or sediment surface texture will be localised to the cable route.

158. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.4 CONSTRUCTION PHASE: INDENTATIONS LEFT ON THE SEABED BY JACK-UP VESSELS AND LARGE ANCHORS

159. The source of this potential effect are the vessels involved in installing turbine or OSP infrastructure, which may utilise jack-up legs or a number of anchors to hold station and to provide stability for the working platform. Where legs or anchors have been inserted into the seabed and then removed, an indentation proportional to the dimensions of the object may remain. The volume and dimensions of the depression may reduce over time in proportion to the rate of sediment transport through the area. Depending upon the nature of the seabed surface sediments, the presence of a depression does not necessarily imply a difference in sedimentary environment in the area of effect. As sediment is not being removed or added, a volume of sediment approximately equal to the volume of the depression will also be locally raised above the original seabed level.

9.5.4.1 Smith Bank

Jack-up Vessel Legs

160. The PDS suggests that a single jack-up vessel leg will have a footprint of approximately 30 m^2, approximately equivalent to a 5.5 m x 5.5 m square cross section or a 6 m diameter round leg end. The typical estimated depth of penetration of a leg is given as 5 m.

161. As the leg is inserted, the already partially consolidated seabed sediments will be firstly compressed downwards and then displaced laterally sideways, probably causing the seabed around the inserted leg to be raised in a series of concentric pressure ridges. The particular response of the seabed will depend upon the actual dimensions of the leg and the local geotechnical properties of the soil.

162. As the leg is subsequently retracted, the force holding sediments laterally will be reduced and some of the material previously pushed sideways will return to the hole via mass slumping under gravity. Additionally, loose sediment will avalanche back into the depression until a maximum stable slope angle (approximately 32˚ from horizontal in sands) is achieved. On this basis, for a 6 m diameter depression, a stable slope angle would be achieved when the maximum depth in the centre is 1.87 m below the original seabed level.

163. The scale of the depression left by a single leg soon after extraction is therefore estimated to be a 6 m diameter conical pit, approximately 1.9 m deep from ambient bed level in the centre and possibly also surrounded by a raised area of seabed. The (positive) volume of sediment remaining above the original bed level will likely be similar but slightly smaller than the (negative) volume of the pit (i.e. an overall lowering of the mean bed level) due to compaction of sediments in the base of the pit by the pressure exerted by the jack-up leg.

164. The sedimentary texture of the pit surface is likely to be similar to that of the surrounding seabed because no sediment is introduced or removed by the jack-up leg and the sediment veneer is considered to be largely uniform (sand or gravely sand) within the upper 5 m.

165. Over the short to medium term, the pits will tend to become shallower and less distinct as storm events resuspended the raised sediment material around the edges of the pit and either redeposit it into the pit or move it elsewhere. There will be an initial tendency for some sediments to be transported through the area to accumulate in the pits if they are sufficiently deep to reduce current speed and/or wave action locally, however, this tendency will decrease rapidly as the pits flatten.

166. Rates of sediment transport associated with a range of combined wave and current conditions normally present within the site on sub-annual timescales were estimated using total load relationships in Soulsby (1997) to be in the range 10^{-6} to 10^{-5} $m^3m^{-1}s^{-1}$. At such relatively low but frequently occurring rates, the total volume of the pit (17.6 m^3) would be refilled by ambient sediment transport in the order of 100 to 1000 hours of active transport. This timescale would be further reduced (due to higher transport rates) during larger wave events. Waves of 4 m height or greater are present for approximately 3% of the year (263 hours). Therefore, such pits are likely to be filled by natural sediment transport on time scales in the order of 0.5 to 4 years following construction.

167. The effects of jack up legs are therefore of a small magnitude, have only a localised onsite effect, are largely temporary on short to medium term timescales and do not affect the identified sensitive physical environmental receptors beyond the range of natural variability.

168. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

Anchors

169. An array of four to six anchors might be used by some work vessels to hold position and provide stability during operations onsite. Anchors used by such large ships are typically of smaller dimensions than the jack-up legs described above and exert their force differently on the seabed. The length of the main body of one such anchor is assumed to be in the region of 1.5 to 3 m.

170. The specific design of the anchor stock, crown and flukes, and so the way in which the anchor interacts with the seabed, will vary depending upon the particular

design used. Generically, the anchor will be initially deposited onto the seabed under its own weight, causing minimal effect disturbance in its own footprint. The anchor will then be pulled horizontally across the seabed for some distance to allow the flukes and crown to penetrate the seabed. Dragging the anchor may leave a short, shallow furrow. Once embedded in the seabed, a ridge of sediment will have been raised in front of the anchor in the direction of pull, partially accumulated from the furrow and partially pushed up by the horizontal pressure on the bed from the anchor pull.

171. To release the anchor, the connecting wire or chain is tensioned vertically, levering the flukes out of the sediment. The anchor is then retrieved through the water column, either to the main vessel or by an anchor handing vessel for redeployment. The act of removing the anchor in this way will redistribute much of the sediment accumulated back to the seabed around or into any hole remaining.

172. The footprint length scale of the disturbance remaining soon after removal of an anchor will be approximately similar to the size of the anchor (1.5 to 3 m). The character of the disturbance may be highly variable (chaotic ridges and depressions) within the footprint of effect. In the worst case, the maximum depth of a conical pit with these footprint dimensions (assuming a stable slope angle of 32˚) is 0.47 to 0.94 m.

173. The sedimentary texture of the disturbed surface is likely to be similar to that of the surrounding seabed because no sediment is introduced or removed by the anchor and the sediment veneer is considered to be largely uniform (sand or gravely sand) within the upper 5 m.

174. In the short to medium term, the disturbed surface will be reworked and flattened to a baseline condition by waves and currents during storm events. No tendency to intercept regional sediment transport is expected because the sediment is essentially only locally redistributed in a small footprint.

175. The total volume of a 1.5 or 3 m diameter pit (0.28 to 2.21 m^3) would be refilled by ambient sediment transport in the order of 7 to 70, or 60 to 600 hours of active transport at the relatively low but frequently occurring typical sediment transport rates described in the previous section, This timescale would be further reduced (due to higher transport rates) during larger wave events. Therefore, such pits are likely to be entirely filled by natural sediment transport on time scales between a single storm event and 2 years.

176. The effects of anchors are therefore of small magnitude, have only a localised onsite effect, are largely temporary on short to medium term timescales and do not affect the identified sensitive physical environmental receptors beyond the range of natural variability.

177. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.5 OPERATION PHASE: CHANGES TO THE TIDAL REGIME DUE TO THE PRESENCE OF THE WIND FARM FOUNDATIONS

178. The source of this potential effect is the interaction between the tidal regime and the foundations of the Wind Farm infrastructure, which will result in a reduction in current speed and an increase in levels of turbulence locally around the structure. Resistance posed by the array to the passage of water at a large scale might possibly distort the progression of the tidal wave into the Moray Firth, also potentially affecting the phase and height of tidal water levels.

179. Within the extent of the Wind Farm site (in the near-field), the effect on tidal currents will be evident as a series of narrow and discrete wake features extending downstream along the tidal axis from each foundation. The wake signature naturally dissipates to near background levels by a distance in the order of ten to twenty obstacle diameters downstream and the maximum extent of any possible direct effect on currents from the whole array is one tidal excursion from the outermost foundation locations. Tidal wakes might possibly interact between foundations but only where the rows of structures are closely aligned to the tidal flow direction (which may vary with time) and provided that the separation between the foundations is sufficiently small for the wake to persist over that distance.

180. At the regional scale, the foundation structures have the potential to effect on the tidal characteristics of:

- Water levels;
- Current speed; and
- Current direction.

181. To quantify the likely magnitude and extent of interaction between the operational scheme and the hydrodynamic regime, the numerical model was used to simulate a representative spring-neap tidal cycle (duration approximately 15 days) for both a baseline and a number of worst case ‘with scheme’ scenarios, including for the largest dimensions of each foundation type at the most dense proposed layout. The effect of a particular development scenario is evaluated by finding the absolute and relative differences between the baseline and corresponding scheme scenario. Descriptions of the changes found are described below.

9.5.5.1 Smith Bank

Water Levels

182. This assessment of potential changes to water levels is based upon the analysis of spatial (over the Wind Farm site and its immediate area) results from the tidal models, with and without the schemes present, over a representative spring-neap tidal cycle.

183. The assessment finds that Jackets do not affect water levels throughout a mean spring-neap cycle by more than 0.001 m (i.e. not a measurable effect).

184. The assessment finds that GBS have a minor modification effect as follows.

185. The maximum magnitude of effect in any location and at any time during a typical spring-neap tidal cycle is a 0.002 m increase in instantaneous tidal water levels (see Figure 9.9). This point occurs in the near–field of the Wind Farm, at the upstream end of the array (i.e. reversing in location during flood and ebb tidal cycles).

186. The greatest (and maximum) effect during a given tidal cycle occurs around the time of peak current speed and the absolute effect is generally greater at higher peak current speeds (i.e. the effect varies slightly in magnitude over the spring-neap tidal cycle).

187. The absolute effect on water levels is much smaller in magnitude (less than 0.001 m) both elsewhere (outside of the Wind Farm site) and at other times (other than spring tides).

188. Given the similarity in processes, a similar (low) order of effect on non-tidal (surge) water levels is inferred.

189. The magnitude of the effect of the array on water levels in both the near-field and the far-field is evidently very small when compared to the natural range of variability in tidal levels (2 to 4 m), non-tidal levels (1 m) and the potential effects of sea level rise (0.08 to 0.14 m). Furthermore, the effect would not be measurable in practice.

190. The effects of the array on water levels will persist for the lifetime of the Wind Farm but are of very small magnitude, have only a local effect and do not affect any of the identified sensitive physical environmental receptors beyond the range of natural variability.

191. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

Currents

192. With respect to coastal processes, it is the potential changes to the highest current speeds and directions that are of most importance due to the consequential effects on patterns of sediment transport. This assessment of potential changes to currents is based upon the analysis of spatial and temporal results from the tidal model, with and without the schemes present, over a representative spring-neap tidal cycle.

193. The assessment finds that Jackets do not affect regional currents throughout a mean spring-neap cycle by more than 0.01 ms^{-1} (less than 2% of baseline conditions, i.e. not a measurable effect).

194. The assessment finds that GBS do not measurably affect tidal currents (by more than 0.01 ms^{-1}) during neap tides. The following comments relate only to GBS during spring tidal periods. The relative scale, pattern and extent of effects described are similar on flood and ebb tides.

195. GBS mainly effect the phase of the current speed signal (peak flows occurs 5 to 10 minutes earlier than the baseline condition, but with no further measurable effect

on tidal current asymmetry). Compared directly, the maximum difference in instantaneous current speed is less than 0.02 ms^{-1} due to the phasing difference and only occurs within a small area of the Wind Farm site (see Figure 9.10). In other parts of the Wind Farm site and at other times, differences are more typically 0.01 ms^{-1} or less. Independent of phasing effects, peak spring flow speed is not decreased by more than 0.01 ms^{-1}.

196. The extent of the effect is largely contained within the Wind Farm site although a very small magnitude of effect (less than 0.01 ms^{-1}) may extend up to 3 km downstream of the site on the flood tide (directed into the Firth) or 5 km on the ebb tide (directed out of Firth). The difference is again mainly attributable to a small adjustment in the phase between the baseline and 'with scheme' current patterns.

197. In relation to current direction, the assessment finds that there is no measurable effect on instantaneous tidal current direction (i.e. differences are less than 5% for current speeds greater than 0.1 ms^{-1}) as a result of either the Jacket or GBS scenarios during spring or neap tides.

198. The indicative arrangement of the worst case number of Wind Farm foundations contains a series of offset rows. The separation distance between adjacent foundations is at least 640 m along two distinct axes orientated approximately 70° by 250°N and 40° by 220°N. The tidal axis within the Wind Farm site varies from approximately 0° by 180°N in the north east to 30° by 210°N in the south west (with some degree of tidal rotation during each flood or ebb cycle). There is therefore a low likelihood of tidal alignment across most of the Wind Farm site at any time and for most of the tidal cycle in areas to the south west.

199. The consequential effects and associated significance of these changes to the tidal regime upon sediment transport and morphological receptors are considered in Section 9.5.7.

200. The magnitude of the effect of the array on current speeds in both the near-field and the far-field is evidently very small when compared to the natural range of variability in tidal current speeds and would not be measurable in practice.

201. The effects of the array on currents will persist for the lifetime of the Wind Farm but are of very small magnitude, have only a local effect and do not affect any of the identified sensitive physical environmental receptors beyond the range of natural variability.

202. A negligible magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.5.2 Designated Coastal Habitats

203. As described above in relation to Smith Bank, no measurable effect on the tidal regime is predicted to occur further than one tidal excursion (order 7 km) outside of the Wind Farm site (measured in the direction of the tidal axis).

204. A negligible magnitude of change within the range of natural variability is therefore assessed to arise in an area of high sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.5.3 Stratification Fronts

205. As described above in relation to Smith Bank, no measurable effect on the tidal regime is predicted to occur further than one tidal excursion (order 7 km) outside of the Wind Farm site (measured in the direction of the tidal axis). As these features are the product of regional patterns in fresh water runoff/salinity (unaffected by the Wind Farm) and the tidal regime (water depth and current speed, also unaffected by the Wind Farm in these locations), there will be no consequential effect on the strength or location of stratification fronts.

206. A negligible magnitude of change within the range of natural variability is therefore assessed to arise in an area of high sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.6 OPERATION PHASE: CHANGES TO THE WAVE REGIME DUE TO THE PRESENCE OF THE WIND FARM FOUNDATIONS

207. The Wind Farm has the potential to effect on the wave regime as individual waves interact with the foundation structures. The foundation structures have the potential to effect on the following wave characteristics:

- Wave height;
- Wave period; and
- Wave direction.

208. To quantify the likely magnitude and extent of interaction between the operational scheme and the hydrodynamic regime, the numerical wave model was run in two modes.

209. Firstly, for a series of frequently occurring and extreme return period conditions (1:1, 1:10 and 1:50 year events for eight cardinal directions) for baseline, GBS and Jacket scenarios, in order to obtain a generic measure of the extent and magnitude of any effects likely to occur during the lifetime of the Wind Farm.

210. Secondly, the same scenario models were run for a two year period (1st January 2007 to 31st December 2008) in order to obtain directly comparative time series data from various locations within the Moray Firth. In both cases, the effect of a particular development scenario is evaluated by finding the absolute and relative differences at all locations between the baseline and corresponding scheme scenarios.

9.5.6.1 Smith Bank

211. Smith Bank is a morphological receptor and as such is not directly sensitive to differences in the absolute instantaneous wave height, period or direction if the modified condition remains consistent with the baseline range of natural variability. However, sufficiently large and persistent changes to wave height and period may have a net effect over time (in conjunction with the possibility of similar effects on

the tidal regime) on patterns of net sediment transport (rates and/or directions). This potential effect is considered separately in Section 9.5.7. Wave directions are not important to these processes as the waves only mobilise sediment and the direction of subsequent transport is determined by any currents present.

212. The following assessment of potential changes to the wave regime is based upon the analysis of spatial results from the wave model, with and without the GBS and Jacket schemes present, over the representative range of return period conditions.

213. In relation to wave height and period within the Wind Farm site, the assessment finds Jackets do not measurably effect wave height or period, i.e. differences in significant wave height are less than 0.05 m (1%) and in wave period less than 0.1 s (1 to 1.5%) in the near or far-field.

214. The main effect of the GBS foundations is to reduce the height of waves passing through the Wind Farm site (see Figure 9.11 to Figure 9.13).

215. The maximum reduction in wave height within the Wind Farm site varies between 0.35 and 1.1 m or 5 to 15% of the incident wave height for all directions and return periods – the greatest absolute and proportional effects are for the largest waves passing through the long axis of the site (i.e. from 45°N). The area of maximum effect on wave height is relatively small (length scale of order 1 km) and is located where waves have transitioned through the greatest width of the Wind Farm site in that orientation.

216. The effect gradually develops in proportion to the distance travelled through the site, i.e. 50% of the Wind Farm site will experience less than 50% of the maximum level of effect, and 25%, less than 25% of the maximum effect, etc.

217. Behind the Wind Farm site, the reduction in wave height recovers towards ambient values at a non-linear rate (i.e. recovering quickly over small distances but smaller magnitude effects can persist over greater distances). These residual effects extend in the direction of wave travel (with some lateral spreading).

218. The maximum effect on wave period is < 0.3 s (3 to 5%). The spatial pattern of the effect is not well defined and the small magnitude of the effect is not measurable in practice.

219. In relation to wave direction, the assessment finds that there is no measurable effect on instantaneous wave direction (i.e. differences are less than < 1%) as a result of either the Jacket or GBS scenarios in the near-field or far-field.

220. The consequential effects and associated significance of these changes to the wave regime upon sediment transport and morphological receptors are considered in Section 9.5.7.

221. The near-field effects of the GBS array on waves are of a small magnitude relative to the range of naturally occurring variability on annual and decadal timescales and do not cause the range to be exceeded. The far-field reduction in wave height is of a relatively small magnitude (likely not measurable in practice in most areas).

222. The near-field (and far-field) effects of the Jacket array on waves are of a very small magnitude relative to the range of naturally occurring variability (and do not cause it to be exceeded). Effects are so small that they would not be measurable in practice.

223. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.6.2 Designated Coastal Habitats

224. The physical characteristics of designated habitats elsewhere in the Moray Firth (identified in Table 9.2) may be variably sensitive to persistent changes in water level, current or wave regimes (irrespective of consequential effects on sediment transport), depending upon the balance of process important for maintaining the site in question. For example, tidal water levels might be important for the exposure characteristics of intertidal habitats and currents and waves might be jointly important for the mobility characteristics of sedimentary habitats.

225. In relation to wave height and period outside of the Wind Farm, the assessment finds that for jackets the foundations do not affect waves by more than 0.05 m (1%) significant wave height or 0.1 s (1 to 1.5%) wave period in the far-field.

226. The main effect of the GBS foundations is to reduce the height of waves passing through the Wind Farm site and to the receptor locations.

227. The maximum magnitude of effect on wave height at the East Caithness Cliffs SAC is of the order 0.2 to 0.3 m (2 to 3% of the incident wave condition) for waves from the east or south east (occurring 29% of the time) and less than 0.1 m (1% of the incident wave condition) for other directions (70.4% of the time).

228. The maximum magnitude of effect on wave height at the Moray Firth SAC and other designated sites with an open coastal aspect are of the order 0.1 to 0.2 m (2 to 3% of the incident wave condition) for waves from the north, north east or east (54% of the time) and less than 0.1 m (up to 2% of the incident wave condition) for other directions (46% of the time).

229. The maximum magnitude of effect on wave height at the Inner Moray Firth and other sheltered or enclosed water bodies is less than 0.05 m (less than 1% of the incident wave condition, i.e. no measurable effect) for all wave coming directions.

230. Effects are only apparent where waves have previously passed through the Wind Farm site – this condition only applies 29% of the time for the East Caithness Cliffs SPA and 54% of the time for the Moray Firth SAC and other open coastal sites (for any wave height). These values are the proportion of time during which any effect might potentially arise. The maximum effects described above will occur even less frequently.

231. GBS foundations do not affect wave period by more than 0.1 s (1 to 1.5%) outside of the Wind Farm site extent. This is not a measurable effect in practice.

232. Beyond the Wind Farm site, values recover towards ambient values at a non-linear rate (i.e. recovering relatively quickly over small distances but smaller magnitude effects can persist over greater distances). These residual effects extend in the direction of wave travel (with some lateral spreading).

233. In relation to wave direction, the assessment finds that there is no measurable effect on instantaneous wave direction (i.e. differences are less than 1°) as a result of either the Jacket or GBS scenarios in the far-field.

234. The relative effect on extreme wave conditions is shown to be of a very small magnitude in relation to the range of natural variability. The effect on less extreme (more frequently occurring) conditions will be correspondingly smaller in both magnitude and extent.

235. The greatest relative and absolute effects will be felt by the East Caithness Cliffs SAC as it is closest to the Wind Farm and the source of the effect. However, any level of effect will only occur for 29% of the time and this coastline is characterised by: rocky cliffs that are not subject to significant erosion by waves on the timescale of the Wind Farm; morphology that is not dependant upon rates and directions of alongshore sediment transport; and designation corresponding to the aerially exposed cliffs, which are above the high water elevation and therefore not dependant upon wave action.

236. The effects on other designated sites, including Culbin Bar SAC, are very small in magnitude both in absolute and relative terms.

237. The effects of the Wind Farm on waves at the designated coastal sites identified are of a small or very small magnitude relative to the range of naturally occurring variability and have no potential to cause any effect on any given site 50 to 70% of the time. The coastal environments exposed to the relatively higher levels of effect are of a morphological type not sensitive to changes in the wave regime.

238. A negligible magnitude of change within the range of natural variability is assessed to arise in areas of high sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.6.3 Recreational Surfing Venues

239. Recreational surfing venues around the Moray Firth are socio-economic receptors that are sensitive to effects (typically reductions) on wave height, wave period and wave direction, i.e. the quality and frequency of certain surfing wave conditions.

240. The following assessment of potential changes to the wave regime is based upon the analysis of wave model results with and without the GBS and Jacket schemes present over a representative two year period. Time series of wave conditions have been extracted from the model results immediately offshore of the identified surfing beaches in the study area. The same frequency analysis has been applied to each data set. Baseline values for each surfing venue may be found in Annex 9A: Baseline Characterisation (ABPmer 2011a).

241. GBS foundations were found to have no effect greater than 0.01 m wave height or greater than 0.1 s wave period at eight out of eighteen venues. Of the remaining ten

venues, effects were typically limited to a 0.01 to 0.02 m decrease (up to 0.04 m in Cullen Bay) in wave height, but no effect on wave period or the frequency of occurrence of any representative conditions.

242. Jackets were found to have no effect (greater than 0.01 m wave height or greater than 0.1 s wave period) at any location.

243. A small magnitude of change within the range of natural variability is therefore assessed to arise in areas of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.7 OPERATION PHASE: CHANGES TO THE SEDIMENT TRANSPORT REGIME DUE TO THE PRESENCE OF THE WIND FARM FOUNDATIONS

9.5.7.1 Smith Bank

244. It is the combined wave and tidal regimes that ultimately control sediment transport and therefore the seabed form within the study area. It was shown in Section 9.5.5 that the Wind Farm causes no measurable change to the speed or directions of tidal currents. It was shown in Section 9.5.6 that GBS foundations will cause a reduction in instantaneous significant wave height within the Wind Farm site of up to 15% (but more typically 5 to 10%) and up to a maximum of 5% in the far-field, which is of the same order as inter-annual and inter-decadal variability in storm intensity. Jackets will have little or no measureable effect (less than 1%) on wave height. Neither GBS nor Jacket foundations will measurably effect wave period or direction.

245. Given no significant effect on the driving parameters, there can be no corresponding difference in the potential rates and directions of sediment transport through the site (provided that the supply of sediment is available for transport).

246. Other sections of this report consider the potential for the construction of the Wind Farm to affect the character or abundance of surface sediments (see Section 9.5.2). Whilst some short to medium term localised increases in sediment thickness are expected, there is not expected to be a significant change in the textural properties of the sediment available for transport. This supports the further conclusion that actual sediment transport rates through the site will not be affected by the Wind Farm.

247. The predicted conceptual effect of a reduction in wave height on sediment transport pathways and resulting morphology is that the central part of the Wind Farm site may tend to accumulate sediment at a slightly higher rate than would have otherwise occurred during the operational lifetime of the Wind Farm. Also, the supply of sediment to areas into the Moray Firth might be slightly less than would have otherwise occurred during the operational lifetime of the Wind Farm.

248. However, as stated above, the absolute difference in sediment transport attributable to the Wind Farm is less than the potential for natural variability over the same period.

249. There will therefore be no effect on the form or function of Smith Bank.

250. A small magnitude of change within the range of natural variability is therefore assessed to arise in areas of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.7.2 Designated Coastal Habitats

251. It was demonstrated above that there will be a negligible effect on sediment transport rates through the Wind Farm site as a result of the presence of the Wind Farm. The main effects on tidal currents and waves are generally confined to the Wind Farm site and are of a lower magnitude elsewhere. Therefore, there will be no corresponding effect on the rate of sediment supply to other parts of the Moray Firth.

252. The effect of the Wind Farm on wave height, period and direction at the location of designated coastal habitats has been considered in Section 9.5.6.2 and was found to be negligible in absolute terms and in the context of natural variability. There will therefore be no corresponding effect on the rates or directions of nearshore sediment transport at these locations.

253. There will therefore be no effect on the form or function of designated coastal habitats.

254. A negligible magnitude of change within the range of natural variability is therefore assessed to arise in areas of high sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.8 OPERATION PHASE: INTRODUCTION OF SCOUR EFFECTS DUE TO THE PRESENCE OF THE WIND FARM FOUNDATIONS

255. The source of this effect is the interaction between the naturally present hydrodynamic regime (waves and currents) and the foundations of the Wind Farm infrastructure. This has the potential to cause localised scouring of sediment, leaving a depression with possibly different sedimentary character, which will persist in some form until the structure is removed during the decommissioning phase. The extent and depth of the scour pit may vary over time and may be limited naturally under certain physical conditions or if scour protection is used; however, a conservative approach will be applied to calculating the maximum expected dimensions, independent of other factors.

256. Depending upon the nature of the seabed surface sediments, the presence of a depression does not necessarily imply a difference in sedimentary environment in the area of effect. Scour protection measures are typically used to mitigate the engineering risk posed by scour and, where used, will largely prevent scour developing; however, the area occupied by the scour protection might also be similarly considered as a modification to the sedimentary environment and may cause a more limited depth and area of secondary scour to develop. The primary scour features assessed here are however considered to be the worst case with regards to scour.

9.5.8.1 Smith Bank

257. The PDS (BOWL, 2011) describes a variety of types and dimensions for scour protection that will likely be installed in conjunction with the different foundation types. Scour protection may be considered an engineering necessity to ensure long term stability of the structures. Scour protection for foundations could include (for example) rock dumping, the placement of gravel filter layers or geo-textile or frond mattresses. Where scour protection is adequately designed and applied, scour will be absent. However, there is a potential for scour to develop where and when scour protection is not applied, possibly in the interim period between installation of the foundation and placement of the protection.

258. Annex 9C: Scour Assessment, (ABPmer, 2011c) provides further detail on the basis of the scour assessment presented in this Section.

259. Using empirical relationships described in Whitehouse (1998), the equilibrium scour depth for each foundation type resulting from waves and currents, both alone and in combination has been calculated and summarised in Table 9.6.

Table 9.6 Summary of Predicted Maximum Scour Depth Assuming Uniform Erodible Sediment

	Foundation Option**						
	Monotower and Gravity Base or Tubular Jacket and Gravity Base				**Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons**		
	50m	**55m**	**60m**	**65m**	**21 m**	**24 m**	**34 m**
Equilibrium Scour Depth (m):							
Steady current	9.0	9.9	10.8	11.7	2.5	2.5	2.5
Waves	2.0	2.2	2.4	2.6	Insufficient to cause scour		
Waves and current	3.2	3.5	3.8	4.2	2.5	2.5	2.5
Global scour	-	-	-	-	0.8	0.8	0.8
Scour extent from foundation* (m)	14.4	15.8	17.3	18.7	4.0	4.0	4.0
Scour footprint* (m^2)	2,914	3,526	4,196	4,925	291	291	291
Structure footprint (m^2)	1,963	2,376	2,827	3,318	11	11	11
Scour volume* (m^3)	12,136	16,153	20,971	26,663	3756	4573	7918

* Based upon the scour depth for steady currents. Footprint and volume values per foundation
** Foundation option type and plan view base dimension

Table 9.7 Total Footprint of the Different Foundation Types With and Without Scour: Beatrice Offshore Wind Farm

	Beatrice Offshore Wind Farm Foundation Option**					
	Monotower and Gravity Base or Tubular Jacket and Gravity Base			**Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons**		
	50m (3.6 MW)	**60m (6 MW)**	**65m (7 MW)**	**21 m (3.6 MW)**	**24 m (6 MW)**	**34 m (7 MW)**
Number of foundations*	277	166	142	277	166	142
Footprint on seabed of all foundations (m^2)	543,888	469,354	471,200	3,141	1,883	1,610
Proportion of site area (%)	0.414	0.357	0.359	0.002	0.001	0.001
Footprint on seabed of all foundations + scour (m^2)	1,351,103	1,165,948	1,170,533	83,672	50,143	42,893
Proportion of site area (%)	1.028	0.887	0.891	0.064	0.038	0.033

* The number of foundations is conservatively calculated as the total permitted site output (Beatrice Offshore Wind Farm, 1 GW) divided by the equivalent nominal rating for each foundation size (3.6, 6 and 7 MW).
** Foundation option type, plan view base dimension and corresponding most likely turbine rating

260. For jacket structures the term "local scour" refers to scour caused by the individual structures which make up the foundation whereas "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.

261. 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.

262. Overall, in terms of scour depth the GBS is predicted to cause the largest effect with a maximum depth of, approximately, 9 to 12 m local to the structure. In reality, this depth is unlikely to be attained, at least in all locations around a given foundation, due to potential constraints arising from the sub-surface geology. The presence of gravel in the upper sandy layers will likely lead to bed armouring in the scour pit that will restrict the overall depth or rate of scour development. Also, the consolidated till surface at, approximately, 5 to 20 m below the seabed is described as layered sandy silty clays of variable density and hardness (Osiris, 2011), and therefore is likely to be generally cohesive, consolidated and largely more resistant to erosion than non-cohesive (sandy) sediments.

263. The extent of scour from the edge of each foundation is also shown in Table 9.6. This is calculated assuming the profile of the scour pit is an inverted cone with slopes at the angle of repose for sand (32°). It is noted that the minimum separation between foundation locations is approximately 642 m and the greatest extent of scour from the centroid of a foundation location is only 51 m. Therefore, scour effects are not predicted to interact or coalesce between foundations.

264. The footprint or area of the scour pit (excluding the foundation) is also provided in Table 9.6, together with the footprint of the foundation for comparison. The greatest volume of scoured material from a single foundation results from the 65 m GBS or GBS plinth with a scoured volume of 26,663 m^3 per foundation. As already discussed, this full volume may not be attained due to geological conditions in the site (and embedded mitigation from the likely placement of scour protection materials within a few metres of the seabed surface as an integral part of the engineering design).

265. Table 9.7 summarises the total foundation and scour footprints and as a proportion of the Wind Farm area. The 3.6 MW layout results in the largest total footprint of scour.

266. The time theoretically required for the majority of scour pit development around all foundations is in the order of hours to days, under flow conditions sufficient to induce scour. This takes the assumption of a mobile uniform non-cohesive sediment substrate. Approximately symmetrical scour will only develop following sufficient exposure to both flood and ebb tidal directions. Waves of a sufficient size to interact with the seabed do not typically cause rapid initial scour directly, but can increase the rate of initial scour development.

267. The effects of the foundations in causing scour are of a small to medium magnitude relative to the range of naturally occurring variability in seabed level but do not cause the normal range of water depths to be exceeded. The effects of scour are limited to only a small proportion of the area of the Wind Farm site and an even smaller proportion of the area of Smith Bank.

268. A small to medium magnitude of change that does not exceed the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.9 OPERATION PHASE: INTRODUCTION OF SCOUR EFFECTS DUE TO EXPOSURE OF INTER-ARRAY CABLES AND CABLE PROTECTION MEASURES

9.5.9.1 Smith Bank

269. Structures introduced into the marine environment and located near to the seabed will interact with the naturally present hydrodynamic and sedimentary regimes, resulting in the potential for sediment scour to occur. The removal of sediment from underneath a section of cable exposed on the seabed can lead to free-spanning and further sediment erosion; exposed cables are also at greater risk of physical damage and will require further intervention to rebury or protect them. Exposure and scour is primarily an engineering risk, often mitigated using cable burial and scour protection.

270. Four options or scenarios for cable installation are being considered as below.

- Bury all cables where seabed conditions allow, and where conditions do not allow - surface lay and protect with other means;
- Bury all cables where seabed conditions allow, and where conditions do not allow - surface lay but do not protect;
- Surface lay cables and protect with other means where feasible.

271. Inter-array cables will be between 0.11 and 0.16 m in diameter and weigh in the order of 30-50 kgm^{-1}. Typically only one cable is required to connect two adjacent foundations, however, it is possible that more than one cable (and route) might converge at offshore substation platforms.

272. Whitehouse (1998) summarises various studies that provide empirical estimates of equilibrium scour depth underneath pipelines (similar in principle to cables). The predicted scour depth in all cases is primarily dependant upon the diameter of the cable. It is also noted that the cable must be significantly exposed for local scour to occur at all and that an oblique orientation of the cable to the ambient tidal or wave forcing will also reduce the predicted effect.

273. Should the cable become exposed, it may cause scouring of the underlying sediments. If the cable is taut or stiff, sections of the cable might become elevated relative to the lowered bed level. If the cable is not taut or stiff, then it will sag to remain in contact with the seabed, irrespective of how much scour occurs. This has been previously observed to lead to self burial of pipelines due to sediment migration into the depression created that partially buries the obstruction, causing

further scour to cease and allowing ambient sediment transport to refill the scour depression. Given the weight of the cable, if exposed it will not be moved on the seabed by either the naturally present tidal or wave regimes.

274. The resulting equilibrium scour dimensions may vary under different circumstances and depending on the dominant forcing. A conservative estimate for all cases is that the maximum depth of scour will be between one and three times the cable diameter (i.e. 0.11 to 0.48 m) and the maximum horizontal extent of any scour effect will be up to fifty times the cable diameter (i.e. 5.5 to 8 m). As such, any depression created will not necessarily be steeply sided. In predominantly sandy areas, the surface of the scour pit will be of similar character to the ambient bed. In more gravelly areas, a gravel lag veneer may initially form as finer sands are preferentially winnowed, but may then become buried with predominantly sandy material following recovery of the seabed if self burial occurs.

275. The effects of scour potentially resulting from the exposure of inter-array cables are considered to be of a negligible magnitude relative to the range of naturally occurring variability. Effects are also largely localised to the cable route and are temporary in nature. The time-scale for reburial following exposure and scouring may be short, medium or long term, depending on the situation.

276. A negligible magnitude of change that does not exceed the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.5.10 DECOMMISIONING

277. Decommissioning activities will be of a similar nature to those already considered in relation to the construction phase of the Wind Farm. Potential effects relating to the construction period were assessed in a previous section and were shown to be not significant in relation to the EIA regulations.

9.6 MITIGATION MEASURES AND RESIDUAL EFFECTS

9.6.1 SUSPENDED SEDIMENT CONCENTRATIONS

278. Effects on SSC of minor significance are predicted in relation to sediment release from dredging and drilling works. The significance of the effect relates mainly to a very localised and temporary increase in SSC in the upper water column that may exceed the range of natural variability.

279. Dredging for GBS structures involves a large total volume of sediment, however, the proportion of the total volume which is released as overspill is relatively much smaller due to the embedded mitigation provided by the design and operational methodology of the machines used.

9.6.2 THICKNESS OF SEDIMENT ACCUMULATION

280. Effects due to sudden sediment accumulation of minor significance are predicted in relation to sediment release from drilling works. The significance of the effect relates partly to a very localised deposition of sandy material around each foundation (order several metres thick) that may exceed the range of natural

variability in sediment mobility or deposition thickness and/or the surface sediment type.

281. Due to the small magnitude and significance of the original effect, it is not recommended that mitigation measures in relation to sediment release are necessary. Residual effects will therefore be the same as previously reported.

9.6.3 SCOUR EFFECTS

282. The assessments in relation to scour around foundations and exposed cables have been based on a 'worst-case' scenario that no scour protection is provided, at least for a sufficiently long time that maximum scour will develop. As a matter of good engineering practice, the development of scour will likely be monitored and the Wind Farm's detailed design will consider whether scour protection should be applied to reduce the extent of scour or to mitigate against the necessity for more intrusive works that may result in further environmental effects.

283. Section 7: Project Description describes the variety of types and dimensions for scour protection that will likely be installed in conjunction with the different foundation types. Scour protection may be considered an engineering necessity to ensure long-term stability of the structures. Scour protection for foundations could include (for example) rock dumping, the placement of gravel filter layers or geo-textile or frond mattresses. Where scour protection is adequately designed and applied, scour associated with the object being protected will be absent. However, secondary scour (associated with the scour protection materials themselves) may occur at a smaller scale (in proportion to the dimensions of the protection material).

284. The extent of the protection must be sufficiently large to afford the desired protection (of a similar length scale to the extent of scour reported). The design of the scour protection will likely take into account the transition from the scour protection to the natural seabed and minimize secondary scouring.

285. The dimensions of secondary scour will be highly variable depending upon the type and design of scour protection chosen, but will be much smaller in volume and extent (in proportion to the much smaller dimensions of the obstacle presented to the flow) than that described in relation to scour around an unprotected structure.

9.6.4 MONITORING AND ENHANCEMENTS

286. A consistent combination of visual, bathymetric surveys may be undertaken pre- and post-construction at selected locations within the Wind Farm site (for locally deposited sands from drilling and for the development of scour). Subsequent surveys can be compared to assess the magnitude (area, depth and volume) of sediment actually accumulated or scoured and the effect on seabed texture or character. Subsequent surveys can then be planned depending on the results of this initial monitoring schedule. In terms of timescales, it is suggested that selected areas are surveyed prior to and post construction. Not all parts of these sites need to be monitored.

287. The results of the monitoring would inform and expand the evidence base with regards to the effects of non-monopile foundation types.

9.6.5 SUMMARY OF EFFECTS

Table 9.8 Summary of Effects

Residual Effects	Sensitivity of Receptor	Magnitude of Effect	Nature	Assessment of Effect
Wind Farm: Construction and Decommissioning Phases				
Smith Bank – Increase in SSC and deposition of sediment (Foundations)	Low	Small - Medium	Negative	Minor (not significant)
Smith Bank – Increase in SSC and deposition of sediment (Inter-array cables)	Low	Small - Medium	Negative	Minor (not significant)
Smith Bank – Indentations on the seabed (Jack-up and anchors)	Low	Small	Negative	Negligible (not significant)
Wind Farm: Operational Phase				
Smith Bank, Designated Coastal Habitats and Stratification Fronts – Changes to the tidal regime	Low High (designated sites only)[1]	Small	Negative	Negligible (not significant)
Smith Bank, Designated Coastal Habitats and Surfing Venues – Changes to the wave regime	Low High (designated sites only)1	Small	Negative	Negligible (not significant)
Smith Bank and Designated Coastal Habitats – Changes to sediment transport	Low High (designated sites only)1	Small	Negative	Negligible (not significant)
Smith Bank – Scour (Foundations)	Low	Small - Medium	Negative	Negligible (not significant)
Smith Bank – Scour (Cables)	Low	Small - Medium	Negative	Negligible (not significant)

[1] Although not necessarily highly sensitive to changes in physical processes, the designations and legal or statutory protection assigned to these sites leads to an assumption of high sensitivity for the purposes of EIA (see section 9.3.2). The effects of the Wind Farm on the species and habitats associated with these designations, are assessed elsewhere within this ES.

9.7 *ASSESSMENT OF CUMULATIVE EFFECTS*

288. Given below is the assessment of cumulative effects of the Wind Farm on physical processes in the marine environment and includes cumulative, in-combination and inter-related effects on water levels, currents, waves, sediment transport and geomorphology in conjunction with other existing or foreseeable planned project/development activities.

289. A CIADD (MFOWDG, 2011) was produced which set out the developments to be considered and the assessment method for each technical assessment and is the basis of this assessment. The CIADD is presented in Annex 5B.

9.7.1 SCOPE OF ASSESSMENT

290. The scope and method of this assessment is as described in the CIADD (MFOWDG, 2011).

291. The assessment of significance of cumulative effects has used the same criteria to determine significance based on the sensitivity of the receptor and the magnitude of the potential change as presented in Section 4: Environmental Impact Assessment Process and Methodology of this ES.

292. The assessment of cumulative effect has been made against the existing baseline conditions as presented in Section 9.3 for the Wind Farm.

9.7.1.1 Geographical Scope

293. As presented in the CIADD the geographical extent of the study area for the cumulative assessment considers both near-field and far-field effects of the Project. In the context of physical processes, near-field refers to the area within the Project site where structures or operations interact directly with the marine environment and cause the greatest magnitude of effect. Far-field refers to areas outside of the Project site where pathways exist for an effect to be translated to a distant sensitive receptor.

294. The geographical scope of the modelling tools used in the present study was also chosen to encompass a sufficiently large area that both the baseline environment and the full extent of any effects of the Offshore Project are adequately simulated and fully contained within the model domain.

295. The geographical scope of the study therefore includes both Inner and Outer parts of the Moray Firth and a large area of the northern North Sea (including the Pentland Firth for tides and the largest open fetches for waves).

9.7.1.2 Developments Considered in Assessment

296. Cumulative physical processes and geomorphology effects may potentially arise from the following developments:

Offshore Wind Farms

- Individual sites within the Moray Firth Round 3 Zone eastern development area;
- Moray Firth Round 3 Zone western development area;

- Forth and Tay offshore wind developments;
- European Offshore Wind Deployment Centre; and
- Beatrice Demonstrator Wind Farm foundations.

Marine Renewables Projects

- Marine energy developments in the Pentland Firth and Orkney waters; and
- The proposed SHETL hub.

Cables

- Beatrice Offshore Wind Farm Offshore Transmission Cable (OfTW);
- Moray Firth Round 3 Zone Offshore Transmission Cable (OfTW); and
- The proposed Viking SHETL cable.

Oil and Gas Industry Infrastructure

- Beatrice and Jacky platforms and associated infrastructure;
- The proposed Polly well; and
- The proposed Caithness and PA Resources infrastructure for existing leases.

Other Marine Stakeholders in the Moray Firth

- Navigation and shipping; and
- Marine and port developments within the Moray Firth.

297. With the exception of the Moray Firth Round 3 Zone, the BOWL OfTW and the SHETL cable, all other developments or activities were scoped out of further assessment for one or more of the following reasons:

- It is located more than one tidal excursion from the Beatrice Offshore Wind Farm site;
- It has no direct fetch for wave effects to interact with that of the Beatrice Offshore Wind Farm site (i.e. there is no pathway connecting the Wind Farm site and the other source of effect);
- It is already part of the baseline; and
- Its relative dimensions are so small that it will not conceptually have any measurable effect on the tidal, wave or sedimentary regimes.

298. The reasons are presented in Table 9.9 below.

Table 9.9 Developments Considered in Cumulative Assessment

Development	Reason for Scoping Out		
	>1 Tidal Excursion	No Direct Wave or Fetch Effects	Lack of Measurable Effect
Forth and Tay offshore wind developments;	X	X	X
European Offshore Wind Deployment Centre	X	X	X
Beatrice Demonstrator Wind Farm foundations	X		
Marine energy developments in the Pentland Firth and Orkney waters;	X	X	
The proposed SHETL hub	X		X
Beatrice and Jacky platforms and associated infrastructure			X
The proposed Polly well	X	X	X
The proposed Caithness and PA Resources infrastructure for existing leases	X		
Navigation and shipping	X	X	X
Marine and port developments within the Moray Firth	X	X	X

9.7.2 CONSULTATION

299. The CIADD (MFOWDG, 2011) was presented to Marine Scotland for review in April 2011 for comment. A summary of consultation relating to cumulative effects is included in Table 9.1 and in Annex 5A.

300. Following these initial comments on the CIADD, scoping opinions were received from Marine Scotland in regard to the Wind Farm (Marine Scotland, 2011) and for the transmission works (Marine Scotland, 2011). A revised methodology was then developed. Subsequent telephone discussions and written responses confirmed that the proposed methodology was considered appropriate and fit for purpose.

9.7.3 PREDICTED EFFECTS

301. The potential effects which have been considered in this section are:

- Changes to the hydrodynamic environment (waves, tides and currents);
- Changes to sedimentary processes and structures (sediment composition, properties, distribution, transport pathways, bedforms); and
- Changes to suspended sediment concentration (on a variety of spatial and temporal scales).

9.7.3.1 Cumulative Effect, Construction Phase: Interaction of Sediment Plumes

302. This section considers the potential cumulative effects on SSC as a result of either foundation installation or cable burial activities.

303. Foundation installation must be completed before the local inter-array cables are laid. For operational safety, it is also unlikely that cables will be simultaneously buried less than an order of 10s of metres from each other, or from any other operation. Disperse effects from dredging or drilling activities elsewhere will only increase levels of SSC at the cable burial site (100s to 1000s of mgl^{-1}) by the order of 1 to 5 mgl^{-1}. Therefore, there is limited or no potential for (measurable) interaction between foundation installation and cable burial activity and so these two sources are separately addressed below.

Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone foundation installation

304. This section considers the cumulative effect on SSC of simultaneously installing multiple foundations in the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone.

305. The effects of dredging and bed preparation for GBS were considered in Section 9.5 and the effects of drilling for Jacket pin piles or were considered in Section 9.5, in relation to the Beatrice Offshore Wind Farm alone. The results indicate that levels of SSC may rise to: 20 to 25 mgl^{-1} locally (50 to 100 m from the source) during operations; 5 to 10 mgl^{-1} in a plume extending up to 500 m downstream and up to 100 m wide during operations; and less than 1 to 5 mgl^{-1} in other locations or in all locations 1 hour or more after of cessation of operations.

306. The results also show that the measurable effects on SSC of installing one foundation will have dissipated by the time that the next foundation is attempted. The previously described effects on SSC are therefore representative of any given foundation installation and are independent of location and relative timing and the cumulative result of interaction between two or more sediment plumes is a linearly additive increase in SSC for the duration of the effect.

307. If foundation installation activities occur simultaneously at multiple adjacent locations, there is a potential that plumes of increased SSC will interact. However, given the minimum spacing of the foundations and the width of the plume, if the adjacent locations are not aligned within 10˚ of the tidal axis, there is no potential for the plumes to interact. If the adjacent locations are aligned along the tidal axis, foundations are located a minimum of 642 m apart so the downstream level of SSC in the sediment plume from the upstream source will have decreased to 5 mgl^{-1} or less. This may cause the levels of SSC adjacent to the downstream source to increase from a maximum of 25 mgl^{-1} alone to 30 mgl^{-1} in combination. The SSC

plume located downstream of the second source might increase from 5 to 10 mgl^{-1} alone by the order of a few units in the combined case. The more disperse effects elsewhere and following cessation of operations (1 to 5 mgl^{-1}) are unlikely to be affected.

308. A small to medium magnitude of change that may locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance which is therefore not significant in terms of the EIA Regulations.

Beatrice Offshore Wind Farm, Moray Firth Round 3 Zone inter-array and transmission cable burial and SHETL cable

309. This section considers the cumulative effect on SSC of simultaneously burying multiple cables in and adjacent to the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone. Outside of the Offshore Project site, simultaneous cable installation activities might arise from burial of the Moray Firth Round 3 Zone OFTO transmission cable and/or the proposed SHETL cable route.

310. The effects of cable burial were considered in Section 9.5 in relation to the Beatrice Offshore Wind Farm inter-array cable alone. The results indicate that cable burial will result in potentially high levels of SSC (100s to 1000s of mgl^{-1}) but only locally to the route (order 10s of metres) and only for a short and temporary period (order of seconds to minutes). The effects of the OfTW transmission cable and SHETL cable burial are assumed to be similar.

All Sources

311. The cumulative effects of plume interaction from a variety of sources are of a magnitude consistent with the natural range of variability (order 100s to 1,000s mgl^{-1} nearbed and order 10s to 100s mgl^{-1} higher in the water column). Local effects around cable burial machines may be potentially in excess of the natural range of variability but will also be only localised and temporary.

312. A small magnitude of change that may locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is of minor significance and therefore not significant in terms of the EIA Regulations.

313. A small to medium magnitude of change locally and temporarily exceeding the range of natural variability is therefore assessed to arise in an area of low sensitivity, resulting in a negative effect of minor significance which is therefore not significant in terms of the EIA Regulations.

9.7.3.2 Cumulative Effect, Operation Phase: Changes to the Tidal Regime

314. The simultaneous presence of the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone foundations does have the potential to produce a cumulative effect on the tidal regime as flows interact with the structures. Any changes to the tidal regime may have a resultant effect on the sediment regime which is considered further in Section 9.7.3.6. At the regional scale, the foundation structures have the potential to effect on tidal characteristics of:

- Water levels;
- Current speed; and
- Current direction.

315. To quantify the likely magnitude and extent of interaction between the operational schemes and the hydrodynamic regime, the tidal model was run over a representative spring-neap tidal cycle (duration approximately 15 days) for both a baseline and a number of 'with scheme' scenarios (all Jackets or all GBS in both developments). The effect of a particular development scenario is evaluated by finding the differences in predicated values at all locations and time steps, between the baseline and corresponding scheme scenario. Descriptions of the changes found are described below. The consequential effects and associated significance of these changes to the tidal regime upon sediment transport and morphological receptors are discussed in Section 9.7.3.6.

316. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

Water Levels

317. This assessment of potential changes to water levels is based upon the analysis of spatial (over the entire development and its immediate area) results from the tidal models, with and without the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone present, over a representative spring-neap tidal cycle.

318. The assessment finds that Jackets do not affect water levels throughout a mean spring-neap cycle by more than 0.001 m (i.e. not a measurable effect). The assessment finds that GBS have a minor modification effect as follows.

319. The maximum magnitude of effect in any location and at any time during a typical spring-neap tidal cycle is a 0.002 m increase in instantaneous tidal water levels (see Figure 9.14 and Section 9.5.5). This point occurs in the near–field of the development, at the upstream end of the array (i.e. reversing in location during flood and ebb tidal cycles).

320. The greatest (and maximum) effect during a given tidal cycle occurs around the time of peak current speed and the absolute effect is generally greater at higher peak current speeds (i.e. the effect varies slightly in magnitude over the spring-neap tidal cycle).

321. The absolute effect on water levels is much smaller in magnitude (less than 0.001 m) both elsewhere (outside of the Wind Farm sites) and at other times (other than spring tides).

322. Given the similarity in processes, a similar (small) order of effect on non-tidal (surge) water levels is inferred.

323. The magnitude of the effect of the arrays on water levels in both the near-field and the far-field are evidently very small when compared to the natural range of variability in tidal levels (4 m), non-tidal levels (1 m) and the potential effects of sea

level rise (0.08 to 0.14 m). Furthermore, the potential effect would not be measurable in practice.

324. The effects of the arrays on water levels will persist for the lifetime of the development but are of very small magnitude, have only a local effect and do not affect any of the identified sensitive physical environmental receptors beyond the range of natural variability.

325. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

Currents

326. This assessment of potential changes to currents is based upon the analysis of spatial and temporal results from the tidal model, with and without the schemes present, over a representative spring-neap tidal cycle.

327. The assessment finds that Jackets do not affect regional currents throughout a mean spring-neap cycle by more than 0.01 ms^{-1} (less than 2% of baseline conditions, i.e. not a measurable effect).

328. The assessment finds that GBS do not measurably affect tidal currents (by more than 0.01 ms^{-1}) during neap tides. The following comments relate only to GBS during spring tidal periods. The relative scale, pattern and extent of effects described are similar on flood and ebb tides.

329. GBS mainly affect the phase of the current speed signal (peak flows occurs 5 to 10 minute earlier than the baseline condition, but with no further measurable effect on tidal current asymmetry). Compared directly, the maximum difference in instantaneous current speed is less than 0.03 ms^{-1} due to the phasing difference and only occurs within a small area of the Wind Farm sites (see Figure 9.15 and Section 9.5.5). In other parts of the Wind Farm sites and at other times, differences are more typically 0.01 ms^{-1} or less. Independent of phasing effects, peak spring flow speed is not decreased by more than 0.01 ms^{-1}.

330. The extent of the effect is largely contained within the Wind Farm sites although a very small magnitude of effect (less than 0.01 ms^{-1}) may extend up to 3 km downstream of the sites on the flood tide (directed into the Firth) or 5 km on the ebb tide (directed out of the Firth). The difference is again mainly attributable to a small adjustment in the phase between the baseline and 'with scheme' current patterns.

331. In relation to current direction, the assessment finds that there is no measurable effect on instantaneous tidal current direction (i.e. differences are less than ±5° for current speeds greater than 0.1 ms^{-1}) as a result of either the Jacket or GBS scenarios during spring or neap tides.

332. The consequential effects and associated significance of these changes to current speeds upon sediment transport and morphological receptors are considered in Section 9.7.3.6.

333. Again, the pattern and maximum magnitude of effects are broadly similar to the case of the Wind Farm alone (considered in Section 9.5) because the two sites are situated adjacent to each other in relation to the tidal axis and therefore do not pose much potential to interact directly.

334. The effects of the array on currents will persist for the lifetime of the Wind Farm but are of very small magnitude, have only a local effect and do not affect any of the identified sensitive physical environmental receptors beyond the range of natural variability.

335. The magnitude of the effect of the arrays on current speeds in both the near-field and the far-field is evidently very small when compared to the natural range of variability and would not be measurable in practice.

336. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.7.3.3 Designated Coastal Habitats

337. As described above in relation to Smith Bank, no measurable effect on the tidal regime is predicted to occur further than one tidal excursion (order 7 km) outside of the Wind Farm sites (measured in the direction of the tidal axis).

338. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.7.3.4 Stratification Fronts

339. As described above in relation to Smith Bank, no measurable effect on the tidal regime is predicted to occur further than one tidal excursion (order 7 km) outside of the Wind Farm sites (measured in the direction of the tidal axis).

340. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.7.3.5 Cumulative Effect, Operation Phase: Changes to the Wave Regime

341. The simultaneous presence of the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone foundations does have the potential to produce a cumulative effect on the wave regime as individual waves interact with them. The turbine and OSP foundations have the potential to effect on wave characteristics of:

- Wave height;
- Wave period; and
- Wave direction.

342. To quantify the likely magnitude and extent of interaction between the operational scheme and the hydrodynamic regime, the numerical wave model was run in two modes.

343. Firstly, for a series of frequently occurring and extreme return period conditions [1:1, 1:10 and 1:50 year events for eight cardinal directions] for baseline, GBS and Jacket scenarios, in order to obtain a generic measure of the extent and magnitude of any effects likely to occur during the lifetime of the developments. The results are shown in Figures 9.16 to 9.18.

344. Secondly, the same scenario models were run for a representative two year period (1st January 2007 to 31st December 2008) in order to obtain directly comparative time series data from various locations within the Moray Firth. In both cases, the effect of a particular development scenario is evaluated by finding the absolute and relative differences at all locations between the baseline and corresponding scheme scenarios.

Smith Bank

345. The following assessment of potential changes to the wave regime is based upon the analysis of spatial results from the wave model, with and without the GBS and Jacket schemes present, over a representative range of return period wave conditions (1 in 1 year to 1 in 50 years).

346. In relation to wave height and period within the Wind Farm sites, the assessment finds that Jacket foundations do not measurably affect wave height or period, i.e. differences in significant wave height are generally less than 0.05 m (1%) and in wave period less than 0.1 s (1 to 1.5%) in the near or far-field.

347. The main effect of the GBS foundations is to reduce the height of waves passing through the Wind Farm sites (see Section 9.5.6).

348. The maximum reduction in wave height within the Wind Farm sites varies between 0.35 and 1.45 m or 5 to 20% of the incident wave height for all directions and return periods – the greatest absolute and proportional effects are for the largest waves passing through the longest axis of the combined sites (i.e. from 45 to 90°N). The area of maximum effect on wave height is relatively small (length scale of order 1 km) and is located where waves have transitioned through the greatest width of the Wind Farm sites in that orientation.

349. The effect gradually develops in proportion to the distance travelled through the sites, i.e. 50% of the Wind Farm sites area will experience less than 50% of the maximum level of effect, and 25%, less than 25% of the maximum effect, etc.

350. Behind the Wind Farm sites, the reduction in wave height recovers towards ambient values at a non-linear rate (i.e. recovering quickly over small distances but smaller magnitude effects can persist over greater distances). These residual effects extend in the direction of wave travel (with some lateral spreading).

351. The maximum effect on wave period is ± 0.3 s (3 to 5%). The spatial pattern of the effect is not well defined and the small magnitude of the effect is not measurable in practice.

352. In relation to wave direction, the assessment finds that there is no measurable effect on instantaneous wave direction (i.e. differences are less than ±1°) as a result of either the Jacket or GBS scenarios in the near- or far-field.

353. The near-field effects of the GBS array on waves are of a small magnitude relative to the range of naturally occurring variability on annual and decadal timescales and do not cause the range to be exceeded. The far-field reduction in wave height is of a relatively small magnitude (likely not measurable in practice in most areas).

354. The near-field (and far-field) effects of the Jacket array on waves are of a very small magnitude relative to the range of naturally occurring variability (and do not cause it to be exceeded). Effects are so small that they would not be measurable in practice.

355. A small magnitude of change within the range of natural variability is therefore assessed to arise in an area of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

Designated Coastal Habitats

356. In relation to wave height and period outside of the Wind Farm sites, the assessment finds that jackets foundations do not affect waves by more than 0.05 m (1%) significant wave height or 0.1 s (1 to 1.5%) wave period in the far-field.

357. The main effect of the GBS foundations is to reduce the height of waves passing through the Wind Farm sites and to the receptor locations.

358. The maximum magnitude of effect on wave height at the East Caithness Cliffs SAC is of the order 0.4 to 0.5 m (4 to 5% of the incident wave condition) for waves from the east or south east (occurring 29% of the time), of the order 0.2 to 0.3 m (2 to 3% of the incident wave condition) for waves from the north east or south (41.4% of the time) and less than 0.1 m (1% of the incident wave condition) for other directions (29.6% of the time).

359. The maximum magnitude of effect on wave height at the Moray Firth SAC and other designated open coastal sites is of the order 0.1 to 0.2 m (2 to 3% of the incident wave condition) for waves from the north, north east or east (54% of the time) and less than 0.1 m (up to 2% of the incident wave condition) for other directions (46% of the time).

360. The maximum magnitude of effect on wave height in the Inner Moray Firth and Enclosed Water Bodies is less than 0.05 m (less than 1% of the incident wave condition, i.e. no measurable effect) for all wave coming directions.

361. Effects are only apparent where waves have previously passed through the Wind Farm sites – this condition only applies 29% of the time for the East Caithness Cliffs SAC and 54% of the time for the Moray Firth SAC and other open coastal sites (for any wave height). These are the proportion of time during which any effect might potentially arise - the maximum effects described above will occur even less frequently.

362. GBS foundations do not affect wave period by more than 0.1 s (1 to 1.5%) outside of the Wind Farm sites. This is not a measurable effect in practice.

363. Beyond the Wind Farm sites, values recover towards ambient values at a non-linear rate (i.e. recovering relatively quickly over small distances but smaller magnitude

effects can persist over greater distances). These residual effects extend in the direction of wave travel (with some lateral spreading).

364. In relation to wave direction, the assessment finds that there is no measurable effect on instantaneous wave direction (i.e. differences are less than ±1˚) as a result of either the Jacket or GBS scenarios in the far-field.

365. The relative effect on extreme wave conditions is shown to be of a very small magnitude in relation to the range of natural variability. The effect on less extreme (more frequently occurring) conditions will be correspondingly smaller in both magnitude and extent.

366. The greatest relative and absolute effects will be felt by the East Caithness Cliffs SAC as it is closest to the Wind Farm sites and the source of the effect. However, any level of effect will only occur for 29% of the time and this coastline is characterised by: rocky cliffs that are not subject to significant erosion by waves on the timescale of the Wind Farm; morphology that is not dependant upon rates and directions of alongshore sediment transport; and designation corresponding to the aerially exposed cliffs, which are above the high water elevation and therefore not dependant upon wave action.

367. The effects on other designated sites are very low in magnitude both in absolute and relative terms.

368. The effects of the Wind Farm sites on waves at the designated coastal sites identified are of a small or very small magnitude relative to the range of naturally occurring variability and have no potential to cause any effect on any given site 30 to 70% of the time. The coastal environments exposed to the relatively higher levels of effect are of a morphological type not sensitive to changes in the wave regime.

369. A medium magnitude of change but within the range of natural variability is therefore assessed to arise in areas of low sensitivity and a small magnitude of change within the range of natural variability is also assessed to arise in areas of potentially medium sensitivity. The resulting effect is negligible.

Recreational Surfing Venues

370. This assessment of potential changes to the wave regime is based upon the analysis of wave model results with and without the GBS and Jacket schemes present over a representative two year period. Time series of wave conditions have been extracted from the model results immediately offshore of the identified surfing beaches in the study area. The same statistical and frequency analysis has been applied to each data set to obtain baseline values (previously listed in Section 9.3.3) and the difference in either the statistics of key events, or the frequency of occurrence of other event types resulting from the presence of the schemes.

371. Jackets were found to have no effect greater than 0.01m wave height or greater than 0.1 s wave period at any venue.

372. GBS foundations were found to have no effect greater than 0.01 m wave height or greater than 0.1 s wave period at ten out of eighteen venues. Of the remaining eight venues, effects were typically limited to a 0.01 to 0.02 m decrease (up to a maximum

of 0.05 m at Lossiemouth, Banff Beach and Sunnyside Bay) in wave height, but no effect on wave period or the frequency of occurrence of any representative conditions.

373. A small magnitude of change within the range of natural variability is therefore assessed to arise in areas of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.7.3.6 Cumulative Effect, Operation Phase: Changes to the Sediment Transport Regime

Smith Bank

374. It is the combined wave and tidal regimes that ultimately control sediment transport and therefore the seabed form within the study area. It was shown in Section 9.5.5 that the Wind Farm causes no measurable change to the speed or directions of tidal currents. It was shown in Section 9.5.6 that GBS foundations will cause a reduction in instantaneous significant wave height within the Wind Farm sites of up to 20% (but more typically 5 to 10%) and up to 5% in the far-field, which is of the same order as inter-annual and inter-decadal variability in storm intensity. Jackets will have little or no measureable effect (less than 1%) on wave height. Neither GBS nor Jacket foundations will measurably affect wave period or direction.

375. Given no significant effect on the driving parameters, there can be no corresponding difference in the potential rates and directions of sediment transport through the sites (provided that the supply of sediment is available for transport).

376. Other Sections of this Section consider the potential for the construction of the Wind Farm to affect the character or abundance of surface sediments (the details for the Wind Farm alone). Whilst some short to medium term localised increases in sediment thickness are expected, there is not expected to be a significant change in the textural properties of the sediment available for transport. This supports the further conclusion that actual sediment transport rates through the sites will not be affected by the Wind Farms.

377. The predicted conceptual effect of a reduction in wave height on sediment transport pathways and resulting morphology is that the central part of the sites may tend to accumulate sediment at a slightly higher rate than would have otherwise occurred during the operational lifetime of the Wind Farm sites. Also, the supply of sediment to areas into the Moray Firth might be slightly less than would have otherwise occurred during the operational lifetime of the Wind Farm sites.

378. However, as stated above, the absolute difference in sediment transport attributable to the Wind Farm sites is less than the potential for natural variability over the same period.

379. There will therefore be no effect on the form or function of Smith Bank.

380. A small magnitude of change within the range of natural variability is therefore assessed to arise in areas of low sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

Designated Coastal Habitats

381. It was demonstrated above that there will be a negligible effect on sediment transport rates through the Wind Farm sites as a result of the presence of the wind farms. The main effects on tidal currents and waves are generally confined to the Wind Farm sites and are of a lower magnitude elsewhere. Therefore, there will therefore be no corresponding effect on the rate of sediment supply to other parts of the Moray Firth.

382. The effect of the Wind Farm arrays on wave height, period and direction at the location of designated coastal habitats has been considered in Section 9.5.6.2 and was found to be not significant both in absolute terms and in the context of natural variability. There will be no corresponding effect on the rates or directions of wave driven nearshore sediment transport at these locations.

383. There will therefore be no effect on the form or function of designated coastal habitats.

384. A small magnitude of change within the range of natural variability is therefore assessed to arise in areas of low to medium sensitivity. The resulting effect is negligible and therefore not significant in terms of the EIA Regulations.

9.7.3.7 Cumulative Effect, Operation Phase: Scour Effects

Smith Bank

385. An assessment of scour effects relating to the turbine foundations for the Beatrice Offshore Wind Farm site alone was previously presented in Section 9.5.8. This section considers the additional cumulative effect of the foundations within the adjacent Moray Firth Round 3 Zone.

386. The Moray Firth Round 3 Zone GBS foundations are assumed to have a base diameter of 55 m, but the number of foundations will vary depending upon the power rating. For the purposes of this assessment, it is conservatively assumed that all foundations in the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone are of the same power rating and that the Moray Firth Round 3 Zone foundations are confined to the eastern development area only. In practice there may be an (as yet unspecified) mixture of power ratings in the Moray Firth Round 3 Zone. The worst case is if the lowest power ratings (i.e. greatest number of foundations) are installed in both Wind Farm sites.

387. Using empirical relationships described in Whitehouse (1998), the equilibrium scour depth for each Beatrice Offshore Wind Farm foundation type resulting from waves and currents, both alone and in combination has been calculated and summarised previously in Table 9.6. Total effect values are provided in Table 9.10 for the Moray Firth Round 3 Zone alone and in Table 9.11 for the Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone combined.

388. The worst case number of turbines and development footprint on the seabed is derived from a combination of information provided by MORL regarding turbine numbers and foundation size, and conservative assumptions made by BOWL regarding the likely extent of scour protection. Whilst it is accepted that the worst

case presented here may represent an overestimate of the number of turbines and development footprint, it is considered to be a sufficiently conservative approach for the purposes of cumulative assessment.

Table 9.10 Total Footprint of the Different Foundation Types With and Without Scour: Moray Firth Round 3 Zone

	Moray Firth Round 3 Zone Foundation Option	
	Monotower and Gravity Base or Tubular Jacket and Gravity Base	**Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons**
	50m (Combination of 3.6 and 5 MW turbines)	**21 m - 34 m (3.6 - 7MW)**
Number of foundations*	420	420
Footprint on seabed of all foundations (m²)	997,848	4,763
Proportion of site area (%)	0.336	0.002
Footprint on seabed of all foundations + scour (m²)	2,478,811	126,868
Proportion of site area (%)	0.835	0.043

Table 9.11 Cumulative Footprint of Different Foundation Types With and Without Scour: Beatrice Offshore Wind Farm and Moray Firth Round 3 Zone

	Foundation Option					
	Monotower and Gravity Base or Tubular Jacket and Gravity Base			**Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons**		
	3.6 MW	**6 MW**	**7 MW**	**3.6 MW**	**6 MW**	**7 MW**
Number of foundations*	697	586	562	697	586	562
Footprint on seabed of all foundations (m²)	1,541,737	1,467,202	1,469,048	7,905	6,646	6,374
Proportion of total site area (%)	0.360	0.342	0.343	0.002	0.002	0.001
Footprint on seabed of all foundations + scour (m²)	3,829,914	3,644,759	3,649,344	210,541	177,011	169,761
Proportion of total site area (%)	0.894	0.851	0.852	0.049	0.041	0.040

9.7.4 MITIGATION MEASURES

389. Mitigation measures for the Wind Farm alone have been provided in Section 9.6.

390. None of the cumulative effects will cause a significantly elevated effect in comparison to that previously assessed for the Beatrice Offshore Wind Farm alone. Therefore, no additional mitigation measures are proposed.

9.7.5 RESIDUAL EFFECTS INCLUSIVE OF CUMULATIVE EFFECTS

391. No significant cumulative effects are predicted as a result of the project, therefore, no significant residual cumulative effects are predicted.

9.7.6 MONITORING AND ENHANCEMENTS

392. Suggestions regarding monitoring of the effects of the Wind Farm alone have been provided in Section 9.6.3.

393. It is not recommended that the scope for monitoring by BOWL be extended to include areas affected (only) by the Moray Firth Round 3 Zone.

9.8 STATEMENT OF SIGNIFICANCE

394. A summary of the effects predicted to arise as a result of the project are presented in Table 9.8.

9.8.1 SMITH BANK

395. Smith Bank may experience localised and temporary modification to levels of SSC in the upper water column during construction, which may exceed the normal range of natural variability. Sandy sediments released during dredging, drilling or cable burial activities may accumulate locally in areas within the Wind Farm site to a thickness (order centimetres to metres) that may exceed the normal (short-term) range of natural variability in seabed level but will not change the surficial sediment character.

396. Other effects of the Wind Farm on tidal, wave and sedimentary regimes will not be significant in relation to the range of natural variability and will not cause the range of natural variability to be exceeded.

397. Effects of the Wind Farm will not significantly affect Smith Bank.

9.8.2 DESIGNATED COASTAL HABITATS

398. Effects of the Wind Farm will not significantly affect designated coastal habitats identified in the present study.

9.8.3 RECREATIONAL SURFING VENUES

399. Effects of the Wind Farm will not significantly affect recreational surfing venues identified in the present study.

9.8.4 STRATIFICATION FRONTS

400. Effects of the Wind Farm will not significantly affect stratification fronts identified in the present study.

9.8.5 CUMULATIVE EFFECTS

401. No significant cumulative effects are predicted as a result of the Wind Farm; therefore, no significant residual cumulative effects are predicted.

9.9 REFERENCES

402. ABPmer, 2010. Proposed Methodology for Coastal Processes EIA for the Beatrice and Moray Firth Offshore Wind Farm Developments. ABPmer Report R1698.

403. ABPmer, 2011a. Beatrice Offshore Wind Farm: Physical Processes Baseline Assessment. ABPmer Report R1795.

404. ABPmer, 2011b. Beatrice Offshore Wind Farm: Numerical Model Calibration and Validation Report. ABPmer Report R1860.

405. ABPmer, 2011c. Beatrice Offshore Wind Farm: Scour Assessment. ABPmer Report R1885#.

406. ABPmer, 2011d. Beatrice Offshore Wind Farm: Cable Landfall Assessment. ABPmer Report R1886#.

407. BOWL, 2010. Beatrice Offshore Wind Farm: EIA Scoping Report.

408. BOWL, 2011. Beatrice Offshore Wind Farm: Project Design Statements (Comprising various reports, workshops and emails).

409. CEFAS, 2011, Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. Final draft.

410. CEFAS, 2011. Guidelines for Data Acquisition to Support Marine Environmental Assessments of Offshore Renewable Energy Projects.

411. COWRIE, (2009). Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide. ABPmer and HR Wallingford, for COWRIE.

412. COWRIE, 2009. Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guidance.

413. DEFRA, 2005. Nature Conservation Guidance on Offshore Wind Farm Development.

414. DEFRA, CEFAS and DfT, 2004. 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.

415. Department of Energy and Climate Change, 2011. Overarching National Policy Statement for Energy (EN-1).

416. Dolphin T., Silva, T., Rees, J., 2011. Natural Variability of Turbidity in the Regional Environmental Assessment (REA) Areas. CEFAS report for the MALSF: MEPF 09-P114.

417. EMEC & Xodus AURORA, 2010. and Consenting, EIA and HRA Guidance for Marine Renewable Energy Deployments in Scotland. Report commissioned for Marine Scotland.

418. Holmes R., Bulat J., Henni P., Holt J., James C., Kenyon N., Leslie A., Long D., Musson R., Pearson S., Stewart H., 2004. DTI Strategic Environmental Assessment Area 5 (SEA5): Seabed and superficial geology and processes. British Geological Survey Report CR/04/064N.

419. Marine Scotland, 2010. Beatrice Offshore Windfarm – Moray Firth: Scoping Opinion. pp28.

420. MCA. Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues. MCA Guidance Note MGN371. Available from www.mcga.gov.uk/c4mca/mgn371.pdf

421. Moray Firth Offshore Wind Developers Group, 2011. Cumulative Impacts Assessment Discussion Document. April 2011. 181pp.

422. Office of the Deputy Prime Minister, 2001. Guidance on Environmental Impact Assessment in Relation to Dredging Applications.

423. Osiris Projects, 2011. Geophysical survey of the Beatrice Offshore Wind Farm.

424. Ramsey DL. Brampton AH. (2000). Coastal Cells in Scotland: Cell 3 - Cairnbulg Point to Duncansby Head. Scottish Natural Heritage Research, Survey and Monitoring Report No 145

425. Reid G., McManus J. (1987). Sediment exchanges along the coastal margin of the Moray Firth, Eastern Scotland. Journal of the Geological Society, Volume 144, 179-185.

426. Scottish Natural Heritage, 2003. Marine Renewable Energy and the Natural Heritage: An Overview and Policy Statement.

427. Soulsby R., 1997. Dynamics of Marine Sands. Thomas Telford, pp249.

428. Surfers Against Sewage, 2009. Guidance on environmental impact assessment of offshore renewable energy development on surfing resources and recreation. http://www.sas.org.uk/pr/2009/pdf09/eia-1.pdf. (Accessed on 6/04/2011).

429. UKCIP09 [http://www.ukcip.org.uk]

430. Whitehouse, R.J.S., 1998. Scour at marine structures: A manual for practical applications. Thomas Telford, London, 198 pp.

THIS PAGE IS INTENTIONALLY BLANK